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## ABSTRACT

Paint in road markings contains microplastics (MP) which can be released by wear from traffic. High emissions of road MPs have been theoretically estimated in Sweden which has placed the road network as the worst MP polluter. Data from field measurements are scarce so if that gap could be filled it would shed light on previous assumptions. Two road run-off treatment systems along the E4 road through Stockholm city were studied for over three years. The primary aim was to cast light on selected mineral filters' capacity to remove dissolved pollutants, e.g. metals. The sediments collected in the two systems' reservoirs were later in focus for a study of MPs. Superficial water in the Lilla Essingen pond and the Gröndal sedimentation reservoir were removed by pumping until the bottom sediment was available for sampling. The pond and the reservoir are outdoor and indoor systems and the first-mentioned receives some stormwater from a housing area. Both systems receive road runoff from the Essinge route of the E4 road by gutters hanging under bridges. Ten sediment samples from each system were investigated for physical parameters and microplastic content. The Lilla Essingen pond stored less sediment than Gröndal due to its smaller catchment area, however, calculated per m<sup>2</sup> runoff area it was the opposite 1.32 kg and 1.09 kg dry weight, respectively. This difference is caused by the pond receiving organic material from lawns within the catchment area. The microplastic analysis included 13 polymers and rubber of which only three connected to road marking paint (RMP). The pattern of microplastics found was consistent for both sediments. The microplastic mass varied generally between 25 and 42,000 µg/kg dry substance. The highest measured amount was styrene-butadiene rubber with 82,200 µg/kg dry substance. The RMP polymers detected were polystyrene (PS), polymethylmethacrylate (PMMA) and polyamide 6 (PA6). In Gröndal sediment, PS and PA6 were found in six of ten and one of ten samples, respectively. In Lilla Essingen sediments, PS and PMMA were found in five of ten and one of ten samples, respectively. The release of polymeric RMP was calculated based on the Gröndal sediment as kg/hectare road marking area and year. The estimated value was 3.83 kg for the road with a traffic intensity of 165,000 annual average daily traffic (AADT). The wear of road markings from state roads has been estimated to vary between 1,500–9,900 tons per year (entire particles) of which the polymer part is 30–396 tons/year. Assume that 30 tons are released from the state roads and the total road marking area is 2,310 hectares; the release is  $30\,000\text{ kg}/23100000\text{ m}^2 = 1.30\text{ g/m}^2/\text{year}$ . A polymer release of 396 tons/year yields  $17.14\text{ g/m}^2/\text{year}$ . The fate of microplastics in that release is unknown other than possible destinies such as transport by road runoff, splash, snow removal, wind, and road sweeping. Difficulties in interpreting these different results depend on a lack of knowledge of how much microplastics leave the road other than through runoff. Field trials must therefore be carried out at a site where runoff, sludge collection, wind dispersion including splash from the road surface, and road maintenance can be measured and controlled. Limitations to the calculations are that some thermoplastic polymers usually found in RMP were not included in the analysis and that part of the analysis method with decantation may have caused losses of microplastics. Although the calculated value in this report is somewhat underestimated, the results indicate low microplastic RMP waterborne emissions from heavily trafficked roads. Sediments and sludge collected over time constitute historical archives that can reflect real conditions, however, more development work needs to be done regarding sampling and, above all, analytical methodology of microplastics in sediments.

*Keywords:* emission, road markings, road runoff, sediment, thermoplastic polymers

## Sammanfattning

Färg i vägmarkeringar innehåller mikroplast (MP) som kan frigöras vid slitage från trafiken. Exempel på vägmarkeringar är körfältslinjer och trappflexlinjer. Höga utsläpp av mikroplast från vägmarkeringar har teoretiskt uppskattats i Sverige vilket har placerat vägnätet som den värsta MP-förorenaren. Data från fältmätningar är knappa så om det gapet kunde fyllas skulle det kunna verifiera eller förkasta tidigare antaganden. Två reningssystem för vägavrinning längs E4:an genom Stockholms stad studerades i över tre år i ett projekt som drevs av Trafikverket i samarbete med KTH. Det primära syftet var att belysa utvalda mineralfilters förmåga att avlägsna lösta föroreningar, t.ex. metaller. Sedimenten som samlades in i de två systemens reservoarer var senare i fokus för en studie av MP. Vattnet i Lilla Essingen-dammen och Gröndal sedimenteringsmagasin togs bort genom pumpning tills botten sedimentet var tillgängligt för provtagning. Dammen ligger under Essinge-bron som på så sätt bildar ett tak och magasinet ligger i ett bergrum. Båda systemen tar emot vägavrinning från Essingesträckningen på E4:an till hängrännor som för dagvattnet till anläggningarna.

Tio sedimentprover från varje system undersöktes med avseende på fysikaliska parametrar och innehåll av mikroplast. Lilla Essingen dammen lagrade mindre sediment än Gröndal på grund av dess mindre avrinningsområde, men räknat per m<sup>2</sup> avrinningsområde var det motsatt förhållande; 1,32 kg/m<sup>2</sup> respektive 1,09 kg/m<sup>2</sup> torrsvikt. Denna skillnad orsakas av att dammen tar emot organiskt material från gräsmattor inom avrinningsområdet. Mikroplastanalysen, utförd av det certifierade laboratoriet Eurofins, omfattade 13 mikroplaster varav endast tre anses vara kopplade till vägmarkeringsfärg (RMP). Mönstret av mikroplast som hittades var konsekvent för de båda undersökta sedimenten. Massan av mikroplast varierade generellt mellan 25 och 42 000 µg/kg torrsbstans. Den högsta uppmätta mängden var styren-butadiengummi med 82 200 µg/kg torrsbstans. De RMP som detekterades var polystyren (PS), polymetylmetakrylat (PMMA) och polyamid 6 (PA6). I Gröndals sediment hittades PS och PA6 i sex av tio, respektive ett av tio prover. I Lilla Essingens sediment hittades PS och PMMA i fem av tio respektive ett av tio prover.

Utsläpp av polymerisk RMP beräknades utifrån Gröndalsedimentet som kg/hektar vägmarkeringsyta och år. Utsläppet uppgick till 3,83 kg för vägsträckan med en trafikintensitet på 165 000 årlig genomsnittlig daglig trafik (ÅDT). Beräkningen per fordon och år är då  $3\,830\,000\text{ mg}/165\,000 = 23,2\text{ mg}$ . Järllskog et al. (2024) publicerade en rapport om mikroplastutsläpp från slitage av vägmarkeringar. De uppskattade att slitaget av vägmarkeringar från statliga vägar varierar mellan 1 500–9 900 ton per år (hela partiklar) och att polymerdelen är 30–396 ton/år. Antag att 30 ton släpps ut från de statliga vägarna och den totala ytan för vägmarkeringar är ca 2 310 hektar; utsläppet är då  $30\,000\text{ kg}/23100000\text{ m}^2 = 1,30\text{ g/m}^2/\text{år}$ . En polymerfrisättning beräknat på 396 ton/år ger 17,14 g/m<sup>2</sup>/år. Mikroplasternas öde i det släppet är okänt annat än möjliga öden som transport med avrinning på väg, stänk, snöröjning, vind och vägsopning. Svårigheter att tolka dessa olika resultat beror på att vi inte vet hur mycket mikroplaster som lämnar vägen på annat sätt än genom avrinning. Fältförsök måste därför utföras på en sådan plats där avrinning, slamuppsamling, vindspridning inklusive stänk/snöplogning från vägytan samt vägskötsel kan mätas och kontrolleras. Begränsningar för beräkningarna är att vissa termoplastiska polymerer inte ingick i analysen och att en del av analysmetoden med densitetssortering och dekantering kan ha orsakat förluster av mikroplaster. Resultaten tyder på att de teoretiska beräkningar som tidigare gjorts i andra undersökningar kan vara överdrivna. Även om det beräknade värdet i denna rapport till viss del är underskattat p g a nämnda metodfel, indikerar resultaten relativt låga RMP-utsläpp av mikroplast via avrinning från hårt trafikerade vägar. Sediment och slam som samlats in över tid utgör historiska arkiv som kan spegla verkliga förhållanden, dock behöver mer utvecklingsarbete göras gällande provtagning och framför allt metodik vid analyser av mikroplast i sediment.

