Emission estimates for diffuse sources
Netherlands Emission Inventory

Road surface wear

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1 Description of emission source

When a road surface is driven on, it becomes worn due to friction caused by road traffic tyres. With road surfaces, it is important to distinguish between asphalt and other road surfaces. Asphalt is a mixture of ≥95% mineral constituents (stone, sand and filler) with a binding agent (≤ 5%). Other road surfaces (concrete, bricks, etc.) are entirely made out of mineral raw materials, such as road metal, clay, gravel and sand. The binding agent used in asphalt may contain other pollutants, such as PAH. This fact sheet starts out by calculating the total (mineral) road surface wear based on the assumptions described in the fact sheet (there is no basic data available for exact calculations). It then makes a distinction between the type of asphalt (tarry versus non-tarry) and finally proposes an indicative estimate of the possible PAH emission due to asphalt wear.

This emission source is allocated to the governmental target sector “Transport” within the National Emission Inventory.

2 Explanation of calculation method

The emissions are calculated by multiplying an activity rate (AR), in this case the traffic intenstity per type of vehicle in the Netherlands in millions of km, by an emission factor (EF) per type of vehicle, expressed in mg of road surface particulates per km.

Emission = AR × EF

Where:
AR = Traffic intensity (km)
EF = Wear of road surface (mg/km)

Any PAH emissions can be calculated as a fraction of the wear generated:

$$E_X = E_s \times X$$

Where:
E_x = Emission of PAH (kg) and
X = PAH content in road surface material (kg/kg).

The emission calculated in this way is referred to as the total emission. A specific proportion of this ends up in surface water: this is the net pollution of the surface water.

3 Activity rates

The activity rate reflects traffic intensity by the various vehicle categories over a number of years. Traffic intensity data is supplied by Statistics Netherlands to the Task Force Traffic and Transport. The Task Force Traffic and Transport then calculates the distribution among the various types of journey (urban driving, rural drving and highway driving) (Klein et al., 2007). The following tables show total traffic intensity for the various types of journey.

Table 1 **Traffic intensity for urban driving, rural driving and highway driving per vehicle category (in millions of km) over a number of years**

Urban driving									
Year	**Passenger cars**	**Motor-cycles**	**Mopeds**	**Vans**	**Lorries**	**Trucks**	**Buses**	**Special vehicles**	
								Light	Heavy
1990	22,665	540	1,537	6,259	759	402	347	63	204
1995	20,723	659	1,193	5,757	420	534	250	36	133
2000	18,491	578	909	6,770	404	734	247	48	187
2004	19,895	711	729	8,394	380	781	247	62	258
2005	19,820	733	909	8,296	372	793	243	66	275
2006	20,137	753	909	8,204	368	828	238	71	293
Rural driving									
Year	**Passenger cars**	**Motor-cycles**	**Mopeds**	**Vans**	**Lorries**	**Trucks**	**Buses**	**Special vehicles**	
								Light	Heavy
1990	29,574	221	171	805	1,159	504	194	13	41
1995	29,763	406	133	2,355	1,039	512	163	15	56
2000	32,723	578	101	5,078	1,001	704	162	20	78
2004	34,815	711	81	6,295	942	749	162	26	108
2005	34,597	733	101	6,222	921	761	159	28	114
2006	35,163	753	101	6,153	912	794	156	30	122
Highway driving									
Year	**Passenger cars**	**Motor-cycles**	**Mopeds**	**Vans**	**Lorries**	**Trucks**	**Buses**	**Special vehicles**	
								Light	Heavy
1990	27,813	126	0	716	1,441	1,124	119	8	27
1995	31,545	291	0	2,355	1,925	1,650	241	9	33
2000	39,979	578	0	5,078	1,855	2,269	239	12	47
2004	42,680	711	0	6,295	1,746	2,412	238	16	65
2005	42,525	733	0	6,222	1,708	2,451	235	17	69
2006	43,116	753	0	6,153	1,690	2,558	230	18	73

4 Emission factors

From a highway management perspective, it is not possible to quantify total road surface wear. After all, road surfaces are not replaced as a result of a specific number of centimetres of wear (thus giving a measure for total wear mass), but as a result of lane construction, damage, cracking, new technology (e.g. the introduction of ZOAB, very open asphalted concrete) or other activities (e.g. maintenance or sewer systems). Estimating total road surface wear is therefore an uncertain exercise.

Emissions to atmosphere

Another approach may be the chemical composition of the material released through road surface wear. With road surface wear, primarily mineral materials are released, although it is not possible to differentiate this mineral material in chemical and morphological terms from (soil) material that is blown off farmland or rinsed out of verges, etc. Part of the released road surface wear particulates will be so small that it is emitted to atmosphere (fine particulates). This emission can be quantified as it is possible to distinguish mineral parts in the fine particulates from other fine particulates (e.g. exhaust emissions) and under certain circumstances these mineral parts

will primarily originate from road surface wear. For instance in a traffic tunnel, the quantity of soil particulates from other sources will be negligible and we can assume that the mineral components are entirely caused by road traffic wear. Denier van der Gon et al. (2003) used this observational data in combination with chemical analyses of PM_{10} to estimate road surface wear in the Maas tunnel (Rotterdam), coming up with an emission factor of 3-4 mg/vkm (vehicle kilometres) for road surface wear. Road surface wear will not be a constant figure, but will depend on the type of road surface material and amount of friction with tyres, which will be higher than average when braking, accelerating and taking corners. The emission factor derived from tunnel measurements is therefore considered to be a lower limit. In the literature (table 2), a figure of 8-10 mg/vkm is generally given for road surface wear emission factors. This is consistent with 3-4 mg/vkm as a lower limit under circumstances less prone to wear. Data from countries such as Norway, Sweden and Austria is (partially) inapplicable for the Dutch situation, because the use of spikes (studded tyres) over the winter months significantly increases road surface wear.

