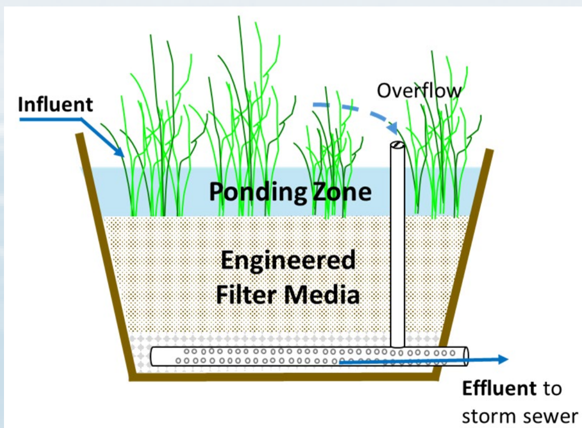
# Field Monitoring of Microplastics Loading and Accumulation in Biofiltration Best Management Practices

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SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

Technical Report 1457

# Field Monitoring of Microplastics Loading and Accumulation in Biofiltration Best Management Practices

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*Southern California Coastal Water Research Project, Costa Mesa, CA*

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Keywords:

Microplastics, Best Management Practices (BMP), field monitoring, runoff, media, bioretention, biofiltration, biofilter, filtration

# Executive Summary

Biofilter best management practices (BMPs) are one of the most common types of BMPs being implemented to address water-quality impacts of urban stormwater runoff. Microplastics (MP) are an emerging contaminant, yet little data are found about how effective existing runoff management infrastructure is at treating them. The study aims to determine how and to what extent existing biofilter BMPs remove MPs from urban stormwater runoff, characterize the mechanisms of treatment, and identify BMP design features that promote MP removal. Researchers sampled runoff and biofilter media in a multi-site field monitoring effort to assess both short-term event-based removal and long-term accumulation. The study leveraged the Southern California Stormwater Monitoring Coalition's (SMC) Regional BMP Monitoring Network to monitor 18 storm events across 7 biofilters representing typical design and implementation by stormwater management agencies in southern California and a range of operating conditions.

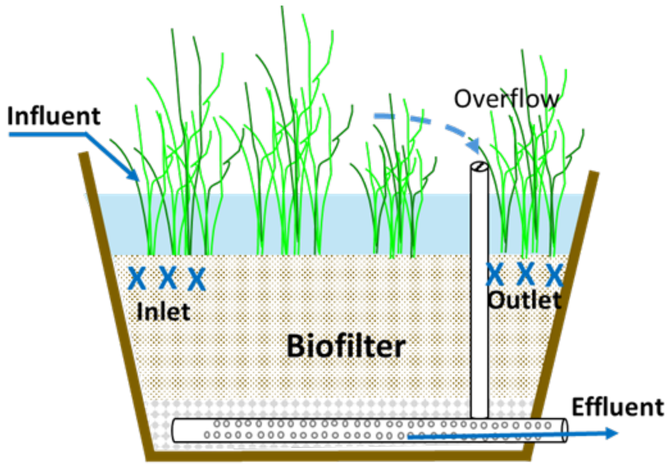
The 7 biofilters reduced MP event mean concentrations (EMCs, a weighted average concentration that reflects the variability of pollutant transport and flow rate during a storm event) by a median of 72% over 18 storm events. The highest single-event removal efficiency was 99.8%. Influent MP EMCs ranged from dozens to 6,850 particles/L. Total MP in runoff was reduced by a median of 93% across 14 events, which accounts for storm size and reduced runoff volume discharged from the BMP. Treatment (as measured by a change in EMCs between influent and effluent) was reasonably consistent across all size fractions: 68% for the dominant 20–63 µm fraction, 85% for 63–125 µm, 91% for 125–355 µm, 100% for 355–500 µm, and 89% for >500 µm. Fragments contributed more than 80% of all MPs in runoff. A total of 16 distinct polymer types were identified in the influent runoff, compared to 10 in the effluent, with olefins being the most abundant group. Black MPs, typically linked to road and tire wear, made up less than 15% of influent and were largely absent from effluent samples.

MP accumulation in the media ranged from tens to >1,000 particles/g dry weight, and varied by BMP, location, and depth of sample collection. Concentrations could differ by 5–10 times within the same BMP, highlighting the heterogeneity of MP capture in biofilter media. Size, morphology, polymer type, and color of media MPs closely mirrored those in influent runoff.

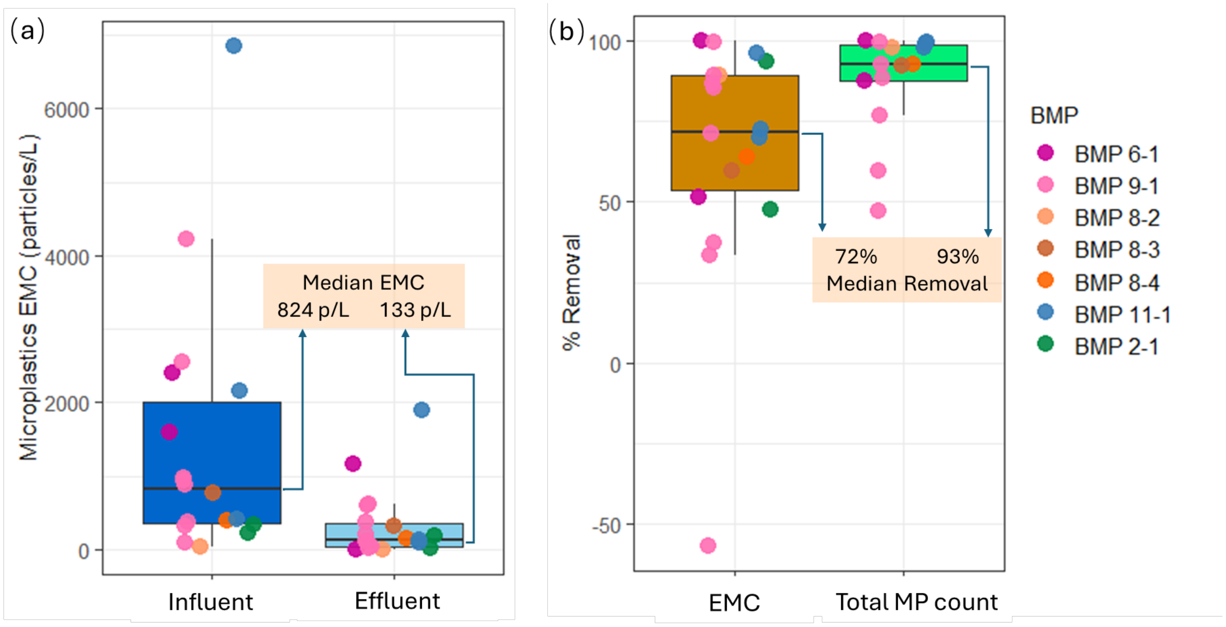
Results showed MPs are predominantly captured by straining within fine pores of the media (the gaps between particles making up the filter media), similar to other particles remaining after extraction. This offers practical evidence that stormwater treatment practices designed to remove particulate contaminants are likely highly effective for MPs. Media pore size was identified as a key factor governing capture, with BMPs containing greater proportions of <20 µm pores showing better retention. Because media pore size distribution is a labor-intensive measurement and uncommon in practice, measuring media particle size distribution is strongly recommended by current design guidance. An index derived from media particle size distribution (curvature coefficient) strongly correlated with the proportion of <20 µm pores and MP retention in the media sampled. The curvature index offers a more practical indicator for successful performance for MPs and optimizing BMP design in future BMPs. Modifying BMP design instructions must consider potential impacts to other treatment or drainage functions.

Beyond treatment performance, the dataset creates new opportunities for advancing MP analysis. Strong correlations between MPs and particle counts across all size fractions suggest that cheaper, faster microscopy-based approaches could be used to quantify MP concentrations in future BMP studies, reducing analysis costs and time for systems with high particle counts. The dataset and findings also set the stage for expanded evaluations across other BMP types, geographic regions, and smaller particle sizes, as well as for exploring ecological and toxicological implications of MP reduction in runoff.

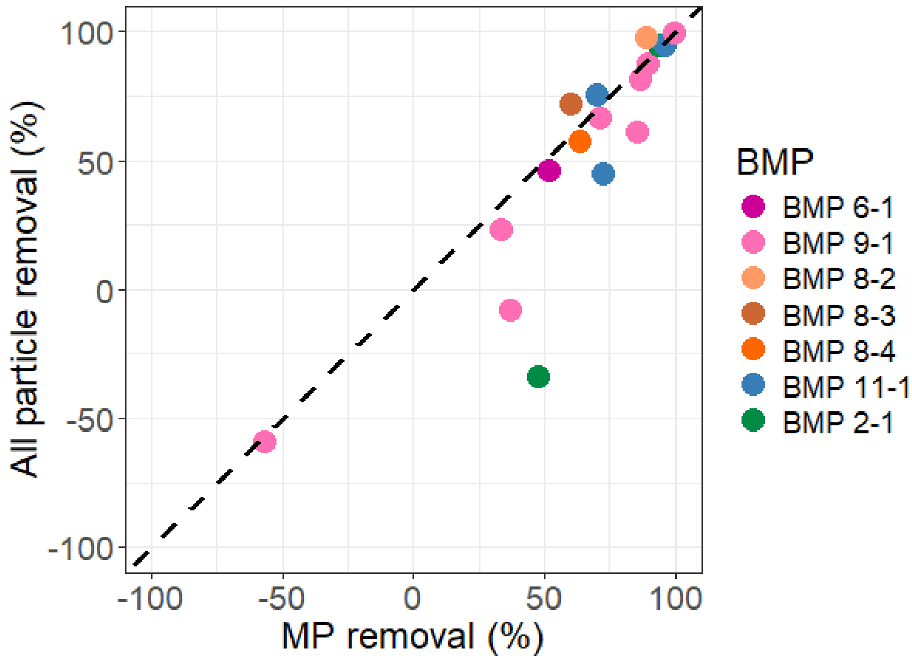
The study provides field-based evidence of biofilter BMP performance across the region in removing MPs, establishes mechanistic understanding that can guide design optimization, and charts clear directions for future monitoring and management. These findings provide a scientific foundation for regulatory agencies, municipalities, and watershed managers addressing MPs in California and beyond.



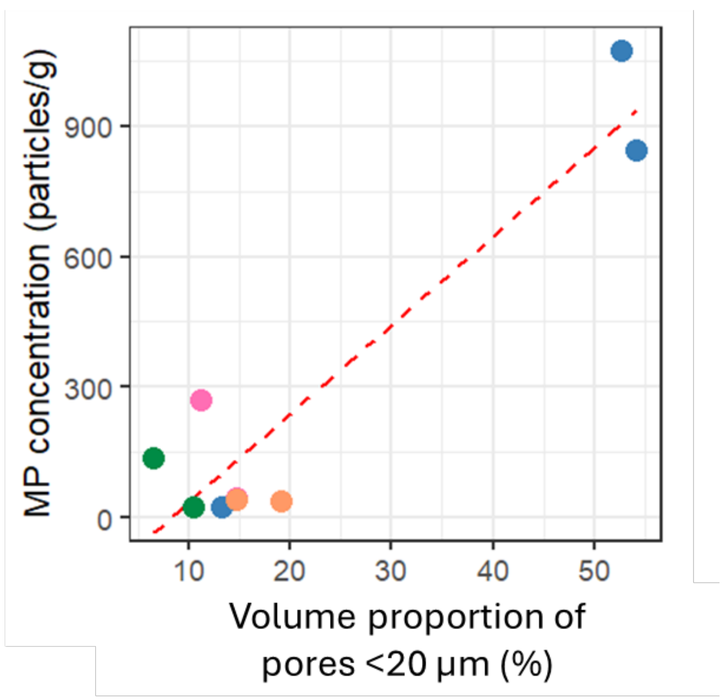

**Field monitoring included storm event sampling influent (untreated) and effluent (treated) runoff, and dry weather samples of engineered media near the inlet and outlet of the biofilters.**




**MPs are efficiently and consistently removed by 7 biofilters during 18 storm events: (a) MP EMCs in the influent and effluent, and (b) event-based removal efficiency of EMCs and $MP_T$ loads. The length of the boxes show the 25$^{th}$ percentile, median, and 75$^{th}$ percentile, with whiskers extending to 1.5 × IQR. Individual points are overlaid and color-coded by BMP identifier.**




**MP Removal is strongly correlated to removal of all particles.**




**12 media samples from 4 biofilters indicate that accumulation of MP in the biofilter media is closely correlated to the proportion of small pores in the media.**

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| | |
|---|---|
| BMP | stormwater best management practice |
| BSM | bioretention soil mix, a.k.a., engineered media |
| EMC | event mean concentration |
| HQI | hit quality index |
| IQR | interquartile range |
| LID | low impact development |
| MAG | microplastic analysis grade |
| MDA | minimum detectable amount |
| MP | microplastics |
| SMC | Southern California Stormwater Monitoring Coalition |
| SCCWRP | Southern California Coastal Water Research Project |

# 1. Project Narrative

## 1.1. Introduction

Stormwater Best Management Practices (BMPs) are at the heart of implementation plans for achieving objectives of the federal Clean Water Act (1972) and the California Porter Cologne Act (1969). These regulatory frameworks aim to protect or restore water quality objectives and beneficial uses. BMPs serve as a critical technological "solution" within the National Pollutant Discharge Elimination System (NPDES) permitting and compliance structure, including total maximum daily loads (TMDLs), municipal separate storm sewer system (MS4) permits, water quality improvement plans, and watershed management plans. Regulatory mechanisms drive BMP implementation, while BMP design and maintenance support functions to achieve compliance objectives and protect water quality.

Microplastics (MP), defined as plastic particles <5 mm long (State Water Resources Control Board 2022), have emerged as a contaminant of concern in stormwater. MPs are diverse in their characteristics, including size, morphology, color, and polymer composition, which may influence their fate and transport in the environment, their behavior during treatment processes, and ultimately their downstream ecological and human health impacts (Kumar et al. 2025; Chanda et al. 2024). Urban runoff is now recognized as a major pathway for MPs to enter the ocean, often contributing higher loads than wastewater discharges due to their widespread occurrence and the diffuse nature of non-point source inputs (Sutton et al. 2016; Bailey et al. 2021; Schernewski et al. 2021; Werbowski et al. 2021; Sewwandi et al. 2024). MPs are not currently regulated in stormwater, therefore neither treatment objectives, nor design criteria, nor operational guidance has been developed for their management using BMPs.

BMPs include a suite of technologies that may be used to treat runoff water quality using physical, chemical, and/or biological processes. Filtration-based BMPs, such as biofiltration, bioretention, and sand filters, hereafter referred to collectively as biofilters, offer the greatest promise for MP removal (Österlund et al. 2023; Ahmad et al. 2025). In contrast, other BMPs that rely primarily on physical settling (a.k.a. sedimentation), such as detention basins and constructed wetlands, are unlikely to achieve effective removal because the low density of many MPs limits sedimentation (Österlund et al. 2023). Biofilters are often referred to as Low Impact Development (LID)-type BMPs. An "LID"-BMP distinction typically refers to distributed, relatively small-footprint engineered systems that manage runoff close to its source, while also providing additional ecosystem services (e.g., urban heat island mitigation, nuisance flooding control, urban habitat) and community benefits (e.g., aesthetics, recreational opportunities). Biofilters constructed by public agencies responsible for stormwater management in southern

California are found across a range of sizes, serving drainage areas of less than one to tens of acres.

Recent state-of-the-art reviews synthesize the growing but still limited evidence for MP occurrence in urban stormwater and their removal by BMPs (Österlund et al. 2023; Ahmad et al. 2025; Hoang et al. 2025; Kwarciak-Kozłowska and Madeła 2025). Among published studies relevant to the climate of southern California, industrial land use was found to be a major contributor to MP occurrence in stormwater runoff (Piñon-Colin et al. 2020), while environmental factors including increased precipitation intensity or depth (Piñon-Colin et al. 2020), and atmospheric deposition (Koutnik 2022) also increased the occurrence of MP in runoff. Across the published literature, reported concentrations in runoff range from non-detect to >10,000 particles/L, with plausible sources including atmospheric deposition, tire, road, and pavement wear, plastic litter, textiles, and construction and landscaping materials.

Only a handful of field studies have assessed MP removal in biofilters, each focused on one BMP at a single location (Gilbreath et al. 2019; Werbowski et al. 2021; Lange et al. 2021; 2022; Smyth et al. 2021; 2024). Collectively, these efforts encompass performance from only three biofilters in total, reporting event-based MP removal ranging from >80% to >99%. While promising, these findings have yet to be confirmed at a broader scale.

Generating field-based MP data is technically and logistically challenging. Reliable quantification of BMP treatment require paired influent and effluent samples, flow-weighted composite sampling to obtain event mean concentrations (EMC), and relatively large sample volumes (>1 L) compared with other analytes. Analytical requirements are even more demanding, requiring specialist instrumentation and analyst training. Quantification and polymer identification for small size fractions (<50 µm) are particularly labor-intensive to analyze as automated processes have yet to be developed, yet they are of particular interest for treatment design and toxicological impact evaluation. Further challenges arise from controlling potential contamination and the intensive analyst training needed to manage the multiple steps of MP analysis. Consequently, very few studies have met all of the requirements to holistically evaluate biofilter treatment efficiency, and none have done so at a regional scale.

The overall technical objective of the current study is to quantify the extent to which existing southern California biofiltration BMPs reduce concentrations and total loads of MP in urban runoff from discharging downstream. Over and above quantifying performance in this context, secondary objectives are to confirm the mechanism(s) of contaminant removal, and explore whether or which design elements influence performance. We hypothesize that MPs are removed predominantly through physical filtration (straining), similar to other particulates. We further hypothesize that the size and shape of retained MPs are influenced by the pore size distribution of the filtration media. Comparing MP characteristics with both particle and pore size distributions offers a pathway to refining media design for improved MP capture, if necessary.

The results of this study provide the most extensive dataset found to date on MP removal by biofilter BMPs, and evaluates how treatment modifies MP occurrence in and characteristics of urban runoff discharging downstream. The success of this study is attributed to leveraging the on-going coordinated, collaborative Southern California Stormwater Monitoring Coalition (SMC) Regional BMP Monitoring Network (Fassman-Beck and Schiff 2022) and in-house analytical capability at SCCWRP. Through this program, paired influent and effluent composite samples were collected from a total of 18 storm events across seven biofiltration BMPs. This study also evaluates MP retention within the biofilter media, providing insight into long(er) term accumulation. We utilized in-house analytical capabilities developed through extensive method development, evaluation, and standardization (De Frond et al. 2023; Thornton Hampton et al. 2023; Lao and Wong 2023; Lao et al. 2024), to enable comprehensive quantification and characterization of MPs by size (within the range 20-5000 µm), morphology, polymer type, and color.

## 1.2. Background – Biofilter BMPs

Biofilter BMPs are engineered, built-in-place stormwater treatment systems intended to capture and treat urban runoff, with supplemental benefits including public amenity value and other ecosystems services. Design of any BMP is site-specific, meaning that a single BMP type can look very different, and have different components or features depending on location, local design guidance, and experience of the designer and construction professionals. Background is provided herein on the design and operation of biofiltration BMPs as they directly relate to how this type of BMP manages stormwater quality. Terminology is established for the purposes of interpreting this study and report, as details differ amongst stakeholders and jurisdictions.

Runoff from the upstream drainage area (runoff source area) enters a biofilter at the surface through one or more inlets, or along the entire perimeter. The influent runoff should form a ponding layer (i.e. a temporary layer of standing water) on the surface of the BMP, and slowly percolate vertically (by gravity) through a layer of engineered media (Figure 1). California jurisdictions often use the term “full capture” biofilter to refer to a biofilter that allows treated effluent to soak into the surrounding soil (Figure 1a). The term “full capture” refers to the capacity to redirect runoff from the surface to the subsurface, resulting in eliminating downstream discharge altogether for storm events up to the design capacity of the BMP. This is also sometimes known as an “infiltration-type BMP”. If/where site conditions inhibit or prohibit treated runoff from soaking into the ground[1], a biofilter is likely to have an impermeable liner and an underdrain (a perforated pipe located at or near the bottom of the BMP) that discharges treated effluent to a downstream storm sewer or other discharge point (Figure 1b). This configuration is known as a “partial capture” or “flow-through” BMP in California, referring to the capacity of the BMP to retain some, but not all of the influent runoff in the engineered media, while the treated excess flows through the system and out of the underdrain. In any/all designs, storms larger than the design intent may produce runoff that exceeds the capture capacity of the BMP. In this case, excess runoff is intentionally routed to an overflow or bypass, discharging safely downstream without treatment (of the excess).

