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TNO report

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Metal fluxes from leaching of sandy soils in agricultural areas in the Netherlands

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Summary

In the past it has been assumed that leaching of heavy metals from soils is very limited. Recently the agricultural research institute Alterra has carried out extensive modelling work to quantify metal leaching. The conclusion of this work was that leaching of metals to surface water is substantial. However, for sandy soils the Alterra estimates of leaching to surface waters appear to be rather low, when taking in mind rather high metal concentrations that are often found in streams in sandy areas of The Netherlands.

An attempt was made in this study to estimate the leaching of (heavy) metals from sandy soils on the basis of metal concentrations and flow rates of waters in sandy agricultural regions. The work was hampered by the limited availability of useful measurement data. Nevertheless a rough estimate could be made on the basis of nine streams in sandy areas. This result is extrapolated to the total of sandy regions in agricultural use. The high variability in leaching rates suggest that the leaching rates obtained are uncertain. It is estimated that the yearly leaching to Dutch surface water of the metals Zn, Cu, Pb, Hg, Ni, Cd and Cr is about 149, 36, 7.9, 0.08, 26, 0.6 and 12 tonnes respectively.

Given the importance of the results and regarding all uncertainties, a dedicated measurement programme is suggested for a more accurate assessment of leaching rates of agricultural as well as natural sandy soils.

Contents

1 Introduction

Gradually more research is being done on diffuse emissions of heavy metals to surface water. The main reason for this is the growing awareness that diffuse emissions contribute substantially to the overall (heavy) metals load. One of the main contributors is expected to be agriculture, more specifically the leaching out of agricultural soils.

The total diffuse emission figures currently included in the Dutch emission inventory do not yet include agricultural emissions of metals to surface waters, but these emission figures will be included in the emission inventories of 2004 and later. The new figures are based on a report by Alterra (Römkens, 2003). The *potential* zinc emission is estimated to be approximately 604 tonnes in 2000.
The emission calculations in the Alterra report are produced by modelling the soil processes (*input* side): the heavy metal flux to surface water is predicted by the distribution of heavy metals from agricultural soil, based on pore water concentration measurements, soil type, concentrations in the soil, land use type, and lateral as well as vertical groundwater flows.

In order to evaluate the outcome of the Alterra study, this study aims at calculating an estimation of the emissions from the *output side*, by attributing heavy metals fluxes in surface waters to the agricultural area. This is done for a selection of waters in the Netherlands. Furthermore, an extrapolation is made to the national level.

The model used by Alterra estimates that the lateral flux of water in sandy soils is very low. Although the concentrations in the lateral streaming water are substantial, the total contribution to the metal load of Dutch surface water appears to be rather small.
In sandy soils water is draining via streams. Measuring the metal fluxes of those streams gives a direct estimation of the amount of metal leached from the catchments, i.e. it measures the output of the soil. The results of the input and the output approach are expected to be comparable, unless other emission sources contribute substantially or non steady-state situations are prevailing.
First estimates on the river Mark (van Tilborg, 2001) in a sandy area the south of the Netherlands indicate that the metal flux of zinc carried by this stream is substantially higher than estimates using the Alterra input approach. In order to evaluate the apparent difference between both estimates, the Foundation for Sustainable Metals (Stichting Duurzaam Bouwmetaal, DBM) has asked TNO to analyse the leaching from sandy soils by studying the metal fluxes of various streams in sandy areas of The Netherlands.

2 Methodology

By multiplication of results of concentration measurements and flow rate measurements of specific streams, an approximation is made of the total heavy metals emission from the catchment area of that stream. Emission sources may include private households, industry, wastewater treatment plants, sewer overflows, emissions from natural origin, atmospheric deposition, and emissions from agricultural soils.

To be reasonably sure that the flux of heavy metals measured cannot be attributed to private households, industries or waste water treatment plants, we used the following criteria for selecting measurement locations:

Required:
1 Brook-type surface waters; 100% fed with water directly coming from the catchment;
2 Catchment area consisting of mainly sandy soils; the limited retardation of groundwater contamination in sand should ensure a low contribution of the “heritage” of contaminations. Furthermore, the high flow speed makes the results more relevant.