Denna studie bör följas upp av fler undersökningar av de insamlade sedimentproverna. Exempelvis bör de glasmikrokulor som observerats i mikroskop studeras i detalj och deras totala vikt bestämmas i Gröndal och Lilla Essingen sedimenten. En sådan analys skulle kunna kasta ljus på mikropärlorna som proxy för vägmarkeringsfärger enligt en nyligen publicerad vetenskaplig artikel. Gröndalsmagasinet och Lilla Essingen är genomströmningssystem med olika skötsel. I Gröndal samlas vägavrinning upp vid varje regn, flockningsmedel tillsätts och partiklar i vattnet sjunker snabbt till botten av magasinet. När magasinet fyllts sker avtappning av klarfasen. Bräddning är sällsynt förekommande. Lilla Essingen dammen har en ständig vattenmassa vars nivå pendlar inom ett intervall beroende på regn. Bräddning förekommer vid extrema flöden. Tillsatsen av ett flockningsmedel i Gröndal ger högst sannolikt förbättrad MP-avskiljning än den traditionella sedimenteringen i Lilla Essingen. Utflödet av MP från dessa system studerades inte noggrant i ett tidigare projekt men analys av några vattenprover visade på mycket låga koncentrationer av MP-partiklar (Agnieszka Renman, opublicerade data). En kompletterande studie på de undersökta platserna bör innefatta provtagning av inkommande och utgående

vägdagvatten för undersökning av sedimenteringens effektivitet. Liknande system med olika och lägre trafikbelastningar till de två studerade bör inkluderas och flödesövervakas från tillståndet av tömda sedimentbassänger till fyllda under en period av minst 2-3 år. Resultaten bör generera kunskap om hur man konstruerar och hanterar nuvarande och kommande dagvattenreningssystem för att minska mikroplast- och gummiföroreningar från vägar och tätorter.

## **Preface**

The Swedish Environmental Protection Agency funded this research and project concerning the wear of road markings as a source of microplastics. The purpose has been to investigate the mass of microplastics, particularly those originating from road markings, accumulated in sediments deposited on the bottoms of two road runoff treatment facilities operated by the Swedish Transport Administration. The effective work, including field, lab and writing, was carried out for over two months. Field sampling and investigations were done at the end of August, the middle week of September, and the end of October, and a few field visits were made in November and December 2024.

The Swedish Environmental Protection Agency case managers were Julia Taylor (in project planning), Åsa Stenmarck and Åsa Andersson.

Stockholm, January 2025

Agnieszka Renman

Project responsible, Docent och forskare i miljöteknik med inriktning mark- och vattenteknik

The author is solely responsible for the findings and conclusions in this report.

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Agnieszka Renman

## Introduction

Since the beginning of 2021, the Swedish Environmental Protection Agency (SEPA) has been tasked by the government to act as the national plastics coordinator. This mission includes pushing for sustainable plastic use, as well as developing and disseminating important knowledge about plastics and microplastics. In 2020, the SEPA produced a current situation analysis, in which various obstacles to achieving sustainable plastic use were reported. Among these, the limited knowledge of the sources and distribution routes of microplastics has been highlighted as an important obstacle. Lack of knowledge base also makes it difficult to assess risks, as well as to set requirements for/control against/inform about reducing leakage. Furthermore, in 2021, the SEPA developed a roadmap towards sustainable plastic use. In the roadmap, "design for resource-smart production and use, including increased wear resistance", as well as "solutions for reduced leakage, design, knowledge dissemination and development" are specified as prioritised development areas for the continued work towards sustainable plastic use. This report defines microplastics as particles smaller than 5 mm originating from polymeric materials, consisting of thermoplastic polymers/thermo-setting polymers, and additive chemicals. Thus, rubber (tyres), road markings and polymer-modified bitumen are also included in the definition.

Road and tyre wear has been identified as the largest quantified source of microplastics nationally. At the same time, there are large knowledge gaps around this source, which is for example highlighted by the Swedish National Road and Transport Research Institute (VTI) in their knowledge compilation on microplastics from road traffic. According to the SEPA, there are indications that wear and tear from road markings give rise to significant emissions of microplastics. In the Nordic countries, these emissions have been estimated at around 50-60 g/person/year, which would correspond to 500-600 tons/year in Sweden. This is roughly in line with previous national estimates. Like other paints, road marking paints cease to meet the requirements of the REACH microplastics definition at the time of use. They are therefore exempt from the ban in the REACH proposal. However, they are still subject to user manuals and reporting requirements according to this proposal. Although emissions of microplastics from road markings are much less than emissions of microplastics from tyres or other paint sources, emissions are on par with emissions from artificial grass granules, if the mentioned emissions are correct.

Since 2018, VTI has had several projects that have focused on increasing the knowledge and understanding of traffic-related microplastics, first in the form of a government assignment (Microplastics from road traffic) in parallel with two doctoral projects, one funded by FORMAS (Contamination and solutions for traffic-related persistent organic pollutants ( POP) and micro/nanoplastics) and one from the Swedish Transport Administration (Occurrence, spread and roadside measures to reduce the spread of microplastics from road traffic).

It has been shown that basically, all VTI road dust samples collected in the field contain a small proportion of road markings. Knowledge about wear from road markings as a source of microplastics is, however, so far very limited, as previous research has mainly focused on wear and lifespan from a safety perspective. Road markings can be found on the road in different designs, for example as lines, raised grooves, symbols and bicycle crossings. Their purpose is to increase safety, and visibility and to guide road users. Road markings are partly worn down by contact with tyres (mainly studded tyres), but can also be destroyed during winter road maintenance (mainly ploughing). Currently, data are few to make it possible to map the extent to which road marking wear contributes to the spread of microplastics, as well as assessments of how these particles could affect the environment.

In a recently completed project, VTI has investigated the theoretical microplastic release from the wear of road markings. The purpose of the study has been, among other things, to estimate the annual wear and tear of road markings in Sweden. VTI notes that there is currently insufficient information to calculate the annual wear and tear of road markings in Sweden. There is a lack of data in sales statistics and amounts of road paint spread on municipal and state roads, which makes it uncertain to produce

credible estimates. However, if the available sales statistics are combined with road network length, previous estimates and an assumed polymer share of 2–4%, it shows that the wear and tear of road markings can be a significant source of microplastic emissions, 40–570 tons/year, which is in the same order of magnitude as boat bottom paint (30–300 tons/year). However, these theoretical estimates should be rejected or validated with measurements in the real environment to understand better how road markings contribute to microplastic emissions in Sweden.

The Essingeleden in Stockholm has the country's highest annual 24-hour traffic (AADT; 165,000 vehicles). The route, where the investigation was done, is mainly built on bridges and therefore the road drainage is collected in gutters mounted under the bridges. The drainage system ends in two underground stormwater treatment plants (Fredhäll, Gröndal) and one open sedimentation pond (Lilla Essingen). The Swedish Transport Administration, in collaboration with KTH, has over the past three years carried out an extensive study on the transport of mainly metals with road runoff and how purification can be made more efficient through filter sand and reactive filter materials. During the final phase, a study of microplastics was also included. The existing infrastructure and the carefully designed sampling system provide great opportunities to study the presence of road marking particles in the runoff in what can be called the "worst-case scenario" for the national road network.

## **Objective**

The project aimed to estimate the total wear of tire-wearing particles (TWP) and road-wearing particles (RWP) with particular reference to road marking particles and how much the national road network contributes to microplastic emissions through the wear of road markings. This was done by studying and quantifying the presence of rubber and polymer particles in sediments collected by road run-off during three years and eight months in the Gröndal stormwater reservoir and the Lilla Essingen stormwater pond and relating this to the total road area and road marking surfaces.

