μrban Plastics

Sources, sinks and flows of microplastics in the urban environment

Heléne Österlund and Emma Fältström

REPORT 7104 | MAY 2023

µrban Plastics

Sources, sinks and flows of microplastics in the urban environment

Project report

by Heléne Österlund and Emma Fältström

SWEDISH ENVIRONMENTAL
PROTECTION AGENCY

Order
Phone: + 46 (0)8-505 933 40
E-mail: natur@cm.se
Address: Arkitektkopia AB, Box 110 93, SE-161 11 Bromma, Sweden
Internet: www.naturvardsverket.se/publikationer

The Swedish Environmental Protection Agency
Phone: + 46 (0)10-698 10 00
E-mail: registrator@naturvardsverket.se
Address: Naturvårdsverket, SE-106 48 Stockholm, Sweden
Internet: www.naturvardsverket.se

ISBN 978-91-620-7104-2
ISSN 0282-7298

Print: Arkitektkopia AB, Bromma 2023
Cover photos: Mikael Svensson/Johnér

MILJÖMÄRKT
3041 0843
TRYCKSAK

Preface

This report describes the main results and conclusions from the project "µrban plastics - Sources, sinks and flows of microplastics in the urban environment" which was financed by the Swedish Environmental Protection Agency, to whom we are grateful for supporting the research. The project was also integrated with, and benefited from, the Vinnova-funded competence centre Drizzle and the Interreg BCR-funded project FanpLESStic-Sea.

The report is authored by Heléne Österlund from Luleå University of Technology (LTU) and Emma Fältström from Sweden Water Research, but many other people have participated in and contributed to the project's sub-studies:

Jonathan Svedin carried out laboratory-based investigations of UV degradation of plastic litter into microplastics, the results of which were evaluated by Lisa Öborn (Öborn et al. 2022). Lisa Öborn also planned and carried out sampling of sediments in storm water gully pots (Öborn et al. 2022). Robert Furén planned and carried out sampling of substrates in biofilter retention systems, the results of which were evaluated by Katharina Lange (Lange et al. 2022). Stormwater sampling was carried out by Gopinath Kalpana with the support of Kerstin Nordqvist and Peter Rosander. The samples from the stormwater study were analysed by Alvise Vianello and Claudia Lorenz at Aalborg University, within the framework of the Fanplesstic-Sea project, and the results were evaluated by Sarah Lindfors (Lindfors et al. 2022). Sampling and sample preparation for wastewater and drinking water used in the flow mapping was carried out by partners in the Fanplesstic-Sea project, and the samples were analysed by Claudia Lorenz and Alvise Vianello at Aalborg University. Sampling of small-scale, on-site wastewater treatment plants for greywater from households was planned and carried out by Mashreki Sami. With this, we would like to thank everyone who contributed to the project through funding and participation, and we hope that the results will be useful to those who read this report.

Luleå, Sweden, February 2023

Heléne Österlund, project leader

List of abbreviations

AADT	Annual average daily traffic
ABS	Acrylonitrile butadiene styrene
ATR	Attenuated total reflectance
DM	Dry mass
EPDM	Ethylene propylene diene monomer rubber
EVA	Ethylene-vinyl acetate
FTIR	Fourier transform infrared spectroscopy
HD	High density
LD	Low density
PA	Polyamide
PAHs	Polycyclic aromatic hydrocarbons
PBT	Polybutylene terephthalate
PC	Polycarbonate
PE	Polyethene, polyethylene
PET	Polyethene terephthalate
PMMA	Poly(methyl methacrylate)
POM	polyoxymethylene
PP	Polypropene, polypropylene
PS	Polystyrene,
PU	Polyurethane
PVC	Polyvinyl chloride
SBR	Styrene-butadiene rubber
SEBS	Styrene-ethylene-butylene-styrene
SR	Styrene rubber
TED-GCMS	Thermal extraction desorption gas chromatography
UV	Ultra violet

Contents

Summary

Microplastics are commonly defined as plastic debris ranging in size from 1 µm to 5 mm. They have been studied in marine and coastal waters since the early 1970s. Several studies have reported that microplastics in the marine environment originate from land-based sources and are released with stormwater and wastewater. For this reason, increasing attention is being paid to urban water systems.

In this project, the pathways of microplastics from terrestrial to aquatic environments were investigated and mapped. Special attention was paid to several aspects of urban stormwater. A conceptual model of a city was developed, to illustrate and map the flows of microplastics in the city and identify the measures that could be taken to control these. The following research questions were investigated: 1) How does the most common plastic (macro) litter from streets break down into microplastic particles? 2) What types and concentrations of microplastics are found in urban stormwater from different catchments? 3) What types and concentrations of microplastics are retained by commonly used stormwater treatment facilities? 4) What types and concentrations of microplastic particles are retained by, and found in effluents from, on-site and small-scale wastewater treatment facilities? 5) Where are microplastics found in urban areas, and what measures can be taken to control microplastic pollution? 6) How do local public actors view their own responsibilities with regards to microplastics in stormwater, and which other societal actors do they perceive to be responsible?

The results showed that microplastics concentrations in stormwater runoff from the road, the parking lot, and the roof top ranged between 267-11400 N/L, 95-1690 N/L and 467-1220 N/m3, respectively (where N is the number of particles). The three most common polymer types at all three sites were polypropene (PP) > polyethene (PE) > polyesters (including PET). However, it is reasonable to assume that other types of microplastics were present in high concentrations, although these were not detected with the applied analytical method: these include tyre and road wear particles, which were not detected because black particles were not included with the analytical technique applied to these samples. Concentrations of microplastics in sediments from stormwater gully pots and bioretention systems varied between 720-25300 N/100 g dry matter (DM) and <9-17300 N/100 g DM. The four most common microplastics in both plant types were PP, EPDM rubber, ethylene vinyl acetates (EVA), and polystyrenes (PS), and a large fraction of the particles were black. Four litter items commonly discarded in the urban environment were exposed to UV light for up to 56 days, corresponding to approximately 2 years of UV radiation in Sweden – a plastic bag (PE-LD), chocolate bar wrapper (PP), a plastic coffee cup lid (PS), and a bottle (PET). The results indicated clear degradation of PS, PP, and PET, and an increased release of microplastics with longer exposure times. For the PE-LD item (a grocery bag), degradation due to UV exposure was not observed over the exposure times used because the numbers of particles released from exposed and unexposed (control) samples were in the same order of magnitude. The emissions of microplastics in the model city were estimated as 7.2 kg/year originating from treated wastewater and 1kg/year for

combined sewer overflows. The estimated load to stormwater was 13 000-17 000 kg/year for microplastics and 2 100 kg/year for tyre wear particles. The largest sources were cigarette butts, followed by paint and tyre wear for stormwater and laundry for wastewater. Tap water, roof runoff, and dust made small contributions. Most of the actors who were identified as having a responsibility could influence emissions to stormwater, either by influencing the introduction of microplastics into society or by affecting the emissions of microplastics to stormwater. The concentrations of microplastics in the different greywater treatment plants varied widely; from non-detected to 1100 µg/L, 130 µg/L, 1000 µg/L, 150 µg/L for PS, PVC, PET and PA respectively. The concentrations in the outgoing water were generally low, indicating relatively good treatment efficiency.

The results in this report can be used to identify which plastics are present in different parts of the urban environment and will facilitate further efforts to identify upstream pollution sources. The flow analysis gives an overview of the flows of microplastics at a city level, highlighting larger and smaller flows, and can be applied to other cities with different characteristics.

There are still several uncertainties when estimating sources of microplastics, and the polymers found in the samples were sometimes not consistent with what would be expected based on the source estimates. This raises the question of whether some sources have been missed, while others might be overestimated. Future research should include field studies of additional treatment techniques and stormwater from catchments with other land use patterns, and cover all seasons of a year. Such studies should also include black particles and tyres and road wear particles in the microplastics analysis, since these represent a significant fraction of the microplastics released from the urban environment.

Sammanfattning

Mikroplast är ett samlingsnamn för små plastfragment i storleksfraktionen 1 µm till 5 mm. Mikroplast har studerats i marina miljöer sedan 1970-talet och flera studier har rapporterat om att denna mikroplast härrör från landbaserade källor och släpps ut via dagvatten och avloppsvatten och mer och mer uppmärksamhet riktas därför mot städernas system för vattenförsörjning av avloppshantering.

I detta projekt har transportvägar för mikroplast från land till vattenmiljöer undersökts och kartlagts. Särskilt fokus har lagts på olika aspekter kring urbant dagvatten. En konceptuell modell har tagits fram som illustrerar och kartlägger flöden av mikroplast i en stad och förslag på åtgärder för att motverka spridningen av mikroplast lyfts. Projektet belyser frågeställningarna: 1) Hur bryts de vanligaste plastskräpen som slängs i städerna ner till mikroplast? 2) Vilken typ och koncentration av mikroplast finns i urbant dagvatten från områden med olika markanvändning? 3) Vilken typ och mängd av mikroplast kvarhålls i vanliga typer av reningsanläggningar för dagvatten? 4) Vilken typ och mängd av mikroplast fångas upp av småskaliga avloppsanläggningar för hushåll och vilka koncentrationer släpps ut? 5) Var i den urbana miljön finns mikroplasten och vilka åtgärder kan vidtas för att minska och begränsa utsläppen? 6) Hur ser lokala offentliga aktörer på sitt eget ansvar att påverka spridningen av mikroplast med dagvattnet och vilka andra samhällsaktörer ser de som ansvariga?

En laboratoriestudie genomfördes för att undersöka nedbrytningen av vanligt förekommande plastskräp (fyra olika) till mikroplast under påverkan av UV-bestrålning. Fältprovtagningar utfördes genom provtagning av dagvatten (tre platser och tre tillfällen) och dagvattensediment från reningsanläggningar (29 dagvattenbrunnar och 9 biofilter) samt avloppsvatten (gråvattenfraktionen) och efterföljande reningsanläggningar (fem filtermaterial för gröna väggar, en typ av biobädd och en typ av mineralullsfilter). För att uppskatta flöden av mikroplaster i urbana vattensystem genomfördes en substansflödesanalys som baserades på uppmätta- och litteraturvärden i en modellstad. En intervjustudie belyste olika lokala aktörers upplevda ansvar i relation till föroreningsspridning av mikroplast via dagvatten.

Resultaten visade att koncentrationen av mikroplaster i dagvattenavrinning från en väg, en parkeringsplats och ett tak låg mellan 267-11400 N/L, 95-1690 N/L respektive 467-1220 N/m3 (där N är antal partiklar). De tre vanligaste polymertyperna på alla tre platser var polypropener (PP) > polyetener (PE) > polyestrar (inkl. PET) , men det är rimligt att anta att ytterligare mikroplaster förekom, t ex däck- och vägslitagepartiklar som inte ingick i analysen. Koncentrationerna av mikroplaster i sediment från dagvattenbrunnar och biofilteranläggningar varierade mellan 720-25300 N/100 g TS respektive <9-17300 N/100 g TS . De fyra vanligaste mikroplasterna i båda anläggningstyperna var PP, EPDM-gummi, etenvinylacetater (EVA) och polystyrener (PS) och en stor andel av partiklarna var svarta. Från UV-nedbrytningen av plastskräp till mikroplast konstaterades en tydlig påverkan på skräp av PS (kaffemuggslock), PP (godispapper) och PET (en flaska) med en ökad frisättning av mikroplaster med längre exponeringstider medan PE-LD (en plastpåse) var i det närmaste opåverkad. Utsläppen av mikroplast i modellstaden

uppskattades till 7,2 kg/år från renat avloppsvatten och 1 kg/år från bräddvatten. Utsläppen till dagvattnet uppskattades till 13 000–17 000 kg/år från mikroplast och 2 100 kg/år från däckpartiklar. De största källorna var syntetiska fibrer från klädtvätt till avloppsvattnet och cigarettfimpar, följt av färg och däckpartiklar till dagvattnet. Dricksvatten, takavrinning och damm var källor med små bidrag till det urbana vattnet. De flesta av de aktörerna som identifierades som ansvariga kunde påverka flödet av mikroplast till dagvattnet, antingen genom att påverka flödet av mikroplast till samhället i stort eller genom att påverka utsläppen av mikroplast till dagvattnet. Koncentrationerna av mikroplast i de olika anläggningarna för rening av gråvatten varierade mycket; från icke-detekterade koncentrationer upp till 1100 µg/L, 130 µg/L, 1000 µg/L, 150 µg/L för PS, PVC, PET respektive PA. Koncentrationerna i utgående vatten var generellt låga vilket tyder på en relativt god reningskapacitet.

Resultaten från denna rapport kan exempelvis användas för att identifiera vilka mikroplaster som förekommer i olika delar av den urbana miljön för att därefter söka utsläppskällorna uppströms i dagvattensystemen. Flödesanalysen ger en överblick över flöden av mikroplast i en stad och åskådliggör större och mindre flöden, vilket kan appliceras på andra städer med andra egenskaper.

Substansflödesanalysen indikerade att det fortfarande finns flera osäkerheter vid uppskattning av källor till mikroplaster, och de polymerer som hittades i proverna överensstämde ibland inte med vad som förväntades baserat på källuppskattningarna. Denna skillnad väcker frågor om vissa källor missats, och vilka som kan vara överskattade. Fortsatta studier bör inkludera fältprovtagningar av ytterligare reningsanläggningar och dagvatten från annan typ av markanvändning och som därtill sträcker sig över årets alla årstider. För dessa studier behöver man säkerställa att analys av svarta partiklar, inklusive däckslitage, ingår i analysen, eftersom dessa utgör stora bidrag till utsläppen av mikroplast.

Utökad sammanfattning

Mikroplast är ett samlingsnamn för små plastfragment i storleksfraktionen 1 µm till 5 mm. Vanligtvis avses både plast- och gummipolymerer samt polymermodifierad bitumen. Mikroplast har studerats i marina miljöer sedan 1970-talet och flera studier har rapporterat om att denna mikroplast härrör från landbaserade källor och släpps ut via dagvatten och avloppsvatten. Fibrer från tvätt av syntetiska material, mikroplast tillsatt i hygienartiklar och städprodukter är exempel på källor till mikroplast i avloppsvattnet. Till dagvattnet kan mikroplast komma från exempelvis slitage av däck och vägbanor, granulat från konstgräsplaner, färg från målade ytor i staden som slits och vittras, men också många ännu oidentifierade källor. Det finns många aktörer, på olika nivåer i samhället, som har möjlighet att påverka flödet av mikroplast i urbana miljöer. Kommuner har identifierats som en sådan aktör som kan påverka flödet av mikroplast på flera sätt, både strategiskt genom exempelvis stadsplanering, och mer praktiskt som ansvarig för exempelvis underhåll av kommunalägda fastigheter och avloppsfrågor.

I detta projekt har transportvägar för mikroplast från land till vattenmiljöer undersökts och kartlagts. Särskilt fokus har lagts på olika aspekter kring urbana dagvattensystem. En konceptuell modell har tagits fram som illustrerar och kartlägger flöden av mikroplast i en stad och förslag på åtgärder för att motverka spridningen av mikroplast lyfts.

Projektet är uppbyggt kring följande frågeställningar: 1) Hur bryts de vanligaste plastskräpen som slängs i städerna ner till mikroplast? 2) Vilken typ och koncentration av mikroplast finns i urbant dagvatten från områden med olika markanvändning? 3) Vilken typ och mängd av mikroplast kvarhålls i vanliga typer av reningsanläggningar för dagvatten? 4) Vilken typ och mängd av mikroplast fångas upp av småskaliga avloppsanläggningar för hushåll och vilka koncentrationer släpps ut? 5) Var i den urbana miljön finns mikroplasten och vilka åtgärder kan vidtas för att minska och begränsa utsläppen? 6) Hur ser lokala offentliga aktörer på sitt eget ansvar att påverka spridningen av mikroplast med dagvattnet och vilka andra samhällsaktörer ser de som ansvariga?

Metod

För att undersöka typ och mängd av mikroplaster i urbant dagvatten valdes tre avrinningsområden i Luleå ut för provtagning: en väg med trafikbelastning på cirka 15000 fordon per dygn, en parkeringsplats samt ett tak. För alla platser samlades dagvatten upp direkt när det passerat en dagvattenbrunn eller lämnade ett stuprör, det vill säga utan föregående rening av något slag. Provtagningen genomfördes på alla plaster samtidigt vid tre tillfällen under hösten 2020. Dessa prover analyserades med tekniken µFTIR efter nödvändig provberedning.

Provtagning genomfördes också av två typer av dagvattenreningsanläggningar; 29 stycken dagvattenbrunnar och 9 stycken biofilter, från vilka ackumulerat sediment samlades in för att bestämma typ och mängd av mikroplaster. I biofilteranläggningarna togs flera prover från olika delar av samma anläggning (avstånd från inlopp samt djup) för att studera var i filtret mikroplaster eventuellt fastläggs.

Proverna från både dagvattenbrunnarna och biofiltren analyserades med tekniken µFTIR samt ATR-FTIR efter nödvändig provpreparering. ATR-FTIR möjliggjorde att också kunna studera svarta partiklar, såväl svarta plastpartiklar som gummipartiklar från däckslitage.

Ovan nämnda fältstudier kompletterades med en omfattande litteraturstudie där forskningen om förekomst av mikroplaster i dagvatten och dagvattenanläggningar samt anläggningars reningseffektivitet sammanställdes utifrån publicerade internationella vetenskapliga studier.