Table 2 Road surface wear emission factors in literature.

Vehicle class	Value mg/vkm	Comments	Source
Not classified	4	Lowest limit	Boulter et al, 2006
Not classified (primarily passenger cars)	3-4	Lowest limit	Denier van der Gon et al., 2003
Not classified	3.8		Muschack, 1990
LDV	7.9	Including tyre wear	CBS, 1998
HDV	38		
Bikes	3.0	NB: estimate, not exact	Corinair Emission Inventory Guidebook, 2003
Passenger cars	3.8		
LDV	3.8		
HDV	7.6		

The derived figure for the share of road traffic wear can be further substantiated via analyses of traffic tunnel studies. Gillies et al. (2001) reported that ~12% of PM_{10} in the Sulpeveda tunnel originated from a geological or mineral source. As the total PM_{10} concentration was also measured, it is possible to derive an emission factor which again corresponds reasonably well with 3-8 mg/vkm.

For comparison purposes, the values used in the RAINS model and CEPMEIP inventory are shown (table 3). Because these values are also based on literature studies, they are not incorporated in the same table as direct observational data (table 2), although they provide a form of assurance for the decisions made.

Table 3 Road surface wear values applied in the RAINS and CEPMEIP models.

Vehicle class	Model	TSP (mg/vkm)	PM_{10} (mg/vkm)	$PM_{2.5}$ (mg/vkm)
Bikes	RAINS[a)]	6	3	1.6
	CEPMEIP[b)]	73	3.65	0
Passenger cars	RAINS	15	7.5	4.2
	CEPMEIP	145	7.25	0
LDV	RAINS	15	7.5	4.2
	CEPMEIP	190	9.5	0
HDV	RAINS	76	38	21
	CEPMEIP	738	26.9	0

[a)] Klimont et al. (2002)
[b)] Visschedijk et al. (2004)

Estimated total road surface wear

The tracer method cannot be applied for total road surface wear. An initial estimate can be made by assuming the same fractioning as for tyre wear, because both emissions are caused by the same (friction) process. This means that the emission of fine particulates is 5% of the total wear; in other words, the total wear is 20 times higher than the emission of fine particulates. Because road surface material is harder than tyre rubber, this figure could be seen as an overestimate, but there is no information available to calculate it more accurately. The fraction of $PM_{2.5}$ in PM_{10} is set at 15%. This fraction is based on fractioning mineral parts in fine particulates by fractions of $PM_{2.5}$ and $PM_{2.5-10}$, as analysed on filters. The distribution by other types of vehicle is carried out following the same distribution as for emissions of PM_{10} due to tyre wear, as there is no data for other types of vehicle.

The proposed emission factors are shown in table 4.

Table 4 Proposed emission factors for road surface wear for 3 vehicle classes.

Class	Total particulates (mg/vkm)	PM_{10} (mg/vkm)	$PM_{2.5}$ (mg/vkm)
Bikes	70	3.5	0.55
Light	140	7	1.1
Heavy	700	35	5.3

Passenger cars, vans and special light vehicles are incorporated in the light class, and lorries, buses, trucks and special heavy vehicles in the heavy class. Bikes (mopeds and motorcycles) are classified as half the value of light.

4.1 PAH emissions from asphalt wear

Asphalt is made up of mineral raw materials and ≤ 5% binding agent. This agent generally used to be (coal) tar, and is now bitumen. The terms tar and bitumen are regularly used interchangeably, but this is not correct. Although the materials have the same dark brown to black colour and both boast excellent bonding properties, they come from different sources and have a different chemical composition.

Tar is a highly viscous mixture of complex high molecular components, obtained from the destructive distillation of coal or wood. Until 1991, coal tar (tar) or a combination of tar and bitumen (tar bitumen) was regularly used in asphalt as a binding agent instead of bitumen. Tar-containing binding agents have a high content of PAH – asphalt mixtures with tar-containing binding agents have PAH concentrations of 100 – 3000 mg/kg. Reference is often made to an average of 1500 milligrams per kilo (mg/kg), although the scarce sample analyses give lower contents, for example 674 mg/kg (Rood et al, 1995) and 998 mg/kg (OCW, 2003 – see table 6). The range in concentrations probably came about because tar and bitumen are mixed. By definition, asphalt (granulate) containing over 75 mg/kg PAH-10 is referred to as tar asphalt granulate (TAG). Due to the collective labour agreement for the construction sector, tar and tar products were definitively no longer used as of 1991, so no new TAG was applied as the (top) road surface layer. As of 1995, it was only permitted to use asphalt granulate containing less than 75 mg/kg PAH 10. In the past, released TAG was also re-used in road foundations, often mixed with other stony materials. As of January 1, 2001 the Dutch Building Materials Decree regulating soil and surface water (BSB) also forbids the re-use of TAG in this way. The main conclusion from the above is that since 1991, no further TAG with a high PAH10 content has been used as the top road surface layer.

