Emission estimates for diffuse sources
Netherlands Emission Inventory

Atmospheric corrosion of lead sheet used as flashings and weatherproofings

Version dated June 2008

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

Lead sheet used on buildings for flashings and weatherproofings

1 Description of emission source

This fact sheet contains a method for calculating emissions resulting from the corrosion of lead sheets used as flashings and weatherproofings on residential, commercial and industrial buildings. Lead is often used in residential, commercial and industrial property to make buildings waterproof in the long term. Corrosion and subsequent runoff of lead is a major source of lead in surface waters. The corrosion of lead sheets in residential dwellings is allocated to the (governmental) target sector "Consumers" and in commercial and industrial property to the governmental target sector "Trade and Services" within the national Emission Inventory.

2 Explanation of calculation method

Emissions are calculated by multiplying an activity rate (AR), in this case the exposed surface area of lead sheets, by an emission factor (EF), expressed in emission per AR unit. This method of calculation is explained in detail in the Guide to the Regional approach to diffuse sources [1].

Emission = AR x EF

Where:
AR = exposed surface area of lead sheets (km^2)
EF = emission factor ($kg/km^2.year$)

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 surface waters.

3 Activity rates

The activity rate is the exposed surface area of lead sheets. This surface area is determined for residential property on the basis of an estimate of the total exposed surface area of lead in 2002: 7.53 km^2 [2]. In 2005, Statistics Netherlands (CBS) [5] came up with a different estimate for the surface area of lead sheets, so this data was then used to support the activity rate, producing a figure of 7.68 km^2. This calculation involves estimating average lead surface areas of various parts of the roof for different types of residential property (detached, semi-detached, corner and terraced dwellings, apartments) and then multiplying this value by the frequency of occurrence and number of residential properties per type. The details of this calculation are shown in Appendix 1.

The trend over time of the exposed surface area is obtained by scaling up the 2002 estimate on the basis of residential property numbers in the period from 1985 to 2005 (see table 1), obtained from CBS [5] and [10]. See Appendix 1 for a detailed description of how the activity rate was calculated.

Table 1: Trend over time of exposed surface area of lead sheets in residential properties.

	1985	1990	1995	2000	2002	2005	2006
Number of residential properties, total (x 1000)	5,289	5,892	6,276	6,651	6,772	6,912	6,914
Index	0.78	0.87	0.93	0.98	1.00	1.02	1.02
Exposed lead surface area (km^2)	5.88	6.55	6.98	7.37	7.53	7.68	7.68

The total surface area covered in lead in commercial and industrial property is based on the calculation by the Van Tilborg Business Consultancy (VTBC) [2] relating to the year 2002 (see table 2). Based on the fact that much of the sheet lead is used for historical buildings, for which the fittings and fixtures do not vary much at all, the total surface area of lead sheets in commercial and industrial property is assumed to be constant over time.

Table 2: Estimate of total exposed surface area of lead sheets in commercial and industrial property in 2005.

Number	Exposed surface area (m^2)	Examples of projects	Total (km^2)
1,000	400	Fort Kijkduin, Sint Bavo Haarlem, Stadhuis Maastricht	0.4
2,000	200	Churches, etc.	0.4
15,000	100	Turrets, dormer windows, gutters	1.5
100,000	10	Smaller applications	1.0
531,000	0	Remaining commercial & industrial property	
Total exposed			3.3

The total exposed surface area of lead sheets in residential, commercial and industrial property therefore amounted to 10.82 km^2 in 2002.

NB to calculate the trend of exposed surface area over time, no sales figures of lead were used. This is because these figures vary considerably from year to year. Furthermore, it is not possible to obtain a more accurate estimate of the total surface area of lead sheets based on these figures than with the currently applied method, among other reasons because the total sales of lead also include other applications.
However, the sales figures of lead are used to validate the result of the current method of estimating surface area. This is described in Appendix 2. The result for 2005 of 10.47 km^2 is in line with the sum of ARs for residential, commercial and industrial property, as described above: 7.68 + 3.3 km^2.

