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MICROPROOF
Micropollutants in Road RunOff

Combined results from the reviews of literature and measurements of organic micropollutants, microplastics and associated substances in road run-off

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1 Introduction

This report provides an overview of sources and emissions of microplastics (chapter 2) and organic micropollutants (chapter 3) released from traffic and roads. The focus of this study is on pollutants that could possibly end up in surface waters.

Emissions from traffic and roads are caused by tyres, asphalt and concrete, brakes, brake fluids, road markings, car coatings, corrosion inhibitors, automotive coolants, fuels, oils and lubricants. Also exhaust from traffic is a major source of emissions, but since these emissions are airborne, this source is not included in this study.

More details can be found in Microproof reports 1.1 and 1.2.

2 Microplastics

In this study, microplastics are defined as small plastic particles (< 5 mm), which are insoluble and slowly degradable. This also includes plastic particles from biogenic origin and rubber particles.

Microplastics are released from a large variety of sources, which can be divided in primary sources (sources where the particles are intentionally small plastic particles, like microbeads in cosmetic products) and secondary sources (sources where large plastic materials break down in microplastics, like paints, tyres, plastic littering, etc).

Microplastics from roads and traffic are released from tyres, brakes, vehicle parts, asphalt and road markings. Several countries have made an inventory to calculate emissions of microplastics from all types of sources. Table 1 provides an overview of microplastics that are released from traffic and roads, including emission factors reported in literature (expressed in milligram per vehicle kilometre, mg/vkm). These emission factors represent the total amount of microplastic that is released (on the road surface, soil and surface water together), and not only the part that ends up in surface waters. This table does not include emission factors for microplastics from brakes and vehicle parts, because detailed information on these sources was not available. It is expected that these sources are relatively small.

From Table 1, it appears that tyres are the largest source of microplastics from roads and traffic. The average emission factor for microplastics from tyres is 90-270 mg/vkm, while emission factors from road marking and asphalt are in the range of 0.2-15.3 mg/vkm.

Microplastic concentrations have been measured in surface waters and oceans. These studies mainly focused on polyethylene (PE), polypropylene (PP) and polystyrene (PS). Monitoring data for microplastics from road-related sources are scarce. At present the only published study is an application note on FT-IR imaging (Olesen et al., 2017). They analysed stormwater and sediments from an urban stormwater pond and found (total) microplastic concentrations of 26 mg/kg dry sediment and 4.5 µg/L in the stormwater. The plastic materials present were polyethylene, polypropylene, polyvinyl chloride, polystyrene, polyurethane and zinc stearate coated particles. This study did not address tyre particles as the applied technique was not suited for that purpose.

Table 1 Emission factors for microplastics released from traffic and roads (mg/vkm). This includes the total microplastic amount that is released from traffic and roads (which end up on the road surface, in the soil and in surface waters)

Sources	Emission factor	Unit	Reference
Tyre wear, passenger cars	50-132	mg/vkm	Gustafsson, 2001; Hillenbrand et al., 2005; GRPE, 2013; Azarov et al., 2013; Klein et al., 2017
Tyre wear, light commercial vehicles	102-320	mg/vkm	GRPE, 2013; Azarov et al., 2013; Klein et al., 2017
Tyre wear, trucks/commercial vehicles	546-1500	mg/vkm	Hillenbrand et al., 2005; GRPE, 2013; Azarov et al., 2013; Klein et al., 2017
Tyre wear, buses	267-700	mg/vkm	Gustafsson, 2001; Hillenbrand et al., 2005; GRPE, 2013; Klein et al., 2017
Tyre wear, motorcycles	39-47	mg/vkm	Hillenbrand et al., 2005; Klein et al., 2017
Tyre wear, average	90-270	mg/vkm	Pant & Harrison 2013; Sundt et al., 2014; Lassen et al., 2015
Asphalt	0.19	mg/vkm	Microplastic emission of 1500 ton divided by total vehicle kilometers (data from Magnussen et al., 2017)
Road marking	2.43-15.27	mg/vkm	Microplastic emission of 100-690 ton divided by total vehicle kilometres (data from Lassen et al., 2015)
Brakes	-	-	No data available
Vehicle parts	-	-	No data available

3 Organic micropollutants

Annex A provides an overview of organic micropollutants that are released from traffic and roads. For each pollutant, it is indicated from which emission sources these pollutants are released, including relevant references. More details are presented in Microproof reports 1.1 and 1.2.