The engineered media is the primary work horse of the biofilter for stormwater management. It should provide two main functions: (1) retain runoff and (2) treat contaminants. The media’s ability to retain runoff, i.e., act like a sponge, prevents or minimizes the total volume of downstream discharge, and thus the ability to carry contaminants to receiving environments. Treatment refers to the ability to influence contaminant concentrations. This may be achieved in a biofilter through physical processes of filtration, settling/sedimentation, physical or chemical sorption, and/or supporting organisms responsible for biological contaminant transformations. Different mechanisms are relevant for different contaminants. Both media functions can be manipulated through media design.

The ponding zone promotes contaminant removal by sedimentation, i.e. settling by gravity of particulate and particulate-bound contaminants. The anticipated low density of plastics and short duration of ponding suggests that sedimentation will be a less important MP contaminant removal mechanism in biofilters compared to media filtration. Long-term contaminant removal processes may include uptake by vegetation, but the contaminants must first be trapped in the media to become available to the plants. In any case, contaminant uptake is unlikely a meaningful mechanism for MP removal, especially in comparison to media filtration.

[1] Local design guidance often defines criteria regarding whether to design for infiltration. Infiltration characteristics of in-situ soils may physically limit feasibility, as BMPs must drain within a specified time period to prevent, for example, mosquito breeding or the system going anoxic. Other prohibitions, for example, may be related to proximity to building foundations or buried infrastructure that could be damaged by wet soils, or in the vicinity of contaminated soils that might be mobilized by water ingress.

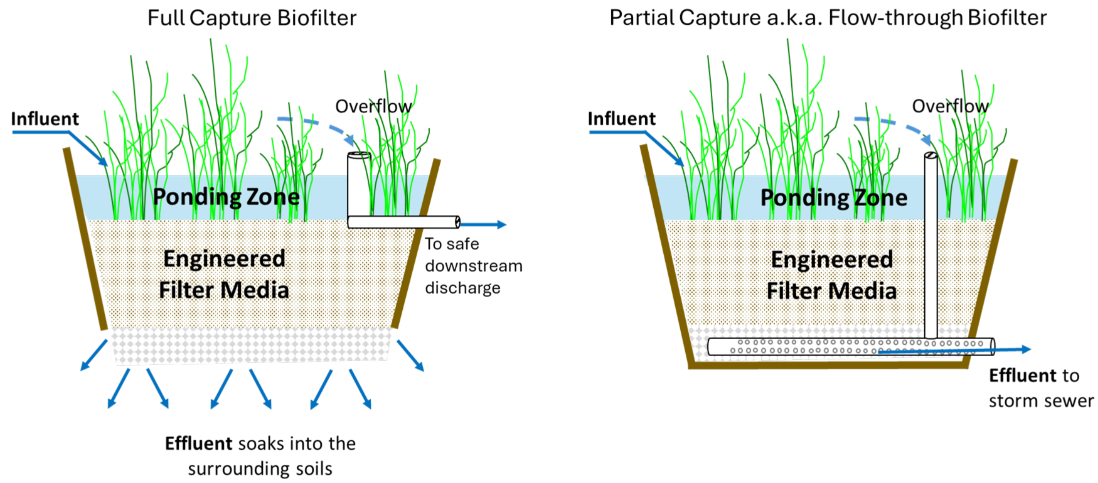


**Figure 1. Conceptual biofilters: (a) Full capture biofilters discharge (infiltrate) treated effluent to the surrounding soils; (b) Partial capture biofilters discharge treated effluent to storm sewers or other downstream point.**

MPs are particulate matter that are most likely removed by physical filtration in a biofilter. Specifically, MPs should be captured in the media through the filtration mechanism of straining (Figure 2). As runoff percolates from the ponding zone into the engineered media, particulate matter (comprised of MP and non-polymer particles) is physically caught in the pore space (the gaps) between the particles that make up the media. MPs and other particulate matter are captured by pores that are smaller than their own size. Media is made up of non-uniform size particles creating a distribution of pore sizes that may change over time due to compaction, use, and clogging by all previously trapped particulate matter - all of which in theory should decrease pore sizes and thus might improve the potential to capture smaller particulates. Conversely, excessive compaction or clogging may inhibit flow through the media such that more runoff bypasses or overflows without treatment, thus indicating the need for maintenance to restore hydraulic capacity.

Engineered media is a deliberate combination of aggregate, mineral, and organic particulate matter designed to achieve specific fluctuations or characteristics including water storage, hydraulic (flow) control, and water quality treatment. BMP design manuals typically establish a range of media performance criteria for which the design engineer must find products or materials that are fit for purpose. General materials are offered as a starting point, but there is an expectation that candidate materials or mixtures are tested prior to installation. Typically, the treatment expectation of BMP design is for common stormwater contaminants, namely sediment, nutrients, and heavy metals. There is no existing design guidance for the removal of MPs.

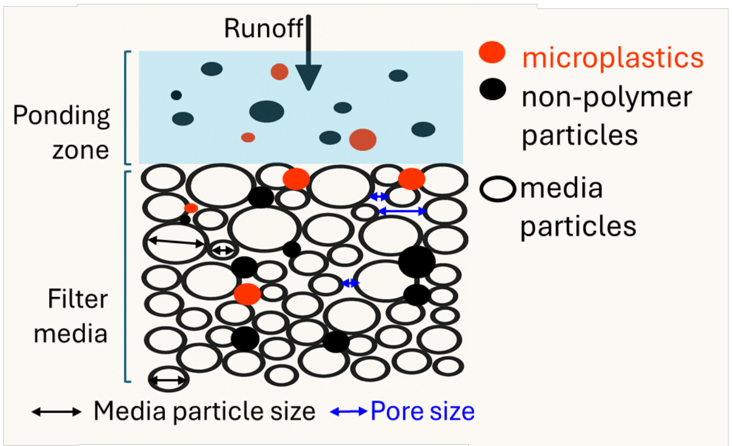


**Figure 2. MP removal by straining in a biofilter, illustrating capture of particulate contaminants, including microplastics and non-polymer particles.**

A plethora of BMP design guidance manuals are found across California; however, guidance for specifying engineered media, a.k.a. biofiltration soil mix (BSM), share many common instructions. Typically, the basic materials for BSM are a combination of 70-85% (by volume) sand and 15-30% compost. The particle size distribution of the sand is usually required to meet specifications for ASTM C-33 concrete sand, or similar. The intention of the sand's particle size distribution is to provide a starting point for meeting hydraulic criteria, i.e. balancing rapid-enough drainage with "adequate" retention time for contaminant removal. There are also a range of tests intended to evaluate whether the media mixture might leach common stormwater contaminants of concern (e.g. nutrients and heavy metals), and will support plant life. Each/all of these characteristics are supposed to be evaluated prior to installation, but in practice this is not often the case.

There are no specifications or test procedures in California BMP design manuals for water storage criteria (which is indicative of retention capacity), although these have been established in the stormwater literature for biofilters and green roofs (Davis et al. 2012; Fassman and Simcock 2012). There are also no specifications for pore-size distributions; it is a characteristic that can be measured in a laboratory, albeit through a laborious analytical process (Liu 2016). Research is prevalent in the wider water treatment literature regarding filter design and operation.

## 1.3. Objectives and Scope

This study quantifies MP in untreated urban runoff flowing into and treated runoff discharging from selected biofiltration BMPs, and MP accumulated in biofilter media over the service life at the time of sampling. The data generated include counts (concentrations), morphology, color, and plastic (polymer) type; all of these parameters were quantified according to five size fractions. The scope excludes source identification or interpreting data in the context of the downstream aquatic environment.

The specific objectives of this project are to:

- Generate a robust, consistent data set to quantify likely MP concentration and total load reductions using existing biofilter-BMPs in southern California.
- Empirically evaluate physical characteristics of engineered filter media that promote MP capture using biofilter-BMPs.
- Explore indicators of maintenance needs to support biofilter-BMP performance.
- Develop evidence-based recommendations for effective biofilter design, operations, and management strategies as solutions to mitigate MP pollution from urban runoff.

The technical approach adopted for the current project was to collect data from multiple field-scale BMPs concurrently, in order to generate a multi-storm data set within the 2-year time period of the project while accounting for the infrequency of rain events in Southern California. Urban stormwater runoff is known to be highly variable (Clary et al. 2020), thus it is necessary to sample many events in order to enable robust statistical evaluation.

The seven individual BMPs selected for monitoring represent a subset of the BMPs being monitored within SMC's BMP Regional Monitoring Network. The ability to leverage the on-going SMC initiative was critical to balance the cost of monitoring with the high analytical cost for MP quantification and identification, while amassing a large data set. The data collection and data analysis methods herein are consistent with "typical" BMP water quality monitoring studies (Geosyntec and Wright Water Engineers 2009), supplemented by MP-specific field quality assurance and quality control sampling.

## 1.4. Methods

### 1.4.1 Site descriptions

Wet-weather (stormwater runoff) and dry-weather (engineered biofilter media) sampling were conducted at seven biofilters (Figure 3) in the SMC Regional BMP Monitoring Network (Fassman-Beck and Schiff 2022). These BMPs are routinely monitored during wet weather for a range of conventional stormwater contaminants (e.g., sediments, nutrients, heavy metals) under a standardized work plan and quality assurance project plan (QAPP), enabling cross-site comparison. Site identifiers are withheld for confidentiality in accordance with SMC standard practice.

All BMPs monitored for MPs were designed to capture runoff from the 85th-percentile storm[2] and are partial-capture biofilters (lined systems that discharge treated runoff via underdrains, Figure 1b). The BMPs receive only wet-weather flow; they intercept runoff directly from the land surface before discharging into the MS4 or other downstream waterway. Land uses contributing runoff to the BMPs included roadways, parking lots, and public parks. The diversity of monitored installations provides a basis for assessing the overall efficiency of these BMPs for MP removal at the site (BMP) scale, and represent typical southern California biofilters owned and operated by public agencies responsible for stormwater management. Additional site characteristics, such as year of installation, design storm depth, loading ratio, and media depth, are summarized in Table 1. BMP 11-1 reflects a notable design distinction with greater media depth than found in the other monitored BMPs. Further details on individual sites and the monitoring equipment configurations for each BMP are provided in Appendix A.

[2] The size of a water quality treatment BMP is calculated based on the volume of runoff generated from the "water quality design storm" occurring over an area of interest (aka a drainage area or catchment). In most Southern California jurisdictions, the water quality design storm is defined as the depth of rainfall for which 85% of storms on an annual basis are less than or equal to this storm depth. Subsequent calculations are used to determine the associated runoff volume for the drainage area, and then the size and depth of BMP required to treat the runoff. The magnitude of the $85^{th}$ percentile differs by location, but the BMP sizing procedure is consistent across the region, meaning that the size of each BMP relative to its drainage area is consistent across all BMPs monitored. Performance can be directly collated and compared because sizing and data collection procedures are consistent.


**Figure 3. Biofilters monitored in this study. Only one photograph of the three parallel BMPs constructed along the same highway is shown in the top right corner.**

**Table 1. Site information for monitored BMPs.**

| BMP name code | Land use in drainage area | General shape | Operating Since | Drainage area (acre) | Design storm depth (in) | Design runoff capture volume ($ft^3$) | Loading Ratio[a] | Surface area ($ft^2$) | Media depth (in) |
|---|---|---|---|---|---|---|---|---|---|
| 6-1 | 75% of multi-lane road and 25% of parking lot | Rectangular | 2019 | 0.6 | 0.53 | –[b] | 14 | 1792 | 24 |
| 9-1 | 65% of multi-lane road and 35% of park/open space | Rectangular | 2020 | 1.3 | 0.46 | 1458 | 8 | 352 | 18 |
| 8-2 | Multi-lane road | Oval | 2019 | 5.8 | 0.85 | 4792 | 85 | 2980 | 24 |
| 8-3 | Multi-lane road | Rectangular | 2019 | 4.9 | 0.85 | 2178 | 15 | 32230 | 24 |
| 8-4 | Multi-lane road | Rectangular | 2019 | 6.0 | 0.85 | 3049 | 7 | 17840 | 24 |
| 11-1 | Parking lot | Rectangular | 2018 | 0.7 | 0.61 | 1405 | 39 | 804 | 37 |
| 2-1 | Public park | Triangular | 2019 | 4.3 | 0.52 | 5077 | 28 | 6520 | 24 |

[a] Loading ratio: Contributing drainage area divided by BMP surface area.
[b] Design runoff capture volume was not available; design flow rate was 5.58 cubic feet per second

## 1.4.2 Sampling

A summary of collected samples is provided in Table 2. Paired influent-effluent runoff samples from 18 storm events were collected from seven BMPs. The extent of wet weather/runoff sampling at an individual BMP is at the discretion and the resource allocation of the SMC member agency conducting the sampling. For example, BMP 9-1 was sampled more extensively compared to the other BMPs. Engineered media samples were collected by SCCWRP at two or more locations from four BMPs. Media samples were collected at an additional depth (5–10 cm) beyond the standard 0–5 cm surface layer in BMP 9-1 as a one-off opportunity to preliminarily investigate the variability of MP occurrence in media.

**Table 2. Summary of samples collected from each BMP**

| BMP name code | Number of storms sampled (runoff from influent & effluent) | Media sampled? | Media sample location |
|---|---|---|---|
| BMP 6-1 | 2 | No | – |
| BMP 9-1 | 8 | Yes | Inlet and outlet (two depths in each location) |
| BMP 8-2 | 1 | Yes | Forebay and outlet |
| BMP 8-3[a] | 1 | No | – |
| BMP 8-4[a] | 1 | No | – |
| BMP 11-1[b] | 3 | Yes | Inlet and outlet |
| BMP 2-1[c] | 2 | Yes | Inlet and outlet |
| Total | 18 storm events, 7 BMPs | 4 BMPs | |

[a] BMPs 8-2, 8-3, and 8-4 are considered field replicated BMPs; they are located along the same highway and reflect a single design. As such, media samples from BMP 8-2 are considered as representative of all three BMPs.

[b] This BMP has a single influent channel that splits into two distinct paths as it discharges into the BMP. Media samples were collected along each path and are reported separately.

[c] This BMP has two influent/inlet points. Runoff was sampled separately at each point, and the average was used to represent the overall influent. Media samples were collected near each inlet and are reported separately.

### *Runoff*

Paired influent-effluent runoff samples from BMPs were collected between February 2024 and April 2025, spanning two wet-weather seasons. Each BMP was sampled for 1–8 events (Table 2). Flow-weighted composite samples were collected either via autosampler or mixed manually using the post-processing method (Tiernan et al. 2024) from discrete samples collected by an autosampler. In all cases, aliquots contributing to the composite sample were collected over the duration of the entire storm event. Additional details on sampling methods are described in the SMC BMP Regional Monitoring Network Work Plan (Fassman-Beck and Schiff 2022). Flow-weighted composite runoff sample volumes for MP analysis ranged from 1–8 L.

Field and equipment blanks were collected to compensate for the inevitable use of plastic in sample collection equipment. Automated samplers are essential equipment to operate a comprehensive, representative BMP field monitoring program at “reasonable” cost. An example is shown in Figure 4, including an empty bottle for collecting a field blank during a subsequent storm. Equipment types/models are limited, and all are predominantly made of plastic, including Teflon-lined tubing for sample withdrawal and low- density-polyethylene (LDPE) bottles for sample collection. The scope of the current investigation, to sample from multiple BMPs and up to 18 storm events, was made possible by leveraging the extensive instrumentation (and personnel) already in place for the SMC’s ongoing BMP Regional Monitoring Network. Quality assurance and quality control (QA/QC) sampling is described in more detail in Section 1.4.5.


**Figure 4. Example instrument configurations used for collecting flow-weighted composite samples of biofilter influent and effluent. (a&b) refrigerated autosampler uses collection "bottles" (in blue) with disposable plastic liners; (c) component equipment for flow and sampling uses a single, large volume, plastic composite sample collection bottle.**

## *Media*

Media samples were collected within four of the biofilters (BMPs 2-1, 8-2, 9-1, 11-1) between June and July 2024 (i.e. during the dry weather season) (Table 2). Samples were collected on a single occasion from each BMP. Media samples from BMP 8-2 are considered representative of three parallel BMPs (8-2, 8-3, 8-4) constructed along the same highway. BMP 6-1 was not sampled because of resource limitations coupled with the late onset of runoff sampling from this BMP relative to the project end date.

Composite media samples were generated from two separate locations for each BMP. To account for potential spatial heterogeneity of flow paths and accumulation within each BMP, a single composite media sample was collected near the forebay or the inlet(s), and another composite sample was collected near the outlet. Each composite sample was obtained using a stainless steel soil auger (3-1/4" Regular Auger, AMS, American Falls, ID) at 2–3 adjacent points (depending on BMP size) and mixed in an aluminum tray to combine (Figure 5). Most samples were collected as a 0-5 cm depth core. Additional deeper core (5-10 cm) were collected at BMP 9-1 to identify whether media depth should be investigated in future research. Plastics were avoided in the sampling equipment that came into direct contact for media collection, with the exception of blue nitrile gloves worn by the field crew.

Composite samples were split into two portions for laboratory analysis: ~10 g for MP analysis and ~500 g for media particle size distribution analysis. An additional intact core (Figure 5, right) was collected nearby by directly inserting a 100 or 250 mL stainless steel ring (METER Group, Pullman, WA). The sample was used to determine the in-situ media pore-size distribution (Section 1.4.4). Field blanks were also collected during media sampling, as described in Section 1.4.5.


**Figure 5. Media collection for composite and intact core samples. Intact cores were used only for measuring media pore-size distribution.**

### 1.4.3 Laboratory analysis for MPs

Laboratory analysis of a flow-weighted composite sample of stormwater runoff yields an event mean concentration (EMC), which is a single sample of runoff whose characteristics proportionally reflect the variable flow and contaminant concentrations experienced during the course of a single storm event (Tiernan et al. 2024).

Standard methods for the analysis of MPs in stormwater runoff or media/soil have not yet been established in the literature. We provide detailed methods herein to support interpretations, based on SCCWRP's experience developing methods for analysis of MP in drinking water (State Water Resources Control Board 2022), coupled with experience in stormwater runoff sampling.

The workflow for laboratory analysis of runoff and media samples covers four steps (Figure 6):

1. Sieve samples to separate into designated size fractions.
2. Extract potential MPs from other materials, such as organic matter that may be stuck to particulates, using digestion and/or density separation.
3. Count particles using microscopy.
4. Identify which of the remaining particles are polymers, and document polymer type, color, and morphology using FTIR spectroscopy.

