Emission estimates for diffuse sources
Netherlands Emission Inventory

Coal tar based coating, inland navigation

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NETHERLANDS NATIONAL WATER BOARD - WATER UNIT
In cooperation with DELTARES and TNO

Coal tar based coating, inland navigation

1 Description of emission source

This fact sheet provides a calculation method for emissions caused by the leaching of paint products applied to professional inland vessels when they are being hosed down, moored in port or while sailing. This document is limited to PAH-based coatings. Epoxy/bitumen coatings are alternatives containing no PAHs or only trace amounts of PAHs.

Wear on PAH-based coatings of inland vessels is a significant diffuse source of PAH emissions into surface waters. Although new application of PAH-based coatings has been prohibited in the Netherlands since 1996, the national inspection campaign conducted by the department of Public Works & Water Management in 2002 revealed that some inland vessels (12%) are still protected by PAH-based coatings (coal tar) [1].

This emission source is allocated to the governmental target sector “Transport” within the National Emission Inventory. This fact sheet does not address emissions caused by the leaching of paint products on pleasure craft.

This document is limited to the PAH-based coatings because there is insufficient reliable data on other coatings that may be found in use in professional inland navigation, such as copper-based coatings.

2 Explanation of calculation method

Emissions are calculated by a simple method which involves multiplying an activity rate (AR), in this case the "wet surface area x route covered" of inland vessels on Dutch routes, by an emission factor (EF) per substance, expressed in emission per unit of AR. The effects of the policy measures are processed as a degree of penetration in the occurrence of PAH-based coatings as compared to alternatives.

$$E_s = AR \times F_t \times EF_{t,,s}$$

Where:

E_s = Emission of substance (s), in kg
AR = Wet surface area x route covered on Netherlands route, in m^2-km
F_i = Degree of penetration of coating type t (fraction)
$EF_{t,,s}$ = Emission factor for coating t and substance s, in kg /m^2-km

The emission calculated in this way is referred to as the total emission. As it relates to direct discharge into surface waters, the total emission is the same as the net load of the surface water.

3 Activity Rates

The activity rate is the total number of kilometres of wet ship area on inland routes. This activity rate, "m^2-km of wet surface area," is determined by multiplying the number of route travel kilometres per CBS ship class [3] by the number of m^2 per ship per CBS class, taking into account the loaded and empty journeys.

The surface area of a ship is calculated according to Mumford's equation [2]:

surface area = L x (1.7 x D + B)

Where:

L = length (m)

D = depth (m)

B = width (m)

The number of m^2 per ship and CBS class is shown in the table below.

Table 1: CBS classification of inland vessels and number and surface area in 2000 [3]*

CBS Class	Number of vessels	Surface area [m^2]	m^2/vessel (average)
CBS_1	839	209,192	249
CBS_2	1094	407,819	373
CBS_3	1156	607,349	525
CBS_4	1341	1,020,722	761
CBS_5	1616	1,685,080	1043
CBS_6	612	790,362	1291
CBS_7	770	1,223,751	1589
CBS_8	132	252,893	1916

* including foreign ships on Dutch waterways

This classification is used to derive a weighted number of "m^2-km of wet surface area," loaded and unloaded, per year and across the various classes, and determine the nature of the route (inland or foreign). This derivation assumes that the wet surface area of an unloaded ship is half that of a loaded ship:

wet surface area x route covered loaded $= \Sigma_{class}$ travel kilometres per CBS vessel class full x number of m^2 per vessel per CBS class

wet surface area x route covered unloaded $= 0.5 \times \Sigma_{class}$ travel kilometres per CBS vessel class empty x number of m^2 per vessel per CBS class

The total "m^2-km of wet surface area" is the sum of the loaded and unloaded "m^2-km of wet surface area."

Finally, the activity rate "m^2-km of wet surface area on inland route" is obtained by multiplying the percentage of inland route [3] by the total "m^2-km of wet surface area." See the table below. The percentage of inland route is the percentage of wet surface area times route traversed (m^2-km) that takes place in the Netherlands. This differs from the percentage duration in the Netherlands used for the calculation of emissions of discharge of domestic waste water from shipping vessels, which is based on a percentage of the kilometres travelled.

