Emission estimates for diffuse sources
Netherlands Emission Inventory

Antifoulants in marine coatings, recreational boats

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In cooperation with DELTARES & TNO

Antifoulants in marine coatings, recreational boats

1 Description of emission source

The emission source covers emissions caused by the leaching of paint products applied to recreational boats when they are being hosed down, moored in port or while travelling.
This emission source is allocated to the governmental target sector "Transport" within the Dutch Pollution Release and Transfer Register (PRTR), called Emission Inventory.

2 Explanation of calculation method

Emissions are calculated by multiplying an activity rate (AR), in this case the number of recreational boats in the Netherlands, by an emission factor (EF) per substance, expressed in emission per AR unit. The effects of the measures are taken into account in the emission factors. This method of calculation is explained in detail in the Guide to the Regional approach to diffuse sources [20].
The emission calculated in this way is referred to as the total emission. As it relates to direct discharge to surface waters, the total emission is the same as the net contamination of the surface water.

3 Activity rates

For the period from 1975 to 1990, the number of craft derived from [20] is applied in combination with interpolation of the years 2004 and 1997. The number of recreational boats in 1997 is based on a number of estimates and determined by the Netherlands Recreation Foundation [2].
According to [19] there were 187,740 recreational boats in use in 2004, and in the absence of more recent information this figure has been retained for subsequent years. The values for the interim period (1997 to 2004) have been interpolated.

It has been assumed that vessels that have been in dock for a prolonged period do not need antifoulant paint.

Table 1: Numbers of recreational boats in the Netherlands

Year	Activity rate (number of recreational boats)	Reference
1985	210,750	1
1990	217,750	1
1995	250,000	1
2000	231,889	2
2005	187,740	2
2006	187,740	2

4 Effects of policy measures

A number of measures have affected the use of certain types of antifoulant paint. These are:

- The introduction of copper-free antifoulant paint: The number of alternatives to copper-based antifoulant paint on the market has been increasing for a number of years. In reference [3, p. 39] it is estimated that in1995 about 20% of all antifoulant paint used contained no copper. Hardly any copper-free antifoulant paint had been used in 1990. The percentages for the period 1990 to 1995 have been determined by linear interpolation. It is assumed that the proportion of copper-free antifoulant paint used between 1996 and 1998 remained stable at 20%.
- A ban on copper-based antifoulant paint: The use of copper-based antifoulant paint on recreational boats was prohibited as from the start of 2001. This ban was reversed in 2005. The detailed history is as follows:
  2001: A survey conducted by the sailing magazine *Zeilen* in 2001 found that about half of all boats had an environmentally-friendly coating [4];
  2002: The Ministry of Housing, Spatial Planning and the Environment's inspectorate conducted an intensive enforcement campaign in 2002, removing copper-based products from the shelves. 128 businesses were visited during this operation, and 23 were found to be in violation of the regulations. This gives a compliance rate of 80% [5]. The magazine survey found a slightly lower percentage; 31% of the respondents said that they did still use copper-based paint [4]. However, the sailing magazine *Zeilen* took the view that the sample was not representative as vessels sailing in marine waters were over-represented. In addition, the survey only related to non-motorised craft. It was decided that the proportion of craft in 2002 that still had copper-based antifoulant paint was 25%;
  2004: The level of compliance with the prohibition on inland waterways in 2004 appeared to be good. Occasional instances of copper-based paints were seen in sea ports. Furthermore, copper-based paints were not prohibited in Belgium or Germany, so that vessels with a home port in those countries (3% of vessels in Dutch waters [b]) could still be treated with copper-based antifoulant paint [7]. In total, up to 14% of boats had been treated with such products in 2004;
- *2005*: The ban on copper-based antifoulant paint for recreational boats was rescinded for five brands of paint. This put a stop to the decline observed over previous years, and the figure remained at 14% in 2005.
- Ban on PAH-based coatings: With effect from 1/10/96, the maximum packing size of PAH-based coatings that could be held in store or sold was reduced to 25 litres. A complete ban on the use of these products took effect on 1/7/1997. Their use declined by 25% in 1996 and by 50% in 1997. The reduction stabilised at 80% as from 1998. A survey conducted by the sailing magazine *Zeilen* [4] in late 2002 found no cases of PAH-based coatings;
- Prohibition on organotin-based (TBT) antifoulant paint: The Netherlands banned the use of organotin on yachts less than 25 metres long as of 1/1/1990. It is assumed that the use of organotin-based antifoulant paint had already declined by 50% in 1990, and that it was no longer in use at all as from 1993.

The table below shows the estimated trend of antifoulant paint use over time.