## **Material and methods**

The project lasted six months, starting in August 2024. Sediments were sampled over two days and prepared for further analysis at KTH. Complementary field investigations of road areas and markings were continuously performed from September to December 2024.

### Study areas

The Lilla Essingen runoff water treatment plant catchment area is made up of the E4 road (Essingeleden), also including 12 % of a housing area on the island of Lilla Essingen (Fig. 1). The catchment area can be separated into three main sections. The highway Essingeleden, Gamla Essinge Broväg and the housing area cover a total asphalt road run-off area of 17,945 m<sup>2</sup> (Table 1). The annual average daily traffic (AADT) in Essingeleden is 165,000 vehicles. The Lilla Essingen runoff water treatment plant, with its sedimentation pond, is located under the bridge (Fig. 1). The run-off is collected in gutters hanging under the bridge and discharged by gravity flow to the sedimentation pond (Fig. 2). The stormwater from the housing areas (12% of the entire catchment area) is discharged by pipes to the sedimentation pond. The sedimentation is sequential and controlled by the level in the sedimentation pond, thus the water levels will vary between minimum water level (1.0 m) and maximum water level (1.4) during operation. At high flows, bypass/overflow is done before the sedimentation pond. The catchment area for the Gröndal runoff water treatment plant covers an area of 25,800 m<sup>2</sup> (Fig. 1; Table 1). It consists solely of road surface with asphalt and has an AADT of 165,000 vehicles. Two gutters

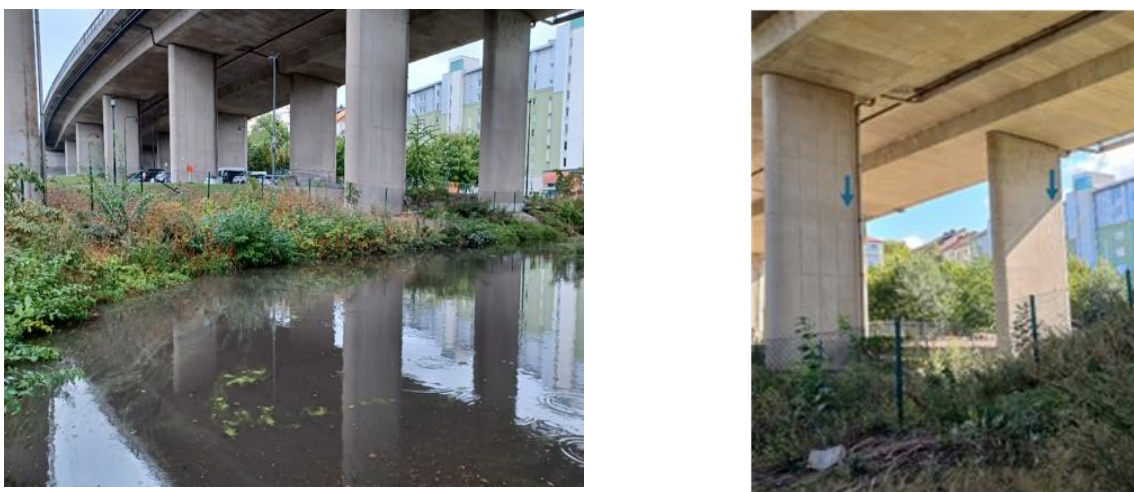


**Figure 1:** Catchment areas for Lilla Essingen RWTP (left) and Gröndal RWTP (right). Arrows showing the direction of runoff water to the runoff treatment plants. Maps based on <https://kartor.eniro.se/m/1PJ1A>.

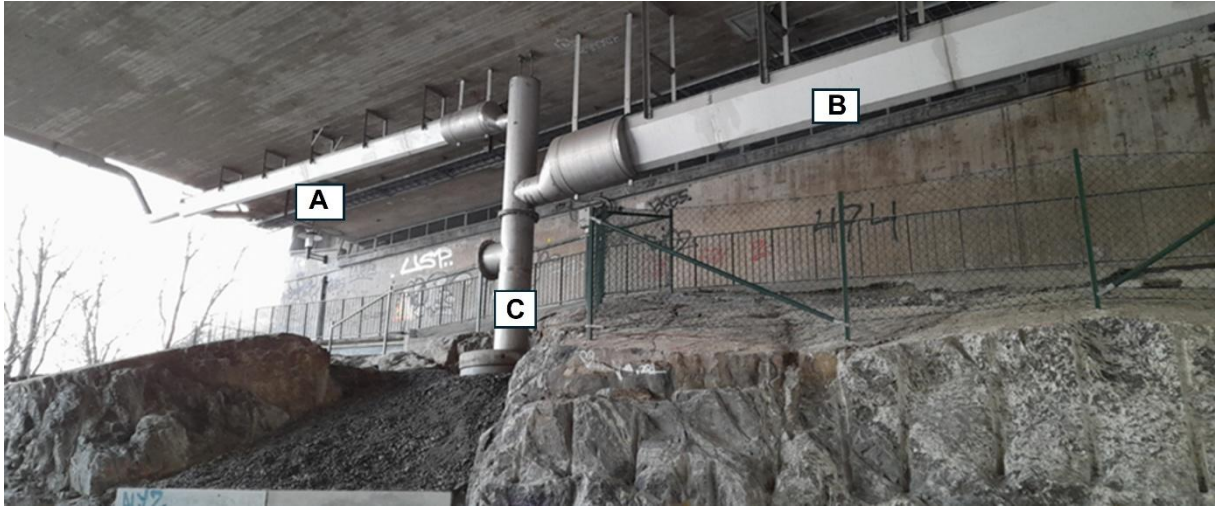
collect the road run-off (Fig. 3), transporting it to the Gröndal runoff water treatment plant (RWTP). The Gröndal runoff water treatment plant comprises a sand trap and a sedimentation basin. At the beginning of the basin, an aluminium-based chemical flocculant is added to accelerate the separation of finer particles. The sedimentation is sequential and controlled by the turbidity and level in the basin; thus, the water levels will vary between the minimum water level (0.9 m) and the maximum water level (2.0 m) during operation. At high flows, an overflow pipe diverts the water.

**Table 1:** Calculated road areas discharging run-off to the Gröndal and Lilla Essingen sedimentation plants and the share of road marking in contact with traffic and precipitation.

	Lane lines (m <sup>2</sup> )	Stair-flex lines (m <sup>2</sup> )	Other road markings (m <sup>2</sup> )	Total road marking area (m <sup>2</sup> )	Total road area (m <sup>2</sup> )
Gröndal	227	636	2.4	865.4	25,800
L. Essingen	105.3	308	-	413.3	17,945



**Figure 2:** The Lilla Essingen treatment pond, situated below the Essinge-leden bridge of the E4 highway, filled to its maximum storage volume. (Cf. Fig. 4). The arrows show the downflow pipes from gutters hanging under the bridge.