Preferred:
3 Catchment area dominated by agricultural soils, in order to exclude or minimize influences of urban and industrial areas and natural soils;
4 No wastewater treatment plant situated in the catchment basin.

The preference for sandy soils practically limited the research area to the eastern part of the Netherlands (East of Almere).

Based on the above criteria, a number of streams were selected. For these streams the annual fluxes of heavy metals were calculated. Concentration measurement data sets of heavy metals and the corresponding daily flow rates were collected for a number of succeeding years. Daily fluxes were calculated by multiplication of daily flow rates with corresponding concentrations. Averages were taken from the daily fluxes and scaled to estimated yearly fluxes.

Data was collected from the following sources:
- Water boards (Waterschap Veluwe, Waterschap Vallei en Eem, Waterschap Regge en Dinkel, Waterschap Rijn en IJssel, Waterschap Mark en Weerijs)
- The Commission of Integral Water management (CIW)
- Literature

From these data year(s) for which the best data was available, were chosen to make a calculation of the yearly flux of metals. Flow rates were usually measured continuously. However the measurement of concentrations of heavy metals generally was done on a monthly basis. In order to calculate annual heavy metal fluxes, the daily calculated fluxes for the days available were averaged and extrapolated to an annual flux for each of the basins.
Next, for the purpose of comparison of different catchments the annual fluxes were divided by the areas of the individual catchments, resulting in annual fluxes of metals emission per hectare.

Finally, these values were averaged among the catchments and multiplied by total sandy agricultural area in the Netherlands. The result of this calculation is an estimation of national metal emissions of sandy soils in mainly agricultural areas.
A map of the sampling location of the streams that were studied is showed below in figure 1 and a summary of stream names and responsible water boards is given in Table 1.

Figure 1 Map of sampling locations in the Netherlands.

Table 1 Streams under study.

Stream	Responsible water board
Mark	Mark en Weerijs
Hierdensebeek	Veluwe
Schuitenbeek	Veluwe
Middelbeek	Vallei en Eem
Wiel	Vallei en Eem
Luntersebeek	Vallei en Eem
Heiligenbergerbeek	Vallei en Eem
Veengoot	Rijn en IJssel
Grote beek	Rijn en IJssel

3 Results

3.1 General characteristics

In Table 2 general characteristics are given of the streams under study. The basin area indicates the area of the catchment of the stream upstream of the sample location.

Table 2 Characteristics of streams under study.

Stream	Basin area (ha)	Location of measurements
Mark[1)]	21799	Duivelsbrug (Breda, south side)
Hierdensebeek[2)]	2500	No. 24354 (Hierden)
Schuitenbeek[3)]	3544	No. 25200 (Putten)
Middelbeek	1837	No. 25251 (Nijkerk)
Wiel[4)]	1928	No. 26102 (Nijkerk)
Heiligenbergerbeek	7000	No. 29742 (Amersfoort)
Luntersebeek	7300	No. 28003 (Scherpenzeel)
Veengoot	6076	't Sikkeler, Ruurlo
Grote beek	8847	Spaensweg, Steenderen

[1)] *Wastewater treatment plant (Chaam)*
[2)] *21% natural area*
[3)] *15% natural area*
[4)] *Includes the larger part of a 367 ha bird reserve*

All waters in Table 2 are located in areas covered with sandy soils predominantly covered by agricultural crops and pastures.

The Mark drains an agricultural region south of the city of Breda. This region consists of only a few small villages, with no industry. It is not likely that there is a large direct influence of industry and villages on the metal load in the Mark. A rather small wastewater treatment plant ("Chaam", about 600,000 m^3/year) is discharging metals in the area. The heavy metal fluxes of the Mark are corrected by the fluxes attributable to this sewage water treatment plant. Furthermore, an unknown part of the basin is located in Belgium.

Hierdensebeek and Schuitenbeek are located in the northern part of the Veluwe. Wastewater treatment plant and industrial discharges are not present in these streams, according to information given by the Veluwe Waterboard. Furthermore, the Veluwe Board states that a limited part (see Table) of the area is nature; other functions are negligible. Given the characteristics mentioned these streams were chosen as the best match given the criteria set in this research inquiry.

The catchment area of the Hierdensebeek roughly accommodates 60% of the calf farms (veil production) of the Veluwe region. A treatment installation for calf manure was installed in 1985. Since 1994, liquid calf manure is transported to the treatment plant by pipeline.

