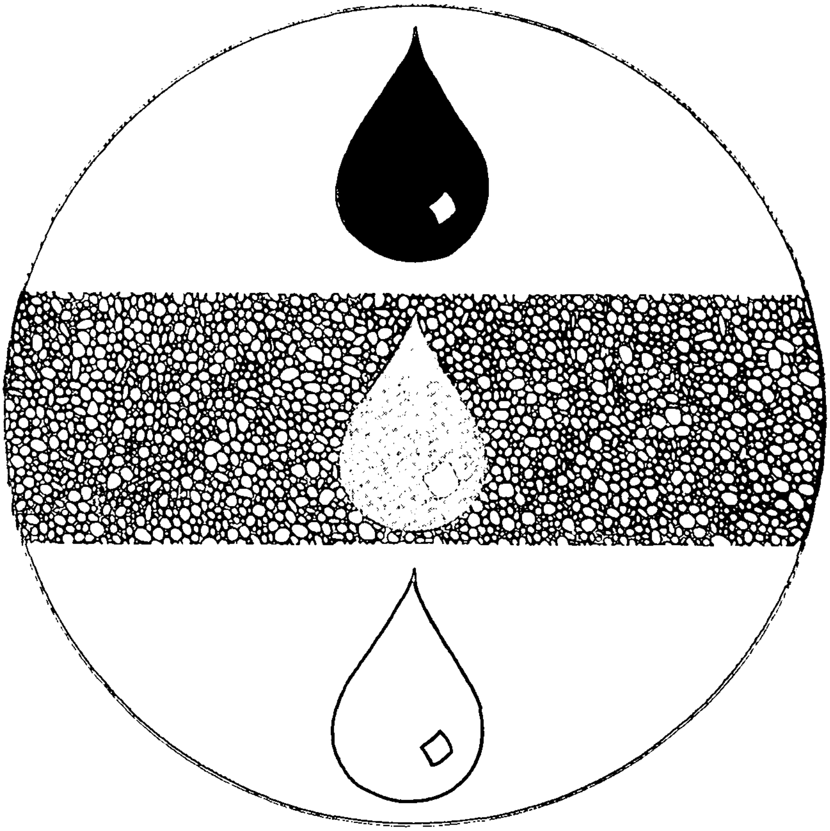
RAPID INFILTRATION OF WASTEWATER

By Kaj Nilsson and Peter Englöv



Reprint from VATTEN 35/3: 212–221, 35/4: 317–328, 1979

Mr. Hans van Damme

With the compliments of the

Senior Adviser

Drinking Water Programmes

United Nations Children's Fund

VATTEN 35/3: 212—221, 1979
35/4: 317—328, 1979

RAPID INFILTRATION OF WASTEWATER

by KAJ NILSSON and PETER ENGLÖV, VIAK AB, Krusegränd 42 C, S-212 25 Malmö, Sweden

Introduction

During the last decades there has been a growing interest in rapid infiltration as a method for treatment and disposal of wastewater. In Sweden rapid infiltration has been used for a broad spectrum of settlements from single households up to villages with more than 500 inhabitants.

Rapid infiltration was for a long time considered mainly as a method to get rid of the wastewater. The reason for this was probably due to the lack of knowledge of the treatment effects which are obtained by the infiltration process.

In order to elucidate problems on treatment effects the National Swedish Environmental Protection Board (SNV) decided at the end of the 1960s that some infiltration plants should be tested as regards function and influence on ground water quality (VIAK AB 1973). These preliminary studies were followed by more systematic investigations between 1973 and 1978. The research program was financed by the SNV Research Council and VIAK AB.

In this and a following report a short account is given of the results obtained within the project. A more detailed discussion is to be found in the final report (Nilsson & Englöv 1979).

Purpose and scope

The research program has been concentrated primarily on the following goals:

a) More dependable evaluation of infiltration conditions and treatment effects
   - in different types of soils
   - with wastewater of different pretreatment
   - under different load conditions
   - at different temperatures

b) Clarification as far as possible of the chemical and biochemical processes taking place in and under the infiltration plant

c) Clarification of the influence of wastewater infiltration on ground water at different distances from the plant.