Markiewicz et al. (2017) reviewed the emission of organic micropollutants related to traffic and roads. They found that a large number of these substances is associated to traffic and roads and ranked them as priority pollutants according to their environmental impacts and mass flow. They found the following priority order: polycyclic aromatic hydrocarbons (PAHs) > alkanes C20 - C40 > alkylphenols > phthalates > aldehydes > phenolic antioxidants > bisphenol A > oxygenated-PAHs > naphtha C5 - C12 > amides > amines.

Grung et al. (2017) performed a data register study to identify the amounts of organic micropollutants in products related to motorized transport in Norway. They found that the products contained hazardous substances present in problematic amounts. The most important prioritized compounds were methyl tertiary butyl ether, benzene, tetrachloroethylene, hydrazine, medium-chain paraffins, tetraborates, nonylphenols and its ethoxylates, decamethylcyclopentasiloxane, and the tetraborate orange lead.

For the pollutants in Annex A, it is known or expected that they are released from traffic and roads. Only for a few pollutants, it is quantified how much of the pollutant is released per vkm. Table 2 shows the emission factors from these substances for several sources.

Table 2 Emission factors for organic micropollutants (µg/vkm). This includes the total amount that is released from traffic and roads (which ends up on the road surface, in the soil and in surface waters)

Sources	Chemical	Short name	CAS number	Emission factor	Unit	Ref
Tyres	1,3-Diphenylguanidine	DPG	102-06-7	46.50	µg/vkm	1)
	2-Benzothiazolone	BTON	934-34-9	3.00	µg/vkm	1)
	2-Mercapto benzothiazole	MBT	149-30-4	1.13	µg/vkm	1)
	4-Aminodiphenylamine	4-ADPA	101-54-2	2.55	µg/vkm	1)
	4-Hydroxydiphenylamine	4-HDPA	122-37-2	6.30	µg/vkm	1)
	Aniline		62-53-3	0.30	µg/vkm	1)
	Benzothiazole	BT	95-16-9	5.25	µg/vkm	1)
	Cyclohexyl amine	CHA	108-91-8	4.95	µg/vkm	1)
	Diphenylamine	DPA	122-39-4	0.32	µg/vkm	1)
	N-(1,3-dimethylbutyl)-N'-phenyl-1,4-phenylenediamine	6-PPD	793-24-8	150.00	µg/vkm	1)
	N-cyclohexyl-1,3-benzothiazol-2-amine	NCBA	28291-75-0	0.30	µg/vkm	1)
	PAH-8			4.20	µg/vkm	2)
Brakes	Polyalkylene glycol ethers			4.85	µg/vkm	3)
	N-alkanoic acids			2.92	µg/vkm	3)
	PAH-16			0.09	µg/vkm	3)
Lubricants	PAH-16			7.25	µg/vkm	4)

1) Unice et al., 2015 (concentration in fresh TRWP) combined with an average rubber emission factor of 150 mg/vkm (average of Pant and Harrison, 2013; Lassen et al., 2015; Sundt et al., 2014)
2) Pan et al, 2016 (tyres with Bay-H%<= 0.35%), combined with an average rubber emission factor of 150 mg/vkm (average of Pant and Harrison, 2013; Lassen et al., 2015; Sundt et al., 2014)
3) Emission factor of brakes (Grigoratos et al., 2015) multiplied with content (Rogge et al., 1993)
4) Lubricant leakage of 10 mg/vkm (Klein et al., 2017) multiplied with PAH content (Deltares and TNO, 2016)

Many of the organic micropollutants have not or only sporadically been measured in stormwater runoff, road dust and soil. The group of organic micropollutants which have been monitored most frequently is PAH, for example by Tromp et al. (2012), Vollertsen et al. (2009), Brongers (2010), Best et al. (2002), Velsen (1997), Tromp (2005), Berg et al. (2009), Grauert et al. (2011), Grauert et al. (2012), Stephansen (2014), Zhang et al. (2017), Majumdar et al. (2017), Schipper et al. (2003).

For other organic micropollutants than PAH, the number of field measurements becomes sporadic. Relevant studies are carried out by Seitz & Winzenbacher (2017), Kloepfer et al. (2005), Reddy & Quinn (1997), Holsteijn (2014), Baumann & Ismeier (1998), Gasperi et al. (2014), Dsikowitsky & Schwarzbauer (2015).