En laboratoriestudie genomfördes för att undersöka nedbrytningen av vanligt förekommande plastskräp till mikroplast under påverkan av UV-bestrålning för att imitera solljus. Plastskräpen bestod av plastpåse av polyeten (PE-LD), chokladkaksförpackning av polypropylen (PP), kaffemuggslock av polystyren (PS) och flaska (PET). Provbitar av skräpen bestålades under 7, 28 eller 56 dagar vilket motsvarar cirka 0.25, 1 respektive 2 års UV-mängd vid utomhusexponering i Sverige. Efter exponering analyserades hur mycket partiklar som lossnade från provbitarna med µFTIR.

För att kartlägga flöden av mikroplast i den urbana miljön användes en metod som bygger på substansflödesanalys. Till kartläggningen användes två typer av data. När det var möjligt användes resultat från provtagningen som genomförts inom projektet samt projektet Fanplesstic-Sea. För identifierade källor där det inte fanns mätdata från projektet användes litteraturvärden för att uppskatta bidraget. Flödena beräknades för en modellstad som byggde på de städer där provtagning skett. I flödesuppskattningen låg fokus på utsläpp till avloppsvatten och dagvatten, men även flöden till avfall och jord inkluderades. Till flödesuppskattningarna introducerades också två typer av åtgärder. Dels förebyggande åtgärder, såsom förbud mot att tillsätta mikroplast i produkter, och dels reningstekniker, som till exempel filter i tvättmaskiner eller ytterligare rening på avloppsreningsverket. För att undersöka vilka aktörer som har ansvar och möjlighet att påverka flödena av mikroplast i dagvatten genomfördes en intervjustudie med sju kommunala tjänstemän i en kommun med 50 000 invånare belägen i södra Sverige.

Ett urval av små avloppsanläggningar för behandling av hushållens gråvattenfraktion (dvs bad-, disk, och tvättvatten) testades med avseende på inkommande och utgående vatten till anläggningarna. Två anläggningar var enskilda avlopp med ett hushåll anslutet varav den ena bestod av en biobädd över ett sandfilter och den andra av ett mineralullsfilter. En ytterligare anläggning var en pilotanläggning med aggregerat gråvatten från ett helt kvarter med 900 personekvivalenter anslutna. Endast en delfraktion avleddes till pilotanläggningen som bestod av så kallade ”gröna väggar”, dvs behållare med växter i substrat som utgör filtermaterial för avloppsvattnet att filtreras genom. Fem olika substrat testades parallellt. Alla anläggningar provtogs vid tre olika tillfällen. Efter nödvändig provberedning analyserades proverna med TED-GCMS.

Resultat och diskussion

Koncentrationerna av mikroplaster i dagvattenavrinning från vägen, parkeringen och taket låg mellan 267–11400 N/L, 95–1690 N/L respektive 467–1220 N/m3 (där N är antal partiklar). Trots att endast tre avrinningshändelser provtogs per plats, varierade koncentrationerna över ett stort intervall. Det största antalet polymertyper detekterades i dagvatten från parkeringen där PP>PE>PET/polyestrar>PU, akryl>PS, PVC, ABS och PU-färger detekterades med koncentrationerna i fallande ordning. I takavrinningsproverna detekterades sex plastpolymerer; PP>PE>PET/polyestrar>PU>PA och PVC. Fem polymertyper detekterades i vägavrinningen; PP>PE>PET>akryl>PA. Svarta partiklar ingick inte i analysen för dessa prover, därför är det rimligt att anta att ytterligare mikroplaster förekom, inklusive däck- och vägslitagepartiklar, även om de inte upptäcktes med den analysteknik som tillämpades (µFTIR).

Koncentrationerna av mikroplaster i dagvattenbrunnars sediment och biofilteranläggningars filtermaterial varierade mellan 720-25300 N/100 g torrsubstans (TS) respektive <9-17300 N/100 g TS. De sex vanligast förekommande polymertyperna var PP>EPDM>EVA>PS>SBR>PE och PP>EVA>PS>EPDM>PVC>PE, i fallande ordning, för brunnar respektive biofilter. Andra förekommande polymertyper inkluderar PMMA, PET, PCT, PLA, PUR, PA, fenoxihartser, akrylfärg, cellulosaacetat, SEBS, POM och PBT. En betydande andel av de detekterade mikroplasterna var svarta och kunde kvantifieras tack vare att analyserna med µFTIR kompletterades med ATR-FTIR. Vidare konstaterades att mediankoncentrationerna av mikroplast i biofilteranläggningarna minskade signifikant från ytskiktet (0-5 cm) av filtermaterialet till skiktet på 10-15 cm djup från 448 till 136 partiklar/100 g. För de filter som hade försedimentering erhölls högsta koncentrationerna i denna del av anläggningen. Detta tyder på att mikroplasterna fastläggs redan i biofiltrens övre lager vilket borgar för en god reningsförmåga.

Litteraturstudien visade att de vanligaste polymertyperna i dagvattenprover var polyestrar, PE, PP, PS, PA, PVC och PU. I de fall däckpartiklar var inkluderade i analyserna så förekom de oftast i högst koncentrationer. Det tycks därmed inte skilja sig nämnvärt vilka typer polymerer som förekommer. Även om det bara rör sig om ett fåtal studier (14 stycken) och prover (189 stycken) så har studierna genomförts i ett flertal länder på flera kontinenter. Flera olika analystekniker och provtagningsmetodiker hade tillämpats vilket försvårar ytterligare jämförelser mellan studierna. Uppmätta koncentrationer i de olika studierna rörde sig mellan 0,3-8600 N/L. Av de studier som sammanställdes med avseende på mikroplast i reningsanläggningar för dagvatten var det huvudsakligen biofiltertekniker som hade testats med avseende på rening. Reningsgraden i dessa var hög, 70 procent eller mer för alla storleksfraktioner över 20 µm. Fastläggningen av mikroplast i biofiltrens övre filterlager i studien genomförd inom detta projekt kan därmed bekräftas.

Resultaten från nedbrytningen av plastskräp under UV-bestrålning indikerade en tydlig nedbrytning av PS, PP och PET i jämförelse med oexponerade (kontroll) prov, och en ökad frisättning av mikroplaster med längre exponeringstider. PP var mest känslig för UV-exponering följt av PS och PET. Efter 56 dagar hade 31 N/cm^2, 21 N/cm^2, samt 16 N/cm^2 exponerad yta avgetts från PS, PP respektive PET. PP uppvisade dock ännu högre antal partiklar efter 26 dagar då 58 N/cm^2 noterades, även om den totala massan mikroplast var högre på grund av bildandet av större mikroplastpartiklar efter 56 dagar. För plastpåsen gjord av PE-LD observerades ingen nedbrytning under UV-exponeringen eftersom antalet partiklar som frigjordes från exponerade och oexponerade (kontroll)prover var i samma låga storleksordning. Det finns dock många andra faktorer än bara UV-ljus som påverkar fragmenteringen, såsom mekanisk, termisk och biologisk nedbrytning, samt kemiska tillsatser till plasten som kan påverka nedbrytningen. Därför kan andra plastföremål gjorda av samma polymerer visa andra nedbrytningsmönster än exemplen i denna avgränsade studie.

Utsläppen av mikroplast i modellstaden med 100 000 invånare uppskattades till 7,2 kg/år från renat avloppsvatten och 1 kg/år från bräddvatten. Utsläppen till dagvattnet uppskattades till 13 000–17 000 kg/år för mikroplast och 2 100 kg/år från däckpartiklar. Om endast de flöden som baserats på mätdata inkluderas, uppskattas utsläppen till dagvattnet till 120 kg/år för mikroplast. Utsläppen av däckpartiklar baseras bara på mätdata och påverkas därför inte. Resultaten bekräftar tidigare studier i att utsläppen till avloppsvattnet kan vara stora, men utsläppen efter avloppsrening är mycket lägre. Den största källan till mikroplast i avloppsvattnet var syntetiska fibrer från klädtvätt. Till dagvattnet var den största källan cigarettfimpar, följt av färg och däckpartiklar. Dricksvatten, takavrinning och damm var källor som hade med små bidrag till det urbana vattnet. Det mesta av mikroplasten i dammet förväntades i stället hamna i det fasta avfallet. Nedskräpning av större plast kan ge upphov till mikroplast vid fragmentering, men det bedömdes vara för osäkert för att uppskatta. Utsläpp från konstgräsplaner till dagvattnet tycks variera mycketstort mellan planer och uppskattades därför inte. Det finns fortfarande många osäkerheter gällande att uppskatta källor till mikroplast och de polymerer som återfanns i proverna stämde inte alltid med det som förväntades baserat på källuppskattningarna. Denna skillnad kan betyda att vissa källor missas medan andra överskattas. Vidare baseras mätuppskattningarna på endast ett fåtal prover och under en kort tidsperiod.

Flera åtgärder har föreslagits för att minska mängden mikroplast, främst för källor till avloppsvatten. Om ett förbud mot all avsiktligt tillsatt mikroplast skulle införas, samt att invånarna slutade skölja färgpenslar i diskhon och filter i tvättmaskiner var obligatoriska, finns det potential att minska utsläppen till avloppsreningsverket med 30–50%. Ett extra reningssteg på avloppsreningsverket skulle kunna minska utsläppen ytterligare, men från låga nivåer. Motsvarande beräkningar för dagvattenrening har inte kunnat göras på grund av ett bristande underlag av data.

De kommunala tjänstemän som intervjuades identifierade flera typer av aktörer som ansvariga för mikroplast i dagvatten både på lokal, regional, nationell och internationell nivå. De flesta av de identifierade aktörerna kunde påverka flödet av mikroplast till dagvattnet, dels genom att påverka flödet av mikroplast till samhället i stort, genom exempelvis lagstiftning, och dels genom att minska utsläppen av mikroplast till dagvattnet. Kommunen sågs som ansvarig för de utsläpp deras verksamhet gav upphov till, men av vissa även som en lokal förebild. Kommunen som undersöktes i det här projektet hade vidtagit åtgärder för att minska spridningen av mikroplast till dagvatten genom åtgärder för att stoppa granulat från konstgräsplaner, minska nedskräpning och cigarettfimpar i staden, samt uppströmsarbete gentemot verksamheter med utsläpp till dagvattnet. En ökad frekvens på tömningar av dagvattenbrunnar var också en åtgärd som vidtagits med mikroplast i åtanke. Den övergripande handlingsplanen för mikroplast bidrog till att få en struktur på arbetet och bibehålla frågan på agendan. Vissa informanter nämnde dock att det finns en risk att mikroplastfrågan får ett allt för stort fokus gentemot andra viktiga miljöfrågor för kommunen. Begränsade ekonomiska resurser för att kunna genomföra mer kostsamma åtgärder och begränsad kunskap om vilka åtgärder som gör störst nytta identifierades som utmaningar. Kunskapen som finns att tillgå varierar också mellan flöden, vilket kan göra att olika avdelningar inom kommunen har olika utmaningar.

Fyra typer av mikroplastpolymerer detekterades i både inkommande och utgående vatten till gråvattenanläggningarna: PVC, PS, PET och PA. Dessutom detekterades PP och PE i låga koncentrationer i enstaka prover. Koncentrationerna var mycket varierande bland de nio prover som togs från de tre olika platserna – från odetekterade koncentrationer upp till 1100 µg/L, 130 µg/L, 1000 µg/L, 150 µg/L för PS, PVC, PET respektive PA. Generellt var utgående koncentrationer från alla system låga, <30 µg/L för alla kvantifierade polymertyper, med undantag av ett prov från ett av filtermaterialen (hampa) i den gröna väggen där koncentrationer upp till 58 µg/L och 114 µg/L av PVC respektive PET oförklarligt detekterades. Tyvärr går det inte att göra direkta jämförelser av uppmätta koncentrationerna i gråvatten och dagvatten eftersom olika analystekniker har använts där den ena kvantifierar mikrplast med avseende på antal partiklar (dagvattenproverna) och den andra med avseende på massan mikroplast (gråvattenproverna).

Fortsatt forskning

Substansflödesanalysen indikerade att det fortfarande finns flera osäkerheter vid uppskattning av källor till mikroplaster, och de polymerer som hittades i proverna överensstämde ibland inte med vad som förväntades baserat på källuppskattningarna. Denna skillnad väcker frågor om vissa källor missats, och vilka som kan vara överskattade. Mer jämförande studier mellan källuppskattningar och mätningar samt mer långtidsstudier med fler prover spridda över året behövs för att öka förståelsen för stora källor till mikroplast i den urbana miljön. Eftersom nedskräpning kan vara en betydande men högst svårkvantifierade källa till mikroplast från den urbana miljön, vilket även framgår i laboratorieförsöken med UV-bestrålning, bör fortsatta undersökningar kring detta genomföras.

Dessutom bör källorna till mikroplasterna som detekterats i denna studie identifieras för att kunna förhindra eller minska deras utsläpp till miljön, i de fall det behövs. Detta ”uppströmsarbete” kan förstärkas med resultaten från substansflödesanalysen. Framtida forskningsstudier bör också omfatta ytterligare vanligt förekommande reningstekniker, t.ex. dammar, oljeavskiljare och olika filter, samt därtill nyutvecklade, innovativa tekniker för att avgöra vilka som kan användas till att avskilja mikroplast och däckpartiklar mest effektivt och var i dagvattensystemet dessa tekniker bör placeras. Det är också viktigt att kommande studier som undersöker mikroplast i dagvattensammanhang tillämpar analytiska metoder som kan kvantifiera de vanligaste förekommande polymertyperna inklusive svarta partiklar, till exempel ATR-FTIR, pyr-GCMC eller TED-GCMS.

Vidare behövs ytterligare forskning för att kunna dra starka slutsatser om variationerna i gråvattenkvalitet med avseende på mikroplaster och det finns därtill ytterligare reningstekniker tillgängliga för att utvärdera reningseffektiviteten. Det kan också vara av intresse att utföra storleksfraktionering av mikroplasterna och studera hur det påverkar reningseffektiviteten.

1. Introduction

Microplastics are commonly defined as plastic debris ranging in size from 1 μm to 5 mm, and they include both manmade polymers (derived from petroleum or petroleum by-products), and non-synthetic polymers such as natural rubber and polymer modified bitumen, used in e.g. asphalt (Magnusson et al. 2016a). Particles smaller than that are commonly referred to as nanoplastics. Microplastics in marine and coastal waters have been studied since the early 70s (Carpenter et al. 1972, Carpenter and Smith 1972, Van Cauwenberghe et al. 2015). Several studies have reported that microplastics in the marine environment originate from land-based sources (Wagner et al. 2014). Once present in a receiving waterbody, microplastics may be ingested by aquatic fauna and either incorporated into their tissue or excreted in their faeces. Further, due to their hydrophobic properties, microplastics have a propensity to adsorb a wide range of organic substances such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls, pesticides etc. (Frias et al. 2010) and thereby enhance the transport of, and subsequently an organism’s level of exposure to, these pollutants.

1.1 Domestic wastewater

It has been suggested that wastewater is one important pathway by which microplastics reach the environment (Magnusson et al., 2016). In Sweden, most wastewater is treated at wastewater treatment plants. The retention capacity of microplastics at wastewater treatment plants is generally around 90%, and sometimes as high as 99% (Habib et al., 2020; Hu et al., 2019; Sun et al., 2019). Retention levels of over 90% have been reported for Swedish wastewater treatment plants (Tumlin and Bertholds, 2020). Nonetheless, elevated levels of microplastics have been found in waters receiving treated wastewater (Estahbanati and Fahrenfeld, 2016). The retained microplastics are transferred to the sewage sludge or, if removed in early treatment steps, incinerated (Murphy et al., 2016). The application of sewage sludge to agricultural land has been put forward as one potential pathway by which microplastics reach the terrestrial environment (Nizzetto et al., 2016). However, another study found that the microplastic content of such soils was similar to soil fertilised with mineral fertiliser, except when particularly high quantities of sludge had been applied (Ljung et al., 2018). Other sources of microplastics in the soil may include plastic mulching, littering, irrigation and flooding, and atmospheric deposition (Bläsing and Amelung, 2018).

In sparsely populated areas and small villages, domestic wastewater is treated on site. In Sweden, there are 625 000 rural on-site sanitation systems, serving about 12% of the population (Olshammar, Ek et al., 2015), many of which are in operation year-round. The most frequently used treatment systems are drain fields, which account for 30% of all systems, and facilities with only a septic tank and no further treatment (26%).Other treatment systems include sand filters (14%), holding tanks (11%), and package plants (2%) (Olshammar et al., 2015). In many cases, the effluent is discharged directly into natural water bodies. These existing treatment systems have recently received increasing attention due to their large number and their location in close proximity to sensitive natural waters. However, the concentration of microplastics in the effluent from these systems has not yet been investigated.

