Emission estimates for diffuse sources
Netherlands Emission Inventory

Atmospheric corrosion of galvanised steel and sheet zinc

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NETHERLANDS CENTRE FOR WATERMANAGEMENT
in cooperation with DELTARES and TNO

Corrosion of galvanised steel and sheet zinc

1 Description of emission source

This fact sheet contains a method of calculating run-off emissions from sheet zinc and galvanised steel, caused by atmospheric corrosion, in various applications. This is an important emission source of zinc to the environment. The table below summarises the relevant emission sources and governmental target sectors to which emissions are allocated within the National Emission Inventory.

Table 1: Sources and target sectors in this fact sheet

Emission sources	**Target sector**
Sheet zinc	
• zinc roofs and gutters on residential dwellings	Consumers
• zinc roofs on commercial and industrial buildings	Trade and services
Galvanised steel	
• galvanised steel in greenhouses	Agriculture
• galvanised steel in nuts and bolts	Construction
• galvanised steel in constructions, structural steelwork, facades and sheds, etc.	Construction
• galvanised steel in other applications, fencing etc.	Consumers
• galvanised steel in street furniture	Transport
• galvanised steel in vehicles and trailers	Transport
• galvanised steel crash barriers on the highway	Transport
• galvanised steel in high-tension poles [1)]	

1) The zinc used in high-tension poles is entirely coated, which means that no zinc in these poles is exposed. Therefore, high-tension poles do not cause any emissions.

2 Explanation of calculation method

Emissions are calculated by multiplying an emission activity rate (AR), in this case the surface area of zinc exposed to precipitation, by an emission factor (EF), expressed in emission per activity rate (AR) unit. This method of calculation is explained in detail in the Guide to the "Handreiking Regionale aanpak diffuse bronnen" [1].

$$\text{Emission} = AR \times EF$$

Where:
AR = Area of stock at risk (km^2)
EF = Emission factor ($tonne/km^2/year$)

The emission calculated in this way is referred to as the total emission. A specific part of the total emission ends up in surface water: this is the net load of the surface water.

3 Activity Rates

The activity rate is the area of zinc (stock at risk in the form of sheet zinc or galvanised steel) that is exposed. For both the exposed area sheet zinc and galvanised steel a calculation method is demonstrated by Van Tilborg [2,3] :

- The exposed area of sheet zinc in roofs and gutters is assessed applying commercial data on zinc sales, with correction of installation losses and the rate of replacement of roofs and gutters;
- The exposed area of galvanised steel in various applications is calculated in a similar manner using market data, correcting for improved coatings and assuming amounts for replacement of zinc lost in the environment.

Details of both calculations are shown in appendix 1. The result is an estimate of the total amount of stock of atmospheric exposed zinc at risk in the Netherlands, shown in table 2 .

Table 2: Estimate of the total stock of atmospheric exposed zinc at risk in the Netherlands (km^2)

Emission sources	1990	1995	2000	2005	2006
Sheet zinc					
• zinc roofs and gutters on residential dwellings	14.8	15.2	15.7	16.2	16.2
• zinc roofs on commercial and industrial buildings	9.9	10.1	10.5	10.8	10.8
Galvanised steel					
• galvanised steel in greenhouses	1.5	1.6	1.8	2.0	2.0
• galvanised steel in nuts and bolts	0.9	1.1	1.3	1.4	1.4
• galvanised steel in constructions, structural steelwork, facades and sheds, etc.	5.5	6.4	7.8	9.5	9.8
• galvanised steel in other applications, fencing etc.	4.0	4.4	5.0	5.5	5.5
• galvanised steel in street furniture	0.1	0.1	0.1	0.1	0.1
• galvanised steel in vehicles and trailers	0.7	0.7	0.8	0.9	0.9
• galvanised steel crash barriers on the highway	7.7	8.6	9.6	10.6	10.7
• galvanised steel in high-tension poles [1)]	0.0	0.0	0.0	0.0	0.0

1) The zinc used in high-tension poles is entirely coated, which means that no zinc in these poles is exposed. Therefore, high-tension poles do not cause any emissions.

