Emission estimates for diffuse sources
Netherlands Emission Inventory

Road traffic tyre wear

September 2008

Authors: H. ten Broeke, J. Hulskotte and H. Denier van der Gon
(TNO Built Environment and Geosciences)

NETHERLANDS NATIONAL WATER BOARD - WATER UNIT

Road traffic tyre wear

1 Description of emission source

This fact sheet sets out a method for calculating emissions resulting from tyre wear in road traffic. Tyre wear causes an emission of tyre particulates, comprising fine particulate matter (PM_{10}, $PM_{2.5}$), coarse particulate matter, metals (in particular zinc) and PAH. 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 separately for various vehicle categories. Emissions are calculated by multiplying an activity rate (AR), in this case the number of kilometres driven on Dutch roads, by an emission factor (EF), expressed in emission per AR unit.

$$E_s = AR \times EF$$

Where:

E_s	=	Emission of particulates (kg),
AR	=	Traffic performance, distance covered on Dutch road network (mln km) and
EF	=	Emission factor (kg/mln km).

The PM, PAH, metal and zinc emission can be calculated as a fraction of the wear generated:

$$E_X = E_s \times X$$

Where:

E_x	=	Emission of component X (kg) and
X	=	Content of component X in tyres (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 performance by the various vehicle categories over a number of years. Traffic performance 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, rural and highway driving) (Klein et al., 2007). The following tables show total traffic performance for the various types of journeys.

Table 1 – Traffic performance for urban, rural 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

Highways

Year	Passenger cars	Motor-cycles	Mopeds	Vans	Lorries	Trucks	Buses	Special vehicles	
								Light	Heavy
1990	27,813	126		716	1,441	1,124	119	8	27
1995	31,545	291		2,355	1,925	1,650	241	9	33
2000	39,979	578		5,078	1,855	2,269	239	12	47
2004	42,680	711		6,295	1,746	2,412	238	16	65
2005	42,525	733		6,222	1,708	2,451	235	17	69
2006	43,116	753		6,153	1,690	2,558	230	18	73

4 Emission factors

4.1 Emission factors for tyre wear in general and for particulate matter from tyres

The Task Force Traffic and Transport has already defined emission factors for tyre wear for all vehicle categories. The aim of this fact sheet is to extend this data to include emissions of PAH and heavy metals, and where necessary, to adjust the other emission factors.

The emission of particulate matter and other components is calculated on the basis of the total quantity of tyre particulates (tyre wear) generated through wear per kilometre driven. This can be calculated in a number of different ways.

1. "Mileage approach". Based on the number of vehicle kilometres per vehicle type, the number of tyres per vehicle type, the average mileage at which tyres are worn and the weight loss between new and old tyres, it is possible to calculate the total tyre rubber loss. All tyre rubber released through wear is considered to be released as particulates (fine + coarse).
2. "Sales approach". The sales approach is based on the European tyre sales figures and corresponding Dutch market share. Based on the average weight loss during the life of a tyre per vehicle type, it is possible to work out the total amount of tyre particulates generated in the Netherlands.

3. "Direct measurement": (Fine) particulates through tyre wear can be directly determined by taking samples of (fine) particulates from roads and then analysing the particulates collected for specific tracers that are unique for tyre wear, such as styrene butadiene rubber or organic zinc compounds. As the concentration of tracer in tyre particulates is known, it is also possible to calculate the total concentration of fine particulates through tyre wear based on the tracer concentration. Based on the data obtained and traffic data, it is possible to work out a wear factor (see also Dannis, 1974; Baumann *et al.,*1997; Fauser, 1999). However, this is not an easy way of working out a total wear factor, because to do so it is also necessary to take samples of emissions to water and the soil. It is nevertheless a good way of ascertaining emissions to a specific compartment (e.g. atmosphere).

The required data for calculating the total tyre particulates generated annually in the Netherlands based on the mileage approach and sales approach can be found in BLIC/ZOPA (2001a,b) and Blok (2005), in addition to the traffic intensity data provided by Statistics Netherlands. For 1998, both independent approaches give a total emission of 10.8 (mileage approach) and 11.2 (sales approach) kilotonnes of tyre particulates a year. Both independent estimates are satisfactorily consistent with each other, demonstrating that this provides a good basis on which to found specific emissions to a compartment.

Many studies have been carried out to ascertain the proportion of tyre wear emitted as PM_{10} and $PM_{2.5}$. Table 2 provides an overview of the emission factors for tyre wear published in the literature. The data provided relates to emission factors to atmosphere. This means that TSP (total suspended particles) cannot be compared with the total amount of tyre particulates generated as calculated using the methods described above in points 1 and 2, because these methods also include the share of wear that is so coarse it is not emitted to atmosphere.

The data provided in table 2 is used to further substantiate and possibly to adjust the emission factors previously proposed by the Task Force Traffic and Transport. The result of the emission factors review is presented in table 3. There are limited changes compared to the emission factors previously used by the task force. The most robust approach is based on the share of PM_{10} in the total wear amounting to approximately 5% (see also Pierson and Brachaczek, 1974). Validation is not easy because tyre wear depends on driving cycle and location. The approach for calculating PM_{10} as a fraction of total tyre particulates is so robust because the division by compartment remains clear and the mass balance for total particulates continues to correspond. For passenger cars, it is possible to make a comparison between the emission factor based on the fraction PM_{10} and directly measured values (table 2). The average PM_{10} emission factor based on the literature study is 7 mg/vkm[1] with a range of 1-14 mg/vkm (table 2). Although this is slightly higher than the value of 5 mg/vkm predicted on the basis of total tyre particulates, it is not significantly different in view of the range in the literature data and uncertainty with respect to the exact percentage. The average of 7 mg/vkm is also influenced by two relatively high values (13 and 14 mg/vkm, whereas the majority of the measurements suggest ~5 mg/vkm (table 2). It is therefore recommended for the time being to keep the emission factor for passenger cars at 5 mg/vkm corresponding to 5% of 100 mg/vkm total tyre particulates.

Specific wear factors are not known for tyres of vehicle categories trucks, buses, mopeds and special vehicles. Data on lorries is also extremely scarce (table 2), however weight loss during the life of a tyre is known for this vehicle category (BLIC/ZOPA, 2001a,b) and the percentage fine particulates can be worked out based on the assumed fraction of 5% PM_{10} of total tyre particulates. $PM_{2.5}$ emission factors have only just been published (see also table 2). Based on the available literature, the $PM_{2.5}$ fraction of tyre wear has been assumed as 20% (range 0-40%). The $PM_{2.5}$ share is not certain and may well be adjusted in the near future if more data becomes available.

The overview of recommended emission factors (table 3) shows that the emission factors for total tyre wear are round values, emphasising that – in view of the uncertainty – it does not make sense to further divide these values; it is more important to maintain clear consistency between the vehicle categories and PM_{10} fractions.

[1] vkm = vehicle kilometre

Table 2 – Literature data for tyre wear and distribution to fractions of fine particulates

$TSP^{1)}$	PM_{10}	$PM_{2.5}$	Comments	Source
(mg/km/vehicle)				
Passenger cars				
2 – 5				Cadle and Williams (1974)
7.5 – 25				Pierson & Brachaczek (1974)
	4	1.4		Fishman (1998)
	5	1.25		USEPA Part 5 (2002)
	1 – 5			Annema et al. (1994), Van den Brink (1996)
	14		0.5 µm < $d^{2)}$ < 10 µm	Subramini (1971)
	8		d < 0.5 µm	Subramini (1971)
	5		Model output	Singh and Colls (2000)
7	5			Keuken et al. (1999)
	6.1	0	PM_{10} ± 1.1	Rauterberg-Wulf (1999)
2				Doki et al. (2002)
80				Baumann et al. (1997)
1 – 5				Stark (1995)
32 – 110				Garben et al. (1997)
53	13			Hüglin et al. (2000)
	24 (15-50)			Warner et al. (2002); Luhana et al. (2004)
52 – 110				Gebbe et al. (1997)
2-100	7 (1 – 14)	1.3		Average values and range
Lorries and buses				
32	20			Keuken et al. (1999)
	< 32		(2.5 µm < d < 10 µm)	Rauterberg-Wulf (1999)
180 – 240				Baumann et al. (1997)
20				Doki et al. (2002)
770				Garben et al. (1997)
800	200			Hüglin et al. (2000)
100 – 550				Gebbe et al. (1997)

1) TSP = Total Suspended Particles
2) d = diameter

Table 3 – Tyre wear and emission to fine particulates per vehicle category

Vehicle class	Tyre wear	PM_{10}	$PM_{2.5}$
	mg/vkm		
Mopeds	23	1.2	0.25
Motorcycles	50	2.5	0.5
Passenger cars	100	5	1
Vans	140	7	1.4
Trucks	495	25	5
Lorries	600	30	6
Buses	360	18	3.6
Special vehicles (light)	140	7	1.4
Special vehicles (heavy)	600	30	5

4.2 Emission factors for PAH from tyres

There is a limited number of studies and reports available on PAH in vehicle tyres. A Swedish study provides the PAH content in extender oils with a high aromatic content (KemI, 2003). Aromatic extender oils are added to the tread rubber of tyres. These oils contain significant quantities of PAH. Combined with data from BLIC (2002) specifying the average addition of aromatic extender oils to tyres, it is possible to calculate the content of PAH.