1.2 Urban stormwater

Urban stormwater provides a transport pathway for a wide range of substances originating from activities and surfaces/materials present in the urban environment, including metals, polycyclic aromatic hydrocarbons (PAHs), oil and grease, pesticides, and surfactants (Zhgeib et al. 2011). During dry weather, particles and pollutants accumulate on streets and other urban surfaces, and are then mobilised and transported in the dissolved or particulate phase as a function of the high energy of stormwater runoff (e.g. Borris et al. 2016). Recent reports from environmental institutes and authorities in the Nordic countries have suggested that urban stormwater is probably also a significant – but under-investigated – pathway through which microplastics reach the (marine) environment (Sundt et al. 2014, Lassen et al. 2015, Magnusson et al. 2016, Andersson-Sköld et al. 2020). These studies suggest that microplastics originate from a range of sources such as road and tyre wear, brake linings, degrading litter, road markings, and paint. Every year around 5-6 litter items per m^2 are cleaned from the roads in Swedish cities, and this is just a small fraction of all litter (Håll Sverige Rent 2017). 26% of this is plastic litter of quite large particle size; i.e. macro litter. Weathering causes these macroscopic plastics to degrade into smaller pieces – microplastics. A previous study has shown that a single plastic lid for a paper coffee cup generated millions of microplastic particles after just seven days of UV exposure in the lab (Lambert and Wagner 2016). Analysis of atmospheric fall-out in Paris identified an estimated yearly load of 3,000-10,000 tonnes of microplastics, consisting primarily of synthetic or natural/synthetic compositions, over the greater Paris area (Dris et al. 2016). Measurement of microplastics in coastal waters has shown increased concentrations after rain events (Moore et al. 2002). Despite this, the main sources of the microplastics found in specific environments have yet to be identified. This study will make a major contribution to filling this gap.

Many of the stormwater treatment facilities already in place today were designed to retain particle and particle-associated pollutants. These systems have the potential to also retain microplastics. Gully pots, ponds, and oil separators are three of the most commonly used stormwater treatment techniques, and biofilters are increasing rapidly. While ponds are end-of-pipe solutions, gully pots, oil separators, and biofilters are generally located upstream in the urban water system, close to the pollution source which may be a parking lot, road, or industrial area. Stormwater biofilters are treatment systems which typically consist of a vegetated swale or basin underlain by a filter medium which works partly as a mechanical filter. The removal of suspended solids by stormwater biofilters often exceeds 80-90% (e.g. Blecken et al. 2010, Hunt et al. 2012), meaning that biofilters have the potential to be good candidates for microplastic removal as well. Oil separators are primarily designed to retain petroleum products but also have compartments for sedimentation of sand and grit. In addition, lighter microplastics may be associated with the oil phase, floating on the water phase (Crichton et al. 2017). Since these systems are frequently used for stormwater that may be expected to contain high concentrations of microplastics, their potential for retaining these types of pollutants is particularly important.

1.3 Sources of microplastics to wastewater and stormwater

The two main sources of microplastics in wastewater are households and enterprises. Tap water, which is used by both households and enterprises, may contain microplastics that can end up in wastewater after use. However, the concentration of microplastics in tap water has been shown to be low (Kirstein et al., 2021; Mintenig et al., 2019). Other sources of microplastics that may be transported in wastewater are synthetic fibres which are released when synthetic materials are washed (Belzagui et al., 2019; Cesa et al., 2020; De Falco et al., 2018) and plastic microbeads that are added to personal care (Cheung and Fok, 2016; Napper et al., 2015) and cleaning products (van Wezel et al., 2016). Household dust can also contain microplastics (Dris et al., 2017). Dust may end up in wastewater, for example through mopping floors. Further, paint can contain microplastics which, if painting equipment is rinsed in the sink, may end up in the wastewater (Verschoor et al., 2016).

The microplastics that end up in stormwater originate from activities and structures in the urban area. Some of the largest contributing sources relate to roads, including tyres, road markings and brake wear (Kole et al., 2017). Atmospheric deposition can also be a large source (Szewc et al., 2021; Wright et al., 2020). Wear and removal of painted surfaces can be another source of microplastics in urban stormwater (Verschoor et al., 2016). The plastic pile and the granulate, consisting of ground up car tyres which are used as infill, on artificial turfs, also risk spreading into stormwater (Verschoor et al., 2021). As mentioned above, plastic litter (Galafassi et al., 2019) and cigarette butts (Belzagui et al., 2021) can become sources of microplastics when they degrade.

1.4 Measures to control microplastic pollution and the actors responsible

Although pollution from microplastics has only been on the agenda for a few decades, many measures for controlling such pollution have been proposed, and a few have been implemented (Fältström and Anderberg, 2020). As yet there is no legislation that comprehensively deals with microplastics. However, several countries have imposed a ban on adding microplastics to personal care products which are rinsed off (e.g., facial wash and toothpaste) (Kentin and Kaarto, 2018). Personal care products are also addressed in proposed EU legislation on all intentionally added microplastics (European Chemicals Agency, 2020). This legislation concerns both personal care products that are rinsed off and those that are left on the skin (e.g., moisturising lotions and cosmetics), as well as cleaning products. Microplastics in paints would not be prohibited under this legislation. Instead, consumers would be informed on how to clean painting equipment. The proposed legislation also addresses the addition of granulate to artificial turfs, the two options under consideration being a ban on the use of rubber granulate or a dispersal limit of 7g/m[2].

Microplastic pollution can be controlled either through centralised treatment of waste- and stormwater or through decentralised treatment closer to its sources. An example of decentralised treatment is filters in washing machines which can retain over 70% of fibres (Browne et al. 2020; Napper et al. 2020) and thus reduce the microplastic load in wastewater. Another option is to carry out treatment centrally, at a wastewater treatment plant. Various studies have reported high retention capacities for treatment technologies such as disc filters (Simon et al., 2019), biofilters for tertiary treatment (Liu et al., 2020), sand filters (Talvitie et al., 2017), membrane bioreactors (Lares et al., 2018), and dissolved air flotation (Talvitie et al., 2017). Large-scale treatment of stormwater was tested within the FanpLESStic-Sea project[1]. A single test showed that treatment achieved a high level (93%) of retention of microplastics and a moderate level (47%) for tyre wear particles. tests are needed to confirm that these retention levels can be reliably reproduced.

Many actors at different levels of society have both the opportunity and responsibility for controlling microplastic flows in urban areas: these include producers, national and local authorities, and citizens (Fältström and Anderberg, 2020). Municipalities have been highlighted as one type of actor who can impact microplastics in various ways, both at a strategic level, for example through physical planning, and at a practical level, for example through their responsibility for maintenance of municipally owned facilities and in their role as a water utility (KIMO Sverige, 2017).

---

[1] Information about the treatment technology can be found here: Template FanpLESStic-sea fact sheet (swedenwaterresearch.se)

2. Project scope and limitations

In this project, pathways of microplastics from the terrestrial to the aquatic environment were investigated and mapped. Special attention was paid to urban stormwater, which has been severely under-investigated as a pathway for microplastics (Österlund et al. 2023). A conceptual model was developed, to illustrate and map the flows of microplastics in a city and identify the measures that could be taken to control these.

The following research questions were investigated:

1. How does the most common plastic (macro) litter from streets break down into microplastic particles?
2. What types and concentrations of microplastics are found in urban stormwater from different catchments?
3. What types and concentrations of microplastics are retained by commonly used stormwater treatment facilities?
4. What types and concentrations of microplastic particles are retained by, and found in effluents from, on-site and small-scale wastewater treatment facilities?
5. Where are microplastics found in urban areas, and what measures can be taken to control microplastic pollution?
6. How do local public actors view their own responsibilities with regards to microplastics in stormwater, and which other societal actors do they perceive to be responsible?

Developing new methods for microplastics analysis was beyond the scope of this project. However, microplastics analysis methods were carefully chosen, and carried out in collaboration with researchers and commercial laboratories who are at the forefront of developing methods for microplastics analysis. The boundaries of the conceptual model developed for this project were where urban water systems meet the receiving waters.

3. Methods

To fulfil the aims and objectives of the µrban Plastics project, laboratory studies and field sampling were conducted, literature reviews were carried out, and microplastics flows were assessed. The methods applied to these activities are described in sections 3.1, 3.2, and 3.3, respectively.

3.1 Laboratory studies

3.1.1 UV degradation of plastic litter items

Laboratory tests were carried out on plastic litter commonly discarded in the urban environment (Öborn et al. 2022). The selected items were a plastic bag made of low-density polyethylene (PE-LD), a chocolate bar wrapper made of polypropylene (PP), a plastic coffee cup lid made of polystyrene (PS), and a bottle made of (Figure 1). The items were cut up into 4x4 cm pieces and exposed to UV radiation (type: UVA 340 nm 40 W T12 lamp) for 7, 28, and 56 days, to simulate outdoor exposure in Sweden for 3 months, 1 year, and 2 years, respectively. After exposure, the plastic items were rinsed in deionised water, and loose microplastic particles formed by UV degradation were released to the water phase in an ultrasonic bath. The water was filtered (10 µm pore size) and the filters were analysed with micro Fourier-transform infrared spectroscopy (µFTIR) at an external laboratory (ALS Scandinavia AB), to determine the number and sizes of the particles released (Öborn et al. 2022a).

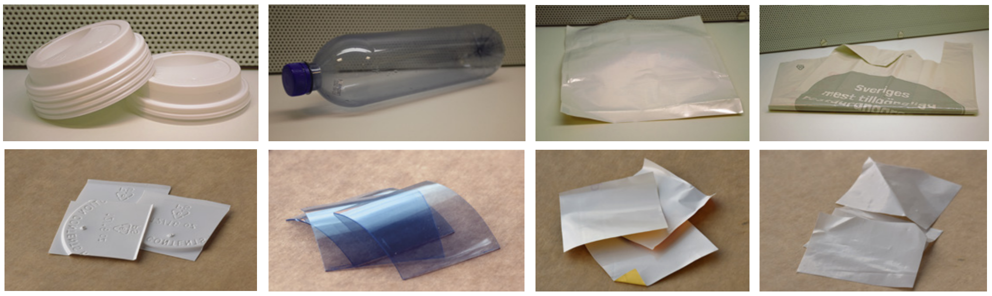


Figure 1 Photos of the examined litter a) coffee cup lid (PS), b) water bottle (PET), c) chocolate bar wrapper (PP) and d) plastic bag (PE-LD) and the respective material test pieces.

3.2 Field sampling and microplastics analysis

Samples for microplastics analysis were taken from different parts of the urban stormwater system and on-site wastewater treatment systems. The sampling strategy and analysis are summarised in Table 1 and described below.

Table 1 Summary of collected samples, sample preparations and applied analytical techniques

Area	Sample matrix	No of sites	No of samples	Sample volume/ mass	Analysed size fraction	Density separation (g/mL)	Analytical technique	Notes
Storm-water	Roof runoff	1	3	68-564 L	>10 µm	1.9	µFTIR	Volume weighed samples from a coated steel roof
	Parking lot	1	3	1.5-4.3 L	>10 µm	1.9	µFTIR	Time weighed samples taken at a gullypot inlet
	Road runoff	1	3	0.6-2.0 L	>10 µm	1.9	µFTIR	Time weighed samples taken at a gullypot inlet
	Gully pot sediment	26	26	50 g	>40 µm	1.7	µFTIR + ATR-FTIR	Bottom sediment
	Biofilter substrate	9	33	50 g	>20 µm	1.7	µFTIR + ATR-FTIR	Sediment from different parts and depth of biofiltrations
On-site waste-water treat-ment	Greywater from package plants	2	12	1-	>10 µm	1.5	TED-GCMS	Influent and effluent to two onsite treatment facilities
	Greywater from green walls	1	15	1-60 L	>10 µm	1.5	TED-GCMS	Influent and effluent to four filter material settings of a green wall system.

3.2.1 Sampling from stormwater systems

STORMWATER RUNOFF

Stormwater runoff samples were collected simultaneously at three sites in the city of Luleå, on three occasions (October 5, November 2 and 5 in 2020). The three sites were characterised by a parking lot (PL), a road (Road) (AADT=15000 vehicles/d), and a coated steel rooftop (Roof) (Figure 2). The selection of sites was based on assumptions about where high concentrations of microplastics may be present (the two trafficked areas), and a reference site representing long- and short-distance atmospheric deposition (the roof top). The road and parking lot runoff samples were collected manually, directly from the inlet to the gully pots, and the roof runoff was collected from the downspout (Figure 2-4). A summary of rain depth, antecedent dry days, and rain duration is presented in Table 2. Time proportional samples were collected from the road and parking lot every 15th or 30th minute, and pooled into one composite sample. Runoff from the rooftop was collected in 110-litre steel barrels and the whole water volume was filtered directly in the field by pumping the water through a filtration unit (stainless steel, 78 mm in diameter, 10 µm pore size), based on the method described by Renberg (2019). When a filter clogged it was exchanged for a new filter. Several filters were used for each sampling occasion. The filtrate was discarded on-site while the filters were kept and placed into petri dishes for transportation to the laboratory. The data obtained from this study was further used for the substance flow analysis of microplastics in a model city, described in section 3.4.

Table 2 Rain event characteristics (data obtained from Lindfors et al. 2023)

Sampling date	ADD	Rain depth	Rain duration
Oct 5, 2020	7	3.1	5 h
Nov 2, 2020	0	11	4 h 50 min
Nov 5, 2020	2	0.8	2 h 30 min

Figure 2. The PL parking lot catchment (left) and the arrangement with a funnel/spout at the gully pot inlet to facilitate the sampling (right).

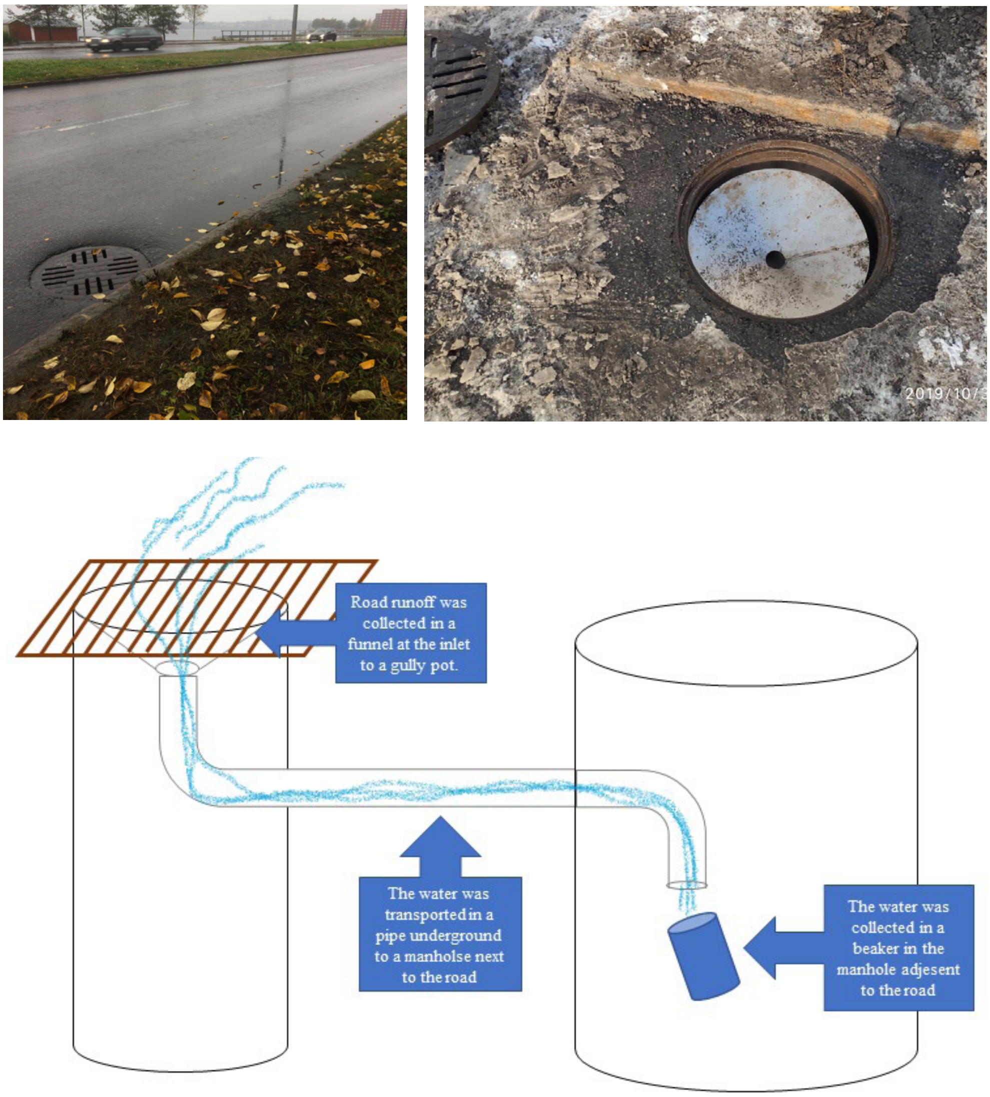


Figure 3. The Road sampling site (top left). A stainless-steel funnel is placed below the grid, collecting the runoff directly as it comes from the road surface and bypassing the gully pot (top right). The water was directed to a manhole located in the grass strip next to the road, where it was collected (bottom).

