TNO Environment, Energy and Process Innovation

Nederlandse Organisatie voor
toegepast-natuurwetenschappelijk
onderzoek / Netherlands Organisation
for Applied Scientific Research

Laan van Westenenk 501
Postbus 342
7300 AH Apeldoorn
The Netherlands

www.mep.tno.nl

T +31 55 549 34 93
F +31 55 541 98 37
info@mep.tno.nl

TNO-report

R 2003/138

Metal Balance of Sewer Systems
First evaluation of current knowledge in the Netherlands

Date	March 2003
Authors	J.H.J. Hulskotte, M.Sc. R.N. van Gijlswijk, B.Sc.
Order no.	31934
Keywords	sewers metals balance emission
Intended for	Stichting Duurzaam Bouwmetaal

Table of contents

1. Introduction

Until now, little research has been done on the behaviour of heavy metal inputs in sewer systems. The aim of the present study is to map out the extent and nature of the available knowledge according to mainly Dutch literature from the last two decades on the behaviour and fate of the metals zinc, copper and lead entering sewer systems.
More specific the goals of the study are:
To provide an inventory of the data that are needed to draw up a heavy metal balance of separated and mixed sewer systems in the Netherlands, to check to what extent such information is available for the Dutch situation, and to formulate a research plan according to the data gaps.

Since in the Netherlands almost all urban waste water is collected in sewer systems, urban metal flux to surface waters is also routed via sewer systems. This fact underlines the importance of a good understanding of processes in sewer systems in relation to urban metal fluxes into surface waters.

The starting point of the study is a qualitative description of processes that influence metal mass balances in sewer systems.
Secondly, the study evaluates the available literature dedicated to the processes described. This evaluation concentrates on whether the information allows any degree of quantification of the process involved.
Thirdly, a linear regression analysis is carried out of the zinc mass balances of about 400 Dutch wastewater treatment plants. Tentative statistical conclusions are drawn about source strengths and the importance of regional influences.
Finally, conclusions are drawn about the possible overall importance of the processes in quantitative respect.

2. General description of types of sewer systems

In the Netherlands 4 different types of sewer systems are in use nowadays: mixed sewers (including improved mixed), separated, improved separated and pressurized sewers. The total pipe length by type of sewer is given in the table below.

Table 2.1 Sewer systems in the Netherlands (2002), total pipe length (km).

Type of Sewer	Length of pipe
Mixed	46,702
Separated	9,967
Improved separated	15,962
Pressurised	13,822

Ref: [1]

In the next sections a description is given of the different systems.

2.1 Mixed sewer system

The mixed sewer system is the most common system in the Netherlands. In the end of the nineties of last century 75 percent of sewer systems still were of the mixed type [2]. In mixed sewer systems residential and industrial wastewater is transported to the wastewater treatment plant together with atmospheric precipitation. Simplicity and low connection costs (about € 2,800.-- per house connected, [3]) are the main advantages [4] of this type of sewer systems.
One disadvantage are that the surface water is (unnecessarily) loaded with organic matter, heavy metals, PAH (Polycyclic Aromatic Hydrocarbons) due to overflow during heavy rainfall. Furthermore, the WWTP have a high wastewater load [4].
One disadvantage is that there is an overflow to the surface water of substances such as organic matter, heavy metals, and PAH. Furthermore, the WWTP have high wastewater loads during storms, which causes a temporary drop in the removal efficiency regarding pollutants.

2.2 Improved mixed sewer system

This system resembles the first, except for the fact that overflow sites are equipped with storm water retention basins. The basins are emptied back into the sewer when the hydrological capacity has turned back to normal. This system reduces overflow by a certain rate, depending on the capacity of the retention basins.

2.3 Separated sewer system

The separated sewer system redirects atmospheric precipitation water to a second, separate rainwater sewage pipe. So the WWTP can be dimensioned smaller and no overflows occur in the 'dirty water' system [4]. Costs are about € 3,600.-- per house connected [3].
However, according to CUWVO [5] the environmental load of surface water in a separated sewer system is about the same as it is in a mixed sewer system. This is caused by the contamination of atmospheric run-off with several pollutants.

2.4 Improved separated sewer system

In this type of sewer system, the rainwater normally runs into the wastewater sewer and is discharged to surface water during severe rainfall only. This results in lower emissions to surface waters [4]. A connection costs about € 4,100.-- per house connected [3]. The positive effect is limited, since in this situation only 20-30% of the rainwater is actually discharged to surface water [3], [2].
All newly built residential areas in the Netherlands have (improved) separated sewer systems. Also, existing sewer systems are gradually being turned into separate systems.

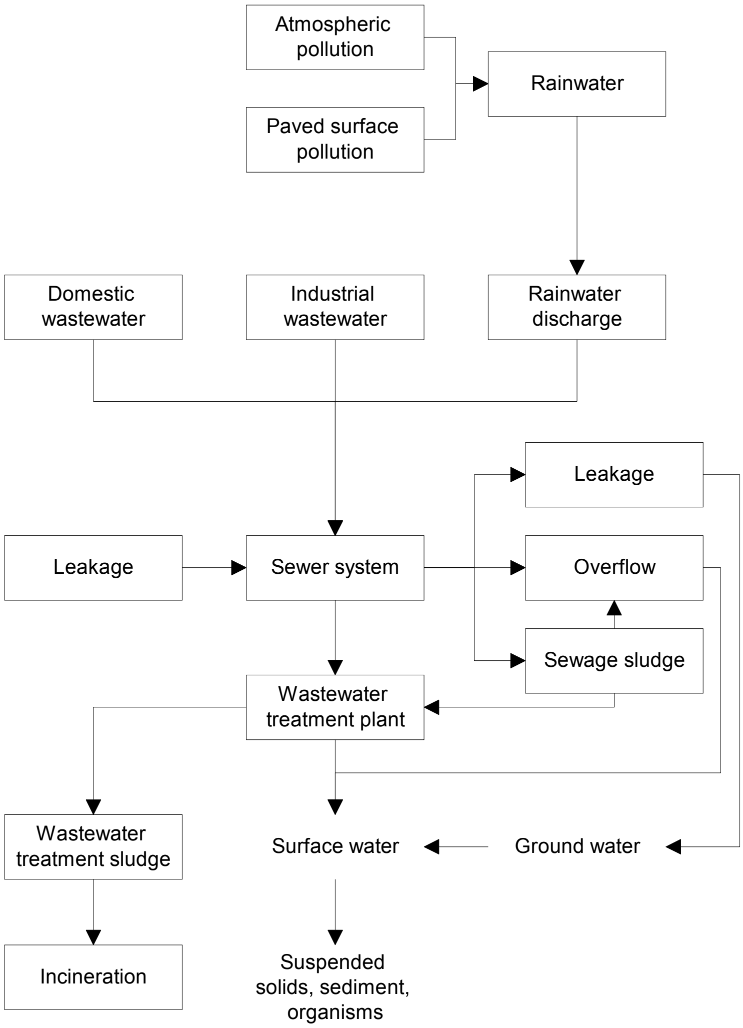

Figure 2.1 Overview of the mixed sewer system.