On behalf of the Danish Ministry of the Environment, Nilsson *et al* (2005) collected a number of used tyres and directly measured the content of various PAH components in these tyres. LUT (2004) and NBI (2004) did the same for crushed car tyres used as additional soil infill for sports grounds. The literature values are compiled in table 4. Total PAH is defined in table 4 as: the sum of individual types of PAH comprising the 10 PAHs according to the definition of the Ministry of Housing, Spatial Planning and the Environment (VROM) and benzo[b]fluoranthene, or VROM-PAH + 1.

Table 4 – Measured PAH content in car tyres (mg/kg/tyre)

Source		**Nilsson *et al.*, *2005***		**KemI, 2003 BLIC, 2002**	**Baumann *et al*, 1998**		**LUT, 2004**	**NBI, 2004**
PAH component	**Total PAH**	P[1)]	L[1)]	P 13% HA oil	P	L	P	P
Fluoranthene	Yes	9.4	15.4	1.4	7.4	3.8	4.3	7.5
Pyrene		24.2	33.2	3.3	14.0	3.5	17.0	23.5
Benzo[a]fluorene				0.1				
Benzo(a)anthracene	Yes	0.8	0.9	4.4	1.0	0.7	8.5	1.3
Chrysene	Yes	5.5	5.3	51.3	7.0	2.3	6.0	2.2
Benzo[b+j+k]fluoranthene	Yes	1.8	2.1	*4.2*	3.8	1.9	5.8	3.0
Benzo(b)fluoranthene	Yes	*6.4*	*6.4*	9.5	*6.4*	*6.4*	3.3	2.4
Benzo[e]pyrene		5.5	5.9	14.7				
Benzo(a)pyrene	Yes	1.3	2.6	1.7	3.0	0.4	3.0	2.1
Dibenzo[a,j]anthracene				0.6				
Dibenzo[a,h]anthracene		1.2	0.8	0.7	0.1	0.2	0.5	1.1
Indeno(1,2,3-c,d)pyrene	Yes	2.3	1.0	0.8	0.1	0.4	0.2	0.8
Benzo(ghi)perylene	Yes	12.9	7.3	2.3	0.5	2.4	6.0	3.6
Ananthrene				0.9				
Naphthalene	Yes	*1.6*	*4.5*	*1.6*	2.7	4.5	0.6	0.4
Acenaphthene					0.1	1.0	0.3	0.2
Acenaphthalene					0.4	0.3	5.6	0.6
Fluorene					0.1	4.4	0.2	0.4
Phenanthrene	Yes	*4.3*	*2.3*	*4.3*	4.2	2.3	4.3	5.5
Anthracene	Yes	*0.8*	*0.1*	*0.8*	0.7	0.1	0.8	2.0
Total (VROM-PAH + BbF)		46.9	47.9	82.3	36.8	25.2	42.8	30.8

NB: PAHs in red are the PAH components forming part of the calculated total PAH.
[1)] P = Passenger cars, L = Lorries

There are a few gaps completed in the PAH components table that are included in the total. According to the definition of total PAH, Baumann *et al.* (1998), LUT (2004) and NBI (2004) analysed the highest percentage thereof (91% compared with 64% for other sources). The gaps completed using (average) data from other sources are shown in italics. For benzo[b]fluoranthene content in lorry tyres, it was not possible to find any derivative values due to a lack of data, so the values for passenger car tyres were used. Based on table 4, the total PAH content in vehicle tyres is estimated at 45 (±18) mg/kg/tyre. The range is restricted in view of the number of different makes and types of tyre. Table 5 shows the total PAH values according to other literature sources. Where no range is specified in table 5, only the average value was documented.

Table 5 – Total PAH values in tyres according to other sources

Total PAH content (mg/kg) in tyres per vehicle class according to literature sources						
Vehicle class	Lorry			Passenger car		
Source	min.	max.	average	min.	max.	average
CSTEE (2003)	13.5	31.5	22.5	18	112	65
Rauterberg-Wulff (2003)				30	360	195
LUT (2004)						62
NBI (2004)						67
TUV (Noordermeer, 2006)						47
Hofstra (2006)			14			33
TNO (Noordermeer, 2006)			90			112

To reach a definitive emission factor for passenger cars and lorries, it is necessary to compare a number of factors with each other. Directly analysing PAH in tyres is obviously the most direct approach. The documented totals (as per table 5) can best be used as a means of checking the calculations. Nilsson *et al.* (2005) carried out their analyses on shredded tyres used in playgrounds as fencing and/or soft landing pads. The data published by LUT (2004) and NBI (2004) relates to shredded tyres used as infill for sports grounds. It is not therefore necessary to take into account any leaching-out effect, as according to the specified sources most PAHs have already been included in the rubber matrix, which means that any leaching-out effect is minimal. Baumann *et al* (1998) analysed 2 different tyres for PAH, but it is not known which type of tyre is involved, and therefore whether or not this tyre belongs to a category with a low PAH content in the extender oil. The approach applied by the Swedish National Chemicals Inspectorate (KemI) in 2003 is more or less the same as direct analysis, given that aromatic extender oils are the most common source of PAH in tyres. This approach also eliminates measurement error as a result of PAH degrading in tyre rubber. However, various values are indicated for the content of these oils in tyres (range 10-37%), and this leads to variation in the definitive PAH contents in tyres.

Another problem is in defining total PAH. This means that where a study for the EU reports a value as the total PAH, this value has a lower PAH content than the same sample if it had been reported under the VROM-PAH definition, quite simply because there are fewer PAH components in the EU PAH definition. Based on the data available, a general profile of PAH types has been elaborated in relation to the total PAH in vehicle tyres (table 6). This profile is used in the further calculations of PAH emissions due to tyre wear. Although in table 4 there are still a few other individual PAH values, these are not calculated separately because there is very little information available, and it is not known for sure whether the non-inclusion of these PAH values in other studies in fact means that they were not measured or that they were not present. The approach selected assumes the low percentage of HA extender oil (14%; BLIC 2002) for the European market with the PAH content therein as reported by the KemI (2003). A calculation was then performed to convert EU-PAH values to VROM-PAH values, based on the profile set out in table 6. This approach provides a VROM-PAH content of ~100 mg/kg tyre particulates corresponding to the profiles applied here with an EU-PAH content of ~70 mg/kg. The value of 100 mg/kg total PAH effectively corresponds to the data set out in table 5 and is slightly higher than the values given in table 4. These content values are also in line with information relating to the expected reduction of PAH content after the directive restricting the use of PAH-containing extender oils in tyre production entered into force (EU Directive 2005/69/EC). It is expected that this will cause the PAH content to drop by a factor of 10 in order to comply with the new directive. With the values selected here, the content of benzo[a]pyrene would drop to 0.5 mg/kg and content of EU-PAH would drop to 7 mg/kg, whereas the norms would be 1 and 10 mg/kg respectively. This appears to correspond well.

Table 6 –General profile of PAH types compared to total PAH

General PAH PROFILE in tyres	
PAH type	**Content in tread rubber** mg/kg
Fluoranthene	19.1
Benzo(a)anthracene	6.5
Chrysene	24
Benzo(k)fluoranthene	9.1
Benzo(b)fluoranthene	16.4
Benzo(a)pyrene	5.4
Benzo[e]pyrene	6.9
Indeno(1,2,3-c,d)pyrene	1.98
Benzo(ghi)perylene	12.6
Naphthalene	7.2
Phenanthrene	10.9
Anthracene	2.1
Dibenzo[a,h]anthracene	1.65
TOTAL VROM-PAH+BbF	100
TOTAL EU-PAH	70

4.3 Emission factors for heavy metals

Tyre rubber contains traces of (heavy) metals that contribute to the emission. Based on a limited set of literature data, an indicative chemical profile has been elaborated (table 7). Table 7 shows that out of the metals, only zinc is present in tyre rubber in significant concentrations. Zinc is present in relatively large quantities because it is added as a catalyst in the vulcanisation process in the form of ZnO. According to the literature, the average tyre rubber contains approximately 1% ZnO (which corresponds to 0.8% Zn). Converted to a content based on mass, this value becomes 8000 mg/kg. This is the lower limit of the profile in the table. Blok (2005) refers to BLIC/ZOPA (2001a,b) and presents zinc content in tyres of 0.95% for passenger cars, 1.3% for vans and 1.7% for lorries. See table 8 for the complete estimate of zinc emissions (BLIC/ZOPA, 2001 – cited in Blok, 2005) and an overview of the proposed fractions of metals in tyre rubber to be used when calculating metal emissions as a result of tyre wear.