All houses in the rural area around Elspeet and Uddel are currently connected to the sewer system.

The catchment area of the Schuitenbeek contains fewer calf farms, but the population of general cattle farms and poultry farms is larger.

Middelbeek and Wiel collect water from the agricultural polders between Nijkerk, Amersfoort and Putten. Part of the water from the Wiel basin can be led through Arkervaart; however, how often this happens has never been measured.

Part of the catchment area of the Heiligenbergerbeek has an agricultural function. Furthermore, natural soils are present in the neighbourhood of Leusden, Woudenberg, Maarn and Maarsbergen. The disconnected area of the cities is relatively small (1-5% disconnected from sewer). Effluents of the wastewater treatment plants are discharged outside the region (Valleikanaal).

The larger part of the catchment area of the Luntersebeek is used by agriculture. Rural estates (nature) exist near Scherpenzeel and Renswoude. Luntersebeek is part of an ecological connection zone.

Veengoot and Grote beek are located in the eastern part of the Netherlands (Achterhoek). Both were selected by the Rijn & IJssel Waterboard for having no specific industrial or residential emission sources. The streams' sources are within the Netherlands. Grote Beek has an SED function: Specific Ecologic Goal. This implies that the stream has the official status attributed as having good potential to develop into an ecologically valuable water, whereas some anthropogenic influence is still present. Veengoot has no specific ecological goal or function.

3.2 Water quality and quantity data

The annual heavy metal fluxes are calculated volume-proportional, as described in Chapter 2. In table 3 the annual fluxes are shown for several heavy metals.
All individual measurements, on which the results in Table 3 are based, can be found in appendix A.

Table 3 Annual metal fluxes of different streams (kg).

Stream	Year	Zn	Cu	Pb	Hg	Ni	Cd	Cr
Mark*	1998	7493	754	164				
Hierdensebeek	1995	159	32	3.6	0.14	47	1.1	9.9
Hierdensebeek	1998	148	34	5.4	0.12	25	0.86	8.4
Schuitenbeek[1]	1995	2075	509	58	0.49	359	6.4	154
Schuitenbeek[1]	1998	389	53	12	0.48	82	0.95	20
Veengoot	2001	101	29	-	-	59	-	14
Grote beek	2001	-	16	-	-	-	-	2.1
Middelbeek	1997-1998	205	35	14		34		
Wiel	1993-1998	349	104	28		93		
Luntersebeek	1993-1998	879	312	88		166		
Heiligenbergerbeek	1996-1998	356	340	75		119		

**) corrected for the emission of "Chaam" WWTP in 1998 (CBS)*

A dash (-) indicates that all concentration measurements were below the detection limit.

In Table 4 the annual fluxes of the streams are divided according to basin area, resulting in heavy metals emissions per ha. In this calculation, we assume the emission from nature to be equal to the emission from agricultural soils (per ha); in other words, the calculation is done for the total basin area, regardless of the function. This could lead to an underestimation of the contribution from agriculture in case that the leaching from natural soil would be lower than that of agricultural soil.

Table 4 Metal fluxes from different catchments with sandy soils in the Netherlands (gramme/ha.year).

Stream	Year	Area (ha)	Zn	Cu	Pb	Hg	Ni	Cd	Cr
Mark	1998	21799	343,7	34,6	7,5				
Hierdensebeek	1995	2500	63,5	12,8	1,4	0,1	18,7	0,5	3,9
Hierdensebeek	1998	2500	59,1	13,5	2,2	0,0	10,0	0,3	3,4
Schuitenbeek[1]	1995	3544	585,6	143,6	16,4	0,1	101,2	1,8	43,6
Schuitenbeek[1]	1998	3544	109,8	15,1	3,5	0,1	23,2	0,3	5,7
Veengoot	2001	6076	16,6	4,7			9,7		2,3
Grote beek	2001	8847		1,8					0,2
Middelbeek	1997-1998	1837	111,6	18,8	7,8		18,3		
Wiel	1993-1998	1928	180,9	53,8	14,5		48,5		
Luntersebeek	1993-1998	7000	125,6	44,6	12,6		23,7		
Heiligenbergerbeek	1996-1998	7300	48,8	46,6	10,3		16,3		
Average flux			174	42	9	0.09	31	0.71	14
Standard deviation			*125*	*22*	*4*	*0.06*	*20*	*0.45*	*15*
Standard deviation (relative)			*72%*	*54%*	*45%*	*65%*	*65%*	*62%*	*105%*