3. Description of Processes and Mass Balance

In this chapter the mass balance of sewer systems is discussed in general terms. The complete mass balance can be described by a limited number of processes which occur in sewer systems.

3.1 Mass balance and general processes in sewers

Figure 3.1 presents a cross-section of a single sewer duct. This single sewer duct however can also represent all combined sewer systems of the Netherlands. The arrows show the fundamental processes in relation to the overall mass balance.

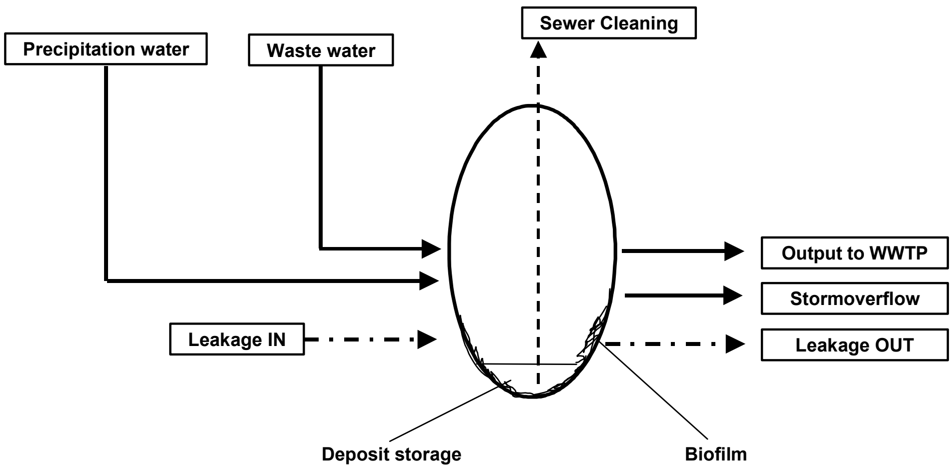

Figure 3.1 Fundamental processes in mixed sewer systems.

Using Figure 3.1 a mass balance equation can be constructed from mixed sewer systems by putting the processes in the general formula:

OUTPUT = INPUT - ACCUMULATION

Using figure 3.1 and the general formula a table (table 3.1) can be constructed wherein the various processes are categorized under the three items of the formula.

Table 3.1 Mass balance of a mixed sewer segment.

OUTPUT	=	INPUT	-	ACCUMULATION
Output to WWTP*)		Waste water		Deposit storage (Cesspit-sludge)
Combined sewer overflow		Deposition/Precipitation		Biofilm
Sewer Cleaning		Leakage IN		
Leakage OUT				

*) WWTP = Waste water treatment plant.

In the following paragraphs we will discuss the nature and the state of the knowledge of the individual processes listed in Table 3.1.

3.2 Output of metals from sewer systems

3.2.1 Output of metals to WWTP

In the Netherlands, the output of metals from sewers to urban wastewater treatment plants (WWTP) is measured on a regular basis for each individual plant. The results of the measurements are annually collected by the Statistics Netherlands (CBS) and transferred to the national emission inventory. The total mass of influx is estimated by adding metals in sludge and metals in effluents [6]. Although figures of individual plants fluctuate from year to year, the total influx on a national scale can be considered to be fairly accurate as in principle all WWTP are monitored every year. The annual national accuracy of the most important metals (zinc, copper, lead) is here estimated to be better than ± 10 per cent.
The tables below show the results of the CBS questionnaire sent to owners of WWTP.
The variability between years is clearly visible. Except for the emissions trends that are downward generally, the cause of the variability is often attributed to differences in weather characteristics between years. The amount of precipitation is an especially important factor.

Table 3.2 Annual supply (influent) of heavy metals to WWTP in the Netherlands (tons).

Year	Copper	Chromium	Zinc	Lead	Cadmium	Nickel	Mercury	Arsenic
1995	189	32	451	81	1.5	31	0.7	5.6
1996	152	22	405	52	1.6	30	0.6	4.6
1997	157	17	368	47	0.8	26	0.5	5.4
1998	166	21	445	59	1	30	0.5	6.9
1999	166	21	463	56	1	31	0.5	6
2000	150	20	388	51	0.9	24	0.5	5.7

Ref: [7]

Table 3.3 Annual removal of heavy metals in sludge from WWTP in the Netherlands (tons).

Year	Copper	Chromium	Zinc	Lead	Cadmium	Nickel	Mercury	Arsenic
1995	140	19	341	63	0.7	11	0.5	2.8
1996	140	19	317	52	0.6	11	0.5	2.5
1997	135	17	300	48	0.6	12	0.5	2.6
1998	136	18	330	54	0.6	13	0.5	3.9
1999	147	20	355	57	0.6	14	0.5	3.9
2000	131	17	319	51	0.5	11	0.4	3

Ref: [7]

Table 3.4 Annual effluents of heavy metals from WWTP in the Netherlands (tons).

Year	Copper	Chromium	Zinc	Lead	Cadmium	Nickel	Mercury	Arsenic
1995	23	6.8	124	10.5	0.4	13.4	0.2	2.6
1996	18	5.4	109	8.3	0.4	14.2	0.2	2.2
1997	22	5.3	93	9.6	0.3	16.1	0.1	2.5
1998	20	6.1	123	8.1	0.3	14.3	0.1	3.2
1999	20	6.5	114	8.6	0.4	16.3	0.2	3
2000	18	5.4	106	9.2	0.4	12.5	0.1	2.8

Ref: [7]

It is unknown whether these annual fluctuations are mainly attributable to differences in influx into sewers systems or are also caused by the metals which are already stored in deposits in sewer systems. A robust answer on this question could be useful for the development of new strategies for the diminishing of emissions from effluents and combined sewer overflows. In paragraph 3.3.1 some conclusions from research in France are presented.

3.2.2 Combined Sewer Overflows

Generally metal fluxes of combined sewer overflows (CSO) directly to surface water are nowadays recognized as an important emission source with respect to local water quality. In 1998, for instance, the official estimate of total zinc flux to surface water by combined sewer overflows in the Netherlands was 16 tons, comparable to 123 tons of zinc in WWTP effluents.
The accuracy of the metal flux estimate by the combined sewer overflows, however, is considered to be very low. This is also recognized by the RIZA experts. For this reason, a project was started to improve the emission estimation protocol for CSO [8].
The current figures are based on research in the 1980s called NWRW [9]. In this research it was found that the hydrological flux of water transferred to surface water was between 30 mm/year and 485 mm/year, depending on the particular sewer

system investigated. The average amount was 177 mm/year. This can be compared to an average precipitation of 800 mm/year in the Netherlands.

In the PROMISE model [10] used by RIZA to estimate the metal flux of combined sewers, a theoretical distinction is made between Dry Weather Flux (DWF) and Rain Weather Flux (RWF). In the model it is assumed that all emission processes are closely related to one of the two fluxes. For instance, organic load of private households is considered to be related to DWF while zinc emissions of building materials are considered to be closely related to RWF. The rationale behind this distinction is that the CSO are only active for 1 per cent of the time while emissions of private households are continuous. Consequently, according to the PROMISE model, 1 per cent of the residential emissions is considered to be transferred to surface waters by CSO. On the other hand, the emission of zinc to surface water is considered to be related to the total amount of rainwater (RWF) that is transferred to surface water by Combined Sewer Overflows which is assumed to be 22 per cent – the later figure being exactly 177 mm/800 mm as established in the NWRW research program.