Table 7 – Contents of types of metal in tyres

Metal type	Concentration range (mg/kg)	Metal type	Concentration range (mg/kg)
Ag	0.08	Mg	32 – 444
As	0.8	Mn	2 – 14
Al	81 – 956	Mo	2.8 – 10
Ba	0.9 – 4.1	Na	610
Ca	113 – 1,500	Ni	0.9 – 50
Cd	0.28 – 4.96	Pb	1 – 160
Co	0.88 – 39	Sb	2
Cr	0.4 – 49	Se	4 – 20
Cu	1.8 – 69	Sr	1.16 – 3.13
Fe	2 – 2,800	Ti	195
K	180	V	1
Li	0.23 – 2.3	Zn	8,000 – 13,500

Source: Malmqvist (1983), Hewit *et al.* (1990), Brewer (1997), Legret *et al.* (1999), San Miguel *et al.* (2002).

Table 8 – Summary of estimated metal contents in various types of rubber

Metal	Tyre type			Source
	Passenger cars	**Vans**	**Lorries**	
	%			
Cadmium	1			EPA
Chromium	10			
Copper	50			
Nickel	50			
Lead	100			
Antimony	1			
Selenium	10			
Zinc	0.95	1.3	1.7	Blok (2005); BLIC/ZOPA (2001a,b)

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

There is usually more acceleration and braking within urban areas than within rural areas or 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 tyre wear per km driven within urban areas is therefore higher than outside these areas, there is little data available to properly substantiate this. The limited information available is summarised in table 9.

Table 9 – Effects of driving style and environment on emission factors

Condition	**Value**	**Unit**	**Source**
Highway – 120 km/h	24	mg/km/tyre	Dannis (1974)
Taking bends – 50 km/h	490		
Road bends in urban areas	30	mg/km/tyre	Le Maitre *et al.* (1998)
Driving gently	12		
Driving "professionally"[1)]	70		
Dry conditions	150	%	
Winter compared to summer	140		

[1)] "Driving professionally": Accelerating quickly, keeping to the maximum speed as much as possible and braking little.

Data published by Dannis (1974) and LeMaitre et al. (1998) confirms that bendy roads cause greater wear. The extremely high value recorded by Dannis (1974) is no longer considered to be realistic. Thanks to advances in technology, the properties of tyres (such as wear resistance and grip) have significantly improved in the period since Dannis conducted his study (early 1970s). The data set out in table 9 clearly shows that wear per kilometre is greater when there are lots of bends and when during acceleration, as in urban traffic, but does not provide an exact ratio. As an initial estimate, it is assumed that emission factors within urban areas are a factor 2 higher per kilometre driven than on motorways and secondary roads. This is based on the ratio between values measured by Le Maitre et al., but only "driving gently" is considered to be an underestimation of current motorway traffic. Table 10 sets out the definitive differentiated emission factors.

Table 10 – Derived emission factors of tyre wear for urban driving, rural driving and highway driving (mg/km)

Name of substances	**Vehicle category**	**Urban driving**	**Rural driving**	**Highway driving**
Coarse particulates	Passenger car	158	79	79
	Motorcycle	71	36	36
	Moped	23	12	-
	Van	190	95	95
	Lorry	1,014	507	507
	Truck	785	393	393
	Bus	495	248	248
	Special vehicle (light)	167	84	84
	Special vehicle (heavy)	712	356	356
PM10	Passenger car	8	4	4
	Motorcycle	4	2	2
	Moped	1	1	-
	Van	10	5	5
	Lorry	53	27	27
	Truck	41	21	21
	Bus	26	13	13
	Special vehicle (light)	9	4	4
	Special vehicle (heavy)	37	19	19
PM2.5	Passenger car	1.6	0.8	0.8
	Motorcycle	0.8	0.4	0.4
	Moped	0.2	0.2	-
	Van	2.0	1.0	1.0
	Lorry	10.6	5.4	5.4
	Truck	8.2	4.2	4.2
	Bus	5.2	2.6	2.6
	Special vehicle (light)	1.8	0.8	0.8
	Special vehicle (heavy)	7.4	3.8	3.8

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

4.5 Adjustment factor for ZOAB

ZOAB (very open asphalted concrete) has been used on Dutch motorways since 1985. This concrete contains a greater number of pores than the DAB (densely asphalted concrete) used until then. Because of this open structure, the coarse proportion of the tyre particulates generated is captured in these pores. Because the amount of ZOAB used on Dutch motorways has grown since 1985, the emission values have been adjusted accordingly. Table 11 shows the adjustment to the values as of the introduction of ZOAB

Table 11 – Adjustment factors for ZOAB. (source: Klein et al. 2007).

Year	**ZOAB on motorways (%)**	**Component**		
		Metals	**PAH**	**Particulate**
		Reduction factor		
		20	2.5	20
		Adjustment factor		
1980-1984	0.0	1.00	1.00	1.00
1985	0.5	1.00	1.00	1.00
1986	1.3	0.99	0.99	0.99
1987	2.0	0.98	0.99	0.98
1988	2.8	0.97	0.98	0.97
1989	5.6	0.95	0.97	0.95
1990	10.4	0.90	0.94	0.90
1991	13.9	0.87	0.92	0.87
1992	16.9	0.84	0.90	0.84
1993	22.4	0.79	0.87	0.79
1994	25.9	0.76	0.84	0.76
1995	30.9	0.71	0.81	0.71
1996	36.9	0.65	0.78	0.65
1997	42.7	0.60	0.74	0.60
1998	47.9	0.55	0.71	0.55
1999	50.4	0.52	0.70	0.52
2000	53.0	0.50	0.68	0.50
2001	55.5	0.47	0.67	0.47
2002	59.8	0.43	0.64	0.43
2003	62.2	0.41	0.63	0.41
2004	65.0	0.38	0.61	0.38
2005	68.0	0.35	0.59	0.35
2006*	71.0	0.33	0.57	0.33

The adjustment factor in table 11 is the fraction by which the emission is multiplied. This fraction is calculated using the percentage of ZOAB on Dutch motorways. For example, for 2006, the ZOAB fraction is 71%. The adjustment factor for metals is therefore [(1-0.71) + (0.71/20 (=reduction factor for metals, see table 12))] = 0.33.

4.6 Overview of profiles used

The calculated profiles are presented in this section. The totals are set out in table 12, differentiating the values.

Table 12 – Profiles applied for calculating emissions of PAH and heavy metals

Category	Component	Vehicle class	
		Light[1)]	**Heavy**[2)]
PAH	Anthracene	2.10E-06	6.80E-07
	Benzo[a]anthracene	6.50E-06	2.10E-06
	Benzo[a]pyrene	5.40E-06	1.70E-06
	Benzo[b]fluoranthene	1.64E-05	5.30E-06
	Benzo[ghi]perylene	1.26E-05	4.00E-06
	Benzo[k]fluoranthene	9.10E-06	2.90E-06
	Chrysene	2.40E-05	7.70E-06
	Phenanthrene	1.09E-05	3.50E-06
	Fluoranthene	1.91E-05	6.10E-06
	Indeno[1,2,3-cd]pyrene	1.98E-06	6.30E-07
	Naphthalene	7.20E-06	2.30E-06
Metals	Zinc (as Zn)	9.50E-03	1.70E-02
	Cadmium (as Cd)	1.00E-06	1.00E-06
	Chromium (as Cr)	1.00E-05	1.00E-05
	Arsenic (as As)	1.00E-06	1.00E-06
	Copper (as Cu)	5.00E-05	5.00E-05
	Nickel (as Ni)	5.00E-05	5.00E-05
	Lead (as Pb)	1.00E-04	1.00E-04
	Antimony (as Sb)	1.00E-06	1.00E-06
	Selenium (as Se)	1.00E-05	1.00E-05

[1)] Passenger cars, motorcycles, mopeds, vans and special light vehicles
[2)] Lorries, trucks, buses, and special heavy vehicles.

5 Effects of policy measures

EU Directive 76/769/EC (EU, 2005) specifies that on January 1, 2010, no new tyres are allowed to be launched on the market that are manufactured with aromatic oils containing more than 1 mg/kg benzo[a]pyrene or more than 10 mg/kg EU-PAH. The following compounds fall within the scope of PAH components regulated by the EU: Benzo[a]pyrene, benzo[e]pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene and dibenzo[a,h]anthracene.

This means that the emission factors as of 2010 will drop to a definitive value of 20 mg/kg/tyre, given that – in view of the data ascertained and calculations based thereupon – the total content of VROM-PAH + 1 is approximately equal to twice the content of PAH components designated by the EU. With constant traffic performance per vehicle, this value will be achieved in the end after 5 years (worse case scenario) as of the date of introduction. This is based on the following assumptions:

- As of December 31, 2006, every vehicle is provided with tyres with a PAH content of 70/mg/kg/tyre. Once these tyres have worn through, they are replaced with tyres with a PAH content of 20 mg/kg/tyre.
- The average life of the tyres is 50,000 km, so they have to be removed and replaced after 50,000 km.
- Traffic performance in 2010 will not differ much compared to previous years. This seems to be an acceptable trend, because there is little leeway in the traffic performance values for 2004, 2005 and 2006.