The area of sheet zinc in residential dwellings has been verified by Van Tilborg [2] using a separate calculation method. This validation is described in appendix 2 and the result confirms the values given in table 2.

4 Emission factors

The emission factors for runoff of atmospheric exposed zinc vary according to the application and depend on a number of parameters including SO_2 concentration in precipitation. This means that emission factors are dependent on time and location. The horizontal or vertical orientation of the surface from which material can run off is also a significant parameter.

The Netherlands is divided into two regions in terms of atmospheric SO_2 concentration [4]. Region 1 has lower SO_2 concentrations than region 2, and also higher runoff rates. Region 2 comprises Zeeland, Zuid-Holland and the south-western part of Noord-Brabant (29% of the population) and region1 is made up of the rest of the Netherlands (71% of the population).

The SO_2 concentrations are taken from the national air quality monitoring network operated by the National Institute for Public Health and the Environment (RIVM) [5]. A brief explanation of these SO_2 concentrations is contained in appendix 3. For emission sources linked to areas with relative higher SO_2 concentrations, the higher emission factor for region 2 is used. The sources linked to these areas are crash barriers (because of exhaust gases from road traffic), greenhouses (because of high atmosphere humidity) and commercial and industrial buildings and construction sites (because they are likely to be in industrial locations). The other sources are distributed among the regions on the basis of population data. Consequently, 71% of the activity rate is in region 1 with a low emission factor, and 29% is in region 2 with a high emission factor.

The final country averaged emission factor for a source in a given year is calculated as

$$EF = (\%\ region\ 1 \times EF_{region\ 1} + \%\ region\ 2 \times EF_{region\ 2}) \times correction\ factor$$

The reasons for this approach are given below. Table 3 contains the values for $EF_{region\ 1}$ and $EF_{region\ 2}$. The percentages for regions 1 and 2 and the correction factors are given in table 4.

- SO_2 dependence
The dependency of the zinc runoff rate on the atmospheric SO_2 concentration is calculated on the basis of a formula given by Odnevall [6]:

$$\text{Zinc runoff rate } (g/m^2/year) = 1.36 + 0.164 \times [SO_2]\ (\mu g/m^3)$$

Table 3: Runoff rates for zinc ($g/m^2/year$)

	1990	1995	2000	2005	2006
region 1	3.49	2.65	2.01	1.84	1.76
region 2	5.36	3.76	2.89	2.75	2.65

- Spatial orientation
Measurements runoff conducted by the National Institute of Water Management and Waste Water Treatment (RIZA) show that the rate is almost four times higher from horizontal zinc surfaces compared to vertical surfaces (3.6 and 0.91 g/m^2 per year respectively). A correction factor for Odnevall's emission factors has been calculated on the basis of these measurements and information about the orientation of the various sources. It is implicitly assumed that Odnevall's measurements relate to an inclined orientation. The correction factor is worked out as (% vertical x 0.91 + % horizontal x 3.6)/2.38 (where 2.38 is the average rate of runoff), and is applied in the table below. Reference [4] (chapter 3.1) states that Odnevall's ratio can be used with the current concentration.

Table 4: Distribution of sources between regions 1 and 2, and correction factors.

Emission sources	region 1	region 2	vertical orientation	EF correction factor
Sheet zinc				
• zinc roofs and gutters on residential dwellings	71%	29%	*	1
• zinc roofs on commercial and industrial buildings	0%	100%	*	1
Galvanised steel				
• galvanised steel in greenhouses	0%	100%	60%	0.84
• galvanised steel in nuts and bolts	71%	29%	50%	0.97
• galvanised steel in constructions, structural steelwork, facades and sheds, etc.	0%	100%	80%	0.59
• galvanised steel in other applications, fencing etc.	71%	29%	70%	0.71
• galvanised steel in street furniture	71%	29%	90%	0.50
• galvanised steel in vehicles and trailers	71%	29%	60%	0.84
• galvanised steel crash barriers on the highway	0%	100%	72%	0.71
• galvanised steel in high-tension poles	71%	29%	85%	0.55

The exposed area calculation takes account of the fact that half the area is not exposed. This means that the spatial orientation is already reflected in the calculation.