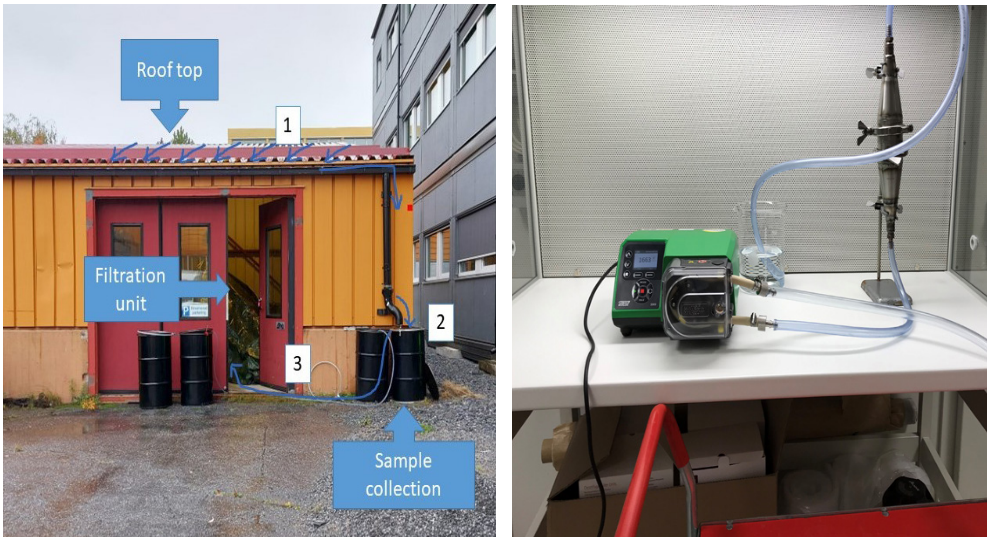


Figure 4. Left: Runoff from the rooftop (1) was drained via gutters and collected in barrels at the downspout outlet (2). Thereafter the water was pumped through a tubing and filtered directly (3). Once the sampling was complete, the filters were taken to the laboratory for subsequent preparation and analysis. Right: The filtration unit and pump applied for filtration.

SEDIMENT FROM STORMWATER TREATMENT FACILITIES

Sediment was collected from two types of stormwater treatment facility in Sweden (Stockholm area) and the United States (Ohio and Michigan): these facilities comprised 29 gully pots and nine bioretention systems.

Gully pots' primary function is to drain water from roads into a sewer system to prevent flooding. There is usually a sediment trap in the bottom which retains the coarse size fractions of the sediment load transported by the stormwater. Gully pots are ubiquitous in urban areas and, although they are not primarily designed for treatment of pollutants, the sheer number of them means that the volume of sediment they retain every year is substantial.It was hypothesised that sediment from gully pots would give a qualitative and quantitative insight into the composition of microplastics found in different parts of the urban environment. Sediment was taken from 29 gully pots in the Stockholm area, Sweden, located in residential roads (locations denoted Res1-12), industrial areas (locations denoted Ind 1-6), parking lots (locations denoted Car 1-6), and parks and pedestrian walkways (locations denoted Ped1-5) (Öborn et al. 2022b). The gully pots had been accumulating sediment since they were last cleaned of sediment approximately one year prior to sample collection. Before taking the samples the standing water was emptied with a pump. Then the sediment was collected in a wedge-shaped piece from the centre to the wall of the gully pot, through the whole depth of the sediment. This comprised between an eighth and half of the total sediment volume in each pot. (Figure 5).

Figure 5. A schematic description of how the sampling of gully pot sediment was conducted (left) and the tool used for retrieving the sediment from the gully pots (right).

The number of stormwater bioretention systems being installed to improve stormwater quality is steadily increasing. Bioretention systems are nature-based treatment technologies which reduce sediment and a range of pollutants in stormwater. These systems contain a filter medium (often sand, gravel, and/or soil) and vegetation which retains pollutants through bio-/geochemical and physical processes. The water enters at the surface, where it is temporarily held while it percolates through the filter material and drains at the bottom. To prevent the filters from clogging, some bioretention systems are equipped with forebays, i.e., a pre-sedimentation trap. Filter material including accumulated stormwater sediment was collected from nine bioretention facilities (Figure 6) which had been in operation for between 7 and 12 years (Lange et al. 2022). From each bioretention system, three to four samples were taken. Two samples were distributed horizontally at the surface of the filter (0-5 cm depth) and one was collected from deeper layers (10-15 cm depth). Six of the biofilters were designed with a pre-sedimentation forebay in front of the inlet to the facility, to retain coarse sediment. In these cases an additional sample was taken from the forebay (Figure 6). In total 33 samples were taken.

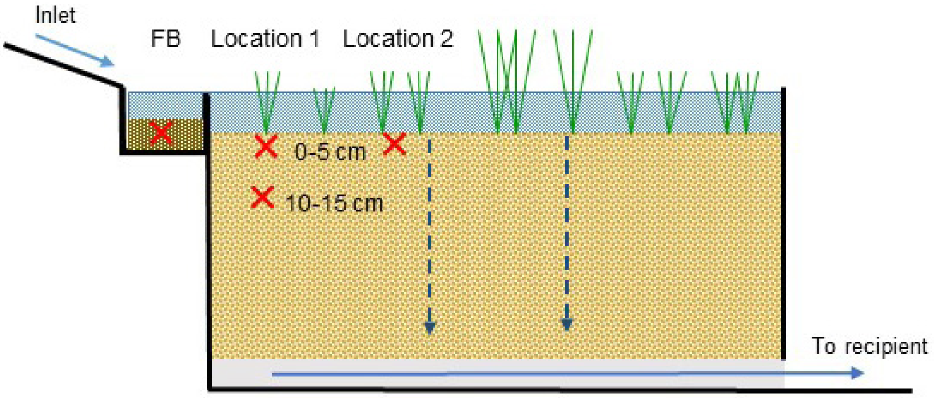


Figure 6. Schematic representation of a bioretention system. Schematic representation of a bioretention system and locations in which the filter material samples were taken. The first sample was taken from the forebay (FB) if that existed. The second and third samples were taken from the top layer (0-5 cm depth) and 10-15 cm depth, close to the inlet, and the fourth sample was taken from the top layer closer to the middle of the filter. (Figure from Lange et al. 2023)

All samples were thoroughly mixed in stainless steel trays before taking a subsample which was then sent to external laboratories for sample preparation and analysis.

3.2.2 Sampling from onsite-greywater systems

Greywater (i.e., household wastewater sourced from baths, showers, bathroom sinks, and laundries) was collected from the influents and effluents of two types of on-site treatment facilities in Sweden, package plants[2] and green walls[3], to evaluate their capacity to remove microplastics.

PACKAGE PLANTS

Two package plants in Södertälje, Sweden, (Site 1 and Site 2), which are already in operation treating greywater from individual households, were selected for further investigation (Sami, 2022b). Sampling was carried out from the influent and effluent on three consecutive days. On each day at each site, 1 L of influent water was collected with a Ruttner water sampler (KC, Denmark). The effluent water was collected over a full day (6 am to 3 pm) in 80 L stainless steel containers. At the end of the day this water was filtered directly at the site through a 10 µm stainless steel filter. Between 8 and 56 L was collected, of which between 5.6 and 48 L was filtered. Filter volumes were lower than collected volumes due to clogging, and filtration was stopped after four filters became clogged up. The filters were taken to the LTU Environmental Laboratory where the filter residues were sonicated and transferred into 250 mL water samples, which were then sent to an external laboratory for analysis.

---

[2] Package-plants are prefabricated units for small scale wastewater treatment.

[3] Green walls are vertical structures of vegetated containers. The treatment systems are based on plants and substrate/filter media. The treatment principles are similar as for bioretention systems, i.e., the systems retain pollutants by bio-/geochemical and physical processes.

GREEN WALLS

The green wall system was a pilot plant at RecoLab[4] which treats a fraction of the greywater flow from one district in the city of Helsingborg (commonly referred to as "H+") with around 700 person equivalents. Four filter materials were evaluated in parallel: Hemp, Biochar, Pumice, and Compost Soil (Sami et al. 2022a). Each material was tested in triplicate. Therefore, in total 12 lines were tested in parallel. Each line was fed with 4.5 L of greywater per day, and a 14-day composite sample was collected from the effluent water, resulting in 60 L sample volume. 1 L influent samples were collected the day before the test commenced and on the first and second day after the test ended. The samples were filtered and sonicated as described above under "Package plants".

3.2.3 Sample pre-treatment and analysis

During the course of this project several analytical techniques were applied to the analysis of microplastics. These included thermal extraction desorption gas chromatography mass spectrometry (TED-GCMS), µFTIR imaging, and attenuated total reflectance (ATR-) FTIR. Whichever sampling technique was used, some pre-treatment of both waters and sediments was generally needed, to reduce the sample matrix, concentrate the analytes, and extract microplastics from the water phase to a solid phase (in case of liquid samples). Normal pre-treatment included oxidation with Fenton's reagent and H_2O_2, density separation with $FeCl_2$ (1.7-1.9 g/mL; see Table 1 for details for specific samples) and filtration. For a fraction of the samples, additional enzyme catalysed breakdown of organic matter was needed.

The techniques used for each sub study are summarised in Table 1 above. The significant differences between the techniques used have an impact on the conclusions can be drawn from the results. TED-GCMS gives concentrations based on the mass of specific polymer types in a sample. The total mass is determined, with no consideration of size fractionation, i.e., a big particle will have a larger impact on the mass than a small particle but individual particles are not distinguished. With µFTIR imaging, a surface is scanned and individual particles are detected and characterised with respect to their polymer composition. The projected area of the particle can be determined and the volume (and mass, if the density of the polymer is known) of the particle can be estimated (see e.g. Liu et al. 2019 for further details). Therefore, the number of particles with a certain polymer composition, their size, and total mass can be estimated. A disadvantage with this technique is that particles containing carbon black are not detected because they absorb all IR radiation and generate no spectrum to analyse. Microplastics containing carbon black include, for example, RTWP and black-coloured plastics. Applying ATR-FTIR, these types of microplastics can be characterised. However, this technique does not support imaging and therefore the size of the particle cannot be determined, only the polymer type. Furthermore, while the µFTIR technique can generally measure particles down to 10 µm, ATR-FTIR demands larger particles of at least 40 µm. The major differences between the techniques are summarised in Table 3.

---

[4] www.recolab.se

Alongside the pre-treatment and analysis of the sediments, a subsample of each sediment was dried, to determine the microplastics concentration in the samples' dry mass (DM).

Table 3. Major differences between three analytical techniques applied.

	TED-GCMS	µFTIR	ATR-FTIR
No of polymer types	10, including tire wear	~40, black particles excluded (e.g. tire wear)	~40, black particles included
Lower size cut-off	5 µm[1)]	10 or 20 µm (depending on lab)	40 µm
Reported unit	Weight per mass or volume	Number of particles per mass or volume	Number of particles per mass or volume
Particle shape enabled	No	Yes, if run in imaging mode	No
Other	The sample is consumed by the analysis	Semi quantitative weight per mass or volume may also be determined[2)]	Includes also particles with carbon black which are not included with µFTIR

1) Lower size cut-off is possible but was not applied in this study.
2) The particle volume is estimated from the width and length of the particle. Densities of the specific plastics are applied to calculate particle mass.

3.2.4 QA/QC

Several types of blank and control samples were prepared in parallel with the field and laboratory work. The results from the blanks and controls were evaluated along with the sample results. Sampling equipment and containers were made of glass or stainless steel, as far as possible. In the field, care was taken to handle the samples down-wind to protect them from textile fibres from researchers' clothes. The water used for rinsing and sample preparation was either deionized and filtered (1.2 µm glass fibre filter) or tap water which has been shown to contain low levels of microplastics.

3.3 Literature review

The available scientific literature on the sources, transport, and retention of microplastics in the urban stormwater system was collated and analysed in a critical review (Österlund et al. 2023). Literature searches focused on peer-reviewed articles, academic theses, and conference proceedings in Scopus®, the Web of Science®, and Google Scholar® databases, and peer-reviewed government or university reports. The keyword "microplastic" was used to identify papers on that topic. This was then combined with the terms "urban runoff" OR "stormwater" and other relevant terms for specific topics (e.g., stormwater control measures, SCM; snow; atmospheric deposition).

3.4 Mapping urban microplastics flows

To assess and map the flows of microplastics in urban areas, an approach based on substance flow analysis was used. Substance flow analysis is a comprehensive systems approach for analysing stocks and flows of different elements (van der Voet, 2002). The system is first defined, and the relevant flows identified and then quantified *(ibid).* A comprehensive literature review of research studies and grey literature reports on microplastic sources related to urban waters was used to identify flows. The subsequent quantification was carried out using two types of data: 1) strategic measurements (sampling and analysis) of selected flows, which were used to estimate yearly values and are here referred to as *measurement-based estimates;* and 2) literature values which were applied to identified sources where measured values were not available, which are referred to as *source-based* estimates. Emissions to stormwater and wastewater were the focus of this assessment, but solid waste and urban soils were included as compartments where microplastics may be deposited. For more details on how the estimations were made for each flow see section 3.3 of Fältström (2022).

The sampling and analysis of microplastics was carried out in different cities around the Baltic Sea by project partners in the FanpLESStic-Sea project. All of these samples, taken from different compartments in the urban water cycle (including the collected stormwater described in section 3.2.1), were analysed using the same techniques, i.e., µFTIR imaging for plastic particles (c.f. section 3.2.3) and pyrolysis (pyr-) GC-MS for tyre wear particles. In order to obtain comparable values, it was critical to apply the same analytical protocol to all data used in the substance flow analysis. Because the sampling was carried out in different cities, a semi-hypothetical model city was developed to quantify flows. The attributes of the semi-hypothetical city build on those of the cities from which the microplastics were sampled and are summarised in Table 4.

Table 4: Characteristics of the semi-hypothetical model city of relevance to microplastics flows in the city.

City characteristics	Number of inhabitants	110 844
	Area (city centre)	26 km^2
	Impervious surfaces	44%
	Distribution of impervious surfaces	37% Buildings 26% Roads 11% Parking lots 26% Miscellaneous
	Distribution among vehicle types	84% Passenger cars 10% Goods vehicles/vans (>3.5 tonnes) 5% Mopeds/motorcycles 1% Lorries/trucks 0.2% Buses
Urban water system	Combined sewer system	9% of city area
	Wastewater treatment process	Mechanical treatment Activated sludge process Post-precipitation with ferric chloride.
	Volume of wastewater treated	11 million m^3/year
	Inflow and infiltration	20% of water volume at inlet
	Combined sewer overflows	3000 m^3/year
	Distribution of the combined sewer overflows	91% stormwater 7% grey water 2% black water
	Connected industries that release microplastics	None
Artificial turfs	Number of artificial turfs	12
	Type of material	styrene-butadiene rubber and polyethylene pile

Two types of measures to control the flows of microplastics were introduced into the model city: preventative and treatment. Preventive measures encompassed bans or limitations on releases, and behavioural change. The preventive measures that were introduced build on the proposed European Union legislation on all intentionally added microplastics (European Chemicals Agency, 2020), which concerns artificial turfs (complete ban or dispersal limit of 7 g/m^2), personal care products, and cleaning products. For the purposes of this assessment, it was also assumed that the inhabitants in the model city changed their behaviour to stop rinsing painting equipment in the sink.

Regarding treatment, both decentralised treatment at the source and centralised treatment of wastewater or stormwater were considered. Literature values on the removal efficiency of filters in washing machines (74-78%) were used for the flow of synthetic fibres from laundry (Browne et al., 2020; Napper et al., 2020). For centralised treatment at the wastewater treatment plant literature values were derived from two papers, which had used the same analytical method that was used to derive the measurement-based value for wastewater effluent, to exemplify the impact of additional treatment techniques on emissions from the wastewater treatment plant. These were a biofilter for tertiary treatment (Liu et al., 2020) and a disc filter (Simon et al., 2019). Both of these treatment technologies showed an increased retention of microplastics. The disc filter retained 76% and the biofilter 89% of microplastics, measured by mass.

3.5 Interviews with actors in a case city

Interviews were carried out in a case municipality, to explore the views of municipal actors on the issue of microplastics in relation to stormwater management, and their views on responsibilities with regards to the flow of microplastics. The chosen municipality is located in the southern part of Sweden and has approximately 50 000 inhabitants. The municipality was chosen because it has documented work on the microplastics issue in the form of a microplastics action plan. The chosen municipality was also located in a region for which there is documented work on microplastics at the regional level, and this was viewed as important because connections between governance levels (for example support from the regional level to the local level) were of interest.

To select interview respondents, sources of microplastics to stormwater that was highlighted in the flow mapping were linked to responsibilities of particular divisions within the case municipality. Seven divisions (or units within a division) were identified (Table 5). The head of each of the identified divisions/units was then contacted for an interview. On two occasions, the head of the division/unit referred us to another employee who was then interviewed (Table 5).

Table 5: The divisions or units within the divisions that were identified and the role of the respondents who were interviewed (reproduced from Fältström and Carlsson, 2023).

Division/Unit	Role of the respondent
City planning	Plan architect
Water and wastewater unit	Environmental engineer
City environment unit	Head of unit
Solid waste management	Head of unit
Property management unit	Head of unit
Service unit	Head of unit
Environmental division	Head of division

The interviews were performed between October 2021 and January 2022. The interviews were each 40-80 minutes long and were conducted virtually due to the Covid-19 pandemic. All interviews were recorded with the respondent's consent. The interviews were auto transcribed using the software Trint[5] and afterwards revised by the interviewer to assure complete accuracy. The transcriptions were then coded into four themes. The first theme concerned concrete measures that had been taken by the municipality, and challenges and success factors related to the measures taken. The second theme concerned respondents' views on their own responsibility and which other actors they saw as responsible. The third and fourth themes concerned support needed from other levels and other actors' opportunities to act, respectively.