- Passenger cars and vans are responsible for the largest proportion of PAH emissions (combination of high PAH content in tyres and highest traffic performance).

Table 13 sets out the values based on the above assumptions that are required for calculating PAH emissions.

Table 13 – Values used for calculating PAH emissions beyond 2010

Variable	**Unit**	**Value**
Traffic performance 2010 (passenger cars and vans)	km	$1.9 \cdot 10^{11}$
Tyre life	km	$5.0 \cdot 10^{4}$
Number of passenger cars and vans: (source: http://www.milieuennatuurcompendium.nl/ indicatoren/nl0026-Aantal-motorvoertuigen.html?i=15-103)	n	$8.2 \cdot 10^{6}$
Average distance covered per vehicle	km/year	$1.5 \cdot 10^{4}$
Average tyre life	year	3.5

It is assumed that tyres are replaced after an average of 3.5 years. Because some less frequently used vehicles will continue driving with the old type of tyres which may continue to be replaced using tyres from stock, it will take longer before their tyres are fully replaced with low-content PAH tyres. It is therefore assumed that in 2015, only tyres with a lower PAH content will be used. If linear implementation is assumed, the emission factor will drop each year by 20% from 2010 to 2015 (from 70 mg/kg EU-PAH to <10 mg/kg EU-PAH, or from 5.4 mg/kg benzo[a]pyrene to <1 mg/kg benzo[a]pyrene) compared to the value for 2010.

6 Emissions calculated

Tables 14 to 17 show the emissions for various categories of vehicles per year. The emissions are calculated by multiplying the activity rate (table 1) by the emission factors set out in table 3 and the fractions of specific substances in tyre particulates, as shown in table 6 and 8. All emissions are expressed in kg per year. EU Directive 76/769/EC (EU, 2005) is also further calculated in a forecast for PAH emissions in 2015. This was based on an estimate of traffic performance in 2015 (A. Hoen, MNP, personal memo, 13/11/2007).

Table 14 – Emissions to soil due to tyre wear, (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	8	8	8	8	8	8	9
Arsenic compounds (as As)	8	8	8	8	8	8	9
Cadmium compounds (as Cd)	8	8	8	8	8	8	9
Chromium compounds (as Cr)	83	81	82	83	81	80	90
Copper compounds (as Cu)	414	403	412	414	405	402	451
Lead compounds (as Pb)	827	806	825	829	810	804	903
Nickel compounds (as Ni)	414	403	412	414	405	402	451
Selenium compounds (as Se)	83	81	82	83	81	80	90
Zinc compounds (as Zn)	95,885	93,162	94,208	93,336	91,179	90,512	101,225
Phenanthrene	74	75	82	86	85	85	10
Anthracene	14	14	16	17	16	16	2
Fluoranthene	130	131	144	151	149	149	17
Chrysene	163	165	181	190	187	187	22
Benzo[a]anthracene	44	45	49	51	51	51	6
Benzo[a]pyrene	37	37	41	43	42	42	5
Benzo[b]fluoranthene	111	113	123	130	128	128	15
Benzo[k]fluoranthene	62	63	68	72	71	71	8
Benzo[ghi]perylene	85	87	95	100	98	98	11
Indeno[1,2,3-cd]pyrene	13	14	15	16	15	15	2
Naphthalene	49	49	54	57	56	56	7
Coarse particulates	8,271,834	8,059,469	8,246,013	8,288,135	8,100,064	8,042,759	9,028,951

Table 15 – Direct emissions to surface water due to tyre wear, (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	1	1	1	1	1	1	1
Arsenic compounds (as As)	1	1	1	1	1	1	1
Cadmium compounds (as Cd)	1	1	1	1	1	1	1
Chromium compounds (as Cr)	6	7	7	6	6	6	6
Copper compounds (as Cu)	32	33	34	32	31	31	32
Lead compounds (as Pb)	64	65	67	65	63	62	65
Nickel compounds (as Ni)	32	33	34	32	31	31	32
Selenium compounds (as Se)	6	7	7	6	6	6	6
Zinc compounds (as Zn)	7,545	7,670	7,723	7,352	7,114	6,999	7,301
Phenanthrene	6	6	7	7	7	7	1
Anthracene	1	1	1	1	1	1	0
Fluoranthene	10	11	12	12	12	12	1
Chrysene	12	13	15	16	15	15	2
Benzo[a]anthracene	3	4	4	4	4	4	0
Benzo[a]pyrene	3	3	3	3	3	3	0
Benzo[b]fluoranthene	9	9	10	11	10	10	1
Benzo[k]fluoranthene	5	5	6	6	6	6	1
Benzo[ghi]perylene	7	7	8	8	8	8	1
Indeno[1,2,3-cd]pyrene	1	1	1	1	1	1	0
Naphthalene	4	4	5	5	5	5	1
Coarse particulates	641,044	650,544	670,900	648,880	628,560	619,135	646,995

Table 16 – Emissions to sewers within urban area due to tyre wear, (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	4	3	3	4	4	4	5
Arsenic compounds (as As)	4	3	3	4	4	4	5
Cadmium compounds (as Cd)	4	3	3	4	4	4	5
Chromium compounds (as Cr)	38	33	33	37	37	37	48
Copper compounds (as Cu)	188	165	166	184	183	185	240
Lead compounds (as Pb)	375	331	331	367	366	371	481
Nickel compounds (as Ni)	188	165	166	184	183	185	240
Selenium compounds (as Se)	38	33	33	37	37	37	48
Zinc compounds (as Zn)	41,967	36,199	37,051	40,758	40,734	41,279	53,277
Phenanthrene	35	31	31	34	34	34	4
Anthracene	7	6	6	7	7	7	1
Fluoranthene	61	55	54	60	60	60	8
Chrysene	76	69	67	75	75	76	10
Benzo[a]anthracene	21	19	18	20	20	21	3
Benzo[a]pyrene	17	15	15	17	17	17	2
Benzo[b]fluoranthene	52	47	46	52	51	52	7
Benzo[k]fluoranthene	29	26	26	29	28	29	4
Benzo[ghi]perylene	40	36	35	40	39	40	5
Indeno[1,2,3-cd]pyrene	6	6	6	6	6	6	1
Naphthalene	23	21	20	23	23	23	3
Coarse particulates	3,753,656	3,306,865	3,311,876	3,672,317	3,664,531	3,705,810	4,808,998

Table 17 – Emissions to atmosphere due to tyre wear, (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	1	1	1	1	1	1	1
Arsenic compounds (as As)	1	1	1	1	1	1	1
Cadmium compounds (as Cd)	1	1	1	1	1	1	1
Chromium compounds (as Cr)	7	6	6	6	6	6	7
Copper compounds (as Cu)	33	31	32	32	32	32	37
Lead compounds (as Pb)	65	62	63	65	64	64	75
Nickel compounds (as Ni)	33	31	32	32	32	32	37
Selenium compounds (as Se)	7	6	6	6	6	6	7
Zinc compounds (as Zn)	7,514	7,087	7,194	7,319	7,193	7,180	8,367
Phenanthrene	6	6	6	7	6	6	1
Anthracene	1	1	1	1	1	1	0
Fluoranthene	10	10	11	11	11	11	1
Chrysene	13	13	13	14	14	14	2
Benzo[a]anthracene	3	3	4	4	4	4	0
Benzo[a]pyrene	3	3	3	3	3	3	0
Benzo[b]fluoranthene	9	9	9	10	10	10	1
Benzo[k]fluoranthene	5	5	5	5	5	5	1
Benzo[ghi]perylene	7	7	7	8	7	7	1
Indeno[1,2,3-cd]pyrene	1	1	1	1	1	1	0
Naphthalene	4	4	4	4	4	4	1
Fine particulates (PM10)	651,532	618,630	630,283	649,994	638,805	637,407	746,364
Fine particulates (PM2.5)	130,306	123,726	126,057	129,999	127,761	127,481	149,273

7 Release into environmental compartments

Table 18 shows the distribution of wear emissions to the various environmental compartments, as currently used by the Task Force Traffic and Transport. Emissions of fine particulates (PM_{10}) are assigned 100% to the atmosphere compartment in all cases. The distribution of fine particulates to atmosphere is not under review. However, the division of coarse particulates to the various environmental compartments is reviewed and revised in this fact sheet.

Table 18 –Distribution percentages for tyre particulates to compartments, as applied to date (source: Klein et al.,2007)

	Tyre particulate		
	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 target group (Klein et al., 2007)

Distribution for urban driving

100% distribution of emissions within urban areas to the sewers (table 18) 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 19).

Table 19 – 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 contamination, 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 particulate matter is 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 contamination (decreasing contribution to sewers)
- A part of the soil material in unpaved ground will leach 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 leaches into the sewers, it is necessary to take a slightly higher input to the sewers into consideration. An input of 60% into the sewers is therefore selected as the provisional value.