Organic micropollutants concentrations in runoff published in the abovementioned studies are presented in Annex B.

4 Conclusion

Microplastics are released from a large variety of sources, including littering, households (laundry, beauty products, etc), paints and industry. Microplastics are also released from traffic and roads, including the wear of tyres (rubber particles), brakes, asphalt, road marking and vehicle parts. Emission factors per source (traffic and roads only) are presented in Table 1. Tyre wear is deemed to be the largest source of microplastics emissions from traffic and roads.

The list of pollutants released from cars and roads (as presented in Annex A) is quite extensive, but still not complete. For some sources, no literature was available on the exact composition of the material and thereby on the exact composition of the emissions. However, the list in Annex A presents a comprehensive overview of the pollutants that are released from cars and roads.
For some pollutants, it was possible to calculate an emission factor (see Table 2). This was mainly possible for pollutants released in tyre wear, which is the largest source of emissions from cars and roads.

This study revealed a variety of organic micropollutants that are released from road transport to the environment, but it was concluded that the number of actual measurements is limited. It is recommended to perform more measurements in road run-off on organic micropollutants and microplastics. For some of these pollutants, measurements have been carried out. Table 3 presents the pollutants that could be relevant for water quality and should be measured more frequently in road run-off and/or surface water.

Table 3 Relevant organic micropollutants from this study. This tables indicates whether the pollutant is a priority substance within the Water Framework Directive (WFD), and whether emission factors and/or concentrations in runoff have been measured.

Source	Substance	Short name	CAS number	Priority substance in WFD	Emission factor in Table 2	Concentration in runoff in Table 6 or Table 7
Tyres	Benzothiazole	BT	95-16-9		X	X
	Mercaptobenzothiazole	MBT	149-30-4		X	X
	Benzothiazolone	BTON	934-34-9		X	
	Hydroxybenzothiazole	OHBT	934-34-9			X
	Benzothiazole-2-sulfonate	BTSA	941-57-1			X
	2-(methylthio)-benzothiazole	MTBT / MeSBT	615-22-5			X
	2-Morpholinobenzothiazole	24MoBT	4225-26-7			X
	Cyclohexylamine	CHA	108-91-8		X	
	Dicyclohexylamine	DCHA	101-83-7			
	Hydroxydiphenylamine	4-HDPA	122-37-2		X	
	Aminodiphenylamine	4-ADPA	101-54-2			
	Aniline		62-53-3		X	
	PAH			X	X	X
Brakes and brake fluid	Polyglycol ethers				X	
	Boric-acid-ester					
	Tributylphosphate		126-73-8			
	Triethanolamine		102-71-6			
	PAH			X	X	X
Car coatings	Hexa(methoxymethyl)melamine	HMMM	3089-11-0			X
	Nonylphenol ethoxylates	NP1EO, NP2EO	9016-45-9, 20427-84-3			X
	Octylphenolethoxylates	OP2EO, OP2EO	51437-89-9, 2315-61-9			X
	Bisphenol A	BPA	80-05-7			X
Coolants	Benzotriazole		95-14-7			
	Tolyltriazole	TT	29385-43-1			X
	Mercapto benzothiazole	MBT	149-30-4			X
Other	Diisodecyl phthalate	DIDP	26761-40-0			X
	Di(2-ethylhexyl)phthalate	DEHP	117-81-7	X		X
	Tris(1-chloropropan-2-yl) phosphate	TCCP	13674-84-5			X
	Nonylphenol monocarboxylate	NP1EC	3115-49-9			X
	Nonylphenol	NP	104-40-5	X		X
	4-tert-octylphenol	OP	140-66-9	X		X

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Annex A: Organic micropollutants and sources

Table 4 and Table 5 provide an overview of organic micropollutants and polycyclic aromatic hydrocarbons that are released from traffic and roads. For each pollutant, it is indicated from which emission sources these pollutants are released, including relevant references. More details are presented in Microproof reports 1.1 and 1.2.

Table 4 Overview of organic micropollutants that are released from traffic and roads, including emission sources that are responsible for these pollutants.

