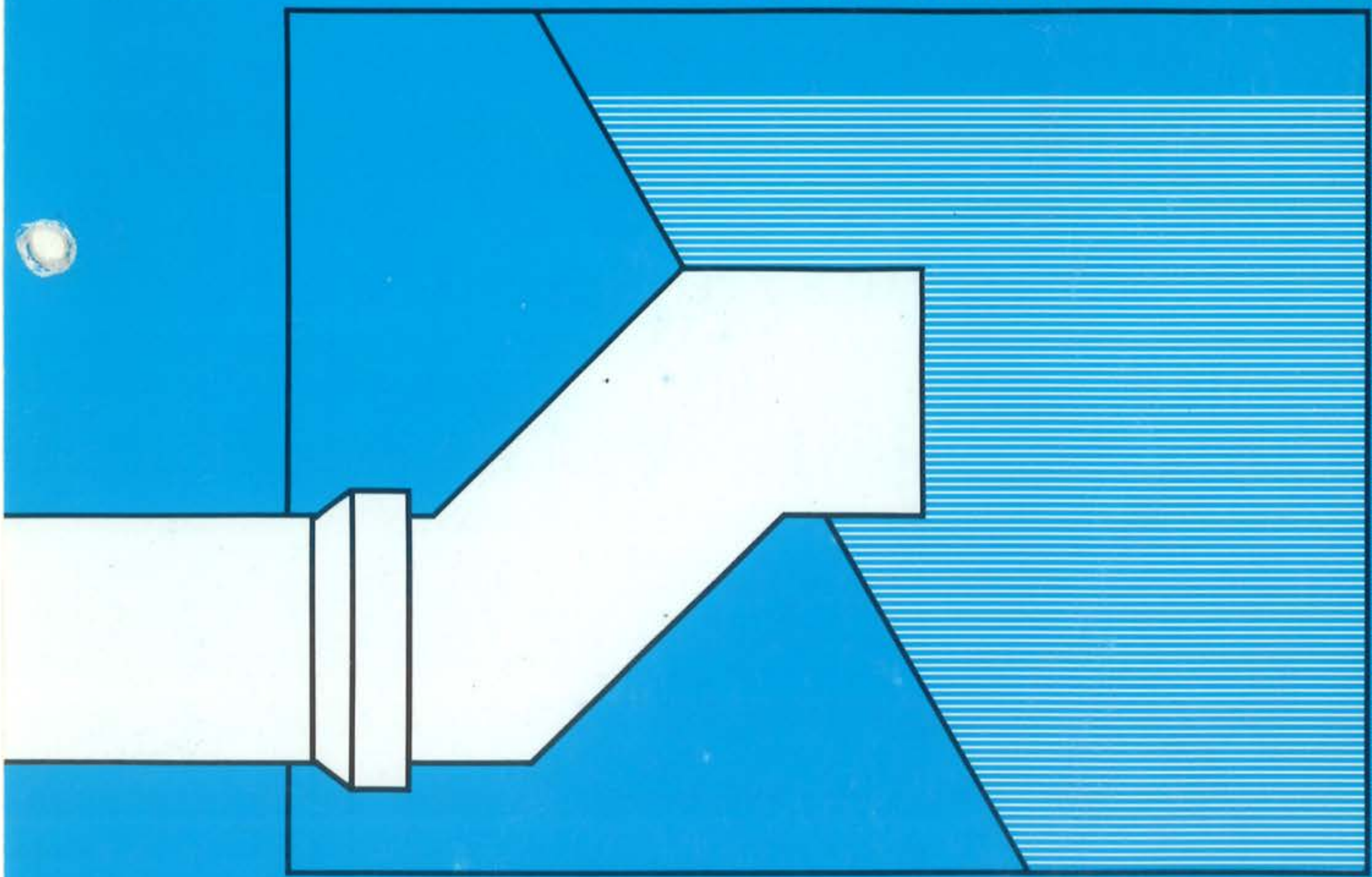
1454

NWRW

NATIONAL WORKING PARTY ON
SEWERAGE AND WATER QUALITY

Final report of the 1982 - 1989 NWRW research programme
Conclusions and recommendations

Foundation for Applied Waste Water Research stora



Ministry of Housing, Physical Planning and Environment

NWRW
NATIONAL WORKING PARTY ON
SEWERAGE AND WATER QUALITY

Final report of the 1982 - 1989 NWRW research programme
Conclusions and recommendations

June 1991

Ministry of Housing, Physical Planning and Environment (VROM)

Ministry of Housing, Physical Planning and Environment
ISBN 90 346 2569 9
Price Dfl. 50,-

Distribution:
SDU Publishers
P.O. Box 20014
2500 EA 's-Gravenhage
Netherlands

Orders should specify the ISBN-code and an address for delivery.

Bibliographical Data

1 Report number Final report	**7 File number**
2 Title Final report of the 1982-1989 NWRW research programme Conclusions and recommendations	**8 Date of publication** November 1989 **9 Internal report number** A 1374.10.100
3 Authors J.W. van Sluis, D. ten Hove and B. de Boer	**10 Journal number**
4 Project management DHV Water BV Laan 1914, No. 35 P.O. Box 484 3800 AL Amersfoort	**11 Contract number** DGMH/DWB/3038407 August 30th 1988
5 Commissioning authority Ministry of Housing, Physical Planning and Environment (VROM), Department of Water Supply, Water, Soil and Ground Water	**12 Type of report and timing** Final research report September 1988 - August 1989
6 Project title NWRW report	

13 The final report of the NWRW research programme discusses the results obtained in the individual projects and presents a series of general conclusions. Recommendations are made as to how such results can be applied to improve the management of sewer systems and water quality. To facilitate their wider implementation, a number of tools are outlined of relevance to the design and management of sewer systems.

14 Advisory committee NWRW plenary committee See Appendix 1	**15 Complementary reports** Reports of the individual NWRW projects.	
	16 Number of pages 66	**17 Price** f 50,-

18

Foreword

Over the last twelve months, environmental management in the Netherlands has received a considerable boost with the publication of the National Environmental Policy Plan, the Third National Policy Document on Water Management and "Zorgen voor morgen". These documents have served to bring home the importance of preserving the environment to a wider audience. It therefore seems appropriate that 1989 should also see the publication of the final report in a series issued by the National Working Party on Sewerage and Water Quality (NWRW), summarising the results of its comprehensive six-year research programme.

The NWRW was established at the beginning of the 1980s by the Ministry of Housing, Physical Planning and Environment (VROM) and the Foundation for Applied Waste Water Research (STORA) to investigate how waste discharges from sewer systems affect the quality of surface waters. In particular, the NWRW was given the task of monitoring of such discharges and their effects under a range of field conditions in order to assess the relevance of various theories developed on the subject in the 1970s.

Over the last six years, an impressive array of projects has been carried out by various engineering consultants and research institutes as part of the NWRW research programme. However, none of this would have been possible without the assistance of the many municipal and provincial authorities, water quality control boards and government departments that participated in the programme. Their valuable contributions are gratefully acknowledged.

The present report aims to summarise the results of the individual research projects within the context of the overall NWRW programme and to formulate a set of general conclusions and recommendations. The findings of each of the individual research projects have been reported separately. I am confident that with the completion of the NWRW programme, sufficient data are now available for municipal authorities to be able to design and manage their sewer systems effectively. The findings of the NWRW programme should also assist the water boards in their attempts to develop meaningful requirements for controlling discharges into surface waters.

In the final analysis, the success of the present research programme will be judged by what happens to the quality of surface waters in the Netherlands in the coming years. The spotlight will be particularly focused on surface water quality in urban areas. The information and expertise that have been generated will provide a sound basis for managing water as a resource of life.

M.K.H. Gast, NWRW Chairman
November 1989

0. Summary and conclusions

0.1. Aims and objectives

In the effort to address the problem of surface water pollution in the 1970s, it was decided to enlarge the capacity of sewage treatment in the Netherlands. Consequently, the contamination of Dutch surface waters decreased, with particular reductions being noted in the discharge of oxygen-consuming substances. Although the water quality improved significantly in this period, it had been expected that even better results would have been achieved. Questions were raised as to what extent the discharges from non-point sources, such as those from sewer systems, were impeding further progress.

Dutch Water quality control authorities screen the sewer plans submitted to them in regard to the impact of overflows on water quality. They were however hampered in doing so because of a lack of meaningful standards. It was common practice to evaluate the plans in terms of the overflow frequency and pumping capacities rather than on the size and quality of the receiving water. This was felt to be a serious omission.

In a paper published by the Foundation for Applied Waste Water Research (STORA) in 1976[1], three issues were identified which needed to be addressed before the design of sewers could be improved and effective water quality criteria formulated, namely:
- how serious are overflows from sewers in relation to other sources of surface water pollution?
- what is the relationship between the design parameters for sewer systems and the discharge of pollutants?

What happens in a sewer?

- *what impact do sewer overflows and stormwater discharges have on receiving waters?*

Following on from the pioneering work carried out by STORA in measuring waste fluxes from sewer systems, the National Working Party on Sewerage and Water Quality (NWRW) was set up in 1982 with the specific aim of increasing scientific understanding in the above areas. The present NWRW research programme, which was instituted in 1983 to address these issues, has taken six years to complete. The direct costs involved amounted to a total of Dfl. 13 million. The main findings of the research programme are summarised below.

0.2. Research findings

0.2.1. Sewer systems

More than ninety percent of the sewer networks in the Netherlands is of the combined type. Together these sewer systems have some 12,000 outlets, the majority of which (85%) discharge into small, stagnant or semi-stagnant waters. The remaining ten percent of sewer districts have separate systems, with a few thousand stormwater outlets.

0.2.2. Predicting combined sewer overflows

Assessments of various numerical simulation models have shown that none of the methods currently available is able to predict the onset of individual overflows with sufficient accuracy. Discrepancies between theory and practice were found in more than 50% of the cases. Not only did storms that were expected to lead to overflows not have the predicted effect, but supposedly benign rainfall also resulted in overflows. Nevertheless, predictions of the total quantity of stormwater discharged over a twelve-month period were found to be within 20% of the measured values. It is evident that municipal authorities responsible for sewer systems, and water control boards would benefit considerably from more accurate predictive models. Preparatory work aimed at developing an improved hydraulic model has included performing a sensitivity analysis to determine the relative importance of the various parameters involved.

0.2.3. Overflow volumes

Analysis of the overflows from combined sewer systems over a twelve-month period shows the preponderance of small discharge events and the occurrence of relatively few large discharges. Reducing the frequency of discharge events can therefore restrict the number of minor overflows and hence reduce the total amount of water discharged throughout the year. Nevertheless, this approach is unlikely to affect major discharges from combined sewer systems.

1 *Veldkamp, F.B. Riolering en waterverontreiniging. Probleemstelling. Stichting Toegepast Onderzoek Reiniging Afvalwater (STORA), The Hague.*

0.2.4 *Discharge of pollutants from combined sewer systems*

The magnitude of the waste load discharged from systems of combined sewers is predominantly determined by the small number of major discharge events that occur throughout the year. Depending on the concentration of pollutants present, heavy rainfall can be responsible for some 15-80% of the total annual waste flux. Large variations can occur in both the average annual waste flux and the average concentration of pollutants discharged per overflow. The largest and smallest annual waste fluxes and average pollutant concentrations recorded in four combined sewer systems are given in the table below.
The magnitude of the annual waste flux from a particular sewer system is primarily determined by the quantity of stormwater discharged and hence indirectly by the storage capacity of the sewers. The lowest figures given in Table 0.1 refer to the sewer system with the largest storage capacity (Bodegraven), while the highest figures refer to the system with the smallest storage capacity (Kerkrade). Guidelines have been drawn up for predicting the waste flux from sewer systems on the basis of these measured values.

On a relative basis, the annual waste flux attributable to overflows in combined systems with large storage capacities is likely to be considerably smaller than residual domestic discharges from sewage treatment plants (stps). However, in the case of sewer systems with small storage capacities, the proportion of oxygen-consuming substances, heavy metals and dry suspended solids discharged as a result of sewer overflows is likely to be much higher than the corresponding amounts contained in effluent from sewage treatment plants, whereas the proportion of total phosphorous and Kjeldahl nitrogen discharged is likely to be smaller.

Table 0.1. - The highest and lowest annual waste fluxes and average concentrations of pollutants for four combined systems in the Netherlands.

substance	measured annual waste flux		average pollutant concentration per overflow
	(g/cap.a)	expressed as a proportion of domestic waste after treatment (%)	(mg/l)
BOD	71 - 1583	9 - 197	40 - 124
COD	273 - 6263	4 - 91	148 - 389
TKN	19 - 301	1 - 22	10 - 15
total P	4 - 70	1 - 14	2 - 5
TSS	191 - 15946	40 - 3315	105 - 320
			(mg/m³)
lead	0.1 - 4.6	25 - 1270	42 - 162
zinc	0.7 - 13.8	31 - 600	357 - 472
chromium	0.02 - 1	25 - 1212	10 - 21
copper	0.2 - 4	8 - 203	67 - 113
nickel	0.02 - 0.5	6 - 151	8 - 19
mercury	0.01 - 0.2	167 - 3000	0.5 - 43
cadmium	0.01 - 0.05	50 - 250	1 - 10

What is discharged into surface waters?

0.2.5. *Discharge of pollutants from separate sewer systems*

Measurements performed in systems with separate sewers have shown that considerable variations can be expected in both the average annual waste load from such systems and the average concentration of pollutants discharged per overflow event. The highest and lowest annual waste fluxes and pollutant concentrations recorded in systems with separate sewers in Amsterdam and Heerhugowaard are given in Table 0.2. These data have been used as the basis for predicting typical waste loads from both separate sewer systems and separate systems with an improved design[2] (figure 2.1.).

2 *An improved design of separate sewer systems implies the (re)construction in such a way that during dry weather flow and low intensity rainfall the flow in the storm drain is diverted to the foul water network. To achieve this overflow weirs at the outlets and connections between the two systems with non-return valves are constructed.*
During heavy rainfall both networks will be filled, but only the drain system will overflow to the surface water. Mixing of foul water and stormwater is not occurring. After the storm the systems are emptied via the sewage treatment plant.
A separate network constructed in the described way has the advantage that any waste water entering the drainage system will at dwf be transported to the sewage treatment plant. The same applies for stormwater flows of small magnitude. The investigations carried out have shown that the discharge of pollutants is greatly reduced with the above design modifications, which in the present report will be referred to as the "improved separate system".

Table 0.2. -Annual waste fluxes and average concentrations of pollutants discharged from the outlets of two separate systems in the Netherlands

substance	annual waste flux (g/inw.a)	average pollutant concentration per discharge (mg/l)
BOD	105 - 178	2.5 - 7.5
COD	783 - 2619	36 - 69
TKN	45 - 178	2.2 - 4.2
total P	7 - 23	0.3 - 0.6
TSS	331 - 3684	29 - 37
		(mg/m^3)
lead	0.6 - 1.2	7 - 103
zinc	4 - 6.3	88 - 319
chromium	0.4 - 0.6	7 - 31
copper	0.6 - 0.7	9 - 53
nickel	0.3 - 0.4	5 - 24
mercury	0.04	
cadmium	0.03	

It can be seen that the annual waste load from separate sewer systems is comparable to that discharged from combined systems (see section 0.2.4). Surface water quality monitoring has shown, however, that particular problems can be encountered with separate systems due to the concentration of heavy metals and micropollutants contained in the run-off from industrial estates. Discharges from storm sewers are relatively frequent events. Hence, the degree of dilution in surface waters tends to be more favourable than in the case of combined systems. The use of improved rather than standard separate systems is to be preferred as the latter tend to produce higher storm waste loads.

0.2.6. Surface run-off

Although the waste load discharged from sewers is practically independent of the composition of the chemical precipitation, the type of surface onto which the precipitation falls can have a significant effect. Storm run-off in residential areas with low traffic volumes tends to be relatively unpolluted, whereas the concentrations of heavy metals and micropollutants in the run-off from busy roads, car parks and industrial sites can be extremely high. Guidelines have therefore been drawn up to decide when it is appropriate to drain impervious surfaces separately and divert the stormwater directly to the surface water or to maintain the drainage to the combined network.

0.2.7. System layout

The quantity of pollutants emitted from combined sewer systems during overflows is depending on the amount of

What are the effects?

sewer sludge that settles in the sewers during dry spells and storms with low intensities. A further factor of importance has to do with the layout of the network. In many instances the overflow is connected to the main network by means of a large diameter sewer. In this sewer sedimentation will easily occur. The sedimentation is even more manifest if houses are connected to this sewer line. It is therefore recommended to disconnect the houses and transport the sewage by means of a seperate line to the main network. Relocating the overflow structure might be taken into consideration to.

0.2.8. The effect of stormwater overflow control devices (CSOs)

The judicious use of overflow control devices in sewer systems can considerably lessen the discharge of pollutants into surface waters. By reducing the concentration of suspended matter, many of the adsorbed pollutants are also retained. Introducing the facilities listed below can improve COD fluxes by the following amounts:

- stormwater sedimentation tanks: 65%
- swirl concentrators: 40%
- improved weir chambers: 25%

0.2.9. Impact on the quality of surface waters

In general, the effects of sewage discharges into surface waters are most keenly felt in the immediate vicinity of the outlets. Such effects can either be transient or persist for some time. They are not always easy to identify as they can often be masked by pollution from other sources. Floating material can cause considerable irritation as it normally remains visible in the vicinity of the outlet for several weeks or even months.

In stagnant waters, settlable solids frequently collect around sewer outlets. The effects associated with these materials are usually highly localised, such as increased sediment oxygen demand and above-average levels of bacteria in the sediment, both of which could last for up to several months. In addition, high concentrations of heavy metals and organic micropollutants often persist for many years in the sediment around such outlets.

Whether discharged stormwater is likely to cause discernible effects in the water phase primarily depends on the amount of mixing that takes place with the receiving water. The worst effects are generally associated with outlets positioned at the dead end of drainage ditches.

In the case of large receiving waters, oxygen levels usually drop for relatively short periods of time (varying from a few hours to a number of days) following stormwater discharges, whilst high bacterial counts can persist for some days or even weeks. During the first few hours after the discharge, the turbidity of the water is likely to increase, which could be followed by excessive algal growth in subsequent weeks if sufficient light is available and if the water remains essentially stagnant.

The presence of faecal bacteria in the water phase and in the bed sediment is a good indicator of sewer overflows having taken place. In the longer term, discharges of this type are likely to reduce the diversity of flora and fauna present, which, therefore, is a good indicator of overflows. In the course of the present research programme some 60 locations were monitored and described comprehen sively in order to assess the impact of such discharges on the quality of surface waters.

Visible pollution

0.3. Recommendations applicable to sewer systems

0.3.1. Existing sewers in areas with level ground

Combined sewer systems

It has been shown that for systems that on average have less than ten overflow events a year the theoretical overflow rate is generally unsatisfactory as a yardstick for the amount of pollutants discharged. Assessments of the water quality effects of such systems must be judged from the total annual waste load and from the magnitude of peak loads.

Reducing the waste flux from sewers is an effective method of lessening the impact of sewer overflows on surface waters. Such reductions can be achieved by increasing the storage capacity of sewer systems and/or the capacity of stormwater pumps.

Further measures that can be considered are:

- relocating of overflow structures near large surface waters
- disconnecting of house connections from overflow sewers
- reshaping of manhole bottoms to prevent sedimentation
- replacing circular sewers by i.e. egg shaped sewers
- installing overflow control structures (sedimentation basins, swirl concentrators etc.)
- reduction of the connected impervious surfaces

Which of the above measures is to be preferred depends very much on local conditions. In many instances, it wil be more appropriate to introduce measures of this type when renovation work is being carried out.

Separate sewer systems

Reconstruction of separate sewer networks in such a way that during dry weather flow and low intensity rainfall the flow in the storm drain is diverted to the foul water network (improved designs) is generally recommended. Routing potentially polluted storm run-off from industrial estates via dwf sewers can also have beneficial effects.

0.3.2. Existing sewers in sloping areas

In areas where the ground is sloping, significant benefits can be achieved by using stormwater control facilities or measures to retard the discharge. However, before such measures are introduced, a thorough analysis of the local situation should be made.

0.3.3. New sewer systems

In view of surface water quality requirements preference should be given in flat areas to installing improved types of separate sewer systems.

0.4. Recommendations applicable to surface waters

A number of measures have been identified to help improve surface water quality by modifying the conditions in the relevant receiving water:

- recirculation (during and immediately after sewer overflows);
- removing sludge from the bed of the receiving water at regular intervals;
- increasing the size of the surface water, for example by constructing a pond;
- improving initial mixing at the outlet;
- local aeration after discharges have occurred provided that the bed sediment is not resuspended.

0.5. Final conclusions

Discharges of stormwater and overflows from combined sewers can often seriously impair the quality of surface waters, particularly in the case of stagnant or semi-stagnant waters. Although many of the effects are highly localised, they need not always be transient and can, in certain cases, persist for considerable periods of time. At some of the sites investigated as part of the NWRW programme, difficulties were encountered in identifying the full range of effects due to the presence of background emissions from other sources. As further action is taken to control such emissions, the problems associated with sewer overflows will become more prominent at these sites.

Example of small receiving water

The results show that there is a direct correlation between the degree of impairment at a given location, and both the magnitude of the maximum discharge event and the annual waste flux. As a consequence, it is recommended that these parameters be used to assess the pollution problems associated with combined sewer systems, rather than simply relying on a calculated overflow frequency. For more precise assessments, distinctions should be made between the different types of pollutant involved.

Although it is not possible to give general design guidelines because of local variations, the present programme has shown that sewer systems can be improved in a number of ways. The main conclusions that can be drawn are that:

- discharges from combined sewer systems on an annual basis are of the same order of magnitude as those from separate sewer systems;
- sewage discharges tend to reduce the variety of flora and fauna in surface waters and also lead to accumulations of faecal bacteria, heavy metals and micro-pollutants in the bed sediment near overflow outlets as well as producing visible contamination;
- waste fluxes from improved separate sewer systems are normally lower than those from alternative designs. As the former systems have the least impact on the quality of surface waters, they are generally to be preferred;
- it is advisable to arrange for sewers to discharge into large, non-stagnant surface waters that do not have to meet special quality standards;
- storm run-off from residential areas with low traffic volumes may be discharged directly into open surface water;
- run-off in other areas is likely to be contaminated with heavy metals and micro-pollutants;
- stormwater sedimentation facilities are to be preferred for increasing the total storage capacity of systems where the hydraulic capacity of the sewers is considered to be adequate;
- in areas with shallow gradients other measures to abate water pollution caused by overflows have to be taken than in sloping areas;
- optimising the layout of adequately-designed sewer systems that are regularly maintained can help to improve their performance.

In addition:

- guidelines have been formulated for deciding when it is appropriate to disconnect storm sewers carrying surface run-off;
- a method is given to determine the waste flux from a given sewer system;
- a set of reference reports has been issued to enable assessments of the likely impact of sewer overflows at a given location.

Using the above information can contribute to substantially reducing pollution of the receiving surface waters from sewer systems.

1. Introduction

1.1. Background to the NWRW programme

To be effective, sewer systems must collect and remove waste water from residential areas without impairing the health of local residents or unduly affecting the quality of surface waters. In countries with a temperate climate, sewers also have the function of collecting and removing stormwater.