Table 2: Wet surface times x route traversed (m^2-km) and percentage of inland route

Wet surface times x route traversed (m^2-km) and percentage of inland route		
Year	wet surface area x route covered (m^2-km)	% inland route [3]
1985	1.33E+11	44%
1990	1.31E+11	44%
1995	1.22E+11	42%
2000	1.30E+11	45%
2005	1.06E+11	43%
2006	1.16E+11	49%

The resulting activity rate "m^2-km wet surface area on inland route" is shown in the table below.

Table 3: Activity rate, wet surface area x route covered (m^2-km) on inland route

Activity Rate **Wet surface area x route covered (m^2-km) on inland route**	
year	
1985*	5.82E+10
1990*	5.73E+10
1995	5.17E+10
2000	5.87E+10
2005	4.55E+10
2006	5.67E+10

* For the period 1985-1993, the activity rate is estimated based on the number of active Dutch inland vessels, indexed at 1994 [4]. For the division of Dutch and foreign routes, the division prior to 1994 (44%) is used.

4 Emission factors

Emission factors, PAH-based coating
To determine an emission factor in keeping with the activity rate "wet surface area times route covered," the emissions determined for 1995 via the previous protocol [2] (prior to the effective date of the PAH decree, 1996) are assumed.

In 1995, an emission factor of 4 kg PAH-10 per active inland vessel was used for PAH-10 [7] and there were 9030 active inland vessels, which covered a total of 122 billion km of wet ship area.

The emission factor for PAH-10 [4] is adjusted to the activity rate "wet surface area times route covered." For this adjustment, this value is converted for the base year 1995:

Emission factor, PAH-10	=	4 kg PAH-10 per inland vessel	x	9030 inland vessels	/	$1.22\ .10^{11}$ m^2 km	=	$2.96\ 10^{-7}$ kg PAK 10 per m^2 km

A composition profile is used to derive emission factors for the individual PAHs from this emission factor for PAH-10. The profile for PAH-based coatings is derived form the Ministry of Housing, Spatial Planning & the Environment's Coal Tar Chain Management Study [5].

Emission factors for bitumen coating
The emission factors for PAHs from bitumen coating are based on a composition profile for bitumen from the Emission Inventory [6]. This composition profile is then assigned to the standards that apply according to the PAH decree for the individual PAHs in coating. These standards are (per kg of coating) no more than 150 mg Anthracene, 500 mg Phenathrene, 150 mg Fluoranthene and no more than 50 mg for the sum of Benzo[a]anthracene, Chrysene, Benzo[k]fluoranthene, Benzo[a]pyrene, Benzo[g,h,i]perylene and Indeno[1,2,3-cd]pyrene.

The table below shows the composition profiles for PAH-based and bitumen-based coating.

Table 4: Profiles, PAH coating and bitumen coating and requirements under PAH decree

PAH	**PAH coating [5]**	**Bitumen [6]**
	%	**%**
Naphthalene	66%	
Anthracene	3.2%	
Phenanthrene	6.5%	14.8%
Fluoranthene	6.5%	10.1%
Benzo[a]anthracene	3.2%	4.8%
Chrysene	3.2%	20.1%
Benzo[k]fluoranthene	1.6%	10.1%
Benzo[a]pyrene	3.2%	10.1%
Benzo[g,h,i]perylene	3.2%	20.1%
Indeno[1,2,3-cd]pyrene	3.2%	10.1%

The emission factor for PAH-10 for bitumen is determined by scaling the emission factor for PAH-based coating (170,000 mg/kg) at the maximum PAH content according to the PAH-resolution. Under the PAH-resolution, bitumen may contain a maximum of 850 mg PAH/kg in coating.

