Emission estimates for diffuse sources
Netherlands Emission Inventory

Oil spills by shipping on the Netherlands Continental Shelf

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

Oil spills by shipping on the Netherlands Continental Shelf

1 Description of emission source

These are emissions resulting from the discharge of oil-contaminated water on the Netherlands Continental Shelf (NCP) as evidenced by observations from air surveillance. The most likely emission source of these oil observations is the shipping sector. The emissions from ships may occur in various ways:

- normal, permitted discharges from oil-water separator systems on board
- illegal discharges of bilge water
- illegal discharges of oil sludges remaining after purification of heavy fuel oil on board
- illegal discharges of leachate and ballast water
- discharges resulting from emergencies

Because the observations of oil slicks are the basis used, no distinction of the underlying causes can be made.
This emission source is allocated to the governmental target sector "Transport" within the national emissions inventory.

2 Explanation of calculation method

Determining the emissions involves the simple calculation of multiplying an activity rate (AR), in this case the amount of mineral oil spilled on the NCP as estimated based on observations and extrapolation, with an emission factor (EF) for each substance, expressed in emission per unit of AR, in this case the average content of individual PAH in mineral oil.

The assumption is that by far the bulk of the oil discharged at sea consists of mineral oil.
The PAH emission is then calculated by multiplying the mineral oil emission by the average PAH content of the mineral oil, using the formula:
PAH emission = mineral oil emission * PAH content of mineral oil

The average PAH content of the mineral oil was obtained by making an assumption on the percentages of the various oil types in the oil slicks observed.
The emission calculated in this way is referred to as the total emission. Because this form of emission involves direct discharge into surface waters, the total emission is the same as the net load to the water.

3 Activity rates

The air observations made by RIKZ, the National Institute for Coastal and Marine Management (an agency of Public Works & Water Management), are described in a MARIN report [1]. The following passage is based on this report.
Oil slicks at sea are detected primarily using SLAR (Side Looking Airborne Radar). The observations were made during a range of different types of surveillance aircraft flights. The reports distinguished are:

- Remote sensor reports: during flights in which pollution sites are only counted;
- NAT-reports: in the national administration flights (NAT), flights follow a more or less fixed pattern at a considerable height; Observing pollution sites is one of the tasks of these flights. Larger sites are verified visually, which means that the oil slicks can be inspected by the Coast Guard at a closer distance;
- SHIP reports: these are identified during the Shipping Policy Plan flights. During these flights, the aircraft descends towards selected ships and conducts visual checks.

In NAT flights, the aircraft flies higher so it is able to scan for pollution over a wider area. Additionally, there is no stopping at each ship, as with (SHIP), so a much greater forward distance per flight hour can be covered. The NAT reports make up a multi-year reliable consistent measurement series.
The observations are indexed in the categories "pollutants" and "oil contamination." The following "pollutants" are classed outside of the category of "oil contamination."

- contaminations of unknown nature or not verified
- vegetable or animal oils
- chemicals

Table 1 shows a list of the observation results [2] of the NAT flights reported over a long series of years. This shows that the number of observations per flight hour has been approximately cut in half in a period of twelve years. It also shows that the volume of the average oil slick has diminished by a factor of nearly 10.

Table 1 Overview of observations from NAT flights concerning oil stains

Year	Flight	Oil slicks	Total oil slick surface	Total oil slick volume	N Number of oil slicks	Oil slick surface	Oil slick volume	V Estimated volume per oil slick
	Hours	Number	km^2	m^3	Slicks/ flight hour	Per flight hour	m^3 per flight hour	m^3/slick
1992	236	66	83.03	214.88	0.28	0.35	0.91	3.3
1993	497	118	103.72	250.86	0.24	0.21	0.5	2.1
1994	405	103	71.39	112.03	0.25	0.18	0.28	1.1
1995	478	83	63.6	177.76	0.17	0.13	0.37	2.2
1996	477	86	112.49	96.98	0.18	0.24	0.2	1.1
1997	693	124	176.85	142.16	0.18	0.26	0.21	1.2
1998	579	75	80.8	42.62	0.13	0.14	0.07	0.5
1999	545	69	163.61	150.67	0.13	0.3	0.28	2.2
2000	586	127	127.85	85.04	0.22	0.22	0.15	0.7
2001	551	77	128.79	70.34	0.14	0.23	0.13	0.9
2002	473	44	33.69	19.23	0.09	0.07	0.04	0.4
2003	484	69	64.89	33.59	0.14	0.13	0.07	0.5
2004	608	65	66.42	25.71	0.11	0.11	0.04	0.4
2005	663	55	72.25	40.05	0.08	0.11	0.06	0.7
2006	764	40	53.24	54.59	0.05	0.07	0.07	1.4