Distribution for rural driving

The distribution of emissions of coarse fraction of tyre particulates within rural areas is more complex than within urban areas. Blok conducted a fairly extensive study in this respect (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 drift. In this respect, we assume that the finest fraction of this 30% (approximately 5% fine particulate matter) will be transported further away via atmospheric transport. According to Blok, the largest proportion (25 of the 30%) distributed via drift does not travel further than 4.5 m (other roads) to 6 m (motorways) from the edge of the road. 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 value will be less than 50% of the surface area between 4.5 and 6 metres from roads. As an initial estimate, we assume a value of half of 25%, rounding off downwards, which gives an estimate of 10% direct emissions to surface water.

Table 20 provides the new proposed division of tyre particulates to the various environmental compartments.

Table 20 – Proposed distribution percentages for tyre particulates to compartments

	Atmosphere	Soil	Surface water	Sewers
	%			
Fine particulates (incl. metals)				
Urban driving	100	0	0	0
Rural driving	100	0	0	0
Highway driving	100	0	0	0
Coarse particulates (incl. metals)				
Urban driving	0	40	0	60
Rural driving	0	90	10	0
Highway driving	0	90	10	0

8 Spatial allocation

The spatial allocation of emissions is worked out on the basis of a set of digital maps held by the Netherlands Environmental Assessment Agency (PBL). 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] for a list of available locators), as not every conceivable parameter can be used as a locator. That is why the locator judged to be the best proxy of the activity rate of the emission in question is used. In some cases, one source is distributed via more than one locator. This is the case with tyre wear on secondary roads, 80% of which is broken down via traffic density on motorways and 20% via the number of residential dwelling units within rural areas. It is assumed that the distribution of emissions throughout the country mirrors the national distribution of the locator.

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

Table 21: Summary of emission spatial allocation method

Element	Locators
Tyre wear, highway driving	Traffic density on motorways
Tyre wear, rural driving	Traffic density on secondary roads, 80%
Tyre wear, rural driving	Number of residential dwelling units within rural area, 20%
Tyre wear, urban driving	Number of inhabitants per 500x500-metre grid cell

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

Traffic density for highway driving and rural driving (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:

- Highways (trunk roads): passenger cars and vans
- Highways (trunk roads): freight and other traffic
- Regional roads: passenger cars and vans
- Regional roads: freight and other traffic
- Urban roads: passenger cars and vans
- Urban roads: 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 ”Adviesdienst Verkeer en Vervoer” (AVV) (see also Molder, 2007). Density data (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 motorways on the basis of censuses conducted by AVV and relate to 2005. The values for regional roads and roads in the urban area are modelled data based on a model called the ”Nieuw Regionaal Model” (NRM) operated by the AVV and cover 2005. This model uses counted numbers 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 PBL 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 data 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.

9 Comments and changes in regard to previous version

The calculation method has changed in the following points compared to previous publications (see also Klein et al., 2007):

- Emission factors for fine particulates. Changes compared to previous emission factors used by the Task Force Traffic and Transport are limited; they are made as a result of using set fractions PM10 and PM2.5 in the total produced tyre particulates for each vehicle category (see also section 4.1)
- Distribution of emissions to soil and sewers within urban areas (see also section 7)
- Distribution of emissions to soil and water within rural areas (see also section 7)
- Contents and derived emission factors of metals and PAH from tyre wear.

A concise comparison between old and new emission factors for fine particulates is provided in the table below. No comparison is shown for special vehicles, as this category is now divided into light and heavy special vehicles. PM2.5 emission factors were not included in previous documents.

Vehicle class		**Tyre wear**	**PM_{10}**	**$PM_{2.5}$**
		mg/vkm		
Passenger cars	New	100	5	1
	Old	92	4.6	-
Vans	New	120	6	1.2
	Old	120	6	-
Lorries [1)]	New	600	30	6
	Old	495	24.75	-
Trucks	New	495	25	5
	Old	495	1.25	-
Buses	New	360	18	3.6
	Old	360	18	-
Motorcycles	New	50	2.5	0.5
	Old	46	8.3	-
Mopeds	New	23	1.2	0.25
	Old	23	1.2	-

[1)] Assuming lorries with an average of 10 tyres

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:

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 regularly updated by the Task Force Traffic and Transport and can be classed under A.

The distribution of emissions among individual compartments is very uncertain, so category D applies here. In this respect, there is again 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 of emission calculation	**Reliability classification**
Activity rates	A
Emission factor – total	B
Emission factor – PM_{10}	D
Emission factor – $PM_{2.5}$	D
Emission factor – PAH	C
Emission factor – zinc	B
Distribution among compartments	D
Emission pathways to water	B
Spatial allocation	B

The most significant area for improvement is:
The manufacture of tyre rubber is a complex chemical process in industry, using a large number of chemicals, including potentially toxic substances such as dithiocarbamates and organic nitrogen compounds. However, it is not known to what extent these substances are still present in the end product and may be released as such. If data becomes available in this respect in the future, the fact sheet is to be updated on this point.

11 Request for reactions

Any questions or comments on this working document should be addressed to: Richard van Hoorn, Centre for Water Management, +31 (0)320-298491, email richard.van.hoorn@rws.nl or Joost van den Roovaart, Deltares, +31 (0)6-57315874, email joost.vandenroovaart@deltares.nl.

12 References

Annema (ed) et al. – Basisdocument fijn stof – (1994) – RIVM report no. 710401029, Bilthoven, the Netherlands, 1994.

Baumann, W. et al. – Exemplarische Erfassung der Umweltexposition ausgewählter Kauschukderivate bei der bestimmungsgemäßen Verwendung in Reifen und deren Entsorgung –UBA-FB 98-003, 1997.

BLIC, Tyre particulates as a source of PAHs in the environment, cited in CSTEE (2003), 2002.

BLIC and ZOPA (2001a). Comments on the 17 November draft RAR of Zn and compounds, Letter of Alex Coursier, 2 February 2001 (UMZC/Mktg/AC05/02/01); cited in Blok (2005)

BLIC and ZOPA. (2001b) Industry comments on RAR draft of February 2001. Releases of zinc to the environment from the wearing of tyres, Letter of April 27, 2001; cited in Blok (2005)

Blok, J. – Environmental exposure of road borders to zinc –Science of the Total Environment 348 (2005), 173 – 190.

Brewer, P. – Vehicles as a source of heavy metal contamination in the environment (unpublished) – MSc thesis, University of Reading, Berkshire, UK, 1997. Cited in http://vergina.eng.auth.gr/

Cadle, S.; Williams, R. – Environmental degradation of tire-wear particles – Rubber chemistry and technology (53) 1978, 146 – 158.

CSTEE, 2003, Opinion of the scientific committee on toxicity, ecotoxicity and the environment (CSTEE) on "Questions to the CSTEE relating to scientific evidence of risk to health and the environment from polycyclic aromatic hydrocarbons in extender oils and tyres", Adopted by the CSTEE during the 40th plenary meeting of 12-13 November 2003

Dannis, M. – Rubber dust from the normal wear of tires – Rubber chemistry and technology 47 (1974), 1011 – 1037.

Doki, S.; Kunimi, H.; Takahasi, K. – Estimation of tire emission factors by roadside observation – Japan Clean Air Program (JCAP II), paper presented at 43rd annual meeting of Japan Society for Atmospheric environment, 2002.

Emission Inventory Guidebook – Road Vehicle Tyre & Brake Wear, Snap Code 070700/070800 – 2003

EU (2005) EU Directive 2005/69/EC on restrictions on the marketing and use of certain dangerous substances and preparations (polycyclic aromatic hydrocarbons in extender oils and tyres)

Evaluation of pollutant loadings in the runoff waters from a major rural highway – Legret, M.; Pagotto, C. – The Science of the Total Environment 235 (1999), 143-150.

Fauser, P., J. C. Tjell, H. Mosbaek and K. Pilegaard, Quantification of Tire-Tread Particles Using Extractable Organic Zinc as Tracer. Rubber chemistry and technology, 72, 969-977, 1999.

Fishman, R. – Tire wear contributions to ambient particulate matter – Msc thesis, Sever Institute of Technology, Washington University, 1998.

Garbet et al. – Emissionskataster Kraftfahrzeugverkehr Berlin 1993 - IVU GmbH Berlin, Gutachten im Auftrag der Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie, Berlin, unveröffentlicht, 1997.

Gebbe et al. –Quantifizierung des Reifenabreibs von Kraftfahrzeugen in Berlin –ISS-Fahrzeugtechnik, TU Berlin, i. A. der Senatsverwaltung für Stadtentwicklung – Umweltschutz und Technologie, Berlin 1997.

Hewit, C.; Rashed, M. – An integrated budget for selected pollutants for a major rural highway – The Science of the Total Environment (93), 375 – 384, Elsevier Science, 1990.

Hofstra U. (2006), Instrooirubber op kunstgrasvelden uit geshredderde autobanden. Onderzoek naar milieu- en gezondheidsrisico's. Intron.

Hüglin, C.; Gehrig, R. – Anteil des Strassenverkehrs an den PM10- und PM2,5-Immisionen, Chemische Zusammensetzung des Feinstaubes und Quellenzuordnung mit einem Rezeptormodell, Kurzfassung – NFP41/C4, Bericht Nr 801.583.d, BBL/EDMZ, Bern, Switzerland, 2000.