Bitumen is a petroleum product. It is obtained by distilling crude petroleum selected for the process subject to specific pressure and temperature conditions. It is a mixture of complex compounds that can be shown as a dispersion of asphalts and resins in an aromatic oil with a high boiling point. Bitumen is a solid substance at ambient temperature. The PAH content of bitumen is low. The Dutch bitumen application consultancy (Nabit, 1996) determined the PAH content in 14 bitumen samples from 7 refineries. The overall result was a PAH content (10 PAH) of less than 3 mg/kg bitumen. A European study reported an average PAH content of 26 mg/kg (Concawe, 1994). However, the first figure (3 mg/kg) seems to be more representative for the Netherlands. Based on 5% binding agent, this gives a PAH content in asphalt of 0.15 mg/kg.

Table 5 Example of PAH in tar asphalt granulate (TAG).

Name of individual PAH compound	Example of TAG (5 mass % binding agent: bitumen/road tar 85/15)	
	(mg/kg)	(%)
Benzo[a]anthracene	74	7.4
Benzo[a]pyrene	67	6.7
Benzo(ghi)perylene	35	3.5
Benzo[b]fluoranthene	90	9.0
Benzo[k]fluoranthene	25	2.5
Chrysene	73	7.3
Phenanthrene	367	36.8
Fluoranthrene	232	23.2
Indeno[1,2,3-cd]pyrene	34	3.4
Naphthalene	1	0.1
Total for PAH10 in this example	998	100

Source: OCW (2003)

There is almost no literature available on the release of PAH due to road surface wear of TAG. Klein et al (2000) conclude that the emissions of PAH from road surface wear are not significant for the entire period from 1980 to 1999, based on an internal memo from 1996. However, it is not easy to ascertain the exact reasons substantiating this conclusion. To facilitate a quantitative analysis, a number of assumptions have been made, making it possible to estimate the emission of PAH due to road surface wear based on total road surface wear. Assumptions have to be made for the following:

- The PAH10 content of TAG prior to 1991 (table 6),
- The PAH10 content of existing AG (table 6),
- The fraction of roads and category of roads where TAG is still present (table 7)
- The number of kilometres driven on these roads (for rural areas, see table 1).

Table 6 PAH10 content of TAG and AG.

Material	Total PAH10 in	
	Binding agent	Asphalt (5% binding agent) (mg/kg)
tar	5-20%	1500[1)]
bitumen	10-30 (mg/kg)	0.5 -1.5
bitumen_mix NL	3 (mg/kg)	0.15

[1)] This is an uncertain figure and could be overestimated by a factor of 1.5-2 if the 2 analyses in Rood et al. (1995) and OCW (2003) are representative. However, two analyses is too small a basis on which to draw this conclusion.

It is assumed that the TAG fraction within urban areas is negligible. On the one hand, a large number of roads within urban areas are not made of asphalt. On the other, all the asphalt laid after 1991 no longer contains TAG and it is assumed that asphalt roads in urban areas laid before

1991 (or at least the top layers of these roads) have since been replaced due to maintenance and refurbishment work, such as work on sewers or other underground work.
For highways, it is assumed that in 2005 all the asphalt prior to 1991 had either been replaced or provided with a new top layer or metalling. The share of TAG is therefore zero in 2005, and the share in 1990 is estimated to be 85%. This last figure may well be an overestimate, but there is no reliable data available. The fact that asphalt on highways is replaced relatively quickly is confirmed by the sharp increase in the amount of ZOAB on Dutch highways since 1990 (see also Klein et al. 2007).
Asphalt in rural areas is replaced significantly less quickly. The same share of asphalt in 1990 is assumed as on highways, with the assumption that in 2015 all TAG-containing asphalt prior to 1991 will have been replaced.

Based on the above, it is possible to estimate the presence of TAG on Dutch roads (table 7). For the interim years, a linear decrease is assumed.

Table 7 Estimate of presence of tar asphalt granulate (TAG).

Highways		Rural areas	
Year	*TAG fraction*	*Year*	*TAG fraction*
1990	0.85	1990	0.85
1991	0.79	1991	0.82
1992	0.73	1992	0.78
1993	0.67	1993	0.75
1994	0.61	1994	0.71
1995	0.55	1995	0.68
1996	0.49	1996	0.65
1997	0.43	1997	0.61
1998	0.36	1998	0.58
1999	0.30	1999	0.54
2000	0.24	2000	0.51
2001	0.18	2001	0.48
2002	0.12	2002	0.44
2003	0.06	2003	0.41
2004	0.00	2004	0.37
2005	0	2005	0.34
2006	0	2006	0.31
2007	0	2007	0.27
2008	0	2008	0.24
2009	0	2009	0.20
2010	0	2010	0.17
2011	0	2011	0.14
2012	0	2012	0.10
2013	0	2013	0.07
2014	0	2014	0.03
2015	0	2015	0

4.2 Emission factors for urban driving, rural driving and highway driving

There is usually more acceleration and braking within urban areas than within rural areas and on highways. There are also more corners and bends, the road network is more dynamic and the relative differences in speed are greater. Although it is known that this is the reason for greater tyre and brake wear per km driven within urban areas than outside these areas, there is no data to quantify this for road surface wear. However, road surface wear is the result of the same processes as brake and tyre wear, so as an initial estimate, by analogy with brake and tyre wear, it is assumed that emission factors within urban areas are a factor of 2 times higher per kilometre

driven than on highways and within rural areas. For further substantiation of this conclusion, please refer to fact sheets on tyre wear and brake lining wear. Table 8 shows the final differentiated emission factors.