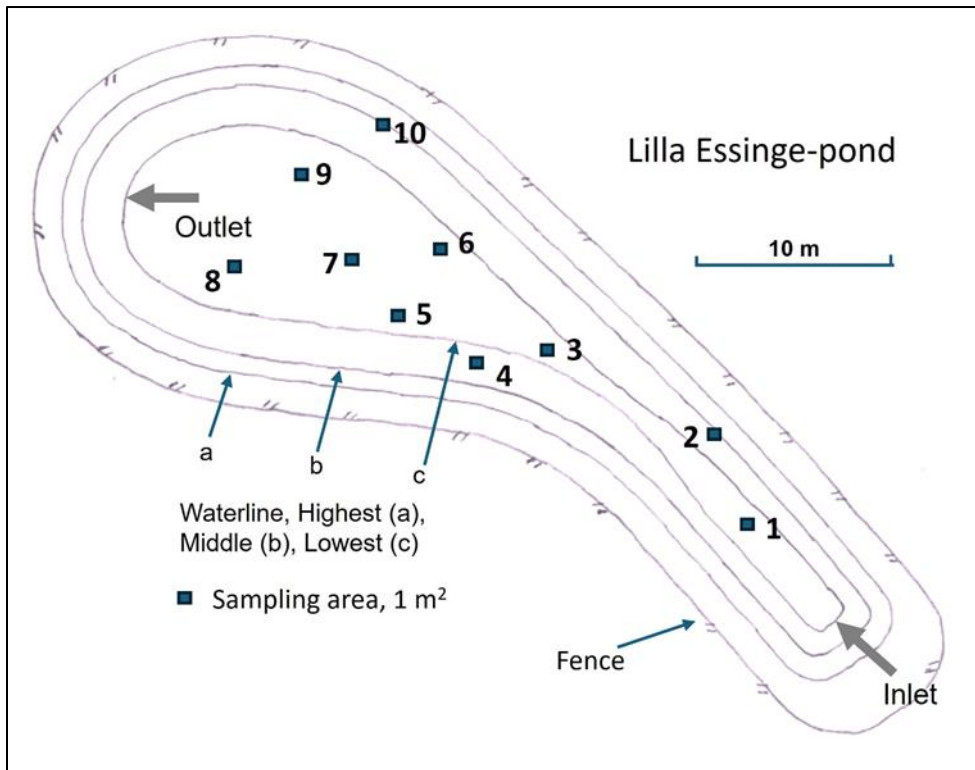
**Figure 3:** Gutters to the Gröndal runoff treatment plant. A. Gutter collecting run-off from the bridge between Gröndal and Stora Essingen; B. Gutter transporting runoff from the southeast E4 road; C. Incoming pipe to the Gröndal RWTP.

### Sediment sampling

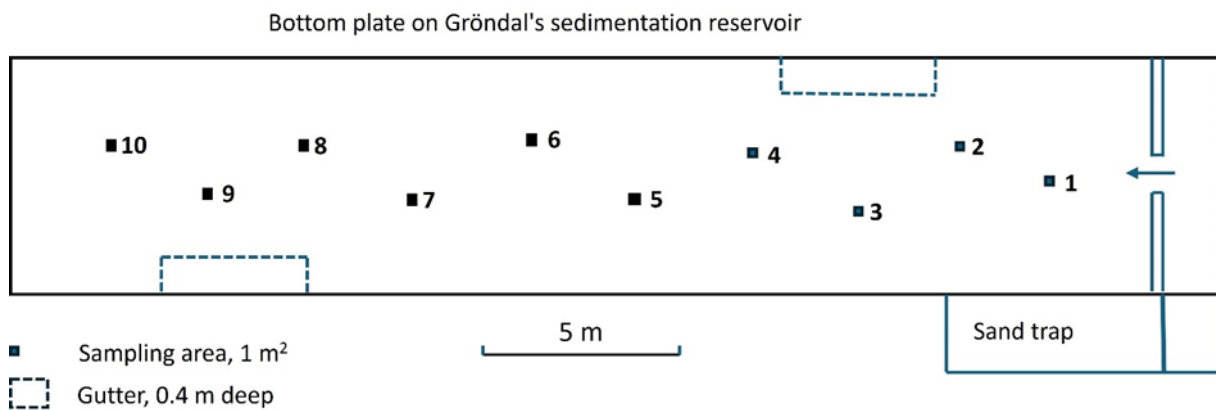
To facilitate sampling of the sediments in the two runoff treatment plants the supernatant water was carefully removed by pumping over two days. It was possible to fully expose the sediment in the sedimentation pond at Lilla Essingen. However, the sediment in the sedimentation tank in the Gröndal runoff treatment plant had more unconsolidated sediment, posing a risk for unintended removal during emptying. Thus, the pumping was stopped when reaching a water depth of approximately 30 cm from the bottom of the sedimentation basin. Ten sediment samples, evenly distributed over the sedimentation pond and sedimentation basin, were collected. In addition, one field blank was also gathered at both plants and one sample from the sand trap at the Gröndal runoff treatment plant (Figs.4 and 5). A 1x1 m boundary was applied in situ around each sampling point, using a steel shovel. The square meter area and associated volume were thoroughly mixed before a 10 L stainless steel bowl was filled and the sediment remixed with a long-handled metal spoon. Samples were taken into glass jars received from the accredited laboratory Eurofins. The shovel was washed between sampling points with the water available in the RWTP. To avoid plastic contamination from the inside of the metal lid, pieces of aluminium foil were placed as protection. The samples were stored in a refrigerator at 4 °C until analysis. The analysis included field blanks. For more information, see Figure 6.

### Sediment volume estimation

The sediment depth was measured at the places where the samples were collected, plus ten more places distributed evenly over the sediment-covered area. These data were used to calculate the wet sediment volume in each system. After determining the dry bulk density using known volumes and weights from drying sediment, the organic content was calculated from loss of ignition data (see Section Sample processing and analysis).



**Figure 4:** Distribution of sampling points in the Lilla Essingen treatment pond.



**Figure 5:** Distribution of sampling points in the Gröndal sedimentation basin from inlet (1) to outlet (10).



**Figure 6:** Left fig., Sediment sampling in the Lilla Essingen sedimentation pond. Right fig., sampling in the Gröndal underground treatment system. White arrows show high and low water levels in the sedimentation basin.

### Sample processing and analysis

To determine water content, dry weight, and loss of ignition (LOI) 20 to 30 g of each sediment sample was drawn for analysis. The sediment samples were dried in heat-resistant porcelain cups over 24 hours at 105 °C, cooled in a desiccator and then weighed. The LOI was subsequently determined after heating in a muffle furnace at 550 °C for 2 hours. The LOI was calculated to determine the sediment's natural organic matter content, including synthetic microplastics and rubber.

The sediments' electrical conductivity (EC) and pH were measured in the supernatant after centrifuging the wet sediment at 3,500 rpm for 10 minutes.

Samples for light and scanning electron microscope (SEM) studies and image preparation were washed with ultrapure distilled water in three successive layers of stainless metal sieves with mesh sizes 500, 250 and 60 µm. Possibly occurring organic and inorganic debris, > 500 µm (e.g. plant residue, leaves, sand grains) was removed after washing.

The inorganic material in the particulate material was determined using 3 g (wet weight) of the sampled sediments. The sample was mixed with 240 mL ultrapure distilled water in 250 mL glass bottles received from the ALS Life Sciences Laboratory ([www.alsglobal.se](http://www.alsglobal.se)). A qualitative particle determination was performed with SEM, equipped with an energy-dispersive detector to determine elements with an atomic number >5 (ALS analysis A-4g). Before the SEM analysis, the water was filtered through a gold-coated polycarbonate (PC) membrane filter.

The samples for microplastic and rubber analysis (>27 µm) were sent to the accredited laboratory Eurofins ([www.eurofins.se](http://www.eurofins.se)) together with samples for oil analysis. Oil can interfere with the density

separation of microplastics and rubber. The laboratory has developed an internal method to calculate the weight of particles with reporting limits, i.e. weights below the limit of quantification (LOQ). The sediment is treated to remove the matrix and concentrate microplastics on a filter with specific pore sizes. This is done by density separation with CaCl<sub>2</sub> and with 10% KOH solution to remove natural organic matter. After KOH filtration, which is either done on a small filter or a large filter depending on the amount of particles remaining in the samples, the samples are transferred to EC cups for analysis on pyr-GCMS. Equipment used was 1) Pyrolyzer (incl. Auto-shot sampler AS-1020E, Multi-shot pyrolyzer EGA/PY-3030D, Multifunctional Splitless Sampler MFS-2015, 2) GC (Agilent 8890 GC-system) and 3) MS (Agilent 5977B GC/MSD). Their analysis is not accredited. The scheme of the analysis package and which microplastics that are relevant to the paint used in road markings are shown in Table 2.