4 Emission factors

Because of its good adaptability and resistance to corrosion, lead is a suitable building material. Its resistance to corrosion is largely attributable to its patina, a thin layer on the surface that is difficult to penetrate. Under normal conditions, this layer is formed by oxygen, CO_2 and water vapour from the air, and comprises lead oxides, lead carbonate, lead sulphites and lead sulphates. It is only the formed lead carbonate ($Pb(CO_3)_2$) that bonds poorly and is therefore subject to runoff. It is interesting that sulphur dioxide and sulphuric acid (acid rain) actually seem to have a positive effect, because they precede to the formation of lead sulphate which bonds well. It is not known how the surface chemistry of the lead has been affected by the decreasing acid concentration in the rain over the course of years. It is very likely to have neither a positive or negative effect on the runoff quantity, given that the leaching of lead carbonate and lead oxides plays a more important role [3], [4].

A value of 2.2 g/m^2.year is taken as the runoff factor. This value is based on results obtained from a study carried out by the Netherlands Centre for Water Management (RIZA) to measure contaminants in runoff from building materials [5]. Van Mourik et al. [6] provide measuring values for lead leached from lead sheets in façades at different angles in urban as well as rural areas. The majority of residential, commercial and industrial property is located in urban areas. Furthermore, the distribution among the various orientations of roofs is not known. For this reason, the mean of the two extreme values for urban areas was selected as the emission factor (2.2 g/m^2).

Table 3: Measurements of lead leached out from lead sheets in g/m^2.year [6]

	Rural areas	Urban areas
Roof below 7°	3.30	3.50
Roof below 45°	2.50	2.70
Facade below 90°	0.82	0.88

5 Effects of policy measures

No information is available on measures to reduce the emission of lead from lead sheets.

6 Emissions calculated

The table below shows the total calculated emissions.

Table 4: Lead emissions from sheets in residential, commercial and industrial property (kg)

	1985	1990	1995	2000	2002	2005	2006
Residential property	12,897	14,367	15,304	16,218	16,513	16,855	17,011
Commercial and industrial property	7,260	7,260	7,260	7,260	7,260	7,260	7,260
Total	20,157	21,627	22,564	23,478	23,773	24,115	24,271

7 Release into environmental compartments

It is assumed that 100% of emissions from residential property enters the sewer system. With commercial and industrial property, it is assumed that 70% of emissions goes into the sewer system and 30% pollutes the soil [2], [7].

Table 5: Distribution of lead emissions from sheets in residential, commercial and industrial property among the various compartments (kg)

	1985	1990	1995	2000	2002	2005	2006
Residential property – sewers (rwf)	12,897	14,367	15,304	16,218	16,513	16,855	17,011
Commercial/industrial property – sewers (rwf)	5,080	5,080	5,080	5,080	5,080	5,080	5,080
Commercial/industrial property – soil	2,180	2,180	2,180	2,180	2,180	2,180	2,180

8 Description of emission pathways to water

Emissions to water arise as a result of emissions from the sewer system, combined sewer overflows, and effluents from urban waste water treatment plants. The fact sheet "Effluents from waste water treatment plants and sewer systems" [8] describes this in further detail. All the lead emissions described above take place via rainwater flow (rwf).

9 Spatial allocation

The spatial distribution 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 [9] 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 6: Summary of spatial allocation method

Element	Locators
Sheet lead	
• Residential property	Number of inhabitants per grid cell measuring 500x500 metres
• Commercial and industrial property	Number of inhabitants per grid cell measuring 500x500 metres

The method used to determine the locators is described in [9]:

Number of inhabitants
The number of inhabitants per grid cell measuring 500x500 metres is derived from the MNP'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 figures 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.

10 Comments and changes in regard to previous version

With effect from 2006, the emission factor dropped from 5.0 to 2.2. The reason for this was the publication of results of measurements taken by Van Mourik et al. [6].