KEMI: HA oils in automotive tyres – prospects of a national ban. Report on a government commission. Swedish National Chemicals Inspectorate, 27 March 2003.

Keuken, M.; Teeuwisse, S.; ten Brink, H.M. – Research on the contribution of road dust emissions to PM10 concentrations in the Netherlands – TNO Report Nr. R99/505, TNO-MEP, Apeldoorn, The Netherlands, 1999

Klein J., A. Hoen, J. Hulskotte, N. van Duynhoven, R. Smit, A. Hensema, D. Broekhuizen, Methoden voor de berekening van de emissies door mobiele bronnen in Nederland, Taakgroep Verkeer en Vervoer van het project Emissieregistratie, October 2007, http://www.emissieregistratie.nl/

Legret, M.; Pagotto, C. – Evaluation of pollutant loadings in the runoff waters from a major rural highway – The Science of the Total Environment (235), 143 – 150, 1999.

LeMaitre, O. M. Süssner and C. Zarak – Evaluation of tyre wear performance, SAE technical paper series 980256, International congress and Exposition, Detroit, Michigan. 1998

Luhana, L.; Sokhi, R.; Warner, L.; Mao, H.; Boulter, P.; Mccrae, I.; Wright, J.; Osborn, D. – Particulates – Characterisation of Exhaust Particulate Emissions from Road Vehicles, Deliverable 8: Measurement of non-exhaust particulate matter, Version 2.0 – October 2004

LUT (Lulea University of Technology) - Technical and Environmental Properties of Tyre Shreds Focusing on Ground Engineering Applications; 2004: http://epubl.ltu.se/1402-1536/2004/05/index.html

Malmqvist, P-A – Urban storm water pollutant sources – Chalmers University, Gothenberg, Sweden, 1983.

Molder, R. te, 2007. Notitie ruimtelijke verdeling binnen de emissieregistratie. Een overzicht.

NBI (Norges Byggforskninginstitutt) Oppdragsrapport, Potensielle helse- og miljoeffekter tilknyttet kunstgressystemer-sluttrapport. Byggforsk rapport O-10820. 15p, 2004

Nilsson, N.; Feilberg, A.; Pommer, K. – Emissions and evaluation of health effects of PAHs and aromatic mines from tyres –Survey of Chemical Substances in Consumer Products, No. 54 2005.

Noordermeer (2006) Stellingname betreffende beantwoording Kamervragen 2050603510 door de Staatsecretaris van Volksgezondheid, Welzijn en Sport. Universiteit Twente, Faculteit Technische Natuurwetenschappen, Rubbertechnologie.

Pierson, W.; BrachrcZek, W. – Airborne particulate debris from rubber tires – Rubber chemistry and technology (47), 1275 – 1299, 1974.

Rauterberg-Wulff A – Tire wear as source of PAH, Umweltbundesamt, Berlin CSTEE/2003/18/4, 2003

Rauterberg-Wulff, A – Determination of emission factors for tire wear particles up to 10 microns by tunnel measurements, Proceedings Of The Eighth International Symposium Transport and Air Pollution Including Cost 319 Final Conference, Sturm, P.J.;. [Ed.];, Graz, Austria, 31 May - 2 June 1999, Report Institute for Internal Combustion Engines and Thermodynamics, Vol. 76, pp 265-72, 1999

Rauterberg-Wulff, A.; Israel, G.W.; Pesch, M.; Schlums, C. – Bestimmung des Beitrags von Reifenabtrieb zur Russimmision an stark befahrenen Strassen – VDI Berichte NR. 1228, 1998

San Miguel, G; Fowler, G.; Sollars, C. – The leaching of inorganic species from activated carbons produced from waste tyre rubber - Water research (36), 1939 – 1946, 2002.

Singh, R.; Colls, J. – Development and Preliminary Evaluation of a Particulate Matter Emission Factor Model for European Motor Vehicles – Journal of the Air & Waste Management Association 50, 1805 – 1807, Technical Paper, 2000.

Stark, R. – Environmental impact of a tyre – Kautschuk Gummi Kunststoffe (48), 448 – 453, 1995.

Subramini, J. – Particulate air pollution from automobile tire tread wear – PhD dissertation, University of Cincinnati, 1971. Geciteerd in Fishmann, 1998.

Techn. Univ. Berlin, Fachgebiet Luftreinhaltung – Untersuchung über die Bedeutung der Staubaufwirbelung für die PM10 Immission an einer Hauptverkehrsstrasse - (2000).

US-Environmental Protection Agency, Office of Mobile Sources – Software-based algorithm for calculating emissions from mobile sources PART5, Version as of 2002 – US-EPA 2002.

Van den Brink, R. – Deeltjesemissie door wegverkeer, emissiefactoren, deeltjes-grootteverdeling en chemische samenstelling - RIVM report no. 772002008, Bilthoven, the Netherlands, 1996.

Warner L.R., Sokhi R.S., Luhana L., Boulter P.G., McCrae I. - "Non-Exhaust Particle Emissions from Road Transport", Graz University of Technology – Transport and Air Pollution Symposium, Proceedings Volume I, pp 265-272, 2002.

Appendix 1 – Emissions from light / heavy vehicles per compartment

Table B1: Emissions from light road vehicles to sewers within urban areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	3.0	2.7	2.6	3.0	3.0	3.0	3.9
Arsenic compounds (as As)	3.0	2.7	2.6	3.0	3.0	3.0	3.9
Cadmium compounds (as Cd)	3.0	2.7	2.6	3.0	3.0	3.0	3.9
Chromium compounds (as Cr)	30	27	26	30	30	30	39
Copper compounds (as Cu)	150	136	132	150	150	151	195
Lead compounds (as Pb)	300	273	265	300	299	302	390
Nickel compounds (as Ni)	150	136	132	150	150	151	195
Selenium compounds (as Se)	30	27	26	30	30	30	39
Zinc compounds (as Zn)	29,155	26,325	25,746	29,328	29,308	29,639	37,762
Anthracene	6.2	5.6	5.4	6.1	6.1	6.2	0.8
Benzo[a]anthracene	19	17	17	19	19	19	2
Benzo[a]pyrene	16	15	14	16	16	16	2
Benzo[b]fluoranthene	48	44	43	48	48	48	6
Benzo[ghi]perylene	37	34	33	37	37	37	5
Benzo[k]fluoranthene	27	24	24	27	27	27	3
Chrysene	71	64	62	70	70	70	9
Phenanthrene	32	29	28	32	32	32	4
Fluoranthene	56	51	50	56	56	56	7
Indeno[1,2,3-cd]pyrene	5.8	5.3	5.1	5.8	5.8	5.8	0.8
Naphthalene	21	19	19	21	21	21	3
Coarse particulates	3,000,039	2,726,076	2,646,885	2,999,931	2,992,425	3,021,143	3,896,381

Table B2: Emissions from heavy road vehicles to sewers within urban areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.8	0.6	0.7	0.7	0.7	0.7	0.9
Arsenic compounds (as As)	0.6	0.5	0.5	0.5	0.5	0.5	0.7
Cadmium compounds (as Cd)	0.8	0.6	0.7	0.7	0.7	0.7	0.9
Chromium compounds (as Cr)	8	6	7	7	7	7	9
Copper compounds (as Cu)	38	29	33	34	34	34	46
Lead compounds (as Pb)	75	58	66	67	67	68	91
Nickel compounds (as Ni)	38	29	33	34	34	34	46
Selenium compounds (as Se)	8	6	7	7	7	7	9
Zinc compounds (as Zn)	12,811	9,873	11,305	11,431	11,426	11,639	15,514
Anthracene	0.5	0.4	0.5	0.5	0.5	0.5	0.1
Benzo[a]anthracene	1.6	1.2	1.4	1.4	1.4	1.4	0.2
Benzo[a]pyrene	1.3	1.0	1.1	1.1	1.1	1.2	0.2
Benzo[b]fluoranthene	4.0	3.1	3.5	3.6	3.6	3.6	0.5
Benzo[ghi]perylene	3.0	2.3	2.7	2.7	2.7	2.7	0.4
Benzo[k]fluoranthene	2.2	1.7	1.9	1.9	1.9	2.0	0.3
Chrysene	5.8	4.5	5.1	5.2	5.2	5.3	0.7
Phenanthrene	2.6	2.0	2.3	2.4	2.4	2.4	0.3
Fluoranthene	4.6	3.5	4.1	4.1	4.1	4.2	0.6
Indeno[1,2,3-cd]pyrene	0.5	0.4	0.4	0.4	0.4	0.4	0.1
Naphthalene	2	1	2	2	2	2	0
Coarse particulates	753,616	580,789	664,991	672,386	672,106	684,666	912,616