5 Effects of policy measures

One measure affecting zinc emissions is the process of coating galvanised steel, which is now much more common than it used to be. This effect is taken into account when working out the activity rate (AR): the area of the stock at risk (see table B1.3, appendix 1).

One measure that has affected the distribution of emissions among compartments is the increase in the number of greenhouses that drain into the sewers. This is because more greenhouses are connected to the sewer system. It is estimated that the proportion of emissions ending up in the soil in 1990 was 75%. By 2005 this figure had fallen to 25%, with 50% of emissions ending up in the sewers. The remaining 25% of emissions into surface water has not changed (see table 6).

6 Emissions calculated

Zinc emissions from sheet zinc and galvanised steel are calculated by multiplying the exposed area (table 2) by the emission factor (table 3). The emissions are thereupon corrected using the correction factor from table 4. The emission values are given in table 5.

Table 5: Total Zinc emissions from sheet zinc and galvanised steel (tonnes/year)

Emission sources	**1990**	**1995**	**2000**	**2005**	**2006**
Sheet zinc					
• zinc roofs and gutters on residential dwellings	59.73	45.10	35.58	34.11	32.74
• zinc roofs on commercial and industrial buildings	52.92	38.02	30.29	29.72	28.66
Galvanised steel					
• galvanised steel in greenhouses	6.75	5.05	4.37	4.62	4.48
• galvanised steel in nuts and bolts	3.52	3.17	2.85	2.86	2.82
• galvanised steel in constructions, structural steelwork, facades and sheds, etc.	17.38	14.19	13.30	15.42	15.37
• galvanised steel in other applications, fencing etc.	11.45	9.28	8.04	8.22	7.92
• galvanised steel in street furniture	0.20	0.15	0.11	0.11	0.09
• galvanised steel in vehicles and trailers	2.37	1.75	1.52	1.59	1.52
• galvanised steel crash barriers on the highway	29.28	22.94	19.70	20.71	20.12
• galvanised steel in high-tension poles	0.00	0.00	0.00	0.00	0.00

7 Release into environmental compartments

The compartment distribution is summarised in table 6 [8]. It is assumed that all emissions from residential dwellings into water enter the sewers directly. In the case of emissions from cash barriers, it is assumed that 90% enters the soil and 10% enters surface water. For greenhouses in 2005, it is assumed that 25% of emissions enter the soil, 50% the sewers and the remaining 25% ends up in surface water. For all other sources the distribution between emissions entering the soil and emissions entering the sewers is set at 30% and 70% respectively.

Applying these assumptions to the emissions from table 5 allows us to work out zinc emissions to seperate compartments (sewers, surface water and soil) as shown in table 7.

Table 6: Distribution of total emissions into environmental compartments

Emission sources	**soil**	**surface water**	**sewers (rwd)**
Sheet zinc			
• zinc roofs and gutters on residential dwellings			100%
• zinc roofs on commercial and industrial buildings	30%		70%
Galvanised steel			
• galvanised steel in greenhouses 1)	25%	25%	50%
• galvanised steel in nuts and bolts	30%		70%
• galvanised steel in constructions, structural steelwork, facades and sheds, etc.	30%		70%
• galvanised steel in other applications, fencing etc.	30%		70%
• galvanised steel in street furniture	30%		70%
• galvanised steel in vehicles and trailers	30%		70%
• galvanised steel crash barriers on the highway	90%	10%	
• galvanised steel in high-tension poles			

1) The distribution of emissions from greenhouses has changed over the years. The figure given above applies only to 2005 and 2006. The corresponding values for soil and surface water in 1990 and 1995 were 75% and 25% respectively. In 2000 this distribution between soil, surface water and sewers had already shifted to 50%, 25% and 25%.