Chemical	Short name	CAS number	Sources	Reference
(1,4-dimethylpentyl)phenylenediamine	77PD	3081-14-9	Tyres	Baumann & Ismeier, 1998
1,3-Diphenylguanidine	DPG	102-06-7	Tyres	Unice et al., 2015
1H-Benzotriazole		13351-73-0	Corrosion inhibitors	Loos et al., 2013
2-(methylthio)-benzothiazole	MTBT	615-22-5		
2,2′-Dithiobis(benzothiazole)	MBTS	120-78-5	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
2-Benzothiazolesulfonic acid	BTSO3H	21465-51-0	Tyres	Unice et al., 2015
2-Benzothiazolone	BTON	934-34-9	Tyres	Unice et al., 2015
2-Hydroxybenzothiazole	OHBT	934-34-9	Tyres	Reddy & Quinn, 1997
2-Mercapto benzothiazole	MBT	149-30-4	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
2-Methylbenzothiazole	MeBT	120-75-2	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
2-Methylthiobenzothiazole	MeSBT	615-22-5	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
2-Morpholinobenzothiazole	24MoBT	4225-26-7	Tyres	Reddy & Quinn, 1997
4-Aminodiphenylamine	4-ADPA	101-54-2	Tyres	Unice et al., 2015
4-Hydroxydiphenylamine	4-HDPA	122-37-2	Tyres	Unice et al., 2015
4-Methyl-Benzotriazole		29878-31-7	Corrosion inhibitors	Loos et al., 2013
4-Nitrodiphenylamine	4-NDPA	836-30-6	Tyres	Unice et al., 2015
4-Nitrosodiphenylamine	4-sDPA	156-10-5	Tyres	Unice et al., 2015
4-tert-octylphenol	OP	140-66-9	Vehicles	Gasperi et al., 2014
5-Methyl-Benzotriale		136-85-6	Corrosion inhibitors	Loos et al., 2013
Aniline		62-53-3	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
Benzothiazole	BT	95-16-9	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015; Reddy and Quinn, 1997

Chemical	Short name	CAS number	Sources	Reference
Benzothiazole-2-sulfonate	BTSA	941-57-1		
Benzotriazole		95-14-7	Brake fluid	US Patent 6339050 B1
			Automotive coolants	Lijima et al., 2002
Bis(triethoxysilylpropyl)tetrasulfide	SI69	40372-72-3	Tyres	Unice et al., 2015
Bisphenol A	BPA	80-05-7	Brake fluid	US Patent 6339050 B1
Boric-acid-ester			Brake fluid	US Patent 6339050 B1
Cyclohexyl amine	CHA	108-91-8	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
			Brake fluid	US Patent 6339050 B1
Di(2-ethylhexyl)phthalate	DEHP	117-81-7	Vehicles	Björklund, 2010
Dibutyl amine		111-92-2	Brake fluid	US Patent 6339050 B1
Dibutylhydroxy toluene		128-37-0	Brake fluid	US Patent 6339050 B1
Dicyclohexylamine	DCHA	101-83-7	Tyres	Baumann & Ismeier, 1998
Diisodecyl phthalate	DIDP	26761-40-0	Vehicles	Björklund, 2010
Diisononyl phthalate	DINP	28553-12-0	Vehicles	Björklund, 2010
Di-n-butyl phthalate	DBP	84-74-2	Vehicles	Björklund, 2010
Diphenylamine	DPA	122-39-4	Tyres	Unice et al., 2015
Diphenylurea		102-07-8	Tyres	Unice et al., 2015
Hexa(methoxymethyl)melamine	HMMM	3089-11-0	Car coatings	Dsikowitsky & Schwarzbauer, 2015
Mercapto benzothiazole	MBT	149-30-4	Automotive coolants	Lijima et al., 2002
Methylbenzothiazole	MeBT	120-75-2	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
Methyl-Benzotriazole		29385-43-1	Brake fluid	US Patent 6339050 B1
			Corrosion inhibitors	Loos et al., 2013
N-(1,3-dimethylbutyl)-N’-phenyl-1,4-phenylenediamine	6-PPD	793-24-8	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
N,N'-ditolyl- and N,N'-diphenyl-p-phenylenediamine	DPPD/DTPD	74-31-7 / 620-91-7	Tyres	Baumann & Ismeier, 1998
n-alkanoic acids			Brakes	Rogge et al. 1993
N-butylaniline		1126-78-9	Tyres	Unice et al., 2015
N-cyclohexyl-1,3-benzothiazol-2-amine	NCBA	28291-75-0	Tyres	Unice et al., 2015
N-Cyclohexyl-2-benzothiazole	CBS	95-33-0	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
N-Isopropyl-N'-phenyl-1,4-phenylenediamine	IPPD	101-72-2	Tyres	Baumann & Ismeier, 1998
Nonylphenol	NP	104-40-5	Vehicles	Gasperi et al., 2014
Nonylphenol and its ethoxylates	NP/EOs	104-40-5/9016-45-9	Vehicles	Björklund, 2010