1 *The measurements of the Schuitenbeek in 1995 show relative high flows in combination with high metal concentrations. Those in 1998 show low flows with limited metal concentrations. Both measurements reflect the behaviour of a natural stream. No indication for an accidental anthropogenic input exists.*

Some of the metals were not measured at all locations, resulting in blank fields in the table above. Also, in some situations there were not enough valid measurement data available (less than three valid measurements).

Averages and standard deviations are given in the lower section of Table 4. For the calculation of the average figures, every stream was weighted equal. Veengoot and Grote beek were not taken into account in the calculations, because the values in Table 4 seemed unreliable (out of range and highly uncertain - based on a few measurements only). Uncertainty of the calculated fluxes is discussed in chapter 4.

3.3 Extrapolation to a national flux from sandy soils

Based on soil type classification within the STONE-model and the corresponding areas and land use distributions (Römkens 2003), a number of sandy soil types were selected that are predominantly used for agricultural purposes. Following soil types were taken in order to extrapolate a national flux from sandy soils:

Podzol Z12 (8)
Podzol Z8 (9)
Podzol Z8g (10)
Podzol Z8x (11)
Enkeerd (12)

A total area of 8.58 thousand km^2 in the Netherlands is covered by these sandy soils, according to data within the STONE-model. The average fluxes per hectare taken from table 4 are extrapolated with this total area to a national total for the whole of the Netherlands. The result of the extrapolation is given in Table 5. It should be noted that the extrapolation applies to sandy soils only.

Table 5 Extrapolated fluxes of metals from Dutch sandy (agricultural) soils (tonne/year).

Zn	Cu	Pb	Hg	Ni	Cd	Cr
149	36	7.9	0.08	26	0.6	12

4 Discussion

4.1 Comparison with other studies

First, a comparison of emission figures from several literature sources is made, followed by a discussion of the quality of the current results.
Table 6 shows a comparison with previous estimations of the fluxes of heavy metals from agricultural soils.

Table 6 Comparison of metal fluxes from different literature sources (tonne/year).

Metal	This report sandy soils only	Alterra, 2003 (2000) sandy soils[1] only	Alterra, sandy lateral +vertical	Alterra, 2003 (2000) all soils[2]	CCDM, 2002 (2000) (agricultural load to surface water)	RIVM, '97/'98 (1994/1995) cattle/arable farming on sandy soils[3]	
Zinc	149	9.4	89	250	4.3	210	140
Copper	36	0.2	1,7	28	0.1	35	48
Lead	7.9	0.4	3.5	12.4	34	5.1	7.7
Mercury	0.08	-	-	-	0.0		
Nickel	26	0.5	1,5	14	0.0		
Cadmium	0.6	0.1	1,4	0.8	0.0	1.2	0.9
Chromium	12	-	-	-	0.0		

1) Figures from the Alterra report (Römkens, 2003) recalculated by TNO for the STONE soil types that are used for the calculations in this report (see Section 3.2). This includes sandy soils predominantly used for agriculture only.

2) Figures from the Alterra report (Römkens, 2003) for all Dutch agricultural soils, including clay and peat, and sandy soil types with little agricultural use.

3) Leaching estimates from Groot, M.S.M. et al., 1997/1998, for cattle farming (left) and arable farming. Figures originally given in gramme/ha (for comparability the emissions have been multiplied by the area of the STONE soil types that are used in this report – 8,576 km^2).

The CCDM figures are used in the most recent Dutch emission inventory (year 2000 figures), which do not contain a contribution from metal leaching from soils as a source of emissions. CCDM intends to take leaching figures into account in the emission inventory of next year. Even when taking into account the uncertainty of the calculated figures in this report, the current emission inventory figures seem to be an under-estimation (the reported lead emission is due to the use of lead shot for hunting).