The distribution among the compartments changed in terms of quantification in 2006. It is now accepted that 100% of emissions from residential properties goes into the sewer system. In the previous version, the distribution was 7% directly to water, 3% to soil and 90% to the sewer system. With commercial and industrial property, it is now accepted that 70% of emissions goes into the sewer system and 30% of emissions goes into the soil. The previous distribution was 20% entering the sewer system and 80% emissions into the soil. The reason for making this change is that RIZA no longer considered the previous distribution to be realistic. For this reason, the distribution of emissions is equated with the distribution for sheet zinc in commercial and industrial property, and the distribution for galvanised steel in structures [10]. This distribution also corresponds more closely to older literature on this source [7].

In 2008, the activity rate was recalculated on the basis of Appendix 1; this change also changes emissions recorded in previous years. The recalculation was based on data published by CBS (Data Statistisch Jaarboek CBS 2005 [12]), plus a number of considerations made by RIZA [13]. The differences arising by applying the old and new method are shown in table 7.

Table 7: Consequences of change in method for the activity rate

Old method	**1985**	**1990**	**1995**	**2000**	**2002**	**2005**	**2006**
Residential property	12,500	13,930	14,840	15,730	15,990	16,340	-
Commercial/industrial property	7,260	7,260	7,260	7,260	7,260	7,260	-
Total	19,760	21,190	22,100	22,990	23,250	23,600	-
New method	**1985**	**1990**	**1995**	**2000**	**2002**	**2005**	**2006**
Residential property	12,897	14,367	15,304	16,218	16,513	16,855	17,011
Commercial/industrial property	7,260	7,260	7,260	7,260	7,260	7,260	7,260
Total	20,157	21,627	22,564	23,478	23,773	24,115	24,271
Difference	*400*	*440*	*460*	*490*	*520*	*520*	-

11 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 [9]. 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. This means that we can classify the emission factors in category C. The activity rate for residential property is based on a comprehensive model incorporating considerable experience from the sector. However, the number of residential properties used to recalculate the trend over time is an estimate, which does not take into consideration changes in building methods and materials used. For this reason, the accuracy of the activity rate is classified in category C. Category C is also applied for commercial and industrial property.
The distribution of emissions among the various compartments for commercial and industrial property is based on generic understanding within the emission registration scheme. It is assigned category C. Uncertainty in emission pathways to water is at a low level: B. Finally, the spatial allocation of emissions is ultimately fairly reliable, so the reliability classification is B.

Element of emission calculation	**Reliability classification**
Activity rates	
- Residential property	C
- Commercial/industrial property	C
Emission factor	C
Distribution among compartments	
- Residential property	B
- Commercial/industrial property	C
Emission pathways to water	B
Spatial allocation	B

The most significant areas for improvement are:

- With respect to the activity rate, it is possible to make improvements by collating and processing data on changing usage of lead over the course of time.
- There is a wealth of good measuring data available on lead runoff. It is also possible to improve the derivation of emission factors based on these measurements in emission factors by collecting data on the number of residential properties/commercial and industrial properties in urban as well as rural areas, in addition to data on the orientation of roofs. This data can be used to come up with a weighted average of all measuring results as described in table 4.
- Spatial allocation of emissions could be made more accurate by allocating emissions to individual sewer systems.

12 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.

13 References

[1] CIW/CUWVO werkgroep VI, February 1997. Handreiking Regionale aanpak diffuse bronnen. Annex 1, para. 2.2

[2] Van Tilborg Business Consultancy (VTBC, 2007) Schatting blootgesteld loodoppervlak t.b.v. de EmissieRegistratie, Van Tilborg, Velp.

[3] Lembrechts, P.; Vandewalle, B. – Verbindingen van natuursteen door het aangieten met lood van ankerstaven: technologie en alternatieven, 2001

[4] Davis, A., Shokouhian, M., Ni, S. – Loading estimates of lead, copper, cadmium and zinc in urban runoff from specific sources – Chemosphere vol. 44, no. 5, 2001

[5] CBS, Statline, 2007

[6] Mourik, W. van, Mijle Meijer H.J. van der, Tilborg W.J.M. van, Teunissen R.J.M., Emissies van bouwmaterialen, vaststelling van afspoelsnelheden op basis van metingen aan proefopstellingen, RIZA report 2003.027, ISBN 9036956412, November 2003.