**Table 2:** The Eurofins analysis package for microplastics and rubber (>27 µm) with reporting limits given.

Polymer/Rubber compound*	Abbreviation	Reporting limit (µg/kg DS) <sup>1</sup>	Road marking indicator
Polyethylene	PE	<5	
Polypropylene	PP	<8	
Polystyrene	PS	<2	Thermoplastic polymer
Acrylonitrile butadiene styrene	ABS	<4	
Polymethylmethacrylate	PMMA	<4	Synthetic thermoplastic polymer
Polycarbonate	PC	<20	
Polyvinylchloride	PVC	<50	
Polyetentareftalate	PET	<4	
Polyamide 6	PA6	<2	Thermoplastic construction polymer
Polyamide-6.6	PA 6.6	<20	
Polybutadiene *	PBD	<20	
Polyisoprene *	PIP	<20	
Styrenebutadienrubber *	SBR	<5	

<sup>1</sup>Rubber and microplastics have not been found above LOQ (Limit of quantification), i.e. nothing has been found or has been in quantities too small to be reported.

### Estimation of road markings wear

The visible wear of road markings was calculated by filming and photographing the road surfaces on several occasions during the autumn of 2024. Since these are side-view images taken from a car and not vertical images of the road surface, the extent of the wear can only be estimated approximately. Information on intervals for painting road markings was obtained from personnel at the Swedish Transport Administration.

## Results and discussion

### Sediment volumes produced by runoff from the road surfaces

The sampled sediments in the runoff treatment plants accumulated for three years and eight months (44 months). The sediments had a character of wastewater sludge, black colour, and some smell of faeces, and in the case of Lilla Essingen also a notable smell of oil.

The sediment volume in the Lilla Essingen sedimentation pond was less than that found in the Gröndal sedimentation basin (Table 3). However, the calculated sediment mass per m<sup>2</sup> runoff area at Lilla Essingen was 1.32 kg/m<sup>2</sup> and Gröndal 1.09 kg/m<sup>2</sup> dry weight.

**Table 3:** Total dry substance (DS) calculated for Lilla Essingen and Gröndal systems sediment. The share of organic matter which includes microplastics and rubber is shown.

Treatment system	Water content (%)	Wet sediment volume (m <sup>3</sup> )	Bulk density Kg/m <sup>3</sup>	Total dry substance (Kg)	Dry substance organic matter (Kg)
Lilla Essingen	36.97	64.14	1 110	23,717	1 520
Gröndal	45.22	62.37	1 055	28,203	1 438

### Characterisation of the sediment in Gröndal and Lilla Essingen treatment systems

The sediments in the two systems differed in biological, chemical and physical parameters (Table 4). However, there was a striking similarity between the two sediments in the dominant mineralogical content. The sand trap (GRs) sediment had the lowest LOI since the smallest particles and organic debris were flushed into the large sedimentation system. The differences in parameters are related to Gröndal being an underground facility while Lilla Essingen is an open sedimentation pond. The Essingeleden bridge covers the pond which partly prevents direct rainfall, however, pollutants and debris can reach the water, as proved by the finding of pieces of crushed stone and concrete in the sediment. A small contribution of stormwater from the adjacent housing area may also have an impact. A significant difference in EC was observed in sediment pore water from Lilla Essinge and Gröndal sediment (Table 4) due to the influence of road salt. In Gröndal the retention time is notably shorter, thus the salt washes more readily away due to the more frequent emptying and filling up. The Lilla Essingen sedimentation pond is rich in water and bottom fauna. In summer, the sedimentation pond is regularly visited by waterfowl.

**Table 4:** General characterisation parameters for Gröndal (GR) and Lilla Essinge (LE) sediments. One sample was taken from the sand trap (GRs)(Sw. sand fång) where the coarse particles can settle before the runoff enters the main sedimentation reservoir.

Parameter and unit	GR	GRs	LE
LOI, %	5.1 ± 0.60	4.45 ± 0.41	6.49 ± 0.52
pH	6.87	-	7.21
EC, mS/cm	3.77 ± 0.32	-	12.61 ± 5.9
Colour	Black	Light black	Black
Grain size, mm	< 1	< 8	< 5
Visible biota	No	No	Yes



**Figure 7:** Water insects (dragonfly larvae, water bugs) observed in large populations in the Lilla Essingen pond. Photo taken in the perforated bucket where the drainage pump was installed.

### Particle analysis

The particle analysis performed on the two sediments and road runoff at Lilla Essingen showed clearly the dominating content of silicate mineral particles probably originating from road wear (Table 5). Small amounts of particles contain silica, zinc and titanium, which can be released from road marking paint, but also from many other sources in the road environment. Titanium-rich particles were detected in Gröndal sediments. Rutile titanium dioxide (TiO<sub>2</sub>) is always used in road marking paint because it yields high opacity (Burghardt et al., 2023). Binders in paint are polymeric resins and fillers are composed of e.g. calcium carbonate. Polymeric additives are not detected with particle analysis, however, they can be attached to the particles. Plastic, paint and rubber containing silica can, however, be found by the analysis showing 5% content in Lilla Essingen sediment and road runoff. Silica-containing particles were surprisingly not found in the Gröndal sediments. However, the silicon-rich particles were abundant and the difference between these two particles in the analysis is unclear (Table 5).

**Table 5:** Percentage distribution of mineral and inorganic particles in composite sediment samples from the Lilla Essingen pond, the Gröndal treatment system, and Lilla Essingen road runoff.

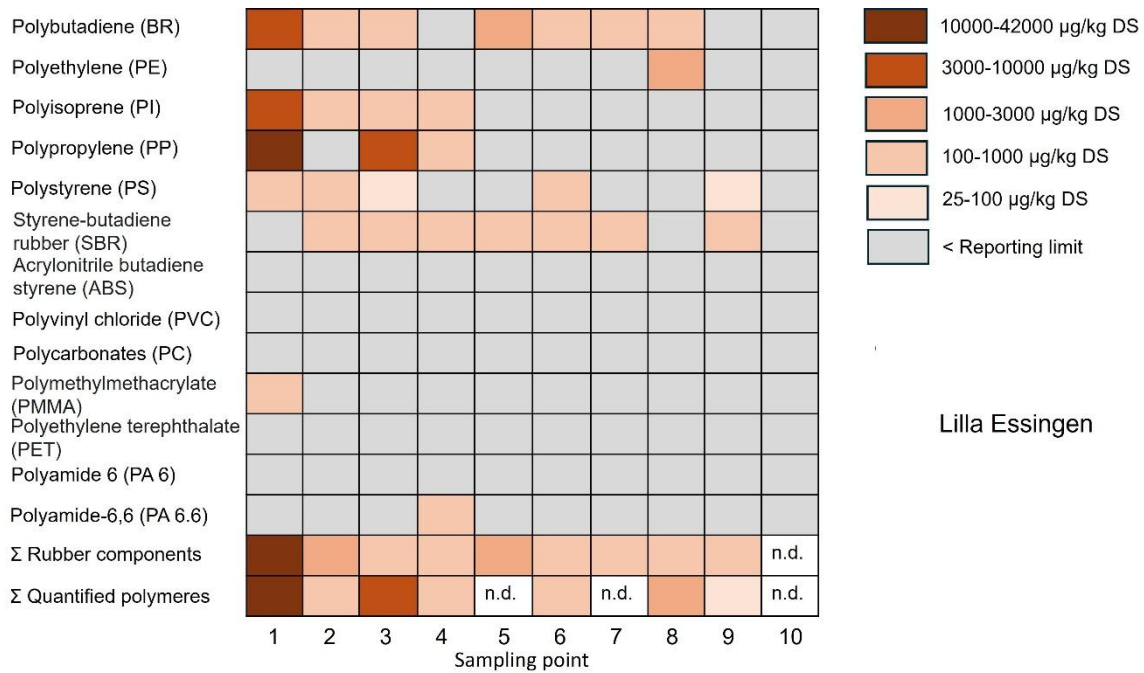
Particle analysis	L. Essingen (%)	Gröndal (%)	Road runoff L. Essingen (%)
<b>Minerals and inorganic particles</b>			
Silicon-rich particles (e.g. silicate minerals)	85	85	90
Silicon dioxide, SiO <sub>2</sub>	5	10	5
Calcium-rich particles (e.g. construction dust)	-	< 5	-
<b>Other particles</b>			
Silica-containing particles (e.g. plastic, paint, rubber)	5	-	5
Iron-rich particles (e.g. rust)	< 5	< 5	-
Zinc-rich particles (e.g. paint)	< 5	-	-
Titanium-rich particles (e.g. paint)	-	< 5	-