---

[5] https://trint.com/

4. Results

4.1 Breakdown of macro plastic litter into microplastics

Results from the accelerated weathering of the four plastic litter materials (PE-LD, PS, PET, and PP) are presented in Figure 7. The results indicate clear differences between the materials regarding the number of particles released during the different exposure times. Of the plastics tested, PE-LD was the least affected by UV-radiation. Fewer than 0.2 particles/cm^2 were detected from the exposed samples, which was of the same magnitude as the unexposed control sample, meaning that no release of microplastics as a result of UV radiation was apparent. Results for both PS and PET showed that the number of particles released increased with exposure duration and obtained maximum concentrations (31 and 16 particles/cm^2, respectively) after 56 days. PP produced the largest number of particles after 28 days' exposure (58 particles/cm^2), which then decreased after 56 days (21 particles/cm^2). This could possibly be explained by further degradation of particles to below 10 µm, the lower size limit for detection.

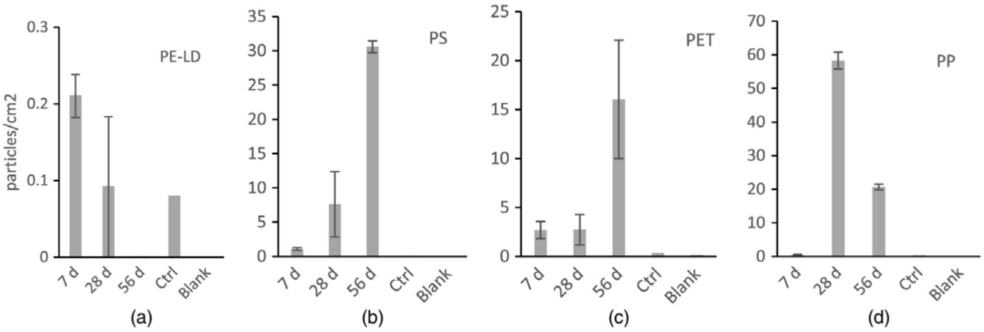


Figure 7 Number of particles released per cm2 from exposed: (a) PE-LD; (b) PS; (c) PET; and (d) PP, and mean values for nonexposed control samples and blanks. Mean values shown with bars for maximum and minimum values of duplicate samples. For the exposure times, control sample or blanks without bars, no particles of the polymer in question were detected in the samples. (Figure from Öborn et al. 2022.)

The mass of microplastic particles released by PS and PP was estimated after 28 and 56 days' UV exposure. The PS coffee cup lid released 3.8 and 3900 µg/cm^2 and the PP chocolate bar wrapper released 5.1 and 3700 µg/cm^2 after 28 and 56 days, respectively. In contrast to the number of particles released, the mass of the particles released increased with time for both materials, indicating the formation and release of larger particles over time. Further details can be retrieved from Öborn et al. (2022).

4.2 Microplastics in stormwater runoff

The concentrations and polymer compositions of microplastics in runoff from a road, a parking lot, and a roof top, on three sampling occasions, are presented in Figure 8. Despite including only three sites and three sampling occasions in this study, it is clear that the concentrations of microplastics in stormwater may vary greatly both between sites and within sites. The lowest concentrations were detected in the roof top runoff (95 particles/m^3), and the highest concentrations in road runoff (11400 particles/L). The most abundant polymer detected in every sample was PP, followed by PE and polyester (including e.g. PET). Other polymer types were detected included acrylic, polyurethane (PU; including PU paints), PA, polyvinyl chloride (PVC), PS, and acrylonitrile butadiene styrene (ABS).

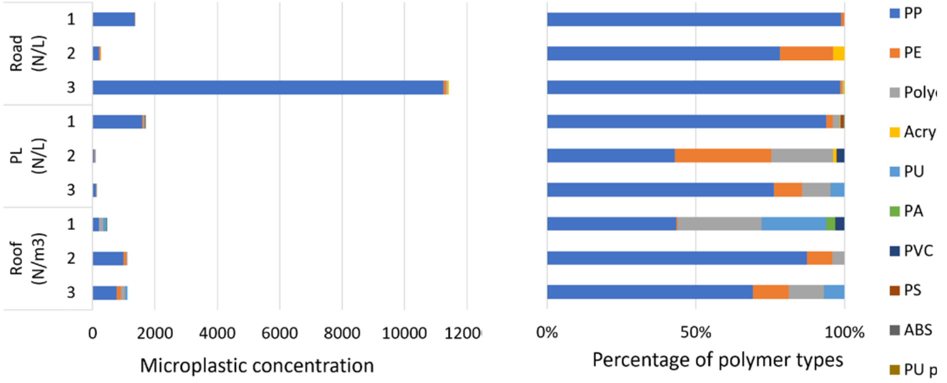


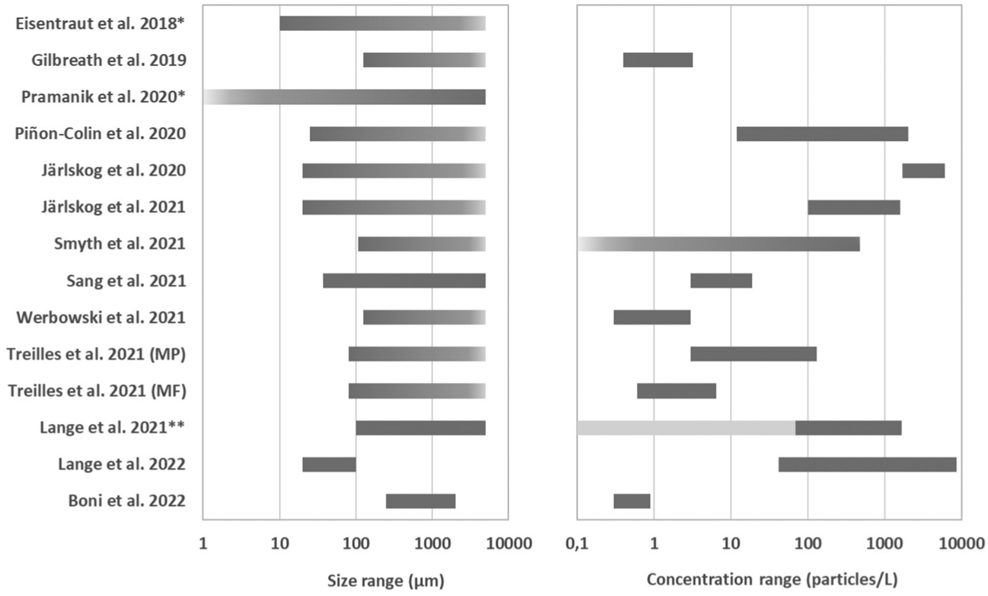
Figure 8. Microplastic concentration (left) and composition (right) of analysed stormwater from a road, a parking lot (PL), and a roof top, on three occasions. Note that, while the concentrations of PL and Road runoff are reported in MPs/L, the roof runoff is measured in MPs/m^3. Black particles were not included in the analysis. (Based on data from Lindfors et al. 2022.)

To assess whether the microplastics in the roof runoff originated from the roofing material and/or gutters, their coatings were also analysed. No matches were detected, indicating that the source of the microplastics was dry and wet atmospheric deposition and not the roofing material.

Based on the µFTIR imaging analysis, estimations of the distribution between fibres and particle shaped microplastics were carried out for each stormwater catchment. In all catchments, particles dominated over fibres, the respective shares of particles being 86% (road), 62% (PL) and 71% (roof).

4.2.1 International review of microplastics concentrations in stormwater

The international review, which compiled all available data on microplastics concentrations in urban stormwater runoff published in research journals up to June 2022, illustrated that measured concentrations vary widely (Österlund et al. 2023). Overall, measured microplastics concentrations ranged between 0.3 (or non-detected) to 8600 particles per litre of stormwater. It was suggested that this is partly due to different size ranges and types of microplastics being included in different studies, and different strategies for sampling, including both volume proportional sampling covering full runoff events from start to finish and single grab samples, being applied. Figure 9 summarises the concentration ranges obtained, and size ranges measured in the 14 papers identified.



**Eisentraut et al. (2018) and Pramanik et al. (2020) do not report concentrations*
*** Lange et al. (2021) specify a detection limit of 67 particles/L but report values below this concentration for some samples. These cases are indicated by light grey shading.*

Figure 9. Particle sizes (left) and concentration ranges (right) reported in selected studies on MP in stormwater. In the size range plot, grey shading indicates that no maximum size was reported; a maximum size of 5 mm is assumed because this value is often taken as an upper bound when defining MP. (Graphs obtained from Österlund et al. 2023.)

In several of the reviewed studies, different particle size fractions were measured. All of these studies showed that the microplastics in the smaller fractions were more abundant than in the larger fractions. Furthermore, the most abundant microplastic type in stormwater was tyre and road wear particles, followed by textile fibres, films, fragments, and paint particles. The main polymer types constituting these particles were polyesters/PET, PE, PP, PS, PA, PVC, and PU.

4.3 Microplastics in sediment from stormwater treatment facilities

Two types of stormwater treatment system were investigated with respect to microplastics content in collected sediment – gully pots and bioretention systems. In addition, an international literature review of microplastics in stormwater treatment systems was carried out. The results from the studies are reported in the following sections 4.3.1-4.3.3.

4.3.1 Gully pots

The concentrations and polymer compositions of microplastics in sediment from 29 gully pots, located in areas with different land use (parks and pedestrian, Ped; Industrial, Ind; residential, Res; and parking lots, PL) are presented in Figure 10. The sediments contained microplastics in concentrations ranging between 720-25300 number (N)/100 g DM. The median and mean concentrations were determined to be 2850 and 4070 N/100 g DM, respectively, with a standard deviation of 5050 N/100 g DM. The most frequently detected plastic polymer was PP, which was found in all 33 samples, followed by ethylene propylene diene monomer rubber (EPDM), Ethylene-vinyl acetate (EVA), PS, and styrene-butadiene rubber (SBR), which were found in 22, 21, 17 and 16 samples, respectively. It was found that a large portion of microplastics were black (median percentage of black particles was 23%), including all PE polymers detected.

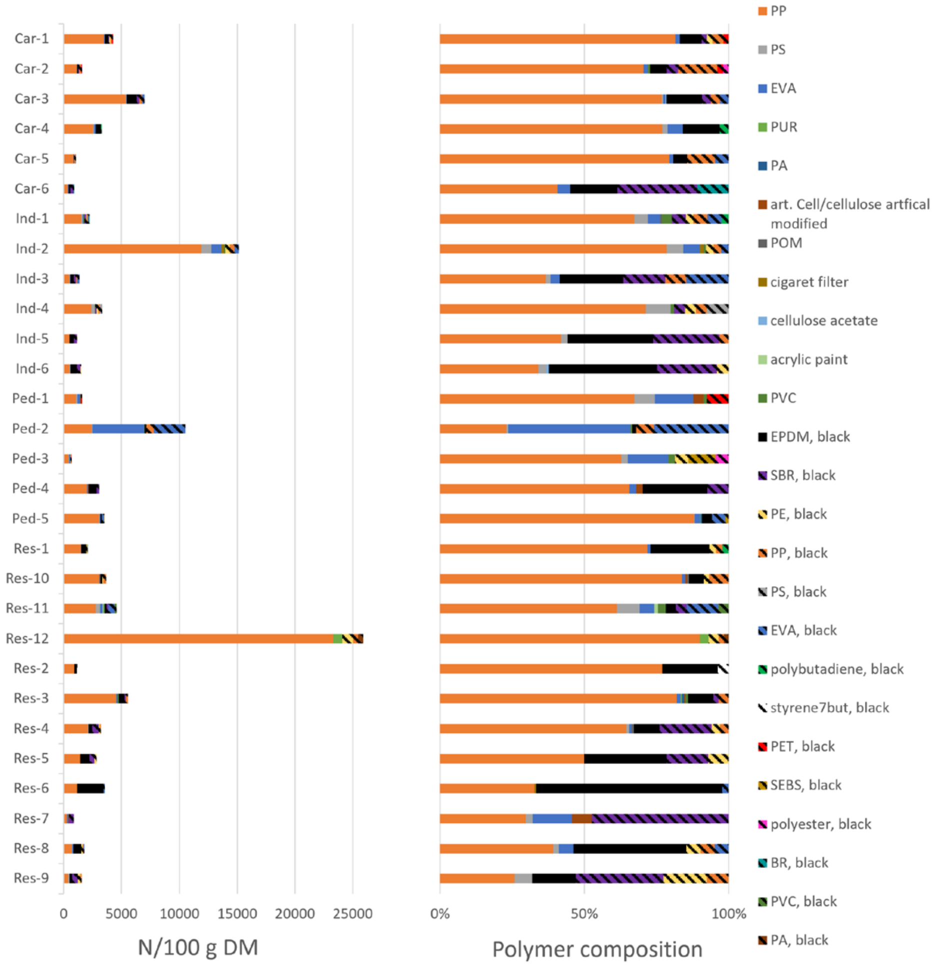


Figure 10 Microplastic concentration (left) and polymer composition (right) of sediments from gully pots located in parking lots (Car), industrial/commercial areas (Ind), parks and pedestrian areas (Ped) and residential areas (Res). Black particles were included in the analyses and these are presented separately (striped fields). (Based on data from Öborn et al. 2022b.)

4.3.2 Bioretention systems

The concentrations and polymer compositions of microplastics in different parts of bioretention systems are shown in Figure 11. Microplastics concentrations ranged between non-detected (<9) and 17300 N/100 g sediment. The median and mean concentrations were determined to be 3110 and 1770 N/100 g DM, respectively, with a standard deviation of 854 N/100 g DM. Measurements of the polymer composition showed that PP, EVA, PS, and EPDM rubber were the most abundant polymer types in the bioretention systems investigated. They were detected in 31, 24, 20, and 19 samples, respectively. It was found that a large portion of microplastics were black (median percentage of black particles was 39 %). Further, microplastic median concentrations decreased significantly from the surface layer (0-5 cm) of the filter material to the layer at depths of 10-15cm, from 448 to 136 particles/100 g. The distance to the inlet (Location 1 in comparison to Location 2) did not significantly affect the surface accumulation of microplastic particles. For the biofiltration systems designed with a pre-sedimentation forebay, the highest concentrations were obtained in the forebays.

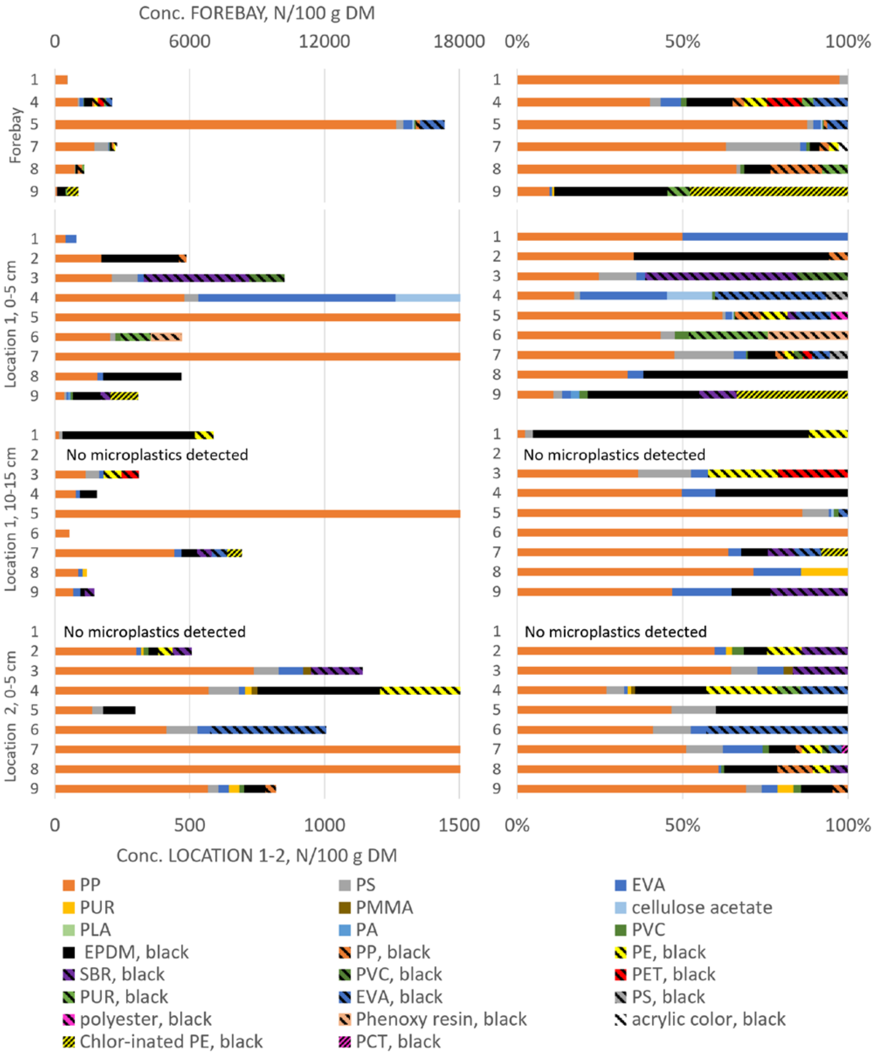


Figure 11 Microplastic concentration (left) and composition (right) of filter media from different locations (forebay, location 1, and location 2) and depths (0-5 cm and 10-15 cm) (c.f. Figure 7) of nine bioretention systems. Black particles were included in the analysis and are reported separately. (Graphs made from data in Table 2 in Lange et al 2023). Note that the concentrations in the forebays are presented using a different scale.