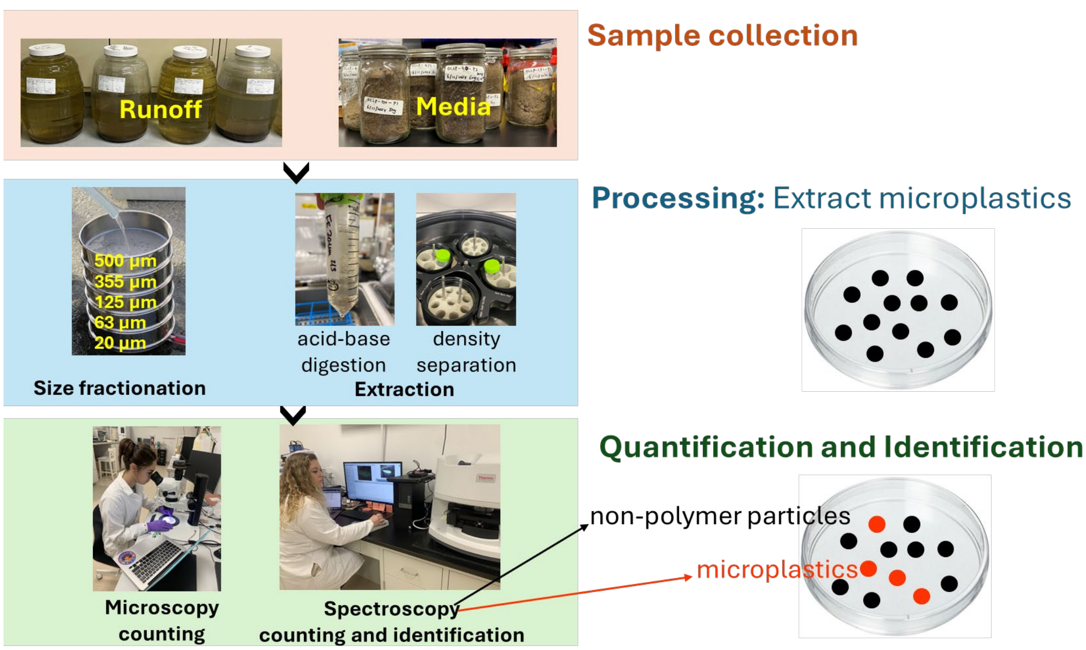


**Figure 6. Laboratory analysis workflow to quantify, identify, and characterize MPs 20 µm to >500 µm.**

## *Materials*

Polycarbonate track etch (PCTE) membrane filters of 20 µm and 1 µm pore size and 47 mm diameter were purchased from Sterlitech (Auburn, WA). Sulfuric acid ($H_2SO_4$, 98%), methanol, and sodium bromide were purchased from Thermo-Fisher Scientific (Chino, CA). Potassium hydroxide (KOH) pellets were purchased from Sigma-Aldrich (St. Louis, MO). All solvents were Optima grade or higher.

Microplastics-analysis-grade (MAG) water and MAG methanol (i.e., MP-free water and methanol) were prepared by filtering deionized water or methanol, through a 1 µm PCTE membrane filter to remove particulates larger than that size (State Water Resources Control Board 2022). Solutions of sulfuric acid and KOH were prepared into appropriate concentrations with MAG water. All glass materials for sampling and laboratory use were washed with DI water and kilned at >450 °C for 4 hours to ensure any remaining organic matter was destroyed.

Amber glass solvent bottles (4 L) from Thermo-Fisher Scientific were used to collect equipment blanks. Runoff samples received from the field were also transferred into these bottles and stored for subsequent extraction and analysis. Wide-mouth glass mason canning jars (950 mL) from Uline (Pleasant Prairie, WI) were used as containers for field blanks and media. Full-height stainless steel sieves (20.3 cm diameter, 6.67 cm height, and 5.08 cm depth) were purchased from Hogentogler & Co. (Columbia, MD). Conical polypropylene centrifuge tubes (50 mL) were purchased from VWR (Radnor, PA). Petri dishes and disposable glass Pasteur pipets were purchased from Sigma-Aldrich. Low emission slides were purchased from Kevley Technologies (Parma, OH). Surrogate polyethylene MP microspheres, consisting of blue (600-710 µm), green (300-355 µm), and red (75-90 µm) of 0.98-1.0 g/mL density, were purchased from Cospheric (Santa Barbara, CA).

## *Extraction*

Runoff samples and media samples were stored in the dark at 4 °C until extraction.

### Runoff

Runoff samples, processed in up to 4 L units, were size fractionated through a sieve stack (20 µm, 63 µm, 125 µm, 355 µm, and 500 µm). A 63 µm sieve was used in place of the 50 µm sieve often used in MP analysis, as 63 µm corresponds to a sand-silt distinction and is commonly used for classifying particulates in stormwater studies (Semadeni-Davies 2013). Particles retained on each sieve were rinsed with MAG water into a vacuum filtration system equipped with 20 µm PCTE filters. After filtration, the filters containing runoff particles were rinsed with MAG methanol to facilitate drying.

An acid/alkaline digestion method was used to extract MPs from runoff samples. This method, developed in-house at SCCWRP, has been shown to efficiently remove both organic and inorganic particulate interferences from aqueous matrices (Lao et al. 2024). Filters from size-fractionated runoff samples were carefully transferred into 50 mL centrifuge tubes and air-dried overnight to remove residual MAG water or methanol. Once dry, approximately 5 mL of 80% $H_2SO_4$ was added dropwise into each centrifuge tube. Each tube was agitated for 5 min, either by hand or vortex mixer, to ensure particles were thoroughly exposed to the acid. The acid-digested sample was then diluted with 30-35mL of MAG water before pouring into a sieve of the corresponding size fraction. The filtrate was discarded, and solids retained on the sieve were rinsed into a clean centrifuge tube using approximately 30 mL of 20% KOH solution. Tubes were capped and incubated at 48 °C for 24 h for alkaline digestion. The resulting sample was again transferred onto a sieve of the corresponding size fraction with the aid of MAG water. The filtrate was discarded, and solids retained on the sieve were transferred into a clean centrifuge tube with MAG water. The centrifuge tube contents were then filtered onto a 20 µm PCTE filter and placed onto petri dishes for storage and subsequent enumeration by visual microscopy.

**Media**

A combination of density separation (Langknecht et al. 2023) and the acid/alkaline digestion procedure described above was used to extract MPs from media samples. . A 10 g portion of wet composite media was subsampled after homogenization by hand mixing. The subsample was transferred to a centrifuge tube and mixed with approximately 35 mL of sodium bromide solution (1.4 g/mL), which separates most polymers from the surrounding media matrix, but not those with higher densities. Each sample was agitated by hand for 1 min and then centrifuged at 4700 rpm for 5 min to separate MPs from inorganic particles in the media. To size fraction the sample, supernatant containing potential MPs and other particles was decanted from the centrifuge tube into a sieve stack containing the same five sieve sizes as were applied for runoff samples (20 µm, 63 µm, 125 µm, 355 µm, and 500 µm). The remaining particles were collected from the sieves and filtered through a PCTE filter using MAG water and methanol, and were subsequently subjected to the digestion procedure described above. A separate aliquot of wet media was dried at 105°C for 12 h to determine moisture content, which was used to normalize MP concentrations to the dry mass of the media.

## *Quantification*

**Microscopy**

Extracted particles on the filters were counted following the guidelines from a previous interlaboratory comparison study (Kotar et al. 2022), using a LAXO microscope equipped with a Z203P digital camera (Mill Creek, Washington). A polar coordinate grid was placed beneath the petri dish to facilitate navigation across the filter and prevent recounting of the same particles. All particles on each filter (representing a specific size fraction) were counted. When particle counts exceeded the number that could be practically counted (approximately 1000 particles), a subsample was counted instead (International Organization for Standardization 2025). Subsample microscopy was conducted using the aforementioned polar coordinate grid, which divided the filter into four quadrants. Particles within the first 15-30 degrees of each quadrant were counted, corresponding to 16-32% of the entire filter area. The proportion of the subsampled area relative to the total filter area was used to calculate total particle counts.

**Spectroscopy**

After microscopy, particles on the filters were transferred into 1.2 mL amber glass vials by gently scraping the filter with a metal spatula. The spatula was rinsed with MAG methanol onto the filter, and the rinsate was transferred to the vial via glass pipette. The methanol was evaporated under a gentle nitrogen stream. Once dry, a small volume of MAG methanol (<0.2 mL) was added to resuspend particles. The suspension was drop-cast onto Kevley low-emission microscope slides in three circular spots of minimal diameter to restrict the deposition area. Slides were stored in petri dishes with loosely fitted lids in a fume hood to dry while minimizing airborne contamination. Complete transfer of particles from the filters to the slides were confirmed by visual and microscopic inspection.

Chemical composition of particles was identified by Fourier-transform infrared spectroscopy (FTIR), using a Nicolet iN10 MX Infrared Imaging Microscope (Thermo Scientific, Madison, WI), following the procedures of De Frond et al. (2023). Particles were identified using one of the two approaches: manual scanning of individual particles or automatic mapping (Cowger et al. 2025). In both approaches, FTIR spectra were recorded for individual particles, and hit quality indexes (HQIs) were assigned by comparison with available spectral libraries. These libraries comprised 30 instrument-provided collections, publicly available databases (e.g., Open Specy, FLOPP, FLOPP- e), and in-house references. A threshold of HQI ≥ 60% was applied for positive identification of chemical composition (State Water Resources Control Board 2022). In addition to chemical composition (e.g., MPs vs. non-MPs, and specific polymer types), particle color and morphology were recorded following established characterization keys.

For the manual identification approach, up to 75 particles were analyzed for each slide. If fewer than 75 particles were present, the full sample was analyzed, which was generally the case for size fractions >355 µm. Smaller size fractions often contained more than 75 particles, making full analysis impractical (De Frond et al. 2023). This 75-particle threshold was recommended as a necessary subsampling strategy to ensure a representative chemical composition of the entire sample, yielding <20% relative standard deviation (RSD) (De Frond et al. 2023).

Automated mapping approach was applied when slides met the following criteria: (1) particle count high enough to justify the time required for map generation, (2) particles within the 63–500 µm size range, and (3) minimal fiber presence, since automated mapping is less effective for fiber identification. Spectra of fibers not captured by automated mapping were collected by using the manual identification approach.

Mapping was applied to each circular area. Since maps were limited to 3.5 × 3.5 mm, larger areas were covered by generating two maps per circular area. From the Omnic Picta program, High Dynamic Range (HDR), data (.dat), map (.map), and JPEG files were exported and processed using an R script (Cowger et al. 2025). The script compiled particle details—including chemical composition, maximum and minimum length, HQI, aspect ratio, circularity, and RGB values—into an Excel file for analysis. Color was determined by converting RGB values to hexadecimal codes and displaying them as colored cells using a custom module developed in Excel's Visual Basic editor; these were then assigned to color keys by the analyst. Morphology was assessed manually from the original mosaic images.

**Calculations**
For MP analysis, MP concentrations are reported as MP counts per liter of runoff (particles/L) or per gram of dry media (particles/g). For each sample, the total MP count was obtained by summing across all five size fractions, and this total was then normalized by the processed runoff volume or media dry weight to calculate concentrations. For this quantification, only particles confirmed as synthetic polymers by FTIR spectroscopy (HQI ≥ 0.6) were classified as MPs; particles with lower HQI values or identified as non-polymers were excluded.

When every particle in a size fraction was analyzed spectroscopically (rather than subsampled), the MP count for that fraction was taken directly from FTIR identifications. When only a subset of particles was analyzed (e.g., in the 20-63 µm fraction with high particle loads) for spectroscopy, the fraction of particles confirmed as synthetic polymers by FTIR was scaled to the total number of particles counted by microscopy (De Frond et al. 2023). If only a portion of the filter was counted during microscopy, the microscopy count was scaled to the area of the whole filter.

Distributions by particle characteristics (polymer type, color, morphology) were derived directly from spectroscopic identifications, expressed as proportions within each category. These proportions were averaged across size fractions without weighting by particle abundance in each size fraction.

For "all" particle analysis, including MPs and non-polymer particles, the calculation followed the same procedure as above, except without restricting counts to synthetic polymers.

### 1.4.4 Laboratory analysis for engineered media characterization

Particle size distribution of media was determined using a modified method from ASTM D422- 63 (ASTM 2013). Approximately 500 g of dried material was sieved through a series of sieves ranging from 0.025 to 5.6 mm. The mass retained on each sieve was recorded to construct the cumulative particle size distribution. $D_{10}$, $D_{30}$, $D_{50}$, $D_{60}$, and $D_{90}$ sizes, corresponding to the diameters below which 10%, 30%, 50%, 60%, and 90% of the sample mass, respectively, are finer were calculated by linear interpolation between sieve sizes. The uniformity coefficient ($D_{60}/D_{10}$) and the curvature coefficient $(D_{30})^2/(D_{10}xD_{60})$ were calculated to characterize the particle size gradation of the media.

Pore size distribution of media was derived from water retention curves measured on intact cores collected in the field (Jabro and Stevens 2022), following the method of Liu (2016). The water retention curve was measured using HYPROP system (METER Group), which employs a pair of tensiometers and a pressure transducer to record matric tension between +0.3 kPa to -100 kPa. The instrument continuously tracks the loss of moisture from the media over time during evaporation while simultaneously measuring matric tension. Matric tension is the negative pressure exerted by capillary and adsorptive forces that hold water within the pore spaces of the media. It reflects the energy required to remove water from the pores and thus provides an indirect measure of pore size. Matric tension, expressed in matric head *h* (cm), can be converted to equivalent cylindrical pore radii (*r*, cm) using Eq. 1:

$$r = \frac{2\sigma}{\rho g |h|} \approx \frac{0.146}{|h|} \quad \text{[Eq. 1]}$$

where $\sigma$ is the surface tension of water (0.073 N/m at 20 °C); $\rho$ is the density of water (998 kg/m$^3$), and $g$ is the gravitational acceleration (9.8 m/s$^2$).

After conversion, cumulative moisture release from the media was expressed as a function of pore size. Pore sizes were binned into fractions corresponding to MP size fractions (i.e., <20 µm, 20-63 µm, 63-125 µm, 125-355 µm, 355-500 µm, and >500 µm), and the water (mass) released from each size fraction was determined from the curve. Water mass was converted directly to volume. To estimate the relative number of pores in each fraction—consistent with MPs being quantified by counts—the water volume in each fraction was normalized by the square of the mean pore radius within that fraction, assuming cylindrical pore geometry. This approach converts water content into a pore-number distribution across the relevant size fractions. The average result from the two tensiometers installed in each media sample was reported.

## 1.4.5 Quality Assurance/Quality Control (QA/QC)

QA/QC measures were applied to assess contamination, quantify background levels, and evaluate recovery. Results for background levels and blank samples are available in the web application (Section 1.4.7) and the summary of QA/QC results is discussed in Section 1.5.7.

Contamination was tracked using multiple blank types (as summarized in Table 3), including field-collected blanks (field, equipment, and split blanks) and laboratory blanks (procedural and air blanks). Each field sample—whether runoff, media, or field blank—was accompanied by a laboratory procedural blank that underwent all steps of the MP analysis. Laboratory procedural blanks were therefore used to establish background levels during analysis and to determine the batch minimum detectable amount ($MDA_B$) for each sample. Both sample and field blank results were compared against the $MDA_B$ associated with each sample. MP extraction efficiency was evaluated using surrogate recovery.

### *Contamination control and assessment*

Significant effort was made to mitigate and quantify contamination from airborne particulates and/or equipment used during sampling and analysis. These measures included, but were not limited to, pre-cleaning of sampling containers, collecting blanks throughout the sampling and laboratory analysis workflows, and employing processing and analysis procedures designed to minimize plastic and particulate contamination.

All non-volumetric glassware used in the laboratory was kilned at 500 ˚C for 4 hours to destroy all organic matter and MPs, then covered with aluminum foil. Equipment remained covered until use, and was rinsed with MAG water as needed. During sample processing, all personnel wore cotton lab coats and nitrile gloves to minimize sample contamination by plastic particulates. All plastic materials used during processing were made of non-shedding grade plastic, which is considered appropriate for MP studies, provided they are tested for shedding (State Water Resources Control Board 2022).

Table 3 summarizes the types of blanks collected, including their purpose, deployment, and location/frequency, covering the full workflow from field sampling to laboratory analysis. These measures are generally consistent with QA/QC guidelines in existing standard operating procedures (SOPs) (State Water Resources Control Board 2022), with additional adjustments for stormwater sampling. For example, equipment blanks and split blanks were incorporated to assess potential contamination from field autosampler equipment and manual compositing processes, respectively. These processes are essential for representative stormwater sampling and cannot be easily replaced in the field, so blanks were collected to assess potential contamination.

**Table 3. Summary of blank types, including purpose, deployment timing, sampling location and frequency, and blank matrix.**

| Type | Purpose | Deployment | Location/Frequency | Matrix |
|---|---|---|---|---|
| Equipment blanks | Assess potential MP contribution from autosampler to runoff samples | Pre and/or post wet season | End of first wet season; start and end of second wet season[a] | 4 L MAG water pumped through autosampler tubing and liners |
| Field blanks for runoff | Assess atmospheric deposition during runoff collection | During field sampling | Each monitoring station for each storm event | 1 L jar of MAG water placed next to autosampler with the lid open |
| Field blanks for engineered media | Assess atmospheric deposition during media collection | During field sampling | Each BMP; same blank deployed for multiple sampling locations within the BMP | 1 L jar of MAG water placed next to sampling location with the lid open |
| Split blanks for runoff | Assess contamination during manual compositing of runoff samples | During runoff compositing | Each compositing activity (when sample aliquots are "split" and combined into a composite) | 1-L jar of MAG water placed next to compositing location with the lid open |
| Procedural blanks | Assess contamination during laboratory processing of a field sample (runoff, media, or a blank) | During laboratory processing and analysis | Each batch of laboratory samples[b] (up to 8 samples) | An aliquot of MAG water (0.5—1 L) processed through the same laboratory procedures as field samples |
| Air blanks | Assess atmospheric deposition of particulates in laboratory environments | During laboratory processing and analysis | Placed all the time in six commonly used areas of laboratory (the fume hood, inside and outside the clean cabinet, sink, microscope, and FTIR instrument) | 47mm PCTE filter (5 µm pore size) in uncovered petri dish |

[a] Autosampler equipment is fixed in place for the duration of a sampling season. Sampling for this project was initiated while the SMC BMP Monitoring Networks' wet season monitoring was already in progress; thus equipment blanks were only collected at the end of the first season so as not to disrupt the overall monitoring program. They were collected at the beginning and end of the second season.

[b] A laboratory sample refers to a single unit that undergoes the complete laboratory procedure. Laboratory samples may differ from the original field sample; for example, one influent runoff field sample can be split into five laboratory samples after size-fractioning. All laboratory samples within the same batch are processed using identical procedures, which may or may not correspond to the original grouping of field samples.

## *Method detection amount (MDA)*

The detection limit of MPs was determined based on batch-specific minimum detectable amounts ($MDA_B$, Eq. 2) (Lao and Wong 2023). $MDA_B$ provides a metric for the extent of contamination in individual laboratory sample batches. MP counts above the $MDA_B$ are considered detectable and quantifiable.

$$MDA_B = N_b + 3 + 4.65\sqrt{N_b} \quad \text{[Eq. 2]}$$

where $N_b$ is the particle count of the associated procedural blank.

In addition, $MDA_A$ was calculated to establish overall background level for the study, i.e., the minimum detection across all samples analyzed. The $MDA_A$ was calculated for total MP counts, by representative morphology (fragments, fibers, and others) and for each size fraction.

$$MDA_A = \overline{N_b} + 3 + 3.29 \times SD \times \sqrt{1 + \frac{1}{n}} \quad \text{[Eq. 3]}$$

where $\overline{N_b}$ and SD represent the average and standard deviation, respectively, of MP counts from all procedural blanks analyzed, and n is the number of procedural blank measurements.

Each field sample (runoff or media) was associated with a procedural blank and, therefore, a corresponding $MDA_B$. Both the field samples and their associated field-collected blanks (field, equipment, and split blanks) were compared against the corresponding $MDA_B$ to determine whether MP counts were at detectable and quantifiable levels. The $MDA_A$ was provided as a study-wide reference.

**Blank evaluation**

Blank MP counts lower than the $MDA_B$ of the associated sample are interpreted as minimal MP presence that is not detectable or quantifiable given levels of interferences from background particulates.

Blank MP counts exceeding the $MDA_B$ but remaining below the corresponding sample MP counts are flagged with a Type I identifier in the data management system (Section 1.4.7) , whereas blanks exceeding both the $MDA_B$ and the sample counts are flagged with a Type II identifier (Table 4). Flags indicate detectable and quantifiable MPs in blanks, reflecting different levels of potential contamination.