In 1976, the Foundation for Applied Waste Water Research (STORA) published a paper setting out the major issues concerning pollution from sewer systems [1]. Most of the questions raised were related to the topics outlined below.

A. Corroboration of design standards.
   It was felt that for the assessement of the merits of the various sewer systems by the water quality control boards, further information was needed to be able to relate design standards to water quality criteria. Not only the amount of sewage discharged from stormwater outlets and overflows was seen as being important in this context, but also the flux of pollutants transported in the aqueous phase.
B. Comparisons with other sources of pollution.
   It was anticipated that as the quality of the effluent from sewage treatment plants began to improve, stricter standards would be introduced to control direct discharges of untreated sewage from sewer systems. The municipal authorities were concerned that this could have serious cost implications.

It was generally agreed that not enough was known about the fundamental and practical aspects of these issues to be able to address the specific problems that had been raised. Before investing large sums of money in constructing new sewers and renovating existing systems, it was considered prudent to carry out further research to increase basic understanding of the underlying issues.
The General Management Committee of the Foundation for Applied Waste Water Research (STORA) agreed with the Minister of Housing, Physical Planning and Environment (VROM) that a working party should be set up to plan and coordinate the necessary research. It was originally envisaged that the NWRW working party should sit for five years. However, in view of the workload, this was later increased to seven years. The composition of the NWRW working party is given in Appendix 1.

1.2. Terms of reference

The NWRW working party was given the task of increasing the general level of understanding about the design, construction and maintenance of sewer systems, including relevant overflow control structures. Particular reference was made to generating knowledge about the impact of discharges from sewers on the quality of surface waters and to broadening the experience of dealing with such matters in practical situations. To facilitate the coordination and management of the research programme, the NWRW working party compiled a plan [2], setting out the terms of reference of the individual projects (see Section 2.3). The Ministry of Housing, Physical Planning and Environment (VROM) together with the Foundation for Applied Waste Water Research (STORA) provided a *f* 12.8 million research budget, which enabled much of the work to be subcontracted to engineering consultants and research institutes.

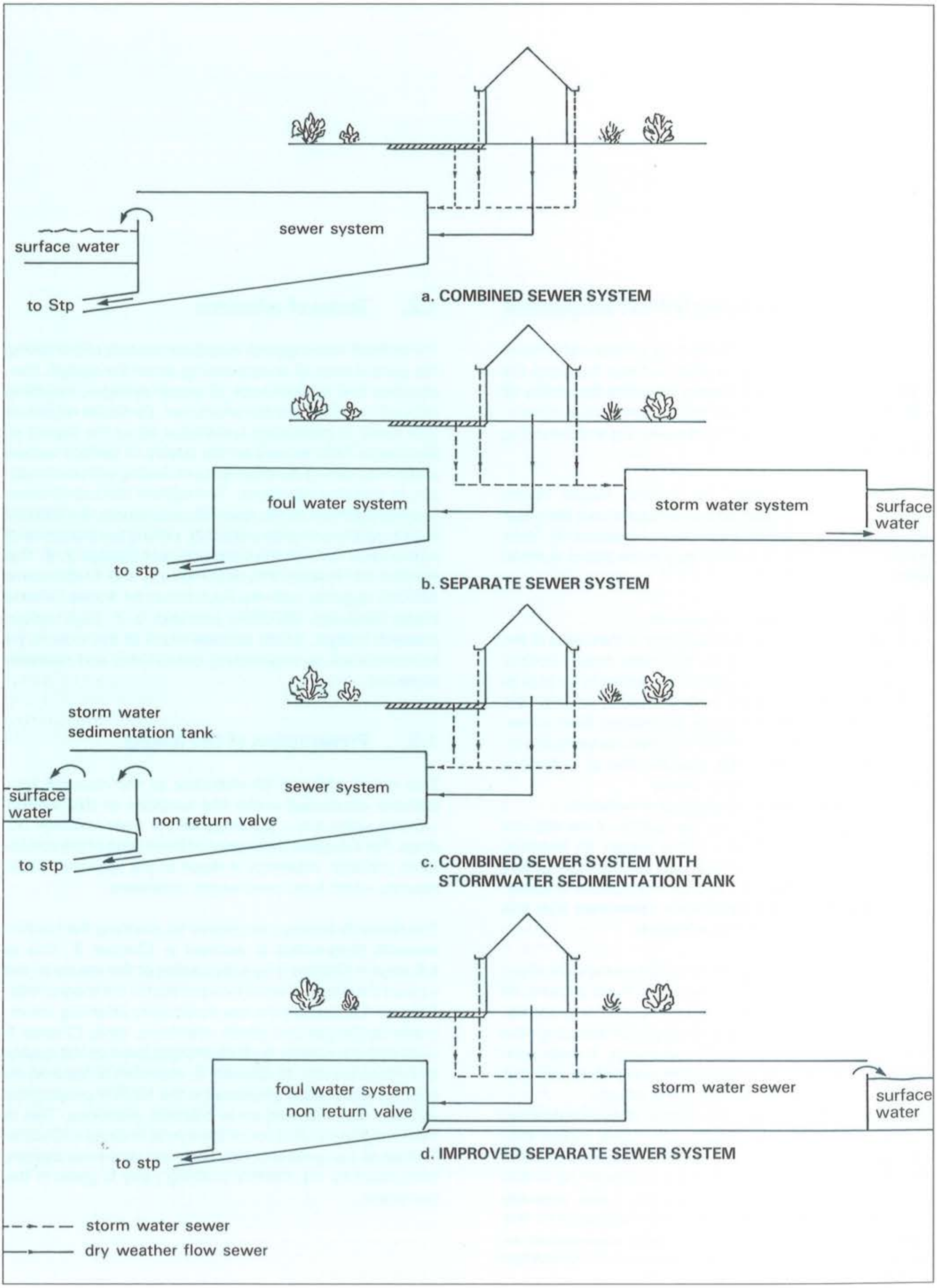
1.3. Presentation of the results

This report contains an overview of the research programme conducted under the auspices of the NWRW working party and a summary of the main research findings. For a detailed discussion of the results of the constituent projects, reference is made to the relevant VROM reports, which have been issued separately.

The research strategy developed for planning the NWRW research programme is outlined in Chapter 2. This is followed in Chapter 3 by a discussion of the results of the various themes that were incorporated in the programme. Chapter 4 discusses the key parameters affecting stormwater discharges and sewer overflows, while Chapter 5 highlights the effects such discharges have on the quality of surface waters. In Chapter 6, attention is focused on how the knowledge generated in the NWRW programme can best be implemented in practical situations. This is followed by an evaluation of the overall findings in Chapter 7. A list of the general conclusions and recommendations formulated by the NWRW working party is given in the Summary.

[1] Veldkamp, F.B. Riolering en waterverontreiniging. Probleemstelling. Stichting Toegepast Onderzoek Reiniging Afvalwater, The Hague.
[2] Nationale Werkgroep Riolering en Waterkwaliteit, Onderzoekplan, VROM & STORA, 1983.

Figure 2.1. - The main types of sewer system in the Netherlands



2. Research objective and strategy

This chapter discusses the aims and objectives of the NWRW programme and how the overall research plan was formulated. It also reviews many of the issues that were confronting the water quality control boards and municipal authorities at the time the NWRW working party was instituted.

2.1. Criteria for system choice and design (A)

Sewer systems in the Netherlands generally have two distinct functions: the collection and removal of domestic and industrial waste water, and the collection and removal of stormwater. In view of technical and financial constraints, it is often difficult to combine both functions satisfactorily. Since sewer systems and sewage treatment plants are only designed to handle sewage flows of up to a few times that of the prevailing dry weather flow, it is common practice to discharge stormwater directly into surface waters as far as it cannot be stored, transported or treated.

In traditional combined sewers, stormwater that enters the system generally becomes mixed with waste water already present in the sewers. After heavy rainfall, the amount of water in the system can increase dramatically, which often leads to overflows. As a result, appreciable quantities of diluted waste water are discharged into surface waters. A further complication is that sludge which has been deposited in the sewers under dry weather conditions can also be discharged as it is resuspended due to the relatively high flow rates.

In sewers with an independent stormwater system, rainwater is collected separately and discharged directly into local surface waters, while the effluent from dwf sewers is routed via sewage treatment plants. Nevertheless, stormwater collected in this way is also polluted, as it may contain appreciable amounts of refuse or be contaminated with air-borne pollutants. Moreover, it is not uncommon for sewage to enter the stormwater system due to faulty connections. Schematic representations of the main types of sewer system in the Netherlands are given in Figure 2.1 (a and b). Improved designs have also been developed in an attempt to reduce the discharge of pollutants from sewer systems (see Figure 2.1 c and d). However, as yet the use of such improved systems and the application of overflow control structures is somewhat limited.

Although it was realised prior to the NWRW programme that stormwater discharges and overflows from sewers represented a serious threat to the quality of surface waters, little was known about the extent of the potential problems, or whether system design and better manage-

How to make a proper design?

ment procedures could mitigate these effects. Much of the information that was available at this time was only of a qualitative nature. No firm data had been collected on which quantitative design standards for sewers could be based specifically to address the water quality issue. Moreover, it was felt that measures to reduce waste discharges from sewers were poorly understood. After reviewing the situation, the following key questions were identified in relation to design criteria for sewer systems [2]:

A1. How can design criteria be related to a particular type of receiving water and prescribed water quality standards?

A2. Under what circumstances is a given type of sewer system to be preferred (combined versus separate systems)? To what extent do faulty connections in separate sewer systems affect the quantity of pollutants discharged into surface waters?

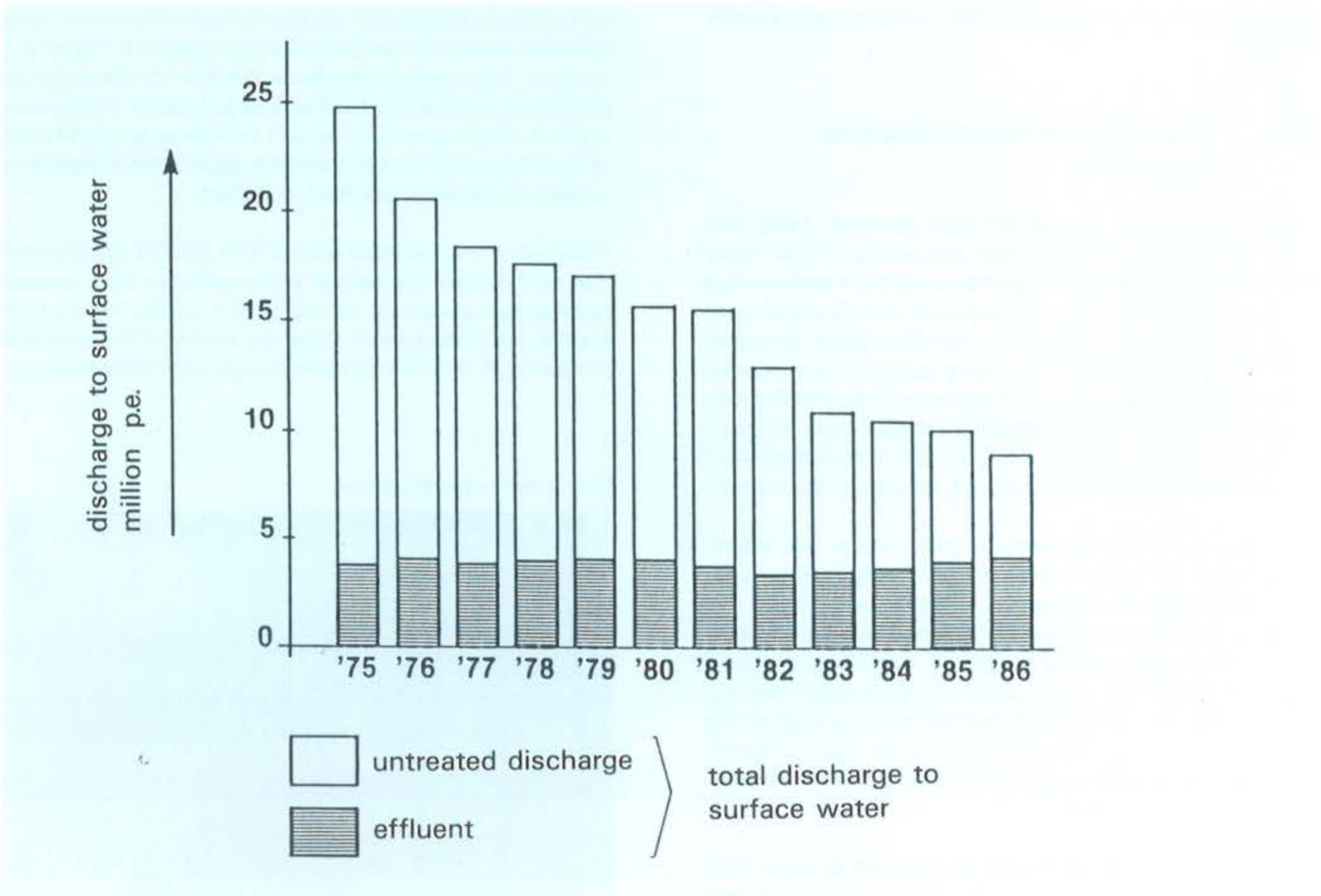
A3. What are the risks associated with disconnecting storm sewers carrying surface run-off in combined systems so as to allow such run-off to be discharged directly into surface waters?

A4. Are the reductions in overflow frequency that can be achieved by expanding the capacity of sewer systems by, for instance, installing storage sewers justified if the amount of sludge released per discharge event is increased as a result? Can the quality of surface waters be expected to improve if after the installation of storage sewers the amount of pollutants discharged during major overflow events is not reduced?

2.2. Comparisons with other sources of pollution (B)

The introduction of the Surface Waters Pollution Act in the Netherlands in 1970 stimulated attempts to control waste water discharges. In the initial phase, attention was primarily focused on oxygen-consuming substances, with the spotlight shifting to nutrients and micro-pollutants at a later stage. As the sewer network was extended to cover more of the country and greater emphasis was placed on modern biological sewage treatment methods, the pollution of surface waters with oxygen-consuming substances rapidly declined (see Figure 2.2 [3]).

Figuur 2.2. - Reduction in the load of oxygen-consuming substances into the surface water (Source: CBS data, with supplementary information from DBW/RIZA)



[3] Central Bureau of Statistics (CBS), Milieufacetten, Cijfers bij milieubeleidsthema's, 1988.

Although the introduction of such measures meant that in general, the quality of Dutch surface waters improved, a number of specific problems still remained. For instance, the pollution from non-point sources and the ingress of water-borne contaminants from other areas became more prominent as a result. With the decline in significance of primary sources of pollution, the effects of secondary sources associated with unrestricted nutrient emissions also became more apparent.

As more urban areas were connected to the sewer network, the problems associated with surface water pollution tended to shift from how to deal effectively with continuous waste discharges to how best to tackle incidental emissions. The pace of urbanisation meant that the network of discharge points also expanded.

With the general improvement in the quality of Dutch surface waters in the late 1970s and early 1980s, pressure began to increase for stricter controls on waste discharges from sewers. However, at the time, little was known about the effectiveness of increasing the storage capacity of sewers and whether overflow control facilities could be used to reduce surface water pollution. It was felt that reliable data were needed before meaningful cost-benefit analyses could be performed to asses the advantages of replacing or modifying sewer systems.

2.3. Salient features of the NWRW research plan

The research strategy adopted by the NWRW working party was primarily concerned with understanding the relationship between sewer design, the discharge of pollutants and the quality of surface waters. In planning the NWRW research programme [2], attention was initially focused on the following issues:

- the relationship between sewer design and the quantity of pollutants discharged;
- the effect of overflow control facilities (stormwater sedimentation tanks, swirl concentrators, micro-sieves etc.);
- the relationship between the amount of pollutants discharged and the quality of surface waters;
- the optimisation of sewer systems in relation to waste loads, costs and discharge requirements (including maintenance standards and the quality of the waste water entering the sewers).

It was eventually decided not to include optimisation studies in the NWRW programme, because of the difficulty of making general statements on this subject. Moreover, it was felt that the competent authorities would be in a better position to judge the merits of individual cases, assisted by outside consultants, where necessary.

The main part of the NWRW research programme was aimed at collecting actual field data in order to characterise waste discharges from sewers and to assess the impact of such discharges on the quality of surface waters. In the majority of cases, reliance was placed on straightforward simulation methods to interpret the data. However, in certain projects, it was necessary to develop a deeper understanding of the fundamental processes taking place in sewer systems and in surface waters to allow the information to be generalised. Eleven main themes were identified in the NWRW research plan:

1. Characterisation of sewer systems;
2. Water quality control board experiences and observations;
3. Literature study on the effectiveness of combined sewer overflow structures (CSOs);
4. Temporal and spatial precipitation distributions;
5. The relationship between waste flux and sewer design parameters;
6. The deposition and entrainment of sludge in sewer systems;
7. Pollution levels in surface run-off;
8. The performance of overflow control structures;
9. Characterisation of the effects of waste discharges on surface water quality;
10. Detailed water quality impact assessments related to waste discharges from sewers;
11. Measures to improve surface water quality.

The STORA project on waste discharges from sewers (38b), which was already in progress at the time the NWRW working party was inaugurated, was integrated in the NWRW research programme as part of Theme 5. Moreover, three research projects were added in the course of the programme, as it became clear that organic micro-pollutants and heavy metals could have a greater impact on surface water quality than was originally thought (Theme 12).

Particular emphasis on field measurements

3. Summary of the results

3.1. General

The NWRW research programme has generated a substantial volume of information, the salient features of which are summarised in this chapter. The results of the individual projects are reported separately in a series of reports issued by the Ministry of Housing, Physical Planning and Environment (VROM).

3.2. Themes 1-3 - Characterisation studies

In the Netherlands there are about 12,000 combined sewer overflows, the majority of which (85%) discharge into small and/or semi-stagnant receiving waters. Some ten percent of the sewer districts in the Netherlands have separate systems, with a few thousand stormwater outlets.

Water as an integral part of the urban landscape

Surveys carried out in the initial phase of the NWRW programme (Theme 2) showed that there was a large body of support among the water quality control boards for developing sewer design criteria capable of incorporating water quality standards. In addition, much interest was shown in the benefits to be derived from better sewer maintenance and in particular how successful increasing the degree of circulation in surface waters could be.

The literature study which reviewed the application of overflow control structures (Theme 3) formed the basis for the detailed practical assessments described in Theme 8.

3.3. Theme 4 - Variations in precipitation and the suitability of predictive models

It is general practice in the Netherlands to predict overflow frequences and overflow volumes on the basis of a simplified precipitation/discharge model. The model is fed by rainfall data collected at the site of the Dutch main meteorological station.
Although the incidence of heavy rainfalls differs markedly from one place to the other (project 4.1), the model is regarded applicable for all places in the Netherlands because of uncertainness in other model parameters. Project 4.2. has shown however that the differences between calculated and the measured frequencies and volumes was larger than expected. Moreover it appeared that storms which based on model calculation should have led to overflows did not do so and vice versa.
Nevertheless, predictions of the total quantity of stormwater discharged over a twelve-month period were found to be in reasonable agreement with the measured values.

Calculations performed using literature data in Project 4.3 showed that a number of parameters which were not included in the models, such as run-off coefficients, could have a major effect on the accuracy of the predictions. It was therefore concluded that many of these tools could be improved by precisely modelling the rate at which precipitation enters the sewers. Incorporating recorded precipitation levels rather than simply relying on approximate methods for estimating rainfall figures using rainfall duration curves for one station would, it was felt, enhance the accuracy of such models. Notwithstanding this, it was shown that a single run-off coefficient was insufficient to model the differences between precipitation levels and the quantity of stormwater entering sewers.

Sensitivity analyses performed with literature data also revealed that factors such as evaporation, infiltration and surface detention have a significant effect on the calculation of precipitation losses from different types of impervious surfaces. In addition, delays in the rate at which run-off arrives at sewers should not be neglected for precise calculations.

3.4. Theme 5 - Waste fluxes from sewer systems

3.4.1. General

An extensive series of measurements was carried out at various locations in the Netherlands to determine the waste fluxes from combined, and separate and improved separate sewer systems. The following section reviews the main characteristics of the different monitoring locations and summarises the data collected. Reference is made to Chapter 4 for a detailed discussion of the results obtained.

3.4.2. Combined sewer systems

During the period 1981-1987, an extensive monitoring programme was instituted at four combined sewer systems at Loenen (Municipality of Apeldoorn), Oosterhout, Bodegraven and Kerkrade. The results obtained for Loenen are representative of a residential area in undulating rural countryside. In contrast, Oosterhout has a predominance of new housing estates many comprising low-rise buildings with a few high-rise blocks. The sewer system in Bodegraven is typical of that found in many of the well-established urban centres in the Netherlands. Much of the property in Bodegraven consists of low-rise buildings used for residential, retail and industrial purposes. The area chosen for investigation in Kerkrade is typical of housing estates in hilly areas. In the latter case, attention was focused on the waste load in the influent to the "Vloedgraaf" stormwater sedimentation tank. This facility was specifically constructed to augment the storage capacity of the system in Kerkrade, which because of the hilly nature of the terrain has a relatively steep hydraulic gradient. In a related project (Theme 8.2 - see Section 3.7), the pollutant loading in the effluent discharged from the "Vloedgraaf" stormwater sedimentation tank was also studied.

The main characteristics of the monitoring locations and a summary of the key discharge parameters are given in Table 3.1. It can be seen from this table that the volume of stormwater discharged as a result of sewer overflows in Loenen and Kerkrade was significantly higher than the corresponding amounts discharged in Oosterhout and Bodegraven. This was attributed principally to differences in the storage capacity and stormwater pump capacities in the various locations.

Significant variations were also found in the effective run-off coefficients at the various sites, which ranged from 0.5 to 1.5. Seasonal influences were particularly strong, with the run-off coefficients in winter being higher than those in summer. At all four monitoring sites, run-off coefficients in excess of 1 were recorded at various times throughout the year. This suggests that precipitation falling on unpaved surfaces was also entering the sewer systems. It was particularly noticeable that run-off from unpaved surfaces in hilly areas was more pronounced than that in districts where the terrain was virtually flat.

3.4.3. Separate and improved separate sewer systems

During the period 1983-1985, waste fluxes were monitored at two separate sewer systems in Heerhugowaard and Amsterdam-Holendrecht. After the first series of measurements was completed in Heerhugowaard, the system was converted to an improved separate sewer system. Monitoring was subsequently resumed, which allowed comparisons to be made between separate and improved sepearate sewer systems.

The comparison could only be rough because the investigation periods did not coincide.