Table 8 Derived emission factors for road surface wear for urban driving, rural driving and highway driving (mg/km).

Name of substance	Vehicle category	Urban driving	Rural driving	Highway driving
Coarse particulates	Passenger car	215	108	108
	Motorcycle	88	44	44
	Moped	88	44	0
	Van	215	108	108
	Lorry	1,100	550	550
	Truck	1,100	550	550
	Bus	1,100	550	550
	Special vehicle (light)	215	108	108
	Special vehicle (heavy)	1,100	550	550
PM10	Passenger car	11	5.5	5.5
	Motorcycle	5	2.5	2.5
	Moped	5	2.5	0
	Van	11	5.5	5.5
	Lorry	58	29	29
	Truck	58	29	29
	Bus	58	29	29
	Special vehicle (light)	11	5.5	5.5
	Special vehicle (heavy)	58	29	29
PM2.5	Passenger car	1.7	0.8	0.8
	Motorcycle	0.8	0.4	0.4
	Moped	0.8	0.4	0.0
	Van	1.7	0.8	0.8
	Lorry	8.7	4.4	4.4
	Truck	8.7	4.4	4.4
	Bus	8.7	4.4	4.4
	Special vehicle (light)	1.7	0.8	0.8
	Special vehicle (heavy)	8.7	4.4	4.4

NB: Emission factors for coarse particulates are rounded to whole numbers, and emission factors for PM10 and PM2.5 are rounded to 1 decimal place.

5 Effects of policy measures

Until 1990, tar and tar products were used on a large scale in roadbuilding, as a binding agent in asphalt, for surface treatment work and for the reconstruction of roads. Tar asphalt granulate (TAG) contained significant quantities of PAH. As of January 1, 1991 no further tar-containing binding agent was used in the Netherlands in asphalt production, and only bitumen was used as the binding agent. The content of PAH in bitumen (replacing tar as the binding agent) is <1.5 mg/kg (RIVM, 1995). This means that the PAH content in existing asphalt granulate is a factor of ~ 1000-10000 lower than in TAG. PAH emissions due to wear of asphalt and top layers applied after 1990 are therefore negligible. This means that after 1990, PAH emission due to road surface wear only occurs when driving on roads with a top layer dating back to before 1991. Because of the process of phasing out TAG, the emissions of PAH due to road surface wear will decrease over time to zero in 2015, based on the assumption that all TAG will have been replaced by 2015.

6 Release into environmental compartments

The distribution of wear emissions by the various environmental compartments, as currently used by the Task Force Traffic and Transport, is shown in table 9. Emissions of fine particulates are assigned 100% to the atmosphere compartment in all cases. The distribution of fine particulates to atmosphere is not under review. However, the distribution of coarse particulates to the various environmental compartments is reviewed and revised in this fact sheet (as per the fact sheet on tyre wear).

Table 9 Distribution percentages for road surface wear particulates to compartments, as applied to date (source: Klein et al., 2007).

	Tyre particulates		
	atmosphere	soil	water
	%		
Fine particulates (incl. metals)			
Urban driving	100	0	0
Rural driving	100	0	0
Highway driving	100	0	0
Coarse particulates (incl. metals)			
Urban driving	0	0	100
Rural driving	0	80	20
Highway driving	0	80	20

Source: Methodology report Traffic task group (Klein et al., 2007)

Distribution within urban areas

100% distribution of emissions within urban areas to the sewers (table 9) is not probable. A GIS overlay of the land use database of the Netherlands with sewer areas in the emissions registration scheme reveals that exactly 50% of the surface area of sewer areas comprises paved ground (see table 10).

Table 10 Results GIS overlay / sewer areas.

Aggregate name	Ground area [ha]	Sewer area [ha]
Ground – paved	433,649	341,061
Ground – unpaved	2,893,753	336,033
Ground - semi-paved	50,136	16,016
Total	3,377,538	693,109

The fact that 50% of the sewer area is paved does not necessarily mean that 50% of the emissions from the deposition of coarse particulates will fall on the sewers. In the sewer environment, runoff coefficients are used to determine the amount of rainwater falling in the sewer area that goes into the sewers. A runoff coefficient of 50% is frequently applied. In a recent study carried out by the Netherlands Organization for Applied Scientific Research (TNO) in the service areas of two municipal wastewater treatment plants in North Brabant in 2005, runoff coefficients of 50% and 90% were measured for Den Bosch and Asten respectively.
Because water acts as the medium for transporting the pollution, an obvious starting point for calculations would be the distribution of water among the compartments.