Chemical	Short name	CAS number	Sources	Reference
Nonylphenol diethoxylate	NP2EO	20427-84-3	Vehicles	Gasperi et al., 2014
Nonylphenol monocarboxylate	NP1EC	3115-49-9	Vehicles	Gasperi et al., 2014
Nonylphenol monoethoxylate	NP1EO	9016-45-9	Vehicles	Gasperi et al., 2014
N-phenylformamide		103-70-8	Tyres	Unice et al., 2015
N-tert-Butyl-2-benzothiazolesulfenamide	TBBS	95-31-8	Tyres	Baumann & Ismeier, 1998
Nµ-(p-Phenylene)ditoluidine	DTPD	620-91-7	Tyres	Baumann & Ismeier, 1998
Octylphenol diethoxylate	OP2EO	2315-61-9	Vehicles	Gasperi et al., 2014
Octylphenol monoethoxylate	OP1EO	51437-89-9	Vehicles	Gasperi et al., 2014
Organic acid (Sebacic acid, Terephthalic acid)		111-20-6;100-21-0	Automotive coolants	Lijima et al., 2002
Phosphoric acid		7664-38-2	Automotive coolants	Lijima et al., 2002
Poly(1,2-dihydro-2,2,4-trimethylquinoline)	TMQ	26780-96-1	Tyres	Baumann & Ismeier, 1998
Polyalkylene glycol			Brake fluid	US Patent 6339050 B1
polyalkylene glycol ethers			Brakes	Rogge et al. 1993
Polyethylene glycol monomethyl ether		9004-74-4	Brake fluid	US Patent 6339050 B1
Polyethylene monobutyl ether		9004-77-7	Brake fluid	US Patent 6339050 B1
Polyethylenepropylene glycol monomethyl ether			Brake fluid	US Patent 6339050 B1
Polymethacrylate	PMMA	80-62-6	Automotive coolants	Lijima et al., 2002
p-tert-Butyl sodium		1716-12-7	Automotive coolants	Lijima et al., 2002
Sodium benzoate		532-32-1	Automotive coolants	Lijima et al., 2002
Sodium borate		1303-96-4	Automotive coolants	Lijima et al., 2002
Sodium boric acid		1330-43-4	Automotive coolants	Lijima et al., 2002
Sodium carbonate		497-19-8	Automotive coolants	Lijima et al., 2002
Sodium chromate		7777-11-3	Automotive coolants	Lijima et al., 2002
Sodium hydroxide		1310-73-2	Automotive coolants	Lijima et al., 2002
Sodium molybdate		10102-40-6	Automotive coolants	Lijima et al., 2002
Sodium monohydrogen phosphate		7558-79-4	Automotive coolants	Lijima et al., 2002
Sodium nitrate		7631-99-4	Automotive coolants	Lijima et al., 2002
Sodium nitrite		7632-00-0	Automotive coolants	Lijima et al., 2002
Sodium polyphosphate		10361-03-2	Automotive coolants	Lijima et al., 2002
Sodium silicate		1344-09-8	Automotive coolants	Lijima et al., 2002

Chemical	Short name	CAS number	Sources	Reference
Stearic acid	SAD	57-11-4	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
Sulphur	S	7704-34-9	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015
Tolyltriazole	TT	29385-43-1	Brake fluid	US Patent 6339050 B1
	TT	29385-43-1	Automotive coolants	Lijima et al., 2002
Tributyl phosphate		126-73-8	Brake fluid	US Patent 6339050 B1
Triethanol amine		102-71-6	Brake fluid	US Patent 6339050 B1
			Automotive coolants	Lijima et al., 2002
Triethylene glycol monoethyl ether		112-50-5	Brake fluid	US Patent 6339050 B1
Tris(1-chloropropan-2-yl) phosphate	TCCP	13674-84-5		
Zinc nitrate		19154-63-3	Automotive coolants	Lijima et al., 2002
Zinc oxide	ZnO	1314-13-2	Tyres	Baumann & Ismeier, 1998; Unice et al., 2015

Table 5 Overview of polycyclic aromatic hydrocarbons (PAHs) that are released from traffic and roads, including emission sources that are responsible for these pollutants.