Table 2: Distribution of antifoulant paints used on recreational boats (%)

Year	TBT/Cu-coating	PAH-coating	Cu-coating (TBT-free)	Cu-free coating
1985	96	4	0	0
1990	48	4	48	0
1995	0	4	77	19
1996	0	3	77	20
1997	0	2	78	20
1998	0	1	79	20
1999	0	1	77	22
2000	0	1	72	27
2001	0	0.4	48	52
2002	0	0.4	24	76
2003	0	0.4	19	81
2004	0	0.4	14	85
2005	0	0.4	14	85
2006	0	0.4	14	85

The percentages for the periods 1985 to 1990 and 1990 to 1995 have been interpolated.

5 Time series of activities

Using the emission factors for 1985 listed under section 4 and the reduction percentages listed under section 5, we can calculate a time series of vessel numbers with a particular type of antifoulant paint in the reference years.

Table 3: Number of recreational boats with various types of antifoulant paint

Year	TBT/Cu-coating	PAH-coating	Cu-coating (TBT-free)	Cu-free coating
1985	202,320	8,430	0	0
1990	104,520	8,710	104,520	0
1995	0	10,000	192,000	48,000
2000	0	1,855	166,960	63,074
2005	0	751	27,035	159,954
2006	0	751	27,035	159,954

6 Emission factors

Emissions from PAH coatings

The total consumption of PAH coatings in 1985 is estimated at 16,000 l (20,000 kg) [7]. Consequently, it is estimated that approximately 8,430 boats have a PAH coating. The inland shipping coating fact sheet [8] contains an estimate on average emissions of the 10 PAH substances designated by the Ministry of Housing, Spatial Planning and the Environment per vessel. This emission, based on an average surface area of 800 m^2 per vessel, is 4 kg per boat per year. On this basis, the equivalent emissions of these substances from recreational boats can be estimated at 0.1 kg. The table below gives a complete PAH emission profile for recreational boats.

Table 4: PAH emission profile for recreational boats (kg/year)

PAH	Emission (kg per recreational boat per year)
Naphthalene	0.06630
Anthracene	0.00324
Phenanthrene	0.00647
Fluoranthene	0.00647
Benzo[a]anthracene	0.00324
Chrysene	0.00324
Benzo[k]fluoranthene	0.00159
Benzo[a]pyrene	0.00324
Benzo[g,h,i]perylene	0.00324
Indeno[1,2,3-cd]pyrene	0.00324
Total (PAH 10)	0.10000

Emissions from TBT-based coatings

It is estimated that in 1985 emissions of copper and tin caused by leaching from copper- and/or TBT-based antifoulant paint was 18,500 kg/year and 770 kg respectively [5]. Regarding the number of boats in use in 1985 (excluding those with a PAH coating), this works out at 92.10^{-3} kg of copper and 3.810^{-3} kg of tin per boat per year.

Emissions from TBT-free coatings

Following the withdrawal of TBT, the copper content of TBT-free paint is around 25%. This number is based on information from a decision by the Netherlands Board for the Authorisation of Plant Protection Products and Biocides (CTB) [9], in which a clear prohibition was imposed on various antifoulant paints. Many of the products referred to in this letter were permitted for use on recreational boats. The CTB's plant protection product database showed their copper content to be around 25% [10]. A litre of antifoulant paint with this degree of copper content weighs 1.3 kg, making the copper content 330 g per litre.

Recreational boats in the Netherlands have an average underwater surface area of 22.5 m^2 [11]. Assuming that each boat receives on average one coat of antifoulant paint per year, the amount of antifoulant paint applied each year is 2.25 litres. Half of this wears off or dissolves, and as a result the annual copper emission is 375 g.

On the basis of the antifoulant paints currently permitted for use on various types of vessels, including recreational boats, on the CTB website [10], the following distribution can be calculated: 25% of boats are treated with a substance containing diuron, 25% with a substance containing triazine, and 2.5% with a substance containing zineb or ziram. In the case of antifoulant paints containing biocides, the biocide content is on average about 10% of the copper oxide content. It can therefore be estimated that for the period after 1993 diuron emissions are 4% of copper emissions (9 g per boat per year). Triazine emissions amount to 9 g per boat per year, and zineb and ziram emissions to 1 g per boat per year.

In addition, 25% of registered antifoulant paints also contain zinc oxide at a concentration of 30% of the copper content (28 g per boat per year).

Emissions from copper-free coatings

Copper-free antifoulant paints can be divided into hard, self-polishing and biocide-free types. The first group contains 9% dichlofluanid and the second group 32% dichlofluanid. According to Sikkens [12], about half of all copper-free antifoulant paints sold in 2004 were of the hard type, while 30% were self-polishing and the remainder were biocide-free. This means that on average copper-free antifoulant paints contain 5.5% dichlofluanid. Assuming consumption levels of 2 litres per boat per year and a loss of 50%, this gives dichlofluanid emission values of 55 g per boat per year.