The amount of water transferred by the CSO to surface water however has a very wide range, i.e. approximately one order of magnitude. The amount of water is probably not the most important parameter for flux of metals [11]. The amount of organic material that is transferred could be just as important or more important, since the major part of the metals is probably bound to organic material (once in the sewer system, 60-95% of the heavy metal amount is present in the suspended sludge [4], [12]) and the metals concentration in solution is probably relatively low during heavy rainfall when CSO become active.

The area of hard surface [11] is advised as the most useful parameter to estimate the amount of organic load transferred.

However according to several authors, cited by [13], runoff probably is not the most important source of storm water pollutant loads. Deposits in sewers are found to play an important role not only during storm events but even on an annual time scale.

This would imply that intermittent cleaning of sewers is a possible option for reduction of emissions of CSO as is demonstrated in a French investigation [24]. This option is, as far as known by us, until now not discussed in studies in the Netherlands.

The accuracy of the national totals of metal fluxes via the CSO is rather difficult to estimate because there are multiple quantitative unknown factors involved. We try to estimate upper and lower limits here.

Assuming that the amount of cesspit sludge[1] removed via CSO is equal to the amount of cesspit sludge removed by sewer cleaning (about 100,000 tons containing 300 mg/kg), the amount of zinc would be about 30 tons which is in the same order of magnitude as the 16 tons estimated by RIZA in the National

[1] Cesspit sludge is the material that is deposited in cesspits in order to assure easy flow of waste water through the sewer systems.

Emission Inventory. Since there are 15,000 Combined Sewer Overflows [1] in the Netherlands, this would imply that on the average about 6 tons of sludge (dry matter) could be emitted to surface water via each Combined Sewer Overflows. Regarding the state and the relative small surface of the receiving surface waters of CSO the calculated inputs seem to be rather high. The lower range of the emissions by CSO would be about 5 tons zinc, assuming 1 per cent (equal to estimated Dry Weather Flux) of the total output of zinc to WWTP.
Based on the upper and lower limits explained before the conclusion can be that the emissions of zinc by CSO is 16 tons ± 50 per cent.

3.2.3 Sewer Cleaning

The denominator 'sewage sludge' is used here to discriminate the sludge in the sewer from wastewater treatment sludge (WWTP sludge).
Cesspit sludge and sewage sludge are usually considered to be one stream because of their similar treatment. Both are collected by the sanitation department of local authorities. Sanitation waste (WWTP-sludge) amounted to 984 kilotons in 1999; the contribution of sewage and cesspit waste is 94 kilotons [14].

From a national point of view on fluxes of metals to surface water, cesspit sludge is not interesting because practically all sludge that is separated from sand is transferred to WWTP. This fact implies that in the national statistics of metals the amount leaving sewers via cesspit sludge is already contained in figures about metal output to WWTP.

3.2.4 Leakage Out

Some small-scale studies are known about leakage from sewer systems [4] [15]. These studies indicate that leakages of sewer systems have generally only a very local impact on soil quality just beneath leaking sewer pipes as a consequence of sludge drag-out.
Leakage was shown to occur only in sewer pipes installed before 1960 because technical improvements in pipe junctions dated later proved to be effective against leaking [14].
Taking into account that most residents live in the lower part of the country where leaking out of the sewers is not likely because of high groundwater levels.
This circumstance combined with the fact that more than 80 per cent of the sewer systems are build after 1960 [1] or have been renovated, it can be argued that 'leaking out' probably is not a very important phenomenon from the viewpoint of the total metal mass balance of sewers.
During removal of old sewer pipes, the surrounding soil is removed (so-called 'slit soil'). This is a mixture of gravel, sand, clay and sewage sludge, which is released at an estimated annual rate of about one million m^3 (based on 2% sewer pipe replacement) [4]. No data are available on the fraction of leaked sludge removed

placement) [4]. No data are available on the fraction of leaked sludge removed via this route.

So far, there are no data as to a possible substantial impact on national mass balances of metals.
From the linear regression analysis (see paragraph 2.2.2) of input and output of WWTP, there seems to be a possibility that leakage of sewer systems may occur when chemical factories are connected. This conclusion is based only on preliminary statistical evidence. Confirmation by physical examination in selected cases is necessary.

3.2.5 Rainwater sewers

Rainwater sewers collect the storm water and urban run-off in case of a separated sewer system. In the Netherlands the area of impervious surface that is drained by pure rainwater sewers is about 61.000 hectares [16]. Based on figures in table 2.1 it is estimated that about 38.000 hectares is improved separated sewers and about 23.000 hectares is separated.
An estimation of emissions related to discharges of (not improved) rainwater sewers is given in table 3.7 together with official national emission estimates.

Table 3.7 Emissions calculation of separated sewers compared to official data

Substance	Emission Source category	Emission Factor [17]	Dimension	Volume [1], [16]	Dimension	Emission (ton/yr) Calculated	Emission (ton/yr) [18]
Copper	Atmospheric deposition (total)	10	g/ha.yr	23,000	ha	0.23	0.35
	Road traffic	0.3	g/house.yr	613,000	houses	0.18	0.08
	Building materials	n.a.				n.a	
	Total					**0.4**	**0.4**
Lead	Atmospheric deposition (total)	95	g/ha.yr	23,000	ha	2.2	1.7
	Road traffic	0.12	g/house.yr	613,000	houses	0.07	13.1
	Building materials	4.5	g/house.yr	613,000	houses	2.8	
	Total					**5.0**	**14.8**
Zinc	Atmospheric deposition (total)	200	g/ha.yr	23,000	ha	4.6	1.5
	Road traffic	8.6	g/house.yr	613,000	houses	5.3	32
	Building materials	13	g/house.yr	613,000	houses	8.0	
	Total					**17.8**	**33.5**

From table 3.7 is concluded that rainwater sewers (not improved) can be a substantial emission (local) source of metals to surface waters. Depending on basic assumptions estimated emission amounts of emissions can differ by a factor of two but the order of magnitude seems to be correct.
Official figures from the National Emission Inventory about zinc and lead from rainwater sewers could be too high as a consequence of overestimation of the contribution of building materials based on outdated figures.
The emission of metals from rain water sewers on a national scale is comparable or greater than the emission of metals by CSO from mixed sewers. The total area covered by rain water sewers however is considerable less than that of all mixed sewers. This could imply that local impact of rainwater sewers on concentrations of heavy metals in urban water is important. Seen in this light it is somewhat surprising that attention of national water policy towards sewer systems is mainly directed to the abatement of emissions from CSO by improving mixed sewer systems and redirecting rainwater of hard surfaces to infiltration systems.