However, there are various factors leading to deviations upwards and downwards:

- An amount of water evaporates, whereby the running-off surface area is greater than the surface area that can be derived from precipitation and water going into the sewers. If the deposition of precipitating particulates is distributed reasonably homogeneously, the running-off surface is a good measurement for the quantity of emission that runs off. However, on unpaved ground, part of the contamination is filtered off, whereby the

quantity of pollution per quantity of water (concentration) in the unpaved ground reduces (decreasing contribution to sewers)

- Coarse particulates are deposited closer to the source. The source is the surfaced road. The deposition will therefore be more concentrated there on the road and as a result emissions will be greater in ratio to the quantity of water (concentration) (increasing contribution to sewers)
- A proportion of the contamination on the roads will be collected via street refuse. This proportion does not end up in the sewers. The majority of street refuse is coarse sand that contains relatively little pollution (decreasing contribution to sewers)
- A part of the soil material in unpaved ground will rinse into the sewers. Pollution will have accumulated in this soil material over the course of time, originating from tyre wear among other sources. This means that a small part of the pollution originally accumulated in the soil will still end up in the sewers (increasing contribution to sewers).

These counteracting processes make it difficult to reach a quantitatively well-founded decision. It can definitely be stated that the quantity of emissions going into the sewers is below 100%. It is hereby proposed (until better measuring data is available) to assume that 50% goes into the sewers within urban areas instead of 100%. However, because a part of the pollutant loading from the soil still rinses into the sewers, it is necessary to take into consideration a slightly higher input to the sewers. An input of 60% into the sewers is therefore selected as the provisional value.

Distribution within rural areas

The distribution of emissions of coarse fraction of road surface particulates within rural areas is more complex than within urban areas. Blok conducted a fairly extensive study on tyre particulates (Blok, 2005). According to Blok, approximately 70% of the total quantity of material largely ends up in the soil of the verges via the mechanism of run-off. According to Blok, the remaining 30% is distributed via the mechanism of drifting. In this respect, we assume that the finest fraction of this 30% (approximately 5% fine particulates) will be transported further away via atmospheric transport. According to Blok, the largest proportion (25 of the 30%) distributed via drifting does not travel further than 4.5 m (other roads) to 6 m (highways) from the edge of the road. Although the study carried out by Blok (2005) describes wear and spread of tyre particulates, it is assumed here that this argument is also generally applicable for road surface wear, as tyre wear and road surface wear are the result of the same process. It is not known what share of the surface area situated at 4.5 to 6 metres alongside roads is made up of ditches, but the figure will be less than 50% of the surface area between 4.5 and 6 metres from roads. As an initial estimate, we assume a figure of half of 25%, rounding off downwards, which gives an estimate of 10% direct emissions to surface water.

Based on the assumptions and considerations set out above, a new distribution of road surface wear particulates by the various environmental compartments is proposed (see table 13).

Table 11 Proposed distribution percentages for road surface wear by compartments.

	Atmosphere	Soil	Surface water	Sewers
	%			
Fine particulates				
Urban driving	100	0	0	0
Rural driving	100	0	0	0
Highway driving	100	0	0	0
Coarse particulates				
Urban driving	0	40	0	60
Rural driving	0	90	10	0
Highway driving	0	90	10	0

7 Emissions calculated

The emissions calculated are shown in the tables below. A forecast for 2015 is also outlined. Table 12 shows the total emissions presented per reference year, incl. the forecast for 2015. Tables 13 to 16 show emissions to soil, surface water, sewers and atmosphere respectively. A further distribution of emissions is shown in the appendices, according to road surface location (urban driving, rural driving or highway driving) and vehicle class.

All emissions are in kilograms.

Table 12 Total emissions (kg) of PAH, coarse and fine particulates, reference years.

Substance	1990	1995	2000	2004	2005	2006	2015
Phenanthrene	2,685	2,061	1,405	752	687	634	0
Fluoranthene	1,698	1,303	888	475	434	401	0
Chrysene	534	410	279	150	137	126	0
Benzo[a]anthracene	541	415	283	152	138	128	0
Benzo[a]pyrene	490	376	257	137	125	116	0
Benzo[b]fluoranthene	659	505	345	184	168	155	0
Benzo[k]fluoranthene	183	140	96	51	47	43	0
Benzo[ghi]perylene	256	197	134	72	65	60	0
Indeno[1,2,3-cd]pyrene	249	191	130	70	64	59	0
Naphthalene	7	6	4	2	2	2	0
Coarse particulates [a)]	16,739,542	15,865,449	16,089,764	16,555,061	16,294,116	16,278,450	18,950,354
Fine particulates (PM_{10}) [a)]	864,283	818,991	830,441	854,007	840,680	839,906	977,188
Fine particulates ($PM_{2.5}$)	129,642	122,849	124,566	128,101	126,102	125,986	146,578

[a)] NB: Total particulates = Coarse particulates + Fine particulates

Table 13 Emissions (kg) of PAH and coarse particulates to soil per reference year.