**Table 4. Summary of flagged sample conditions and interpretation of flag types used in this study**

| QA/QC sample type | Condition | Flag type | Interpretation |
|---|---|---|---|
| Field collected blanks (field, equipment, and split blanks) | Sample > Blank ≥ $MDA_B$ | Type I | Blank MP level quantifiable but lower than sample count |
| | Blank ≥ Sample ≥ $MDA_B$ | Type II | Blank MP level quantifiable and higher than sample count |
| Runoff or media samples | Sample<$MDA_B$ | Type III | Sample MP level not detectable or quantifiable |
| | Any blank ≥ Sample ≥ $MDA_B$ | Type II | MP level in one or more blanks is higher than the sample level |

* Flags are color-coded in the data management web application: Type I = yellow, Type II = red, Type III = grey

**Sample evaluation**

Samples with MP counts above the $MDA_B$ and higher than all corresponding field blank values are not flagged and are interpreted as detectable and quantifiable, with MP counts exceeding those of all field-collected blanks analyzed in this study.

Samples with MP counts below the $MDA_B$ are flagged with a Type III identifier, suggesting minimal MP presence that is not detectable or quantifiable (Table 4). Samples with MP counts above the $MDA_B$ but lower than any corresponding blank counts are flagged as Type II, suggesting potential contamination from one or more blank sources, as indicated by the associated blank flags. Flagged sample results should therefore be interpreted with caution.

All $MDA_B$ values, blank results, and flag statuses are displayed in the web application (Section 1.4.7). Overall, MP counts were evaluated against both the $MDA_B$ and blank values. Sample MP counts were not adjusted for MPs in blanks or $MDA_B$ values, consistent with best practices in MP analysis (State Water Resources Control Board 2022). Results without any flags represent samples exceeding the $MDA_B$ with no corresponding blanks exceeding sample values (i.e., no red flags).

### *Surrogate recovery*

Surrogate particles were spiked into laboratory samples to assess recovery. A total of 30 polyethylene microspheres—10 each of blue (600–710 µm), green (300–355 µm), and red (75–90 µm)—were added to the initial samples prior to the first steps of processing. Surrogate particles were quantified during post-processing microscopy along with all other particles.

## 1.4.6 Data analysis

All figures and analyses are produced in R 4.5.1 using RStudio. Statistical analyses were used to identify environmental factors influencing MP concentrations in influent runoff and design factors influencing MP removal in biofilters. For example, the potential influence of storm characteristics on untreated (influent) runoff MP EMCs, potential relations between the concentration of total particles counted in microscopy and MPs identified using FTIR spectroscopy, and potential relations between media characteristics and MP capture, were explored using a linear regression (*lm* function) and Pearson correlation analyses (*cor* function). Correlation coefficients ($r$) range from –1 to 1, with values closer to –1 or 1 indicating stronger correlations and values near 0 indicating weaker relationships; correlations with $p < 0.05$ were considered statistically significant. The influence of media depth on treated runoff (effluent) quality (MP EMCs) was explored using a Wilcoxon Rank Sum test at p=0.05 level of significance.

BMP performance for stormwater quality improvement is most commonly quantified in terms of the ability to treat contaminants and the ability to retain runoff. Treatment is defined as reducing the EMC of a contaminant in untreated runoff. Retention is the function of retaining runoff in the media or enabling runoff to soak into the ground such that the volume of runoff discharged downstream is reduced compared to the volume that entered the BMP.

Treatment is commonly measured in the stormwater industry and research in terms of EMC removal efficiency. The treatment efficiency for MPs for a given storm event is measured as the change (Δ) between the influent and effluent EMC relative to the influent EMC, and is calculated as per Eq. 4:

$$\Delta EMC\ (\%) = \frac{EMC_{inf} - EMC_{eff}}{EMC_{eff}} \times 100\% \qquad \text{[Eq. 4]}$$

where $EMC_{inf}$ and $EMC_{eff}$ are the EMCs of influent and effluent (particles/L), respectively.

The combination of treatment and retention produces an assessment of the ability to impact the total number of microplastics for the storm event, a.k.a., the total MP load ($MP_T$). The removal efficiency for total MP particle load between the influent and effluent was calculated as per Eq. 5:

$$\Delta MP_T\ (\%) = \frac{(V_{in} \times EMC_{in}) - (V_{eff} \times EMC_{eff})}{(V_{in} \times EMC_{in})} \times 100\% \qquad \text{[Eq. 5]}$$

where $V_{inf}$ and $V_{eff}$ are the volumes of influent and effluent (L), respectively. This assessment approach is analogous in the BMP industry to evaluating contaminant mass loads, which is commonly applied in watershed management planning for conventional stormwater contaminants.

### 1.4.7 Web Application — Data Management and Visualization

An automated tool (https://sccwrp.shinyapps.io/bmp_microplastics_shiny/) was developed using open-source programming in R studio to process laboratory outputs into MP EMCs and loads, conduct data analysis, and generate associated visualizations. This custom-built data analysis and visualization tool operates in conjunction with a centralized database where datasets are stored and includes quality assurance checks. The tool enhanced data organization and consistency, which is critical for checking, analyzing, visualizing, and exporting MP results given the large number of particles (thousands) and their characteristics (size, morphology, color, and polymer identity). In addition to MP concentration and characterization results, the tool tracks variables such as sample volume/weight and provides comparisons between BMP influent and effluent. It also displays results for all blanks and $MDA_B$ values associated with each sample, organized by size fraction. For more detailed information about the tool, refer to the app's "Overview" page and explore the Results and QA/QC tabs.

The data visualization tool is publicly available, and allows users to download all data and QA/QC results produced in this project.

## 1.5. Results

### 1.5.1. Overall occurrence and treatment efficiency

Eighteen storms were sampled from January 2024 to May 2025, with rain depth ranging from 0.25–3.23 in. The monitored events covered a wide range of operating conditions compared to the design storm sizes (0.46–0.85 in). Approximately 40% of the monitored storms fell within ±30% of design storm depth, which implies that the data set offers reasonable insight into MP removal in southern California biofilters overall.

MP occurrence in untreated and treated wet weather runoff was evaluated by exploring EMCs. Event-by-event treatment is evaluated by the comparison between occurrence in the influent and effluent (Eq. 4), and the total number of MP particles (i.e., loads) entering and exiting BMPs for each event (Eq. 5). Figure 7 (a) summarizes MP EMCs in influent and effluent, while (b) shows treatment efficiencies, expressed as percent removal, for both MP EMCs and $MP_T$ loads per event. Table 5 provides a statistical summary across all storm events and BMPs. Detailed results for individual BMPs and storm events may be explored in the web application referenced in Section 1.4.7.

Untreated, influent EMCs measured in runoff in this study were highly variable, ranging from dozens to 6850 particles/L. Treated, effluent concentrations were substantially lower and exhibited less variability, as indicated by the narrower interquartile range (IQR), suggesting that biofilters effectively reduce MP concentrations at the site scale and produce comparatively consistent effluent quality.

All but one event showed positive MP removal. The median treatment efficiency across all events was 72%, indicating overall substantial reduction in MP EMCs. Almost all MPs were removed in two events; the effluent EMCs in these events were 3 particles/L and 15 particles/L. One event in BMP 9-1 exhibited "negative removal", where the effluent EMC exceeded the influent EMC, meaning that the BMP contributed MP to the runoff; this event was statistically identified as an outlier for the dataset. It is also noted that the data point is an outlier compared to the other 7 events measured for this BMP. No definitive cause for MP export during this event was identified (e.g., storm size or timing). It is common in BMP performance studies to periodically measure export of conventional contaminants.

The median $MP_T$ load reduction was 93% (IQR: 88-99%). The apparent greater removal expressed by changes in $MP_T$ compared to changes in EMCs is due to what each metric represents: EMCs represent MP counts per unit volume (i.e., per liter) of runoff. $MP_T$ gives the total number (count) of MPs in the runoff. Each metric will be influenced by the volume of water in consideration. Where there is less runoff volume discharged downstream because the BMPs retains runoff, fewer MPs are carried downstream as well.

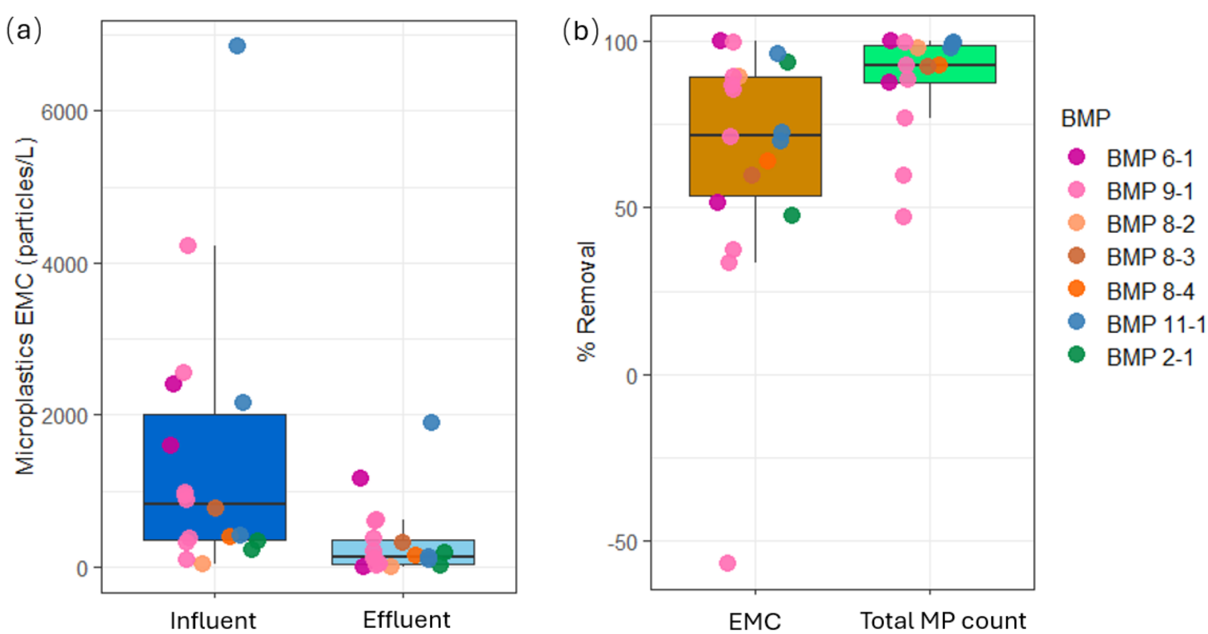


**Figure 7. (a) MP EMCs in the influent and effluent, and (b) event-based removal efficiency of EMCs and $MP_T$ loads. The length of the boxes show the 25th percentile, median, and 75th percentile, with whiskers extending to 1.5 × IQR. Individual points are overlaid and color-coded by BMP identifier.**

**Table 5. MP EMCs and treatment efficiency results summary statistics.**

| Metric | Minimum | Maximum | Median | IQR | Events (#) |
|---|---|---|---|---|---|
| Influent EMC (particles/L) | 29 | 6850 | 824 | 345−2008 | 18 |
| Effluent EMC (particles/L) | 3 | 1897 | 133 | 41−357 | 18 |
| Treatment efficiency for EMCs (DEMC, %) | -57 | 99.8 | 72 | 54−89 | 18 |
| Treatment efficiency for $MP_T$ loads ($DMP_T$, %) | 47 | 99.9 | 93 | 88−99 | 14[a] |

[a] Flow data was not available for 4 events, precluding calculation of $MP_T$.

### 1.5.2. Influence of environmental factors on EMCs in runoff

Influent EMCs were evaluated qualitatively across land uses (roadway, parking lot, and public park) and quantitatively against storm characteristics, including rain depth, peak intensity, and antecedent dry period, using Pearson correlation. Among storm characteristics, only antecedent dry periods showed a statistically significant correlation with influent EMCs (Figure 8), with longer dry periods linked to higher concentrations (i.e. longer dry periods increase pollutant build-up on land surfaces, leading to greater wash-off in the subsequent storm). In contrast, precipitation characteristics such as rain depth or intensity —previously reported to elevate MP concentrations (Piñon-Colin et al. 2020; Smyth et al. 2021; Lange et al. 2021)—showed no effect here, possibly due to the multi-location sampling design. Effluent EMCs were evaluated against the ratio of rain depth to design depth, as storms exceeding the design size may reduce treatment performance. No significant correlation was observed between rain depth/design depth and effluent EMC (Figure 9), further emphasizing the conclusions about consistent performance (i.e. more severe operating conditions do not compromise effluent quality). For land uses, qualitative observation suggests that influent concentrations were generally lower (<25$^{th}$ percentile) for the BMP receiving runoff from a public park (BMP 2-1) relative to roadway and parking lot sites (i.e. all other sites).

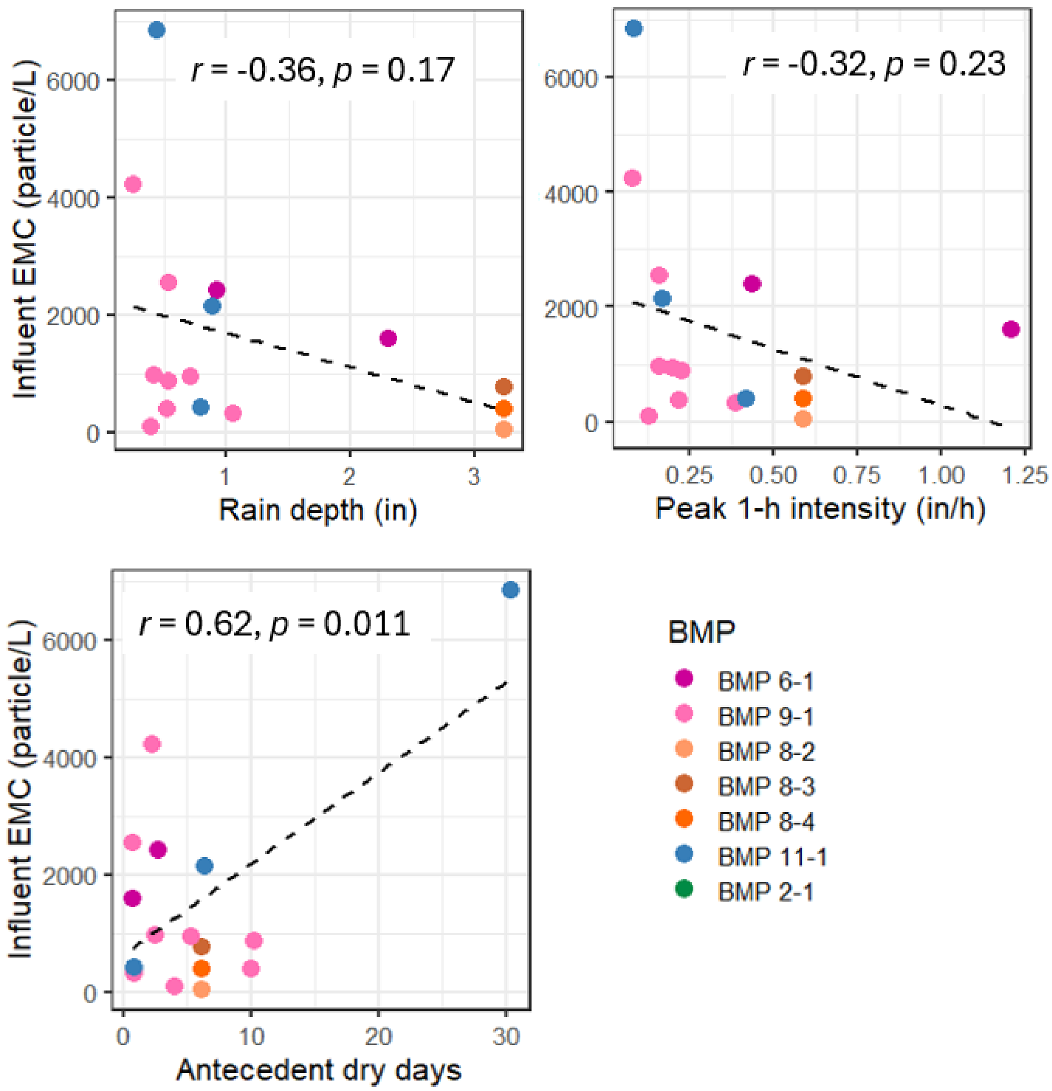


**Figure 8. Pearson correlations (*r*) between storm characteristics and influent EMCs. Statistical significance (*p*) is indicated at *p*<0.05. Dashed lines are included only to illustrate the direction of trends.**

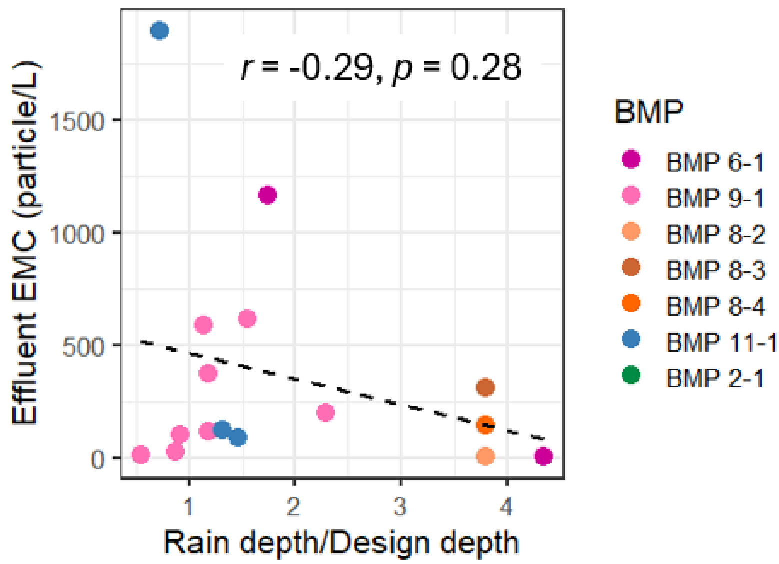


**Figure 9. Pearson correlations (*r*) between storm characteristics and effluent EMCs. Statistical significance (*p*) is indicated at *p*<0.05. Dashed lines are included only to illustrate the direction of trends.**

### 1.5.3. Evaluation of runoff MPs by size fraction

MP concentrations were further assessed by size fraction (Figure 10). Both influent (untreated) and effluent (treated) were dominated by the smallest size fraction evaluated (20–63 µm), with this dominance even more pronounced in the effluent. This pattern aligns with general observations in urban runoff, where MP particles of smaller sizes typically prevail (Liu, Alvise, et al. 2019; Öborn et al. 2024).

The 20–63 µm size fraction accounted for >90% of total MPs in the effluent. Despite this dominance, MPs in this size fraction still showed a substantial decrease due to biofilter treatment — the median concentration dropped to 121 particles/L in the effluent, corresponding to a treatment efficiency of 68% (IQR: 39−92) for this size fraction (Table 6). Treatment effects are visually evident, as demonstrated by the example slides from a single storm event in BMP 9-1 (Figure 11). Although this efficiency was lower than that of larger size fractions (all others were above 85%), overall treatment efficiency across all measured sizes remained high.