The results obtained in Heerhugowaard are particularly relevant for newly built residential areas where traffic volumes are relatively low. In contrast, the Amsterdam-Holendrecht data are more representative of a modern

Table 3.1. - Salient features of the combined sewer systems studied in the NWRW programma including the relevant discharge parameters

Characteristics		Loenen	Oosterhout	Bodegraven	Kerkrade*
number of inhabitants		2050	2270	4075	8052
draining area	(ha)	15.8	11.6	22	60
Storage capacity of sewers	m^3	895	620	1726	467
	(mm)	5.7	5.3	7.8	0.8
stormwater pumping capacity	(mm/h)	0.80	0.97	0.44	0.30
theoretical overflow frequency	(1/a)	10	9	6	80
monitoring period	(a)	3.5	4.7	4.2	1.0
measured overflow frequency	(1/a)	15.7	11.6	7.9	56
No. of monitored overflow events	(-)	55	55	33	56
No. of events analysed	(-)	44	32	27	52
discharge rate	(mm/a)	120	74	30	485

*Excluding stormwater sedimentation tank.

urban residential district where traffic volumes are relatively high. A further difference between the two areas is that Heerhugowaard has a predominance of low-rise buildings, while Amsterdam-Holendrecht has a significant number of high-rise buildings. In both districts, industrial activity is minimal and provisions have been made to disconnect the ground water drains from the storm sewer. No evidence was found in either area of waste water entering storm sewers as a result of faulty connections.

The main characteristics of the monitoring locations and a summary of the key discharge parameters are given in Table 3.2. It can be seen from this table that the average volume of stormwater discharged in Amsterdam-Holendrecht per overflow event was lower than that discharged in the separate sewer system in Heerhugowaard. The fact that many of the buildings in the Amsterdam-Holendrecht area have flat roofs, which tend to retain water and promote evaporation, is thought to have led to higher precipitation losses in the latter district than in Heerhugowaard.

Sand deposits in sewers

Table 3.2. - Salient features of the separate and improved separate sewer systems studied in the NWRW programma including the relevant discharge parameters

Characteristics		Amsterdam (sep.)	Heerh.waard (sep.)	Heerh.waard (impr. sep.)
number of inhabitants	(-)	1365	1100	1100
number of dwellings	(-)	452	522	522
type of dwellings		flats	low rise	low rise
drainage area	(ha)	4.2	6.8	6.8
length of storm sewers	(m)	1250	2900	2900
volume of storm sewers	(mm)	4.3	7.3	7.3
monitoring period	(a)	1.9	1.1	1.7
No. of monitored overflow events	(-)	93	79	18
average volume discharged per overflow event	(mm)	6.9	11.5	6.8

3.5. Theme 6 - Transport processes in sewer systems

Research carried out in the NWRW programme has shown that flow profiles in weir chambers and large sewers are often less than ideal and that discontinuities can occur at pipe connections due to the way sewers are laid. As a result, significant quantities of sludge are frequently deposited in sewers during dry weather. The majority of this sludge is readily settlable and highly polluted. Up to 12% of the internal volume of large transport and storage sewers can be taken up with sandy sludge residues. Consequently, the bottom of such sewers often resembles a "mini river bed", with the dry weather sewage flow meandering through deposited sediment (predominantly sand with pebbles) and various obstacles.

Even at rainfall with moderate or high intensities the flow rates in many of the large sewers in the Netherlands were found to be relatively low. Reasons for this are the limited hydraulic gradients in such systems and the equalisation of water levels due to stormwater simultaneously entering the system at a large number of points. The problem is compounded by shifts in accumulated deposits in small size sewers after moderate rainfall.

On the basis of the research carried out in Theme 6 of the NWRW programme, the following conclusions and recommendations have been formulated:
- combining the functions of the collection, transport and storage of sewage in a single system is generally not conducive to optimising waste water transport efficiency;
- factors such as the degree of meshing in sewer systems, hydraulic gradients, dry weather flows, storage capacities, material selection etc. can have a significant impact on the entrainment and deposition of sludge;
- normally, house connections do not accumulate pollutants;
- preference should be given to designing the combined networks in such way that the dwf will not be impeded by

structural obstacles and that the gradients of the invert allow for flow conditions as optimal as possible and to positioning overflow outlets so as to minimise the pollution discharged into surface waters;
- on site, more emphasis should be placed on installing hydraulically smooth systems than simply laying sewer pipes;
- management and maintenance policies should be explicitly aimed at optimising waste removal performance.

3.6. Theme 7 - Diverting surface run-off

Diverting surface run-off is a relatively simple method for reducing overflow frequencies in combined sewer systems. By delaying or reducing the amount of storm water that enters the system, significant reductions can be achieved in hydraulic loading rates. However, on site monitoring of the quality of surface run-off has shown that it is often contaminated with Kjeldahl nitrogen and suspended matter and that it can have appreciable BOD levels. Invariably, traces of micropollutants are also present.

The contamination levels detected in run-off samples collected in the NWRW programme were found to contravene the water quality control boards' quality standards for receiving waters, irrespective of the surface on which the run-off was collected. In each case, the concentration of contaminants contained in the surface run-off was such that at least one of the prescribed limit values was exceeded.

Much of the pollution found in the surface run-off was attributed to non-point sources such as exhaust gases, abrasion products from tyres and road pavements and corrosion residues. In general, the concentration of polycyclic aromatic hydrocarbons (PAHs) and organochlorine pesticides detected in the run-off from roads was higher than the permitted levels, while the amounts of lead, polychlorinated biphenyls (PCBs) and chlorinated phenols gave less cause for concern. In a number of instances, the surface run-off from roofs was found to contravene the permitted limits for lead, zinc and PAHs. Rather surprisingly, this also occured with the levels of organochlorine pesticides.

It generally proved possible to relate the composition of the surface run-off collected on industrial estates either to the nature of the business activities performed on site (e.g. zinc at a galvanising works) or to the function of the surface in question (PAHs etc. from roads). It should, however, be noted that large variations were observed in both the concentrations of pollutants present in surface run-off and the waste loads discharged at individual sites. For instance, differences of up to a factor of 10 were noted depending on the severity of the rainstorm.

On balance, it was concluded that disconnecting the run-off from certain industrial estates, busy sections of roads and car parks should be avoided. However, disconnecting the surface run-off from roofs and roads in residential areas should generally pose less of a problem. The full range of options available in this context is discussed in Chapter 6.

Disconnection techniques have been discribed. Attention is not only focused on how the quality of the run-off influences the method to be adopted, but consideration is also given to the role played by factors such as the proximity and size of surface waters, the groundwater level and the condition of the soil.

3.7. Theme 8 - The performance of CSO control structures

The main purpose of overflow control structures is to reduce the concentration of pollutants in the overflow so as to minimise the impact of overflows on surface water quality. The introduction of control structures should only be contemplated when excessive contamination levels are present such as can occur in combined sewer systems.

Stormwater sedimentation tank

An inventory of overflow control facilities made as part of project 3.1 highlighted the potential that exists for the following types in the Netherlands:
- stormwater sedimentation tanks;
- swirl concentrators;
- improved weir chambers.

Four projects were carried as part of Theme 8 of the NWRW programme to assess the performance of these devices under practical conditions. Reference is made to Section 4.8 for a detailed analysis of the results. A follow-up project carried out as part of Theme 9 investigated the use of artificial marshes to lessen the impact of sewer overflows on the quality of surface waters [4] (see also Section 3.8). Assessments of the efficiency of stormwater sedimentation tanks were carried out at two locations: Amersfoort and Kerkrade (projects 8.1 and 8.2). The reduction in the waste flux at both of these facilities was expressed as a percentage of the pollution loading in the influent (see Table 3.3).

[4] Kessens, A.J., Vos, L. (1984), Het biezenbassin als randvoorziening ter plaatse van een overstort, H_2O 17(21) 487-90.

Table 3.3. - Removal efficiency of stormwatersedimentation tanks relative to influent concentrations (%)

substance	Amersfoort	Kerkrade
COD	69	62
TSS	76	65

It was shown that although significant improvements were made in COD levels and comparable reductions could be achieved in BOD levels, the removal rates for Kjeldahl nitrogen and total phosphorous were less spectacular. No attempts were made to quantify the removal efficiencies of the latter constituents. It should be noted that the figures quoted refer specifically to measurements done when the retention basins were overflowing. The over-all efficiency of course is higher because of storage effects.

Research into the effectiveness of swirl concentrators was carried out in Goes (project 8.3). By comparing the removal efficiencies obtained in a swirl concentrator with the performance of conventional weir chambers, it was possible to express the results on a net efficiency basis (see Table 3.4).

Table 3.4. - Removal efficientcies obtained in a swirl concentrator at Goes

substance	net removal efficiency %
COD	40
BOD	36
TKN	22
total P	21

In project 8.4, conducted in Rotterdam, attention was focused on the performance of improved weir chambers. Here, the reduction in the waste load discharged from a high-sided weir chamber relative to the pollution loading in the influent was monitored (see Table 3.5).

Swirl concentrator

Tabel 3.5. - Removal efficiencies obtained in a high-sided weir chamber in Rotterdam

substance	removal efficiency %
COD	27
TSS	20
BOD	13
TKN	7
total P	7

3.8. Theme 9 - Generalised impact on the aquatic environment

It was found that stormwater discharges and sewer overflows could have noticeably different effects on surface waters both in a physico-chemical sense (oxygen balance, nutrient loading, concentration of micropollutants) and in bacteriological terms.
Moreover, significant variations were identified in terms of the range of aquatic communities affected and sensory perception levels. As part of the generalised environmental impact assessments, the nature, seriousness and persistence of the effects were correlated with factors such as the overflow frequency and the measured waste flux (expressed in terms of an annual pollution load and a maximum discharge event). In addition, detailed consideration was given to the dimensions and hydraulic characteristics of receiving waters in order to assess the gradation in effects with distance from the outlets.

The most significant effects were observed in small stagnant (and isolated) waters irrespective of the distance from discharge points. In larger waters, with appreciable circulation currents, the degree of dispersion and dilution meant that the direct effects tended to be less prominent. Nevertheless, even in such waters, it was not uncommon to find evidence of domestic refuse and bacteriological contamination at appreciable distances from the outlets.

Although in certain cases, the use of CSO control structures in conjunction with combined sewer systems was shown to lessen the impact of sewer overflows on surface water quality, it was found that in small surface waters, stormwater sedimentation tanks and swirl concentrators had a minimal effect. In contrast, the results obtained with an artificial marsh system to which the outlet discharged were very encouraging, with little evidence of pollution discernible in the receiving water. However, in view of the scale of the investigations carried out, it was not possible to draw firm conclusions about the relative merits of such facilities.

In general, the impact of discharges from separate sewer systems was less marked than in the case of sewer overflows from combined systems. Notwithstanding this, significant effects were attributed to stormwater discharges, especially from industrial sites. In particular, oil films were frequently visible on the surface of receiving waters at these locations and evidence was found of extremely high levels of micropollutants, such as zinc, in the bed sediment.

Studies conducted in areas with improved separate sewer systems revealed a general absence of deleterious effects in the receiving water. It should be noted, however, that the number of systems that were monitored is small and that these had only recently been constructed. This precludes the opportunity of making assessments about the possibility of long-term effects due to, for instance, accumulation over several decades.

In the course of the NWRW programme, deleterious effects on surface water quality have been monitored at some sixty locations, with the objective of providing a database to facilitate predictions on the basis of comparisons.

3.9. Theme 10 - Detailed water quality impact assessments

Parallel to the generalised water quality impact assessments (Theme 9), two of the smaller surface waters were selected for more detailed investigations (Theme 10). The results of these supplementary studies corroborated many of the findings described above. For instance, relatively intensive transient effects were observed near the outlets that discharged into the two surface waters in question. This was evidenced by temporary increases in the oxygen demand and the amount of suspended matter present. In general, the higher levels of bacterial pollution detected in these surface waters were found to be of a less transient nature, as were the changes in the plankton populations. The most persistent deleterious effects observed at the two locations concerned the presence of sludge deposits containing heavy metals and the level of bacteriological contamination of water and sediment.

It was clearly shown that sludge deposits in such waters impaired the development of the more sensitive species of macrofauna. The increased sediment oxygen demand and the release of nutrients exerted a permanent effect, but were particularly noticeable in the first days and weeks after an overflow event.

Assimilation of these results led to the development of a mathematical model to predict how water quality parameters such as biochemical oxygen demand, suspended matter content, dissolved oxygen, and bacterial levels are likely to vary as a function of time. Despite differences in the hydraulic characteristics of various receiving waters, use can nevertheless be made of several of the process constants included in the model when simulating the conditions at other locations. These include the degradation rate of organic compounds (as BOD), the decay rates of specific bacteria, the settling velocity distribution of sludge particles and the sediment oxygen demand.

3.10. Theme 11 - Measures to improve surface water quality

After a literature review on possible measures to mitigate the effects of sewer overflows on surface water quality in the first phase of Theme 11, it was subsequently decided to initiate a follow-up study on the effects of circulation, aeration and the vegetation present in receiving waters. Where possible, performance assessments were based on practical data and use made of the findings of other projects in the NWRW research programme.

On this basis it was tentatively concluded that:

- increased circulation around overflow outfalls can have a beneficial effect on surface water quality;
- receiving waters with a large capacity are less susceptible to the effects of waste discharges;
- water plants can mitigate the effects of sewer overflows in surface waters.

Flow monitoring in Loenen

By applying these conclusions to practical situations, guidelines were drawn up for calculating the preferred size of receiving water for a given discharge volume. In this respect, a distinction was made between "stagnant" waters (ponds etc.) and "flowing" water.

A number of discrepancies were, however, highlighted in applying the guidelines, which were thought to have been caused by a general paucity of data and uncertainties in overflow rates. Notwithstanding this, the guidelines are still felt to offer a useful rule of thumb for design purposes.

4. Discharge of pollutants

4.1 Introduction

In this chapter, an overview is given of typical waste fluxes recorded at sewer systems in the Netherlands (Section 4.2). This is followed by a discussion of the factors that affect waste fluxes (Sections 4.3, 4.4 and 4.5) and the facilities that can be used to reduce such discharges (Sections 4.6 and 4.7). Finally, a method is outlined for predicting the waste fluxes from various types of sewer system (Section 4.8).

In discussing the factors that affect waste discharges from sewers, a distinction has been made between the performance of combined, separate and improved separate sewers systems. Specific reference has been made to the importance of precipitation height and the likely impact of the topographical features which characterise particular sewer districts. Various categories of pollutants have been defined, such as organic contaminants (as expressed in the form of BOD, COD, TKN and total P), suspended solids and heavy metals.
As it was never intended to quantify all the factors affecting waste discharges from sewers in the NWRW programme, some effects have been discussed in qualitative terms.
In this report CSO control structures (sedimentation basins etc.) and the disconnection of impervious surfaces from combined sewers got special attention in relation to their different impact on improving surface water quality.

A sewer overflow

4.2 Waste flux monitoring

4.2.1. General

An extensive monitoring programme was instituted as part of Theme 5 of the NWRW programme to quantify the waste fluxes from various types of sewer system in the Netherlands (see Section 3.4 for the characteristics of the different systems). In the following sections the results of the investigations carried out at combined, separate and improved separate systems are discussed. The observed waste fluxes are compared with the pollution load discharged into the sewers by households.

4.2.2. Waste fluxes from combined sewer systems

An overview of the waste flux data collected at four combined sewer systems in the Netherlands is given in Table 4.1. In general, the picture that emerges at each site over a prolonged period is one of a relatively large number of minor discharges and a small number of major discharge events, with the latter accounting for by far the greater part of the total waste load in such period.

Reference to Table 4.1 shows significant differences between the magnitude of the annual waste fluxes and the maximum discharge events at the various monitoring sites. The largest pollution loads were recorded at Kerkrade, although it should be noted that these data refer specifically to the quality of the sewage discharged into the existing stormwater sedimentation tank. In contrast, Bodegraven was found to have the smallest waste loads, which was to be expected since the volume of waste water discharged as a result of sewer overflows at Bodegraven was some 22 times lower than at Kerkrade and the contamination levels were also lower.

Extremely high concentrations of organic pollutants and suspended solids detected in some individual discharge events at Oosterhout, which contributed to the higher than average annual contaminant levels reported at this location. The extremely high pollutant levels in Oosterhout were thought to have been a direct result of a number of houses having been connected to the overflow sewer rather than to the main system. As the dry weather flow in this peripheral sewer section would probably have been insufficient to prevent sedimentation, it is likely that substantial quantities of polluted sludge would have been deposited near the overflow. Much of this sludge would have subsequently been discharged from the overflow sewer after heavy rainfall.

On balance, it can be concluded that the highest average pollutant levels recorded during overflows at the four sites were comparable with the contaminant concentrations normally found in undiluted domestic waste water. It therefore seems reasonable to postulate that in view of the ratio of stormwater and waste water normally present in

Table 4.1. - Waste flux data and pollutant levels from combined sewer systems

Waste flux	Loenen		Oosterhout		Bodegraven		Kerkrade	
substance	average annual waste flux (g/cap.a)	maximum discharge event (g/cap.)	average annual waste flux (g/cap.a)	maximum discharge event (g/cap.)	average annual waste flux (g/cap.a)	maximum discharge event (g/cap.)	average annual waste flux (g/cap.a)	maximum discharge event (g/cap.)
BOD	293	109	381	135	71	46	1583	174
COD	2728	1719	1367	513	273	186	6263	1084
TKN	86	45	69	25	19	11	301	31
total P	29	18	21	5	4	2	70	9
TSS	3229	2477	948	469	191	151	15946	5417
lead	1.16	0.51	0.70	0.29	0.09	0.08	4.57	0.76
zinc	2.54	0.84	2.21	0.60	0.72	0.41	13.84	1.78
chromium	0.10	0.07	0.10	0.03	0.02	0.01	0.97	0.23
copper	0.72	0.32	0.82	0.35	0.15	0.13	3.96	2.63
nickel	0.10	0.07	0.05	0.02	0.02	0.01	0.53	0.10
mercury	0.18	0.99	0.01	0.02	0.01	0.00	0.02	0.00
cadmium	0.04	0.07	0.01	0.00	-	-	0.05	0.01
Pollutant levels	Loenen concentration per overflow event		Oosterhout concentration per overflow event		Bodegraven concentration per overflow event		Kerkrade concentration per overflow event	
substance	average (mg/l)	maximum (mg/l)	average (mg/l)	maximum (mg/l)	average (mg/l)	maximum (mg/l)	average (mg/l)	maximum (mg/l)
BOD	39.9	141.2	124.4	1747	40.4	157.8	74.6	232.0
COD	271	877	389	4723	148	530	243	725
TKN	10.4	26.3	15.2	147.8	9.7	22.4	13.4	31.7
total P	2.9	7.2	4.8	45.5	2.1	6.0	3.0	7.5
TSS	303	1201	260	3943	105	429	320	1081
	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)
lead	162	500	108	510	42	165	130	452
zinc	358	950	359	1650	357	1170	472	1584
chromium	19	100	10	44	11	36	21	57
copper	88	205	113	760	67	215	92	2175
nickel	19	100	9	65	8	21	13	50
mercury	43.1	210	1.7	34	1.2	4.5	0.5	0.7
cadmium	9.6	100	1.4	5.7	1.5	15.0	2.5	40.9
volume of storm water discharged (m^3/cap.a)	9.2		3.8		1.6		36	

Note: The average and maximum concentration mentioned in the table refer to individual events. The average concentration should not be compared with the average yearly concentraction that can be calculated using data from table 3.1. and annual waste fluxes.

combined sewer systems, the maximum pollutant levels recorded were due to the entrainment of sludge. A good correlation was also found between the concentration of suspended solids and the levels of heavy metals present. This can be explained by the fact that most heavy metals are easily adsorbed onto sludge particles. On average, the concentration of heavy metals in sewer overflows in Bodegraven was considerably lower than at the other locations. This was thought to have been chiefly due to the low suspended solids content found in Bodegraven. Conversely, the abnormally high levels of mercury and cadmium found in Loenen were attributed to specific local sources of non-domestic nature.

4.2.3. Waste fluxes from separate and improved separate sewer systems

The pollutant fluxes from two separate and one improved separate system have been measured. The results are presented in table 4.2. At each location, the average pollution load per discharge event was considerably lower than the annual waste load, regardless of the type of contaminant (thus once again emphasising the extent to which waste loads are determined by a relatively small number of major discharge events). Reference to Table 4.2 shows that the concentration of pollutants in stormwater discharged in Amsterdam was higher than that in Heerhugowaard. This applied not only to the concentration of organic micropollutants, but also to the levels of suspended solids and heavy metals. Nevertheless, the annual waste load in Heerhugowaard was higher than that in Amsterdam. This can be explained by the fact that the per capita area of impervious surfaces in Heerhugowaard is almost twice as high as that in Amsterdam and that the average amount of stormwater discharged per overflow event in Heerhugowaard is also twice as high (see table 3.2).

Comparisons between the concentration of heavy metals discharged from separate sewer systems with the corresponding emissions from combined sewer systems shows that the maximum pollutant levels associated with the former type of system in Amsterdam were even higher than the average emission levels from the combined sewer systems monitored in the NWRW programme (Table 4.1). The main reason for such high concentrations of pollutants in stormwater discharges in Amsterdam was thought to be the entrainment of accumulated sludge in gully pots and sewers after heavy rainfall.

After the conversion of the sewer system in Heerhugowaard to an improved separate system, the waste load decreased considerably. The reduced waste fluxes that

Table 4.2. - Waste flux data and pollutant levels from separate and improved separate sewer systems

Waste flux	Separate system		Separate system		Improved separate system	
	Amsterdam		Heerhugowaard		Heerhugowaard	
substance	average annual waste flux (g/cap.a)	maximum discharge event (g/cap)	average annual vuiluituitworp (g/cap.a)	maximum discharge event (g/cap)	average annual waste flux (g/cap.a)	maximum discharge event (g/cap)
BOD	105	12	178	15	20	7
COD	783	88	2619	250	235	98
TKN	45	4	178	9	13	4
total P	7	1	23	2	3	1
TSS	331	143	3684	563	582	202
lead	1.20	0.20	0.57	0.07	0.11	0.04
zinc	4.02	0.69	6.30	0.49	2.10	0.72
chromium	0.39	0.04	0.58	0.06	0.05	0.01
copper	0.62	0.04	0.71	0.07	0.08	0.02
nickel	0.29	0.02	0.36	0.04	0.03	0.01
mercury	-	-	0.04	0.02	-	-
cadmium	0.03	0.00	-	-	-	-
Pollutant levels	Amsterdam concentration per discharge event		Heerhugowaard concentration per discharge event		Heerhugowaard concentration per discharge event	
substance	average (mg/l)	maximum (mg/l)	average (mg/l)	maximum (mg/l)	average (mg/l)	maximum (mg/l)
BOD	7.5	46.3	2.5	5.6	3.5	6.9
COD	68.9	480.8	35.9	71.1	39.3	91.1
TKN	4.2	11.6	2.2	4.7	1.9	3.0
total P	0.6	3.4	0.3	0.8	0.4	1.0
TSS	29.2	913	36.7	161	134	840
	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)
lead	102.6	1250	6.6	20	17.7	44
zinc	318.9	2050	88.2	160	459.3	1677
chromium	31	180	7.2	22	12.4	41
copper	53	210	9.2	45	13.7	42
nickel	23.9	140	4.7	11	5.1	15
mercury	-	-	0.1	0.4	-	-
cadmium	0.2	0.8	-	-	-	-

Note: The average and maximum concentration mentioned in the table refer to individual events. The average concentration should not be compared with the average yearly concentration with can be calculated using data from table 3.1. and annual waste fluxes.

were recorded can almost entirely be attributed to the lower discharge volume achieved with the improved sewer design (volumetric reduction 1:7.5). Notwithstanding this, the average levels of suspended solids and heavy metals detected in stormwater outlets in Heerhugowaard increased after the conversion. This was attributed to the fact that in an improved separate system, overflows only occur during heavy rainfall. The high entrainment rates that are produced under such circumstances were thought to have increased the concentrations of particular pollutants.