4.3.3 International review of microplastics in stormwater treatment systems

There are no treatment techniques which have been developed specifically to target microplastics in stormwater. However, an array of techniques, developed and already used for other targeted substances, is available. The review of studies to date (June 2022) which evaluate stormwater treatment with respect to microplastics presented data about stormwater retention ponds, biofiltration systems, constructed and natural urban wetlands, and stormwater floating treatment wetlands (Österlund et al. 2023). Influent and effluent concentrations of microplastics were only investigated for bioretention systems (and equivalents), and one gross pollutant trap. The reported reduction rates obtained in these studies are summarised in Table 6. Overall, biofiltration systems seem to be promising for reducing microplastics in stormwater. More than 70% of the microplastics larger than 20 µm were retained by such systems. A non-vegetated sand filter tended to remove microplastics less efficiently than the vegetated bioretention system that was evaluated alongside it, although the difference was not statistically significant. The gross pollutant trap did not have any effect at all on microplastics concentrations.

Table 6. Summary of studies evaluating stormwater control measures with respect to reduction of microplastics. Data obtained from Österlund et al. (2023).

Reference	Type of system	Size range(s)	Reduction rate
Werbowski et al. 2021	Rain garden	>125 µm	91-98%
Smyth et al. 2021	Bioretention system	>106 µm	84% (median)
Lange et al. 2021	Pre-sedimentation chamber/ Gross pollutant trap	100-5000 µm	No reduction
	Bioretention system and sand filter		>70%
Lange et al. 2022	Pre-sedimentation chamber/ Gross pollutant trap	20-100 µm	0.06±56%
	Bioretention system		92±6%
	Sand filter		-152±513%

4.4 Microplastics in on-site wastewater treatment facilities

4.4.1 Greywater treatment with package plants and green walls

Of the nine plastic polymers analysed with TED-GCMS, five were detected and quantified in the influent or effluent to package plants treating greywater from two households and a pilot green wall system treating aggregated greywater from a district based on 700 person equivalents. The polymers detected were PVC, PS, PET, polyamide (PA), and PP. The non-detected polymers were polycarbonate (PC), poly(methyl methacrylate) (PMMA), and natural rubber. The results of these measurements are illustrated in Figures 12 and 13.

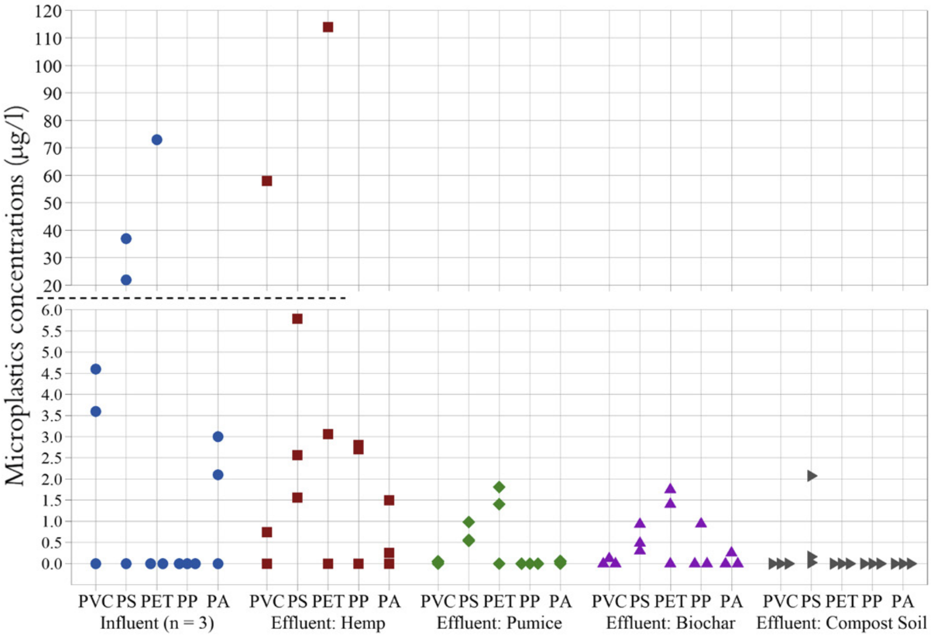
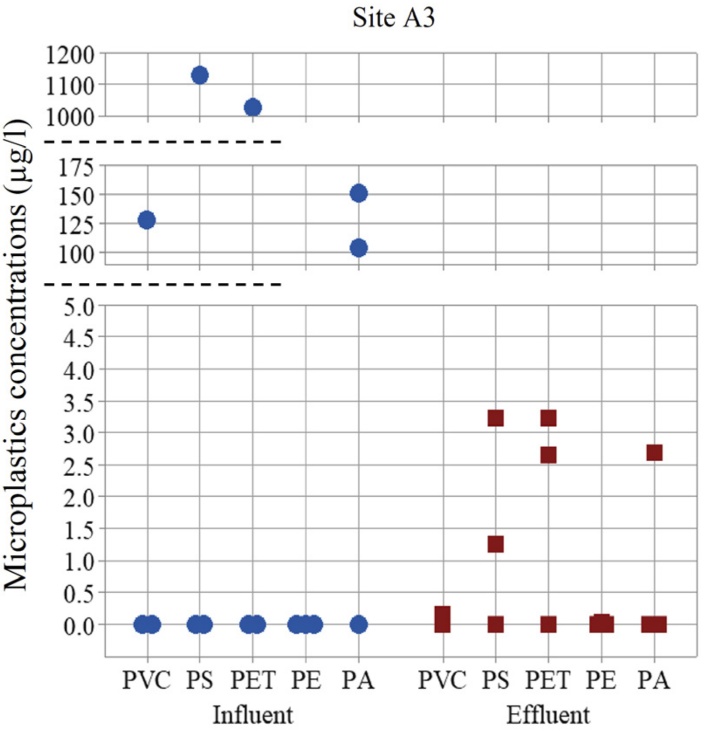


Figure 12. Influent (blue) and effluent concentrations of microplastics to a green wall system with hemp (red), pumice (green), biochar (purple), and compost soil (grey) substrates. Concentrations below detection limit were set to zero. Note the broken y axis. Data obtained from Mashreki et al. 2022b.



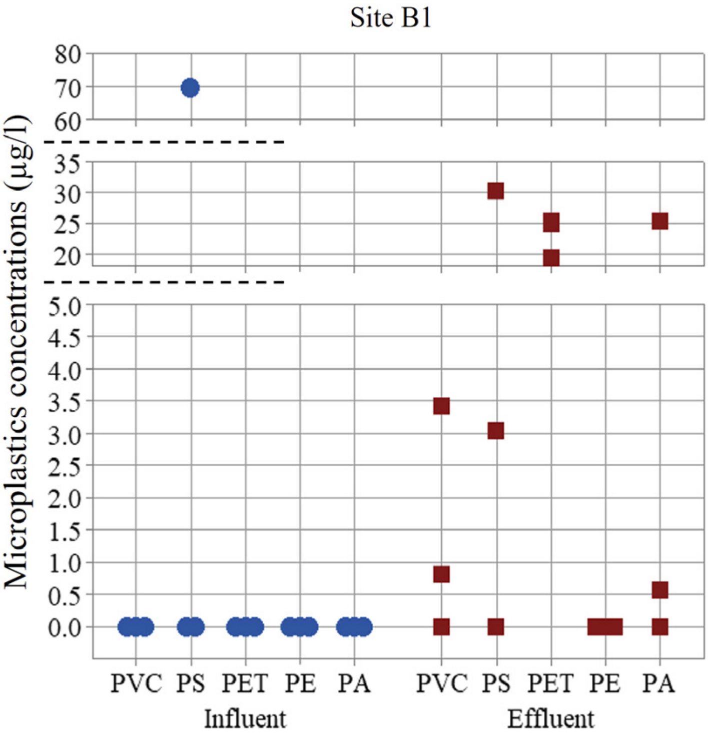


Figure 13. Influent (blue) and effluent (red) concentrations of microplastics in two greywater treatment package plants (Site A3 and Site B1). Concentrations below detection limit were set to zero. Note the broken y axes. Data obtained from Mashreki et al. 2022a.

Two of the three samples of influent to the green wall system contained detectible concentrations of microplastics (Figure 12). High concentrations of PET and PS were detected, at 73 μg/L and 37 μg/L, respectively. Influent PVC and PA concentrations were occasionally detected but at levels below 5 μg/L. Effluents from all filter media except hemp showed very low concentrations of microplastics (<2 μg/L) although PET and PS were frequently detected. One of the hemp effluent replicates was, surprisingly, discharging more microplastics than the concentration found in the influents. PVC and PET were present at levels of 58 μg/L and 114 μg/L, respectively, and the source of these could not be determined.

The highest influent concentration of microplastics was seen at site 1 on the third sampling occasion, when the concentrations of PVC, PS, and PET were 130 μg/L, 1100 μg/L, and 1000 μg/L, respectively. On the other sampling occasions at the same site, only PA was observed, at concentrations of 100 μg/L and 150 μg/L. The effluent concentrations at Site 1 were generally low, below 4 μg/L. At site 2, just one polymer, on a single occasion, was detected in the influent (PS; 70 μg/L) and the effluents from Site 2 showed higher polymer concentrations than the influent, particularly of PET. The effluent concentration of PET on the three sampling occasions ranged between 19-25 μg/L. Low concentrations of PVC, PS, and PA (<3 μg/L) were detected in the effluent on the first sampling occasion, and higher concentrations on the third occasion when 3, 30, and 25 μg/L were measured for PVC, PS, and PA, respectively.

4.5 Flows of microplastics in urban areas

The emissions of microplastics to receiving waters in the model city were estimated to be 7.2 kg/year originating from treated wastewater and 1kg/year from combined sewer overflows. The estimated load to the stormwater was 13 000-17 000 kg/year for microplastics and 2 100 kg/year for tyre wear particles (1500 kg/year from roads and 630 kg/year from parking lots) (Figure 14). If just the measurement-based values are taken into consideration, the load to stormwater was estimated to be 120 kg/year for microplastics while the emissions from tyre wear were not impacted. Cigarette butts had the highest load of microplastics, followed by exterior paint in stormwater and laundry in wastewater. The formation of microplastics from plastic litter was deemed too uncertain to quantify. Tap water, roof runoff, and dust all made small contributions. Most of the dust was estimated to end up in solid waste when it was vacuumed. Artificial turfs had high potential emissions at the source, but the amount that could end up in stormwater or leave the facility at all was determined to be too uncertain to assess and likely to vary greatly between fields.

The preventive measure of a ban on personal care products and cleaning products, as well as behavioural change to stop rinsing painting equipment, would decrease the load from households to the wastewater treatment plant by 9-49%. Filters in washing machines would reduce emissions from laundry from 290-4 700 kg/year to 64-1 200 kg/year. In total, the load to the wastewater treatment plant would decrease from 1 200-5 800 kg/year to 670-2 000 kg/year if all measures were implemented. The yearly emissions from the wastewater treatment plant were estimated to be 7.2 kg/year. Those emissions would decrease to 0.8 kg/year if a biofilter were installed, and 1.8 kg/year if a disc filter were installed.

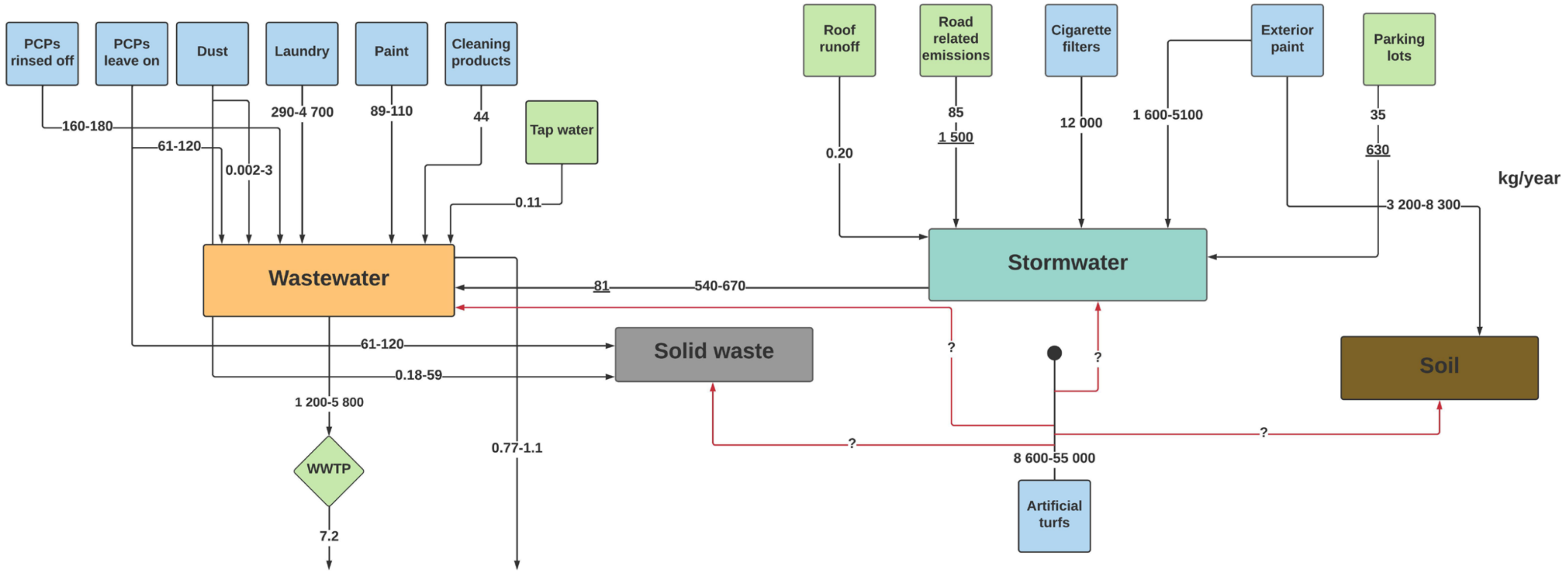


Figure 14. Overview of microplastics and tyre wear particles (underlined values) in the semi-hypothetical model city in kg/year. The blue boxes are source-based estimates, and the green boxes are Measurement-based estimates. PCPs stands for personal care products and WWTP stands for wastewater treatment plant. Republished from Fältström (2022).

The rubber infill stood for 97-98% of the estimated emissions from the artificial turfs, which would be eliminated if such infill materials were prohibited. If, instead, legislation set a dispersal limit, the total emissions from all fields in the model city would be 550 kg/year, which represents a reduction of 93-99%. However, as mentioned above, the amount of rubber infill that actually leaves the facility and the amount that is returned to the fields is very uncertain and can vary greatly between fields.

4.6 Actor responsibility

A wide range of actors at the local, regional, national, and international levels were identified by the respondents in this study. Some of these actors had opportunities to prevent the introduction of plastics or microplastics into society, while others had opportunities to control emissions of microplastics.

4.6.1 Municipal responsibility

Municipal employees generally perceived that their respective division/unit held some responsibility for the occurrence of microplastics in stormwater. In particular, several respondents stated that they were responsible for the emissions that occur as part of their practice. In addition to viewing their division/unit as responsible, respondents saw the municipality as a whole as responsible. However, while some respondents saw the municipality as responsible for long term strategies, others viewed it as primarily responsible for implementing concrete measures. Further, some respondents thought that the municipality had a responsibility to be a local role model, while others saw the municipality as having an equal level of responsibility as other local actors._

The microplastics action plan in the case municipality was initiated by politicians and had been approved by the municipal assembly. Several respondents saw the microplastics action plan as a good way to structure the relevant work within the municipality, and yearly reporting made sure the issue was always on the agenda. However, there was some concern that the microplastics issue gets too much attention in comparison to other important environmental issues.

Three of the units that were interviewed (service unit, water and wastewater unit, and city environment unit) were assigned specific responsibilities as part of the municipal microplastics action plan, and this led to measures being taken. These measures related to artificial turfs and to aggregated stormwater. For the artificial turfs, shoe brushes were installed adjacent to the fields, with boxes to capture the granulate released by brushing. At one field granulate traps were also installed. Further, the snow clearance regime was changed so that small amounts of snow were pushed to the edges of the field and left there. With this procedure, the granulate could be brushed back once the snow had melted. With regards to aggregated stormwater, an information campaign was launched about littering in the stormwater system, directed towards the public, and the gully pots in the municipality were emptied more frequently than they had previously been. Further, when the water and wastewater unit was in contact with enterprises in the so-called upstream work (Swe: *uppströmsarbete*), microplastics became one of the aspects to be considered. The measures were taken within the existing budget, and more costly measures had not been implemented because no additional financial means had been made available. Limited knowledge about microplastics in stormwater and measures to control microplastics led to uncertainties as to which measures would be most efficient.

In addition to measures that were taken as part of the microplastics plan, the solid waste management unit implemented a measure against littering. The unit took a decision not to collect plastic on their waste collection routes when weather conditions were so windy that the plastic risked being spread into the environment. The motivation for this practice was that they have a reputation as municipal actors and need to be seen as trustworthy, a reputation that would be harmed if they contributed to littering. Littering of cigarette butts was another issue that had been raised as problematic for the city. Measures relating to this source were not part of the microplastics plan. Instead, a separate project, involving several of the municipal divisions, was initiated to combat the issue of cigarette butts specifically.

4.6.2 Other responsible actors

The respondents identified several other actors with some responsibility for microplastics in relation to stormwater. At the local level these included property owners who are responsible for the litter that ends up on their land, users of artificial turfs, and all enterprises that handle plastic in their production. The general public was also seen as responsible, both for the products they use and for reducing emissions, by not littering and by correctly using the measures in place at sites covered with artificial turf.