Using the composition profiles and the emission factors for PAH-10, the individual emission factors are then calculated for the individual PAHs in PAH-based coating and in bitumen coating, by applying the formula

$$EF_{PAH\ i} = EF_{PAH10} * PAH\%_{,i}$$

Table 5: Emission factors, PAH coating and bitumen coating in kg/m2-kmt

PAH	EF PAH-coating	Bitumen coating
Total (PAH 10)	2.96E-07	1.48E-09
Naphthalene	1.96E-07	
Anthracene	9.56E-09	2.19E-10*
Phenanthrene	1.91E-08	1.49E-10
Fluoranthene	1.91E-08	7.05E-11
Benzo[a]anthracene	9.56E-09	2.97E-10
Chrysene	9.56E-09	1.49E-10
Benzo[k]fluoranthene	4.69E-09	1.49E-10
Benzo[a]pyrene	9.56E-09	2.97E-10
Benzo[g,h,i]perylene	9.56E-09	1.49E-10
Indeno[1,2,3-cd]pyrene	9.56E-09	1.48E-09

* A computational error came into the calculation of the emission factors, by which emission factors were assigned to PAH-10 components that have no source of emission. This will be accounted for in the following version of this fact sheet.

The epoxy coatings contain no PAH at all.

5 Effects of policy measures

Calculating the PAH emission requires an estimate of the ratio of the various types of coatings in use in inland navigation. Under the Environmentally Hazardous Substances Act, use of PAH-based coatings has been prohibited since 1 July 1997. This means that virtually all inland vessels were protected with a PAH-based coating up until 1996. The average lifetime of a PAH-based coating is approximately 3 years. For the period after 1996, when PAH-based coatings could no longer be applied in the Netherlands, these coatings will therefore have been gradually replaced by alternatives. The 2002 national inspection campaign by the department of Public Works & Water Management [1] revealed that in 2002, 12% of inland vessels were still protected by PAH-based coatings. It is also assumed that the method of applying the coating determines what type of coating is used. Of the users using a substitute product, 20% applied it themselves and 52% had the coating applied by a shipyard. For the remainder of inland vessels, the type of coating applied is less clear, and combinations may be in use. It is assumed that users who apply their coating themselves do so with the easier to use bitumen coating, and that shipyards apply primarily epoxy coatings. For 2002, it can be reported that 23% of inland vessels were protected with bitumen coating and 65% of vessels were protected with epoxy coating. For the years 1997-2002, an assumption was made of how the phase-out of PAH-based coatings and increase of alternative bitumen and epoxy coatings could have taken place. See the table below.

Table 6: Proportions of coating types from 1985 on

year	PAH coating	Bitumen	Epoxy
1985	100 %	0 %	0 %
1990	100 %	0 %	0 %
1993	100 %	0 %	0 %
1994	100 %	0 %	0 %
1995	100 %	0 %	0 %
1996 [1]	100 %	0 %	0 %
1997	80 %	5 %	15 %
1998	60 %	10 %	30 %
1999	40 %	15 %	45 %
2000	12 %	20 %	60 %
2001	12 %	23 %	65 %
2002 [2]	12 %	23 %	65 %
2003	12 %	23 %	65 %
2004	12 %	23 %	65 %
2005	12 %	23 %	65 %
2006 [9]	12 %	23 %	65 %

A study of ships conducted by the department of Public Works & Water Management's Water Unit [9] indicates that the values for 2006 correspond to the reported data. A forecast for 2007 (as actual data for 2007 are not yet available) points to a drop in the percentage of PAH coating, to 6%. A study consisting of interviews with boat masters suggests coating types as indicated in the table below:

Table 7: Forecast of proportions of coating types from 2007 on

Type of coating	Number	Percentage
Epoxy	51	41
Bitumen (low PAH content)	28	23
PAH-based	7	6
Chlorinated rubber	4	3
Other	6	5
Unknown	27	22

It should be noted, however, that a margin of error of 9% must be allowed for these values. The percentage of epoxy coating appears to drop from 2006 to 2007, as does the percentage of PAH-based coating. However, the amount of data on which these forecasts are based does not guarantee sufficient certainty to change the percentages. The epoxy coating is the exception, but because this coating is not a source of PAH emission, this is less relevant.