Influence of fault connections of separated sewers
In the normal situation rainwater sewers are discharging directly to surface waters and are not connected to sewers that are connected with WWTP. However in a very limited number of cases of fault connections rainwater sewers may discharge on WWTP. As long as the percentage of fault connections of rain water sewers stays under 10 percent no extra discharges of CSO may be expected [19]. It is expected that this is the situation in virtual all cases.
However a small percentage of fault connections of the polluted (dry weather) water stream of (not improved) separated sewer systems may in rare cases cause serious local water pollution [20].

3.3 Input of sewer systems

In contrast to output, the input of sewer systems (the sum of all indirect emissions) is much more difficult to establish. The main reason for this is that the emission sources are very numerous and emission estimation is a complex procedure. Of course, a large quantity of data is collected on an regular basis within the National Emission Inventory. Nevertheless, scientific verification of emission data remains difficult.

3.3.1 Waste water including urban run-off and atmospheric deposition

The input of sewer systems comprises two main flux categories:
- Urban waste water
- Industrial waste water

Urban waste water contains three major source categories:
- Waste water from private households
- Atmospheric precipitation containing material from diffuse sources
- Atmospheric deposition

Industrial waste water comes from a wide variety of industrial activities. Two fundamental methods of assessment are in use:
- Periodic measurements, also used for imposing environmental fees
- Estimation based on production and emission factors

The present report makes a first attempt at scientific verification (see Appendix 1 for details) of zinc emissions to sewer systems, on the basis of the emission data that are available in the Dutch emission inventory.

A linear regression analysis was performed on the measured output of zinc of 393 individual WWTP and the emission according to the National Emission Inventory. Emission data of the National Emission Inventory [21] were clustered in three independent categories of source allocation methods and emission assessment methods. This kind of input/output analysis is possible in the Netherlands thanks to the fact that the emission inventory includes a GIS-system that connects all individual WWTP to individual sewer areas. As a consequence indirect emissions in the emission inventory are directly connected to these particular sewer areas.
The three main emission categories discerned in the regression analysis were:
- residential emissions (including diffuse sources)
- measured industrial emissions
- estimated emissions of small and medium-sized businesses.

Table 3.8 Results of multiple linear regression analysis, zinc output as a function of input categories of WWTP, N = 393.

Source category	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Residential emissions	**1.33**	0.04	35.33	0.0000	1.25	1.40
Industrial (measured)	**2.05**	0.30	6.91	0.0000	1.47	2.64
S/m businesses (estimated)	**2.47**	0.58	4.23	0.0000	1.32	3.62

The results of the statistical analysis show a very high degree of correlation (R^2=0.90) between calculated input (sum of indirect emissions) and measured output (sum of influents) for the 393 individual WWTP.
This is also demonstrated in the figure below. However, from the slope of the figure 3.2 it can be concluded that about 40 per cent of the emissions of zinc in the year 2000 are missing in the current emission inventory. The results of the multiple linear regression analysis give estimations about the coefficients that could be chosen to correct the emission figures. The results of the regression analysis show a very high degree of statistical significance. In agreement with this high degree of statistical significance, the given confidence intervals are not very broad.

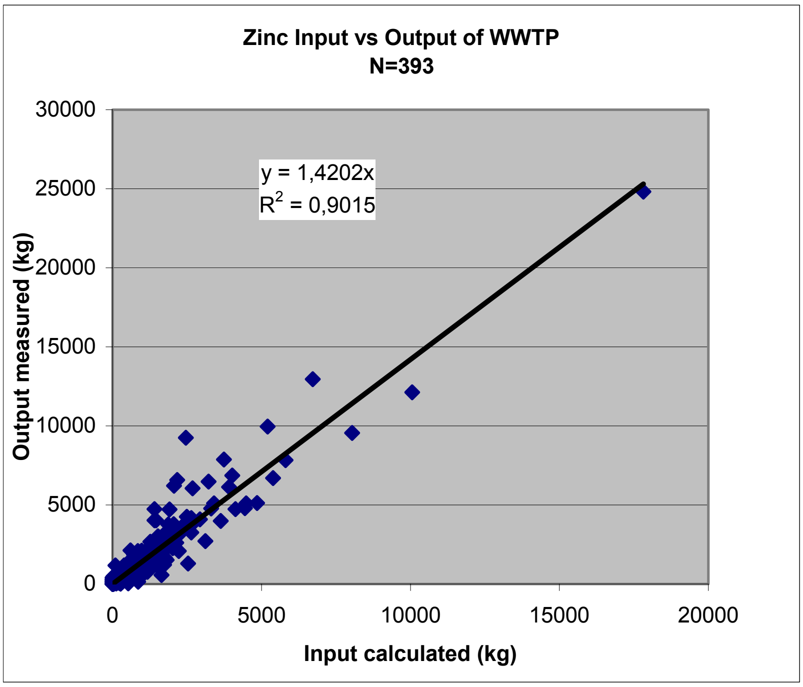

Figure 3.2 Relation between output of WWTP and estimated input.

Using the results from the linear regression analysis, a best fit for the emissions can be derived. This is shown in the table below.

Table 3.9 Suggested adjustments to national emission inventory of zinc based on multiple linear regression analysis.

Source category	**Emission Inventory (ton)**	**Coefficients**	**Estimated Emission (ton)**	**Difference (ton)**
Residential emissions	292.0	1.33	388.4	96.4
Industrial (measured)	13.9	2.05	28.5	14.6
S/m businesses (estimated)	17.0	2.47	42.0	25.0
Total	322.9		458.9	136.0

There is one known physical explanation for correcting residential emissions. Atmospheric deposition was not included in the results of the inventory. According to a recent investigation [16], the amount of zinc from atmospheric deposition entering WWTP via sewers is estimated to be about 32 tons. This means that about 100 tons of zinc is still missing in the national emission inventory. The linear regression analysis suggests that about 40% of this may be of industrial origin and the rest would be related to residential emissions. Most likely candidates of emission sources in the residential range are the major sources of zinc related to residents: car tire wear, human excreta and zinc metal corrosion. The deviation is not necessarily caused by a miscalculation of primary emissions. Even a very small deviation of (weather-dependent) run-off coefficients could also be a plausible explanation for slightly underestimating average emissions to sewers.

Although the outcome of the National Emission Inventory correlates well with the measurements of individual WWTP, it is interesting to investigate the possibility of systematic deviations.

First, a histogram is made to see what the frequency distribution of residues looks like.