It was observed that appreciable quantities of contaminated drainage and leak water were discharged into surface waters in Amsterdam and Heerhugowaard via the storm sewers. The levels of heavy metals found in water from these sources constitute a background waste load. However, this load has been excluded from the data in Table 4.2.

4.2.4. Comparison of the waste fluxes from combined and separate sewer systems

Comparison of the waste flux data given in Tables 4.1 and 4.2 shows that the improved type of separate sewer system performs substantially better than either a combined sewer system or a normal type of separate sewer system. For further corroboration see the water quality impact discussed in Section 5.4.2 (Theme 9). It can also be seen from the tables that the average annual waste fluxes from separate sewer systems are of the same order of magnitude as those from combined sewer systems. However, as the waste load from separate sewer systems tends to be distributed over a larger number of discharge events, average pollutant levels tend to be lower. For further details see Tables 4.1 and 4.2.

Residential area Heerhugowaard

4.2.5. Comparisons with domestic waste fluxes

The extent to which the average annual waste fluxes from combined and separate sewer systems vary in relation to domestic waste loadings is shown in Table 4.3. For comparison purposes, a distinction has been made between "raw" domestic waste flows contained in the influent to sewage treatment plants and net domestic waste production, which represents the residual waste load in the effluent from sewage treatment plants. The basic data on domestic waste production rates given in Table 4.3 have been taken from [5]. The net waste production figures were calculated using generic treatment efficiencies for each substance.

No comparisons have been made with the waste fluxes from improved separate sewer systems as the composition of stormwater discharges from such systems is highly

Table 4.3. - Comparison of annual waste fluxes from combined and separate sewer systems with pollution loadings in domestic sewage

Substance	A domestic waste production rates (stp influent) (g/cap.a)	B net domestic waste production rates (stp effluent) (g/cap.a)	Combined systems*: range of average annual waste fluxes as a percentage of "A" and "B"		Separate systems: range of average annual waste fluxes as a percentage of "A" and "B"	
			column A	column B	column A	column B
BOD	16032	802	1-10	9-197	1-1	13-22
COD	34310	6862	1-18	4-91	2-8	11-38
TKN	3360	1344	1-9	1-22	1-5	3-13
total P	840	504	1-8	1-14	1-3	1-5
TSS	16032	481	1-99	40-3315	2-23	69-766
lead	0.9	0.36	10-508	25-1270	63-133	158-333
zinc	8.1	2.3	9-171	31-602	50-78	175-274
chromium	0.2	0.08	10-485	25-1212	195-290	488-725
copper	6.5	1.95	2-61	8-203	10-11	32-36
nickel	0.5	0.35	4-106	6-151	58-72	6-103
mercury	0.02	0.006	50-900	167-3000	200	666
cadmium	0.05	0.02	20-100	50-250	60	150

**The upper and lower limits defined for combined systems refer primarily to waste flux data collected at Kerkrade and Bodegraven respectively.*

[5] Het inwonerequivalent getoetst. Stichting Toegepast Onderzoek Reiniging Afvalwater (STORA), Rijswijk, 1985.

Residential area in Amsterdam-Holendrecht

dependent on the characteristics of the site on which the surface run-off is collected and hence is independent of domestic waste production rates. Although to a certain extent, the same comment can be made on analogies with normal separate sewer system, it is felt that in the latter case such comparisons are more justified since they give an indication of the possible effect of faulty connections to the storm sewer on waste flux levels.

Reference to Table 4.3 shows that at best the average annual loadings of organic pollutants discharged fromboth combined and separate sewer systems only amount to 1-2% of the organic content in untreated waste of domestic origion. At worst, the discharge of organic pollutants from combined systems is between 8-18% of the corresponding waste of the corresponding domestic waste loadings and some 1-8% in the case of separate systems.

The data collected in this part of the NWRW programme serve to demonstrate that waste fluxes from separate sewer systems can effectively be doubled if a few percent of the connections are faulty. It is also apparent that the quantities of heavy metals and suspended solids discharged from sewer systems can be considerably higher than the corresponding amounts found in untreated domestic sewage. This implies that a significant proportion of these pollutants originates from non-domestic sources such as surface run-off. The contrast would have been even more marked had data been collected from industrial areas, where the concentrations of such contaminants are higher (see also Themes 7 and 9).

The upper and lower limits defined for combined systems refer primarily to waste flux data collected at Kerkrade and Bodegraven respectively.

4.3. The influence of meteorological factors on waste fluxes

4.3.1. General

A number of meteorological factors are known to affect the magnitude of waste fluxes discharged from sewer systems. Of particular importance in this context are:

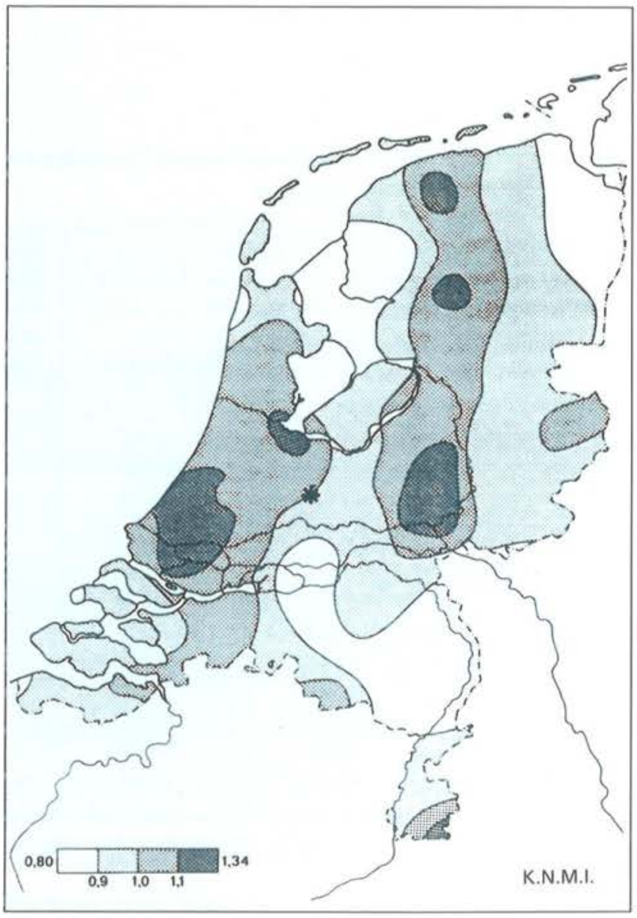
- distribution of precipitation areas
- rainfall intensities
- dry weather periods
- airborne pollutant concentrations.

The effect of each of these factors is discussed in more detail below.

4.3.2. Spatial distribution of precipitation

As there are significant differences in the incidence of heavy storms in various parts of the Netherlands, the frequency of sewer overflows tends to vary from place to place (Theme 4.1). However, the NWRW research results did not support the view that either the intensity or amount of precipitation of invidual storms is location related. It can therefore be concluded that for specific sewer systems in given types of terrain, the average waste flux associated with individual overflow events should be comparable throughout the Netherlands. Nevertheless, when assessing the annual waste load discharged from sewers, a correction factor may need to be applied to take account of regional differences in overflow frequencies. Figure 4.1 illustrates the various correction factors used for comparing

Figure 4.1. - Correction factor to predict sewer overflow frequencies for various regions using rainfall observations at De Bilt (*). Comparisons are valid for systems with a storage capacity of 7 mm and a stormwater pump capacity of 0.7 mm/h



waste fluxes from sewer systems in the Netherlands with a storage capacity of 7 mm and a stormwater pump capacity of 0.7 mm/h.

4.3.3. Precipitation intensities

The levels of organic pollutants and suspended solids discharged from combined sewer systems via stormwater overflows can be significantly affected by the degree to which sludge deposits in sewers are resuspended (Theme 5). The mechanics of the entrainment process primarily depend on flow velocities: the higher the flow velocity, the more sludge is churned up.

In a given sewer system, flow velocities are largely a function of the inflow intensity, which is defined as the product of the run-off coefficient and the intensity of the precipitation. Research carried out as part of Theme 5 of the NWRW programme has shown that COD and BOD levels in stormwater overflows can be reasonably well correlated with the maximum 15 minutes average inflow intensity registered of a rainstorm. A good correlation was also found between the "overflow intensity" (i.e. the discharge rate from a sewer system per hectare of impervious run-off surface) and the COD, BOD and suspended solids loadings. These findings are illustrated in Figures 4.2 and 4.3, which

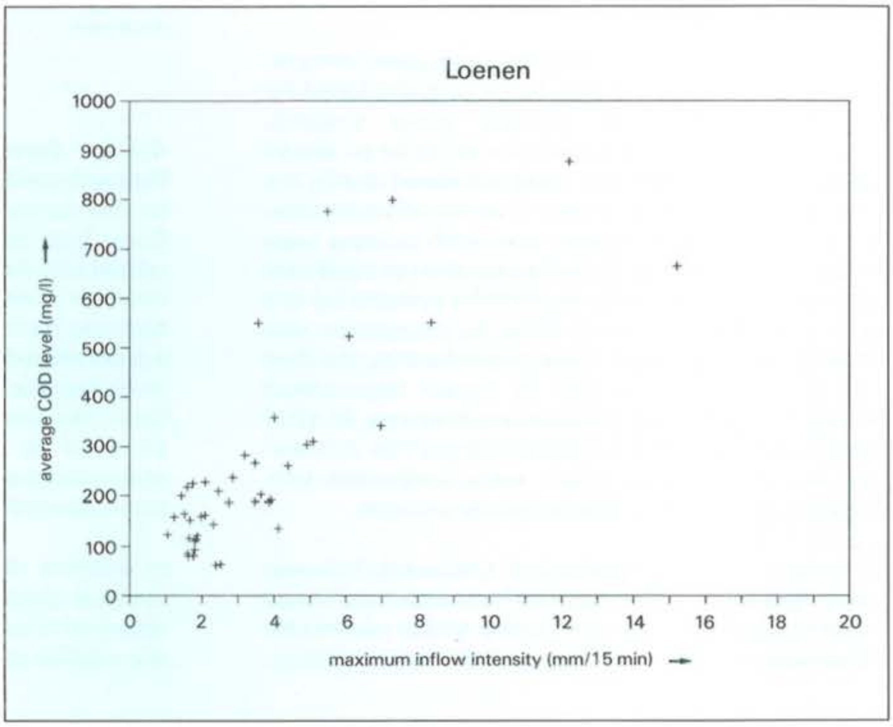


Figure 4.2.
Average COD levels as a function of the maximum inflow intensity (fifteen minutes period) at Loenen monitoring station

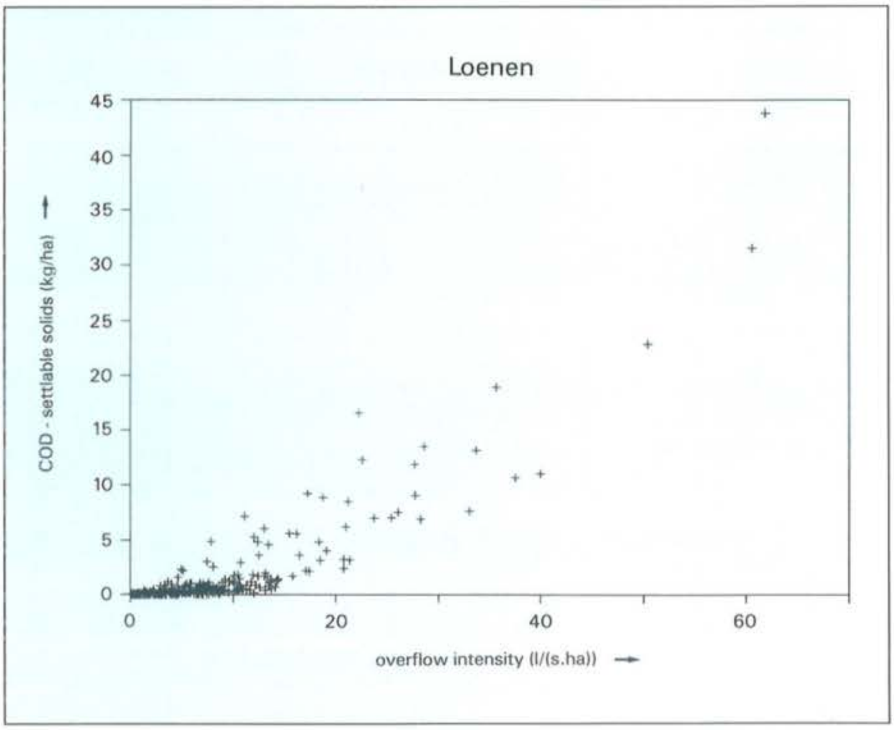


Figure 4.3.
COD loading of settlable solids as a function of overflow intensity at Loenen monitoring station

show the correlation between COD levels and the sewer entry intensities at Loenen and the associated overflow intensities and the chemical oxygen demand of the settlable solids present.

Although none of the investigations in this part of the NWRW programme was specifically concerned with relating the level of heavy metals discharged from stormwater overflows to sewer entry intensities, there are sufficient grounds for assuming that a reasonable correlation exists between these parameters. This hypothesis is supported by the fact that on the one hand, a reasonable correlation exists between sewer entry intensities and suspended solids levels (see Figure 4.4) and that on the other hand, heavy metal loadings have been found to be directly related to suspended solids levels.

Evidence of a definite correlation between sewer entry intensities and organic pollutant levels was also found for standard and improved separate sewer systems. However, this relationship was shown to be of limited practical importance in the areas monitored during the NWRW programme (see Theme 5) as the concentrations of contaminants in discharges from such systems were generally of a low level. The only indication of significant rises in pollutant concentrations in these systems (up to a factor of 10 higher) occurred when the precipitation was extremely intense. Under these circumstances, the flow velocities were high enough to entrain accumulated deposits on the street, in gully pots and in sewers. Much of this material was subsequently discharged into local surface waters, producing waste loads comparable with those associated with combined sewer systems.

By analogy with the hypothetical relationship between heavy metal levels and sewer entry intensities in combined sewer systems, it is assumed that a similar relationship should apply to discharges from separate sewer systems.

A car park

4.3.4. Duration of dry weather periods

Research carried out as part of Themes 5, 6 and 8.3 showed that contrary to what had been expected, the waste fluxes from combined sewer systems could not be correlated with the length of the dry weather period prior to an overflow event. These findings were, however, contradicted in other studies (Theme 8.4), where evidence of a direct relationship between these parameters was found, albeit that this was based on a limited number of observations. The anomaly of the various sets of results can be explained by the fact that it is unusual for all the accumulated sludge built up during a period of dry weather to be removed from sewers during a single overflow event.

In addition, the data collected from separate sewer systems showed that pollutant levels in stormwater appeared to be independent of the length of the preceding dry weather period. Research work carried out as part of

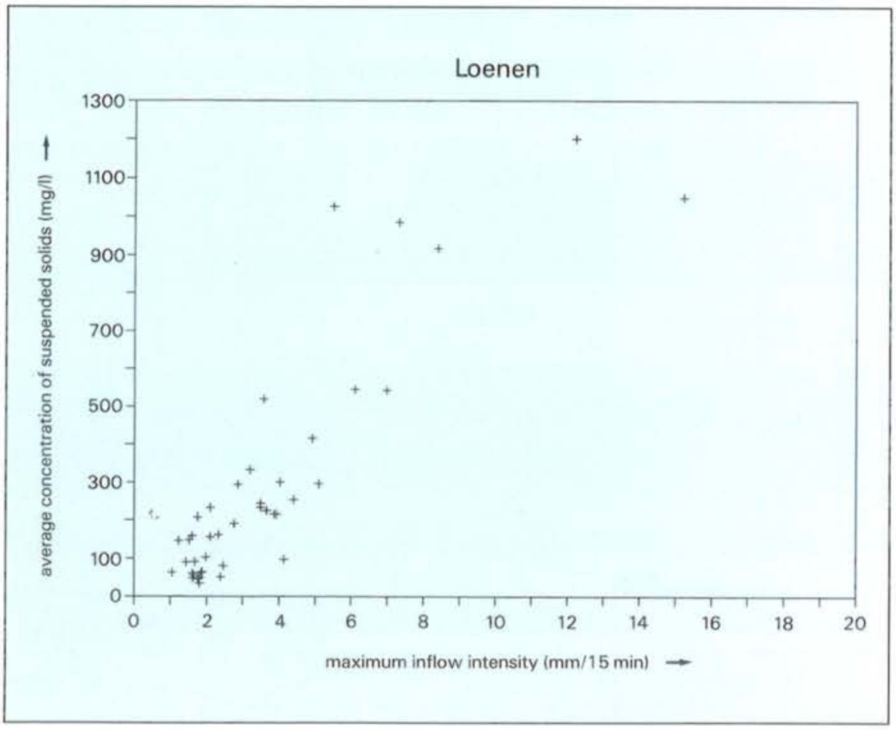


Figure 4.4.
Average levels of suspended solids as a function of the maximum inflow intensity (fifteen minutes period) at Loenen monitoring station

Theme 7 also supported the view that the pollutant levels in surface run-off were independent of the duration of dry weather periods.

4.3.5. Air-borne pollutant concentrations

Research carried out in the NWRW programme (Themes 5 and 7) has shown that although much of the precipitation in the Netherlands is contaminated with dust particles before it reaches the earth's surface, the average concentration of contaminants in rain droplets is virtually insignificant compared with the pollution levels in sewers.

4.4. The influence of topographical and related features on waste fluxes

4.4.1. General

Many of the topographical and other features that characterise particular sewer districts are known to have a significant effect on the waste fluxes in these areas. The key parameters to be considered in this context are:

- surface gradients;
- permeability factors;
- surface usage;
- street cleaning and maintenance schedules;
- groundwater quality;
- waste water sources.

The importance of each of these factors is discussed in detail below.

4.4.2. Surface gradients

Since both flow velocities and the available (static) storage capacity in sewers are related to the hydraulic gradients, the slope of the terrain in a given sewer district can have an important effect on the discharge of organic pollutants into surface waters. This is particularly true in the case of combined sewer systems.

In hilly terrain, sewer gradients are often such that even the dry weather flow is sufficient to prevent excessive sludge accumulation. The effect of appreciable flow velocities in hilly districts is clearly illustrated by the fact that in Kerkrade pollutant levels during major overflow were actually observed to fall, before stabilising at a lower level (see also Section 4.8).

Analysis of the data collected in the NWRW monitoring programme showed that the levels of organic pollutants discharged from sewer systems in hilly terrain cannot be effectively correlated with sewer entry intensities (Section 4.3.3). This can be explained by the relatively high flow velocities that occur in such sewers even at low entry intensities. Consequently, any accumulated sludge in these sewers becomes entrained in the initial stages of storms and is quickly discharged due to the relatively low storage capacity of such systems. After the sludge has been removed from the system, the concentration of pollutants in the stormwater that is discharged drops accordingly.

Stormwater sedimentation tank at Kerkrade

In contrast, the levels of suspended solids discharged from sewer systems in hilly terrain was found to correlate reasonably well with sewer entry intensities. The fact that much of this material enters the sewers in surface run-off

After the rain...

is particularly significant. As the volume of surface run-off is directly related to the intensity of the precipitation, the concentration of suspended solids in such discharges is largely a function of the sewer entry intensity.

Research has also shown that the magnitude of the waste fluxes from such systems is closely related to the volume of stormwater discharged. Overflow volumes in hilly districts are generally greater than those recorded in other areas because:

- sewers in steeply inclined terrain have a limited storage capacity;
- run-off coefficients, which reflect the amount of run-off that reaches the sewers, are normally higher for sloped surfaces than for level ground.

4.4.3. Permeability and other surface properties

The NWRW results indicate that the type of surfaces found in given sewer districts could have a significant effect on both the amount of run-off entering the local sewers and pollutant loadings. The permeability and nature of specific surfaces such as concrete, asphalt, slate, zinc etc. were found to be particularly important in this respect. A clear link was, for instance, established between on the one hand, the presence of zinc ions in sewer discharges and metal roof gutters, and on the other hand, between asphaltic wear products and road surfaces (Theme 7.1).

Studies carried out as part of Theme 4.3 showed that factors such as the permeability and moistening of surfaces and surface detention could have a marked impact on the inflow intensity and amount of stormwater entering sewers. Data taken from the literature suggest that infiltration rates are likely to vary from between 30 mm/h for unpaved surfaces and 10 mm/h for porous paved surfaces to zero for impervious surfaces. Moreover, estimates of the inherent storage capacity of surfaces, which take account of moistening and surface ponding, vary from 0.2 mm for sloping impervious surfaces to 3.0 mm and above for unpaved surfaces.

4.4.4. Surface usage

The use of the impervious surfaces for various activities, transport, parking areas, etc. markedly influences the degree of pollution of the drained stormwater (Theme 7.2). For example, particularly high pollutant levels were detected in the run-off from roads and industrial sites. In certain cases, the contaminant concentrations in such run-off were even found to exceed the average pollutant levels discharged from combined systems. For further details of the degree of pollution associated with specific surfaces see Section 6.2.2.

4.4.5. Street cleansing and maintenance schedules

Streets and roads that are in a poor condition can harbour twice as much dirt as well-maintained surfaces (Theme 7.1). However, considerable improvements can be made with frequent sweeping (once or twice a week). It was shown that by adopting such a policy, it was possible to reduce the average pollutant levels in stormwater discharges by 10-30%. In view of the levels of pollutants involved, it was concluded that such policies are of more relevance to areas with separate sewer systems.

4.4.6. Groundwater quality

In many sewer districts, significant quantities of groundwater enter the sewer system via surface drains that are connected to the sewers and by infiltration. However, in the case of combined and improved separate sewer systems, the impact of groundwater infiltration on surface water quality is minimal since a large proportion of the groundwater is routed via sewage treatment plants. As groundwater entering a normal type of separate sewer system is likely to be discharged directly into local surface waters, the implications for the latter type of system can be more serious. Under such circumstances, the high levels of heavy metals sometimes found in groundwater can pose a significant threat to surface water quality (Theme 5). Data collected at separate sewer systems in Amsterdam and Heerhugowaard showed that on average, some 200 mm of groundwater were discharged into local surface waters via stormwater systems on an annual basis.

4.4.7. Waste water sources

When assessing the quality of sewage discharged from stormwater overflows in combined sewer systems, it is important to consider the type of waste water that is usually carried in such systems. In spite of the fact that high pollutant levels are generally associated with industrial areas, appreciable levels of contaminants can also be found in non-industrial districts. For example, high levels of mercury were detected in stormwater in Loenen (up to 200 times the average concentrations found at the other monitoring sites), which could not be attributed to normal domestic activities.

4.5. The impact of sewer characteristics on waste fluxes

4.5.1. Combined sewer systems

4.5.1.1. General
The type of sewer system can play an important part in determining the magnitude of the waste flux discharged into surface waters. The key parameters which affect waste fluxes from combined sewer systems are:
- storage capacities;
- stormwater pump capacities and sewage pump switching levels;
- overflow frequencies;
- sewer system layout;
- maintenance aspects;
- CSO control structures

The impact of the various parameters is discussed in Sections 4.5.1.2 - 4.5.1.5 below, with a detailed review of the performance characteristics of CSO control structures being given in Section 4.6.