6 Emissions calculated

The table below shows annual emissions for the various substances expressed in kg/year. The emissions are calculated by multiplying the emission factors by the activity rate.

[1] Effective date PAH resolution

[2] PAK-inventarisatie Landelijke Actie 2002, RWS [1]. In May 2007 a new PAH inventory is executed by the Netherlands National Water Board. Therefore, the percentage of PAH coating has remained equal to that of 2002.

The occurrence of these coatings and the activity rate can then be used to calculate the PAH emission using the emission factors for the individual PAHs for the various types of coating. See the table below.

Table 8: Estimated emission of PAH from coatings of inland vessels (kg/year)

Year	total (PAH 10)	Naphthalene	Anthracene	Phenanthrene	Fluoranthene	Benzo[a]anthracene	Chrysene	Benzo[k]fluoranthene	Benzo[a]pyrene	Benzo[g,h,i]perylene	Indeno[1,2,3-cd]pyrene
1985	17,205	11,372	556	1,112	1,112	556	556	273	556	556	556
1990	16,964	11,213	548	1,096	1,096	548	548	269	548	548	548
1995	15,288	10,105	494	988	988	494	494	243	494	494	494
2000	3,489	2,295	115	226	225	116	114	57	116	114	130
2005	1,630	1,067	54	106	105	55	54	27	55	54	68
2006	1,025	665	35	67	66	36	34	18	36	34	51

7 Release into environmental compartments

The full amount of the emissions identified here is discharged to the surface water. Emissions to the soil are assumed to be negligible.

8 Emission pathways to water

The emissions calculated here are direct emissions to water.

9 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 [11] 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.
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 9: Summary of spatial allocation method

Element	Locators
Coating, inland navigation	Professional inland navigation

The method used to determine the locators is described in [13]:

Professional inland navigation
The allocation is determined by multiplying the number of vessels per waterway segment by the length of that segment (in kilometres). A distinction is made between push-towing and other inland navigation.
The latter category is in turn subdivided into two classes based on cargo capacity.

Data on numbers of inland vessels originate from Statistics Netherlands (CBS); location and length of shipping lanes originate from the National Roads Database.

10 Comments and changes in regard to previous version

In the present document, the "total number of kilometres of wet ship area on inland routes" is used as the activity rate. A previous version of this document [4] used the "number of active Dutch inland vessels" as activity rate. The new activity rate only takes into account the inland routes traversed by the ships. Additionally, the new activity rate takes into account the emissions originating from foreign inland vessels in the Netherlands.

11 Accuracy and indicated subjects for improvement

The method used in the Emission Inventory publications has been followed as far as possible in classifying the quality of information [8]. 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.

In general, we can conclude that the emission factors are based on a limited number of measurements of several years ago, which have been extrapolated to the present based on certain assumptions. This means that we can classify the emission factors in category C. The activity rate is updated by Statistics Netherlands regularly, and can be classified under category A.
As far as the distribution of emissions among individual compartments and emission pathways is concerned, it is clear that all the emissions directly enter the surface water, so category A applies here. Finally, the spatial allocation of emissions is ultimately fairly reliable, so the reliability classification is B.

Element of emission calculation	Reliability class
Activity Rates	A
Emission factors	C
Distribution among compartments	A
Emission pathways to water	A
Spatial allocation	B

The main areas where improvements could be made are:
- Periodic monitoring of the use of different types of coatings on a representative selection of sailing inland vessels could improve the present assessment of emissions
- This document is limited to the PAH-based coatings because there is insufficient reliable data on other coatings that may be used in professional inland navigation, such as copper-based coatings
- The computational error in the calculation of the emission factors could be repaired. The percentages as given in table 4 are correct, but the emission factors in table 5 must be corrected
- The data from the department of Public Works & Water Management's Water Unit [9] should be adopted

12 Request for reactions

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13 References

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