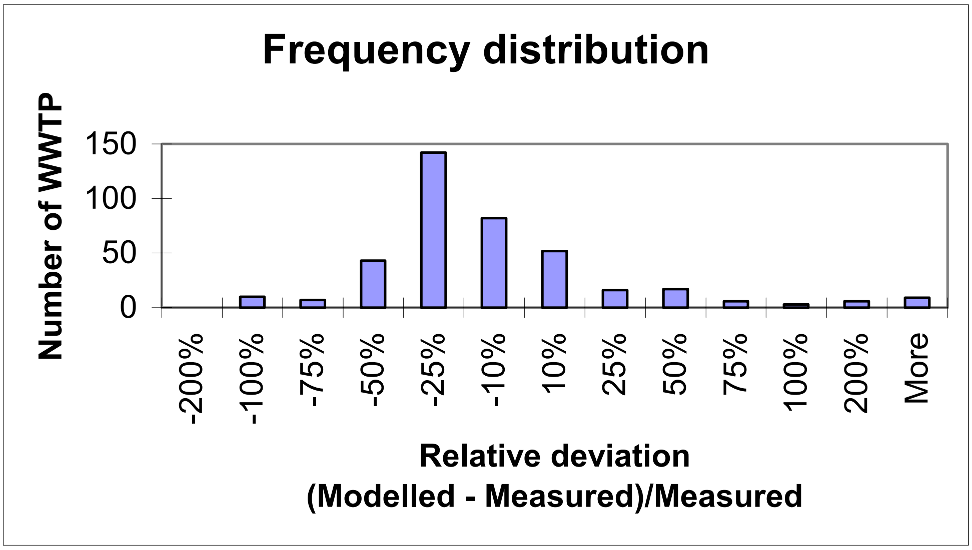

Figure 3.3 Frequency distribution of relative deviation of measured vs. modelled input of zinc to WWTP.

Figure 3.3 shows that emissions are generally underestimated but that there are a number of relatively high overestimations of emissions. The precise nature of these overestimations is not clear. Probably, most deviations have a local cause that cannot be investigated without considering local factors of importance (for instance geographical detailed storm data from the year of interest).
The possibility that a number of sewer systems emissions that enter sewers do not end up in the WWTP may not be excluded as a possible cause of the latter phenomenon.
In this report we conclude with a map of sewer systems in the Netherlands and it shows the related under- and overestimation of zinc emissions to WWTP.

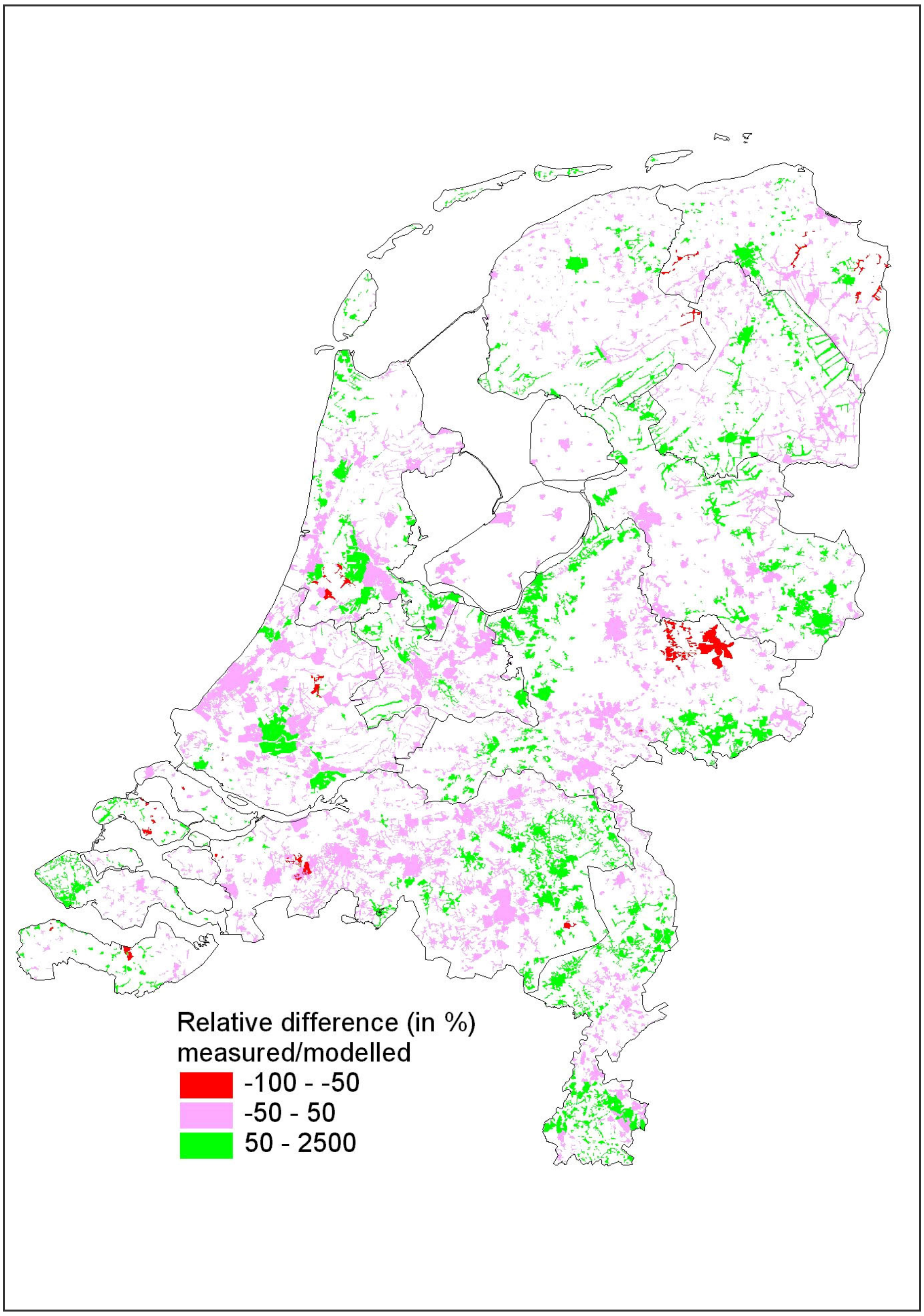

Figure 3.4 Geographical distribution of difference measured/modelled zinc input in WWTP.

From the map it is concluded that under- and overestimations seem to be strongly geographically clustered but a single, simple explanation does not offer itself. So an extended investigation is necessary to reveal the cause of the regional distribution of under- and overestimation.

General conclusions about input of WWTP

- Overall national level zinc emissions to sewers (WWTP) are quite well understood.
- Underestimation can probably be attributed to industrial sources (40%) and urban run-off coefficients (60%).
- On a local scale, deviation of average emission factors and unknown processes may be of greater importance.

3.3.2 In-leaking

Systematic knowledge or data about groundwater leaking into sewer systems is not available.
In Amsterdam, groundwater levels near sewer pipes are monitored systemically in order to prevent leaking of groundwater into sewers [22]. Drops in groundwater levels are considered to be a signal of possible damage to sewer pipes. When substantial leaking is found to occur, preventive actions are carried out. It is unknown whether other cities in the Netherlands with high groundwater levels have comparable methods for preventing groundwater from leaking into sewer systems.
On a national level, an analysis could be made in which groundwater levels are related to the wastewater volume of individual WWTP.

3.4 Accumulation in sewer systems

3.4.1 Deposit storage

As sewer pipes can function for more than fifty years [1], a simple mass-balance point of view can easily prove that over a long time period of many years deposit storage cannot be a very important net sink of heavy metals in sewers. However, for shorter periods and in the case of a new and clean system, a substantial fraction of metal emissions can remain trapped in sewer systems.