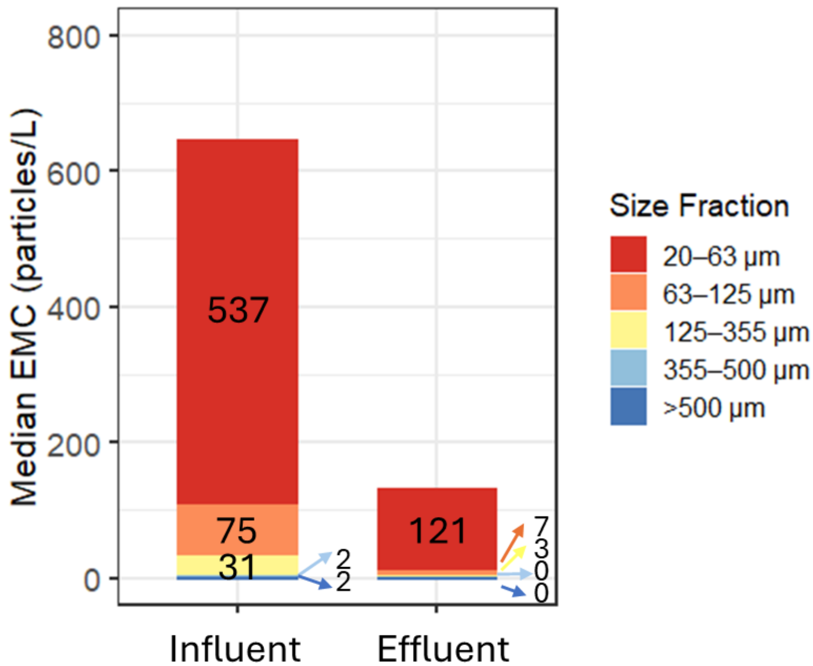


**Figure 10. Median EMCs of each size fraction, shown as stacked bars for influent and effluent. IQRs of EMCs and treatment efficiencies for each size fraction are provided Table 6.**

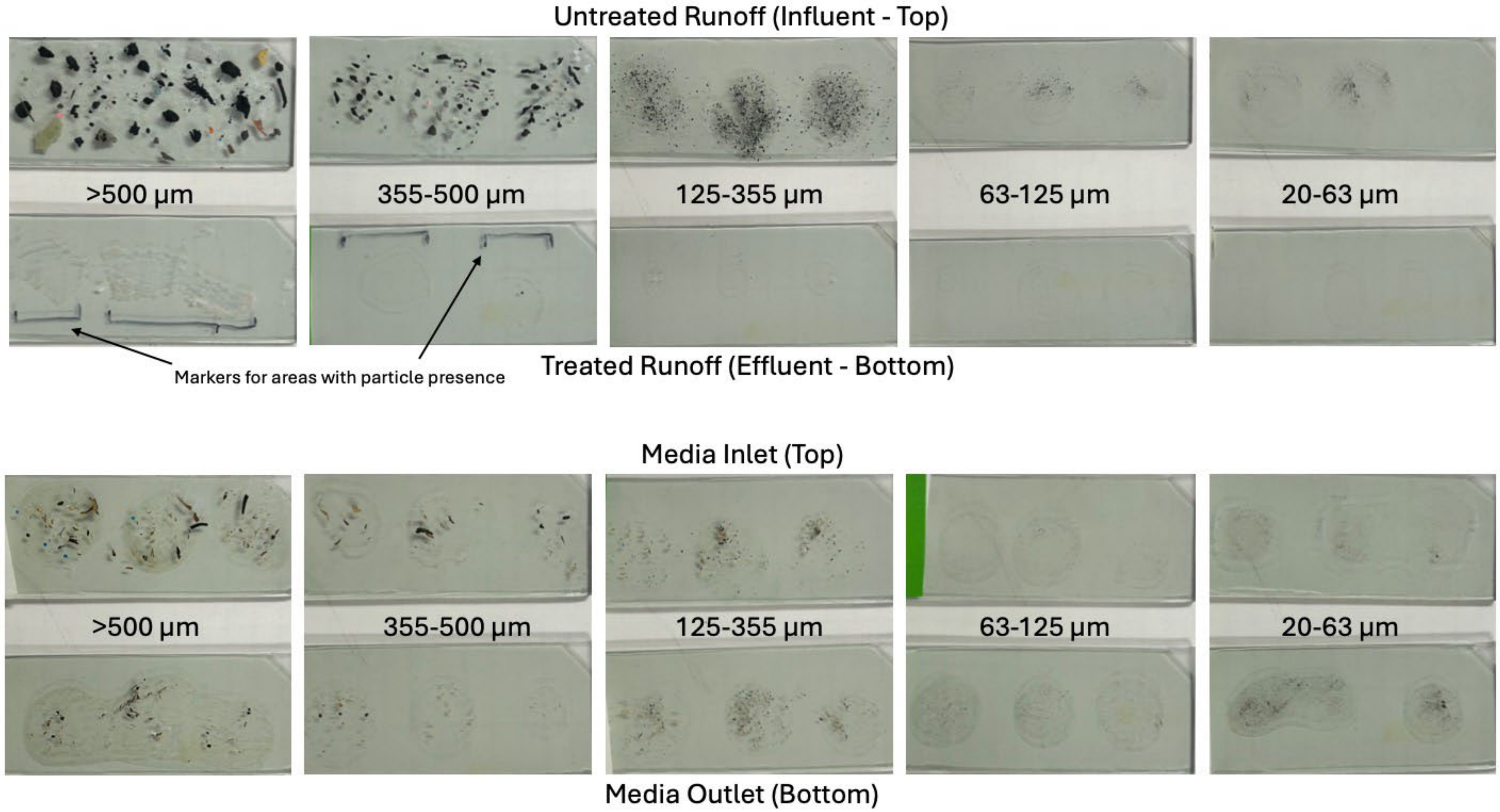


**Figure 11. Extracted and size fractioned particles from one BMP 9-1 sampling event: runoff (upper) and media (lower) . Slides are grouped by particle size (left to right: >500 µm, 355-500 µm, 125-355 µm, 63-125 µm, 20-63 µm). The slides in each row, from top to bottom, show extracted particles from influent runoff, effluent runoff, media near the inlet, and media near the outlet.**

**Table 6 Statistics of MP EMCs and treatment efficiency by size fraction.**

| Size fraction | Influent | | Effluent (particles/L) | | Treatment efficiency (DEMC, %) | |
|---|---|---|---|---|---|---|
| | Median | IQR | Median | IQR | Median | IQR |
| 23-63 μm | 537 | 191−1687 | 121 | 32−320 | 68 | 39−92 |
| 63-125 μm | 75 | 15−180 | 7 | 3−18 | 85 | 39−97 |
| 125-355 μm | 31 | 4−86 | 3 | 2−6 | 91 | 30−97 |
| 355-500 μm | 2 | 1−5 | 0 | 0 | 100 | 94−100 |
| >500 μm | 2 | 0−6 | 0 | 0−1 | 89 | -57−100 |

### 1.5.4. MP concentrations in biofilter media

Engineered media samples were collected from multiple locations within each of 4 BMPs representing particles captured and accumulated over the service life of each BMP. MP concentrations in the resultant 12 engineered media samples, are shown in Figure 12 and Table 7. Concentrations ranged from tens to >1000 particles/g (dry weight basis), with substantial heterogeneity observed both among BMPs and between locations where samples were collected (in the vicinity of the inlet and the outlet locations. Variations across sites appear to be influenced by BMP service years, size, and influent MP concentrations. The assumption herein is that all MP measured in the media are attributed to runoff capture; virgin media for any of the BMPs was not available for assessment.

BMP 8-2 showed the lowest MP concentrations in its media, which may be explained by the lowest monitored influent MP concentration across all events coupled with the largest surface area of the monitored biofilters (i.e. there is more area over which the low EMC influent is spread for treatment (Table 1)). In contrast, BMP 11-1 exhibited the highest media MP concentrations. It is the oldest system monitored at six years of operation (Table 1) and had among the highest influent EMCs, with 2 of 3 monitored events exceeding the 75$^{th}$ percentile influent EMC (Figure 7 (a)). High concentrations were observed at both media sampling locations where the inlet discharges into BMP 11-1, indicating substantial MP retention at this location.

When MP concentrations in media were evaluated by size fraction, patterns were broadly consistent with those observed in influent runoff. The smallest fraction (20–63 μm) dominated across all BMPs, followed by the 63–125 μm fraction, indicating that MPs retained in the filter media largely mirrored the size profile of incoming runoff. This trend is visually evident in the slides prepared for spectroscopy, as shown in Figure 11, using BMP 9-1 media as an example.

Engineered media samples were collected in the vicinity of the inlet and the outlet of each BMP. Spatial heterogeneity in MP accumulation was expected, as these locations represent the closest and farthest points as surface flow enters and travels through the BMP. We hypothesized that preferential or more frequent flow through the media in the vicinity of the inlet might be experienced in smaller, more frequently occurring storms and/or in BMPs with rapidly infiltrating engineered media, resulting in higher concentrations in these locations. The variability between inlet and outlet locations within the same site was as high as 5–10 fold; however, no consistent inlet-outlet patterns were observed. Spatial variability within BMPs is likely governed by site-specific factors such as BMP structure and hydraulic design. Although data are limited, additional sampling at a deeper layer (5–10 cm) at BMP 9-1 indicated vertical heterogeneity, though it was less pronounced than the lateral variability between the same locations.

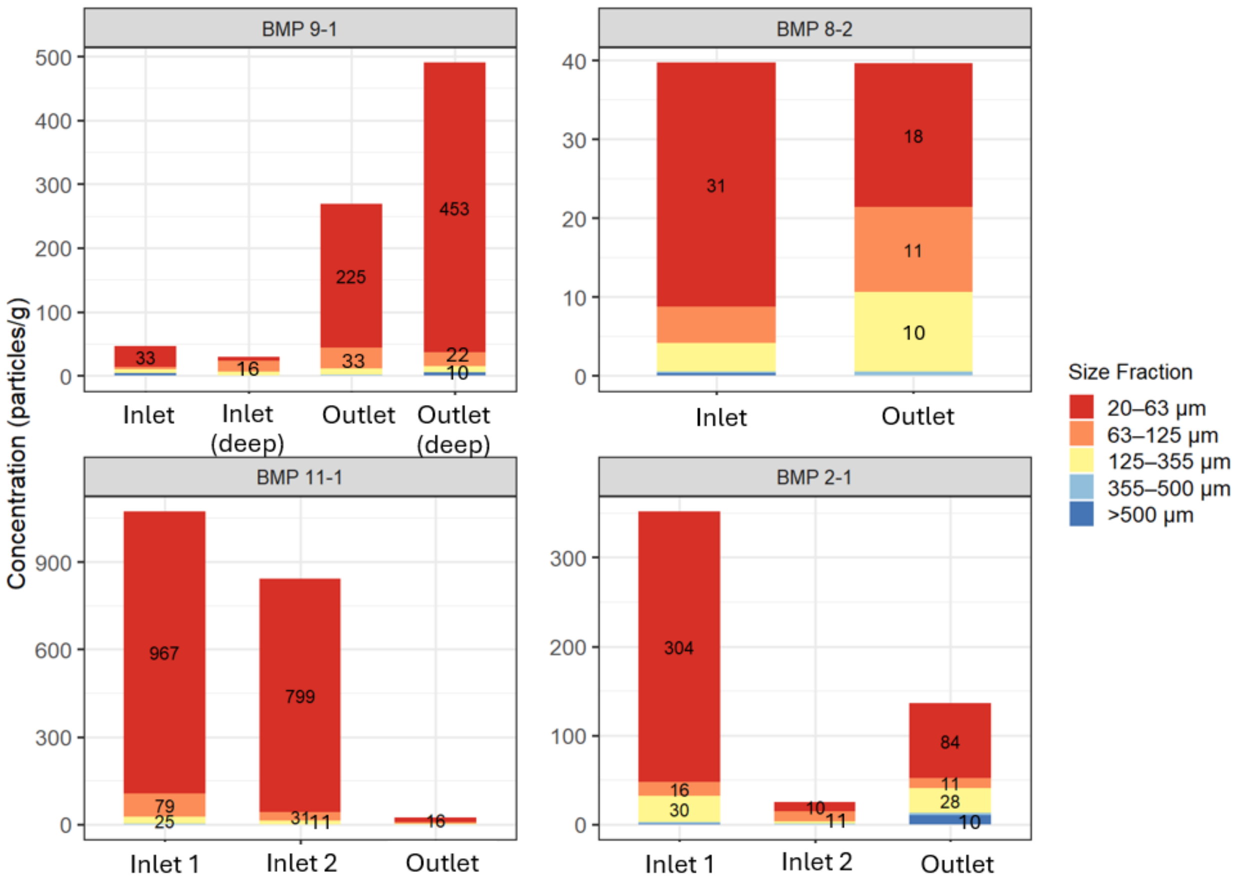


**Figure 12. MP concentrations in BMP media, reported as particles per gram dry weight, across different BMPs and sampling locations within each BMP. Concentrations are further broken down by size fractions, with values for each size class labeled on the bars. Bars labeled "deep" represent samples collected from the 5–10 cm depth, while all other samples represent the surface layer (0–5 cm).**

**Table 7 MP concentrations (particles/g) in biofilter media by size fraction.**

| BMP | Sampling Location | 20-63 µm | 63-125 µm | 125-355 µm | 355-500 µm | >500 µm | Total |
|---|---|---|---|---|---|---|---|
| BMP 9-1 | Inlet | 33 | 3 | 6 | <1 | 4 | 46 |
| | Inlet (deep) | 7 | 16 | 7 | 0 | 0 | 30 |
| | Outlet | 225 | 33 | 9 | 2 | 0 | 269 |
| | Outlet (deep) | 453 | 22 | 10 | 0 | 5 | 490 |
| BMP 8-2 | Forebay | 31 | 5 | 4 | 0 | 0 | 40 |
| | Outlet | 18 | 11 | 10 | 1 | 0 | 40 |
| BMP 11-1 | Inlet 1 | 967 | 79 | 25 | 1 | 1 | 1073 |
| | Inlet 2 | 799 | 31 | 11 | 1 | 0 | 843 |
| | Outlet | 16 | 6 | 1 | 0 | 0 | 24 |
| BMP 2-1 | Inlet 1 | 304 | 16 | 30 | 2 | 1 | 352 |
| | Inlet 2 | 10 | 11 | 3 | 1 | 0 | 25 |
| | Outlet | 84 | 11 | 28 | 3 | 10 | 136 |

### 1.5.5. MP morphology, chemical composition, and color

Figure 13 shows the proportions of MP morphology, chemical composition, and color in runoff and media samples.

Fragments dominated the morphology of MP in runoff samples, contributing more than 80% of all MPs. Fibers made up less than 10%, which is lower than values reported elsewhere (Kwarciak-Kozłowska and Madeła 2025; Wolfand et al. 2023). The proportion of fibers is likely underestimated, as fibers are more difficult to extract than other morphology. Effluent runoff samples showed a slightly higher proportion of fiber and fiber bundles, but trends overall were subtle with respect to any shifts in morphology due to BMP treatment. Fibers and fiber bundles have been shown to be more difficult to remove in other water matrices (Patterson 2021; Asadi et al. 2025).

A total of 16 distinct polymer types were identified in the influent runoff, compared to 10 in the effluent. Olefins were the most abundant group, encompassing polyethylene (PE), polypropylene (PP), and cyclic olefin polymers. Among individual polymers, PE and PP were most prevalent, followed by polystyrene (PS) and polyurethane (PU). These findings on polymer types are consistent with the literature for MPs in urban runoff (Bailey et al. 2021; Kwarciak-Kozłowska and Madeła 2025; Hoang et al. 2025; Liu, Alvise, et al. 2019; Liu, Olesen, et al. 2019) and reflect the widespread use of these polymers in consumer goods and single-use plastics. A clear shift was not observed in overall polymer distributions due to BMP treatment, though the number of distinct polymer types decreased.

In terms of color, clear and white particles were most abundant in runoff samples, followed by brown, black, and grey colors.

The morphology, chemical composition, and color of MPs in the media generally reflected those observed in the influent runoff. Olefins (including PE and PP) and PS fragments dominate media samples, with clear, brown, black, and white as the most common colors. Only limited retention of fibers and fiber bundles was observed in the media.

Source identification was outside the scope of this study; however, black particles were further analyzed to assess their likelihood of representing road and tire wear particles (Figure 14). Overall, black MPs accounted for less than 15% of all MPs by color. The polymer distribution among black MPs was consistent with the overall polymer distribution observed across all color categories (Figure 13 (b)), with olefins, PE, and PP remained the dominant components. In addition to these common polymers, several road- and tire-derived materials were detected in the influent, including rayon, acrylic, and rubber (Lange et al. 2023; 2021; Monira et al. 2021; Öborn et al. 2024), as well as polymers identified as tire wear particles in the spectral library. In contrast, the effluent exhibited a lower proportion of black MPs and reduced chemical diversity. Notably, these road- and tire-derived polymers were largely absent from effluent samples.

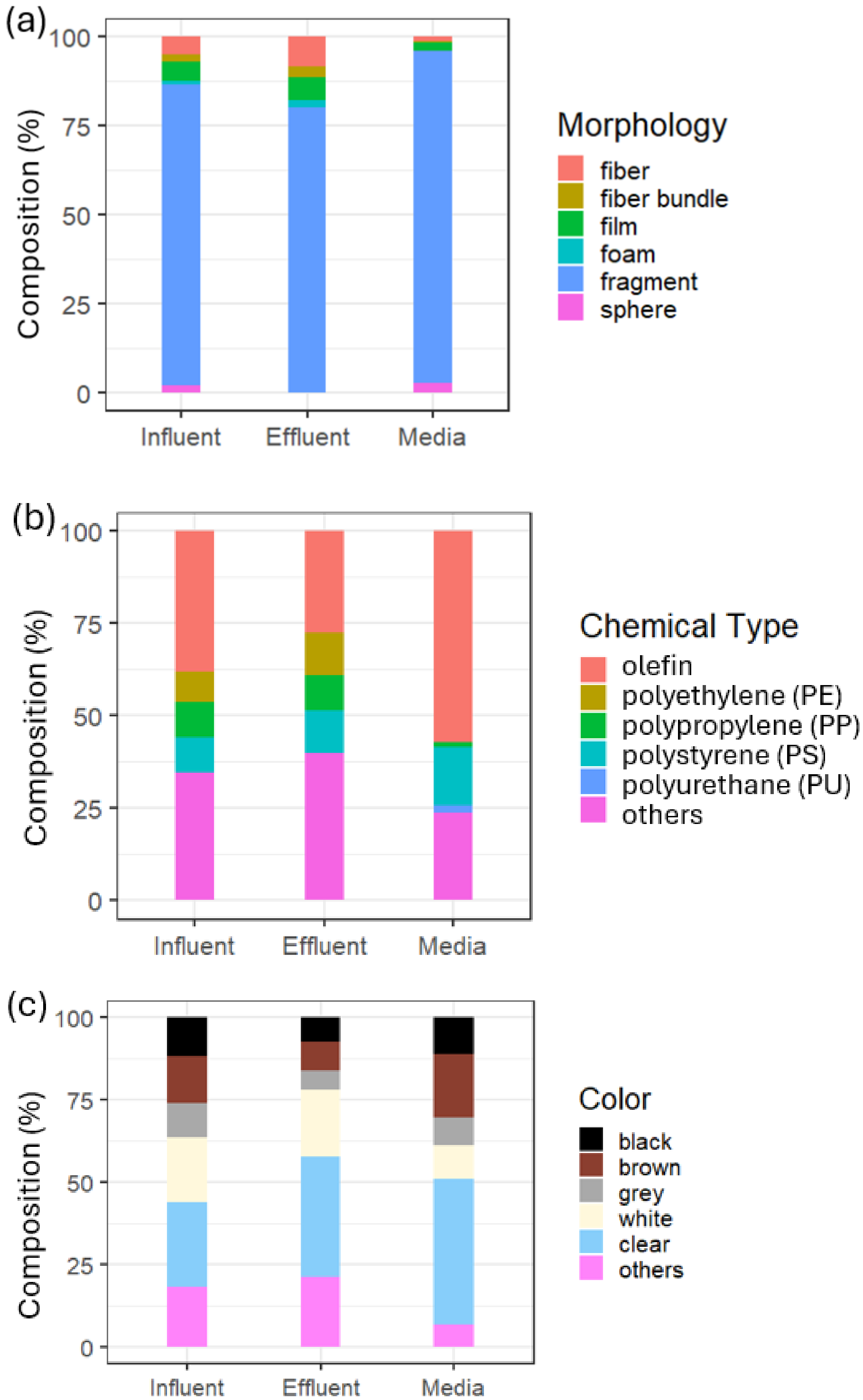


**Figure 13. Median composition of MPs by morphology, chemical type, and color identified during spectroscopy for influent and effluent runoff samples, and media samples. Chemical type is shown for the five most abundant polymer types; "others" includes 10 less abundant polymers identified in this study and polymers without a specific chemical assignment ("other polymer"). Colors are also presented for the five most abundant categories, with the remainder grouped as "others".**

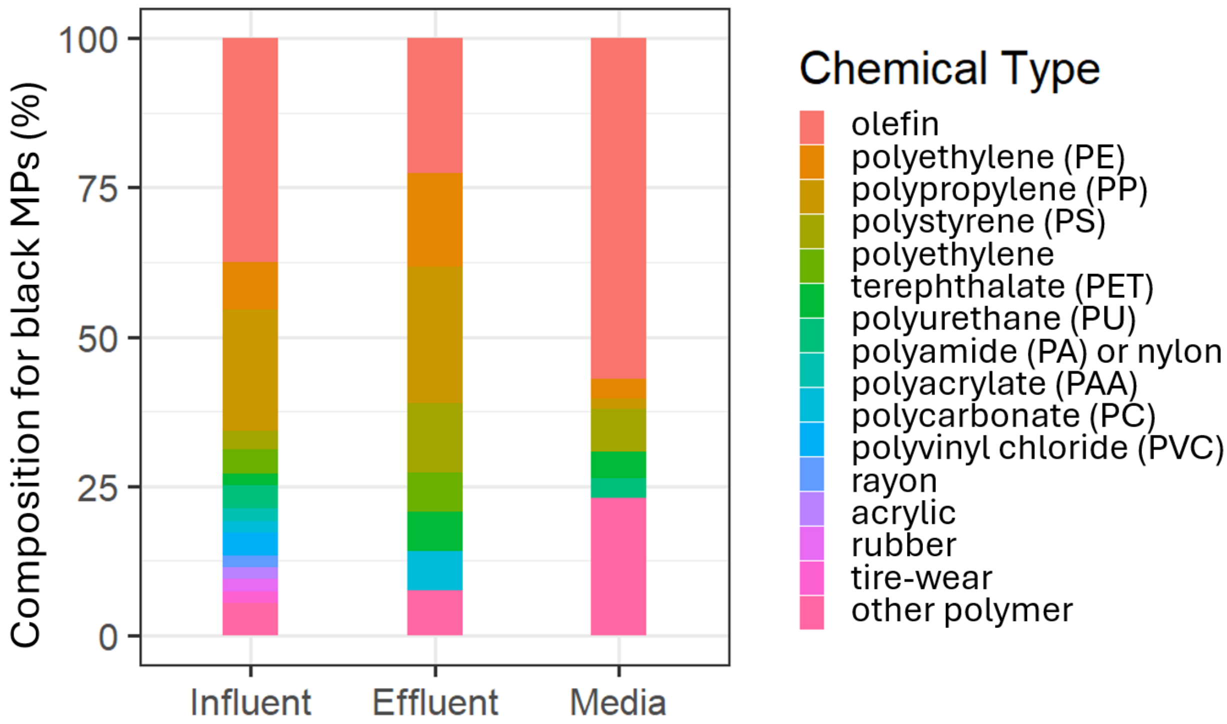


**Figure 14. Median composition of black MPs by chemical type.**

### 1.5.6. Biofilter media particle- and pore-size distribution

The particle size distribution of the biofilter media, a parameter specified in biofilter BMP design guidance for sand, was analyzed and compared against the recommended sand gradation range (Figure 15, red brackets). Most media fell within the design guidance limits, further confirming that the monitored BMPs can be considered representative of southern California biofilters. The minor exception is BMP 11-1, which contained fewer fine particles (<1000 µm) and therefore a higher proportion of coarse media.