#### Microplastics and rubber in sediments

The results of the MP and rubber analysis performed on the sediment samples from the two studied sites are shown in Figures 8 and 9. The longitudinal distribution from the inlet (sample point 1) to the outlet (sample point 10) shows a pattern of more deposition closer to the inlet zone. This is clear for the Gröndal system where the sediment layer thickness slowed down towards the outlet. The highest concentrations of rubber components are found in the inlet zones but spread over the entire sedimentation areas. The quantified polymers are also deposited to a higher degree in the inlet zone. The sum of polymers is unfortunately not given by the Eurofins laboratory for points 1 and 2 in the Gröndal case. The MP analysis included 13 microplastics and rubber components but only eight of them were detected in Lilla Essingen sediment and five in the Gröndal.

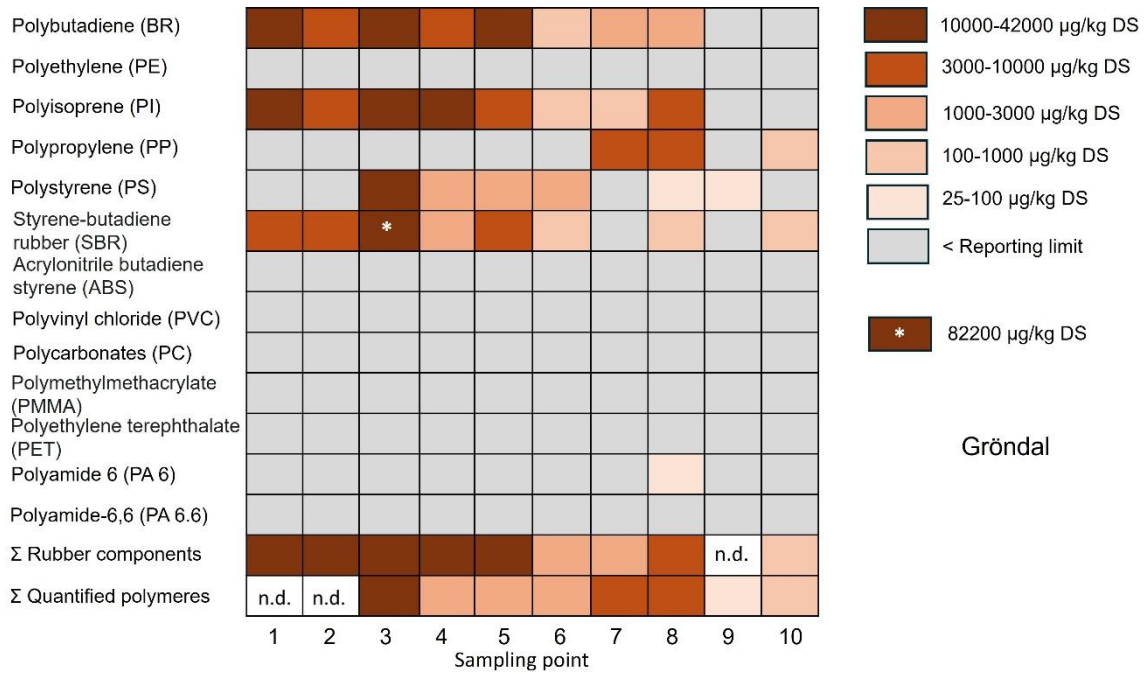
The highest reported concentration in one sample was for SBR rubber, 82,200 µg/kg DS. The road marking paint is known to be composed of a few thermoplastic polymers. The Eurofins analysis includes PS, PMMA and PA 6. In Lilla Essingen sediments, the PS was found in five samples and distributed over the entire area. The points with missing PS can have different reasons, e.g. analytical problems, sampling technique or random effects. PS was missing in the Gröndal sampling points 1 and 2 which is suggested to be related to the analytical procedure since the two following points 2 and 4 had high and quite high PS concentrations. The PMMA, like other polymers considered attached to the glass beads common in the superficial painting layer, was surprisingly only detected at sampling point 1 in the Lilla Essingen sediment. Glass microbeads are potential carriers of road marking paint residues, although this was not visibly evident in soils and sediments according to Turner et al. (2024).

The PA 6 was found only at one sampling point, number eight in the Gröndal investigated sediment.



Lilla Essingen

**Figure 8:** Concentrations of rubber components and microplastic polymers (PS, PMMA, PA 6) in road runoff sediment accumulated for three years and eight months in the Lilla Essingen sedimentation pond. Reporting limit = below the limit of quantification. No data = n.d.

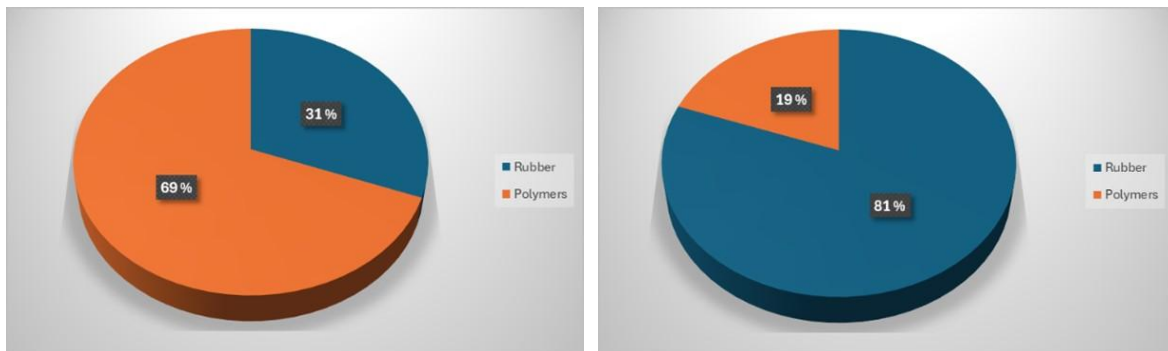


Gröndal

**Figure 9:** Concentrations of rubber components and microplastic polymers (PS, PMMA, PA 6) in road runoff sediment accumulated for three years and eight months in the Gröndal sedimentation facility. Reporting limit = below the limit of quantification.