4.5.1.2. Storage capacities
Both the overflow frequency and quantity of stormwater discharged from combined sewer systems are known to be dependent on the available storage capacity. Sewer systems with a large storage capacity are therefore generally associated with low overflow frequencies and small discharge volumes.

Research carried out in the NWRW programme failed to show a clear relationship between the pollutant levels in stormwater discharged into surface waters and the storage capacity of the sewer system in question. Although sludge accumulation in large diameter sewers having a gradual bottom slope is likely to be more pronounced than in small diameter sewers with a steeper slope (Theme 6), this need not necessarily lead to increased pollutant levels in the stormwater discharged from such systems (Theme 5). For instance, data collected at the sewer system in Bodegraven, which had the largest storage capacity of the four combined systems monitored in the NWRW programme, showed that the levels of pollutants discharged at this site were relatively low. It was postulated that the low flow rates in the large diameter sewers at Bodegraven could have allowed sufficient time for sludge that had been resuspended to resettle in the sewers before it reached the overflow outlets, hence limiting the pollutant levels in the stormwater discharged. A further factor which could have contributed to the low contaminant concentrations at Bodegraven was the degree of dilution due to the substantial volumes of water that collect in systems with such a large storage capacity.

A gully pot

Despite the low average concentration of suspended solids in discharges at Bodegraven, the levels of dissolved solids (i.e. material which does not settle within one hour) at the different monitoring sites were roughly comparable (Theme 5). This was seen as confirming the importance of the sludge retention mechanism at Bodegraven.

Parallel studies concerning sewer systems with small storage capacities showed that accumulated deposits of sewage sludge could be completely removed from sewers in hilly areas after heavy rainfall. Under such circumstances, the stormwater flowing through the system is considered to have a flushing action (Theme 5).

4.5.1.3. Stormwater pump capacities and sewage pumps switching levels
Although the effect of stormwater pump capacities on waste fluxes did not form the subject of a separate investigation within the context of the NWRW programme, it is recognised that under certain circumstances, pumping capacities can play an important role in controlling waste loads.

The capacity of stormwater pumps can, for instance, have a direct effect on overflow frequencies and the amount of stormwater discharged. Increasing the capacity of stormwater pumps normally lowers overflow frequencies and hence reduces waste fluxes. In dry weather, however, the flow rates in sewers are independent of stormwater pump capacities so that sludge accumulation rates are unaffected. Similarly, pump capacities have little effect on the flow rates in sewers during overflow events and hence on the pollutant levels present in the stormwater discharged. In such situations, sewer entry intensities and discharge rates generally have a more marked impact on contaminant concentrations at overflows as these parameters control the degree to which sludge is entrained in sewers.

During dry weather, the sludge accumulation in sewers can be affected by the switching levels chosen to activate and deactivate sewage pumps. If the activation point is set too high, the water level in the pumping chamber could remain well above the bottom level of the influent sewer (Theme 6). As a result, the lowest sections of the sewers will remain filled with water when the pumps are not operating, hence lowering the effectively storage capacity of the system. Under such circumstances, the flow velocities will be reduced, which will promote sludge deposition.

4.5.1.4. Overflow frequencies
The overflow frequency associated with a particular sewer system is largely a function of the storage capacity of the system and the stormwater pump capacity. A given overflow frequency can be achieved with either a large storage capacity and a small pump capacity, or a small storage capacity and a large pump capacity. It was not possible to establish which of the two options is to be preferred.

4.5.1.5. Sewer system layout
Research carried out in the NWRW programme has shown that the layout and morphology of sewer systems can have a considerable effect on sludge accumulation rates and on the discharge of pollutants (Themes 5 and 6). To minimise the deposition of sludge in sewers, the system should be designed so as to facilitate the rapid transport of sewage, including any solid constituents present, to a sewage treatment plant or sewage pump (Theme 6). Studies have shown that sludge deposition is likely to be enhanced by:

- abrupt changes in flow direction;
- too wide a dry weather flow cross section;
- highly interconnected (meshed) sewer systems;
- sand deposition;
- inadequate hydraulic gradients;
- subsidence;
- low lying overflow sewers.

Within the context of Theme 5 it was shown that each of these factors could have a major impact on the waste fluxes from sewer systems. The importance of layout and structural aspects was further underlined by the results obtained from Oosterhout, where abnormally high pollutant levels were recorded during heavy rainfall. This was attributed to the fact that a number of dwellings in the locality had been connected directly to the overflow sewer rather than the main system. The low flow rates occurring in this peripheral sewer section were seen as likely to promote excessive sludge deposition.

4.5.1.6. Maintenance aspects
In assessing to what extent waste fluxes are affected by how well sewer systems are maintained, particular attention was focused on the effect of cleaning such systems on the composition of sludge deposits (Theme 6). Although cleaning was shown to reduce the suspended solids content of sludge, COD levels were found to increase. It was postulated that the washing away of inert material such as sand had probably created vacant sites that had been filled with material having a higher polluting potential. In due course, the deposition of more sand and the onset of mineralisation processes would be likely to reduce the polluting potential of any accumulated material, bringing into question whether there is much to be gained by cleaning sewers.

Although no specific studies were undertaken with the aim of investigating how sludge deposition is affected by the age of sewers, it is assumed that any sedimentation problems would be exacerbated by the higher roughness factors, leakage rates and settlement likely to be encountered in older sewers (Theme 6). Renovating sewer systems can therefore be considered to have some potential for reducing waste fluxes.

During the investigation period it happened more than once that due to pump failures raw sewage was discharged into the surface waters. (Themes 5, 6, 9 and 10). Many of the problems caused by such failures could be mitigated by installing adequate warning systems.

4.5.2. Separate and improved separate sewer systems
The key parameters which affect waste fluxes from separate sewer systems are the occurrence of faulty (illegal) connections and the frequency with which gully pots are cleaned. Faulty connections are difficult to eliminate completely and can, under certain circumstances, constitute a serious source of pollution (Section 4.2.5). Although no faulty connections were actually found in the separate sewer systems in Amsterdam and Heerhugowaard which were investigated as part of Theme 5 of the NWRW programme, the surface water quality at five of the seven separate system sites monitored during the Theme 9 projects was indicative of the existence of foul water connections.

Apart from inflow of raw sewage due to illegal connections, a large part of the waste flux from separate sewer systems originates from contaminated surface run-off. In addition, appreciable levels of sludge can be entrained in stormwater systems as a result of extremely heavy rainfall, which can cause pollutant levels to rise significantly. Although uncertainty exists about the precise location of sludge deposits in separated sewers, substantial quantities of accumulated material are usually found in gully pots. To limit the amount of sludge entrainment in such sewers, it is recommended that gully pots are cleaned on a regular basis.

Comparison of the pollutant concentrations in stormwater discharges from separate and improved separate sewer systems (Theme 5) showed no significant differences in contaminant levels. The substantially lower waste fluxes fount at the improved systems result from the lower volumes of stormwater discharged.

4.6 Combined sewage overflow (CSO) control structures

4.6.1. General
CSO control structures have the primary aim of reducing pollutant concentrations in sewage discharges. To assess the performance of various candidate systems, a series of comprehensive field evaluations was carried out as part of Theme 8. This included a detailed evaluation of the following facilities:

- stormwater sedimentation tanks;
- swirl concentrators;
- improved weir chambers.

The results of the assessment programme are presented in Section 3.7 and the main findings are discussed below.

4.6.2. Stormwater sedimentation tanks

Stormwater sedimentation tanks have a combined function. They are intended to reduce overflow frequencies and discharge volumes by providing additional storage capacity and to reduce the concentration of pollutants present by promoting sedimentation.

High-sided weir chamber

The efficiency of stormwater sedimentation tanks has been assessed at two locations: Amersfoort (project 8.1) and Kerkrade (project 8.2). The sedimentation tank at Amersfoort has a rectangular shape and inlet and outlet on opposite sides, whereas the Kerkrade facility is a circular tank with a central inflow. In spite of the differences in the theoretical overflow frequencies (an average of six times per year in Amersfoort as opposed to twenty-five times per year in Kerkrade) no significant differences were observed in the overall removal efficiencies (see Table 3.3, Section 3.7).

To provide a common basis of comparison, only data relating to overflow events that actually resulted in stormwater being discharged into surface waters (i.e. external overflows) were considered in the assessment. Inclusion of internal overflow data (i.e. overflow events when the sedimentation tanks were only partially filled) would have increased the removal efficiencies shown in Table 3.3 by about 10%.

Although the performance assessments were based on the removal of COD and suspended solids, it is assumed that similar results can be expected for heavy metals as most of these metals are adsorbed onto sludge particles (Theme 5).

The results of the monitoring programme have shown that stormwater sedimentation tanks will operate satisfactorily with a 2 mm storage capacity. For sewer systems with an overflow frequency of between 5-10 times a year, stormwater sedimentation tanks can be expected to reduce COD loads by about 60-70%. This is equivalent to a 30-40% reduction if the comparison is made on the basis of the same net storage capacity. Alternately, the use of such facilities would allow the overflow frequency of a system to be increased by 50% without markedly affecting the annual waste flux (project 8.5).

4.6.3. Swirl concentrators

The main purpose of swirl concentrators is to reduce the amount of settlable solids discharged from stormwater overflows. The reduction in pollutant levels obtained with swirl concentrators relies on the waste being separated through the action of centripetal forces. The additional storage capacity of such systems is negligible.

Typical net removal efficiencies for swirl concentrators are given in Table 3.4 (see Section 3.7). By comparing the performance of a swirl concentrator with that of a conventional weir chamber (project 8.3) it has been possible to express the results on a net efficiency basis. However, care should be taken when using net efficiencies of this type as the conventional weir chambers have some reducing effect by itself.

Although these performance estimates were largely based on COD and BOD removal efficiencies levels, by analogy with the mechanisms put forward for stormwater sedimentation tanks it is assumed that swirl concentrators will also reduce the concentration of heavy metals.

4.6.4. Improved weir chambers

High-sided weir chambers can help to reduce waste fluxes from sewer systems by allowing some of the heavier sewage constituents to settle out prior to discharge. As the storage capacity of weir chambers is relatively small the effect is solely due to sedimentation.

Efficiency data for a typical high-sided weir chamber are given in Table 3.5, Section 3.7 (project 8.3.2). If the capacity for conventional weir chambers to reduce pollution loads is discounted, these data can be considered to represent net efficiencies. However, as was pointed out in the section on swirl concentrators, the validity of such assumptions is somewhat questionable.

When comparing the performance of high-sided weir chambers with that of other CSO control structures it should be borne in mind that the weir chamber monitored

Underground stormwater sedimentation tank at Amersfoort

Table 4.4. - Eficiency of CSO control structures

substance	stormwater* sedimentation tank	swirl concentrator	high sided weir chamber
BOD	65	40	27
COD	65	36	13
TSS	70	-	20
TKN	-	22	7
total P	-	21	7

* *excluding internal discharges (see Section 4.6.2.)*

in Rotterdam was not located in an optimum position. The fact that this weir chamber had been positioned on a dead end of the sewer network could have impaired its efficiency rating.

4.6.5. The impact of CSO control structures on waste fluxes

During the NWRW programme, CSO control structures were shown to perform best with sewage containing appreciable quantities of settlable solids. Such facilities were particularly successful in reducing pollutant levels in stormwater contaminated with sludge. An overview of the efficiencies achieved with the various systems is given in Table 4.4. It can be seen that the removal efficiencies were highest for stormwater sedimentation tanks and lowest for high-sided weir chambers. However, as these data were derived from different sewer systems under various conditions, it is difficult to draw general conclusions about projected efficiency levels.

4.7. Direct discharge of surface run-off

The disconnection of particular aereas draining to combined sewers can be a useful means of reducing overflow waste fluxes. Not only is the overflow frequency likely to be lowered, but the volume of stormwater discharged can also be reduced.

For a sewer system with a storage capacity of 7 mm and a stormwater pump capacity of 0.7 mm/h, decoupling 10% of the total impervious surface in the locality can be expected to reduce the average overflow frequency from 10 to 8 times a year. This would have the added advantage of reducing the volume of stormwater discharged from the sewer system by 10%, assuming that the amount of precipitation entering the system is directly proportional to the drainage area. Provided the concentration of pollutants in the stormwater does not change as a result of the disconnection operation, a corresponding reduction can be expected in the waste flux. Under normal circumstances, the latter assumption can be considered to be rather conservative as the reduced flow velocities which result from lower stormwater volumes should also lower the concentration of pollutants, particularly in sewers close to the outlet. The impact of low flow velocities is clearly evident from the results obtained from the sewer system in Bodegraven, which has the largest storage capacity per unit area of collection surface. A further advantage of disconnecting sewers carrying surface run-off is that it reduces the hydraulic loading at the sewage treatment plants and in the sewer system.

Nevertheless, disconnecting drainage areas is not always appropriate as the surfaces on which precipitation collects can be contaminated. A number of sites were identified in the NWRW programme at which the levels of organic matter and micropollutants in the surface run-off were above the minimum quality standards for surface waters. General guidelines for disconnecting drainage areas are discussed in Chapter 6.

It should be noted that decoupling storm sewers can drastically reduce the flushing action in peripheral sewer sections and hence promote sludge accumulation (Theme 6).

4.8. Waste flux predictions

4.8.1. General

Methods for predicting waste fluxes from both combined and separate sewer systems have been developed on the basis of the findings of Theme 5 of the NWRW programme. Waste fluxes calculated using these methods are generally of sufficient accuracy to assess the likely impact of sewage discharges on surface water quality. However, as the processes taking place in sewers are extremely complex, it is not possible to model all the effects in great detail.

4.8.2. Combined sewer systems

In predicting the pollution load from combined networks a distinction is made between total annual flux and the prediction of the flux per overflow.

The annual waste flux from combined sewer systems can be calculated as the product of estimated mean pollutant levels and the volume of stormwater discharged. A series of estimated mean pollutant concentrations for each of the sewer districts investigated in Theme 5 of the NWRW programme is given in Table 4.5. Specific information is also provided about the settlable solids level and corresponding organic fraction.

Although the estimated mean pollution levels in the table are only strictly applicable to a particular sewer system, they can also be used for establishing waste fluxes in other

Table 4.5. - Estimated mean pollutant concentrations for calculating annual waste fluxes

substance	Loenen		Oosterhout		Bodegraven		Kerkrade	
	total concen-tration (mg/l)	consti-tuents after settling (1 h) (mg/l)	total concen-tration (mg/l)	consti-tuents after settling (1 h) (mg/l)	total concen-tration (mg/l)	consti-tuents after settling (1 h) (mg/l)	total concen-tration (mg/l)	consti-tuents after settling (1 h) (mg/l)
BOD	34	16	59	38	35	30	42	22
COD	330	127	216	111	139	99	170	70
TKN	10	6.2	10	7.7	8.9	8.4	7.9	6.3
total P	2.0	1.8	3.1	2.2	1.8	1.7	1.9	1.5
TSS	394	113	164	43	103	62	453	95
	(mg/m³)	(mg/m³)	(mg/m³)	(mg/m³)	(mg/m³)	(mg/m³)	(mg/m³)	(mg/m³)
lead	135	-	113	-	46	-	123	-
zinc	286	-	340	-	356	-	366	-
chromium	10	-	11	-	10	-	27	-
copper	88	-	125	-	79	-	115	-
nickel	11.1	-	8.5	-	7.6	-	14.2	-
mercury	23.2	-	2.0	-	1.5	-	0.5	-
cadmium	1.4	-	1.4	-	1.4	-	1.5	-

Table 4.6. - Selection criteria for estimating mean pollutant levels in combined sewer systems

maximum height difference (m)	storage capacity (mm)	comparable sewer district (see Table 4.5 for estimated mean pollutant levels)
> 25	< 5	Kerkrade
	5 - 7	(Kerkrade + Loenen)/2
	> 7	Bodegraven
5-25	5 - 7	Loenen
	> 7	Bodegraven
< 5	5 - 7	Oosterhout
	> 7	Bodegraven

Table 4.7. - Return periods of discharge events applicable to sewer systems with a storage capacity of 7 mm and a stormwater pump capacity of 0.7 mm/h

COD (kg/ha)	return periods (year)	BOD solids (kg/ha)	return periods (year)	dry solids (kg/ha)	return periods (year)
30	2.2	10	2.7	20	2.1
60	6.3	20	7.6	40	5.6
90	12.4	30	15.0	60	10.7
120	21.0	40	25.2	80	17.6
150	32.3	50	38.7	100	26.5

sewer districts by means of in- en extrapolation, provided that the conditions are not too dissimilar. To facilitate comparisons, various classes of sewer system are distinguished in Table 4.6. For more precise estimates, interpolation or extrapolation of the data is recommended.

It should be noted that the estimated mean heavy metal concentrations given in Table 4.5 are representative of residential districts. The relevance of such data to industrial areas cannot be guaranteed.

To calculate the waste flux associated with an individual overflow event, distinct approaches given for settlable and non-settlable matter.

To predict the amount of non-settlable material discharged, a statistical approach is used. The likelihood of a given waste flux being discharged can be expressed as the probability of a given pollutant level occurring and the product of the probability of a certain volume of sewage being discharged. Both the projected discharge volumes and average pollutant levels have been found to conform to lognormal frequency distributions. The recurrence times for the COD, BOD and suspended solids fluxes for a sewer system with a storage capacity of 7 mm and a stormwater pump capacity of 0.7 mm/h are given in Table 4.7.

In order to determine the amount of settlable matter likely to be discharged during an individual overflow event, it is

first necessary to estimate the mean pollutant concentrations. As most of the settlable matter in stormwater becomes entrained due to sludge deposits being churned up in the sewers, flow velocities are indicative of pollutant levels. It has been shown that the average flow velocity in the vicinity of an outlet gives a good guide to the levels of settlable matter present in stormwater, provided that account is also taken of the discharge rate and length of the sewers. Partially filled sewers at some distance from the outlet should be disregarded when making such assessments. In addition to using the concept of a "weighted flow velocity", it is proposed that a surface parameter ("A") be adopted to allow for factors such as the diameter of the sewers and the storage capacity and structure of the system.
Effectively, "A" represents the quotient of the overflow rate and the weighted flow velocity.

The waste flux of settable solids has been shown to be a quadratic function of the average discharge rate over a fifteen-minute period (cf. fig. 4.3.) and to be proportional to the surface parameter "A". The amount of settlable material discharged from a given sewer system during an individual overflow event can be calculated using the surface parameter "A" and the average discharge rate over a fifteen-minute period. For more detailed information reference is made to the reports issued for project 5.2. It should be noted, however, that the above method is not applicable to steeply sewers with steep gradients in which the volume of stormwater exceeds the static storage capacity by more than a factor of twenty. In such cases, the replenishment rate is sufficiently high to justify using constant pollutant concentrations i.e. BOD 50 mg/l; COD 200 mg/l.

4.8.3. Separate sewer systems

The following equation can be used to calculate the waste flux from seperate and improved separate sewer systems for individual storm events.

$$V_i = N_i \cdot a_g \cdot v_g$$

where:

V_i	= the waste load associated with storm event i	(kg/ha)
N_i	= the precipitation height of storm event i	(m³/ha)
a_g	= average run-off coefficient	(-)
v_g	= the average pollutant concentration of the stormwater discharged	(kg/m3)

As the run-off coefficient can vary between storm events, it is necessary to correct average pollutant concentrations (v_g) on the basis of measured values. Typical values of v_g for organic pollutants and suspended solids are given in Table 4.8. Although the corrected pollutant concentrations are only strictly valid for the sewer districts in which the monitoring was carried out, the data presented in Table 4.8 can be used to estimate projected levels at other locations. The data collected at Amsterdam-Holendrecht allow assessments to be made of the effects of storm events of both high and low intensity. In this context, high intensity storms are defined as those in which at least one 15 minute period has an average precipitation intensity of 90 l/s.ha or more.
The pollutant concentrations measured during such storms were generally substantially higher than those observed during low intensity storms. Similar data for the Heerhugowaard district are not available as the storm events recorded during the monitoring period did not exceed the abovementioned limit.

It should be noted that special consideration should be given to local factors when assessing the discharge of heavy metals. Particular attention should be focused on the quality of the local groundwater and the likely volumes of drainage water as these can have a significant effect on waste fluxes.

Table 4.8. - Estimated mean pollutant concentrations for calculating waste fluxes from separate and improved separate sewer systems

Amsterdam-Holendrecht, separate system

substance	units	mean pollutant concentration $i \leqq 32$ mm/h (90 l/s.ha)	mean pollutant concentration $i > 32$ mm/h (90 l/s.ha)
BOD	mg/l	45	190
COD	mg/l	5.0	25.0
TKN	mg/l	3.5	8.0
total P	mg/l	0.4	2.3
chloride	mg/l	110	110
TSS	mg/l	16	335

Heerhugowaard, separate system

substance	units	mean pollutant concentration
BOD	mg/l	40
COD	mg/l	2.7
TKN	mg/l	2.2
total P	mg/l	0.3
chloride	mg/l	60
TSS	mg/l	55

Heerhugowaard, improved separate system

substance	units	mean pollutant concentration
BOD	mg/l	45
COD	mg/l	3.0
TKN	mg/l	2.0
total P	mg/l	0.5
chloride	mg/l	27
TSS	mg/l	110

i = precipitation intensity (see text)

5. Impact on surface waters

5.1. General

Discharges from sewer systems have a significant effect not only on the quality of surface waters but also on the condition of the underlying bed sediment. To evaluate the quality of surface waters and bed sediment, state variables of the physical, chemical and biological condition of receiving waters are used in relation to:
- water levels and flow velocities;
- suspended and sedimentary sludge;
- oxygen-consuming substances and oxygen levels;
- nutrients;
- micropollutants;
- bacteria and viruses;
- microflora and microfauna;
- macroflora and macrofauna.

The effect of sewage discharges on the quality of receiving waters and bed sediments can be assessed by making comparisons with the condition of other surface waters. Ideally, the surface waters that are used for reference purposes should be similar to the receiving water under consideration, but unaffected by sewage discharges.
The generalised impact study (Theme 9) was based on parallel observations in both affected and unaffected (reference) water courses on over 60 locations.

5.2. Characterisation of effects on surface waters

5.2.1. Hydraulic and thermal effects

Discharges of sewage into receiving waters can cause considerable disruption in the water phase and can lead to temporary rises in the water level. The onset of discharges can be detected by monitoring the electrical conductivity of the water phase and is generally associated with a low conductivity reading. If there is a large difference in temperature between the receiving water and the discharge stream, the thermal equilibrium of the receiving water may be disturbed. Such effects are most noticeable when the temperature of the receiving water exceeds 20°C or is close to or even below zero. When receiving waters are frozen over, discharges of relatively warm water can cause the ice to melt in the vicinity of overflow points.

5.2.2. Perceptible effects

As sewage discharged from overflow outlets can contain faeces, paper residues, sanitary towels and condoms, waste products of this type are often to be found floating on the surface of receiving waters or attached to water plants. Eventually some of these materials sink to the bottom or become deposited on the shoreline or banks.