PAH	CAS number	Sources	Reference
Acenaphthene	83-32-9	Tyres	Baumann & Ismeier, 1997; Edeskär, 2004; Källqvist, 2005
	83-32-9	Asphalt	Brandt & de Groot, 2001
	83-32-9	Lubricants	Deltares & TNO, 2016
Acenaphthylene	208-96-8	Tyres	Baumann & Ismeier, 1997; Edeskär, 2004; Källqvist, 2005
	208-96-8	Lubricants	Deltares & TNO, 2016
Antanthrene	191-26-4	Tyres	BLIC, 2002; KEMI, 2003
Anthracene	120-12-7	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	120-12-7	Asphalt	Brandt & de Groot, 2001
	120-12-7	Lubricants	Deltares & TNO, 2016
Benzo(a)anthracene	56-55-3	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	56-55-3	Asphalt	Brandt & de Groot, 2001
	56-55-3	Lubricants	Deltares & TNO, 2016
Benzo(a)fluorene	238-84-6	Tyres	BLIC, 2002; KEMI, 2003
Benzo(a)pyrene	50-32-8	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	50-32-8	Asphalt	Brandt & de Groot, 2001
	50-32-8	Lubricants	Deltares & TNO, 2016
Benzo(b)fluoranthene	205-99-2	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	205-99-2	Asphalt	Brandt & de Groot, 2001
	205-99-2	Lubricants	Deltares & TNO, 2016
Benzo(b+j+k)fluoranthene	205-99-2, 205-82-3, 207-08-9	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
Benzo(e)pyrene	192-97-2	Tyres	BLIC, 2002; KEMI, 2003; Nilsson et al., 2005
Benzo(g,h,i)perylene	191-24-2	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	191-24-2	Asphalt	Brandt & de Groot, 2001
	191-24-2	Lubricants	Deltares & TNO, 2016
Benzo(j)fluoranthene	205-82-3	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
Benzo(k)fluoranthene	207-08-9	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	207-08-9	Asphalt	Brandt & de Groot, 2001
	207-08-9	Lubricants	Deltares & TNO, 2016
Chrysene	218-01-9	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005

PAH	CAS number	Sources	Reference
	218-01-9	Asphalt	Brandt & de Groot, 2001
	218-01-9	Lubricants	Deltares & TNO, 2016
Dibenzo(a,h)anthracene	53-70-3	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	53-70-3	Asphalt	Brandt & de Groot, 2001
	53-70-3	Lubricants	Deltares & TNO, 2016
Dibenzo(a,j)anthracene	224-41-9	Tyres	BLIC, 2002; KEMI, 2003
Fluoranthene	206-44-0	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	206-44-0	Asphalt	Brandt & de Groot, 2001
	206-44-0	Lubricants	Deltares & TNO, 2016
Fluorene	86-73-7	Tyres	Baumann & Ismeier, 1997; Edeskär, 2004; Källqvist, 2005
	86-73-7	Asphalt	Brandt & de Groot, 2001
	86-73-7	Lubricants	Deltares & TNO, 2016
Indeno(1,2,3-cd)pyrene	193-39-5	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	193-39-5	Asphalt	Brandt & de Groot, 2001
	193-39-5	Lubricants	Deltares & TNO, 2016
Naphthalene	91-20-3	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	91-20-3	Asphalt	Brandt & de Groot, 2001
	91-20-3	Lubricants	Deltares & TNO, 2016
Phenanthrene	85-01-8	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	85-01-8	Asphalt	Brandt & de Groot, 2001
	85-01-8	Lubricants	Deltares & TNO, 2016
Pyrene	129-00-0	Tyres	Baumann & Ismeier, 1997; BLIC, 2002; KEMI, 2003; Edeskär, 2004; Källqvist, 2005; Nilsson et al., 2005
	129-00-0	Asphalt	Brandt & de Groot, 2001
	129-00-0	Lubricants	Deltares & TNO, 2016

Annex B: Concentrations of organic micropollutants in runoff and stormwater

Table 6 and Table 7 present the concentrations of organic micropollutants and polycyclic aromatic hydrocarbons in runoff and stormwater, as reported in literature.