Both gradation indices, the uniformity coefficient and curvature coefficient, indicate that all media can be considered well-graded (Table 8). Well-graded media typically have uniformity coefficients greater than 4 and curvature coefficients between 1 and 3. The uniformity coefficients for all samples were close to or above 4, except for the outlet of BMP 11-1 (2.8), indicating a relatively broad range of particle sizes. Curvature coefficients were mostly 1±0.3, near the lower end of well-graded range; although it is noted that the inlet of BMP 11-1 exhibited higher values (1.8 and 2.4).

The pore size distribution was further examined, as pores are hypothesized to be the primary sites where MP capture occurs. Pores were categorized by diameter (corresponding to MP size fraction), and their contributions were evaluated in terms of both volume occupied (Figure 16 (a)) and the number of pores in each size range (Figure 16 (b)). Two key observations emerged. First, while pore volumes were fairly evenly distributed across size fractions, translating volumes into the number of pores (Section 1.4.4) reveals that pores <20 µm are the most abundant. These small pores can capture MPs across all measured sizes, explaining the high removal observed overall. Second, BMPs with a greater proportion of sub-20 µm pores generally exhibited greater MP removal, highlighting the critical role of small pores for treatment given that MPs in 20–63 µm dominate MP particle population. For example, a higher proportion of small pores was measured in BMP 11-1, which also coincides with greater MP retention measured at this BMP despite having a coarser particle size distribution.

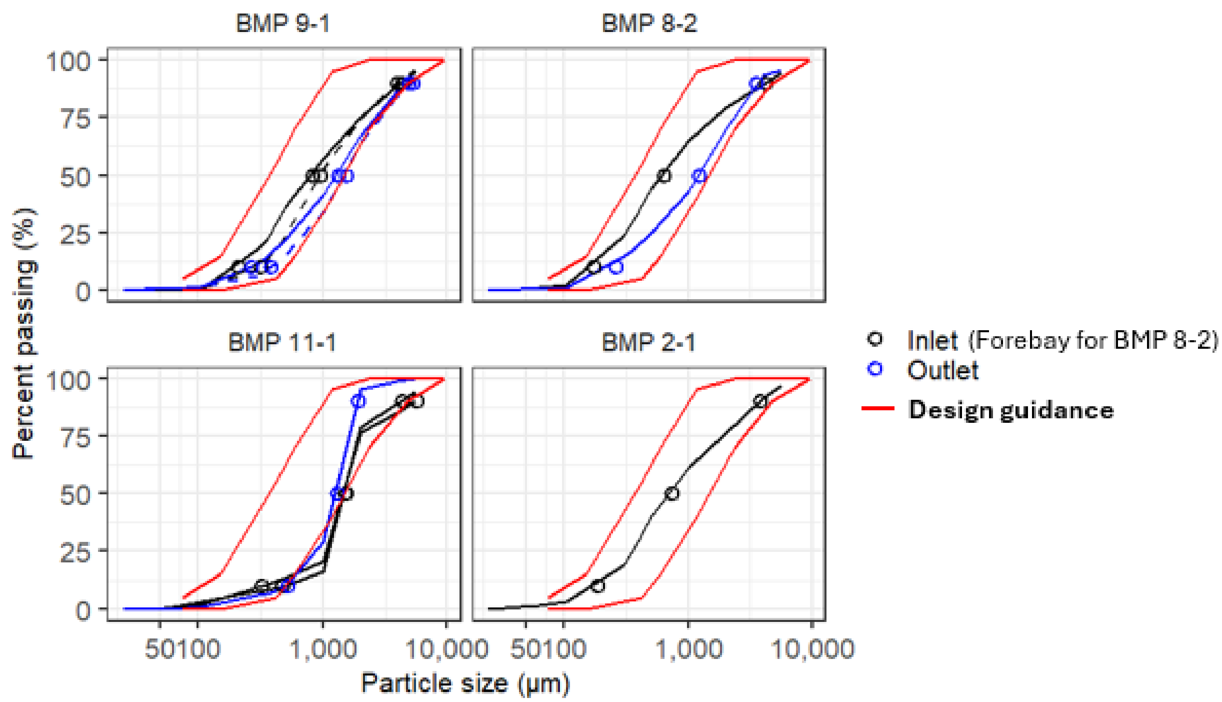


**Figure 15. Particle size distribution of media samples. Black and blue lines represent inlet and outlet samples, respectively; solid lines correspond to shallow depth (0–5 cm) and dashed lines to deep depth (5–10 cm). Open circles indicate $D_{10}$, $D_{50}$, and $D_{90}$. Red brackets illustrate gradation limits for sand in bioretention soil media (BSM) according to local BMP design guidance (Snyder et al. 2020).**

**Table 8. Particle size characteristics (gradation indices) of media samples.**

| BMP | Location | $D_{50}$ | Uniformity Coefficient ($D_{60}/D_{10}$) | Curvature coefficient $(D_{30})^2/(D_{10} x D_{60})$ |
|---|---|---|---|---|
| BMP 9-1 | Inlet | 830 | 5.5 | 0.8 |
| | Inlet (deep) | 960 | 4.3 | 0.9 |
| | Outlet | 1340 | 6.4 | 1.1 |
| | Outlet (deep) | 1530 | 4.9 | 1.1 |
| BMP 8-2 | Forebay | 640 | 5.0 | 0.8 |
| | Outlet | 1270 | 7.1 | 1.1 |
| BMP 11-1 | Inlet 1 | 1540 | 3.6 | 1.8 |
| | Inlet 2 | 1520 | 5.2 | 2.4 |
| | Outlet | 1320 | 2.8 | 1.3 |
| BMP 2-1 | Inlet 2 | 740 | 5.1 | 0.9 |

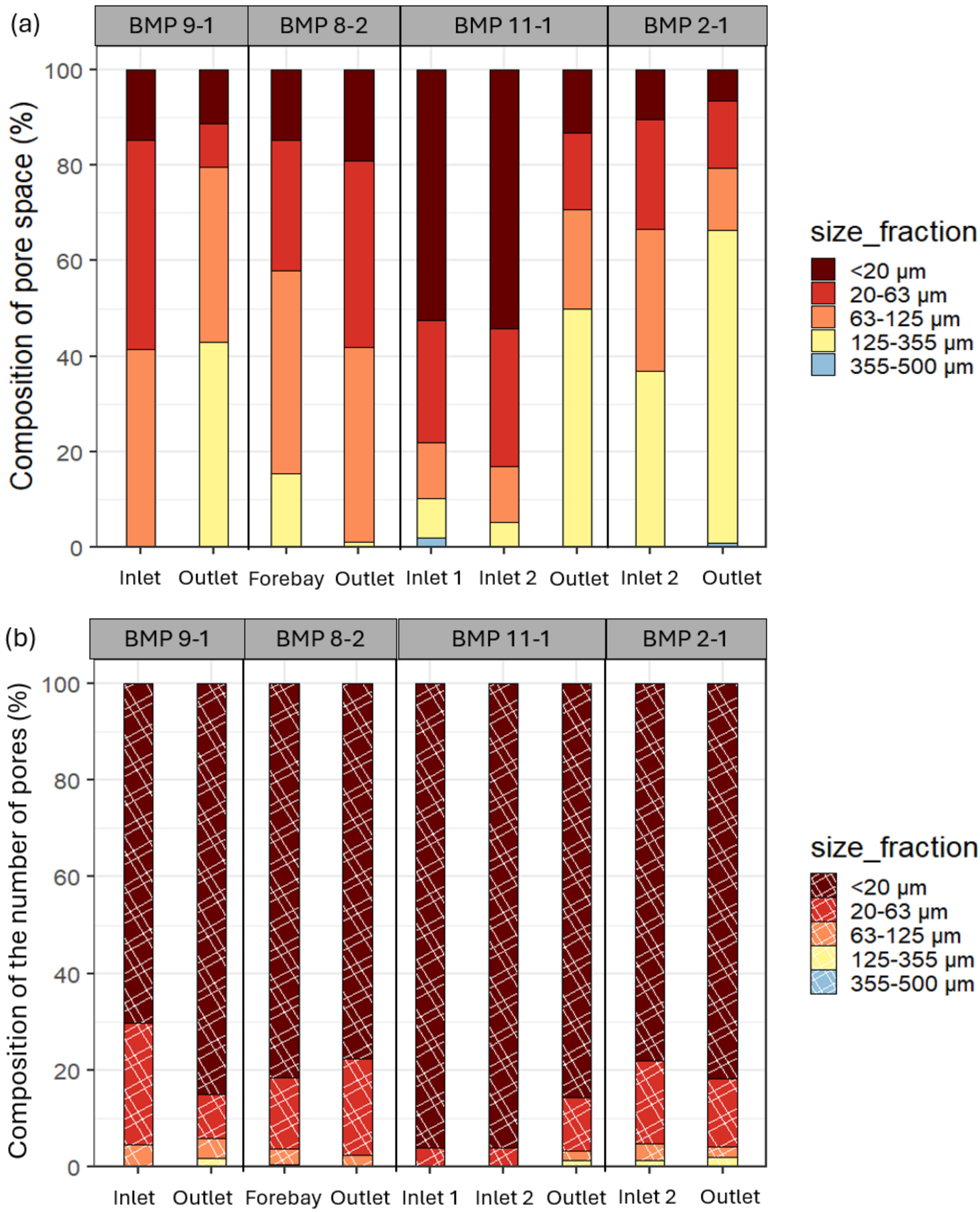


**Figure 16. Composition of pores in media by pore-diameter size fraction: (a) pore space (b) number of pores. Size fractions correspond to those used in MP analysis.**

## 1.5.7. QA/QC

Criteria for evaluating blank levels or recovery have not yet been established for MP analysis, nor have procedures for adjusting sample concentrations due to QA/QC assessment. The procedures used here are consistent with best practices outlined in the SOPs for MP analysis in drinking water (State Water Resources Control Board 2022) and produce QA/QC results comparable to those reported in similar studies (Thornton Hampton et al. 2023; Wong, Lau, Dial, Nguyen, Butler, et al. 2024; 2024).

### *Overall background MP level in laboratory analysis*

Over the duration of the study, air deposition of “all” particles averaged 2.2 ± 1.1 particles per day per location. These values are comparable to those observed in previous in-house studies: 2.0 ± 0.9 and 3.6 ± 3.7 particles per day per location, respectively (Wong, Lau, Dial, Nguyen, Butler, et al. 2024; Wong, Lau, Dial, Nguyen, and Thorton Hampton 2024). Given that the average MP count across all analyzed samples was 3053.9 ± 3921.6 particles per sample, the laboratory environment is not considered a meaningful source of contamination.

The MDA provides a basis for establishing background levels for MP detection and quantification in laboratory analyses. The study applied two types of MDA metrics: a study-wide $MDA_A$, derived from all procedural blanks measured during the study period, and a sample-specific $MDA_B$, based on the procedural blank associated with each individual sample. The $MDA_A$ represents the laboratory’s overall detection and quantification capability and provided as a reference, whereas the $MDA_B$ is used to determine whether MP counts in a given sample are detectable and quantifiable. $MDA_A$ values for total MP counts, and by morphology and size fraction, are presented in Table B1 (Appendix B). All $MDA_B$ values associated with individual samples are documented and accessible through the web application (Section 1.4.7).

The $MDA_A$ for total MP counts across all size fractions was 91 particles. $MDA_A$ values for individual size fractions ranged from 8 to 35 particles, with smaller particle counts (<125 µm) in the 30s and larger particle counts (>355 µm) below 10. These values are well below the MP levels measured in this study, with 4 out of 50 samples (38 runoff plus 12 media) showing total MP counts below $MDA_A$.

When compared to $MDA_B$, only 2 sample results were below the detection, indicating that MPs were detected and quantified in nearly all runoff and media samples analyzed in this study. The two results, considered detectable but not quantifiable, are flagged in the web application.

### *Potential contamination assessment from field sampling*

Blanks collected at various stages of sampling were compared against overall $MDA_A$ and $MDA_B$ associated with sample, and sample MP counts to assess potential contamination during field sample collection (field and equipment blanks) and sample compositing (split blanks). Each sample had an associated laboratory procedural blank and $MDA_B$; however, not all field blank types were available for and applicable to every sample. All $MDA_B$ and blank results are documented and accessible through the web application (Section 1.4.7).

A total of 47 field-collected blanks were analyzed, all from the first year of sampling. Field-collected blanks were not analyzed in the second sampling season because first year results demonstrated strong overall contamination control and to balance logistical and resource constraints.

None of total MP counts in blanks exceeded the $MDA_A$, suggesting that the MPs detected in field-collected blanks were blow the laboratory's overall detection capability. When blank values were compared to $MDA_B$, a portion (18 out of 47) of the field-collected blanks were flagged in yellow, indicating detectable and quantifiable MPs in these blanks. When blank values were compared directly to sample MP counts, none of the field collected blanks were flagged in red, i.e., MP counts in blanks were lower than those in their corresponding samples. MPs in blanks accounted for 10.0±14.2% of the corresponding sample MP counts. Yellow flags appeared sporadically across blank types, with no evidence of systematic contamination from a single source.

A few blanks for specific size fractions were flagged in red, typically when MP counts in field samples in those fractions were low. When results were aggregated across all size fractions, MP counts in field samples exceeded blank levels and were no longer flagged in red.

Overall, assessment of field-collected blanks, based on comparisons with $MDA_B$ and sample MP counts, indicates that contamination was effectively controlled and that the equipment used for sampling (e.g., autosamplers for runoff) is suitable for MP analysis, provided that blank levels are quantified and best practices are followed.

### *MP extraction efficiency*

Extraction efficiency of MPs from samples was evaluated using spiked surrogate recovery tests with microspheres of three different sizes. Recoveries from runoff and media samples (Table B2 and Table B3, Appendix B) were similar, and showed that larger particles had higher recoveries (>85% in both runoff and media for 600-710 µm spheres), whereas smaller particles exhibited lower mean recoveries and greater variability (36±32% in runoff and 42±29% in media for 63-125 µm spheres). This indicates that MPs in the smaller size fractions may have been more abundant and dominant than indicated by the measured results. These results are consistent with findings from another microplastic study that used the same extraction method for ambient river water , which reported recoveries of 87±59%, 73±21%, 51±27% for 600-710 µm, 300-355 µm, 63-125 µm spheres, respectively, reflecting the extent of potential particle loss during extraction.

# 1.6 Discussion

Biofilters are perhaps the most common type of BMP installed during recent development and TMDL compliance plan implementation. The data set developed herein includes 18 paired influent and effluent flow-weighted composite samples from a broad representation of the "same" biofilter type BMPs, providing a robust basis for evaluating treatment effectiveness. To our knowledge, this represents the largest compilation of paired EMCs for MP treatment by BMPs in urban stormwater runoff. The dataset also uniquely combines runoff and media sampling, enabling assessment of both event-based treatment effectiveness and long-term accumulation over years of service—an approach not achieved in previous studies. Finally, the data covers a wide range of particle sizes (20 µm to >500 µm) and includes detailed characterization by morphology, polymer type, and color, expanding its utility for future analyses.

The data presented herein provide a representative, regional-scale assessment of MP treatment in biofilters operated by public agencies responsible for stormwater management in southern California. Sizing criteria and media characteristics (including dominant features of particle size distribution and depth) were used to evaluate how well the monitored biofilters reflect regional design guidance. The monitored biofilters encompassed drainage areas of 0.5−6 acres, thereby encompassing BMPs treating small to relatively large drainage areas, and from a variety of urban land uses (Table 1). The BMPs ranged in age up to 6 years and were all in good operating condition, with no evidence of clogging or compromised functions emerging from monitoring.

## 1.6.1 Event-based treatment efficiency

The 7 southern California biofilters studied herein reduced MP EMCs by a median of 72% over 18 storm events. The highest single-event removal efficiency was 99.8%, consistent with values reported in the literature (>80%). Influent MP concentrations ranged from dozens to 6850 particles/L, capturing much of the range reported in the literature (Österlund et al. 2023; Ahmad et al. 2025; Hoang et al. 2025; Kwarciak-Kozłowska and Madeła 2025). By coupling measurements of EMCs with measured runoff flows, the total number of particles in runoff was reduced by a median of 93% across 14 events.

The data set produced herein greatly expands the state of knowledge on biofilter performance for MP capture from urban runoff. State-of-the-art reviews (Österlund et al. 2023; Ahmad et al. 2025; Hoang et al. 2025; Kwarciak-Kozłowska and Madeła 2025) identified only four such studies on biofilters (Smyth et al. 2021; 2024; Lange et al. 2021; 2022), and two additional studies on a rain garden (Gilbreath et al. 2019; Werbowski et al. 2021). In each of the six studies, only a single BMP was monitored, and collectively, only three distinct BMPs were covered.

Size-specific analysis in this study showed median removal of 68% for the 20–63 µm fraction and 85% for the 63–125 µm fraction, generally aligning with the 71% removal reported by Smyth et al. 2024) for 25–100 µm MPs. The median removal increased with MP size, from 68% to 100% for MPs up to 500 µm. The median removal was slightly lower (89%) for the largest size fraction (>500 µm), likely reflecting the small number of particles detected in this range and potential influence of outliers. Analysis of polymer (chemical) types indicates that the biofilters decrease the diversity of MP polymers as well as reduce overall MP abundance.