Table 7: Distribution of zinc emissions from sheet zinc and galvanised steel for individual compartments (tonnes/year)

Environmental compartment	1990	1995	2000	2005	2006
Soil	52.55	40.14	32.76	32.54	31.53
surface water	4.62	3.56	3.06	3.23	3.13
sewers (rwd)	121.21	91.69	75.95	76.96	74.45

8 Description of emission pathways to water

Emissions to water arise from direct emissions to surface water and indirectly as a result of emissions from the sewage system, overflows, and effluents from urban waste water treatment plants. The fact sheet "Effluents from waste water treatment plants and sewer systems" [9] describes this in further detail. All these forms of zinc emissions take place via rainwater drainage (rwd).

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) drawn up using emission records. These maps present the regional 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 regional distribution of emissions. The range of possible locators is limited (see [10] for a list of available locators), as not every conceivable parameter can be used as a locator. That is why the locator judged 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 to allocate emissions for the various emission sources.

Table 8: Summary of spatial allocation of emissions by emission source

Emission sources	Locators
Sheet zinc	
• zinc roofs and gutters on residential dwellings	Number of inhabitants per grid cell measuring 500x500 metres
• zinc roofs on commercial and industrial buildings	Number of inhabitants per grid cell measuring 500x500 metres
Galvanised steel	
• galvanised steel in greenhouses	Greenhouse area in m^2
• galvanised steel in nuts and bolts	Number of inhabitants per grid cell measuring 500x500 metres
• galvanised steel in constructions, structural steelwork, facades and sheds, etc.	Number of inhabitants per grid cell measuring 500x500 metres
• galvanised steel in other applications, fencing etc.	Number of inhabitants per grid cell measuring 500x500 metres
• galvanised steel in street furniture	Number of inhabitants per grid cell measuring 500x500 metres
• galvanised steel in vehicles and trailers	Number of inhabitants per grid cell measuring 500x500 metres
• galvanised steel crash barriers on the highway	Traffic density on motorways
• galvanised steel in high-tension poles	-

The method used to determine the locators is described in [10]:

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 sewerage area. This map is based on values produced by Statistics Netherlands on numbers of inhabitants and numbers of residential dwelling units in each municipality (for 2005). The distribution of inhabitants among grid cells in a municipality 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.

Greenhouse area
The greenhouse area was calculated using the map of grid cell distribution based on land use produced by the Netherlands national land use register (LGN) and the yearly agricultural census (Statistics Netherlands). This map shows twelve land use categories down to an area of 500 x 500 metres. Total farming acreage is based on values in the yearly agricultural census. The distribution of the various classes throughout the Netherlands is taken directly from LGN5, the national land use database for 2003-2004. Therefore, the total area from the yearly agricultural census is distributed among locations as shown in LGN5.

Traffic intensity on motorways
Traffic intensity on motorways is calculated in the light of information contained in the map of distribution among stretches of road on the basis of mileage. This map contains six categories:

- Highways (trunk roads): personal cars and delivery vans
- Highways (trunk roads): freight and other traffic
- Rural roads: personal cars and delivery vans
- Rural roads: freight and other traffic
- Urban roads: personal cars and delivery vans
- Urban roads: freight and other traffic

Data on the location and length of (stretches of) roads was taken from the database "Nationaal Wegenbestand" (NWB) created by the "Adviesdienst Verkeer en Vervoer" (AVV). Traffic intensity values (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 DVS and relate to 2005. The values for regional and urban roads are modelled data based on a model called the Nieuw Regionaal Model (NRM) operated by the DVS and cover 2005. This model uses census values 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 intensity on urban roads also take account of data from municipality traffic maps and cover 2005. The traffic intensity data from the NRM are derived from PBL/LOK habitat quality statistics, where these values are used in calculating noise levels.

10 Comments and changes compared to previous version

The version produced in November 2007 contains the changes described below.
The method used to quantify zinc emissions has changed in recent years in respect of the activity rates, the emission factors and release into environmental compartments.