At a higher level, producers were seen as responsible for the products that are placed on the market, and suppliers of artificial turfs were seen as responsible for finding solutions to limit emissions from this source. National and European legislators were seen as having a responsibility to introduce taxes or fees on products that release microplastics. At the national level, national authorities were also seen as responsible for providing guidelines and making the issue a priority. National authorities were specifically brought up because their work and guidance can directly support work at the municipal level.

5. Discussion

5.1 Stormwater and treatment systems

Comparing the mean and median values of microplastics concentrations in bioretention systems (median=3110 N/100 g DM; mean=1770 N/100 g DM) and gully pots (median=2850 N/100 g DM; mean= 4070 N/100g DM) we found that the concentrations in gully pots were higher than those in the bioretention systems. These differences may be due to the selection of sampling locations or retention mechanisms. While the gully pot study was conducted in greater Stockholm, Sweden, the bioretention study was conducted in Ohio and Michigan, USA. Therefore, differences in the habits and activities of local inhabitants, climate, and which materials (plastics) are widely used in each society may have contributed to the differences seen in the results. In addition, the original filter substrate itself may "dilute" the microplastics in the biofilters, as a significant part of each sample may contain both the filter substrate and retained stormwater sediment. The two systems also retain different proportions of different sized particles, and by different means, with bioretention systems retaining more material overall than gully pots.

In this project's field studies, only the number concentration of microplastics was determined. It is not unreasonable to believe that a different result may be obtained if instead the mass concentration of microplastics was measured. A high number of microplastic particles of smaller sizes would contribute less to the mass concentration than a low number of larger sized particles, even if their number concentration is higher. It may be hypothesised that the bioretention systems retain smaller particles to a higher extent than gully pots, analogous to what is generally observed with suspended solids in stormwater (Blecken, 2016).

All three of the stormwater related field studies in this project (i.e., stormwater, and gully pot and bioretention sediment) indicated that PP was the most common plastic polymer type found. Other common polymers were PE, PS, polyester/PET, PU, PVC, PA, ABS, and EVA. These findings were supported by the international literature review. For both the gully pot study and the bioretention study, analyses were carried out using both µFTIR and ATR-FTIR, which enabled the polymer identification of black particles. A significant number of the black particles were shown to be plastic polymers and were therefore only detected with ATR-FTIR. These results emphasise the importance of applying analytical techniques which also detects black particles. The analysis of black particles also enabled us to detect EPDM, SBR, and BR rubbers, which would otherwise have stayed undetected as all particles in these samples were black. It is therefore reasonable to believe that these types of polymers were also present in the stormwater samples, although they were not detected.

This project did not set out to investigate the sources of microplastics as such. Probable sources, pointed out in the international literature review (Österlund et al. 2023), include atmospheric deposition, littering and attrition of synthetic textiles and products, and traffic (tyre and road wear). The presence of microplastics in roof runoff (section 4.2 and Lindfors et al. 2022), which was concluded not to be released from the roofing material itself, supports the idea that atmospheric deposition contributes to overall microplastic volumes. However, the microplastics concentrations from this source were rather low, around three orders of magnitude lower than the concentrations in road and parking lot runoff. Furthermore, the detection of black rubber (SBR, styrene rubber; SR, EPDM) in sediment collected from treatment facilities (gully pots and biofilter systems) points to the sources of traffic and tyre wear rubber particles. It can be assumed that other types of plastic polymer detected in the studies also originate from motor vehicles since a wide range of plastics are used in both the interior and exterior of vehicles. For example, PP and ABS may originate from bumpers; high density PE, PA, polybutylene terephthalate (PBT), and polyoxymethylene (POM) from the fuel systems; and PC and ABS from vehicle lights (Modi & Vadhavkar, 2019).

It is also possible that some of the microplastics found originated from degraded plastic macro litter. The laboratory study of UV degradation of four commonly discarded types of debris (section 4.1 and Öborn et al. 2022), confirmed a possible contribution for PS, PET, and PP, all of which were also frequently detected in the stormwater and sediment samples. The PE-LD plastic bag did not, however, show any tendency for UV degradation during the applied exposure time (up to 56 days). It is important to keep in mind that there are many other possible mechanisms of fragmentation beyond just UV-light, including mechanical, thermal, and biological degradation (Yousif and Haddad 2013). Further, additives such as pigments, plasticisers, UV and thermal stabilisers, fillers, etc. may impact such degradation. (Hahladakis et al., 2018). Therefore, other items of PS, PET, PP, and PE-LD may show different degradation patterns than the examples used in this study.

5.2 On-site wastewater treatment

For several reasons, the results from measurement of wastewater and stormwater presented in section 4.3 and 4.4 are not comparable except for qualitative assessment. This is primarily due to the use of different analytical methods While the wastewater samples were analysed using TED-GCMS, and the concentrations reported as mass per volume, the stormwater samples were analysed using µFTIR and reported as numbers per volume. In addition, the number of polymers detected by µFTIR was much higher than that detected by TED-GCMS. Frequently detected polymers in the influent water to grey water treatment systems were PVC, PS, PET, and PA. PET (a polyester) and PA are polymers commonly used in textiles for clothes and can be expected to be found in greywater from washing machines. Furthermore, PS and PET are commonly used in products for food packaging, plastic boxes, and bottles, and microplastics from these may be released when washing and rinsing the dishes (Liu et al., 2021).

Since the influent and effluent samples from each treatment system were not taken simultaneously, and only a limited number of samples was taken, reduction rates for the treatment systems cannot be computed. However, the effluents from the various systems generally contained low concentrations of microplastics compared with influent concentrations. On one sampling occasion, high concentrations of PVC and PET were detected in the effluents from one of the green wall materials (hemp), and the reason for this could not be determined. It cannot be ruled out that that the high polymer signals originated from a few large particles. Additional sampling is needed to be able to fully evaluate the function of these systems with respect to microplastics removal.

5.3 Flows of microplastics in urban areas and actor responsibility

Both the source-based estimates and the measurement-based estimates involve uncertainties that impact the assessment. The source-based estimates often resulted in large ranges due to large differences in the literature values. It can be difficult to determine which part of the range that is most likely. Fältström et al. (2021) compared source estimates to measured values at the inlet of a wastewater treatment plant and found that the measured values at the inlet were at the lower end of range for the source estimates. The measurement-based estimates were based on a few measurements that showed large variations in concentrations, also creating uncertainties. More samples over a longer period may give a more comprehensive view of the flows of microplastics.

The yearly load to receiving waters from wastewater was estimated as 7.2 kg/year from treated wastewater and 1 kg/year from combined sewer overflows. Microplastics emissions to the stormwater were estimated to be 13 000-17 000 kg/year using both source estimates and measurement-based estimates, and 120 kg/year if only measurement-based estimates were used. Stormwater treatment was not introduced to the model city, while as it was assumed that all wastewater was treated at the wastewater treatment plant. It should be noted that the effluent value of the wastewater treatment plant was based on just one sample. However, values between 2.6 and 73 kg/year (Ljung et al., 2018; Tumlin and Bertholds, 2020) have been reported for Swedish wastewater treatment plants that are larger than the one in the model city, using the same analysis method.

Cigarette butts and paint particles were estimated to make large contributions to the microplastics in stormwater. However, neither cellulose acetate, which is associated with cigarette butts, nor polymers commonly associated with paint were ubiquitous in the stormwater samples. This suggests that the load to stormwater from these sources may have been overestimated. There are substantial gaps in current knowledge about microplastics in other urban compartments, such as urban soils. Therefore, it is still uncertain whether the emissions from cigarette butts and paint are overestimated at source, or it is the share to stormwater that is overestimated.

Tyre wear has been highlighted as a significant source of microplastics (Magnusson et al., 2016). In the model city emissions from tyre wear were estimated at 2 tons/year. The load from tyre wear for all of Sweden has, in previous research, been estimated to be around 11 000 tonnes/year (unpublished article by Polukarova et al. (2021), cited in Johannesson and Lithner, 2021). Further, yearly emissions per person have been reported to be in the range of 0.23 to 1.9 kg/capita/year, with the exception of the US, where the estimates are 4.7 kg/capita/year (Kole et al., 2017). If those values are used, emissions in the model city would be 25-210 tons/year, which is much higher than the measurement-based estimates. The estimates for tyre wear for the model city were extrapolated from measurements, and these measurements showed large variation. Further, for the purpose of this assessment, it was assumed that all roads in the city were the same as the road from which stormwater was collected, in terms of size and traffic intensity, which is a large simplification. To further investigate the results, source estimates for the sampled road stretch were performed and compared to measurement-based values. The theoretical contribution was higher than the measurement-based estimates (32 kg/year compared to 0.21 kg/year). However, there are several uncertainties with both estimates and further research is needed to understand more about the discrepancies between measurement-based estimates and source estimates.

The results from the flow mapping should be viewed as an exploration of flows and a contribution to increasing the understanding of potentially large, small, and unidentified flows, rather than as exact or detailed estimates. The results can be used as a starting point for investigating flows in other contexts, and in cities with different characteristics than those assumed for the model city. The municipality which served as a case study had taken action to combat several of the large sources of microplastics in stormwater that were identified in the flow mapping, such as artificial turfs and cigarette butts. The municipal action plan, which guided the work on microplastics within the municipality, was developed using the Swedish EPA's (Swedish Environmental Protection Agency, 2017b) identification and quantification of flows of microplastics. Knowledge gaps were raised as a challenge to implementing more solutions to control microplastics in stormwater. These knowledge gaps are not evenly spread between flows and therefore it may be more difficult to take concrete measures for some flows than others. For example, there are more measures available and accessible for artificial turfs than for tyre wear, even though tyre wear has been estimated to be a larger source in Sweden. Some of the respondents brought up the need for support and guidance from national authorities and other actors at higher governance levels. However, as described above in relation to the flow mapping, microplastics and the pollution from microplastics is still subject to significant uncertainties. Therefore, it is challenging to provide clear recommendations and practical advice at this point. Nonetheless, providing updated, easily accessible information on the current state of knowledge, including what is uncertain and unknown, and where the research frontiers are, may help local actors to form an overview of the issue.

6. Conclusions and future research needs

Conclusions from the project are summarised below, and organised to respond directly to each of the research questions presented in the introduction.

How does the most common plastic (macro) litter from streets break down into microplastic particles?

Four litter items, which are commonly discarded in the urban environment, were exposed to UV light for up to 56 days, corresponding to approximately 2 years of UV radiation in Sweden. The items were a plastic bag (PE-LD), chocolate bar wrapper (PP), a plastic coffee cup lid (PS), and a bottle (PET). The results indicated clear degradation of PS, PP, and PET under UV exposure, compared with unexposed (control) samples, and an increased release of microplastics with longer exposure times. PP was most sensitive to UV exposure followed by PS and PET. For the plastic bag made of PE-LD, degradation due to UV exposure was not observed over the exposure times used, because the numbers of particles released from exposed and unexposed (control) samples were in the same order of magnitude. However, there are many other factors aside from UV-light which affect fragmentation, including mechanical, thermal, and biological degradation, as well as chemical additives added to the plastics which may impact degradation. Therefore, other plastic items made of the same polymers may show different degradation patterns than the examples in this study: this could be the focus of future studies.

What types and concentrations of microplastics are found in urban stormwater from different catchments?

Microplastics concentrations in stormwater runoff from a road, parking lot, and roof top ranged between 267-11400 N/L, 95-1690 N/L and 467-1220 N/m3, respectively. Although only three runoff events were sampled per site, the concentrations measured varied widely. The highest number of polymers were detected in stormwater from the parking lot where PP>PE>PET/ polyesters>PU, acrylic>PS, PVC, ABS, and PU paints were detected, in descending order of concentration. In the roof runoff samples, six plastic polymers were detected including PP>PE>PET/ polyesters>PU>PA and PVC. Five plastic polymers were detected in the road runoff: PP>PE>PET>acrylic>PA. Black particles were not included in the analysis. It may therefore be reasonable to assume that additional microplastics were present, including tyre and road wear particles, although they were not detected with the applied analytical technique (µFTIR). Future studies into microplastics in stormwater context should apply analytical methods which can quantify these types of particles, for example ATR-FTIR, pyr-GCMC, or TED-GCMS. Moreover, the sources of the polymer types detected in this study need to be identified to enable prevention or reduction of their release into the environment, as needed.

What types and concentrations of microplastics are retained by commonly used stormwater treatment facilities?

This project investigated and reported on two common treatment systems with respect to their microplastics content: gully pots and bioretention systems. The microplastics concentrations found in the gully pot sediment and bioretention systems ranged between 720-25300 N/100 g DM and <9-17300 N/100 g, respectively. The six most frequently detected synthetic polymers were PP>EPDM>EVA>PS>SBR>PE and PP>EVA>PS>EPDM>PVC>PE, in descending order, respectively. Other polymers detected included PMMA, PET, PCT, PLA, PUR, PA, phenoxy resins, acrylic colour, cellulose acetate, styrene-ethylene-butylene-styrene (SEBS), POM, and PBT. Future research should include other types of commonly applied treatment technology, such as ponds, oil separators, various filters, and novel technologies.

What types and concentrations of microplastic particles are retained by, and found in effluents from, on-site and small-scale wastewater treatment facilities?

Four types of microplastics polymer were detected in both influent and effluent greywater from package plants and green wall systems: PVC, PS, PET, and PA. In addition, PP and PE were detected in low concentrations in single effluent samples. The concentrations of microplastics in greywater was highly variable across the nine samples taken from the three different sites – ranging from non-detected to 1100 µg/L, 130 µg/L, 1000 µg/L, 150 µg/L of PS, PVC, PET and PA, respectively. Effluent concentrations from all systems were generally low, <30 µg/L for all detected plastic polymers, apart from a single sample from one replicate of the green wall material (hemp) in which concentrations of up to 58 µg/L and 114 µg/L were inexplicably detected for PVC and PET, respectively. Further research is needed to be able to draw strong conclusions about the variations in greywater quality with respect to microplastics, and there are other treatment techniques available for evaluating removal efficiency. It may also be of interest to perform size fractionation of the microplastics and study how that impacts their removal.

Where are microplastics found in urban areas, and what measures can be taken to control microplastic pollution?

The flow mapping corroborates previous studies in showing that the load to wastewater may be large, but the emissions after wastewater treatment are low. The flow mapping highlighted cigarette butts, paint, and tyre wear particles as major sources to stormwater. Drinking water, roof runoff, and dust made smaller contributions. There are still several uncertainties in estimating the sources of microplastics, and the polymers found in samples were sometimes not consistent with what would be expected from source estimates. This raises the question of whether some sources have been missed, while others may be overestimated. More comparative studies of source estimates and measurements, and more longitudinal sampling campaigns, are needed to increase our understanding of significant sources.

Several control strategies for microplastics have been proposed, mostly for wastewater sources. It would be possible to reduce emissions to the wastewater treatment plant by 30-50% if all control measures were implemented. For stormwater, further research is needed to evaluate current and novel technologies for treatment of microplastics and tyre wear particles, and where in the stormwater system these should be located. Limited knowledge about these types of techniques was also identified as an area on which more guidance and support is needed in the case municipality.

How do local public actors view their own responsibilities with regards to microplastics in stormwater, and which other societal actors do they perceive to be responsible?

Municipal officials identified a range of actors at the local, regional, national, and international levels as responsible for microplastics in stormwater. Most of the identified actors could impact load to stormwater, either by influencing the introduction of plastics or microplastics into society, for example through legislation, or by mitigating the release of microplastics into stormwater. The work of national authorities was highlighted as important in supporting the municipality's work.

The municipality was generally seen as responsible for the emissions that occur as part of their practice, but also as a role model at the local level. Measures to handle microplastics flows from artificial turfs, plastic litter, cigarette filters, and for the aggregated stormwater, had been introduced in the municipality. The comprehensive municipal action plan on microplastics, which had been approved by the governing politicians, enabled structured and aligned work to take place, and kept the issue on the agenda. Limited financial means and limited knowledge were identified as challenges to implementing further measures. Knowledge about flows of microplastics and measures to be taken can differ between flows, and therefore different municipal units face different challenges. Support in terms of information and guidance from higher governance levels was identified as a need. There are many uncertainties related to microplastics, which is why giving clear guidance can be difficult. Nonetheless, providing information about current knowledge, including the uncertainties, may be possible. This study focused on one municipality and future research could broaden its scope by investigating the work of several municipalities, as well as the incentives and challenges in working to control different types of urban pollution.

References

References in bold text were prepared within the present project.

Andersson-Sköld, Y., Johannesson, M., Gustafsson, M., Järlskog, I., Lithner, D., Polukarova, M., Strömvall, A.-M. (2020). Microplastics from tyre and road wear : a literature review. Statens väg- och transportforskningsinstitut.

Belzagui, F., Buscio, V., Gutiérrez-Bouzán, C., Vilaseca, M., 2021. Cigarette butts as a microfiber source with a microplastic level of concern. Science of The Total Environment 762, 144165. https://doi.org/10.1016/j.scitotenv.2020.144165

Belzagui, F., Crespi, M., Álvarez, A., Gutiérrez-Bouzán, C., Vilaseca, M., 2019. Microplastics' emissions: Microfibers' detachment from textile garments. Environmental Pollution 248, 1028–1035. https://doi.org/10.1016/j.envpol.2019.02.059

Blecken, G. (2016). Kunskapssammanställning: Dagvattenrening, Svenskt vatten utveckling, Rapport nr: 2016-05.