The removal of cesspit sludge is essential for the hydrological functioning of sewer systems. Therefore it can be argued that the deposit storage of sludge in sewers must be far less than the total amount of sludge removed. The amount of metals in cesspit sludge in the Netherlands is in the range of 10 per cent of the annual total of sludge from WWTP.
Nevertheless the total mass of deposits in sewers probably is probably larger than the amount of cesspit and sewage sludge that is removed by sewer cleaning. Combining data from total pipe length (73,000 km free flow sewers) in the Netherlands and amount of deposits measured in a sewer pipe (only 1 study in France) delivers an order of magnitude for different types of deposits.

Table 3.5 Sewer deposits and estimated total mass storage.

Type of deposit	Mass (ton/km) Ref. [24]	Total (kton)
Deposit < 400 µm	54	3942
Deposit < 80 µm	8.9	650
Organic Mass	0.014 - 0.047	1 - 3.4
Flushable Mass (1 flush, average of 10)	0.10	7.3

In table 3.5 can easily been seen that the total mass amount of deposits in the sewer systems could be considerable. However the greater part of the mass stored is probably rather inert and consists for the greater part of sand (< 400 µm) and clay (< 80 µm) fractions. A relative small amount of the mass of deposits consists of organic material while a greater amount consists of easy flushable materials.

Sewage sludge composition can show large variations, depending on the nature of the connections and the type of area connected to the sewer system. Results of heavy metal analysis are showed in the table below (see Table 3.6).

Table 3.6 Examples of heavy metal concentrations in sewage sludge matrices.

Substance	Concentration $Metal_p/SS_s$ (mg/kg) Ref. [23]	Concentration $Metal_p/SS_s$ (mg/kg) Ref. [24]	Concentration $Metal_p/SS_s$ (mg/kg) Ref. [24]	Concentration $Metal_p/SS_s$ (mg/kg) Ref. [24]	Concentration $Metal_p/SS_s$ (mg/kg) Ref. [24]
City, year	Hamburg	Marseille,2002	Paris,1999	Paris,1999	Various
Medium	Sewage sludge	Particles 1st flush	Sand deposits (400 µm)	Organic layer	Storm water
Lead	267	208	400-**1870**-10000	197-**214**-335	33-294
Cadmium	4				
Zinc	298	1170	570-**2461**-4047	970-**1270**-1550	1136-1800
Mercury	9.2				
Chromium	24.5				
Nickel	19				
Copper	104				

$Metal_p/SS_s$= metals adsorbed on particles in solution

Regarding the data in table 3.6 heavy metal concentrations are in the same order as concentrations found in sewage sludge.
Assuming an average metal content equal to sewage sludge, the total amount of metals in sewer deposits could be equal to the metal content of sewage sludge productions from 4 years of all WWTP in the Netherlands.

However little is known about the amounts stored and the behaviour of storage deposits through the course of years it is rather likely that sewer deposits act as a big metal buffering storage with variable buffer capacity and variable flushing ability. The buffer capacity might be varying due to flushing during storm events. Very little experimental knowledge however is available about the functioning of such buffering capacity on different time scales (days, months, years). This understanding would also be helpful in a more profound approach of sewer emissions.

3.4.2 Biofilm

Biofilm grows on the interface of water and air against the walls of sewer tubes. Biofilm represents only very small mass fraction of sewers which is relative persistent relative to other deposits as the gross bed sediment and the organic layer [26]. As the composition of biofilm reflects the composition of dry weather pollution it can be used as a tracer of emission sources of several specific hydrocarbons and in some cases also of metals [26], [25].

4. Evaluation and Subjects for Study

4.1 General Conclusion

Surprisingly little information of fundamental processes and behaviour of metals in sewer systems is found in the Netherlands literature of water quality management. This observation is in contrast with numerous studies about the development of environmental policies towards the collection and treatment of urban waste water in the Netherlands. Therefore it seems that the utilization of more fundamental knowledge in the future possibly could deliver a wider spectrum of more cost-effective approaches in environmental protection against discharges of urban waste water. Considering the increasing intensity of storms as a consequence of climate change this research need probably becomes more urgent in the near future. Although not thorough investigated in this study it shows that foreign literature gives a more profound perspective on internal processes in sewer systems. Possibly foreign literature could be used as a source of inspiration of research to be done in the Netherlands.

4.2 Subjects for study

Table 4.1 shows an evaluation of the available knowledge, as well as an evaluation of the importance of quantification and the ability to quantify, and the quality of current knowledge. This evaluation is based on the information given in chapter 3 of this report.

Table 4.1 Status of current knowledge of sewer mass balance processes with respect to metal fluxes.

OUTPUT	Importance	Quantified	Quality	Research need
Output to WWTP	Very high	Yes	Good	Low
Combined sewer overflow	High	Yes	Low	High
Rainwater sewers	High	Yes	Low	High
Sewer cleaning	Low	Yes	Low	Low
Leakage OUT	Low	No	n.a.	Low
INPUT	**Importance**	**Quantified**	**Quality**	
Waste water	Very high	Yes	High to Medium	Medium
Deposition/precipitation	High	Yes	Medium	Medium
Leakage IN	Unknown	No	n.a.	Unknown
ACCUMULATION	**Importance**	**Quantified**	**Quality**	
Deposit storage	High	No	n.a.	High
Biofilm	Low	No	n.a.	Low

If the overall importance of a process is medium to high – or unknown – and information is either unavailable, scarce or of poor quality, it is important to upgrade the knowledge of that process.
From this perspective, it can be concluded that it is desirable to improve the knowledge and the data available on Combined Sewer Overflows and Rain water sewers and the role of Deposit storage by means of further research. A project is ongoing for the Combined Sewer Overflows. Depending of the outcome it will be advisable to continue the research on this subject.

Leaking-in while still unclear deserves some attention and leaking out probably does, too.

Verification of emissions by linear regression analysis has shown that improvement of the emission inventory methodology for zinc is possible, especially with respect to industrial emissions. On a national scale, the knowledge of residential emissions, including most diffuse sources, seems to be quite well understood. However, in many cases the results of the models on a local scale still deviate from the measurements. It is advisable to prepare similar countrywide studies of mass balances over all individual WWTP on other metals like copper and lead and also for phosphate in order to get a more knowledge about the causes of uncertainties of emissions.

Probably these findings could be further investigated in a combined project, together with the physical explanations for the big differences in the local zinc balances of WWTP, as these show an unexplained high degree of regional clustering across the country. Such a project could also be used to assist local water boards in the improvement of many local emission assessments which are currently in preparation.

5. References

[1] RIONED, **Riool in cijfers 2002 – 2003**, uitgave Stichting RIONED, Ede.

[2] Teunissen, R.J.M., **Regenwater in de stad - deel 1. de samenstelling van (afstromend) regenwater**, RIZA werkdocument 98.090x, Lelystad, June 1998.

[3] Geldof, G.D. et al, **Water in de stad; gescheiden waterstromen - behandelingstechnieken**, RIZA, Deventer, April 1997.

[4] Darwinkel, B. en M. in 't Veld, **De invloed van lekkende rioleringen en overstorten op de grond- en grondwaterkwaliteit**, Tauw Milieu, Deventer, July 1995.