Table B3: Emissions from light road vehicles to soil within urban areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	2.0	1.8	1.8	2.0	2.0	2.0	2.6
Arsenic compounds (as As)	2.0	1.8	1.8	2.0	2.0	2.0	2.6
Cadmium compounds (as Cd)	2.0	1.8	1.8	2.0	2.0	2.0	2.6
Chromium compounds (as Cr)	20	18	18	20	20	20	26
Copper compounds (as Cu)	100	91	88	100	100	101	130
Lead compounds (as Pb)	200	182	176	200	199	201	260
Nickel compounds (as Ni)	100	91	88	100	100	101	130
Selenium compounds (as Se)	20	18	18	20	20	20	26
Zinc compounds (as Zn)	19,437	17,550	17,164	19,552	19,539	19,759	25,175
Anthracene	4.1	3.8	3.6	4.1	4.1	4.1	0.5
Benzo[a]anthracene	13	12	11	13	13	13	2
Benzo[a]pyrene	11	10	9	11	10	11	1
Benzo[b]fluoranthene	32	29	28	32	32	32	4
Benzo[ghi]perylene	25	23	22	25	24	25	3
Benzo[k]fluoranthene	18	16	16	18	18	18	2
Chrysene	47	43	41	47	47	47	6
Phenanthrene	21	20	19	21	21	21	3
Fluoranthene	37	34	33	37	37	37	5
Indeno[1,2,3-cd]pyrene	3.9	3.5	3.4	3.9	3.8	3.9	0.5
Naphthalene	14	13	12	14	14	14	2
Coarse particulates	2,000,026	1,817,384	1,764,590	1,999,954	1,994,950	2,014,095	2,597,588

Table B4: Emissions from heavy road vehicles to soil within urban areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.5	0.4	0.4	0.4	0.4	0.5	0.6
Arsenic compounds (as As)	0.4	0.3	0.4	0.4	0.4	0.4	0.5
Cadmium compounds (as Cd)	0.5	0.4	0.4	0.4	0.4	0.5	0.6
Chromium compounds (as Cr)	5.0	3.9	4.4	4.5	4.5	4.6	6.1
Copper compounds (as Cu)	25	19	22	22	22	23	30
Lead compounds (as Pb)	50.2	38.7	44.3	44.8	44.8	45.6	60.8
Nickel compounds (as Ni)	25	19	22	22	22	23	30
Selenium compounds (as Se)	5	4	4	4	4	5	6
Zinc compounds (as Zn)	8,541	6,582	7,537	7,620	7,617	7,760	10,343
Anthracene	0.3	0.3	0.3	0.3	0.3	0.3	0.0
Benzo[a]anthracene	1.1	0.8	0.9	0.9	0.9	1.0	0.1
Benzo[a]pyrene	0.9	0.7	0.8	0.8	0.8	0.8	0.1
Benzo[b]fluoranthene	2.7	2.1	2.3	2.4	2.4	2.4	0.3
Benzo[ghi]perylene	2.0	1.5	1.8	1.8	1.8	1.8	0.2
Benzo[k]fluoranthene	1.5	1.1	1.3	1.3	1.3	1.3	0.2
Chrysene	3.9	3.0	3.4	3.5	3.5	3.5	0.5
Phenanthrene	1.8	1.4	1.6	1.6	1.6	1.6	0.2
Fluoranthene	3.1	2.4	2.7	2.7	2.7	2.8	0.4
Indeno[1,2,3-cd]pyrene	0.3	0.2	0.3	0.3	0.3	0.3	0.0
Naphthalene	1.2	0.9	1.0	1.0	1.0	1.0	0.1
Coarse particulates	502,411	387,193	443,328	448,257	448,071	456,444	608,411

Table B5: Emissions from light road vehicles to atmosphere within urban areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.3	0.2	0.2	0.3	0.3	0.3	0.3
Arsenic compounds (as As)	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Cadmium compounds (as Cd)	0.3	0.2	0.2	0.3	0.3	0.3	0.3
Chromium compounds (as Cr)	2.6	2.3	2.3	2.6	2.6	2.6	3.3
Copper compounds (as Cu)	13	12	11	13	13	13	17
Lead compounds (as Pb)	25.6	23.2	22.6	25.7	25.6	25.9	33.4
Nickel compounds (as Ni)	13	12	11	13	13	13	17
Selenium compounds (as Se)	3	2	2	3	3	3	3
Zinc compounds (as Zn)	2,486	2,245	2,201	2,511	2,509	2,537	3,233
Anthracene	0.5	0.5	0.5	0.5	0.5	0.5	0.1
Benzo[a]anthracene	1.6	1.5	1.4	1.6	1.6	1.6	0.2
Benzo[a]pyrene	1.4	1.2	1.2	1.4	1.3	1.4	0.2
Benzo[b]fluoranthene	4.1	3.8	3.6	4.1	4.1	4.1	0.5
Benzo[ghi]perylene	3.2	2.9	2.8	3.2	3.1	3.2	0.4
Benzo[k]fluoranthene	2.3	2.1	2.0	2.3	2.3	2.3	0.3
Chrysene	6.0	5.5	5.3	6.0	6.0	6.0	0.8
Phenanthrene	2.7	2.5	2.4	2.7	2.7	2.7	0.4
Fluoranthene	4.8	4.4	4.2	4.8	4.8	4.8	0.6
Indeno[1,2,3-cd]pyrene	0.5	0.5	0.4	0.5	0.5	0.5	0.1
Naphthalene	1.8	1.6	1.6	1.8	1.8	1.8	0.2
Fine particulates (PM10)	255,739	232,452	226,226	256,793	256,120	258,536	333,545
Fine particulates (PM2.5)	51,148	46,490	45,245	51,359	51,224	51,707	66,709

Table B6: Emissions from heavy road vehicles to atmosphere within urban areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Arsenic compounds (as As)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cadmium compounds (as Cd)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Chromium compounds (as Cr)	0.7	0.5	0.6	0.6	0.6	0.6	0.8
Copper compounds (as Cu)	3.3	2.5	2.9	2.9	2.9	3.0	4.0
Lead compounds (as Pb)	6.6	5.1	5.8	5.9	5.9	6.0	8.0
Nickel compounds (as Ni)	3.3	2.5	2.9	2.9	2.9	3.0	4.0
Selenium compounds (as Se)	0.7	0.5	0.6	0.6	0.6	0.6	0.8
Zinc compounds (as Zn)	1,117	860	985	996	995	1,014	1,352
Phenanthrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anthracene	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Fluoranthene	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Chrysene	0.3	0.3	0.3	0.3	0.3	0.3	0.0
Benzo[a]anthracene	0.3	0.2	0.2	0.2	0.2	0.2	0.0
Benzo[a]pyrene	0.2	0.1	0.2	0.2	0.2	0.2	0.0
Benzo[b]fluoranthene	0.5	0.4	0.4	0.5	0.5	0.5	0.1
Benzo[k]fluoranthene	0.2	0.2	0.2	0.2	0.2	0.2	0.0
Benzo[ghi]perylene	0.4	0.3	0.4	0.4	0.4	0.4	0.0
Indeno[1,2,3-cd]pyrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Naphthalene	0.2	0.1	0.1	0.1	0.1	0.1	0.0
Fine particulates (PM10)	65,682	50,610	57,939	58,582	58,556	59,649	79,514
Fine particulates (PM2.5)	13,136	10,122	11,588	11,716	11,711	11,930	15,903

Table B7: Emissions from light road vehicles to surface waters within rural areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Arsenic compounds (as As)	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Cadmium compounds (as Cd)	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Chromium compounds (as Cr)	4.5	4.5	4.9	5.0	4.8	4.8	5.0
Copper compounds (as Cu)	22	23	25	25	24	24	25
Lead compounds (as Pb)	44.9	45.5	49.5	49.5	48.1	47.5	49.7
Nickel compounds (as Ni)	22	23	25	25	24	24	25
Selenium compounds (as Se)	4	5	5	5	5	5	5
Zinc compounds (as Zn)	4,286	4,341	4,726	4,741	4,608	4,555	4,748
Phenanthrene	1.0	1.0	1.2	1.2	1.2	1.2	0.1
Anthracene	3.0	3.1	3.6	3.8	3.7	3.7	0.4
Fluoranthene	2.5	2.6	3.0	3.1	3.1	3.1	0.3
Chrysene	7.5	7.9	9.2	9.6	9.4	9.4	1.0
Benzo[a]anthracene	5.7	6.1	7.1	7.3	7.2	7.2	0.8
Benzo[a]pyrene	4.1	4.4	5.1	5.3	5.2	5.2	0.6
Benzo[b]fluoranthene	11	12	13	14	14	14	2
Benzo[k]fluoranthene	5.0	5.3	6.1	6.4	6.2	6.2	0.7
Benzo[ghi]perylene	9	9	11	11	11	11	1
Indeno[1,2,3-cd]pyrene	0.9	1.0	1.1	1.2	1.1	1.1	0.1
Naphthalene	3.3	3.5	4.0	4.2	4.1	4.1	0.5
Coarse particulates	449,332	454,719	494,574	495,306	481,183	475,344	496,847