In stagnant waters, most of the waste products accumulate in the vicinity of discharge points and can become particularly noticeable when entangled in water plants or deposited on banks. If flooding occurs, much of this waste can be carried along substantial distances before being deposited in gardens, fields etc.

Water bottom near an overflow outlet

Oil films or foam layers are also associated with discharges from sewer systems, as are increased turbidity and discolouration of the water phase. These effects are generally most acute near discharge points. Sewage discharges can be accompanied by pungent odours which can persist for several days. In certain cases, the smell is so pervasive that it seriously inconveniences passers-by and residents. The decomposition of waste products deposited on banks or at the bottom of surface waters can aggravate the situation.

5.2.3. *Effects on suspended matter and bed sediment*

As discharges from sewer systems frequently contain appreciable amounts of both fine and coarse suspended matter, receiving waters tend to become discoloured and less transparent immediately after an overflow event. Although most of the coarse material will settle out in less than an hour - unless the prevailing currents are very strong - the finer material may remain in suspension for up to a day and can be dispersed some fifty or more metres from the discharge point.

The thickness of sludge deposits in the direct vicinity of an overflow outlet can vary from a few centimetres to more than a metre. The consistency of such sludge is relatively dense and rather coarse as it usually contains substantial quantities of faeces, paper residues etc. The colour of mature anaerobic sludge is predominantly black. Recent deposits can be identified by their yellow and whitish grey colour. While mature sludge is normally said to have a putrifying odour, surface layers retain the stale smell associated with sewers. Depending on where the sewage originates from, oil residues may be entrained in the sludge.
Compared with the material found in the direct vicinity of an overflow outlet, the sludge layer deposited at some distance from a discharge point is more homogeneous and sometimes even thicker.
It generally has a finer consistency and is darker in colour, signifying more intense anaerobic activity. Sludge of this type has a characteristic putrid smell.

Monitoring station in the pond at Loenen

At distances of over a hundred metres from overflow outlets the thickness of sludge layers gradually diminishes.

5.2.4. *Effects on oxygen-consuming substances and oxygen levels*

Sewage discharges can increase the concentration of ammonia in receiving waters and tend to raise the Biochemical Oxygen Demand (BOD). In the first few days after such an event, the oxygen concentration in the water phase is likely to drop substantially. At one of the sites monitored in the NWRW programme, the oxygen concentration became so depleted that anoxic conditions developed. However, within a week, the concentration of dissolved oxygen and the level of oxygenconsuming substances usually returns to normal.

The oxygen demand in the bed sediment in the direct vicinity of a discharge point is likely to be higher than that registered in the corresponding reference waters. Gas production rates are also likely to be higher close to discharge points. These effects can have a lasting impact on the condition of the surface water in question. For instance, the concentration of dissolved oxygen in the water phase can remain well below the normal background levels. Such effects are most marked in shallow ditches and surface waters where there is little circulation. In general, the severity of these effects diminishes with time (weeks) and distance (hundreds of metres) from the discharge point.

5.2.5. *Effects on nutrients and algal growth*

Discharges from sewer systems can increase the concentrations of nitrogen and phosphorous in receiving waters and hence impair water quality. This situation can last for several days or even weeks. However, no evidence was found during the NWRW programme to support the view that sewage discharges always lead to permanently elevated levels of such contaminants. Moreover, a marked decline in concentration gradients was observed away from the immediate vicinity of overflow outlets. The high levels of nutrients detected at the monitoring station in Loenen during the summer were thought to have been responsible for the development of algae blooms and the displacement of colloidal material present in the water phase.

5.2.6. *Effects on pH levels*

In general, sewer overflows and stormwater discharges only have a limited effect on the pH levels in surface waters. Nevertheless, the discharge of appreciable quantities of stormwater can reduce the high pH levels of water in which a permanent algae bloom has developed, by some 1 or 2 points. Discharges that promote algal growth can in turn lead to higher pH levels.

5.2.7. *Effects on micropollutants*

It is not uncommon to find that immediately after sewage discharges have occurred, the levels of heavy metals and extractable organic chlorine in receiving waters rise dramatically. After about a week, however, the concentration of these contaminants generally returns to the background levels typically found in local reference waters. Under normal circumstances, between 60 and 95% of micropollutants that are discharged are adsorbed onto suspended solids. Following sewer overflows, most

of these contaminants eventually become deposited downstream of the discharge point.
In stagnant receiving waters, the accumulation of contaminants that are persistent or do not readily decompose, such as heavy metals, oil and organic micropollutants, can seriously affect bed sediments, particularly near overflow outlets. Detailed examination of such deposits gives a clear indication of the extent and impact of sewage discharges over a number of years. If highly polluted material is detected in such deposits, great care must be taken when dredging the water course in question.

During the NWRW programme, numerous examples were found of high concentrations of zinc, lead, cadmium and mercury in the bed sediments of receiving waters. This applied not only to areas with combined sewer systems but also to those with separate sewer systems. Although the concentrations of copper found at certain locations exceeded the background levels registered in typical reference waters, the differences were generally less marked than with the other heavy metals. The concentration of arsenic in bed sediments was found to be independent of the proximity to stormwater outlets.

The highest concentrations of heavy metals recorded during the NWRW programme were found in samples of sediment taken from the immediate vicinity of discharge points in small and medium-sized stagnant receiving waters. In larger surface waters, dilution and dispersal mechanisms tended to mitigate such effects. On numerous occasions, both the provisional and recommended sediment quality standards laid down for individual metals were exceeded even at significant distances from discharge points. Most of the infringements related to the concentrations of copper and lead, with fewer problems encountered in the case of zinc and cadmium. In contrast, the concentration of mercury was generally found to be within the prescribed limits.

Samples of sediment taken at the various monitoring stations confirmed the presence of organic micropollutants such as polycyclic aromatic hydrocarbons, polychlorobiphenyls and organochlorine pesticides. Although the concentration of these compounds was frequently found to exceed the levels specified in the provisional guidelines, the prescribed limit values were rarely exceeded. The most serious infringements were associated with the discharge of surface run-off from industrial estates.

5.2.8. Effects on hygiene standards

Sewage that is discharged into surface waters may contain relatively high concentrations of intestinal bacteria as well as human and animal viruses. Moreover, it is not uncommon for sewage to contain appreciable quantities of other bacteria and fungi that are specific to sewer systems. Under certain circumstances, pathogenic bacteria and viruses may also be found although these are usually less common. If high levels of faecal bacteria and viruses are detected in sewage, this is taken to be an indication of the fact that pathogenic bacteria and viruses may be present. Some of the viruses present in sewage are only to be found in their host organisms.

Discharges of sewage into surface waters generally raise the levels of faecal coliforms, streptococci and various bacteriophages. Following sewer overflows, the concentration of faecal coliforms in receiving waters can increase by a factor of 1000 or more. In extreme cases, amplifications of 20,000 have been recorded. Stormwater discharges, in contrast, normally result in much lower increases in coliform levels (10 to 100 times higher).
The effects associated with the discharge of faecal coliforms are likely to extend over a much wider area than those associated with other pollutants. Within seven days of a discharge having taken place, the concentration of faecal bacteria and viruses usually returns to the normal background levels associated with comparable reference waters. However, it has been known for high concentrations of these contaminants to persist for longer periods of time due to the fact that such bacteria can survive in the bed sediment for several months.

Overview of the pond at Loenen showing the measuring stations

Bacteriological contamination is one of the most pervasive forms of pollution to be found in combined and standard separate sewer systems. The concentration of faecal coliforms and the electrical conductivity of surface waters are the most sensitive indicators of whether sewer overflows and stormwater discharges have taken place. These factors provide a useful means of assessing not only the extent and duration of the deleterious effects associated with such discharges, but also the degree of dispersion that takes place.

5.2.9. Hydro-biological effects

During and shortly after sewer discharges, reductions are likely to take place in the local population densities of many of the microphytes, microfauna and species of macrofauna present in receiving waters. Although organisms that are indicative of water pollution are likely to recover first, the speed at which this takes place will be influenced by the rate at which the quality of the water improves. Other factors which can be important in this respect are the condition of the banks and bed sediment, weather conditions, and the presence of an ecological link between the water phase and bank zones that are still inhabited by healthy organisms (recolonisation, inoculation).

Organisms can disappear for substantial periods of time after discharges have taken place and in the case of regular discharge events, can even disappear completely from receiving waters. This can give rise to permanent changes in the make-up of the communities that inhabit such waters. In contrast, an example of short-term effects would involve a dramatic loss of life in the fish population followed by a subsequent recovery of fish stocks. It is important to note, however, that if anoxic conditions occur regularly this is likely to annihilate fish stocks in secluded surface waters.

Short-term effects
During the first few days after sewer discharges, it is quite probable that absolute population densities and the degree of diversity of phytoplankton and zooplankton will decline due to migration, circulation effects and/or mortality. On the other hand, polysaprobic zooplankton which enters surface waters from the sewers is likely to flourish. This has important consequences for the macrofauna (fish) present, which tend to migrate and/or die.

Medium-term effects
In the weeks and months after a discharge event, the variety of macrofauna and plankton present in receiving waters may change, with various species succeeding each other. Such changes are likely to be induced by the low oxygen levels and high levels of organic substances and nutrients that are found in the water phase immediately after sewer discharges.

In surface waters that normally contain large quantities of colloidal material, the supply of light is somewhat limited, which tends to restrict algal growth. Under these circumstances, sewer overflows generally cause the clarity of the water to improve suddenly, thus stimulating algal growth. This in turn, may lead to an increase in the amount of zooplankton present. Population densities normally return to their original levels, however, within weeks or months after an overflow event.

Long-term effects
During the NWRW programme, evidence was found to suggest that most of the groups of flora and fauna present in receiving waters, and particularly sessile diatoms and macrofauna, had been permanently affected due to the regularity with which sewer overflows and stormwater discharges had occurred. The differences between the populations in receiving waters and those in the reference waters were indicative of significant differences in trophic and/or saprobic levels. Both trophic and saprobic levels tended to be higher in receiving waters than those in typical reference waters, with polysaprobic and hypertrophic conditions being observed in extreme cases.

If the intervening period between sewer overflows and stormwater discharges is relatively long, many of the populations present in receiving waters will begin to recover and approach the levels found in reference waters. Nevertheless, unless the water course is dredged or other measures are taken, the effects of an overflow event can persist for many years. In the course of the recovery process, fast growing plankton species that are more or less resistant to pollution are gradually replaced by other species, eventually producing a more balanced eco-

Effects on water plants

system. At Loenen, blue-green algal growth was observed in the water phase.

The variety of species found in polluted bed sediment, is generally considerably inferior to that present in uncontaminated sediment. The higher the levels of organic biodegradable matter and other (micro)pollutants and the lower the concentration of dissolved oxygen the less diverse the resident communities are likely to be. In extreme cases, benthic macrofauna may be totally absent from the area around overflow outlets.

Flowing waters
Although macrofauna tend to be unaffected by sewer discharges in flowing water, the impact on sessile diatoms can be quite marked. This is thought to be due to the fact that diatoms, unlike most fauna, are not mobile and are therefore more susceptible to periodic exposure to pollutants. While population densities of diatoms can be drastically reduced as a result of large overflow events in which individual organisms become dislodged and dispersed, this is unlikely to be the case with most macrofauna as stocks can be readily supplemented by influxes from other areas.

The impact sewage discharges have on ecological communities in receiving waters largely depends on the magnitude of the waste flux and factors such as the type of surface water. As species and combinations of species that are less susceptible to pollution (including replacement communities) tend to dominate in such circumstances, the diversity of life forms in receiving waters decreases accordingly.

5.2.10. The effect of overflow frequency
Comparison of the quality of receiving waters with the basic physico-chemical and bacteriological standards has revealed that:
- the quality of receiving waters into which combined sewer systems discharge generally fails to comply with the minimum prescribed standards on 25 to 100 days a year (irrespective of the presence of peripheral facilities). This assumes an overflow frequency of some 5 to10 overflow events a year and an average recovery period of 5 to 10 days. Under the most unfavourable circumstances, such as sewers with an extremely high hydraulic loading and small stagnant receiving waters, the prescribed quality standards may be contravened on well over 100 days a year. In a number of cases, the permitted levels of contaminants such as faecal coliforms were found to be exceeded by a wide margin.
- although, in general, the presence of peripheral facilities was not found to have a significant effect on the number of days on which water quality standards were contravened, the use of artificial marsh systems was shown to have considerable potential for reducing such periods.
- the quality of receiving waters into which separate sewer systems from housing estates discharge generally fails to comply with the minimum prescribed standards on 50 to 150 days a year, depending on local circumstances. This assumes an overflow frequency of some 50 overflow events a year and an average recovery period of 1 to 3 days. Where relatively new sewer systems have been installed, the number of days on which standards are not met will probably be close to

Overflow outlet along dried-up water course

the lower limit of 50 days, while with established sewer systems (faulty connections) the number is more likely to approach or even to exceed the 150 day limit. However, the degree to which prescribed limit values are likely to be exceeded following discharges from separate sewer systems gave less cause for concern than in the case of discharges from combined sewer systems.
- receiving waters into which surface run-off from industrial estates is discharged are likely to contravene the prescribed quality standards for longer periods of time and to a greater extent than receiving waters into which run-off from residential areas is discharged. Assuming that about 50 discharge events take place a year from separate sewer systems serving industrial estates and that the average recovery period is at least a few days, it is likely that the quality of receiving waters near industrial estates will fail to comply with the required standards on at least 100 to 150 days a year.
- improved separate sewer systems in residential areas have the potential to reduce the period over which water quality standards in receiving waters are contravened to less than 25 days a year (assuming some 10 to 25 overflow events a year and a recovery period of less than a day). In addition, the extent to which the prescribed limit values are exceeded is likely to be relatively low with such systems.
- the general quality of receiving waters into which effluent from improved separate sewer systems is discharged is expected to comply with basic water quality standards most of the time and is therefore also likely to be acceptable in the longer term.

It was found that comparing the quality of receiving waters with prescribed standards can, to a certain extent, mask the impact discharges from the different types of sewer system have on various receiving waters. This is illustrated by the fact that there are no significant differences between the frequencies with which basic water quality standards are contravened in the case of discharges from combined sewer systems and those from (improved) separate sewer systems. Although the number of limit values exceedances in the case of stormwater discharges from separate systems is lower than that associated with sewer overflows from combined systems, the regularity with which stormwater discharges occur is correspondingly higher. At the same time, the degree to which the limits for specific contaminants are exceeded following sewer overflows from combined systems is generally higher than is the case after stormwater discharges from separate systems.

It can therefore be concluded that simply comparing the quality of receiving waters with prescribed standards is an

Long-term effects clearly visible

inadequate basis on which to differentiate between the effects of waste water discharges from combined and separate sewer systems.

Table 5.1. - Overview of the physical, chemical and biological processes that occur in receiving waters classified according to the time required for such processes to take place

Processes	Time scale*
hydraulics (entrainment/mixing)	M-H
acute toxification	M-H
chemical oxidation	M-H
adsorption	H
sedimentatieon and resuspension	H
mass transfer (e.g. volatilisation)	H-D
rapid biochemical decomposition	D
decayof intestinal bacteria	D-W
algal growth	W-M
bio-accumulation	M
decomposition of organic micropollutants	M-Y
increase in benthic fauna	M-Y
increase in fish stocks	Y
sediment accumulation	Y-Dc

* Minutes, Hours, Days, Weeks, Months, Years and Decades.

5.3. Water quality processes

5.3.1. General

Sewage discharges affect the quality of receiving waters via various processes, which take place over different time scales. The rate of recovery of surface waters is also important in this respect. The time available for recovery processes to take effect is largely a function of the recurrence time between overflow events (for combined systems, of the order of weeks or months). Discharges from stormwater systems are a direct consequence of the precipitation levels in a given area and generally occur more frequently than sewer overflows (with typically only a matter of days or weeks in between events). The regularity with which stormwater is discharged from separate sewer systems means that the effects caused by such discharges tend to overlap. Most of the processes taking place in receiving waters can be classified into one of three groups depending on how they relate to the recurrence time between events (Table 5.1). The significance of each of the key processes is outlined below.

5.3.2. Hydraulic processes

Waste water discharged during overflow events undergoes a certain degree of mixing as it enters the receiving water. However, if the temperature and flow conditions are appropriate, it can travel appreciable distances along the surface or the bottom of the receiving water in an undiluted form. The latter phenomenon is typically associated with wide water courses in which the flow currents are weak and as such was not observed during the NWRW programme. The onset of seepage can also promote such effects. If appreciable currents in the water phase exist, a significant degree of mixing will normally take place across the full cross-section of the flow front. Since substantial quantities of stormwater can be discharged during overflow events, this can have a significant effect on the level of receiving waters, particularly in small ponds and ditches. If the excess water is prevented from flowing into surrounding surface waters or entering the groundwater system, water levels can rise by as much as a metre.

Flow velocities in the water phase are related to the change in water levels and the storage capacity of the water course in question. Depending on local circumstances, it may take several hours or even days before water levels return to normal. Factors such as the intensity and duration of storm events, and the facility for accommodating excess water in other surface waters in the area (largely a function of the shape of water courses and of the presence of water plants) are particularly important in this respect, as are the original water level and the prevailing flow conditions. In water courses where the prevailing flow rates are minimal, average residence times can be significantly reduced as a result of sewer overflows. Moreover, major discharge events can have a considerable purging action in small receiving waters that are connected to larger surface waters.

5.3.3. Sedimentation and resuspension

As stormwater is discharged from overflow outlets, it generally enters the water phase with such force that it causes the bed sediment to be churned up. Much of the coarser material that is discharged tends to sink to the bottom fairly quickly or continues to float on the surface. Although any suspended sludge discharged with the effluent sinks more slowly, it usually settles out completely within twenty-four hours. Provided that the flow conditions are not too extreme, the bulk of the solid matter that is discharged is likely to be deposited close to the overflow outlet (i.e within a few hundred metres). The inherent difference in sedimentation patterns between coarse and fine materials results in the composition of the sediment varying as a function of distance from the overflow outlet.

The fact that much of the sediment in the direct vicinity of discharge points (within some tens of metres) is regularly churned up tends to make the sediment layers in this area thinner. Outside the initial mixing zone, sedimentation processes are generally more dominant than resuspension and entrainment. Nevertheless, the resuspension of bed sediment in waters with normal flow velocities of a few decimetres per second) can still contribute to the exchange of adsorbed and dissolved substances and bacteria (release mechanisms). The exchange mechanisms between soil and water are also enhanced by diffusion, dispersion and seepage.
Only higher flow velocities (> 0.5 m/s), resuspension and entrainment mechanisms can become more prominent than sedimentation processes. Although examples of this behaviour were not observed during the NWRW programme, it is known that sewage discharges have little effect under such conditions.
If major discharge events take place in receiving waters with appreciable quantities of very fine suspended or colloidal matter, much of the suspended material can be displaced.

Monitoring equipment

5.3.4. Rapid biochemical decomposition

The biochemical oxygen demand and the Total Kjeldahl Nitrogen (TKN) concentration in the water phase are both likely to rise substantially during sewage discharges. Whilst the impairment of water quality is generally attributed to the presence of contaminants in the effluent, disturbing the bed sediment is also likely to be a contributory factor, as this will increase the amount of degradable matter in the water phase.

In the period immediately after discharge events, much of the sediment which has been disturbed will be redeposited, including any degradable matter present. As a consequence, the biochemical oxygen demand will fall rapidly and should have returned to normal within twenty-four hours. On the other hand, the TKN decomposition process (ammonification, nitrification), which is initiated in the sewer system, may take five to ten days to complete, as could the decomposition of organic matter.

Biochemical degradation processes also take place in the sludge which settles at the bottom of receiving waters. Anaerobic bacteria are responsible for the decomposition processes in the deeper layers of sediment, while aerobic bacteria perform the same task down to a depth of a few millimetres from the surface of the sludge layer. Degradation products, such as ammonium, released by the action of anaerobic bacteria can undergo subsequent oxidation in the upper layer of sediment.

Although the biochemical oxygen demand from the sediment remains virtually constant, the oxygen demand from the water phase can increase significantly in the period after a discharge has taken place. Under certain circumstances, this can cause a substantial drop in the concentration of dissolved oxygen, which, in extreme cases, can lead to anoxic conditions developing. Usually, oxygen levels begin to recover in a matter of days and concentrations should have returned to normal within five to ten days. The main processes which contribute to the oxygenation of the water phase are the photosynthesis of algae and macrophytes and the diffusion of atmospheric oxygen into surface waters. The latter process is promoted by turbulence in the water phase and the former by sunlight.

In systems in which a significant proportion of the water is replenished as a result of seepage, the vertical distribution of dissolved oxygen is predominantly determined by the influx of water containing low levels of oxygen.

Fast flowing waters are generally less affected by low dissolved oxygen concentrations than stagnant waters, as the reaeration processes in fast flowing waters are more effective and the replenishment stocks of clean water are normally higher.

5.3.5. Primary production

The decomposition of organic substances generally leads to the release of nutrients, albeit that the rate of release is slower in bed sediment where anaerobic conditions prevail than where ample supplies of oxygen are present. Ammonium ions that are produced in anaerobic sediment are normally oxidised into nitrite and nitrate after diffusion into the aerobic layer. The presence of such nutrients provides an extra stimulus to the growth of algae and water plants. After a number of weeks, a mature algal growth can develop if circumstances permit. Evidence of nutrient limitation is rarely seen in surface waters in the Netherlands that receive stormwater discharges.

5.3.6. Adsorption, volatilisation and decomposition of micropollutants

During the NWRW programme, the volatilisation and decomposition of micropollutants were only investigated as part of a literature study (project 12.1). However, practical research into adsorption and transport processes with heavy metals was performed in the context of the Theme 10 projects.

The rapid rate of sedimentation of coarse and suspended matter discharged from sewers effectively prevents any large-scale desorption of heavy metals and organic micropollutants. The bulk of these contaminants tends to settle out fairly quickly, with the exception of substances that are not readily adsorbed.

After a number of days or weeks, the degree of diffusion and dispersion is likely to decline, hence limiting the rate of exchange between the soil and water phases. Similar arguments apply to resuspension and sedimentation processes in fast flowing water. In stagnant and semi-stagnant waters, a concentration balance will eventually develop between the water and soil phases, whereas in flowing waters, the concentration gradients will also be affected by dilution caused by the influx of cleaner water. This can result in the release of micropollutants gradually declining, although heavy metals and organic compounds that are not readily degradable may continue to be released from sedimentary deposits for several years.

Many of the organic micropollutants that are contained in sewage are volatile compounds. Examples of extremely volatile micropollutants are C_1-C_3 halogenated hydrocarbons such as trichloromethane, tetrachloromethane and dichlorobenzene. In comparison, hexachlorobenzene tends to evaporate more slowly and benzo(a)pyrene is even less volatile. It is important to note that volatilisation rates are also influenced by flow velocities and wind speeds (replenishment of surface layers).

In addition, a certain amount of organic micropollutants will decompose in the water phase, albeit at various rates and via different routes. Fluoranthene, for instance is broken down much faster than hexachlorobenzene, which may take several years to disappear completely from the water phase. The rate at which organic micropollutants are removed from the water phase can also be affected by replenishment from the bed sediment. This is particularly important in situations where seepage occurs.