Table 5: Emissions from TBT-based paints, copper-based paints and copper-free paints (in kg per boat per year)

Emission	TBT-based	Cu-based, TBT-free	Cu-free
tin	0.0038		
copper	0.092	0.375	
diuron		0.009	
triazine		0.009	
zineb		0.001	
ziram		0.001	
dichlofluanid			0.055

7 Emissions calculated

The tables below show annual emissions for the various substances expressed in kg/year. The emissions were calculated by multiplying the chronological series of activities in section 6 by the activity rate in section 3. The effects of the measures are already incorporated in the emission factors.

Table 6: PAH emissions (kg/year)

Year	Total (PAH 10)	Naphthalene	Anthracene	Phenanthrene	Fluoranthene	Benzo[a]anthracene	Chryse ne	Benzo[k]fluoranthene	Benzo[a] pyrene	Benzo-[g,h,i]pe-rylene	Indeno[1,2,3-cd]pyrene
1985	843	559	27	55	55	27	27	13	27	27	27
1990	871	577	28	56	56	28	28	14	28	28	28
1995	1,000	663	32	65	65	32	32	16	32	32	32
2000	186	123	6	12	12	6	6	3	6	6	6
2005	75	50	2	5	5	2	2	1	2	2	2
2006	75	50	2	5	5	2	2	1	2	2	2

Table 7 shows emissions of tin, copper and biocides.

Table 7: Tin, copper and biocide emissions (kg/year)

Year	Tin	Copper	Diuron	Triazine	Zineb	Ziram	Dichlofluanid
1985	769	18,613	0	0	0	0	0
1990	397	48,811	941	941	105	105	0
1995	0	72,000	1,728	1,728	192	192	2,640
2000	0	62,610	1,503	1,503	167	167	3,469
2005	0	10,138	243	243	27	27	8,797
2006	0	10,138	243	243	27	27	8,797

8 Release into environmental compartments

All the emissions produced by leaching of antifoulant paint on recreational boats directly enter the surface water.

9 Description of emission pathways to water

The emissions calculated here are direct emissions to water.

10 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) 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 and area of agricultural crops. 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 [18] 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 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. A survey conducted by Alterra found that the recreational boats are used about 59 days a year [13]. This means that the boats spend 84% of their time in yacht-basins. The number of docking sites is a significant factor in the distribution of emissions in yacht-basins, with recreational boats being the primary source. The data underlying this number came from the Recreation Knowledge and Information Centre and can be accessed via the Spatial Planning Policy Support and Information System (BORIS) [17].
By analogy with leaching of TBT in the MAM-PEC model [14], leaching levels are about three times higher from boats that are in use than from boats tied up in port. This means that overall 50% of leaching takes place in yacht-basins and 50% on the waterways. Therefore, 50% of the spatial allocation of emissions is based on the number of dockings in yacht-basins and 50% on the distribution of pathways actually taken, as shown in [14], taking data from the Transport Research Centre [15] into account.

11 Comments and changes in regard to previous version

In the past, emissions from antifoulant paint were calculated as activity multiplied by the emission factor. Policies (prohibition of TBT- and copper-based antifoulant paint) had an impact on the emission factor. The method has now switched to a system in which activity (the number of boats) is divided into sub-categories for each coating type. It takes greater account of surveys, such as those conducted on a fairly regular basis by the magazine *Zeilen*. Emission factors can be determined with greater reliance on methods used elsewhere, based on the total area of a particular coating type in use.
Emission factors per boat have been derived, based on an average underwater surface area per recreational boat of 22.5 m^2, for the five coating types (PAH coating, TBT-based coating, TBT-free coating, copper-based coating and copper-free coating). This approach was adopted in 2007.

New information on the number of recreational boats in use in the Netherlands became available in 2005 [19]. They were applied to the years 2005 and 2006 in the course of 2008.

12 Accuracy and indicated subjects for improvement

The method used in Emission Registration publications has been followed as far as possible in classifying the quality of information [16]. 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.

Though the reliability of the emission factors can vary considerably for individual substances and in different years, we can conclude that in general the emission factors are based on a limited number of measurements taken a few years ago that have been extrapolated to the present day on the basis of assumptions. This means that we can classify the emission factors in category C. The same applies to the activity rate.

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 still somewhat unreliable (reliability class D).

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

The main areas where improvements could be made are:
- Improving information about the effects of measures by monitoring the consumption of copper-based and copper-free coatings and biocide-free coatings in the recreational boats sector;
- Improving information about the distribution of various types of antifoulant paint;
- Improving spatial allocation by means of recreational boats countings;

13 Request for reactions

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14 References

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