Activity rates
A number of changes to the methodology [2] have recently improved the way that sheet zinc activity rates are quantified:

- A correction factor for exposed area is no longer applied, as this was already implicitly taken into account in the emission factor;
- Revision of the period from 1955 to 2005 and in the light of this revision of the quantification of the total area of sheet zinc.

A number of changes to the methodology [3] have recently improved the way that galvanised steel activity rates are quantified:

- more accurate estimate of useful life by taking account of products' technical useful life;
- correction for less frequent use of coatings in the period before 1995
- reallocation of emission sources, with some applications previously listed under 'other' being moved to 'building materials';
- application of actual growth factors for the period 1997 to 2005 instead of estimates.

Emission factors
The correction factor shown in table 4 has been applied to the emission factor.

No changes occurred in the 2008 emission inventory.

11 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 [11]. 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.

In general we can conclude that the emission factors are based on a limited number of measurements, and as a consequence they are classified in category C. The activity rate for the area of the stock at risk is based on a comprehensive model incorporating considerable experience from the zinc industries representative. However, this model contains many assumptions of which the origin and accuracy are not entirely clear. For this reason the accuracy of the activity rate is classified in category C.
The release of emissions into separate environmental compartments is quite accurate as far as residential dwellings and commercial and industrial buildings is concerned, and this compartment is classified as B. However, releases for other sources is based more on assumptions and is less reliable: the reliability of these releases is classified as D. The emission route into water is quite obvious as far as residential dwellings is concerned, and is classified as B. For the other sources understanding is less clear, and the appropriate classification here is D. Spatial allocation is primarily based on numbers of inhabitants. For emissions from residential dwellings and commercial and industrial buildings this is a reliable locator (category B), but for other sources locators are less reliable (D).

element of emission calculation	**reliability classification**
Activity rates zinc	C
Activity rates galvanised steel	C
Emission factor	C
Distribution among compartments	C
Emission pathways to water	
- for residential, industrial and	B
commercial buildings	D
- for other sources	
Spatial allocation	
- for residential, industrial and	B
commercial buildings	D
- for other sources	

The most significant areas where improvements could be made are:
- A more substantive description of sources and, associated with this, a better estimate of useful life. This applies particularly to the 'transport' source, where a considerable proportion of the galvanised iron forms part of trailers and similar items, and a useful life of 40 years appears long.
- Improving the allocation of distribution of activity rates (AR) for each source category in regions 1 and 2. Distribution is currently based on the distribution of the number of inhabitants, and for most sources it is assumed that 71% of activity rate (AR) relates to region 1, while for some other sources it is assumed that all of it relates to region 2. Clarifying this situation will have a significant impact on zinc atmospheric runoff rates.

- Investigation of effect of application of deicing salt on the useful life of (and leaching from) street furniture, crash barriers and other traffic-related sources.
- Spatial allocation of emissions could be made more accurate by allocating emissions to separated sewer systems.

12 Request for reactions

Any questions or comments regarding this working paper should be addressed to Richard van Hoorn, Centre for Watermanagement, +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.

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Appendix 1

Sheet zinc

On behalf of the assessment of the atmospheric exposed area of sheet zinc it is important to know how much sheet zinc is produced. Calculation starts with sales data (in tonnes) for the 45 years preceding the reporting year (including that year). Only 85% of the total amount of sheet zinc is actually used, as the remainder is to be considered as construction losses. Another important factor is how much of the sheet zinc produced is used to replace old sheet zinc. The replacement part of total sales has risen from 50% in 1950 to 70% in 2006. According to Van Tilborg [1], market assessments show that replacement of existing zinc accounts for 70% of the rolled zinc market. This proportion does not appear to fluctuate much over time. The replacement market already made up 50% of the total market in 1955, as zinc was in use prior to 1900 and is often replaced before technical life time is expired [2].