Substance	1990	1995	2000	2004	2005	2006	2015
Phenanthrene	2,417	1,854	1,265	676	618	571	0
Fluoranthene	1,528	1,172	799	428	391	361	0
Chrysene	481	369	252	135	123	114	0
Benzo[a]anthracene	487	374	255	136	125	115	0
Benzo[a]pyrene	441	339	231	123	113	104	0
Benzo[b]fluoranthene	593	455	310	166	152	140	0
Benzo[k]fluoranthene	165	126	86	46	42	39	0
Benzo[ghi]perylene	230	177	121	65	59	54	0
Indeno[1,2,3-cd]pyrene	224	172	117	63	57	53	0
Naphthalene	7	5	3	2	2	2	0
Coarse particulates	10,916,880	10,611,863	10,829,590	10,872,024	10,637,279	10,573,259	11,808,632

Table 14 Emissions (kg) of PAH and coarse particulates directly to surface water per reference year.

Substance	1990	1995	2000	2004	2005	2006	2015
Phenanthrene	269	206	141	75	69	63	0
Fluoranthene	170	130	89	48	43	40	0
Chrysene	53	41	28	15	14	13	0
Benzo[a]anthracene	54	42	28	15	14	13	0
Benzo[a]pyrene	49	38	26	14	13	12	0
Benzo[b]fluoranthene	66	51	34	18	17	16	0
Benzo[k]fluoranthene	18	14	10	5	5	4	0
Benzo[ghi]perylene	26	20	13	7	7	6	0
Indeno[1,2,3-cd]pyrene	25	19	13	7	6	6	0
Naphthalene	1	1	0	0	0	0	0
Coarse particulates	844,213	853,137	878,737	850,000	823,926	812,376	845,698

Table 15 Emissions (kg) of coarse particulates to sewers per reference year.

Substance	1990	1995	2000	2004	2005	2006	2015
Coarse particulates	4,978,450	4,400,450	4,381,437	4,833,038	4,832,911	4,892,814	6,296,024

NB: There are no PAH emissions entered here because it is assumed that no TAG is present within urban areas. This may be an overestimate for the 1990 situation, but there is no reliable data available on which to base a better estimate.

Table 16 Emissions (kg) of fine particulates to atmosphere per reference year.

Presented substance	1990	1995	2000	2004	2005	2006	2015
Fine particulates (PM_{10})	864,283	818,991	830,441	854,007	840,680	839,906	977,188
Fine particulates ($PM_{2.5}$)[1)]	129,642	122,849	124,566	128,101	126,102	125,986	146,578

[1)] PM2.5 is a fraction of PM10
NB: No PAH emissions are entered here as it is assumed TAG is only present in rural areas to a limited extent, where there is only a small share of the total kilometres driven in the Netherlands. Emission to atmosphere (fine particulates) is 5% of the total substance and again only 5% of this figure is binding agent, if the road surface is asphalt, of which only a small % is PAH. The remaining PAH emission is negligible.

8 Spatial allocation

The spatial allocation of emissions is assigned on the basis of a set of digital maps held by the Netherlands Environmental Assessment Agency (PBL) drawn up using emission records. These maps present the spatial distribution of all kinds of parameters throughout the Netherlands, such as population density, traffic intensity, area of agricultural crops, etc. For the purposes of emission registration these maps are used as 'locators' to determine the spatial distribution of emissions. The range of possible locators is limited (see [Molder, 2007]), as not every conceivable parameter can be used as a locator. In practice the locator judged to be the best proxy of the activity rate of the emission in question is applied for the distribution of emissions. In some cases, one source is distributed via more than one locator. This is the case with road surface wear in rural areas, 80% of which is broken down via traffic intensity on highways and 20% via the number of residential dwelling units within rural areas. It is assumed that the distribution of emissions throughout the country is proportional to the national distribution of the locator.

The table below shows the locator used for the spatial allocation of the various emission sources.

Table 17 Summary of spatial allocation method

Element	Locators
Road surface wear, highways	Traffic density on highways
Road surface wear, within rural areas	Traffic density within rural areas, 80%
Road surface wear, within rural areas	Number of residential dwelling units within rural areas, 20%
Road surface wear, within urban areas	Number of inhabitants per grid cell measuring 500x500 metres

The method used to determine the locators is described in Molder (2007):

Traffic density on highways and winthin rural areas (see above)
Traffic density on highways is presented in the map 'distribution among stretches of road on the basis of mileage'. This map contains six categories:

- Highway (trunk roads): passenger cars and vans
- Highway (trunk roads): freight and other traffic
- Rural area: passenger cars and vans
- Rural area: freight and other traffic
- Urban area: passenger cars and vans
- Urban area: freight and other traffic

Data on the location and length of (stretches of) roads was taken from the national roads database drawn up by the Traffic and Transport Advisory Service (AVV) (see also Molder, 2007). Density values (average number of vehicles in a twenty-four hour period for the entire year in question x length of the stretch of road) were calculated for highways on the basis of censuses conducted by AVV and relate to 2005. The values for roads in urban and rural areas are modelled data based on the new regional model (NRM) operated by the AVV and cover 2005. This model uses census values and socio-economic and demographic factors such as population and building density, employment opportunities and the types of businesses in the area. Values for traffic density within the urban area also take account of data from local authority traffic maps and cover 2005. The traffic density results from the NRM are derived from MNP habitat quality statistics, where they are used in calculating noise levels.