5.3.7. Decay of bacteria and viruses

Intestinal bacteria and the associated viruses that are discharged into surface waters from sewers tend to disappear from the water phase within two to five days, due to

Hidden effects?

Covering of pond weed

the action of sunlight and as a result of the influx of clean water. Some 10% of such bacteria can become encapsulated in suspended matter and, depending on flow conditions, become deposited on the bed sediment as the suspended matter settles out.

In contrast, high numbers of faecal coliforms are still likely to be found in the upper layer of bed sediment in the vicinity of sewer outlets from combined sewer systems some weeks after an the event. Although increased concentrations of faecal coliforms are also to be found at some distance from discharge points, these will generally be below the levels recorded near the outlets. As coliforms tend to survive longer in sediment than in water, they represent a persistent threat to the quality of surface waters because of the risk of sludge being churned up.

Receiving waters in which a vigorous exchange takes place between the water and soil phases (e.g. as a result of seepage or entrainment of sludge) can be subject to bacteriological pollution for many weeks. If, in addition, the currents in such waters are limited, high concentrations of bacteria and viruses may become a permanent feature of these water courses.

5.3.8. Development of biological communities

Microphytes and microfauna
When the volume of stormwater discharged from overflow outlets is relatively large compared with that of the receiving water in question or when extremely high flow rates occur, a significant proportion of the phytoplankton and zooplankton communities present in such waters may be removed. In the case of more modest discharge events, it is still possible for a considerable amount of disruption to be caused at a local level. In certain types of surface water, major sewer overflows cause much of the extremely fine suspended or colloidal matter to be removed. As the stormwater that enters receiving waters is likely to contain a fresh supply of nutrients, algal growth will be stimulated. Such algae are likely to become visible within a week during sunny weather. Fast growing algae that only survive for short periods of time tend to dominate in such conditions.

The development of a distinct algal growth can mark the onset of a succession of phytoplankton and zooplankton species that can continue for several months. This succession process is likely to proceed undisturbed until the next large discharge event occurs.

In practice, the scale of such disruptions is not usually sufficient to destroy plankton communities completely, but equally well, full recovery is also unlikely due to the regularity with which discharge events occur. As a result, the diversity of species in receiving waters rarely progresses beyond the level of permanently disturbed communities. In fast flowing water, the effects are generally less severe than in semi-stagnant water.

Macrofauna and macrophytes
A significant proportion of aquatic and benthic macrofauna present in receiving waters may be destroyed due to the strong currents that can occur during sewer overflows. In addition, increased mortality rates may be observed as a result of reductions in the concentration of dissolved oxygen that generally follow such discharges. Consequently, the composition of ecological communities may change dramatically. At more sheltered locations such as in the vicinity of banks, the conditions may be less hostile such that various species can survive.

The development or arrival of new macrofauna generally occurs some weeks after a discharge event has taken place. In stagnant waters, this is usually the result of inoculation or recolonisation from more sheltered zones, whereas in flowing waters, new organisms are more likely to arrive from areas upstream of a discharge point. Any recovery of communities of macrofauna that has taken place is likely to be disturbed by subsequent discharge events. Different species tend to dominate after discharge events, with permanently disturbed communities that can resist disruptions and the associated background pollution levels being more pronounced where sewer overflows are a regular occurrence. The numbers of individuals of the species found in such waters generally diminish downstream from discharge points, particularly in the vicinity of banks.

In contrast, discharge events only tend to affect the composition of macrophyte communities in the longer term. Plants with relatively few roots are, for instance, normally found in the vicinity of discharge points. Some tens of metres away from these outlets, nutrient-loving species are likely to dominate, including nitrogen-loving plants such as red mace and starwort.

Careful selection of the type of vegetation in surface waters, combined with regular maintenance activities and the removal of coarse waste material can considerably enhance the aesthetic qualities of stormwater receiving waters.

5.4. Analysis of factors affecting surface water quality

5.4.1. General
The main factors that affect the quality of surface waters that are subject to sewer overflows are:

- the type of sewer system from which such discharges originate. Of particular importance in this respect is the difference between combined and separate sewer systems and the characterisitics of the sewer district in question;
- the type of receiving water, with specific reference to its size and the level of prevailing flow velocities.

For the purpose of discussing the impact of these factors, reliance is placed on the findings of the NWRW programme to simplify some of the complex phenomena involved.

The first simplification that is required concerns the intensity, duration and distribution of the various effects. In most cases, these characteristics can be assumed to be interrelated.

For instance, on occasions when the intensity of effects is above average, it is highly likely that such effects will persist for longer periods of time than would normally be expected and that such effects will impinge upon a far greater area of the surface water than would otherwise be the case. It is therefore assumed that the intensity, duration and spatial distribution of effects will either be equally large or equally small.

A further simplification which is of use in this context concerns the fact that individual effects are often interrelated. Relatively serious, visual pollution, for example, generally coincides with higher than average concentrations of micropollutants, disturbance of the oxygen balance and impairment of hygiene levels and aquatic communities.

5.4.2. The influence of sewer type

In Sections 5.4.2.1 to 5.4.2.3, attention is focused on how the quality of receiving waters is affected by different types of sewer system in residential areas. This is followed by a comparison of the quality of stormwater discharged from separate sewer systems serving industrial estates and that discharged from similar systems in residential areas. In Section 5.4.2.5, other relevant aspects are discussed which are not connected to specific types of sewer system.

It should be noted that as significant variations were found in the waste fluxes discharged from combined sewer systems (see Table 4.1), not every system will conform to the general conclusions outlined below.

Table 5.2. - Overview of the impact of waste emissions from sewer systems on the quality of receiving waters

type of sewer system	type of receiving water			
	size	flow conditions		
		stagnant	semi-stagnant/ drainage	flowing
combined	small	large	large	limited/large*
	medium	mainly large	mainly average	average
	large	limited/large	mainly average	average
combined with CSO control structure	small	-	large	limited
	medium	-	limited/fairly large	-
	large	fairly large	limited	-
separate, residential	small	-	-	-
	medium	-	limited**	-
	large	limited/average	limited	-
separate, industrial	small	-	-	-
	medium	-	fairly large	-***
	large	fairly limited	-	-

Legend:
size of receiving water:
classes defined in Section 5.4.3.
categories for the intensity, duration and distribution of effects:
limited - fairly limited - average - fairly large - large
variation:
limited/large : all categories from limited to large
mainly : predominantly; e.g. mainly large means
no classification : significant spread, not included
- : not investigated
* : large effects in flowing waters refer predominantly to visual pollution
** : also apparent with improved separate systems; no data for improved separate systems in combination with other types of receiving water
*** : limited effects for improved separate systems; no data for improved separate systems in combination with other types of receiving water

5.4.2.1 Combined versus separate sewer systems

It was apparent from work carried out in the NWRW programme that stormwater discharges from separate sewer systems in residential areas have a less serious impact on the physical, chemical and biological quality of receiving waters than sewer overflows from combined systems. The levels of pollutants found in surface waters after stormwater discharges will, on average, be lower than those observed following combined sewer overflows. As a result, the effects of stormwater discharges will generally be of a shorter duration. Nevertheless, the regularity with which stormwater discharges take place usually means that such effects occur more often. Taken together, these factors help to clarify why simply comparing the annual waste loads from separate sewer systems is not an adequate criterion on which to assess the severity of the pollution entering receiving waters, as is the case with combined sewer systems.

In spite of the fact that the impact of discharges from separate sewer systems is generally less severe than from combined systems, appreciable levels of heavy metals, organic micropollutants, bacteriological contamination, oil and other visible pollutants can still be found in the vicinity of stormwater outlets. The presence of faulty connections in a sewer system can considerably increase the pollution content in the stormwater that is discharged. This was clearly demonstrated in the NWRW programme where five of the seven locations were found to suffer from such problems,hence explaining the regularity with which toilet paper and sanitary towels were found near stormwater outlets. The amounts of these materials were, however, significantly smaller than the quantities of sanitary litter found in the vicinity of overflow outlets from combined sewer systems. In most cases, residents that live near stormwater outlets from separate sewer systems are not seriously inconvenienced by the presence of such discharge points.
The short-term physico-chemical effects of stormwater discharges from separate sewer systems in residential areas are generally far less severe than the comparable effects associated with sewer overflows from combined systems. While dissolved oxygen concentrations may fall in receiving waters into which effluent from the latter type of sewer system is discharged and anoxic conditions even develop, this is unlikely to be the case in comparable surface waters into which stormwater from separate sewer systems is discharged. In addition, any increases in BOD, ammonium and total phosphate levels are likely to be lower in receiving waters into which stormwater outlets from sewer systems serving residential areas discharge.

Nevertheless, the run-off from streets and pavements that is diverted to the storm sewers of separate systems can still contain appreciable quantities of bacteriological pollutants. Faulty connections can also add to the pollution load. Under certain circumstances, this can lead to the level of pollution in receiving waters being increased by a factor of 10 to 100, although this is still less than the concentrations likely to be found in surface waters into which overflows from combined sewer systems discharge. In contrast, the bed sediment in the vicinity of stormwater outlets is only likely to show a slight increase in the number of faecal coliforms present.

Stormwater discharges from separate sewer systems in residential areas tend to contain smaller amounts of settlable and floating matter than sewer overflows from combined sewer systems. Consequently, any reductions in transparency or increases in the levels of suspended matter and discolouration of receiving waters should be less marked than in the case of sewer overflows from combined systems.

The proportion of coarse material in the sludge discharged from stormwater outlets is normally less than that found in comparable effluent from combined sewer systems. As a result of this, the sludge layers found in the vicinity of stormwater outlets tend to be thinner and have a more uniform composition than the sludge deposited near sewer overflows.

Regardless of these differences, the levels of micropollutants found in the sediment close to stormwater outlets are usually of the same order of magnitude as those found in the bed sediment in the vicinity of combined sewer overflows. This concerns particularly contaminants such as zinc, lead, cadmium, mercury, copper, polycyclic aromatic hydrocarbons, polychlorobiphenyls and organochlorine pesticides.

In general, the deleterious effects on ecological communities in surface waters into which separate sewer systems in residential areas discharge are less pronounced than those associated with comparable waters into which outlets from combined systems discharge. While discharges from combined sewer systems into small heavily polluted surface waters were found to cause significant numbers of fish to die, such phenomena were not observed in the vicinity of stormwater outlets from separate sewer systems in residential areas.

5.4.2.2. Combined sewer systems with and without overflow control structures

During the NWRW programme, a considerable body of evidence was collected to support the view that CSO control structures can help to reduce the amounts of visible pollution present in receiving waters. It was shown, for instance, that artificial marsh systems were more effective in this respect than other facilities (Theme 9).

Although constructing overflow control structures at combined sewer systems is likely to improve the quality of receiving waters, it is expected that the full benefit of such provisions will be significant only in large flowing waters. In spite of this, a certain degree of improvement was observed in a number of smaller or stagnant waters, particularly with regard to visual pollution. However, no evidence was found to suggest that CSO control structures would significantly lessen the impact of sewage discharges on biological communities, except when artificial marsh systems were employed.

It was concluded that while in the cases investigated, the introduction of CSO control structures had reduced pollution levels to some degree, this had not resulted in acceptable water quality standards being achieved. This was attributed to the fact that although CSO control struc-

Sewer overflow discharging into a large receiving water

tures tend to retain large amounts of settlable matter, appreciable quantities of dissolved materials are allowed to pass through such structures. The results of the Theme 8 studies showed that the effective reduction in pollution due to CSO control structures was less in the case of major discharge events than for minor events. As major discharges tend to have the most pronounced effect on biological communities, it is reasonable to assume that the impact of control structures on the condition of biological communities will be somewhat limited.

5.4.2.3 Separate versus improved separate sewer systems

In general, stormwater discharges from improved separate sewers systems in residential areas only have very minor effects on surface water quality. The impact of such discharges is primarily confined to the area around stormwater outlets and is usually short lived. Most of the deleterious effects associated with such discharges are negligible in comparison with those caused by other sewer systems. This applies particularly to visual effects, physico-chemical parameters (the concentration of suspended matter, transparency, biochemical oxygen demand, the concentrations of oxygen, ammonium, and total phosphate, pH levels, the appearance of the bed sediment, and the concentrations of heavy metals and organic micropollutants in the sediment), and bacteriological and hydro-biological quality. It should, however, be noted that as the systems monitored in the NWRW programme have only recently been installed, it is not possible to make any definitive statements about whether the sediment and hydro-biology of surface waters will be affected in the longer term.

Industrial estate

5.4.2.4 Separate sewer systems at industrial sites versus separate systems in residential areas.

Discharges from separate sewer systems at industrial sites tend to cause more serious pollution than the surface runoff collected in residential areas. The stormwater discharged from industrial sites often contains appreciable quantities of suspended matter (turbidity, discolouration), heavy metals, organic micropollutants or oil. It is not uncommon for such discharges to be accompanied by a distinct smell of oil or petrol. Moreover, receiving waters in industrial areas tend to have higher levels of ammonium, total phosphate and bacteria, especially immediately after such discharges have taken place. Oxygen deficiencies can also occur although totally anoxic conditions are unlikely to develop. Such extreme conditions are even less likely occur in receiving waters in residential areas.

The most polluted bed sediments found in the NWRW programme were in receiving waters into which stormwater from separate sewer systems at industrial sites was discharged. Particularly high levels of heavy metals were found at these locations which greatly exceeded the prescribed limit values.

Furthermore, it was concluded that discharges from separate sewer systems serving industrial estates may affect organisms in receiving waters to an even greater extent than those from combined sewer systems (see Section 5.2.9).

5.4.2.5 The impact of other factors connected with sewer systems

All the locations monitored during the NWRW programme concerned surface waters where discharges of sewage or stormwater took place via single outlets. In practice, however, it is not uncommon to have several discharge points positioned at regular intervals along a given water course. One of the disadvantages of multiple discharge points is that the water quality can be affected over much larger areas and that dispersal patterns can be more complex.

It was found that the water quality was generally poor in surface waters into which sewage from combined sewer systems was regularly discharged (> 10-15/year). In surface waters where the actual overflow frequencies were lower, the water quality was found to be far superior.

5.4.3. Influence of the type of surface water

The effects discharges from sewer systems have on surface waters can be classified according to the size of the water course and the prevailing flow pattern. The degree of flushing can also play an important role. These factors are discussed below.

5.4.3.1. Size of the water system

The receiving waters studied in the NWRW programme have been divided into three groups on the basis of size (Theme 9, see also Table 5.2):

- small waters : widths up to 3 m, depths up to 0.5 m;

- medium-sized waters : widths of 2 to 10 m,
  depths of 0.3 m up to 1.5 m;
- large waters : widths larger than 10 m,
  depths more than 1 m.

Reference to the above categories shows that there is a certain degree of overlap between small and medium-sized surface waters.

In small and medium-sized, semi-stagnant waters, sewage discharges can have a relatively serious impact on water quality, even after minor overflow events. The most pronounced effects were observed in isolated receiving waters such as blind ditches, where the contents of the surface water were completely replaced by the relatively large volumes of sewage discharged. Major sewer overflows were frequently found to increase fish mortality in such cases.
The effects of waste water discharges on medium-sized and large waters are primarily transient and of a local nature, and are predominantly a function of the size of the receiving water, the prevailing discharge pattern, and the ratio of the volume discharged to that of the surface water in question. Water quality is likely to be impaired when average waste fluxes of more than 50 to 70 kg BOD per year are discharged. Such pollution loads are not uncommon in large waters as it is general practice to take maximum profit of potential dilution factors when designing sewer systems.

In deep receiving waters (>0.8 m), sewage discharges only become fully mixed with the receiving water at some distance from overflow outlets. The degree of mixing is also dependent on the position of the discharge pipe, the force of the overflow event, wind and wave motion, the prevailing current and any temperature differences. Under certain circumstances, waste water discharges may be transported along the surface of the water as a continuous layer and can be dispersed much further away than would have been the case if mixing had taken place in the immediate vicinity of the discharge point.

5.4.3.2. Average flow rates

During the NWRW programme, the most serious impairment of water quality was observed in stagnant or virtually stagnant waters, particularly in long, narrow stretches of water, such as at the end of blind ditches. Under these circumstances, the oxygen balance and nutrient concentrations can be distorted for three to seven days. The effect of such discharges may even last several weeks when the volume of effluent discharged is large compared with that of the receiving water. This is often the case with small ditches that have run dry or have relatively low water levels. Such effects are, however, not associated with discharges from improved separate sewer systems as their impact on water quality is only slight, highly localised and of a transient nature.

It should be noted in this context, that certain types of quality impairment may not have been registered in flowing water during the NWRW programme due to the monitoring methods used for the Theme 9 studies. Of particular relevance in this respect are the effects associated with plug flow, which were only observed occasionally in flowing water. Measurements conducted at the Bodegraven location (Theme 10) showed that the concentration of suspended matter and most of the dissolved substances were only affected for up to 24 hours. In spite of this, the impact of such transient changes on ecological communities can persist for several months or years and could be serious, particularly after major discharge events. Serious impairments of this type were actually observed on a number of occasions during the NWRW programme (Themes 9 and 10).

Eutrophic receiving water

The impact of polluted water that was dispersed well outside the immediate area of the monitoring locations was, of course, not studied in the NWRW programme. Although contaminants become more diluted as they are dispersed, it is nevertheless possible that above-average concentrations of pollutants will persist for several weeks in relatively slow moving water. The gradual accumulation of harmful substances in organisms is one of the potential risks associated with sewage discharges.

The immediate effects that sewer overflows have on small and medium-sized receiving waters may be masked by the presence of layers of pond weed, which tend to disturb the oxygen balance in such waters and prevent any changes from being noticed. The persistently poor quality of such waters becomes even more apparent when bad maintenance practices are employed. Other factors such as agricultural operations may also play a significant role in this respect, as is evidenced by the rather poor state of a number of the reference ditches monitored in rural areas. The condition of the bed sediment and aquatic communities in such receiving waters often differs widely from the standards achieved in other reference waters, which also points to a long-term decline in quality.

In receiving waters that are not regularly flushed, most of the short and medium-term effects are comparable to those observed in (semi-)stagnant surface waters of a similar size. Over longer periods of time, regular flushing may lessen the impact waste discharges have on aquatic communities and improve the quality of the bed sediment.

If surface waters are flushed during or soon after sewer overflows, the degree of impairment may be reduced and the deleterious effects may be less persistent. The success of such measures is largely a function of the flow velocities that are achieved. Under the most favourable conditions, the pollutants that are present will be dispersed and diluted to relatively harmless concentrations by the action of flowing water.
When there are "perceivable" currents in surface waters (> 1 cm/s), the effects of discharges are generally noticeable over larger distances than when there is no flow. Nevertheless, discharges from improved separate sewers systems are normally relatively benign in flowing water. The concentrations of pollutants tend to be lower in flowing water than in stagnant water, due to dispersal effects. Dispersal is particularly noticeable in the case of pollutants that are not readily degradable, such as heavy metals in bed sediment and visible pollution on banks. The fact that pollution can sometimes be observed over distances of several hundred metres can result in unsightly situations developing, which may persist for relatively long periods of time.

In flowing waters, most of the coarse material and suspended sludge particles tend to settle out in secluded corners in front of culverts and weirs, at points where the flow profile widens and on the inside of bends in the water course.

In waters with little or no flow, settlable material from sewer systems is generally deposited near discharge outlets. The sludge layers at these points, which may be as thick as several decimetres or even a metre, are often contaminated with non degradable or not readily degradable substances such as heavy metals, oil and organic micropollutants.

Phytoplankton can be a useful agent to monitor the effects of overflows in medium to large-sized waters, while the condition of zooplankton and macrofauna are suitable criteria to assess the quality of smaller stagnant waters. In flowing waters, sessile diatoms can be used to determine the impact of overflows over substantial periods of time.

5.4.3.3. Hydrological connections
Surface waters that are either partially or fully isolated (such as blind ditches) tend to be more seriously affected by sewage discharges than larger stagnant waters or waters that are regularly purged or where there are significant currents. The levels of suspended matter, dissolved oxygen, nutrients, heavy metals, organic micropollutants and bacteriological contaminants are generally affected to a greater degree in isolated waters and may persist for three to seven days.

Gas formation near an overflow outlet

In hydraulically isolated waters, major disruptions to ecological communities can have serious long-term implications. Moreover, any temporary lack of oxygen can cause substantial amounts of fish to die. Such waters are only likely to recover at a slow rate as migration from adjoining waters is normally limited. In surface waters that are totally isolated, fish are often absent.

5.4.3.4. Water plants
Water plants can help to improve the quality of receiving waters in urban areas, particularly if annual maintenance work is carried out at such sites. However, plants in the immediate vicinity of overflow outlets, such as pond weed, may increase the degree of accumulation that takes place.

5.5.5. Predicative tools
During the NWRW programme, impact assessments were carried out at the Loenen and Bodegraven locations (Theme 10). The results of these studies have helped to increase understanding of the processes by which sewage discharges affect water quality. Of particular importance in this respect are the balances that have been derived for settlable material, oxygen-consuming substances, phosphorous and nitrogenous nutrients and specific heavy metals at the Loenen location. These findings have enabled some of the key processes to be described in a semi-quantitative manner.

Moreover, mathematical models have been developed to describe the behaviour of settlable substances, dissolved oxygen, faecal bacteria and various heavy metals. These models can be applied relatively simply to receiving waters having the same hydraulic and chemical characterisitics and (background) chemistry as those of the discharge pond at Loenen. Applying such models to other waters requires a good representation of the hydraulics involved and the mechanisms governing the mixing of waste water in the water course in question. This will allow reasonably accurate predictions to be made about the benefits to be derived from reducing waste fluxes from sewer systems in the context of the substances specified above.

In addition, the individual site reports compiled at the various monitoring locations as part of the Theme 9 studies could be used to facilitate understanding of the effects that will develop in given situations. This aspect is discussed in more detail in Section 6.4.2.

6. Implementation of the results

6.1. General

The main findings of the NWRW programme (Chapters 4 and 5) can be applied in the following ways:
- via direct recommendations on specific subjects;
- as the basis for a more general approach to the problem of sewer overflows.

A set of recommendations has been prepared, which are not only applicable to new and existing sewer systems, but also to receiving waters. These recommendations, which are discussed in Sections 6.2 and 6.3, have been derived on the basis of data collected at the sewer systems and receiving waters investigated as part of Themes 5, 6, 8 and 10. When applying these recommendations to other types of sewer system, corrections must be made to take account of differences in the characteristic features of the locations or sewer systems in question.

A rationale for developing a more general approach to the problems of sewer overflows is discussed in Section 6.4.

Deposits on the inside of a sewer

6.2. Specific measures for sewer systems

6.2.1 Combined sewer systems

The following measures may be taken to reduce waste fluxes from combined sewer systems and to minimise the impact such discharges have on the quality of surface waters:
- avoid positioning overflow outlets at the ends of ditches or along small stagnant waters. It was shown (Theme 9) that placing such outlets at these positions can result in serious contamination of the water phase, bed sediment and banks of surface waters. This can be accompanied by oxygen depletion and pervasive foul smells. In addition, faeces and other contaminants may be deposited among water plants, in the bed sediment and on the banks.