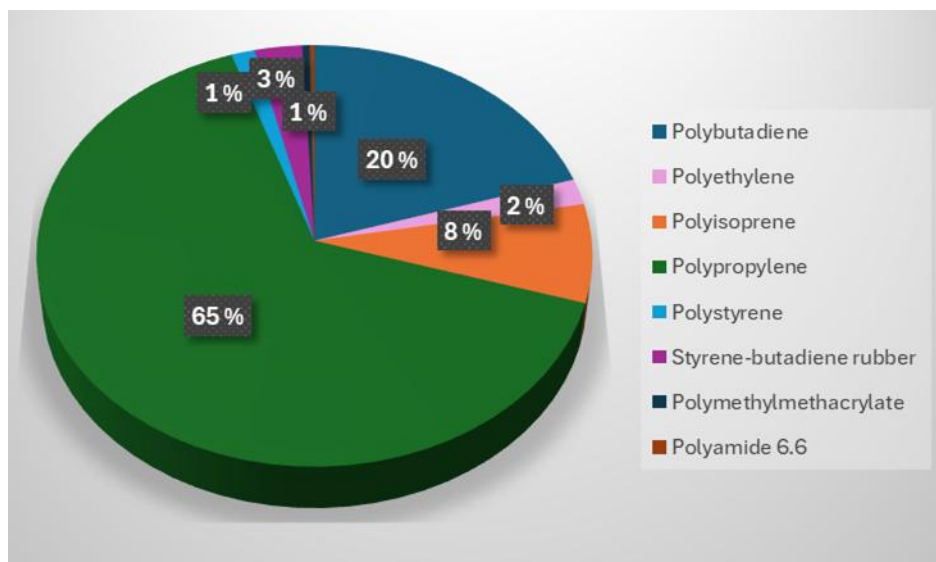
### Comparison of the percentage of polymers and rubber in the two road runoff catchments

The two road runoff catchment sediments studied differ in the composition of microplastics and rubber components, as evident in Figure 10. The reason for this pattern can probably be found in the nature of the catchment areas and the traffic. The Gröndal area is characterized by only traffic areas while the Lilla Essingen area is more multifaceted. In the latter area, people can walk and cycle in some parts and there are smaller green spaces and parking lots. This area has two road exits and one entry point while Gröndal has only one exit and entry point. The open Lilla Essingen pond can collect air and water pollutants from everywhere in its surroundings, however the dominating source of pollution must be the road runoff.

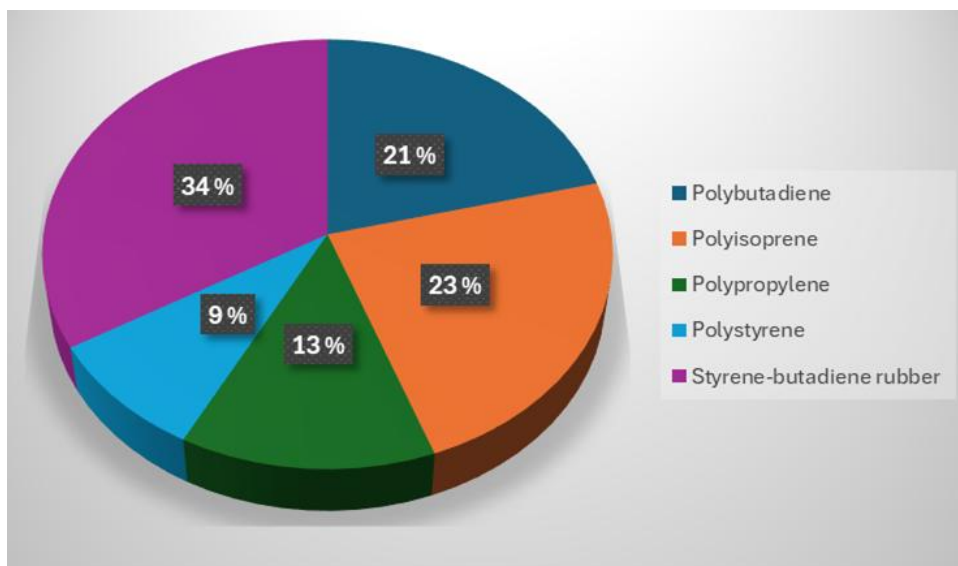


**Figure 10:** The distribution of rubber and polymers in Lilla Essingen (left fig.) and Gröndal (right fig.) sediments.

Looking more into the detailed distribution of polymers and rubber found in the two sediments, it is evident that differences exist (Fig. 11 and 12). The proportion of polymers related to paint in road markings is very small in both cases. Polymers and rubber with a most likely origin from tire wear largely dominate, making the relative contribution of microplastics less from road paint.



**Figure 11:** Distribution of polymers and rubber components in sediment from the Lilla Essingen pond.



**Figure 12:** Distribution of polymers and rubber components in sediment from the Gröndal sedimentation system.

#### A comprehensive inventory of road wear

The Essinge-leden and Gröndal area of highway E4 has frequent road management related to the very high traffic load. According to the Swedish Transport Administration, the road markings must be supervised every second year and asphalt improved or replaced due to the heavy road wear. Precise data on maintenance carried out on the studied road sections could not be obtained, however verbal information received from the Swedish Transport Administration suggests that painting of road lines was possibly carried out once during the period of sediment collection in both treatment systems. Complete asphaltting does not appear to have been carried out; repairs only occur on a limited number of areas of the roadways.

The field investigation performed during autumn 2024 shows that less than 5% of the road markings have visible wear. This mainly occurs at exits and entries of the highway and as there are few, paint-borne microplastics will likely not be found to a large extent in the studied sediments. The vehicles seem to keep their position well between the lane lines as the lines are not much affected by wear. The stair-flex lines and the solid road lines on the edges of the road surfaces are almost unaffected by vehicles but road management with snow ploughing and sand sweeping can probably cause a release of paint and microplastics. Figures 13 and 14 show examples of road marking areas affected by road wear.



**Figure 13:** Road area at the beginning of the exit to Lilla Essingen island. The pond is situated below this part of the bridge. The blue arrow indicates the wear of the lane line. On the right-hand side, the so-called stair-flex line is visible.



**Figure 14:** Road marking wear at the entry (1, 2) on the Gröndal bridge (3, 4) and the exit (5) to the district Gröndal. These markings are on vehicles crossing areas with obvious wear and possible release of paint-borne microplastics.

Mass calculations and affecting factors

The road wear collected in Gröndal runoff treatment plant sediments was 28,203 kg during 44 months, which amounts to 7 692 kg/year including 430 kg/year of organic material (5,1 %). The total road wear load, accumulated in the sediment basin, regarding the catchment area, comes to 2.98 tons/hectares/year. The traffic intensity at the studied road section is 165,000 annual average daily traffic (AADT), and the

permitted speed is 70 km/h. The waterborne road wear transport per vehicle yields 0.0181 kg/hectares/vehicle.

Rubber and polymers weighing 0.054 kg and 0.019 kg respectively, were found in the Lilla Essingen sedimentation pond. In the Gröndal sedimentation basin, 0.5 kg of rubber and 0.136 kg of polymers were found. The share of road marking (RM) polymers (PS, PMMA, PA6) of these total weights in Lilla Essingen and Gröndal sediments were 0.036 and 0.013 kg, respectively. The annual load for the Lilla Essingen runoff treatment plant will be 0.009 kg/year and for the Gröndal runoff treatment 0.004 kg/year.

The road marking areas shown in Table 1 were used to calculate the wear of microplastics per hectare and year. In Table 6 the wear regarding the marking's area is given based on the highest average interval concentration presented in Figures 8 and 9 for polystyrene (PS), polymethylmethacrylate (PMMA) and polyamide 6 (PA 6). In the case of Essinge-leden, one hectare of road marking area (RMA) would release polymers with road runoff of 3.83 kg/year corresponding to 23.2 mg/year/vehicle.

Sweden's state roads have a length of 98,500 km and an assumed average width of 7 m, which gives an approximate RMA of 2,310 hectares (assume 3.35% of the road surface is covered with RM, calculated from the Gröndal area). Järllskog et al. (2024) published a report on microplastic emissions from wear of road markings. They estimated that the total wear of road markings from state roads varies between 1,500–9,900 tons per year (entire particles) and that the polymer part is 30–396 tons/year. Assume that 30 tons are released from the state roads and the total RMA is 2,310 hectares; the release is about 13 kg/ha/year. A polymer release of 396 tons/year yields about 171 kg/ha/year. The fate of microplastics in that release is unknown other than possible destinies such as transport by road runoff, splash, snow removal, wind, and road sweeping. The transport with the runoff from the Gröndal road area is 0.383 g/m<sup>2</sup>/year. a 3.4 to 45 times lower road marking wear than the estimated range by Järllskog et al. (2024). Difficulties in interpreting these different results depend on a lack of knowledge of how much microplastics leave the road other than through runoff. Field trials must therefore be carried out at a site where runoff, sludge collection, wind dispersion including splash from the road surface, and road maintenance can be measured and controlled.