[7] Coppoolse, J. et al., April 1993. Zware metalen in oppervlaktewater. Bronnen en maatregelen. SPEED document. RIZA memo no. 93.012, RIVM memo no. 773003001.

[8] Netherlands National Waterboard, Water Unit, 2008. Effluents from waste water treatment plants and sewer systems. RWS-WD, Lelystad, juni 2008

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

[10] Netherlands National Waterboard, Water Unit, 2008, Atmospheric corrosion of galvanised steel and sheet zinc, RWS-WD Lelystad, June 2008

[11] Most, P.F.J. van der, van Loon, M.M.J., Aulbers, J.A.W. en van Daelen, H.J.A.M., July 1998. Methoden voor de bepaling van emissies naar lucht en water. Publicatiereeks Emissieregistratie, no. 44.

[12] CBS, 2005, Statistisch Jaarboek 2005, Pag. 77 to 80, CBS, Voorburg

[13] RIZA, 2007. Interne notitie: Schatting blootgesteld loodoppervlak t.b.v. emissieregistratie, Reactie op industrieschatting, dated 22 March 2007, RIZA, Lelystad.

Appendix 1: Calculation of surface area of lead sheets in residential property.

A new calculation of the exposed surface area of lead sheets was recently published. The calculation is based on data from Statistics Netherlands for 2005 [10], (Data Statistisch Jaarboek CBS 2005, p. 77 t 80), an inventory produced by van Tilborg et al. [2], plus a number of considerations made by RIZA [11]. The calculation in this appendix shows the improved calculation: the calculated surface area in this annex differs somewhat from the calculated surface area presented in section 3 of this fact sheet.

When estimating the exposed surface area, characteristic dimensions of residential buildings and sheds are assumed. The estimate excludes a number of lead applications, which contribute little or not at all to the total lead surface area (for example, sealing of balconies). Typical dimensions used in calculations include an average depth of 6 metres for residential buildings, shed dimensions 2.5*4 metres and garage length 6 metres.

The result is a quantification of the total surface area covered in lead that is exposed to the atmosphere, as shown in the table below.

Table B0.1: Total exposed surface area of lead sheets in residential property in 2002.

Element	**Total surface area in the Netherlands (km^2)**
Connection between (sloping) roof and vertical wall	0.845
Sheds, garages	1.159
Chimney ducts	
- Sloping roof	2.471
- Flat roof	0.412
Dormer windows	1.221
Roof windows	1.424
Total – residential property	**7.531**

The various elements are calculated as follows.

Connection – sloping roof	Number of residential properties (x1,000)	% residential properties used	Number of residential properties used (x1,000)	Surface area per residential property m^2	Total surface area m^2 (x 1,000)
Detached dwelling	960	8.6%	83	2080	172
Semi-detached dwelling	840	8.6%	72	2080	151
Corner dwelling	818	8.6%	71	2080	147
Terraced dwelling	1858	8.6%	160	2080	333
Other	88	8.6%	8	2080	16
Excluding apartment buildings	4564		394		819
Apartment buildings	2062				
Business with residential space	146	8.6%	13	2080	26
Total number of residential properties	6772		406		845

1) By way of deviation from Van Tilborg et al. (2007), the exposed surface area per residential property for the connection between the sloping roof and vertical wall is assumed to be 2.08 m^2/residential property instead of 1.55 m^2/residential property;
2) An additional consideration made by RIZA is that the connection between the sloping roof and vertical wall is used for all residential properties, excluding apartment buildings;

Sheds and garages	Number of residential properties (x1,000)	% residential properties used	Number of residential properties used (x1,000)	Surface area per residential property m^2	Total surface area m^2 (x 1,000)
Detached dwelling	960	47.0%	451	1.200	541
Semi-detached dwelling	840	47.0%	395	0.600	237
Corner dwelling	818	47.0%	384	0.250	96
Terraced dwelling	1858	47.0%	873	0.250	218
Other	88	47.0%	41	0.600	25
Excluding apartment buildings	4564		2145		1118
Apartment buildings	2062				
Business with residential space	146	47.0%	69	0.600	41
Total number of residential properties	6772		2214		1159

1) The surface areas for detached dwellings and semi-detached dwellings are switched around (see also footnote 3). This led to a slight error in the surface area of sheds and garages and ultimately in a slight error in the total surface area. This has since been corrected.
2) With respect to built-on sheds/garages for corner or terraced dwellings, the proposal published in [10] was used, which assumes a surface area of 0.25 m^2
3) For the category of semi-detached dwellings, 0.6 m^2 was therefore assumed per garage, instead of 1.2 m^2, because with attached dwellings, the garages are usually connected to each other.