MP occurrence and removal closely paralleled that of all particles surviving laboratory extraction, suggesting that MPs behave similarly to other particles during BMP treatment. Removal of particulate matter is dominated by filtration (i.e., straining), regardless of the make-up of the particle. As shown in Figure 17, MP removal (as calculated from spectroscopy results) aligns very closely with removal of all particles (as calculated from microscopy results). The plot shows that most data points fall closely along the line of equal value, with a strong correlation between MP and “all” particle removal ($r$ = 0.89, $p$<0.001).

The ratio of MP to “all” particle counts (i.e. occurrence) in runoff samples was consistent overall, across size fractions, and regardless of influent (untreated runoff) or effluent (treated runoff) condition (Figure 18). Linear regression analysis yields a narrow slope range for all queries, indicating that MPs make up 25-38% of all particles surviving extraction. Strong agreement of each linear model is indicated by a high $R^2$, indicating that the relationship is useful across a wide range of actual concentrations.

Altogether, the similar occurrence and removal behavior between MPs and all particles indicates that particle counts emerging from microscopy, may be a useful surrogate for MP occurrence quantification in urban runoff and subsequent calculations of BMP treatment in future studies.

By assessing the performance across a range of storm events and individual BMPs of the “same” type, this study provides a reasonable estimate of expected treatment efficiency across southern California biofilters and overcomes some limitations of data transferability using this type of performance metric. A benchmark for “acceptable treatment” has not been established for any stormwater pollutant, when expressed as a percent treatment efficiency. By definition, a percent reduction or removal (Eq. 3 or 4) evaluates performance relative to the untreated runoff (influent) condition. Stormwater runoff is known to be highly variable in terms of EMC or volume, from storm to storm at a single location, and from location to location, limiting interpretation of performance from one site or BMP to another. The percent removal calculation assesses treatment against a moving target, and should be interpreted with caution. The evaluation of EMCs from paired inflow and outflow samples provides event-based treatment efficiency for the monitored biofilters at the site scale, during wet weather events. The efficiency performance metric references an impact of the BMP on runoff before it enters a downstream waterbody. As a stand alone metric, percent removal cannot be definitively or quantitatively interpreted in terms of receiving water health or impact. The data collected herein, especially as differentiated by particle size and morphology should contribute usefully to a future investigation linking treated effluent quality and potential receiving water benefit.

The overall high percentage removal of MPs in this study is nevertheless encouraging, but not surprising, given that biofilters have demonstrated strong performance in filtering particulates measured as total suspended solids (TSS) (Clary et al. 2020). TSS is ubiquitous in urban runoff and is perhaps the most commonly measured conventional stormwater contaminant. Lessons learned from optimizing BMP design for TSS in the field may be similarly applicable to enhancing MP retention. It is noted that TSS monitoring at the 7 biofilters herein by the SMC does not yield consistent correlations with MP (unpublished research) and therefore would not be justified as a surrogate measurement, unlike the “all particle” concentrations measured herein; however, this is likely due to the analytical method and differences in the types of particles are physically represented in a TSS measurement.

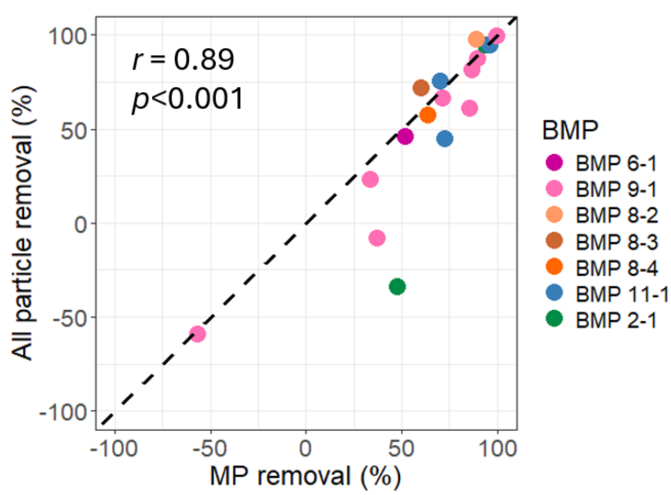


**Figure 17 Pearson correlation between event-based MP percent removal and “all” particle removal, calculated by comparing influent and effluent runoff samples extracted using acid-alkaline digestion method. Pearson correlation coefficients (*r*) and *p*-values are shown with statistical significance considered at $p<0.05$.**

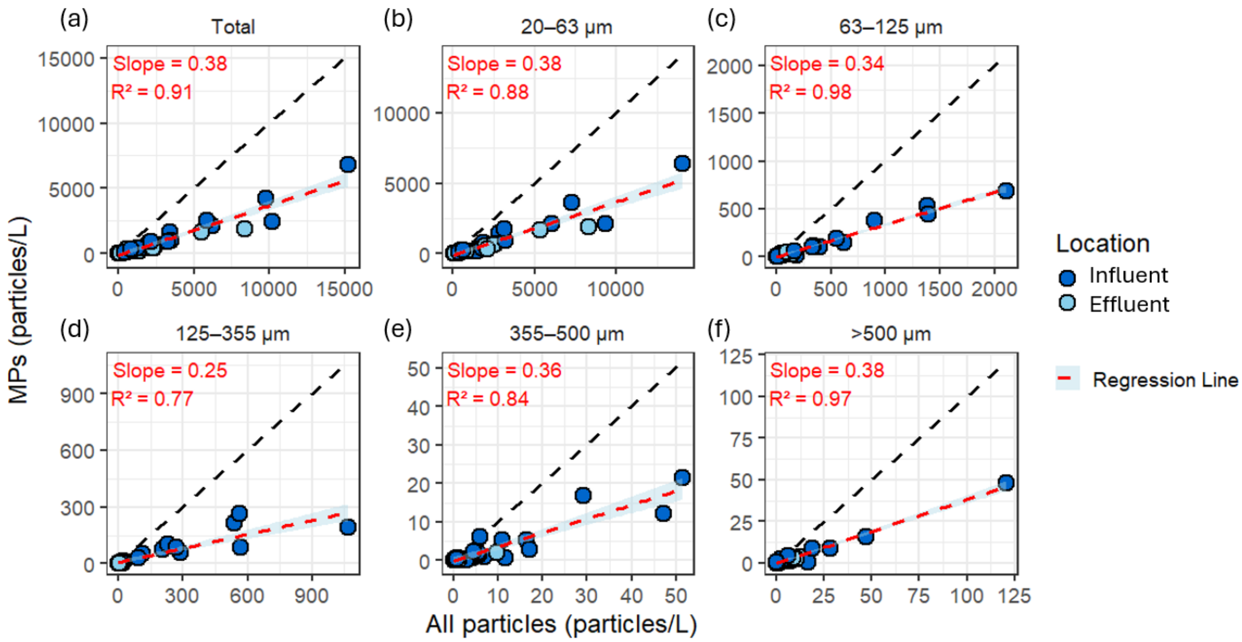


**Figure 18. Linear regressions between "all" particle and MP concentrations in runoff samples extracted using the acid-alkaline digestion method. Panel (a) shows all size fractions combined, while panels (b–f) show individual size fractions. Slopes and $R^2$ values are shown; blue bands represent 95% confidence intervals.**

## 1.6.2 Capture by biofilter media

Substantial variability in MP accumulation in the media was observed in this study. MP concentrations of the four BMPs <6 years old ranged from dozens to >1000 particles/g, and from tens to 200 particles/g when considering only MPs >63 µm. BMP 8-2 had MP concentrations in the media all in the tens. A difference of up to two orders of magnitude were observed among locations within the same BMP in each of the other BMPs monitored (BMPs 2-1, 9-1, 11-1) (Figure 12). Media sampling results coupled with runoff monitoring contribute a more holistic narrative. Storm event runoff sampling demonstrates that MP are removed by the BMP. The consistency in MP characteristics, including size fractions, morphology, chemical type, and color (Section 1.5.5), between influent and media supports that much of the accumulation within media is likely from direct capture of runoff influent, while the characteristics of the media (namely pore size distribution) confirms the potential for particulate capture. Accumulation within media over the service life can be in the 1000s particles/g without indication that BMP maintenance is needed to ensure ongoing runoff treatment. Altogether, this suggests that air deposition or contamination in virgin media are likely minor compared to runoff as a source of MP in the media (despite not being directly measured), and that the BMPs monitored have not yet reached their capacity to capture MP from runoff.

MP concentrations in the media reflect accumulation at the time of sampling, and are therefore, difficult to compare directly across studies because (1) accumulation depends on loading from the surrounding land use and service life, given that the media presumably has not yet reached its retention capacity, (2) capture characteristics depend on media properties, and (3) the reported concentrations vary with the size ranges, detection and analytical methods used. Five field monitoring studies have investigated MP accumulation in biofilter media, all of which focused exclusively on media. Mbachu et al. (2023) reported concentrations of 0-0.5 particles/g from 20 bioretention systems located in suburban residential areas and parks (South East Queensland, Australia), with smallest MP size of 70 µm. Lange et al. (2023) focused on nine older bioretention systems (7–12 years) receiving runoff from various land uses, ranging from commercial to residential, and reported MP concentrations 1.4-4.5 particles/g for MPs >40 µm. Jayalakshmamma (2024) assessed the horizontal and vertical distribution of MPs in three rain gardens representing three different land uses (residential, commercial, and highway), and reported MP concentrations ranging from 0-3 particles/g for MPs >45 µm. Beaurepaire et al. (2025) quantified the spatial and vertical distribution of MP in a biofiltration swale, reporting a median concentration of 108 particles/g (>25 µm). Concentrations measured in the current study are orders of magnitude greater than these four studies, when comparing results according to comparable size fractions, and despite this study representing BMPs that are generally more newly installed. Koutnik (2022) evaluated soils from 14 BMPs receiving runoff from various land uses across Los Angeles, making it the most geographically relevant to the present study. They reported concentrations up to ~3000 particles/g using an optical method with Nile Red staining capable of detecting particles down to 10 µm. This analytical approach does not provide polymer identification, unlike spectroscopy-based methods; nonetheless, results were the most well aligned with the current study in terms of concentrations and geographical representation.

Data from one BMP in this study (BMP 9-1, outlet), although limited, suggests that deeper layers (5–10 cm) can contain higher concentrations than surface samples. This result is in contrast to two other studies that generally concluded that MPs primarily accumulate in forebays and the upper 5 cm of media, with only modest gradients relative to inlet distance to (Koutnik 2022, Lange et al. 2023). Smaller size fractions analyzed in this study may explain the difference, as smaller MPs have been shown to accumulate deeper in sediment compared to larger MPs (Jayalakshmamma 2024). A possibility is that smaller MPs have a higher chance of traveling through media before they encounter pores small enough to capture (i.e., strain) it.

Treated effluent EMCs were grouped according to media depth to explore the potential influence of depth as a design factor. Biofilter design manuals in southern California typically recommend at least 24-inches of media, although 18-inches is allowed in some jurisdictions (Riverside County Flood Control Water Conservation District 2012; Snyder et al. 2020). Effluent

EMCs in the current study were grouped for 18-inch media (1 BMP, 8 events) and > 24-inch media (6 BMPs, 10 events). The single BMP with 18-inch media generally showed a larger range of the IQR in effluent quality (i.e. greater variability) (Figure 19), but a statistically significant difference in effluent quality from the deeper media BMPs was not found, according to a Wilcoxon Rank Sum test at p=0.05 level of significance. Thus, the information currently available does not suggest that deeper media necessarily result in greater MP capture.

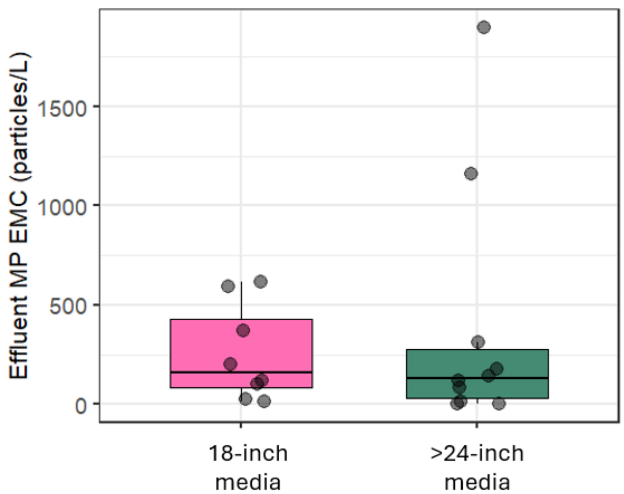


**Figure 19. Comparison of effluent EMCs according to media depth.**

## 1.6.3 Design recommendations

BMP design procedures are found in jurisdictional guidance manuals. These manuals establish calculation procedures to determine the size and footprint of each BMP according to expected rainfall in the region, and the land use and land cover types of the drainage area. In most manuals, guidance or specifications to address contaminant removal within the BMP are largely derived from limited empirical evidence, and more so from best professional judgement. It is noted that design guidance for many BMPs typically lags behind scientific research advances, and the level of detail or specificity varies according to BMP type. To the contrary, the research developed in this report aimed to directly identify the mechanisms of MP removal in BMPs, in order to inform design procedures that may be incorporated into design manuals, as appropriate.

The finding that MPs are primarily removed via straining, along with the observed heterogeneity in concentrations across BMP locations, motivated an exploration of relevant design features. To explore this, particle size distributions of media, already specified in biofilter media design guidance for sand, as well as pore size distributions—previously unexamined but theoretically critical for straining—were analyzed (Figure 15 and Figure 16, respectively).

Four indices ($D_{50}$ and curvature coefficient from particle size distribution, and the proportion of pores <20 µm by number of pores and by volume from pore size distribution) were statistically significantly correlated with MP concentrations ($p$<0.05) measured in the media. Among the factors investigated, the proportion of the volume of <20 µm pores yielded the strongest correlation to MP concentrations ($r$=0.93, $p$<0.001), followed by the proportion of the number of pores <20 µm ($r$=0.86, $p$=0.003), the curvature coefficient ($r$=0.83, $p$=0.003), and the $D_{50}$ ($r$=0.74, $p$=0.015) (Figure 21). The strong correlations between multiple indices with MP concentrations in the media are largely attributed to the intercorrelations among these indices themselves (Figure 20). The proportion of small pores is strongly correlated to the curvature coefficient ($r$=0.91, $p$=0.002), while the relation with $D_{50}$ is less strong ($r$=0.68, $p$=0.066). Koutnik (2022) observed through modeling that $D_{50}$ may be indicative of MP retention in soils near BMPs, but did not find the relation to hold within BMPs.

These results indicate that the proportion of fine pores is a key factor in enhancing MP removal in biofilter media, though this must be balanced with maintaining adequate infiltration rates (small pores restrict water movement through the media). While the proportion of <20 µm-pore volume showed strongest correlation with MP concentrations in the media, pore-size distribution analysis is more labor-intensive process (Liu 2016) than particle size analysis. Therefore, the curvature coefficient may serve as a more practical indicator for informing media design for MP removal.

Finally, filtration at the soil-water interface can eventually lead to clogging, creating a need for maintenance to sustain long-term performance. The biofilters examined in this study appear to be functioning effectively at the time of sampling, including BMPs that have been in service for up to six years. This determination was based on monitoring by the SMC (altogether across the BMP Monitoring Network, 83 individual events were sampled for conventional contaminants by the conclusion of this study, compared to the total 18 events that were sampled for MP). It is important to note that MPs represent only a small fraction of the total particulate load in runoff. Even after extensive extraction to remove organic and inorganic particulates, MPs comprise roughly 3.8 out of 10 particles, as shown in Figure 18 (a). Consequently, maintenance is likely to be driven by the overall particulate accumulation rather than MP-specific load.

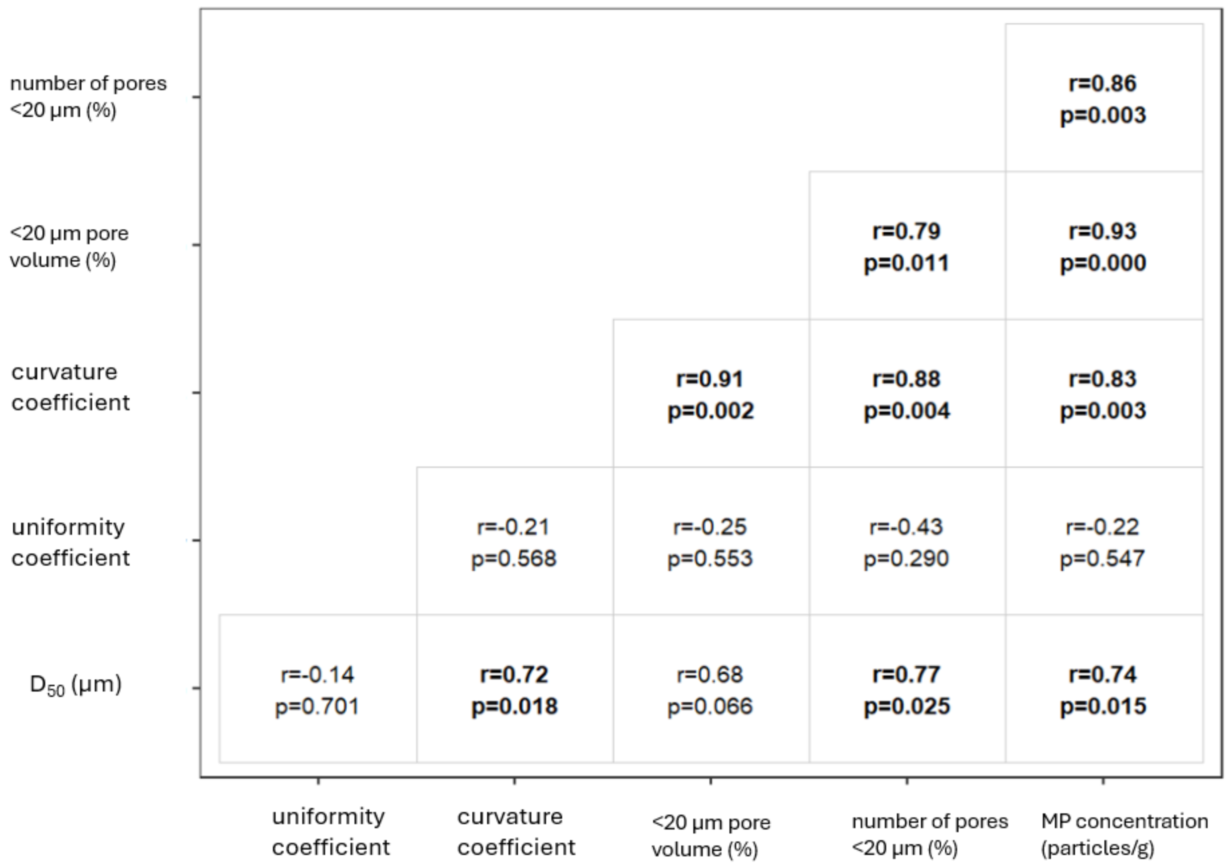


**Figure 20. Pearson correlation matrix showing correlations among indices derived from particle size distribution ($D_{50}$, uniformity coefficient, and curvature coefficient), pore size distribution (percentage of pores <20 µm by number and by volume), and MP concentrations (particles/g) in the media. Texts for correlations with $p<0.05$ (significance level) are shown in bold.**