Table 6 Concentrations of organic micropollutants in runoff and stormwater, as reported in literature

Chemical	Short name	CAS number	Concentration	Unit	Reference
2-(methylthio)-benzothiazole	MTBT	615-22-5	0.11	µg/l	Seitz & Winzenbacher, 2017
2-Hydroxybenzothiazole	OHBT	934-34-9	0.17	µg/l	Seitz & Winzenbacher, 2017
2-Hydroxybenzothiazole	OHBT	934-34-9	5 - 22	µg/l	Kloepfer et al., 2005
2-Hydroxybenzothiazole	OHBT	934-34-9	0.8 - 7	µg/l	Reddy & Quinn, 1997
2-Hydroxybenzothiazole	OHBT	934-34-9	0.81	µg/l	Holsteijn, 2014
2-Mercapto benzothiazole	MBT	149-30-4	0.11	µg/l	Seitz & Winzenbacher, 2017
2-Methylthiobenzothiazole	MeSBT	615-22-5	2.57 - 7.90	µg/l	Baumann & Ismeier, 1998
2-Morpholinobenzothiazole	24MoBT	4225-26-7	0.2 - 0.3	µg/l	Reddy & Quinn, 1997
4-tert-octylphenol	OP	140-66-9	0.06	µg/l	Gasperi et al., 2014
Benzothiazole	BT	95-16-9	5.68 - 11.80	µg/l	Baumann & Ismeier, 1998
Benzothiazole	BT	95-16-9	1 - 5	µg/l	Kloepfer et al., 2005
Benzothiazole	BT	95-16-9	0.4 - 1.4	µg/l	Reddy & Quinn, 1997
Benzothiazole-2-sulfonate	BTSA	941-57-1	12 - 44	µg/l	Kloepfer et al., 2005
Bisphenol A	BPA	80-05-7	0.55	µg/l	Gasperi et al., 2014
Di(2-ethylhexyl)phthalate	DEHP	117-81-7	2.27	µg/l	Holsteijn, 2014
Diisodecyl phthalate	DIDP	26761-40-0	8.60	µg/l	Holsteijn, 2014
Hexa(methoxymethyl)melamine	HMMM	3089-11-0	0.66	µg/l	Seitz & Winzenbacher, 2017
Hexa(methoxymethyl)melamine	HMMM	3089-11-0	0.01 - 0.88	µg/l	Dsikowitsky & Schwarzbauer, 2015
Mercapto benzothiazole	MBT	149-30-4	0.11	µg/l	Seitz & Winzenbacher, 2017
Nonylphenol	NP	104-40-5	0.36	µg/l	Gasperi et al., 2014
Nonylphenol diethoxylate	NP2EO	20427-84-3	0.16	µg/l	Gasperi et al., 2014
Nonylphenol monocarboxylate	NP1EC	3115-49-9	0.47	µg/l	Gasperi et al., 2014
Nonylphenol monoethoxylate	NP1EO	9016-45-9	0.35	µg/l	Gasperi et al., 2014
Octylphenol diethoxylate	OP2EO	2315-61-9	0.01	µg/l	Gasperi et al., 2014
Octylphenol monoethoxylate	OP1EO	51437-89-9	0.02	µg/l	Gasperi et al., 2014
Tolyltriazole	TT	29385-43-1	2.30	µg/l	Seitz & Winzenbacher, 2017
Tris(1-chloropropan-2-yl) phosphate	TCCP	13674-84-5	0.13	µg/l	Holsteijn, 2014

Table 7 Concentrations of polycyclic aromatic hydrocarbons (PAHs) in runoff and stormwater, as reported in literature (mainly Dutch literature)