The amount of newly installed sheet zinc in any selected year can be worked out using the following formula:

$N_Y = S_Y \times F \times (1-R_Y)$

where:

N_Y = Amount of sheet zinc installed in a given year for a new installation (not replacing old sheet zinc), (tonnes)
S_Y = Amount of sheet zinc sold in year Y, (tonnes)
F = Percentage of sheet zinc that is installed (%)
R_Y = Percentage of the sheet zinc used that is installed to replace old sheet zinc in a given year (%)

In order to find out the total amount of exposed sheet zinc in a given year, we must add up the values for newly installed sheet zinc in the preceding 45 years. According to Van Tilborg [2], this period of 45 years is probably sufficient as gutters are replaced every 15 years in most residential dwellings. The total amount of sheet zinc (in tonnes) can be converted into an area figure (in km^2) by multiplying it by 0.000174 km^2/tonne. The factor 0.000174 km^2/tonne is based on the average thickness (0.8 mm) and the specific gravity (0.714 tonnes/m^3) of zinc. One m^2 of zinc that is 0.8 mm thick weighs 1 x 0.008 x 0.714 = 0.00572 tonnes. This is equivalent to a conversion factor of 0.000174 km^2/tonne.

The total area of exposed sheet zinc is determined using the following formula:

activity rate $(AR)_R = \Sigma_{Y=[R-45,R]} (N_Y \times C)$

where:

activity rate $(AR)_R$ = The total amount of sheet zinc that is exposed in reporting year R and that was installed in the previous 45 years (km^2)
$\Sigma_{Y=[R-45,R]}$ = Sum of the exposed sheet zinc in the preceding 45 years
N_Y = Amount of sheet zinc installed in year Y for a new installation (not replacing old sheet zinc) (tonnes)
C = Conversion factor from tonnes → km^2 (here 0.000174 km^2/tonne)

Out of this total figure for exposed area, it is assumed that roofs and gutters account for 60% and commercial and industrial buildings account for 40%.

Table B1.1: Quantification of the exposed area of sheet zinc in 2006. Zinc already installed during the 45 years preceding the reporting year is counted (cumulative exposed area) and taken into account. The formulae used in the calculation are given above.

Year	Market (tonnes)	Installed (tonnes)	Replacement (%)	New sheet zinc (tonnes)	Cumulative exposed weight (tonnes)	Cumulative exposed area (km^2)
1961	7,650	6,503	55%	2,926	2,926	0.5
1962	8,000	6,800	56%	2,992	5,918	1.1
1963	8,350	7,098	56%	3,123	9,041	1.6
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2004	13,500	11,475	70%	3,443	148,906	25.9
2005	13,000	11,050	70%	3,315	152,221	**26.5**
2006	13,000	11,050	70%	3,315	155,536	**27.1**

<u>Galvanised steel</u>

Galvanised steel is used in a variety of applications. Its useful life varies according to its use. In construction, the estimated useful life is 50 years, but only 15 years in transport. Detailed data on consumption of galvanised steel are available for 1995. These data can be used to work out the amount of exposed zinc for each application on the basis of the amount of galvanised steel produced in 1995, using the following formula:

$$E_{1995,A} = S_{1995,A} \times S_A \times e_A$$

where:

$E_{1995,A}$ = Amount of zinc produced in 1995 and exposed in that year, for application A, (km^2)
$S_{1995,A}$ = Amount of zinc sold in 1995 for application A, (tonnes)
S_A = Average area per weight unit for application A, (m^2/tonne)
e_A = Percentage of the area exposed for each application, (%)

Table B1.2: market for galvanised steel in 1995

	Market 1995 (tonnes)	average area [1] (m^2/tonne)	Exposure percentage [1] (%)	Exposed 1995 (km^2)	Useful life (year)
galvanised steel in greenhouses	20,905	40	10%	0.084	25
galvanised steel in nuts and bolts	13,086	40	10%	0.052	30
galvanised steel in constructions, structural steelwork, facades and sheds, etc.	118,863	32,5	8%	0.309	50
galvanised steel in other applications, fencing etc.	28,719	40	20%	0.230	25
galvanised steel in street furniture	1,013	40	8%	0.003	30
galvanised steel in vehicles and trailers	9,521	40	15%	0.057	15
galvanised steel crash barriers on the highway	11,312	42,5	93%	0.445	25
galvanised steel in high-tension poles	462	30	0%	0.000	50
Total	**203,881**			**1.180**	

1) The exposure percentage and the average area were estimated by Van Tilborg [3].