The Alterra figures are based on modelling and were verified with groundwater concentration measurement data.
Compared to the figures about metal fluxes calculated in this report all the figures produced by Alterra as result from the recalculation (designated "sand") are very low. This statement even holds when also the vertical fluxes from the Alterra calculations are taken into account (except for cadmium). In the next section possible explanations for these big differences are discussed.

The estimated leaching figures in the RIVM report have been calculated from groundwater concentration measurement averages at 20 cattle farms on sandy soils in Overijssel, Gelderland, Noord-Brabant and Limburg, and 19 arable farms on sandy soils in Groningen and Drenthe. The figures correspond very well to the leaching figures calculated in this report.

The emission figures resulting from this report are subject to several uncertain factors, which can be split up in measurement uncertainties and model uncertainties. Below an overview of possible sources of uncertainty is given and an indication of their relevance.

4.2 Measurement uncertainties

In general, Table 5 shows a large variability of the area-specific emissions among the streams studied. In Figure 1, for instance, a demonstration of the variability is given for zinc. The regression coefficient between flux and area is high, but this is only due to one stream with the largest basin (Mark).

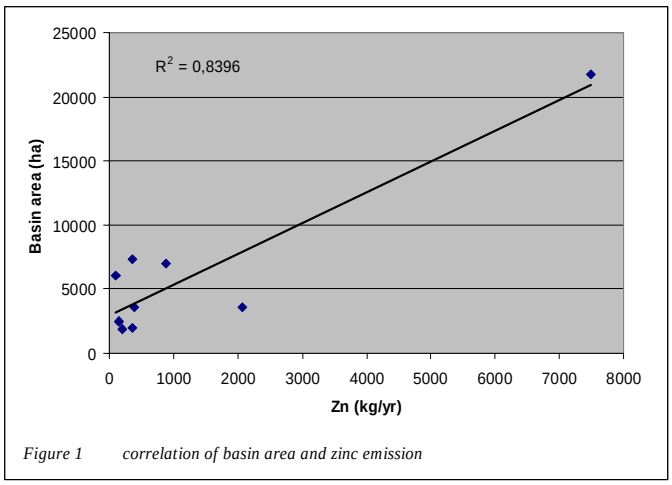

Figure 1 correlation of basin area and zinc emission

Water Flow rates

A first impression of the measurement uncertainties of the flows is given by comparison of the flows that were used in the calculations with a fixed rainfall surplus of 300 mm/year.

Table 7 Calculated flows compared to estimated flows.

Stream	**Calculated flow (mln m3/year) (A)**	**Rainfall surplus (300 mm/year) (mln m3/year) (B)**	**Relative (B)/(A)**
Mark	126,2	65,4	52%
Hierdense beek	7,2	7,5	104%
Schuitenbeek	35,2	10,6	30%
Middelbeek	8,5	5,5	65%
Wiel	20,4	5,8	28%
Luntersebeek	36,6	21,0	57%
Heiligenbergerbeek	20,3	21,9	108%
Veengoot	12,0	18,2	151%
Grote beek	20,3	26,5	131%
		Standard Deviation	44%

From Table 7 it can be concluded that flows do not differ very much from estimated flows. This is to be considered as a first checkpoint of the calculated results. The flows used in the calculations of fluxes are at least in a reasonable range.
The standard deviation of quotients of calculated and estimated flows probably gives an impression of the accuracy of the flows used which is roughly estimated on +/- 44 percent.

Because of the large differences in metal flux in summer and winter, incomplete data sets could lead to an over- or underestimation whenever there is a bias towards summer data or winter data. This is due to the calculation method: for each stream the measurement data are extrapolated to an annual flux (see chapter 2).
The data in this study are not significantly biased towards summer- or winter data, which leads to the conclusion that the data correctly represent the annual metal flux.
Apart from the seasonal variation, the metal flux varies from month to month, which is inherent to the natural character of the system. The effect of this scatter is minor in comparison to the seasonal changes. The use of more measurement data could (statistically) reduce the influence of scatter on the results.

Concentrations
The accuracy of the concentrations measurements will be more dependent from sampling procedures than from analytical procedures. A rough estimation of the accuracy of the measured concentration is +/- 20 percent.