Helmers [3] statistically analyzed the NAT observations of oil slicks referenced above. For the years for which Helmers generated calculations, the results of the Helmers calculation model from table 4.1 are adopted in this fact sheet. This refers to the total estimated quantity of oil per year (TA) in cubic metres, taking into account the effects of wind and the average lifetime of oil slicks.
For the years for which Helmers did not perform a statistical analysis, this fact sheet introduces a simplified estimate method, by which the number of oil slicks observed per flight hour over an entire year (column N in table 1) is multiplied by the average volume of the observed oil slicks in a year (column V) and multiplied by a scale factor (S) of 13,000. The scale factor S is derived by correlating the Helmers results as closely as possible with the input data column V and column N (see table 1). The number of oil slicks observed per flight hour (column N in table 1) can be considered a good measure of the number of contaminations encountered in a year on average. This number is considered representative for the entire NCP surface. The average volume of the oil slicks (column V) is considered the determinate volume per slick in a given year. The scale factor S is necessary to project the number of slicks per flight hour into the total number of slicks on the entire NCP over a year.

The formula for estimating the volume of oil on the NCP is then:

$$O = N \times V \times S$$

Where:

O = estimated volume of oil (m^3/year-NCP)
N = number of slicks/flight hour (1/hour)
V = estimated volume per slick (m^3)
S = number of hours in a year/fraction of NCP covered per flight hour (13,000 is derived from Helmers' results)

Since a year exists of 8760 hours, the fraction of the NCP covered in an hour at a value of S = 13,000 is approximately 0.67 (two-thirds of the NCP).
Assuming that the busy shipping routes are the most relevant, this estimate may well be correct. However, the impression is that two-thirds of the NCP cannot be covered in a flight hour. This would mean that Helmers' estimate is on the low side.

Table 2 Estimated volume of oil discharges on the NCP (activity rate) based on information from National Administration Flights (m^3)

Year	Oil volume (m^3)	Source/Method
1990	20827	Extrapolation
1992	11830	Scaling
1993	8970	Helmers [3]
1994	5067	Helmers [3]
1995	2496	Helmers [3]
1996	2057	Helmers [3]
1997	2396	Helmers [3]
1998	1181	Helmers [3]
1999	1873	Helmers [3]
2000	1803	Helmers [3]
2001	1690	Scaling
2002	520	Scaling
2003	910	Scaling
2004	520	Scaling
2005	785	Scaling
2006	929	Scaling

NB: The volume for the year 1990 is based on an extrapolation of the trend line for the years 1992-2004.

In terms of size, the estimate of the volume of discharged oil is roughly of the same magnitude as a raw estimate by Wulffraat [4], whose estimate for the NCP was approximately 10,000 tonnes of oil (representing roughly 12,000 cubic metres) for the years 1980-1990. Compaan [5] estimated an amount between 5,000 and 14,000 tonnes for 1988, which is very much in line with Wulffraat's estimate.

4 Emission factors

Estimating the average PAH composition of the oil slicks observed is extremely difficult, being that the source of the oil is by no means known in all cases. Nonetheless, this fact sheet makes an attempt to produce an average weighted PAH profile by combining the profiles of various individual components. Firstly, PAH contents for the individual PAHs in various types of oil were obtained from the literature. Next, a variety of references to the literature were used to make an estimate of the components of different types of oil. It can be concluded from the cited report by MARIN [1] that the share of oil discharged as the result of an emergency will be approximately equal to the "operationally" discharged oil.

For this reason, the percentage of the category of oil sludges and tanker leachate is set at 50. Next, an American publication [7] was used to determine the relative percentage of emergency fuel discharges and crude oil.

Reference [6] table E.18 assigns 36% to crude oil, 25% for diesel and light fuel oil combined and 36% for heavy fuel oil. In the table below, these percentages are halved due to the assumed percentage of oil sludges and tanker leachate.

Table 3 Estimate of average content of PAH components in oil discharges (mg/kg)

Substance/Oil type	**Marine diesel oil**	**Heavy fuel oil**	**Crude oil**	**Oil sludges and tanker leachate**	**Average oil discharge**
Assumed share in oil slicks	14%	18%	18%	50%	100%
Density (kg/L)	0.85	0.9	0.85	0.85	0.86
Reference PAH content	**[8]**	**[9]**	**[10]**	**[10]**	**Weighted average**
PAH	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Naphthalene	1080	1000	430	44	430.6
Phenanthrene	750	480	150	55	245.9
Anthracene	150	170	4.3	2	53.4
Fluoranthene	100	240	2	2	58.6
Chrysene	10	196	30	12	48.1
Benzo[a]anthracene	20	90	3	3	21.0
Benzo[b]fluoranthene	*15*	*25*	4	1.7	8.2
Benzo[k]fluoranthene	*15*	*25*	0.07	0.3	6.8
Indeno[1,2,3-cd]pyrene	*15*	*25*	0.08	0.2	6.7
Benzo[g,h,i]perylene	0.35	1	0.08	0.7	0.6
Benzo[a]pyrene	10	44	1.5	0.1	9.6