For the other years, the calculation worked out how much galvanised steel is still in use in the reporting year for all applications. In order to calculate this figure it is important to know how much galvanised steel was produced, starting with the market sales data for galvanised steel (in tonnes). Three other factors affect quantities of exposed galvanised steel:

- *Removal.* It is assumed that 1% is taken out of use prematurely as a result of reconstruction or replacement. This assumption is a conservative estimate by Van Tilborg [3]. So after 30 years, 30% has been removed and 70% is still in place.
- *Coating*. The extent of coating was higher in 1995 than in previous years, and consequently zinc runoff was lower in 1995 than earlier. A correction factor is applied to the 1995 figure to take account of this, ranging from 1.3 in 1950 to 0.9 in 2000 [3].
- *Totally lost zinc.* Zinc continues to run off until there is none left. Historical runoff values indicate that by the reporting year 1995 galvanised steel first installed in 1965 would have lost all its zinc. As some items are replaced sooner than others, and other items retain their zinc for longer because of favourable conditions, we assume a sliding scale of 7 years before the critical year and 11 years afterwards [3].

The total amount of galvanised steel (all applications) produced in a given year that is still producing emissions in the reporting year as a result of runoff (the exposed amount) can be calculated using the following formula:

$$NG_{Y,R} = S_Y \times R_{Y,R} \times c_Y - S_Y \times W$$

where:

$NG_{Y,R}$ = Total amount of galvanised steel produced in year Y still causing emissions in reporting year R, (tonnes)
S_Y = Amount of zinc sold in year Y, (tonnes)
$R_{Y,R}$ = Percentage of zinc produced in year Y that has not yet been removed in reporting year R , (%)
c_Y = Correction for coating in year Y
$W_{Y,R}$ = Percentage of zinc produced in year Y that is totally lost by reporting year R, (%)

A growth factor for each application of galvanised steel is determined to calculate the amount of zinc exposed in a given year. This is done by dividing the total amount of galvanised steel still in use (and that was produced in previous years, throughout its useful life) by the amount produced in 1995 that is still in use. Table B1.3 shows an example of a growth factor calculation for construction in 2006.

The table below shows the calculation for galvanised steel for 2006. The values in the last column (2006 exposure) indicate how many tonnes of galvanised steel that were installed in a given production year were still exposed and still producing zinc emissions in 2006.

Table B1.3: quantification of exposed area of galvanised steel.

Year	Market (tonnes)	Not yet removed (%)	Correction for coating	Worn-out zinc (%)	Exposed 2006 (tonnes)
1956	58,717	51%	1.3	95%	1,908.3
1957	62,529	52%	1.3	95%	2,072.9
1958	66,342	53%	1.3	95%	2,242.4
↓	,	.	.	.	,
	,	.	.	.	,
1995	207,401	90%	1,0	0%	184,587.3
↓	,	.	.	.	,
	,	.	.	.	,
2004	241,713	98%	0.9	0%	213,191
2005	245,526	99%	0.9	0%	218,763
2006	249,338	100%	0.8	0%	199,470
Total used in construction in 2006 (useful life = 50 years)					5,878,794
Growth factor for construction in 2006 compared to 1995					**31.8**

In order to determine the total quantity of exposed zinc for a particular application in 1995 or any other year (i.e. exposed in 1995 or another year but produced in previous years), the exposed area for 1995 must be multiplied by the growth factor, using the following formula:

activity rate $(AR)_{R,A} = E_{1995,A} \times G_R$

where:

activity rate $(AR)_{R,A}$ = Exposed area in reporting year R for application A (km^2)

$E_{1995,A}$ = Amount of zinc produced in 1995 and also exposed in that year (km^2)