[5] CUWVO, **Overstortingen uit rioolstelsels en regenwaterlozingen**, 1992.

[6] Rienks, J., Baas, C., Gommers, P., **Microverontreinigingen in (gezuiverd) stedelijk afvalwater: de feiten op basis van metingen door beheerders van rwzi's uitgewerkt voor de metalen koper, zink en kwik**, H2O, 30, no. 22, 1977.

[7] Statistics Netherlands, 2002, **Statline** (statistical data warehouse), www.cbs.nl.

[8] Klok, G.A.M., **Kwaliteitsverbetering emissieschattingen diffuse bronnen, deelproject rioolemissies**, rapportage fase 1, Haskoning, 21 May 2001.

[9] Sluis, J.W. van et al, **Eindrapportage en evaluatie van het onderzoek 1982-1989**, NWRW, STORA/VROM, November 1989.

[10] Elzenga, J.G. et al., **PROMISE a scenario model for the prognoses of emissions to surface water**, 66 p. in Dutch, 1998.

[11] Veldkamp, R.G.,Wiggers, J.B.M., **Het voorspellen van een extreme vuiluitworp uit gemengde rioolstelsels**, H2O, 30, no. 13, 1997.

[12] Dusny, H.R. et al., **Chemodynamics and transport of trace metals in municipal sewers**, conference proceedings of Sewer Processes and Networks, Paris 2002.

[13] Chebbo, G. et al., **The nature and pollutant role of solids at the water-sediment interface in combined sewer networks**, conference proceedings of Sewer Processes and Networks, Paris 2002.

[14] Darwinkel, B. et al., Lekkende rioleringen, overstorten en bodemkwaliteit, H2O, 30, no. 25, 11 December 1997.

[15] Aukes, C. en D. Hoogstra, **Milieuverontreiniging door lekkende riolering**, afstudeerverslag HBCS Velp, Tauw Intra Consult, Deventer, June 1988.

[16] Duyzer, J.H., Plant, R.A.J., Bleeker, A., **Bepaling van emissies naar water door atmosferische depositie**, TNO report R2002/268, June 2002.

[17] Oosterhuis, M., **Vervuiling van infiltratievoorzieningen**, TNO-MEP, Apeldoorn, TNO-rapport R2002/618, Oktober 2002.

[18] Koch, W.W.R. et al., **Emissiemonitor, Jaarcijfers 2000 en ramingen 2001 voor emissies en afval**, Rapportagereeks Milieumonitor nr. 6, november 2002.

[19] Velde, R.S. van der, Boomgaard, M., **Foutieve aansluitingen bij gescheiden rioolstelsels**, H2O, 29, no. 15, 1996.

[20] Blauw, A.N., et al., **Omgaan met lozingen uit regenwaterriolen**, H2O # 5-1998.

[21] VROM Inspectie, Basic data about sewer systems in the Netherlands over the year 2000.

[22] De la Chambre, R., De Wit, N., **Door oplettende videocamera nieuw riool in de Apollolaan te Amsterdam**, H2O, 21 no. 7, 31 March 1988.

[23] Beichert, J., Hahn, H.H., Fuchs, S., **Stoffaustrag aus Kanalisationen**, Deutsche Forschungsgemeinschaft, 1996.

[24] Laplace, D. et al., **Removal of the organic layer in combined sewer sediment using a flushing gate,** conference proceedings of Sewer Processes and Networks, Paris 2002.

[25] Loo van der, H., Somers, J.B.M., **Slijmhuid in riolen als indicator voor bronnen van organische microverontreinigingen**, H2O, 30, no. 21, 1997.

[26] Rocher, S.A. et al., **Biofilm in combined sewer: wet weather pollution source or/and dry weather pollution indicator**, conference proceedings of Sewer Processes and Networks, Paris 2002.

[27] Timmerman, M. (dir. Zandrecycling Nederland), **Ruim 100.000 ton rioolslib verwerkt tot herbruikbaar zand**, Riolering december 1999, p. 25-29, december 1999.

[28] Janssen, J.G., **Zandwasinstallatie leidt tot 80% minder stort van rioolslib**, Land + water nu, juli/augustus 1989, p. 96-97.

[29] **Afval Verwerking Rijnmond, www.avr.nl**

[30] Verhagen, H., **Monitoring Prioritaire Afvalstoffen, Gegevens 1999**, RIVM/LAE, maart 2001.

[31] **Ontwerp Landelijk AfvalbeheersPlan 2002-2012**

[32] Timmerman, M. (dir. Zandrecycling Nederland), **Ruim 100.000 ton rioolslib verwerkt tot herbruikbaar zand**, Riolering december 1999, p. 25-29, december 1999.

[33] Kruize, R.R., **Kursus: Slibverwerking, 1989, S13: Verwerking inhoud van kolkzuigers**, Stichting postakademisch onderwijs - gezondheidstechniek en milieutechnologie, Delft, 1989.

6. Authentication

Name and address of the principal:
Stichting Duurzaam Bouwmetaal

Names and functions of the cooperators:
J.H.J. Hulskotte, M.Sc.
R.N. van Gijlswijk, B.Sc.

Names and establishments to which part of the research was put out to contract:

Date upon which, or period in which, the research took place:

Signature:	Approved by:
J.H.J. Hulskotte, M.Sc. projectleader	H.S. Buijtenhek, M.Sc. head of department

Appendix 1 Other literature about sewers

Bakker, K. et al, **De vuiluitworp van gescheiden rioolstelsels**, Nationale Werkgroep Riolering en Waterkwaliteit, STORA, Wageningen, October 1988.

Beichert, J., H.H. Hahn and S. Fuchs, **Stoffaustrag aus Kanalisationen**, Deutsche Forschungsgemeinschaft, 1996.

Berbee, R.P.M. et al, **Behandeling afstromend wegwater van snelwegen**, RIZA, Lelystad, February 1996.

Blokker, M. en J. Sicco Smit, **Vuurwerk als diffuse bron van waterverontreiniging, Onderzoek jaarwisseling 1999 -2000**, Waterschap Veluwe, Apeldoorn, December 2000.

Boomen, R.M. van den, **Monitoring risicovolle overstorten**, Witteveen+Bos / Waterschap Vallei en Eem, Deventer/Leusden, March 2001.

Broodbakker, N.W. et al, **Water in de bebouwde omgeving**, Ministerie van LNV en IKC Natuurbeheer, January 1995.

Cursus Rioleringstechniek: Het gebruik van mathematische modellen in de rioleringstechniek: terugblik en vooruitblik, Stichting Postacademisch Onderwijs Gezondheidstechniek en Milieutechnologie, 1998.

Cursus Rioolstelsels: Modellering van rioolstelsels, Stichting Postacademisch Onderwijs Gezondheidstechniek en Milieutechnologie, 1998.

De Graaf, I., J.T.A. Verhoeven en G.B.J. Rijs, **Helofytenfilters voor de verwijdering van microverontreinigingen uit afstromend wegwater (literatuurstudie)**, RIZA werkdocument 97.154x, Lelystad, December 1997.

Decentralised Sanitation and Reuse - concepts, systems and implementation, IWA publishing, 2001.