The discharge of streams is dependent on the periodical rainfall.
For some streams the flow rate and the metals concentrations do not appear to be related, whereas for most waters under study, the measurement data do show a relation between the flow rate and concentrations of heavy metals. High flow rates usually occur in combination with high concentrations (in winter time).
In the calculations flows and concentrations are treated as coupled data in order to minimize the bias that can be caused by above mentioned phenomenon.

High flow rates in streams could cause re-suspension of sediment containing heavy metals. According to this theory, the results could be more depending on stored heavy metals, rather than material currently entering the surface water. However, the streams

selected have been chosen on the basis of the absence of historical contamination in their catchment area. Since also industry, highly populated villages and WWTPs[2] are absent (or corrected for), metals bound to sediment will ultimately originate from previous leaching from the soil. Consequently, metal bound to the re-suspended sediment may originate from leaching in previous years, whereas during the year of the measurements new metal is added to the sediment layer. Over a longer period of time for little disturbed areas (as is the situation in the areas chosen in this study), a steady state of metal input and output via the sediment is assumed. In conclusion it can be stated that all metal present in the streams, be it dissolved or in suspended matter, probably originate from metal leaching from the soil in the catchment area.
The different character of the streams (i.c. the relation between flow rate and concentrations) indicates that different processes like run-off and by-pass flow may in some cases be responsible for the actual load.

4.3 Model uncertainties

Considering the criteria on which the streams are selected the assumption is made that in the selected areas, all the metal present in the streams, be it dissolved, in suspended matter or in sediment has an origin in metal leaching processes from the soil in the catchment area. However, there are several factors that may introduce uncertainty.

Dredging
Removal of metals by dredging is not taken into account. Dredging shifts the metal balance between water and sediment, and could lead to lower measured metal concentrations. When a non-steady state situation has existed in the areas under study this may have influenced results.

Nature
The basins of the streams under study roughly comprise of agricultural soils and natural soils. In the calculations we assumed that the total area is covered by agriculture. After all, this is expected to be the main source of heavy metals in the streams selected. The emission per hectare of heavy metals from natural soils in the basin is very much dependent on local soil characteristics (i.e. pH), and may be higher as well as lower than the emission per hectare from agricultural soil in the basin area. Due to the calculation method, this difference could have influenced the results.

Dry and wet deposition[3]
It is assumed that most of the rainwater in the streams is not to consider as direct input from air but comes through soils. Consequently it is assumed that deposition of metals on surface water due to air pollution contributes to the metal load, but is not expected to play a major role due to the relatively small area of surface water.

Seepage and infiltration
The water flow in the soil in more or less hilly sandy areas differs from that in more flat sandy areas. In the Alterra study brooks fed by sources from upcoming ground water (seepage) that originates from infiltrated rain water at other places (e.g. the Veluwe) are counted as vertical drainage. This emerging ground water may contain, according to the

[2] Waste water treatment plants

[3] *Direct deposition on surface water is meant; deposition on agricultural soils is accounted for in the emissions from agricultural soils.*

Alterra study, lower metal loads because in that situation metals may be retained in the deeper soil layers. On the other hand, the lateral flux to the streams in flat and relatively wet sandy areas (e.g. the Mark) may be underestimated in the Alterra model.

Land use
Differences in land use c.q. agricultural practice might lead to differences in leaching rates. Moreover, in some regions manure is treated, instead of spread on the land (e.g. the basin of Hierdensebeek). This may account for the low emission values for Hierdensebeek.

Land use change
When areas are dehydrated, as is the actual situation in many sandy areas in the Netherlands, inorganic and organic processes may give rise to metal mobilisation processes like oxidation of pyrites or biodegradation of previously stored organic matter.

5 Conclusions

Evaluating metal fluxes from agricultural sandy soils by measuring the metal load in streams results in uncertain figures.
This report discusses some possible causes, of which the following are thought to be relevant: (1) the influence of nature in the basins; (2) amount of usable measurement data (3) seepage and infiltration (vertical fluxes); (4) differences in land use practices; (5) dehydration of natural areas; (6) possible effects of dredging.

Table 8 shows emissions of heavy metals from sandy soils in agricultural areas in the Netherlands, extrapolated from data concerning nine sandy soil regions. Although the figures should be regarded as indicative, they represent measured metal leached from soil.

Table 8 Estimated emissions of sandy agricultural soils in the Netherlands (tonne/year).