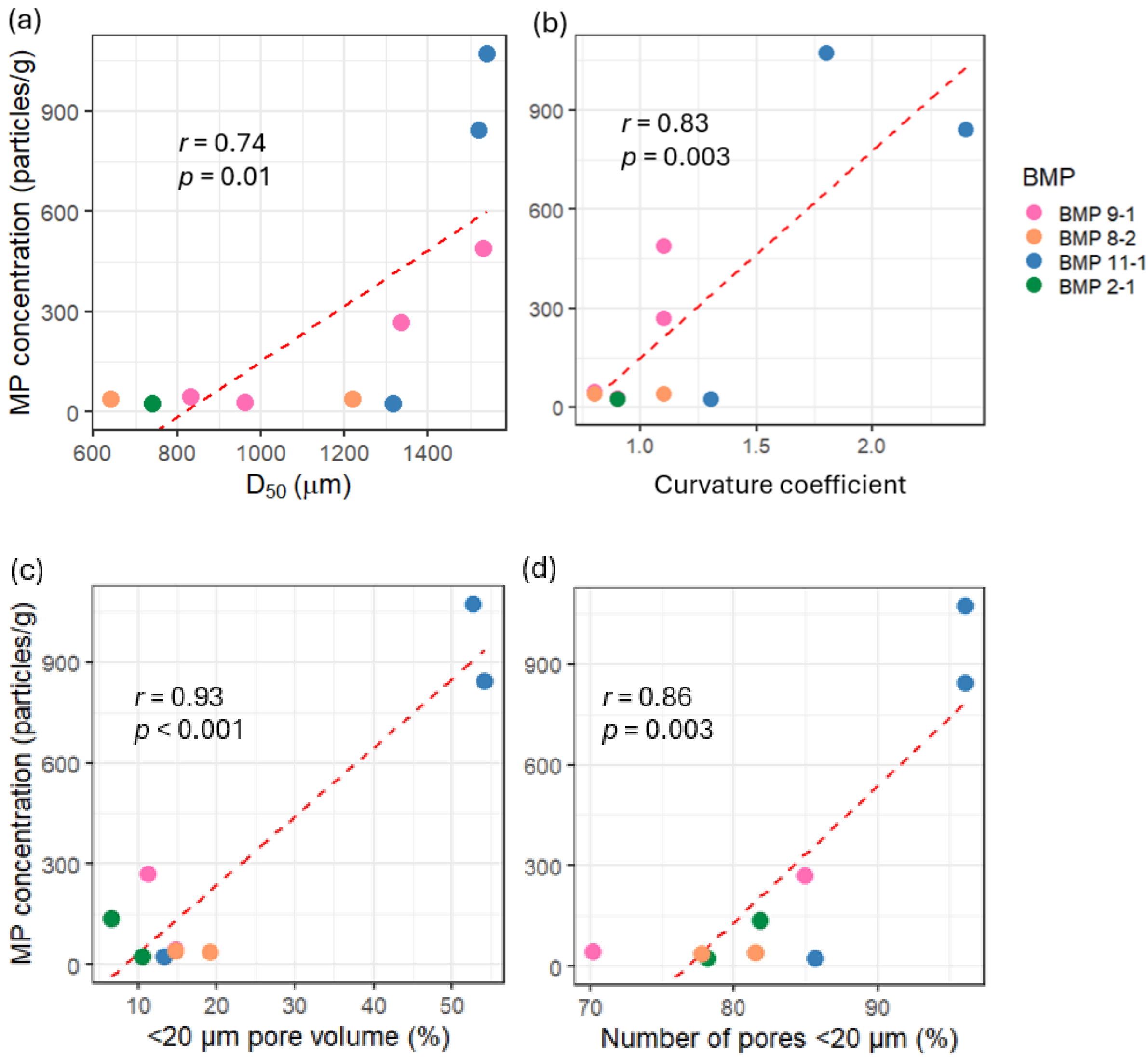


**Figure 21. Pearson correlation between media characteristics and MP concentrations in the media: (a) $D_{50}$ (Table 7), (b) curvature coefficient (Table 7), (c) composition of <20 μm-pore spaces (Figure 14), and (d) composition of the number of pores <20 μm (Figure 12). Pearson correlation coefficients (*r*) and *p*-values are shown with statistical significance considered at $p<0.05$. Red, dashed lines are included to indicate the direction of trend.**

## 1.6.4 Implications for future studies

The comprehensive dataset spanning multiple BMPs and events, along with objectively high MP removal across all size fractions, demonstrates the effectiveness of filtration-based BMPs in reducing pollutant loads from urban runoff. These results provide key insights into media design, highlighting the importance of small pores (<20 μm) for MP retention. Collectively, the findings inform opportunities to streamline MP analysis, optimize biofilter media, and expand future investigations into other BMP types, MP size fractions, and ecological impacts (if any).

(1) “Cheaper and faster” MP analysis

Laboratory analysis to quantify MP is resource-intensive. Analysis time and specialty capital equipment such as FTIR are consistently the biggest cost challenges in MP research. Data from this study establish a strong correlation between MP counts and all particle counts across all size fractions ($R^2$=0.91 overall and $R^2$>0.75 for all fractions, Figure 18), with approximately 3.8 out of ten particles in extracted urban runoff (by acid-alkaline digestion) identified as MPs. A similarly strong regression, with a different slope, was observed by Bailey et al. (2021) for surface water samples >250 µm. Calculations on treatment efficiency likewise followed close agreement between efficiency of all particle removal and MP removal (Figure 17). This suggests that future urban runoff and BMP performance monitoring studies could rely on microscopy-based particle counts alone when the primary objective is quantifying MPs, potentially reducing analysis time by up to 50% (according to time tracking for each analytical step in this study), and hence substantially reducing analytical costs. Concurrent measurements by the SMC on TSS EMCs and removal efficiencies do not provide the same value as a cheaper, faster surrogate measurement.

(2) Expanding applicability of findings

The data collection approach of this study (samples from a wide range of individual BMP installations) yields a reasonable estimate of expected treatment efficiency and effluent MP quality from southern California biofilters. BMP studies that focus on a single installation often offer valuable insights into key features or behavior of that BMP, but may be more limited in transferability of results. Because MPs are primarily removed through straining, the findings from this study are likely transferable to other BMPs and other treatment systems that rely on similar particulate removal mechanisms, such as rain gardens and permeable pavements. Future evaluations should focus on different BMP types.

As solutions for addressing stormwater quality generally, BMPs are expected to treat a wide range of contaminants. The selection of the type of BMP to be installed for a project usually arises from a combination of identifying what is the “best” BMP(s) to address the specific contaminant(s) of concern in a given location, practical factors such as the site’s opportunities and constraints (e.g. space/area available for a BMP, flow paths, presence of existing or planned utilities, safety, etc.), and in some cases, the project owner’s policies or contracting requirements[3]. Increasingly, the ability to maintain the BMP long-term is emerging as a consideration for BMP selection.  In order to better estimate the potential for MP management in urban runoff overall, it is imperative to assess the ability of other BMPs to remove MP.

[3] Anecdotally, some agencies prefer to limit the types of BMPs considered because of prior experience, either internally or with external contractors hired to complete final design and/or execute construction.

(3) Assessing broader environmental impacts

Treatment efficiency herein is evaluated at the site scale, i.e. before runoff enters the downstream waterways. The MP size and morphology data (in particular) gathered in this study could be used to support future evaluation of ecological and toxicological impacts to downstream aquatic environments from urban runoff, including potential reductions in runoff toxicity and contributions to downstream water quality improvements from treatment by biofilters.

While this study provides a strong starting point, future research could expand to particles smaller than 20 µm using techniques such as Raman spectroscopy or quantify MP mass with GC pyrolysis to enable more comprehensive impact assessments. Additionally, identifying the sources of MPs in runoff and media would provide insights for developing source control strategies.

(4) Establish best practices for BMP MP sampling and analysis

No SOPs or QA/QC protocols currently exist for MP sampling and analysis in stormwater runoff or biofilter media. Existing SOPs for MP analysis in drinking water (State Water Resources Control Board 2022) offer a strong starting point; however, stormwater applications require refinement to address runoff-specific contamination pathways and more complex sample matrices. Water quality sampling of BMPs requires significant technical expertise and resources[4]. The use of automated sampling instrumentation to collect sample aliquots over the duration of multi-hour, or even multi-day storm events is critical to implement resource-efficient sampling campaigns. Plastics are integral to most common forms of automated sampling equipment, thus pose an almost unavoidable risk for MP sampling campaigns.

We attempted to balance available resources for sample collection and analysis in this study by leveraging an on-going monitoring program, and quantifying potential contamination through a series of field and laboratory blanks. While this strategy appeared effective (no meaningful contamination was identified), a methodical investigation of collection techniques and required blanks is warranted to support future studies and effective resource allocation.

A methodical investigation of the runoff sample volume required for analysis is also warranted. Leveraging an on-going field monitoring campaign using common runoff monitoring equipment imposed limitations on the volume of runoff available for MP analysis. Furthermore, storm size, and hence total runoff volumes are subject to natural variability, resulting in variable composite

[4] Monitoring best practices intended to cover sampling of a wide range of typical runoff contaminants are documented in a report supported by the American Society of Civil Engineers Environmental and Water Resources Institute (ASCE/EWRI) (Geosyntec and Wright Water Engineers 2009). Caltrans 2020) also offers a stormwater monitoring guidance manual.

volumes. Analysis of samples collected early in the campaign confirmed high MP EMCs. Coupled with investigation of sample replicates, experience suggested that much lower volumes are needed for representative runoff samples compared to drinking water.

Future standardization efforts should focus on developing consistent MDA approaches for quantifying background contamination from both laboratory and field sources, establishing procedures for sample and blank evaluation and flagging, and harmonizing MP quantification methods (e.g., automated versus manual spectroscopy, subsampling criteria). The procedures and datasets developed here can inform future efforts to standardize QA/QC practices and advance BMP-MP monitoring.

# 2. SUMMARY COMPARING THE ACCOMPLISHMENTS WITH THE OBJECTIVES

• Generate a robust, consistent data set to quantify likely total MP load reductions using existing biofilter-BMPs in southern California.

Across 18 storm events at seven southern California biofilters, median MP EMC reduction efficiency was 72%, and median total MP load removal efficiency reached 93%. Effluent (treated runoff) quality had consistently fewer MP and was less variable than influent (untreated runoff), with a median of 133 MP/L in the effluent compared to a median of 824 MP/L in the influent, and IQRs ranging 41-357 MP/L for the effluent versus 345-2008 for the influent. Treatment characteristics were consistent when parsed into five size fractions (20-63 μm, 63-125 μm, 125-355 μm, 355-500 μm, > 500 μm). The dataset developed herein represents the most extensive regional dataset to date quantifying MP occurrence in and treatment by existing biofilter BMPs based on paired influent and effluent flow-weighted composite samples and total MP loads.

• Empirically evaluate physical characteristics of engineered filter media that promote MP capture using biofilter-BMPs.

MPs are primarily removed through straining, where particles are captured by pores smaller than their diameter. Consistent with this mechanism, biofilters with a greater proportion of pores smaller than 20 μm exhibited higher MP retention, highlighting pore size distribution as a key design parameter that can be optimized to enhance MP removal efficiency. The coefficient of curvature, an index derived from media particle size distribution, appears to offer a practical laboratory indicator for potential to accumulate MP in the media, rather than the labor intensive procedure required to measure pore size distribution. Media characterized by curvature coefficients 1±0.3 were strongly correlated to the proportion of pores smaller than 20 μm and MP accumulation.

• Explore indicators of maintenance needs to support biofilter-BMP performance.

Biofilters (up to six years old) assessed in this study demonstrated efficient MP removal, even though they were not specifically designed to target MPs. The results also showed that, even after extensive extraction processes, MPs accounted for only a fraction of the "all" particles (3.8 out of 10), indicating that maintenance needs are likely driven by overall particulate accumulation rather than MPs alone. There was no evidence that clogging or other maintenance issues compromised flow through the biofilters, and hence treatment, during the monitoring campaign.

• Develop evidence-based recommendations for effective LID design, operations, and management strategies as solutions to mitigate MP pollution from urban runoff.

The study demonstrates that current BMP design guidance produces biofilters that efficiently and consistently address MPs in urban runoff. Straining was identified as the primary removal mechanism. If future improvements are desired, pore size distribution is the key parameter that could be explored to further optimize MP retention. It is noted that modifying a design instruction or procedure must consider potential impacts to treatment of other contaminants or the drainage functions provided by BMPs.

# 3. Data management

Data, including raw data, processed data, and quality assurance data, are available via https://sccwrp.shinyapps.io/bmp_microplastics_shiny/ .

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# Appendix A. BMP and Instrumentation Configurations

## BMP 6-1

BMP 6-1 is a rectangular biofiltration basin installed in January 2019. It is designed to reduce pollutant concentrations and loads, as well as flow control (hydromodification). The BMP manages runoff from a 0.6-acre drainage area composed of 75% of roads and highways and 25% of parking lot surfaces.

The BMP is designed to treat a 0.53-inch storm with a design flow rate of 5.58 $ft^3/s$. This BMP has a surface area of 1792 $ft^2$and a loading ratio of 14. It contains 24 inches of biofiltration media over a 15-inch gravel layer. The average ponding depth is 12 inches, and the measured surface infiltration rate is 29 in/h.

Runoff enters and exits the system through 8-inch underdrains. The BMP includes both a perforated underdrain and a bypass feature.

Both inflow and outflow monitoring stations are instrumented to measure flow and water quality. The outflow station also receives water from the overflow, if it occurs.

## BMP 9-1

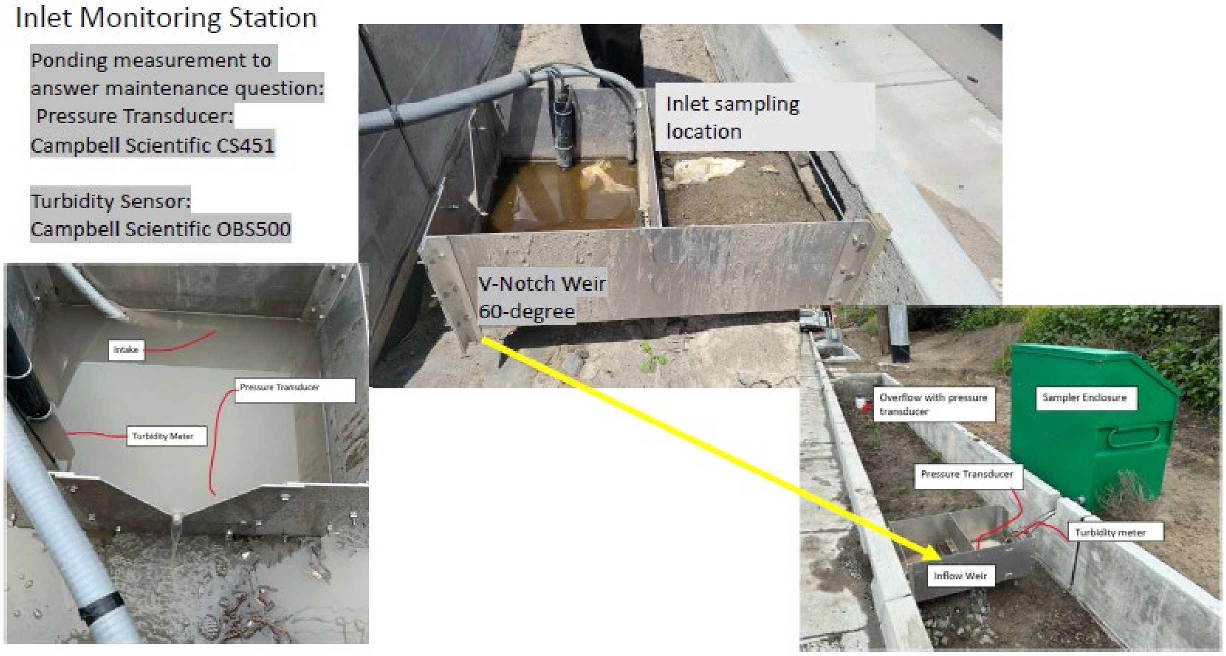
BMP 9-1 is a rectangular bioretention BMP installed in June 2020. It is designed to reduce pollutant concentrations. The BMP manages runoff from a 1.3-acre drainage area composed of 65% of roads/highway surfaces and 35% of park/open spaces. The in-situ soil infiltration capacity is classified as Type D in the NRCS hydrologic soil group, with a soil filtration rate of 6.14 in/h.

The BMP is designed to treat a 0.46-inch storm and capture up to 1458 $ft^3$ of runoff. This BMP has a surface area of 352 $ft^2$and a loading ratio of 8. It contains 18 inches of media over a 12-inch gravel layer. The average ponding depth is 6 inches, and the measured surface infiltration rate is 133 in/h.

The BMP includes both a perforated underdrain and an overflow feature.

Both inflow and outflow monitoring stations are instrumented to measure flow and water quality. The outflow station also receives water from the overflow, if it occurs. The instrument configurations for the monitoring stations at the inflow and outflow are shown in figures below. A rain gauge is installed on site near the outflow.

(a) Inflow (inlet) monitoring station




(b) Outflow (outlet) monitoring station


## BMP 8-2, BMP 8-3, and BMP 8-4

BMP 8-2, BMP 8-3, 8-4 are bioretention basins constructed along the same roads/highway corridor in October 2019. These BMPs are designed to reduce pollutant concentrations and provide flow and flood control (hydromodification).

BMP 8-2 is an oval-shaped bioretention basin that manages runoff from a 5.8-acre drainage area. BMP 8-3 and BMP 8-4 are rectangular basins, managing runoff from 4.9 and 6.0 acres, respectively. All three BMPs are designed to treat a 0.85-inch design storm. Their design capture volumes are 4792 $ft^3$ (BMP 8-2), 2187 $ft^3$ (BMP 8-3), and 3049 $ft^3$ (BMP 8-4).

BMP 8-2 has a surface area of 2980 $ft^2$ and a hydraulic loading ratio of 85. BMP 8-3 has a surface area of 3230 $ft^2$ and a loading ratio of 15, while BMP 8-4 has a surface area of 1784 $ft^2$ and a loading ratio of 7. Each basin contains 24 inches of biofiltration media over a 16-inch gravel layer and is designed for a surface infiltration rate of 2.5 in/h. The average ponding depths are approximately 14, 8, and 9 feet, respectively.

All three BMPs include overflow features and perforated underdrains—four in BMP 8-2 and six each in BMP 8-3 and 8-4.

Each of three BMPs have both inflow and outflow monitoring stations are instrumented to measure flow, water quality, and precipitation. The outflow station also receives water from the overflow, if it occurs.

# BMP 11-1

BMP 11-1 is a rectangular bioretention BMP installed in May 2018 as a retrofit. It is designed to reduce pollutant concentrations and mass, as well as provide flood control. BMP 11-1 manages runoff from a 0.7-acre drainage area composed of 100% industrial surfaces used for fleet vehicle parking. The in-situ soil's infiltration capacity is classified as Type A in the NRCS hydrologic soil group.

The BMP is designed to treat a 0.61-inch storm and capture up to 1405 $ft^3$ of runoff. This BMP has a surface area of 804 $ft^2$ and a loading ratio of 39. It contains 37 inches of media over a 9-inch gravel layer, without a geotextile layer. The average ponding depth is 16 inches, and the measured surface infiltration rate is >100 in/h.

The BMP includes a lined system to prevent subsurface infiltration and an overflow feature.

Both inflow and outflow monitoring stations are instrumented to measure flow and water quality. The outflow station also receives water from the overflow, if it occurs. A rain gauge is located near the BMP. Instrument configurations for the monitoring stations at the inflow and outflow are shown in figures below.

(a) Inflow (influent) monitoring station

(b) Outflow (effluent) monitoring station

# Appendix B. QA/QC

**Table B1. $MDA_A$ calculations derived from MP values in all measured procedural blanks.**

| | Total MP | Morphology | | | Size Fraction | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fragments | Fibers | Other | >500 µm | 355-500 µm | 125-355 µm | 63-125 µm | 20-63 µm |
| $MDA_A$ | 90.6 | 62.7 | 27.3 | 7.9 | 8.3 | 8 | 27.5 | 36.7 | 34.8 |
| $\overline{N_b}$ | 16.5 | 10.61 | 4.67 | 1.22 | 0.67 | 0.67 | 2.33 | 4.56 | 8.33 |
| SD | 21.03 | 15.85 | 5.8 | 1.08 | 1.37 | 1.29 | 6.56 | 8.62 | 6.95 |

**Table B2. Surrogate spike recovery in runoff samples*.**

| | Blue (600-710 µm) | Green (300-355 µm) | Red (63-125 µm) |
|---|---|---|---|
| Sample size (n) | 49 | 49 | 48 |
| Average recovery (%) | 86 | 69 | 36 |
| Standard deviation | 15 | 23 | 32 |

*10 surrogates were spiked for each type of surrogate particle.

**Table B3. Surrogate spike recovery in media samples*.**

| | Blue (600-710 µm) | Green (300-355 µm) | Red (63-125 µm) |
|---|---|---|---|
| Sample size (n) | 18 | 19 | 20 |
| Average recovery (%) | 93 | 70 | 42 |
| Standard deviation | 8 | 28 | 29 |

*10 surrogates were spiked for each type of surrogate particle.