Chimney – sloping roof	Number of residential properties (x1,000)	% residential properties used	Number of residential properties used (x1,000)	Surface area per residential property m^2	Total surface area m^2 (x 1,000)
Detached dwelling	960	68.1%	653	1.000	653
Semi-detached dwelling	840	68.1%	572	0.700	400
Corner dwelling	818	68.1%	557	0.700	390
Terraced dwelling	1858	68.1%	1265	0.700	886
Other	88	68.1%	60	0.700	42
Excluding apartment buildings	4564		3108		2371
Apartment buildings	2062				
Business with residential space	146	68.1%	99	1.000	99
Total number of residential properties	6772		3207		2471

1) Figures for chimneys are not based on those published by van Tilborg et al [2]. The data is based on RIZA's own estimates, using characteristic chimney dimensions [10]

Chimney – flat roof	Number of residential properties (x1,000)	% residential properties used	Number of residential properties used (x1,000)	Surface area per residential property m^2	Total surface area m^2 (x 1,000)
Detached dwelling	960	13.9%	134	0.500	67
Semi-detached dwelling	840	13.9%	117	0.250	29
Corner dwelling	818	13.9%	114	0.250	28
Terraced dwelling	1858	13.9%	258	0.250	65
Other	88	13.9%	12	0.500	6
Excluding apartment buildings	4564		635		195
Apartment buildings	2062				
Older apartments	825	100.0%	824.8	0.25	206
Newer apartments	1237	0.0%	-	0	-
Business with residential space	146	13.9%	20	0.500	10
Total number of residential properties	6772		1480		412

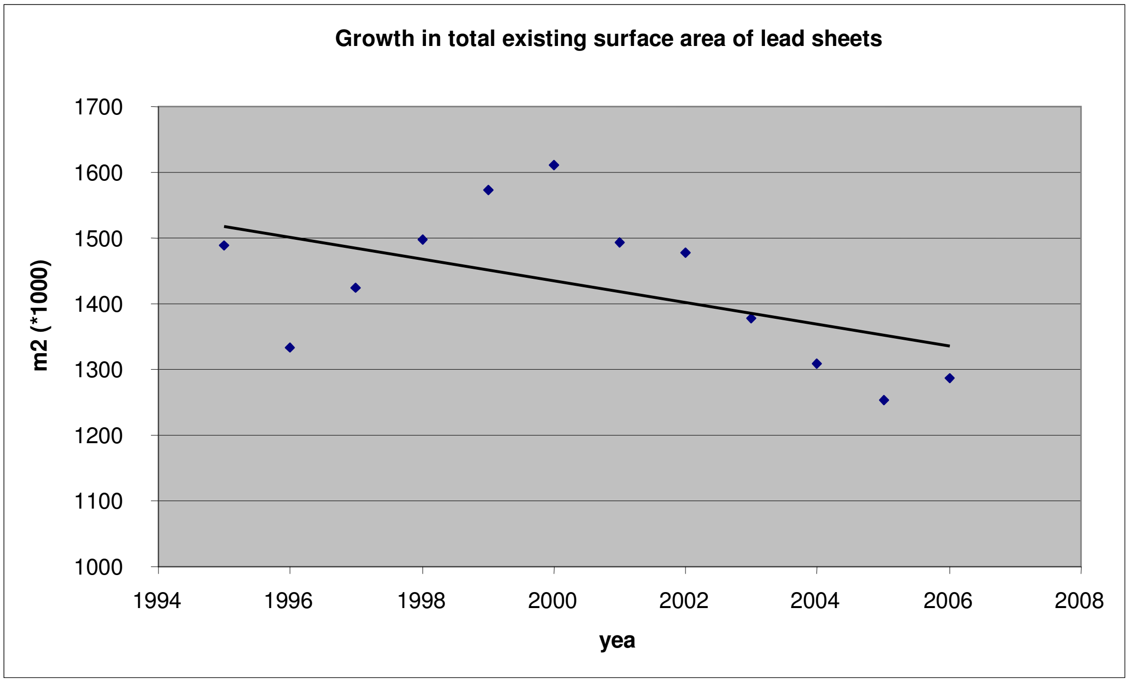
1) Figures for chimneys are not based on those published by van Tilborg et al [2]. The data is based on RIZA's own estimates, using characteristic chimney dimensions [10]