Feenstra, J.F. en P.F.J. van der Most, **Diffuse bronnen van waterverontreiniging**, CUWVO, September 1986.

Geldof, G.D. et al, **Water in de stad; gescheiden waterstromen**, RIZA, Deventer, April 1997.

Geldof, G.D., Hengeveld, H., Idema, S., **Het geïntegreerde stelsel**, H2O, 28, no. 12, 1995

Hermans, R., **Schoon uit het riool - af- en niet aankoppelen in de praktijk**, Stichting RIONED, February 2001.

Hove, D. ten en L.D.M. Wensveen, **Vuiluitworp uit rioolstelsels - Interimrapport inzake het onderzoek naar de vuilemissie van rioolstelsels**, NWRW report no. 5.1, STORA/VROM, January 1987.

Kroon, C., **Vuurwerk en oppervlaktewater - verkennend onderzoek naar de invloed van vuurwerk in de millenniumnacht op de kwaliteit van het afstromende regenwater en het oppervlaktewater**, Waterschap Zuiderzeeland, Lelystad, January 2001

Lambrechts, A.C.W. en S.P. de Jong, **Leidraad aan- en afkoppelen verharde oppervlakken**, Tauw Civiel en Bouw, Deventer, March 1996.

Metingen aan rioolstelsels en oppervlaktewater - eenvoudige metingen en waarnemingen, Stowa, Utrecht, April 1996.

Mulder, J.W.,Geenen, S., Stapel, D., **Optimalisatie in de Rotterdamse afvalwaterketen**, H2O #, 21-2000

Onderzoek naar het voorkomen van zwarte lijststoffen in Noord-Brabant - in de stroomgebieden van Mark en Dintel en Voorste Stroom, Bijlagenrapport, Hoogheemraadschap West-Brabant, Waterschappen De Aa, De Dommel en Maaskant, Provincie Noord-Brabant, Dienst Binnenwateren/RIZA, Ministerie VROM, November 1989.

Peels, C.E. et al, **Kwaliteit van het grachtwater in het bastion van 1982 t/m 1985 gerelateerd aan de lozing van een regenwaterriool**, Ministerie van Verkeer en Waterstaat, Rijkswaterstaat directie Flevoland, 1991.

Pollutants in urban waste water and sewage sludge, DG Environment, EC, 2001.

Schoot Uiterkamp, J., Vele kleintjes… - **Verkenningennota diffuse bronnen**, RIZA nota no. 94.034, April 1994.

Veldkamp, R.G., **Sewer overflow pollution - standardized research data of the NWRW project 1982-1989**, Stichting RIONED, June 1995.

Visser, C.M. en L. Lijklema, **Effecten van microverontreinigingen in rioolwateroverstortingen en regenwaterlozingen op organismen in het ontvangende oppervlaktewater - een oriënterend literatuuronderzoek**, Nationale Werkgroep Riolering en Waterkwaliteit, STORA, Wageningen, March 1987.

Wagemaker, F.H. et al, **Waterverkenningen: Een strategie voor de aanpak van microverontreinigingen in communaal afvalwater**, RIZA nota no. 99.027, January 1999.

Warmer, H., Van huis uit - **Verkenningennota communaal afvalwater**, RIZA nota no. 94.033, April 1994.

Wastewater Enigneering - Treatment, disposal and reuse, second edition, Metcalf & Eddy, inc., New Delhi, 1989.

Waterkwaliteitsbeheer Deel B - Zuivering van afvalwater, CBS, Voorburg/Heerlen, 1999.

Wit, J.A.W. de, **Emissiebeleid zonder grenzen - Verkenningen van communale, industriële en diffuse bronnen van emissies naar water**, samenvattende nota, RIZA nota no. 94.031, April 1994.

Ywema, R., R.W.J. Smulders en W. Geukemeijer, **Slibafzetting in rioolstelsels - fase 1: literatuuronderzoek en inventarisatie van ervaringen**, NWRW report 6.1, STORA/VROM, January 1987.

Zinkemissies afkomstig van huishoudelijke produkten, Haskoning, May 1996.

Appendix 2 Zandrecycling Nederland

Zandrecycling Nederland CV is the largest cesspit and sewage sludge treatment organization in the Netherlands; it is a joint venture of Van der Valk + De Groot, Boskalis-Dolman and AVR-government. Several plants are in use, at which the material is stored and treated [27]. Furthermore, a number of mobile installations with a limited capacity are in use [28], [29]. The produced ‘clean’ sand can be reused in conformity with the Dutch Building Material guideline (*Bouwstoffen-besluit*).

Table A.1 Locations of Zandrecycling Nederland.

Location	Function	Administration
Wolvega		ZRNN
Schiedam	Extractive cleaning, storage Production of sand and secondary raw materials	Boskalis-Dolman
Waalwijk		AVR
Brunssum	Storage, sampling, production of sand and secondary raw materials	Afvalzorg / ZRN
Vlissingen		
Zevenaar		
Leeuwarden	Mobile mineral waste cleaning installation	BVNN/Boskalis Dolman
Groningen	Mobile mineral waste cleaning installation	BVNN/Boskalis Dolman
Assendelft	Storage and treatment installation	Afvalzorg
Heiloo	Storage and treatment installation	G.P. Groot
Almere		
Alkmaar	Landfill Mobile mineral waste cleaning installation	G.P. Groot

The sand cleaning technique is based on a hydrocyclone [28]. The material is brought in suspension under high pressure, and the sand is captured by a sieve. The coarse fraction (stones, plastic, fabric, cans, iron, etc.) is rinsed, de-watered and removed as waste. The slurry can either be added to the influent of a wastewater treatment plant or concentrated in a separate mobile installation [28].

Appendix 3 Treatment of Sludge

Table A.2 shows the destination of cesspit and sewage sludges in 1999 [30].

Table A.2 Destination of cesspit and sewage sludges (1999).

Destination/treatment	Amount (kton)
Total amount	94
Landfill	24
Incineration	-
Composting	1
Separation afterwards	66
(Direct) useful application	3

Landfilling, which still accounted for 26% of sludge in 1999, will be prohibited in the future (regulation is being prepared) [31].

In case of separation, several extracting treatment techniques are used. Usually, five fractions are distinguished: sand, water, coarse fraction, metal fraction and sludge (fine fraction). Sometimes a separate fat-removing step is implemented. The dehydrated sludge and the non-recyclable part of the coarse fraction are landfilled [27]. Since the sand (approximately 80% of the weight) is relatively clean, it can, for example, be re-used in the road construction industry [29]. The aqueous organic fraction, containing most of the heavy metals out of the cesspit and sewage sludge, can be fed to a WWTP [33].

The Dutch draft 2002-2012 National Waste Control Plan (*Landelijk Afvalbeheers-plan*) [31] defines a minimum standard for the treatment of street cleaning waste and cesspit and sewage sludges:
– Cesspit and sewage sludge should at least be separated into an inert (sand) fraction and a rest fraction.
– The rest fraction should be incinerated in such a way that less than 5% of the input has to be landfilled.
– Export for further treatment is prohibited.