Table B8: Emissions from heavy road vehicles to surface waters within rural areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.2	0.2	0.2	0.2	0.1	0.1	0.2
Arsenic compounds (as As)	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Cadmium compounds (as Cd)	0.2	0.2	0.2	0.2	0.1	0.1	0.2
Chromium compounds (as Cr)	1.9	2.0	1.8	1.5	1.5	1.4	1.5
Copper compounds (as Cu)	9.6	9.8	8.8	7.7	7.4	7.2	7.5
Lead compounds (as Pb)	19.2	19.6	17.6	15.4	14.7	14.4	15.0
Nickel compounds (as Ni)	10	10	9	8	7	7	8
Selenium compounds (as Se)	2	2	2	2	1	1	2
Zinc compounds (as Zn)	3,259	3,329	2,998	2,611	2,505	2,444	2,553
Phenanthrene	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Anthracene	0.4	0.4	0.4	0.4	0.4	0.4	0.0
Fluoranthene	0.3	0.4	0.4	0.3	0.3	0.3	0.0
Chrysene	1.0	1.1	1.1	1.0	1.0	1.0	0.1
Benzo[a]anthracene	0.8	0.9	0.8	0.8	0.8	0.8	0.1
Benzo[a]pyrene	0.6	0.6	0.6	0.6	0.6	0.6	0.1
Benzo[b]fluoranthene	1.5	1.6	1.6	1.5	1.5	1.5	0.2
Benzo[k]fluoranthene	0.7	0.7	0.7	0.7	0.7	0.7	0.1
Benzo[ghi]perylene	1.2	1.3	1.3	1.2	1.2	1.2	0.1
Indeno[1,2,3-cd]pyrene	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Naphthalene	0.5	0.5	0.5	0.5	0.4	0.4	0.1
Coarse particulates	191,712	195,824	176,326	153,574	147,377	143,791	150,148

Table B9: Emissions from light road vehicles to soil within rural areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	4.0	4.1	4.5	4.5	4.3	4.3	4.5
Arsenic compounds (as As)	4.0	4.1	4.4	4.4	4.3	4.3	4.5
Cadmium compounds (as Cd)	4.0	4.1	4.5	4.5	4.3	4.3	4.5
Chromium compounds (as Cr)	40	41	45	45	43	43	45
Copper compounds (as Cu)	202	205	223	223	217	214	224
Lead compounds (as Pb)	404	409	445	446	433	428	447
Nickel compounds (as Ni)	202	205	223	223	217	214	224
Selenium compounds (as Se)	40	41	45	45	43	43	45
Zinc compounds (as Zn)	38,575	39,069	42,530	42,667	41,475	40,992	42,734
Phenanthrene	9	9	11	11	11	11	1
Anthracene	27	28	33	34	34	33	4
Fluoranthene	22	23	27	28	28	28	3
Chrysene	67	71	83	86	85	84	9
Benzo[a]anthracene	52	55	64	66	65	65	7
Benzo[a]pyrene	37	40	46	48	47	47	5
Benzo[b]fluoranthene	99	104	121	126	124	124	14
Benzo[k]fluoranthene	45	47	55	57	56	56	6
Benzo[ghi]perylene	78	83	96	100	98	98	11
Indeno[1,2,3-cd]pyrene	8	9	10	10	10	10	1
Naphthalene	30	31	36	38	37	37	4
Coarse particulates	4,043,988	4,092,474	4,451,164	4,457,758	4,330,651	4,278,099	4,471,621

Table B10: Emissions from heavy road vehicles to soil within rural areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	1.7	1.8	1.6	1.4	1.3	1.3	1.4
Arsenic compounds (as As)	1.4	1.4	1.3	1.1	1.1	1.0	1.1
Cadmium compounds (as Cd)	1.7	1.8	1.6	1.4	1.3	1.3	1.4
Chromium compounds (as Cr)	17	18	16	14	13	13	14
Copper compounds (as Cu)	86	88	79	69	66	65	68
Lead compounds (as Pb)	173	176	159	138	133	129	135
Nickel compounds (as Ni)	86	88	79	69	66	65	68
Selenium compounds (as Se)	17	18	16	14	13	13	14
Zinc compounds (as Zn)	29,332	29,961	26,978	23,497	22,549	22,000	22,973
Phenanthrene	1.2	1.3	1.3	1.2	1.2	1.2	0.1
Anthracene	3.7	4.0	4.0	3.7	3.6	3.6	0.4
Fluoranthene	3.0	3.3	3.2	3.0	2.9	2.9	0.4
Chrysene	9.4	10.2	10.1	9.4	9.2	9.1	1.1
Benzo[a]anthracene	7.1	7.7	7.6	7.1	6.9	6.9	0.8
Benzo[a]pyrene	5.1	5.6	5.5	5.1	5.0	5.0	0.6
Benzo[b]fluoranthene	14	15	15	14	13	13	2
Benzo[k]fluoranthene	6.2	6.7	6.7	6.2	6.1	6.0	0.7
Benzo[ghi]perylene	11	12	12	11	11	11	1
Indeno[1,2,3-cd]pyrene	1.1	1.2	1.2	1.1	1.1	1.1	0.1
Naphthalene	4.1	4.4	4.4	4.1	4.0	4.0	0.5
Coarse particulates	1,725,409	1,762,419	1,586,931	1,382,166	1,326,393	1,294,120	1,351,332

Table B11: Emissions from light road vehicles to atmosphere within rural areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.2	0.2	0.3	0.3	0.2	0.2	0.3
Arsenic compounds (as As)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cadmium compounds (as Cd)	0.2	0.2	0.3	0.3	0.2	0.2	0.3
Chromium compounds (as Cr)	2.3	2.3	2.5	2.5	2.5	2.4	2.5
Copper compounds (as Cu)	11	12	13	13	12	12	13
Lead compounds (as Pb)	22.8	23.1	25.2	25.3	24.6	24.3	25.3
Nickel compounds (as Ni)	11	12	13	13	12	12	13
Selenium compounds (as Se)	2	2	3	3	2	2	3
Zinc compounds (as Zn)	2,175	2,208	2,410	2,420	2,353	2,325	2,421
Phenanthrene	0.5	0.5	0.6	0.6	0.6	0.6	0.1
Anthracene	1.5	1.6	1.9	1.9	1.9	1.9	0.2
Fluoranthene	1.2	1.3	1.5	1.6	1.6	1.6	0.2
Chrysene	3.8	4.0	4.7	4.9	4.8	4.8	0.5
Benzo[a]anthracene	2.9	3.1	3.6	3.7	3.7	3.7	0.4
Benzo[a]pyrene	2.1	2.2	2.6	2.7	2.7	2.7	0.3
Benzo[b]fluoranthene	5.6	5.9	6.9	7.1	7.0	7.0	0.8
Benzo[k]fluoranthene	2.5	2.7	3.1	3.2	3.2	3.2	0.4
Benzo[ghi]perylene	4.4	4.7	5.5	5.7	5.6	5.6	0.6
Indeno[1,2,3-cd]pyrene	0.5	0.5	0.6	0.6	0.6	0.6	0.1
Naphthalene	1.7	1.8	2.1	2.1	2.1	2.1	0.2
Fine particulates (PM10)	227,970	231,233	252,145	252,767	245,579	242,579	253,285
Fine particulates (PM2.5)	45,594	46,247	50,429	50,553	49,116	48,516	50,657

Table B12: Emissions from heavy road vehicles to atmosphere within rural areas (kg/year)

Substance	1990	1995	2000	2004	2005	2006	2015
Antimony compounds (as Sb)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Arsenic compounds (as As)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cadmium compounds (as Cd)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Chromium compounds (as Cr)	1.0	1.0	0.9	0.8	0.8	0.8	0.8
Copper compounds (as Cu)	5.1	5.2	4.7	4.1	3.9	3.8	4.0
Lead compounds (as Pb)	10.2	10.4	9.4	8.2	7.9	7.7	8.0
Nickel compounds (as Ni)	5	5	5	4	4	4	4
Selenium compounds (as Se)	1	1	1	1	1	1	1
Zinc compounds (as Zn)	1,736	1,774	1,598	1,391	1,335	1,303	1,360
Phenanthrene	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Anthracene	0.2	0.2	0.2	0.2	0.2	0.2	0.0
Fluoranthene	0.2	0.2	0.2	0.2	0.2	0.2	0.0
Chrysene	0.6	0.6	0.6	0.6	0.5	0.5	0.1
Benzo[a]anthracene	0.4	0.5	0.5	0.4	0.4	0.4	0.0
Benzo[a]pyrene	0.3	0.3	0.3	0.3	0.3	0.3	0.0
Benzo[b]fluoranthene	0.8	0.9	0.9	0.8	0.8	0.8	0.1
Benzo[k]fluoranthene	0.4	0.4	0.4	0.4	0.4	0.4	0.0
Benzo[ghi]perylene	0.6	0.7	0.7	0.6	0.6	0.6	0.1
Indeno[1,2,3-cd]pyrene	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Naphthalene	0.2	0.3	0.3	0.2	0.2	0.2	0.0
Fine particulates (PM10)	102,141	104,335	93,973	81,851	78,550	76,643	80,019
Fine particulates (PM2.5)	20,428	20,867	18,795	16,370	15,710	15,329	16,004