Dormer window with lead	Number of residential properties (x1,000)	% residential properties used	Number of residential properties used (x1,000)	Surface area per residential property m^2	Total surface area m^2 (x 1,000)
Detached dwelling	960	21.6%	207	1.200	249
Semi-detached dwelling	840	21.6%	181	1.200	218
Corner dwelling	818	21.6%	177	1.200	212
Terraced dwelling	1858	21.6%	401	1.200	482
Other	88	21.6%	19	1.200	23
Excluding apartment buildings	4564		986		1183
Apartment buildings	2062				
Business with residential space	146	21.6%	32	1.200	38
Total number of residential properties	6772		1017		1221

Roof window with lead	Number of residential properties (x1,000)	% residential properties used	Number of residential properties used (x1,000)	Surface area per residential property m^2	Total surface area m^2 (x 1,000)
Detached dwelling	960	43.2%	415	0.700	290
Semi-detached dwelling	840	43.2%	363	0.700	254
Corner dwelling	818	43.2%	353	0.700	247
Terraced dwelling	1858	43.2%	803	0.700	562
Other	88	43.2%	38	0.700	27
Excluding apartment buildings	4564		1972		1380
Apartment buildings	2062				
Business with residential space	146	43.2%	63	0.700	44
Total number of residential properties	6772		2035		1424

Appendix 2: Verification based on market figures

The following graph provides an overview of sales in the Netherlands of sheet lead for the period from 1995 to 2006. The high sales figures in the past are attributable to:
1. High level of building activities
2. Extremely large renovation projects
3. A large market for repair/replacement work – this is because in the past there was a high level of consequential damage due to the use of lead that was too thin and inexpert application thereof.
4. An increase in the use of sheet lead as a means of protection against x-rays, radioactivity and noise.



The sales figures are used to estimate the total surface area of lead sheets, which in turn is used to validate the estimate for AR in the fact sheet [2].

The technical life of lead sheets is only a few hundred years, but in practice lead is replaced earlier than this. In the Netherlands, residential properties last an average of approximately 60 years. Over the course of the life of a residential dwelling, a share of the lead is replaced in connection with conversion work, etc. We therefore assume an average replacement term of 50 years for lead.

In 1955, the Dutch market accounted for around 12 ktonnes of sheet lead with an average thickness of 12 kg/m^2, equivalent to 1.0 km^2. In 2005, this figure grew to 22 ktonnes with an average thickness of 15 kg/m^2, equivalent to 1.6 km^2. The mean between these two figures is 1.3 km^2/year.

Of this amount, approximately 6% is used per annum for shielding applications (x-rays + noise). Furthermore, approximately 10% is not installed as it is cut away (for example with roof ducts) or is overlapped so it does not cause runoff. In addition, 20% goes to cavity lead, an application involving no emissions to water. A total of 36% of the lead produced is therefore not used in applications where there is runoff to water. The surface area created annually that leads to runoff is therefore approximately 64% of 1.3 km^2 = 0.832 km^2.

The installed lead surface area that has built up over 50 years can therefore be estimated as 50*0.832 = 41.6 km^2. Approximately 25% of the installed lead is exposed to atmospheric deposition. As a result, the exposed lead surface area amounts to approximately 10.4 km^2.