Metal	Estimated emission
Zinc	149
Copper	36
Lead	7.9
Mercury	0.08
Nickel	26
Cadmium	0.6
Chromium	12

The fluxes shown in table 8 are up to two orders of magnitude higher than the figures from Römkens 2003 selected[4] for sandy soils only (except for cadmium). This leads to the conclusion that there is evidence that the actual emissions from soils in agricultural areas are possibly much higher than modelled in the Alterra report. This conclusion is valid for sandy soils only; on basis of this report, no indication can be given for other soil types.

For sandy soils, the approach followed demonstrates that it is possible to derive leaching rates from direct measurements. However, regarding all uncertainties, a dedicated measurement programme would lead to more accurate leaching rates for sandy soils, and may provide a better understanding of regional differentiation.

[4] *Emission figures in Römkens 2003 are given for all soil types. Based on this report, we recalculated the emissions for sandy soil types predominantly used for agriculture. The soil type / use combinations are in line with the calculations in this report.*

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7 Authentication

Name and address of principal:
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Names and functions of the cooperators:
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Date upon which, or period in which, the research took place:
2003

Signature: Approved by:

R.H.J. Korenromp
Project leader

Ir. H.S. Buijtenhek
Head of Department

A Measurement data

Mark

Month	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)
January	5,4	59	4	1
February	1,7	36	6	1
March	6,1	55	5	1
April	3,2	50	3	1
May	1,3	15	2	1
June	1,8	24	5	1
July	1,0	15	3	1
August	0,5	11	2	5
September	3,8	48	9	2
October	7,6	70	9	1
November	9,2	75	8	2
December	6,4	78	4	1

Hierdensebeek

Date	Q (m^3/s)*	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
1-2-1995	0,19	48	7,8	0,50	8,4	0,16	2,0	0,07
1-3-1995	0,23	30	6,6	0,60	11	0,26	1,8	<0,01
3-5-1995	0,24	17	5,5	0,30	5,5	0,14	1,2	<0,01
7-6-1995	0,26	15	0,07	0,70	6,3	0,19	1,3	<0,001
2-8-1995	0,13	11	5,9	0,70	3,5	0,07	1,2	0,07
8-11-1995		2	4,0	<0,01	4,6	0,09	1,0	0,01
6-12-1995		12	3,8	0,40	5,1	0,10	1,2	<0,001
24-3-1998	0,33	21	4,1	0,70	0,40	0,13	0,9	0,01
30-6-1998	0,19	12	4,0	1,2	5,1	0,09	0,8	0,04
29-9-1998	0,27	18	4,1	0,20	4,7	0,08	1,3	0
22-12-1998		35	5,7	0,10	6,7	0,29	1,2	0

**) For 1995 no flow rate figures are available; the corresponding flow rates for 1998 have been used.*

Schuitenbeek

Date	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
12-1-1995	2,3	49	10	1,3	7,2	0,19	2,9	<0,001
9-3-1995	3,1	47	13	1,4	9,0	0,12	4,1	0,02
13-4-1995	0,20	21	3,8	0,20	5,3	<0,01	1,1	<0,01
6-7-1995	0,03	5,6	2,8	0,20	3,2	0,03	0,9	<0,01
28-9-1995		0,5	2,9	0,30	2,0	<0,00	0,8	0,007
2-11-1995		2,4	3,0	<0,01	2,5	0,02	1,1	0,015
7-12-1995		5,8	1,0	0,07	1,5	0,01	0,3	0,02
24-9-1998	0,48	15	2,3	0	3,6	0	0,9	0
3-12-1998	0,60	29	3,8	1,3	5,8	0,10	1,4	0,05

Middelbeek

Date	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
10-2-1997	0,26							
7-4-1997	0,041	8	1	2	2			0
28-7-1997	0,11	1	1	0	1			0
22-9-1997	0,063	4	1	0	1			0
20-10-1997	0,094							
17-11-1997	0,073	8	1	0	2			0
13-1-1998	0,26	11	1	1	3			
9-2-1998	0,083	9	0	1	1			0
9-3-1998	1,8	34	5	1	5			0
20-4-1998	0,19	9	3	1	3			1
22-6-1998	0,16	14	3	2	3			0
21-7-1998	0,044	4	1	0	2			0
23-9-1998	0,34	4	1	0	1			