Bläsing, M., Amelung, W., 2018. Plastics in soil: Analytical methods and possible sources. Science of The Total Environment 612, 422–435. https://doi.org/10.1016/j.scitotenv.2017.08.086

Boni, W., Arbuckle-Keil, G., Fahrenfeld, N. L., 2022. Inter-storm variation in microplastic concentration and polymer type at stormwater outfalls and a bioretention basin. Science of The Total Environment 809, 151104.

Browne, M. A., Ros, M., & Johnston, E. L. (2020). Pore-size and polymer affect the ability of filters for washing-machines to reduce domestic emissions of fibres to sewage. Plos one, 15(6), e0234248.

Cesa, F.S., Turra, A., Checon, H.H., Leonardi, B., Baruque-Ramos, J., 2020. Laundering and textile parameters influence fibers release in household washings. Environmental Pollution 257, 113553. https://doi.org/10.1016/j.envpol.2019.113553

Cheung, P.K., Fok, L., 2016. Evidence of microbeads from personal care product contaminating the sea. Marine Pollution Bulletin 109, 582–585. https://doi.org/10.1016/j.marpolbul.2016.05.046

De Falco, F., Gullo, M.P., Gentile, G., Di Pace, E., Cocca, M., Gelabert, L., Brouta-Agnésa, M., Rovira, A., Escudero, R., Villalba, R., Mossotti, R., Montarsolo, A., Gavignano, S., Tonin, C., Avella, M., 2018. Evaluation of microplastic release caused by textile washing processes of synthetic fabrics. Environmental Pollution 236, 916–925. https://doi.org/10.1016/j.envpol.2017.10.057

Eisentraut, P., Dümichen, E., Ruhl, A. S., Jekel, M., Albrecht, M., Gehde, M., Braun, U., 2018. Two Birds with One Stone—Fast and Simultaneous Analysis of Microplastics: Microparticles Derived from Thermoplastics and Tire Wear. Environmental Science & Technology Letters, 5(10), 608-613.

Estahbanati, S., Fahrenfeld, N.L., 2016. Influence of wastewater treatment plant discharges on microplastic concentrations in surface water. Chemosphere 162, 277–284. https://doi.org/10.1016/j.chemosphere.2016.07.083

European Chemicals Agency (2020). Opinion on an Annex XV dossier proposing restrictions on intentionally-added microplastics. Committee for Risk Assessment (RAC) and Committee for Socio-economic Analysis (SEAC). a513b793-dd84-d83a-9c06-e7a11580f366 (europa.eu). Accessed: October 9th, 2022.

Fältström, E., 2022. Mapping flows for a model city. FanpLESStic-Sea project. 2.3-Flow-model-final-report.pdf (swedenwaterresearch.se)

Fältström, E., Anderberg, S., 2020. Towards control strategies for microplastics in urban water. Environ Sci Pollut Res 27, 40421–40433. https://doi.org/10.1007/s11356-020-10064-z

Fältström, E. Carlsson, A. (2023) Local action to control microplastics in stormwater – A case study in a Swedish municipality. Submitted to Journal of Environmental Management.

Fältström, E., Olesen, K.B., Anderberg, S., 2021. Microplastic Types in the Wastewater System—A Comparison of Material Flow-Based Source Estimates and the Measurement-Based Load to a Wastewater Treatment Plant. Sustainability 13, 5404. https://doi.org/10.3390/su13105404

Galafassi, S., Nizzetto, L., Volta, P., 2019. Plastic sources: A survey across scientific and grey literature for their inventory and relative contribution to microplastics pollution in natural environments, with an emphasis on surface water. Science of The Total Environment 693, 133499. https://doi.org/10.1016/j.scitotenv.2019.07.305

Gilbreath, A., McKee, L., Shimabuku, I., Lin, D., Werbowski, L., M., Zhu, X., Grbic, J., Rochman, C., 2019. Multiyear water quality performance and mass accumulation of PCBs, mercury, methylmercury, copper, and microplastics in a bioretention rain garden. Journal of Sustainable Water in the Built Environment 5(4), 04019004.

Habib, R.Z., Thiemann, T., Al Kendi, R., 2020. Microplastics and Wastewater Treatment Plants—A Review. JWARP 12, 1–35. https://doi.org/10.4236/jwarp.2020.121001

Hahladakis, J.N., Velis, C.A., Weberb, R., Iacovidoua, E., Purnella, P. (2018) An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling, Journal of Hazardous Materials. doi: 10.1016/j.jhazmat.2017.10.014.

Hu, Y., Gong, M., Wang, J., Bassi, A., 2019. Current research trends on microplastic pollution from wastewater systems: a critical review. Rev Environ Sci Biotechnol 18, 207–230. https://doi.org/10.1007/s11157-019-09498-w

Järlskog, I., Strömvall, A., Magnusson, K., Galfi, H., Björklund, K., Polukarova, M., Garção, R., Markiewicz, A., Aronsson, M., Gustafsson, M., Norin, M., Blom, L., Andersson-Sköld, Y., 2021. Traffic-related microplastic particles, metals, and organic pollutants in an urban area under reconstruction. Science of The Total Environment 774, 145503.

Järlskog, I., Strömvall, A., Magnusson, K., Gustafsson, M., Polukarova, M., Galfi, H., Aronsson, M., Andersson-Sköld, Y., 2020. Occurrence of tire and bitumen wear microplastics on urban streets and in sweep sand and washwater. Science of The Total Environment 729, 138950.J

Johannesson, M., Lithner, D., 2021. Potentiella styrmedel och åtgärder mot mikroplast från däck- och vägslitage. Kartläggning och prioritering (No. 1092). Swedish National Road and Transport Research Institute (VTI), Linköping, Sweden.

Kentin, E., Kaarto, H., 2018. An EU ban on microplastics in cosmetic products and the right to regulate. RECIEL 27, 254–266. https://doi.org/10.1111/reel.12269

KIMO Sverige, 2017. Handlingsplan mot utsläpp av mikroskräp från kommunala anläggningar och verksamheter. Author, Göteborg, Sweden.

Kirstein, I.V., Hensel, F., Gomiero, A., Iordachescu, L., Vianello, A., Wittgren, H.B., Vollertsen, J., 2021. Drinking plastics? – Quantification and qualification of microplastics in drinking water distribution systems by µFTIR and Py-GCMS. Water Research 188, 116519. https://doi.org/10.1016/j.watres.2020.116519

Kole, P.J., Löhr, A.J., Van Belleghem, F., Ragas, A., 2017. Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment. IJERPH 14, 1265. https://doi.org/10.3390/ijerph14101265

Lange, K., Furén, R., Österlund, H., Winston, R., Tirpak, A., Nordqvist, K., Smith, J., Dorsey, J., Viklander, M., Blecken, G-T., 2023. Abundance, distribution, and composition of microplastics in the filter media of nine aged stormwater bioretention systems. Chemosphere 320, 138103.

Lange, K., Magnusson, K., Viklander, M., Blecken, G., 2021. Removal of rubber, bitumen and other microplastic particles from stormwater by a gross pollutant trap - bioretention treatment train. Water Research, 202, 117457.

Lange, K., Österlund, H., Viklander, M., Blecken, G., 2022. Occurrence and concentration of 20–100 µ m sized microplastic in highway runoff and its removal in a gross pollutant trap – Bioretention and sand filter stormwater treatment train. Science of The Total Environment 809, 151151.

Lares, M., Ncibi, M.C., Sillanpää, Markus, Sillanpää, Mika, 2018. Occurrence, identification and removal of microplastic particles and fibres in conventional activated sludge process and advanced MBR technology. Water Research 133, 236–246. https://doi.org/10.1016/j.watres.2018.01.049

Lindfors S., Österlund, H., Lundy, L., Lorenz, C., Vianello, A., Nordqvist K., Gopinath, K., Vollertsen, J., Viklander, M., 2022. Microplastics in stormwater from three urban catchments, manuscript in preparation.

Liu, F., Nord, N. B., Bester, K., Vollertsen, J. (2020). Microplastics removal from treated wastewater by a biofilter. Water, 12(4), 1085. doi:10.3390/w12041085

Liu, W., Zhang, J., Liu, H., Guo, X., Zhang X., Yao, X., Cao, Z., Zhang, T., 2021. A review of the removal of microplastics in global wastewater treatment plants: Characteristics and mechanisms. Environmental International 145, 106277.

Ljung, E., Olesen, K.B., Andersson, P.-G., Fältström, E., Vollertsen, J., Wittgren, H.B., Hagman, M., 2018. Mikroplaster i kretsloppet. (No. 48). Svenskt Vatten Utveckling, Stockholm, Sweden.

Magnusson, K., Eliasson, K., Fråne, A., Haikonen, K., Hultén, J., Olshammar, M., Stadmark, J., Voisin, A., 2016. Swedish sources and pathways for microplastics to the marine environment: A review of existing data. Report number C183, revision 2017-03-21. IVL Swedish Environmental Research Institute.

Mintenig, S.M., Löder, M.G.J., Primpke, S., Gerdts, G., 2019. Low numbers of microplastics detected in drinking water from ground water sources. Science of The Total Environment 648, 631–635. https://doi.org/10.1016/j.scitotenv.2018.08.178

Modi, S., Vadhavkar, A. (2019). Technology Roadmap: Intelligent Mobility Technologies. Center for Automotive Research, Ann Arbor, MI

Murphy, F., Ewins, C., Carbonnier, F., Quinn, B., 2016. Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment. Environ. Sci. Technol. 50, 5800–5808. https://doi.org/10.1021/acs.est.5b05416

Napper, I. E., Barrett, A. C., & Thompson, R. C. (2020). The efficiency of devices intended to reduce microfibre release during clothes washing. Science of The Total Environment, 738, 140412. https://doi.org/10.1016/j.scitotenv.2020.140412

Napper, I.E., Bakir, A., Rowland, S.J., Thompson, R.C., 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. Marine Pollution Bulletin 99, 178–185. https://doi.org/10.1016/j.marpolbul.2015.07.029

Nizzetto, L., Futter, M., Langaas, S., 2016. Are Agricultural Soils Dumps for Microplastics of Urban Origin? Environ. Sci. Technol. 50, 10777–10779. https://doi.org/10.1021/acs.est.6b04140

Öborn L., Österlund, H., Viklander, M. 2022b. Microplastics in gully pot sediment. Manuscript in preparation.

Öborn, L., Österlund, H., Svedin, J., Nordqvist, K., Viklander M., 2022a. Litter in Urban Areas May Contribute to Microplastics Pollution: Laboratory Study of the Photodegradation of Four Commonly Discarded Plastics. Journal of Environmental Engineering, 148(11): 06022004

Österlund, H., Blecken, G., Lange, K., Marsalek, J., Gopinath, K., Viklander, M., 2023. Microplastics in urban catchments: Review of sources, pathways, and entry into stormwater. Science of the Total Environment 858, 159781.

Piñon-Colin, T. d. J., Rodriguez-Jimenez, R., Rogel-Hernandez, E., Alvarez-Andrade, A., Wakida, F. T., 2020. Microplastics in stormwater runoff in a semiarid region, Tijuana, Mexico. Science of The Total Environment 704, 135411.

Pramanik, B.K., Roychand, R., Monira, S., Bhuiyan, M., Jegatheesan, V., 2020. Fate of road-dust associated microplastics and per- and polyfluorinated substances in stormwater. Process Safety and Environmental Protection, 144, 236-241.

Renberg, L., 2019. Mikroskräp i urban miljö: Analys av antropogena partiklar ackumulerade i snö. Master thesis, Luleå University of Technology, Luleå, Sweden.

Sami, M. Hedström, A., Österlund, H., Kvarnström, E., Herrmann, I., 2022b. Removal of microplastics from greywater using a green wall treatment system Conference proceeding to IWA 17th international conference on wetland systems for water pollution control, 6-10 November 2022, Lyon, France.

Sami, M. Hedström, A., Österlund, H., Kvarnström, E., Nordqvist, K., Herrmann, I., 2022a. Efficiency of on-site greywater treatment systems, including microplastics removal. Submitted manuscript.

Sang, W., Chen, Z., Mei, L., Hao, S., Zhan, C., Zhang, W. B., Liu, J., 2021. The abundance and characteristics of microplastics in rainwater pipelines in wuhan, china. Science of the Total Environment, 755, 142606

Simon, M., Vianello, A., Vollertsen, J., 2019. Removal of >10 µm Microplastic Particles from Treated Wastewater by a Disc Filter. Water 11, 1935. https://doi.org/10.3390/w11091935

Smyth, K., Drake, J., Li, Y., Rochman, C., Van Seters, T., Passeport, E., 2021. Bioretention cells remove microplastics from urban stormwater. Water Research 191, 116785.

Sun, J., Dai, X., Wang, Q., van Loosdrecht, M.C.M., Ni, B.-J., 2019. Microplastics in wastewater treatment plants: Detection, occurrence and removal. Water Research 152, 21–37. https://doi.org/10.1016/j.watres.2018.12.050

Swedish Environmental Protection Agency, 2017a. Analys av kunskapsläget för dagvattenproblematiken - Redovisning av regeringsuppdrag (No. NV-08972-16). Author, Stockholm, Sweden.

Swedish Environmental Protection Agency, 2017b. Mikroplaster - Redovisning av regeringsuppdrag om källor till mikroplaster och förslag på åtgärder för minskade utsläpp i Sverige (No. 6772). Author, Stockholm, Sweden.

Szewc, K., Graca, B., Dołęga, A., 2021. Atmospheric deposition of microplastics in the coastal zone: Characteristics and relationship with meteorological factors. Science of The Total Environment 761, 143272. https://doi.org/10.1016/j.scitotenv.2020.143272

Talvitie, J., Mikola, A., Koistinen, A., Setälä, O., 2017. Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Research 123, 401–407. https://doi.org/10.1016/j.watres.2017.07.005

Treilles, R., Gasperi, J., Gallard, A., Saad, M., Dris, R., Partibane, C., Breton, J., Tassin, B., 2021. Microplastics and microfibers in urban runoff from a suburban catchment of Greater Paris. Environmental Pollution 287, 117352.Tumlin, S., Bertholds, C., 2020. Kartläggning av mikroplaster – till, inom och från avloppsreningsverk (No. 2020–8). Svenskt Vatten Utveckling, Stockholm, Sweden.

van der Voet, E. (2002). Substance flow analysis methodology. In Ayres, R. U., & Ayres, L. (Eds.). A Handbook of Industrial Ecology (91-101). Edward Elgar Publishing.

van Wezel, A., Caris, I., Kools, S.A.E., 2016. Release of primary microplastics from consumer products to wastewater in the Netherlands: Release of microplastics from consumer products to wastewater. Environ Toxicol Chem 35, 1627–1631. https://doi.org/10.1002/etc.3316

Verschoor, A., de Poorter, L., Dröge, R., Kuenen, J., de Valk, E., 2016. Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear (No. 2016– 0026). Bilthoven, Netherlands.

Verschoor, A.J., van Gelderen, A., Hofstra, U., 2021. Fate of recycled tyre granulate used on artificial turf. Environ Sci Eur 33, 27. https://doi.org/10.1186/s12302-021-00459-1

Werbowski, L.M., Gilbreath, A.N., Munno, K., Zhu, X., Grbic, J., Wu, T., Sutton, R., Sedlak, M.D., Deshpande, A.D., Rochman, C.M., 2021. Urban Stormwater Runoff: A Major Pathway for Anthropogenic Particles, Black Rubbery Fragments, and Other Types of Microplastics to Urban Receiving Waters. Environmental Science and Technology Water, 1, 1420–1428.

Wright, S.L., Ulke, J., Font, A., Chan, K.L.A., Kelly, F.J., 2020. Atmospheric microplastic deposition in an urban environment and an evaluation of transport. Environment International 136, 105411. https://doi.org/10.1016/j.envint.2019.105411

Yousif, E., Haddad, R. 2013. Photodegradation and photostabilization of polymers, especially polystyrene: Review. SpringerPlus 2(1), 398.
https://doi.org/10.1186/2193-1801-2-398

REPORT 7104 | MAY 2023 ISBN 978-91-620-7104-2 ISSN 0282-7298

µrban Plastics

Sources, sinks and flows of microplastics in the urban environment

Microplastics have been studied in marine and coastal waters since the early 1970's. Several studies have reported that microplastics in the marine environment originate from land-based sources and is released with stormwater and wastewater. More attention is therefore placed on the urban water systems.

This project has mapped pathways of microplastics from the terrestrial to the aquatic environment, with focus on urban stormwater. Some of the questions investigated were which type and what amount of microplastics is to be found in stormwater facilities, how is the most common plastic litter from streets broken down to microplastic particles, where in urban areas are microplastics found and how can the pollution be controlled?

In a model city, the largest sources of microplastics in wastewater were laundry releasing synthetic fibers, while cigarette butts followed by paint and tire wear particles had the largest contributions to the stormwater. Tap water, roof runoff, and dust made small contributions.

The results from this report can be used to identify which plastics are present in different parts of the urban environment and will facilitate further efforts to identify the upstream pollution sources. The flow analysis gives an overview of the flows of microplastics on a city level and can be applied to other cities with different characteristics.

NATUR
VÅRDS
VERKET

SWEDISH ENVIRONMENTAL
PROTECTION AGENCY

Naturvårdsverket, SE-106 48 Stockholm. E-mail: registrator@naturvardsverket.se, www.swedishepa.se
Visiting address Stockholm: Virkesvägen 2. Visiting address Östersund: Forskarens väg 5, hus Ub.
Orders ordertel: +46 8-505 933 40, e-mail: natur@cm.se, www.swedishepa.se/publications