5 Effects of policy measures

The values presented in this fact sheet automatically express the effects of measures, because the values presented are based on observations.
Various measures probably have an impact on the amount of the activity rate. No doubt, one of the best measures is consistent enforcement of existing legislation [11], monitoring the sea and enforcement onboard ships in ports (Port State Control). In this regard we can also identify the implementation of the EU port reception facilities directive and the cooperation of ports in banning "rust-buckets" (http://www.parismou.org).
Additionally, the time and money involved in delivering waste products for collection in port presumably plays a major role in the conduct of shipping personnel [12]. Against the backdrop of fierce global competition, ships cannot allow any loss of time that could result from inefficiently organised collection of waste products. Each port exhibits marked differences in the way in which it implements the port reception facilities directive, both in terms of logistics of collection and rate-setting. In each port, the differences in both the method of collection and, to a lesser degree, the costs/fees involved, are fairly significant.

6 Time series of emission factors

Because there are no known steps that have an impact on the emission factors identified in section 4, the emission factors are assumed to be constant over time.

7 Emissions calculated

The table below shows the development of emissions over time. The emissions are calculated by multiplying the emission factors from table 3 by the activity rate (amount of oil observed) from table 2. The values for mineral oil are rounded to the nearest tonne; the PAHs are rounded to the nearest kg.

Table 4 Emissions of mineral oil and PAH resulting from oil discharges at sea, for reference years

Year Substance	1990	1995	2000	2005	2006
Mineral oil (tonne)	17890	2144	1549	675	799
Nafthalene (kg)	7704	923	667	291	344
Phenanthrene (kg)	4399	527	381	166	196
Anthracene (kg)	955	114	83	36	43
Fluoranthene (kg)	1048	126	91	40	47
Chrysene (kg)	860	103	74	32	38
Benzo[a]anthracene (kg)	376	45	33	14	17
Benzo[b]fluoranthene (kg)	146	18	13	6	7
Benzo[k]fluoranthene (kg)	121	14	10	5	5
Indeno[1,2,3-cd]pyrene (kg)	120	14	10	5	5
Benzo[g,h,i]perylene (kg)	11	1	0,9	0,4	0,5
Benzo[a]pyrene (kg)	172	21	15	6	8

The results shown in the table above correspond to a reasonable degree with previous estimates in the Target Group Study and North Sea shipping policy analysis [13], which, for 1987, identifies a range of benzo(a)pyrene of 123-128 kg per year and a range for fluoranthene of 595-1090 kg per year.
In 1993, Wulffraat [4] estimated the emission of benzo(a)pyrene from oil discharges on the North Sea at 60 kg per year. The amount estimated in table 4 is of a comparable order of magnitude.

8 Release into environmental compartments

The primary emission of the emission source discussed in this fact sheet is discharged entirely into the surface water. The secondary load of sea floor and air that can occur is not an element of this fact sheet.

9 Description of emission pathways to water

The full amount of the emissions is discharged directly into the surface water. There are no emissions of this type into the sewer system.

10 Spatial allocation

The spatial allocation of emissions is assigned on the basis of a set of digital maps held by the Netherlands Environmental Assessment Agency (PBL) drawn up using emission records. These maps present the spatial distribution of all kinds of parameters throughout the Netherlands, such as population density, traffic intensity, area of agricultural crops, etc. For the purposes of emission registration these maps are used as 'locators' to determine the spatial distribution of emissions. The range of possible locators is limited (see [15] for a list of available locators), as not every conceivable parameter can be used as a locator. In practice the locator judged to be the best proxy of the activity rate of the emission in question is applied for the distribution of emissions.
It is assumed that the distribution of emissions throughout the country is proportional to the national distribution of the locator.

In the emissions inventory database, the emissions of seagoing vessels are spatially allocated based on the fuel use per grid cell on the NCP. Because the pattern of oil discharges exhibits some similarity to the pattern of shipping routes, the emissions from oil discharges are likewise spatially allocated based on the fuel use per grid cell in the Emission Inventory.

11 Comments and changes in regard to previous version

There have been no changes made in the methodology for making estimates as compared to previous versions.

12 Accuracy

The method used in Emission Inventory publications has been followed as far as possible in classifying the quality of information [14].
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.

A classification of C can be applied for the activity rate, because the ultimately estimated quantity of oil is based on a mathematical model with a significant margin of uncertainty. The emission factors are based on a reasonable number of measurements of PAH content in oil.
The contents of heavy PAH are obtained based on estimates, combined with a number of assumptions. Consequently, a category of D must be assumed for the emission factors.
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. The spatial allocation of the emissions is not as reliable, because where the ships will discharge cannot be indicated in advance. The assumption is that the ships will discharge where they most frequently sail, but this will not necessarily always be the case, meaning that the reliability classification is C.

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

13 Indicated subjects for improvement

The most significant points for improvement of the emissions in relation to PAH spills by shipping at sea can be identified:

- Measurement of actual PAH and oil content in oil slicks observed;
- Measurement of substances other than PAH in discharged oil (detergents and metals).

14 Request for reactions

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