PAH	CAS number	Concentration	Unit	Reference
Acenaphthene	83-32-9	<0.1	µg/l	Brongers, 2010
Acenaphthene	83-32-9	0 - 0.171	µg/l	Schipper et al., 2003
Acenaphthylene	208-96-8	<0.3	µg/l	Brongers, 2010
Acenaphthylene	208-96-8	0 - 0.079	µg/l	Schipper et al., 2003
Anthracene	120-12-7	<0.03 - 0.05	µg/l	Brongers, 2010
Anthracene	120-12-7	0.007 - 0.08	µg/l	Tromp, 2005
Anthracene	120-12-7	0 - 0.021	µg/l	Schipper et al., 2003
Benzo(a)anthracene	56-55-3	<0.03 - 0.23	µg/l	Brongers, 2010
Benzo(a)anthracene	56-55-3	0.056 - 0.891	µg/l	Tromp, 2005
Benzo(a)anthracene	56-55-3	0 - 0.181	µg/l	Schipper et al., 2003
Benzo(a)pyrene	50-32-8	<0.03 - 0.25	µg/l	Brongers, 2010
Benzo(a)pyrene	50-32-8	0.08 - 0.829	µg/l	Tromp, 2005
Benzo(a)pyrene	205-99-2	0 - 0.193	µg/l	Schipper et al., 2003
Benzo(b)fluoranthene	205-99-2	<0.03 - 0.44	µg/l	Brongers, 2010
Benzo(b)fluoranthene	205-99-2	0.083 - 1.084	µg/l	Tromp, 2005
Benzo(b+j+k)fluoranthene	205-99-2, 205-82-3, 207-08-9	0 - 0.264	µg/l	Schipper et al., 2003
Benzo(g,h,i)perylene	191-24-2	<0.03 - 0.41	µg/l	Brongers, 2010
Benzo(g,h,i)perylene	191-24-2	0.095 - 1.271	µg/l	Tromp, 2005
Benzo(g,h,i)perylene	205-82-3	0 - 0.225	µg/l	Schipper et al., 2003
Benzo(k)fluoranthene	207-08-9	<0.03 - 0.16	µg/l	Brongers, 2010
Benzo(k)fluoranthene	207-08-9	0.028 - 0.456	µg/l	Tromp, 2005
Benzo(k)fluoranthene	218-01-9	0 - 0.153	µg/l	Schipper et al., 2003
Chrysene	218-01-9	<0.03 - 0.44	µg/l	Brongers, 2010
Chrysene	218-01-9	0.104 - 2.169	µg/l	Tromp, 2005
Chrysene	53-70-3	0 - 0.233	µg/l	Schipper et al., 2003
Dibenzo(a,h)anthracene	53-70-3	<0.03	µg/l	Brongers, 2010
Dibenzo(a,h)anthracene	53-70-3	0 - 0.118	µg/l	Tromp, 2005
Dibenzo(a,h)anthracene	224-41-9	0 - 0.025	µg/l	Schipper et al., 2003
Fluoranthene	206-44-0	<0.1 - 0.98	µg/l	Brongers, 2010
Fluoranthene	206-44-0	0 - 3.649	µg/l	Tromp, 2005
Fluoranthene	86-73-7	0 - 0.573	µg/l	Schipper et al., 2003
Fluorene	86-73-7	<0.03	µg/l	Brongers, 2010
Fluorene	86-73-7	0 - 0.061	µg/l	Schipper et al., 2003
Indeno(1,2,3-cd)pyrene	193-39-5	<0.03 - 0.25	µg/l	Brongers, 2010
Indeno(1,2,3-cd)pyrene	193-39-5	0 - 0.134	µg/l	Schipper et al., 2003
Naphthalene	91-20-3	<0.3	µg/l	Brongers, 2010
Naphthalene	91-20-3	0 - 0.214	µg/l	Schipper et al., 2003
Phenanthrene	85-01-8	<0.1 - 0.4	µg/l	Brongers, 2010
Phenanthrene	85-01-8	0 - 0.769	µg/l	Tromp, 2005
Phenanthrene	85-01-8	0 - 0.311	µg/l	Schipper et al., 2003

PAH	CAS number	Concentration	Unit	Reference
Pyrene	129-00-0	<0.1 - 0.88	µg/l	Brongers, 2010
Pyrene	129-00-0	0.09 - 2.47	µg/l	Tromp, 2005
Pyrene	129-00-0	0 - 0.491	µg/l	Schipper et al., 2003
PAH6 [1)]		2.49	µg/l	Brongers, 2010
PAH6 [1)]		0.06 - 0.55	µg/l	van Velsen, 1997
PAH10 [2)]		<0.01 - 5.3	µg/l	de Best et al., 2003
PAH10 [2)]		0.1 - 0.75	µg/l	van Velsen, 1997
PAH16 [3)]		0.6	µg/l	van den Berg, 2009
PAH16 [3)]		2.8	µg/l	Holsteijn, 2014
PAH16 [3)]		0 - 2.838	µg/l	Schipper et al., 2003
PAH16 [3)]		0.01 - 62.19	µg/l	Meland et al., 2016
PAH16 [3)]		0.17 - 1.06	µg/l	van Velsen, 1997

[1)] PAH6 include benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, fluoranthene, indeno(1,2,3-cd)pyrene.

[2)] PAH10 include anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene.

[3)] PAH16 include acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, pyrene.