Wiel

Date	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
11-1-1993	1,3	18	5	1	4			1
19-4-1993	0,20	4	1	0	0			0
5-10-1993	0,73	6	4	1	3			0
13-1-1998	0,50	7	1	0	2			
9-2-1998	0,23	5	0	0	0			0
9-3-1998	3,5	27	6	1	5			0
20-4-1998	0,35	6	3	1	3			0
19-5-1998	0,050	5	3	1	2			
22-6-1998	0,25	2	2	1	2			0
21-7-1998	0,14	1	2	0	2			0
18-8-1998	0,079	21	30	1	2			0
23-9-1998	0,46	3	2	0	4			

Luntersebeek

Date	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
11-1-1993	4,1	32	16	1	4			
29-3-1993	0,91	7	3	0	4			
12-7-1993	2,3	1	3	0	2			
4-10-1993	4,6	24	14	1	5			
26-2-1997	2,9	36	8	1	4			
3-3-1997	0,70	14	3	0	4			
28-4-1997	0,10	9	2	0	2			
23-6-1997	0,063	15	1	0	2			
13-10-1997	0,88	10	3	0	3			
8-12-1997	0,22	8	2	0	3			
12-1-1998	0,64	15	3	0	5			
3-2-1998	0,25	8	2	0	3			
2-3-1998	0,33	7	3	0	3			
6-4-1998	0,53	10	4	0	4			
8-6-1998	0,72	9	3	0	2			
4-8-1998	0,12	6	4	0	2			
10-9-1998	2,7	25	5	1	11			
3-11-1998	5,1	37	9	1	4			
11-5-1998	0,029	3	5		5			
28-5-1998	0,26	10	3	0	1			
7-7-1998	0,049	2	2	0	1			
25-8-1998	0,014	2	2	1	2			
5-10-1998	0,12	39	2	0	4			
7-12-1998	0,29	14	3	1	4			

Heiligenbergerbeek

Date	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
15-2-1994	0,34	35	2	0	3			
12-4-1994	0,56	25	3	0	4			
14-6-1994	0,87	15	4	0	5			
16-8-1994	0,34	15	2	0	3			
25-10-1994	0,60	20	1	0	2			
20-12-1994	0,51	15	2	0	3			
14-2-1995	1,8	23	4	2	6			
3-4-1995	1,3	19	3	2	7			
8-8-1995	0,25	31	6	2	3			
5-10-1995	1,3	3	2	0	2			
13-12-1995	0,19	18	2	1	2			
16-4-1996	0,15	10	1	0	2			
11-6-1996	0,24	7	2	0	2			

Veengoot

Date	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
8-1-2001	1,0	15	4	< 2	7	< 0,1	2	< 0,01
5-3-2001	0,31	10	3	< 2	7	< 0,1	2	< 0,01
7-5-2001	0,12	< 5	3	< 2	9	< 0,1	3	< 0,01
10-7-2001		< 5	2	< 2	4	< 0,1	< 1	< 0,01
11-9-2001	0,062	10	< 1	< 2	11	< 0,1	4	< 0,01
5-11-2001		< 5	1	< 2	< 4	< 0,1	< 1	< 0,01

Grote beek

Date	Q (m^3/s)	[Zn] (mg/m^3)	[Cu] (mg/m^3)	[Pb] (mg/m^3)	[Ni] (mg/m^3)	[Cd] (mg/m^3)	[Cr] (mg/m^3)	[Hg] (mg/m^3)
8-1-2001	2,0	< 5	1	< 2	< 4	< 0,1	< 1	< 0,01
5-3-2001	0,83	< 5	< 1	< 2	< 4	< 0,1	< 1	< 0,01
7-5-2001	0,53	< 5	< 1	< 2	< 4	< 0,1	< 1	< 0,01
10-7-2001	0,008	< 5	< 1	< 2	< 4	< 0,1	< 1	< 0,01
11-9-2001	0,22	< 5	2	< 2	< 4	< 0,1	1,5	< 0,01
5-11-2001	0,25	< 5	< 1	< 2	< 4	< 0,1	< 1	< 0,01

B CIW measurement locations