**Table 6:** Mass of the road markings polymers PS, PMMA and PA 6 per hectare painted area (RMA) and year, calculated from the highest average interval concentrations detected in sediments from the Lilla Essingen pond and the Gröndal sedimentation reservoir.

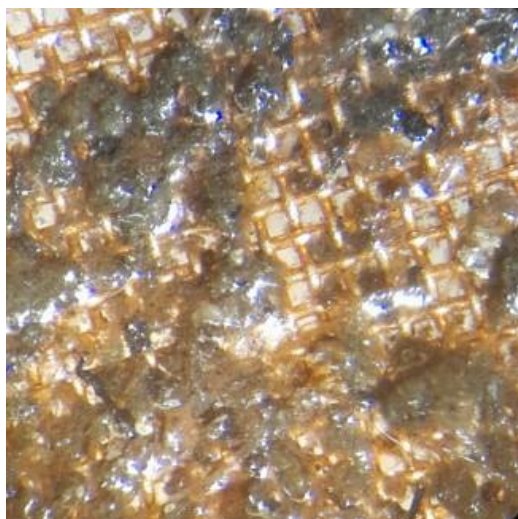
System	Polymer, mass kg/ha RMA/year			
	PS	PMMA	PA 6	Σ TP polymers
L. Essingen	0.06	0.58	-	0.64
Gröndal	3.8	-	0.033	3.83

However, limitations to the calculations based on the present study are that some thermoplastic polymers were not included in the Eurofins analysis and that part of the analysis method with decantation may have caused losses of microplastics. The results indicate, however, that some theoretical calculations previously carried out are greatly exaggerated. Many other investigations in Sweden and abroad have reported hundreds or thousands of tons MPs released to the environment from roads. Brännström et al. (2023) report that road traffic is Sweden's largest source of MPs. They used a simplified method to calculate emissions from different sources and found wear from Swedish road traffic accounting for about 7,674 tons per year. Ejhed et al. (2018) investigated sources, distribution of microplastics and possible solutions to protect Stockholm City's water bodies. They presented the composition of the road marking paint used and the annual paint supply of 773 tons/year to the streets of Stockholm. They

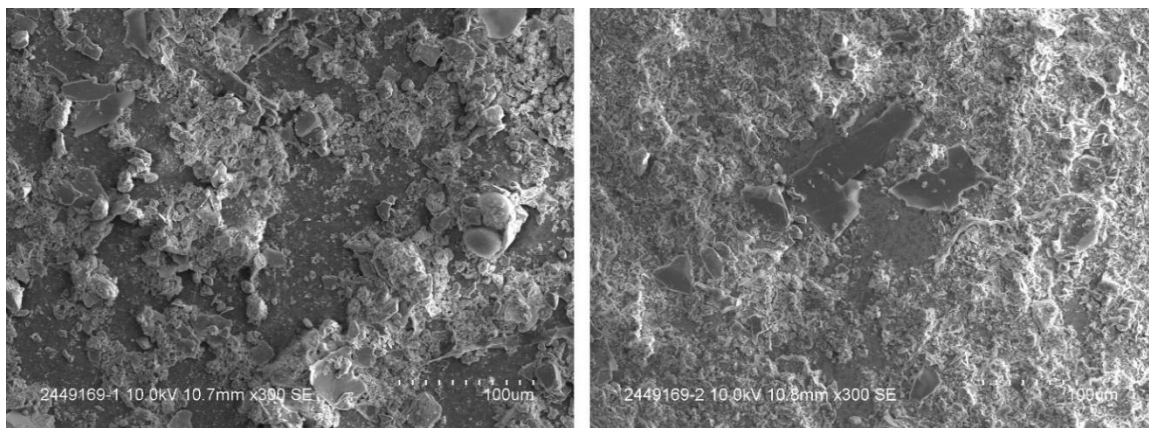
assumed 2–4 % polymers/elastomers content in the paint and a supply of 15–30 tons annually. In the following, some sources of error that may have affected the analyses of the sediments will be discussed.

The method used by Eurofins laboratory to analyse microplastics and rubber in sediments is not accredited. The analysis allows particle identification from size 27  $\mu\text{m}$ . Järtskog et al. (2022) found that road dust contained traffic-derived microplastics in the size range of 2–20  $\mu\text{m}$  and dominated over the size fraction 20–125  $\mu\text{m}$ . This dust can partly end up in road runoff indicating that microplastic analysis should cover smaller fractions than 27  $\mu\text{m}$ . However, the laboratory has shared detailed information about the analysis procedure that cannot be questioned. Still, methods for sampling and detection of MPs are not fully developed and need to be improved (Prata et al., 2019). The occurrence of PMMA in only one sample can be interpreted as an uncertainty in the analytical work. It is known that paint such as PMMA can be attached to the glass microbeads, which probably are removed during density separation in the used analysis. This means that the investigated polymers can be underestimated due to the pre-preparation step in the analytical work. The analytical difficulties have been pointed out by Järtskog et al. (2024) in reply to a paper published by Burghardt & Pashkevich (2023).

The sampling procedure and number of samples can play a role in the final results. However, the current project did not have the time and resources to extend sampling to extend the sampling scheme more than explained in the section "Sample processing and analysis", page 7. The Eurofins laboratory did not report problems in the analytical work because of the PAH in the sediments. The analysis of oil showed high concentrations of total PAH 16, Lilla Essingen 6.4 mg/kg DS and Gröndal 5.6 mg/kg DS. The highest aromatic compound concentration >C16-C35 was shown in Lilla Essingen and Gröndal sediments, 3000 and 3700 mg/kg DS, respectively. Sediments with such concentrations are classified as hazardous waste (Naturvårdsverket, 2022). Preliminary work at the KTH laboratory using a microscope to identify and calculate the number of plastic and rubber remains, indicates a very high mass of glass microbeads and black rubber. The SEM images also indicate microplastics and glass beads (see Figs. 15 and 16). The much higher abundance and mass of e.g. Polystyrene in Gröndal than Lilla Essingen sediments is probably related to the larger runoff area and the use of the PAX precipitation chemical. Yu et al. (2024), Tang et al. (2022) and Jachimowicz & Cydzik-Kwiatkowska (2022) showed in experiments the high efficiency of different precipitation agents in the removal of microplastics from water.



**Figure 15:** Sediment filtered through stainless steel (mesh size 500  $\mu\text{m}$ ). The blue colour is reflected light in glass beads present in the sediment and originating from road marking paint.



**Figure 16:** SEM images of sample from Lilla Essingen sediment (left) and Gröndal (right). Small pieces of glass beads are seen and mineral grains of silicon. The Gröndal sediment contains precipitation products after using PAX, which gives the sediment mass another character than the Lilla Essingen sediment.

### Final remarks

This study should be followed up by more investigations of the collected sediment samples. For instance, the glass microbeads observed in the microscope (Fig. 15) should be studied and estimated in detail in Gröndal and Lilla Essingen sediments. Such analysis could cast light on the microbeads as proxies for road marking paints (Turner et al., 2024). The Gröndal reservoir and the Lilla Essingen pond are managed differently as flow-through systems. The precipitation agent dosing in Gröndal proved more efficient for MP removal than the traditional sedimentation in Lilla Essingen. The outflow of MPs from these systems was not extensively studied in a previous project, however, analysis of a few water samples indicated low levels of MPs in incoming runoff and almost removed after filter media filtration (Agnieszka Renman, unpublished data). A complementary study should include sampling of influent and effluent water and clarify if sediments are valuable archives for studies of waterborne MPs. Similar systems with different and lower traffic loads to the two studied should be included and flow-monitored from the state of emptied sediment basins to filled-up after 2-3 years. The results should gain knowledge of how to engineer and manage current and forthcoming stormwater treatment systems to reduce microplastic and rubber pollution from roads and urban areas. Sediments and sludge collected over time constitute historical archives that can reflect real conditions, but more development work needs to be done regarding sampling and, above all, analyses of microplastics.

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