Number of residential dwelling units within rural area and number of inhabitants per 500x500-metre grid cell
The number of inhabitants per grid cell measuring 500x500 metres is derived from the PBL's map of grid cell distribution based on the number of inhabitants, residential dwelling units and inhabitants per sewage unit. This map is based on values produced by Statistics Netherlands (CBS) on numbers of inhabitants and numbers of residential dwelling units in each local authority (for 2005). The distribution of inhabitants among grid cells in a local authority was calculated using the comprehensive database of address coordinates in the Netherlands (which contains addresses and types of dwelling unit) and the 2003 sewage unit database.

Although road surface wear is probably higher in areas where there is increased friction (a lot of braking, accelerating and turning corners), there is no difference between the wear factors for urban driving, rural driving and highway driving based on the available literature data and studies. Emission factors for all three types of road are therefore kept at the same level for the time being.

9 Comments and changes in regard to previous version

- The assumed fraction of fine particulates in total road surface wear (5%) is the same as previous estimates.
- The quantity of total particulates is calculated on the basis of data on fine particulates emissions. In previous years, road surface wear was specified in 7 vehicle classes, however there is no data available to provide such an exact estimate, so the only categories applied at present are bikes, light and heavy vehicles. Total emissions have only changed marginally.
- In previous years, no estimate was included for PAH emissions due to road surface wear.
- The distribution among compartments has been changed (see section 7).

10 Accuracy and indicated subjects for improvement

The method used in Emission Inventory publications has been followed as far as possible in classifying the quality of information. It is based on the CORINAIR (CORe emission INventories AIR) methodology, which applies the following quality classifications: CORINAIR uses the following quality classifications:

A: a value based on a large number of measurements from representative sources;
B: a value based on a number of measurements from some of the sources that are representative of the sector;
C: a value based on a limited number of measurements, together with estimates based on technical knowledge of the process;
D: a value based on a small number of measurements, together with estimates based on assumptions;
E: a value based on a technical calculation on the basis of a number of assumptions.

Depending on the substance or substance group, the emission factors are based on a varying number of studies carried out in the Netherlands and internationally, which show a greater or lesser degree of variation, again differing per substance. Based on these studies, a class (B, C or D) was selected for emission factors per substance / substance group.

The activity rate is updated by the Task Force Traffic and Transport regularly, and can be classified under category A. The emission factor for fine particulates is based partly on measurements and partly on estimates, because road surface dependence and type of road (lots of bends and corners, within urban areas, rural areas or on highways) are not incorporated in the measurements; it is therefore classified under category C. Total particulates and coarse particulates are calculated on the basis of the fine particulates emission factor, based on an estimated fraction of fine particulates within total particulates. The calculation is extremely susceptible to the assumed fraction, so the emission factor for total and coarse particulates is therefore classified under category D.
The PAH content of TAG is based on a number of measurements but the spread is large and classified under category C. The amount of TAG still remaining on Dutch roads is not accurately known and is based on estimates and deductions.
The distribution of emissions among the various compartments is uncertain, so category D applies here. This is compared with the uncertainty or lack of data about whether road surface wear within urban areas is greater due to more bends, junctions and traffic lights. If the distribution of emissions differs between urban and rural areas, then the distribution of emissions to compartments will also change. In this respect, there is less uncertainty with emission pathways into water, so they are classed as B. Finally, the spatial allocation of emissions is fairly reliable, so it comes into reliability class B.

Element emission calculation	Reliability classification
Activity rates	A
Emission factor – total	D
Emission factor – coarse particulates	D
Emission factor – PM_{10}	C
Emission factor – $PM_{2.5}$	C
PAH content of TAG	C
Fraction of TAG in Dutch road network	D
Distribution among compartments	D
Emission pathways to water	B
Spatial allocation	B

11 Request for reactions

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Appendix 1 – Emissions due to road surface wear

In the following tables, emissions are calculated and differentiated by vehicle class, road surface location (urban, rural and highway) and compartment. Light vehicles include bikes.

Table B1 Emissions (kg) of PAH and coarse particulates to soil per reference year – light vehicles.

Location	Substance	1990	1995	2000	2004	2005	2006	2015
Rural area	Phenanthrene	1,741	1,332	962	552	504	466	0
Rural area	Fluoranthene	1,101	842	608	349	319	294	0
Rural area	Chrysene	346	265	191	110	100	93	0
Rural area	Benzo[a]anthracene	351	269	194	111	102	94	0
Rural area	Benzo[a]pyrene	318	243	176	101	92	85	0
Rural area	Benzo[b]fluoranthene	427	327	236	135	124	114	0
Rural area	Benzo[k]fluoranthene	119	91	66	38	34	32	0
Rural area	Benzo[ghi]perylene	166	127	92	53	48	44	0
Rural area	Indeno[1,2,3-cd]pyrene	161	123	89	51	47	43	0
Rural area	Naphthalene	5	4	3	2	1	1	0
Rural area	Coarse particulates	5,480,972	5,495,212	5,912,520	5,900,625	5,733,945	5,668,076	5,941,338

Table B2 Emissions (kg) of PAH and coarse particulates to soil per reference year – heavy vehicles.