$G_{R,A}$ = Growth factor for reporting year R and application A

Appendix 2
Verification of the quantification of the area of sheet zinc used in residential dwellings

The estimate of the area of sheet zinc was verified by Van Tilborg [2] on the basis of the residential dwellings database held by Statistics Netherlands. This contains the following information:

1. Only dwelling units that do not have flat roofs are installed with gutters;
2. The amounts of guttering vary according to the type of dwelling;
3. In 2002 54% of all zinc sold was used for guttering. It has been calculated that this proportion used to be higher, as the use of zinc for eaves, dormers, roofs and gables has for several years been increasing more rapidly as its use in gutters. The average percentage used in gutters, calculated for the entire period under review (45 years) is estimated at 60%, but might be higher.

The estimate of gutter area on the basis of Statistics Netherland's 2004 residential dwellings database provides information about the number of dwellings in table B2.1.

Table B2.1

	Number (x1,000)	Flat roof 17%	Dwellings with gutters	85% have zinc gutters	Area of zinc guttering m^2/dwelling	Area km^2
Detached dwelling	960	163	797	677	5.92	4,0
Semi-detached dwelling	840	143	697	593	5.18	3,1
Corner dwelling	818	139	679	577	4.44	2,6
Terraced dwelling	1,858	316	1,542	1,311	4.44	5,8
Other	88	15	73	62	4.44	0,3
Total area of guttering						15,7

According to the accompanying spreadsheet, 27 km^2 of rolled zinc was put onto the market as exposed area in 2005 (see table B1.1, appendix 1). The table above indicates that 60% of this would have been used in guttering, equivalent to 16.2 km^2. The outcome of the calculation based on the Statistics Netherlands residential dwellings database (15.7 km^2) appears to be in line with this.

Appendix 3
Explanation of the calculation of SO_2 concentrations and runoff s

The RIVM's national air quality monitoring network provided information about average annual SO_2 concentrations on the basis of 24-hour average readings in µg/m^3 for each measuring station (contact Hans Berkhout, Validation and smog coordinator, RIVM\LVM\Luchtkwaliteit).

There are three types of monitoring stations:

- regional stations (outside urban areas, not affected by local sources)
- urban stations (in urban settings within a radius of 35 metres around the site with fewer than 2,750 vehicles passing the station in a 24-hour period)
- street stations (in urban settings within a radius of 35 metres around the site with at least 10,000 vehicles passing the station in a 24-hour period)

Monitoring stations are divided into two regions in the Netherlands on the basis of their geographical location [3]. The average annual SO_2 concentrations for each measuring point were used to work out average values for four different combinations (see table B3.1):

Table B3.1: Average annual SO_2 concentrations (µg/m^3)

		1990	1995	2000	2005	2006
Region 1	Regional stations	21.53	10.58	6.57	4.83	4.57
	Urban + street stations	25.31	15.96	10.25	9.71	8.95
Region 2	Regional stations	9.29	5.10	2.29	1.82	1.78
	Urban + street stations	14.21	8.79	4.50	3.31	2.65

Then a weighted annual average SO_2 concentration was calculated for each region. As most zinc emissions occur in an urban environment, the SO_2 concentration for the urban + street stations is weighted three times more than SO_2 concentration in the regional stations. Finally, the weighted SO_2 concentration is used to calculate runoff rate by applying Odnevall's formula [5]:

Runoff rate (g/m^2/year) = 1.36 + 0.164 x [SO_2] (µg/m^3)

The tables below give the calculated weighted SO_2 concentrations and the runoff rate for each region in individual years (see tables B3.2 and B3.3).

Table B3.2: Weighted SO_2 concentrations (µg/m^3)

	1990	1995	2000	2005	2006
Region 1	24.37	14.62	9.33	8.49	7.85
Region 2	12.98	7.87	3.95	2.94	2.43

Table B3.3: Runoff rate for zinc (g/m^2/year)

	1990	1995	2000	2005	2006
Region 1	5.36	3.76	2.89	2.75	2.65
Region 2	3.49	2.65	2.01	1.84	1.76