- pay particular attention to the hydraulic design of sewer systems, especially with regard to design details (see Section 4.5.2.5).

- install or use a system layout based on branched rather than meshed sewers.

- maintain sewers in a satisfactory condition. Corroded, subsided or broken sewer pipes can significantly increase the amount of sludge deposited in sewers.

- maintain sewage pumps to an acceptable standard. Malfunctioning of pumps often results in sewer over-

- flows. Such discharges not only affect surface water quality, but the ensuing drop in flow velocities can also cause additional sludge deposition in sewers.

- ensure that the cross-sections of sewer pipes are designed such that there is a sufficiently large depth of flow, even at relatively low discharge rates. This will enable the coarser constituents in waste water streams to be properly entrained.

- enlarge the storage capacity of sewer systems. Larger storage capacities can considerably reduce overflow frequencies and discharge volumes. The best way of increasing the storage capacity of sewer systems is to add stormwater sedimentation facilities.

- separate the transport and storage functions of sewer systems i.e. design sewer pipes solely on the basis of the required hydraulic capacity. Rather than increasing sewer diameters, preference should be given to incorporating stormwater sedimentation tanks to provide any additional storage capacity that is needed to meet prescribed theoretical overflow frequencies.

water discharged will decline. Nevertheless, if the run-off is polluted to such an extent that it does not comply with the prescribed water quality standards, it should not be discharged directly into surface waters. For assessing whether surface run-off should be disconnected or not, reference is made to Table 6.1.

The following methods can either be used separately or in combination (Theme 7) to disconnect surface run-off i.e. by routing the discharge via:

- storm sewers;
- infiltration through porous or unpaved surfaces;
- seepage from underground reservoirs;
- drainage, including the option of temporary storage in the subsoil;
- facilities with a limited discharge capacity, hence delaying the discharge rate;
- either temporary above-ground or underground storage facilities.

It should be noted that the latter two methods only delay the discharge of surface run-off and do not represent disconnection methods in the proper sense. However, as the overall effects are broadly similar, they have been included in the above list. Local circumstances largely determine which technique is to be preferred.

Table 6.1. - Characteristics of impervious surfaces from which it may be appropriate to disconnect surface run-off

disconnection	yes	perhaps	not
type of surface	quiet clinker roads, tiled roofs in residential areas	car parks flat roofs	busy roads, bus stops, passages, market sites
problem substance	suspended matter, PAH, organochlorine pesticides	suspended matter, lead, BOD, BTEX, PAH	suspended matter, lead, BOD, BTEX, zinc, EOCl, PAH, chlorophenols
type of business	paper industry	canning industry, fat processing industry, galvanising industry, transport and storage companies handling oil products	zinc plating industry, paint industry, other industries using organic micropollutants
problem substance		suspended matter BOD, nickel	PAH, zinc, cadmium organochlorine pesticides, chlorophenols

PAH = polycyclic aromatic hydrocarbons
BTEX = benzene, toluene, ethylbenzene and xylene
PCB = polychlorobiphenyls
EOCl = extractable organic chlorine

- install swirl concentrators or high-sided weir chambers. These facilities should only be considered when extra storage capacity is not required.

- disconnect surface run-off (see also Section 6.2.2). By decoupling surface run-off, waste fluxes from combined sewer systems can be reduced, as both the frequency with which overflow events occur and the volumes of

6.2.2. Separate sewer systems

The waste flux from separate sewer systems is largely determined by the type of run-off entering the sewers, the number of faulty connections and the quality of the groundwater.

It is not generally recommended to discharge stormwater originating from industrial estates or areas with high traffic volumes directly into surface waters. This is because of the extremely high levels of pollution normally found in such run-off and the lack of control that can be exercised during calamities (e.g. accidents involving tankers, water used to extinguish fires etc.). It is therefore recommended to convert sewer systems serving locations with highly polluted run-off into improved separate sewer systems.

Separate sewer systems are only suitable for use in residential areas with little traffic and reliable groundwater quality. However, unless care is exercised, the presence of

Back to elliptical cross sections

faulty connections can negate many of the advantages of such systems. During the Theme 9 studies in the NWRW programme, faulty connections were observed at five of the seven locations. Ensuring that faulty connections are eliminated can therefore make a major contribution to reducing waste fluxes from storm sewers.
To promote strict adherence to water quality standards, preference should be given to improved separate sewer systems as these systems were shown to have the best record of compliance with prescribed minimum quality standards.
The installation of such systems is seen as offering the most acceptable long-term solution.

6.3. Measures applicable to surface waters

During the NWRW programme, a certain amount of experience was gained with flushing and aerating receiving waters. Of these techniques, only flushing was found to be effective. The best results were achieved if flushing operations were applied directly after sewer overflows from combined systems. Notwithstanding this, a number of other recommendations can be made about measures to improve surface water quality on theoretical grounds.

- A rule of thumb has been developed to determine how large a surface water should be to accommodate sewer overflows from combined sewer systems. This refers specifically to (semi-)stagnant surface waters. For oxygen concentrations in receiving waters not to drop below 1 mg/l more than once every five years, the following volumes of (semi-)stagnant surface water should be available for every hectare of surface from which run-off is collected and transported via combined sewer systems:
  - 600 m^3 for an average water depth of 1.0 m;
  - 800 m^3 for an average water depth of 1.5 m.

  In addition, special consideration should be given to optimising the degree of mixing in the water phase. It should be noted, however, that this rule of thumb could neither be substantiated nor refuted on the basis of the data collected in the Theme 9 studies.

- For (semi-)stagnant waters into which combined sewer systems are discharged via CSO control structures the same volume ratios apply, provided that these structures do not reduce the quantities of dissolved, biochemically degradable material discharged.

- The construction of ponds to serve as buffers between discharge points and receiving waters is only to be recommended if the quality of such receiving waters has to comply with stricter standards than the basic requirements that have been laid down. Under such circumstances, ponds should be dimensioned on the basis of volume ratios for stagnant waters.

- To promote mixing between waste water discharges and surface waters at discharge points, receiving waters should meet certain requirements:
  * small stagnant surface waters such as blind ditches that are connected with other water courses should not be used as receiving waters for waste water discharges (with the possible exception of discharges from improved separate systems). This should limit the problems encountered when small receiving waters are replenished by relatively large volumes of sewage;
  * recessed corners should be avoided where possible;
  * discharging sewage below the waterline can promote mixing and can also reduce visible pollution.

- Since the churning up of bed sediment should be avoided, it is not desirable to have full mixing over the entire

Domestic sewer connection with elliptical profile

- water depth, or to allow sediment to affect water quality. In both respects, a minimum depth of 1 metre is recommended.

- Extreme levels of pollution can be combated by regular dredging. In view of the costs involved, it is often worthwhile considering using CSO control structures as an alternative measure. After waste fluxes have been reduced, water and sediment quality can be improved more rapidly by a one-off dredging campaign. This is particularly suitable in (semi-)stagnant waters.

- The aeration of receiving waters is particularly effective in (semi-)stagnant waters, but requires the installation of equipment with sufficient aeration capacity. Experience has shown that positioning fountains near overflow outlets does not provide adequate aeration levels. An additional problem is the fact that aeration is more effective in shallow waters but that this increases the risk of churning up polluted bed sediment.

- Avoid positioning plants in receiving waters in such a manner that sewage is prevented from being discharged, unless such measures are likely to promote the degree of mixing in the water phase ("maze effect") or it is desired to reduce prevailing flow rates (artificial marsh system). Vegetation in the vicinity of banks normally has a favourable impact on water quality.

- Visible pollution can be combated by constructing steep banks or reducing the amount by which water levels fluctuate. However, it should be recognised that steep banks cannot be combined with vegetation. Variations in water levels can be limited by either increasing the size of the receiving water in question or reducing the volume of water discharged.

6.4. Generalised approach

6.4.1. Introduction

In order to select the most suitable type of sewer system for given conditions and to set design criteria that take account of the impact sewage discharges have on receiving waters, it is necessary to develop a quantitative framework on which such decisions can be based, utilising the findings of the NWRW programme. In doing so, the phenomena that have been observed in the various sewer systems and surface waters chosen for study must be extrapolated to cover the complete range of conditions found in the Netherlands. The most rigorous approach that could be followed to achieve this objective would be to relate the features of a given sewer district and the desired water quality to specific characteristics of a particular sewer system. This would allow several options to be compared and greatly facilitate the optimisation process. Although a mathematical model would have to be developed for this purpose, this could be formulated using the findings of the NWRW programme.

When the plan for the NWRW research programme was designed, special consideration was given to the need for a generalised framework to be provided for the results. As a consequence, the impact of sewer design on surface water quality was included as a central theme of the

Comparison of effects by means of site characteristics

Theme 9 studies. By investigating this relationship for some 60 monitoring sites, an overview was obtained of the practical conditions likely to influence the choice of optimum solutions. These data can be applied to the design of sewer systems on a comparative basis (see Section 6.4.2). In addition, reference is made to a number of design aids that were developed for sewer systems during the NWRW programme i.e.:

1. a decision tree that can be used to determine under what conditions it is suitable to disconnect surface run-off (see Section 6.2.1, Table 6.1 of this report);
2. a decision tree to select the most appropriate techniques for disconnecting surface run-off (see Report 7.2.1);
3. a methodology for determining average waste loads during sewer overflows and stormwater discharges, based on the sewer systems investigated in the NWRW programme (see Tables 4.5-4.8 of this report).

The findings of the NWRW programme represent a sound database that can be used to guide the development of sewer systems. This information can serve as a starting point for future initiatives as outlined in Section 6.4.3.

6.4.2. Simplified guidelines based on the results of the Theme 9 studies

By investigating the way in which waste fluxes from a large number of sewer systems affect the quality of surface waters and bed sediment (Theme 9), it has been possible to develop a qualitative assessment system that can be used to understand the problems that can arise when certain types of sewer system discharge into particular types of surface water. Comparison of data from the various receiving waters and sewer systems has enabled conclusions to be drawn about how to improve water quality in given situations.

A preliminary estimate of the probable effects of specific waste loads from a given type of sewer system can be obtained from Table 5.2 in relation to certain types of surface water. More information is given in the final report of the Theme 9 studies, especially in the volume covering the description of the locations investigated. The key characteristics of these locations have been included in Table 6.2. In evaluating candidate solutions, due account should be taken of the recommendations given in Section 6.2.

Table 6.2. - Overview of the characteristics of the sewer systems and receiving waters investigated in the NWRW generalised impact monitoring programme (Theme 9)

No.	*locatie*	*sewer system*		*surface water*			*type of water*
		annual overflow frequency	*time for system to empty (hours)*	*size*	*flow*	*drainage*	
I - Combined sewer systems				*a. - small; stagnant*			
1.	Appeltern	5-10	6-15	small	no	no	ditch
2.	Wadenoyen	5-10	6-15	small	no	no	ditch
3.	Winssen	5-10	6-15	small	no	no	ditch
4.	Driebergen/ Rosariumlaan	5-10	≦5	small	no	no	ditch
5.	Klarenbeek	≦4	>15	small	no	no	ditch
6.	Varsselder	≦4	6-15	small	no	no	ditch
				b. - small, semi-stagnant/drainage			
7.	Driebergen/ Welgelegenlaan	≦4	≦5	small	no	yes	ditch
8.	Loil	5-10	6-15	small	no	yes	ditch
9.	Montfoort/ Anne Franklaan	≦4	6-15	small	no	yes	ditch
				c. - small; flowing			
10.	Achterberg	≦4	≦5	small	little	no	ditch/brook
11.	Hall	5-10	6-15	small	little	no	brook
12.	Chaam/Geerakker	5-10	6-15	small	little	no	brook
13.	Chaam/Wolfsdonk	5-10	6-15	small	little	no	brook
14.	Chaam/Rode Beek	5-10	6-15	small	little	no	brook
15.	Doornspijk	5-10	≦5	small	little	no	brook
16.	Kootwijkerbroek	5-10	6-15	small	little	no	brook
17.	Meddo	>10	≦5	small	little	no	ditch/brook
18.	Noorbeek	>10	≦5	small	much	no	brook
19.	Broekland	5-10	>15	small	little	no	ditch/brook
				d. - medium; stagnant			
20.	Apeldoorn/ De Maten	5-10	>15	medium	no	no	moat
21.	Linschoten	5-10	6-15	medium	no	no	ditch
22.	Haarzuilens	≦4	≦5	medium	no	no	ditch
23.	's-Graveland	≦4	≦5	medium	no	no	ditch
24.	Houten Biezen	≦4	>15	medium	no	much	artificial marsh
25.	Montfoort/ Joop Westerweel	≦4	6-15	medium	no	no	moat
				e. - medium; semi-stagnant/drainage			
26.	Bodegraven	5-10	6-15	medium	little	yes	singel
27.	De Meern	5-10	6-15	medium	little	yes	ditch
28.	Nieuwegein/ Jutphaas	>10	≦5	medium	little	yes	ditch
29.	Muiden	5-10	6-15	medium	little	yes	ditch
30.	Veenendaal/ Dragonder	5-10	6-15	medium	little	yes	singel
31.	Wageningen	5-10	≦5	medium	little	yes	singel
				f. - medium; flowing			
32.	Heibloem	5-10	≦5	medium	much	yes	brook
33.	Gorssel	≦4	6-15	medium	much	yes	brook

An example of how such choices can be made on the basis of the data generated in the NWRW programme, is given below.

Question "a"
The NWRW studies have shown that it is essential to consider both water quality and the quality of bed sediment. The parameters to be taken into account concern physico-chemical, biological and visual aspects such as:
- floating waste
- pollution on banks
- settlable matter
- oxygen-consuming substances
- nutrients
- heavy metals
- organic micropollutants
- faecal bacteria and viruses
- phytoplankton populations
- macrophytes
- macrofauna

Question "b"
The following effects could be regarded as being most characteristic:

Transient effects
* oxygen depletion
* increased nutrient concentrations
* increased micropollutant concentrations
* floating waste
* replacement of phytoplankton
* unhygienic bacterial conditions in the water phase

Virtually permanent effects
* eutrophication
* oxygen uptake the bed sediment
* release of nutrients from the bed sediment
* unhygienic bacterial conditions in the water phase
* heavy metals and micropollutants in the bed sediment
* disturbance of aquatic communities leading to mortality of fish in extreme cases.

By selecting a limited number of parameters to characterise and quantify these effects, it should be possible to relate the quality of receiving waters to the occurrence of sewage discharges. Such a method should also take account of the difference between transient and permanent effects. A methodology of this type could produce the following output:

1.characteristic parameters for transient effects:
  - the minimum dissolved oxygen concentration after sewage discharges
  - the maximum ammonium concentration after sewage discharges
  - the maximum concentration of faecal coliforms after sewage discharges
2.characteristic parameters for permanent effects:
  - the average total phosphate concentration in summer
  - the concentration of zinc (or another heavy metal) in the sediment
  - the level of benzo(a)pyrene (or another polycyclic aromatic hydrocarbon) in the sediment
  - the thickness of the sludge layer at a specific distance from discharge points.

Question "c"
Visual effects and biological parameters have not been included in the above lists, as it is not possible to make quantitative predictions of such variables. The proposed approach is based on the assumption that by selecting appropriate physico-chemical monitoring criteria (see below) undesirable effects will not take place, if such criteria are satisfied.

Assessment methodology
It is intended that monitoring criteria are selected for the seven parameters specified above. Provided that special functional requirements or nature preservation conditions can be discounted, use can be made of the limit values laid down for the basic quality of surface waters and bed sediment. Nevertheless, the derivation of appropriate criteria will still be rather complicated due to the time dependence of discharge patterns, the likelihood that particular effects are registered during monitoring, and the differences between monitoring locations. Consideration also needs to be given to the fact that permanent effects could occur due to transient phenomena (such as the absence of fish following oxygen depletion or toxification in isolated waters) when setting standards for transient effects. Furthermore, no limit values have yet been formulated for the thickness of the sludge layers.

Finally, a decision will have to be made regarding which events should bemonitored to establish the onset of transient effects. Consideration could, for instance, be given to monitoring events with a recurrence time of two or five years. For virtually permanent effects, it would seem advisable to adopt the annual waste flux as an acceptance or rejection criterion.

At the end of Chapters 4 and 5, reference was made to the manner in which waste fluxes and their effects on surface water quality could be quantified. Although there is still a lack of understanding about all the factors involved, there are now thought to be sufficient grounds for believing that the findings of the NWRW programme provide an acceptable basis on which to formulate a mathematical model capable of making global quality predictions.

7. Comparison of the research findings with the objectives of the original plan

The general research plan of the NWRW programme was formulated with the aim of improving understanding about the relationship between sewer design, waste fluxes and their effects on surface water quality (question A, Section 2.1). Four specific questions were formulated in the context of the overall plan:

A1. How can design criteria be related to a particular type of receiving water and prescribed water quality standards?

A2. Under what circumstances is a given type of sewer system to be preferred (combined versus separated systems)? To what extent do faulty connections in separate sewer systems affect the quantity of pollutants discharged into surface waters?

A3. What are the risks associated with disconnecting storm sewers carrying surface run-off in combined systems so as to allow such run-off to be discharged directly into surface waters?

A4. Are the reductions in overflow frequency that can be achieved by expanding the capacity of sewer systems by, for instance, installing storage sewers justified if the amount of sludge released per discharge event is increased as a result? Can the quality of surface waters be expected to improve if after the installation of storage sewers the amount of pollutants discharged during major overflow events is not reduced?

Sound design criteria are essential

In addition, it was aimed to provide a better understanding about the relative importance of pollution from sewage discharges and that from other sources (question B, Section 2.2). In how far these questions have been answered and which issues still remain is discussed below.

7.1. System selection and design criteria for sewer systems (question A)

A general comparison of the recommendations listed in Chapter 6 with the questions outlined above shows that the solutions presented are closely related. They are based on a global understanding of what happens in sewers and surface waters, which, although supported by research findings, is still incomplete.

Question A1

The question relating to specific design criteria has not been fully answered. As yet, water balances, dynamic phenomena in sewer systems and the dispersal of pollution in receiving waters is insufficiently understood. This limits the potential for transferring the quantitative results of the NWRW programme to other situations. However, a considerable amount of data has been generated, which can serve as a basis for qualitative comparisons.

Whether sewage discharges into surface waters can be permitted should be assessed on the basis of several, composite criteria. This is required as not all surface waters can be treated in the same manner. In addition, for certain types of pollution, the annual pollution loading is used as the criterion, whereas peak loadings are used to assess other types of pollution. This represents one of the crucial findings of the NWRW research programme.

Furthermore, the NWRW investigation has indicated how important local conditions can be when assessing system design and selection, irrespective of the function of the receiving water in question. Guidelines or design criteria will therefore have to take account of local circumstances. Some important points of relevance to the decision-making process that have come to light as a result of the NWRW programme are outlined in Chapter 6.

Question A2

A reasonable amount of insight has been provided into the effects the various sewer systems have on water quality. A number of specific proposals to improve existing systems are given in Chapter 6. No clear preference has been expressed as to the merits of combined or separate systems. Specific requirements must be adapted to local conditions, so as to make maximum use of all positive points, whilst avoiding potential problems. Improved separate sewer systems which combine the advantages of both types of system are therefore extremely attractive, although individual cases should always be assessed on their merits.

Question A3
As a result of the NWRW programme, a reasonable insight has been gained into the pollution caused by surface run-off, even though a quantitative relationship has not been established between the consequences of disconnecting surface run-off, and overflow frequencies and waste fluxes. Nevertheless, it was recognised that disconnecting surface run-off can significantly reduce the waste load from combined sewer systems. Notwithstanding this, if the run-off is likely to be heavily polluted, it is more appropriate to arrange for collection and discharge via a sewer system.

Question A4
The importance of extra storage capacity in combined sewer systems has become much clearer as a result of the NWRW programme. Whilst large storage capacities were found to be generally attractive, stormwater sedimentation facilities were seen as the preferred way of installing capacities in excess of hydraulic requirements. It is, however, essential to ensure that material that is churned up as a result of the high flow velocities in the sewers is not discharged.

In addition to the answers given above, the NWRW programme has generated specific recommendations with regard to the shape and maintenance of sewer systems, the position and layout of overflow points or stormwater outlets, and measures relating to surface waters.

7.2. The importance of sewer discharges in relation to other sources of pollution (question B)

The question under consideration relates to a comparison of the pollution loadings contained in sewage discharged from overflow outlets with that of the effluent from sewage treatment plants. The findings of the NWRW programme only enable conclusions to be drawn about domestic sources of pollution (Section 4.2). It has, for instance, been shown that a distinction should be made on the basis of the type of pollutant, with sewer discharges representing a relatively important source of heavy metals and polycyclic aromatic hydrocarbons (PAH). Similarly, considerable quantities of oxygen-consuming substances can be discharged from sewers. In addition, it should be noted that sewer discharges represent an intermittent source of pollution, whereas effluent loadings from treatment plants are more regular and normally involve relatively larger surface waters. The reference points chosen for the Theme 9 studies give an overview of the impact of other sources of water pollution at specific locations.

When are conditions really safe?

7.3 Final remarks

In summary, it can be concluded that it has proved possible to obtain a better understanding of the way sewer systems function and the impact sewer overflows and stormwater discharges have on surface water quality by practical research methods. Although further research is required, the NWRW working party feels that the information that has so far been generated should first be put into practice. The data that have been collected should facilitate the design and management of sewers on the one hand, and help to improve surface water quality on the other hand.

Appendix

APPENDIX 1

Composition of the NWRW working party:

- M.K.H. Gast (City of Amsterdam), Chairman
- R.T. Eikelboom (Ministry of Housing, Physical Planning and Environment), Secretary 1982-1985
- J.F.M. van Vliet (Ministry of Housing, Physical Planning and Environment), Secretary, from 1985 onwards
- J.F. Noorthoorn van der Kruijff (STORA)
- L. de Hoogt (National Institute of Public Health and Environmental Protection - RIVM), 1982-1985
- J.S.J Dragt (De Aa Water Control Board)
- I.R.M. Hovenkamp-Obbema (District Water Control Board of Kennemerland and West-Friesland)
- R. Karper (Institute for Inland Water Management and Waste Water Treatment - DBW/RIZA) 1982-1986
- A.H. Dirkzwager (Institute for Inland Water Management and Waste Water Treatment - DBW/RIZA), from 1986 onwards
- J.J. Kwakkel (Municipality of Enschede)
- L.J. Pieterse (City of Rotterdam)
- M.A. de Ruiter (Province of Utrecht)
- H.H. Tolkamp (Limburg Water Purification Board)
- F.H.M. van de Ven (Institute for Inland Water Management and Waste Water Treatment - DBW/RIZA), from 1984 onwards
- A.W. van der Vlies (Water Purification Board of Hollandse Eilanden and Waarden)
- J. Weenink (City of Amsterdam), from 1987 onwards
- J.H.A. van Walraven (District Water Control Board of Rijnland)

The meetings of the NWRW working party were organised by an executive committee assisted by Mr G. Martijnse of the Ministry of Housing, Physical Planning and Environment.

Mr W.C. Witvoet of DHV Raadgevend Ingenieursbureau BV of Amersfoort was responsible for project coordination matters in accordance with Article 8 of the NWRW Statutes.

Design and printing: DHV Facilities BV, Amersfoort, The Netherlands