Location	Substance	1990	1995	2000	2004	2005	2006	2015
Rural area	Phenanthrene	675	522	303	125	114	105	0
Rural area	Fluoranthene	427	330	191	79	72	66	0
Rural area	Chrysene	134	104	60	25	23	21	0
Rural area	Benzo[a]anthracene	136	105	61	25	23	21	0
Rural area	Benzo[a]pyrene	123	95	55	23	21	19	0
Rural area	Benzo[b]fluoranthene	166	128	74	31	28	26	0
Rural area	Benzo[k]fluoranthene	46	36	21	8	8	7	0
Rural area	Benzo[ghi]perylene	64	50	29	12	11	10	0
Rural area	Indeno[1,2,3-cd]pyrene	63	48	28	12	11	10	0
Rural area	Naphthalene	1.8	1.4	0.8	0.3	0.3	0.3	0
Rural area	Coarse particulates	2,116,941	2,183,017	1,996,112	1,749,374	1,681,393	1,643,307	1,669,944

Table B3 Emissions (kg) of PAH and coarse particulates to surface water per reference year – light vehicles.

Location	Substance	1990	1995	2000	2004	2005	2006	2015
Rural area	Phenanthrene	193	148	107	61	56	52	0
Rural area	Fluoranthene	122	94	68	39	35	33	0
Rural area	Chrysene	38	29	21	12	11	10	0
Rural area	Benzo[a]anthracene	39	30	22	12	11	10	0
Rural area	Benzo[a]pyrene	35	27	20	11	10	9	0
Rural area	Benzo[b]fluoranthene	47	36	26	15	14	13	0
Rural area	Benzo[k]fluoranthene	13	10	7	4	4	4	0
Rural area	Benzo[ghi]perylene	18	14	10	6	5	5	0
Rural area	Indeno[1,2,3-cd]pyrene	18	14	10	6	5	5	0
Rural area	Naphthalene	0.5	0.4	0.3	0.2	0.2	0.1	0.0
Rural area	Coarse particulates	608,997	610,579	656,947	655,625	637,105	629,786	660,149

Table B4 Emissions (kg) of PAH and coarse particulates to surface water per reference year – heavy vehicles.

Location	Substance	1990	1995	2000	2004	2005	2006	2015
Rural area	Phenanthrene	75	58	34	14	13	12	0
Rural area	Fluoranthene	47	37	21	9	8	7	0
Rural area	Chrysene	15	12	7	3	3	2	0
Rural area	Benzo[a]anthracene	15	12	7	3	3	2	0
Rural area	Benzo[a]pyrene	14	11	6	3	2	2	0
Rural area	Benzo[b]fluoranthene	18	14	8	3	3	3	0
Rural area	Benzo[k]fluoranthene	5	4	2	1	1	1	0
Rural area	Benzo[ghi]perylene	7	6	3	1	1	1	0
Rural area	Indeno[1,2,3-cd]pyrene	7	5	3	1	1	1	0
Rural area	Naphthalene	0.2	0.2	0.1	0.0	0.0	0.0	0
Rural area	Coarse particulates	235,216	242,557	221,790	194,375	186,821	182,590	185,549

Table B5 Emissions (kg) of coarse particulates to sewers per reference year – both vehicle classes.

Type	Location	Substance	1990	1995	2000	2004	2005	2006	2015
Light	Urban area	Coarse particulates	3,983,944	3,606,528	3,467,223	3,903,898	3,903,494	3,946,260	5,044,266
Heavy	Urban area	Coarse particulates	994,506	793,922	914,214	929,139	929,417	946,554	1,251,758

Table B6 Emissions (kg) of fine particulates to atmosphere per reference year – both vehicle classes.

Type	Group	Substance	1990	1995	2000	2004	2005	2006	2015
Light	Urban area	Fine particulates (PM10)	341,102	308,685	296,717	334,052	334,146	337,834	431,289
Light	Urban area	Fine particulates (PM2.5)	51,165	46,303	44,508	50,108	50,122	50,675	64,693
Light	Rural area	Fine particulates (PM10)	311,762	312,643	336,440	335,815	326,352	322,615	338,061
Light	Rural area	Fine particulates (PM2.5)	46,764	46,896	50,466	50,372	48,953	48,392	50,709
Heavy	Urban area	Fine particulates (PM10)	87,396	69,769	80,340	81,652	81,676	83,182	110,003
Heavy	Urban area	Fine particulates (PM2.5)	13,109	10,465	12,051	12,248	12,251	12,477	16,500
Heavy	Rural area	Fine particulates (PM10)	124,023	127,894	116,944	102,489	98,506	96,275	97,835
Heavy	Rural area	Fine particulates (PM2.5)	18,603	19,184	17,542	15,373	14,776	14,441	14,675

Table B7 Emissions (kg) of coarse particulates to soil per reference year – both vehicle classes.

Type	Location	Substance	1990	1995	2000	2004	2005	2006	2015
Light	Urban area	Coarse particulates	2,655,963	2,404,352	2,311,482	2,602,599	2,602,329	2,630,840	3,362,844
Heavy	Urban area	Coarse particulates	663,004	529,281	609,476	619,426	619,611	631,036	834,506