Investigations

The investigations within the project have followed three principal lines:

- Column experiments
- Case studies of subsurface sand filters
- Case studies of subsurface infiltration plants

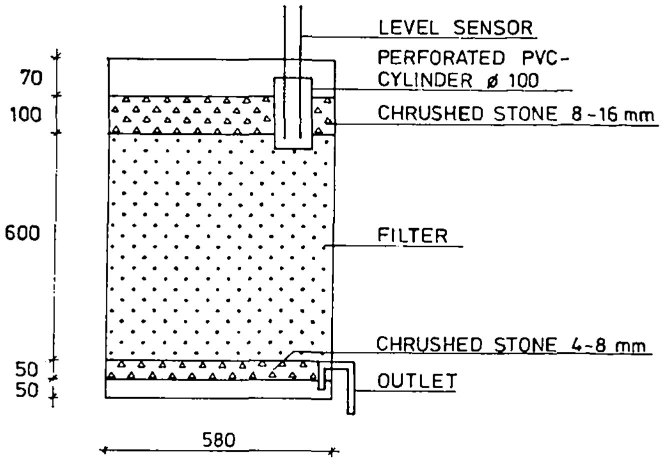


Fig. 1. *Column construction.*

During the column trials certain courses of events such as clogging and physical-chemical and biological processes have been studied more thoroughly. Different parameters, for instance wastewater quality, filter construction and load conditions were varied.

In addition to the column tests the function of five subsurface sandfilters and five infiltration plants was studied. The goal was to find a link between the results obtained during the column experiments and the treatment effects etc obtained during full-scale operation.

Both pilot-scale and full-scale investigations have primarily been concerned with a study of the hydraulic load and of changes in organic substance, bacteria, nitrogen and phosphorus.

Column experiments

The investigations were mainly concerned with analysis of intake and output water in the columns. The parameters studied were as follows:

Table 1. *Column tests.*

Experiment series (year)	Duration (months)	No. of filters	Parameters studied
1974	3.5	6	Preparatory tests Load conditions
1975—1976	9	5	Texture Aerobic/anearobic conditions
1976—1977	12	10	Rock-fragment distribution Pretreatment of waste water Shape of infiltration surface Intermittent load

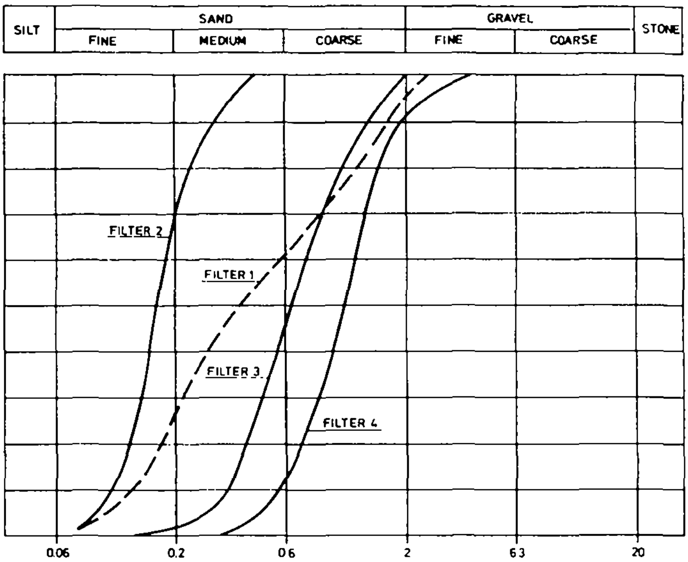


Fig. 2. *Column experiments 1975/76.* Texture, filter 1—4.

Test equipment

The construction of the columns is illustrated in Fig. 1. The load was controlled individually for each filter. When the water surface above the filter had reached down to a certain level, which could be adjusted by means of level sensors, a signal for a new dose was emitted. Provisions were made for incorporating a delay of up to a maximum of ten hours between doses. With the exception of one filter the level sensors were sited in the filter surface.

The crusted surface of these filters was drained between every application so that predominately aerobic conditions could be maintained. In one of the filters the level sensor was positioned 20 mm above the filter surface and a delay time of 0 hours was chosen.

This filter was thus constantly covered with water so that anaerobic conditions prevailed.

Most of the tests were performed with presedimented municipal wastewater. Two filters, however, were loaded with secondary and tertiary effluent.

Filter textures

The test series included four filters with different textures (Fig. 2) but with similar rock contents (Archean rocks).

The filters were loaded with presedimented wastewater. In order to maintain aerobic conditions resting periods of one or a few hours were used.

Hydraulic load

The hydraulic capacity of the filters changed as indicated by Fig. 3. Owing to clogging of the filter surface, the capacity decreased substantially. A state of equilibrium

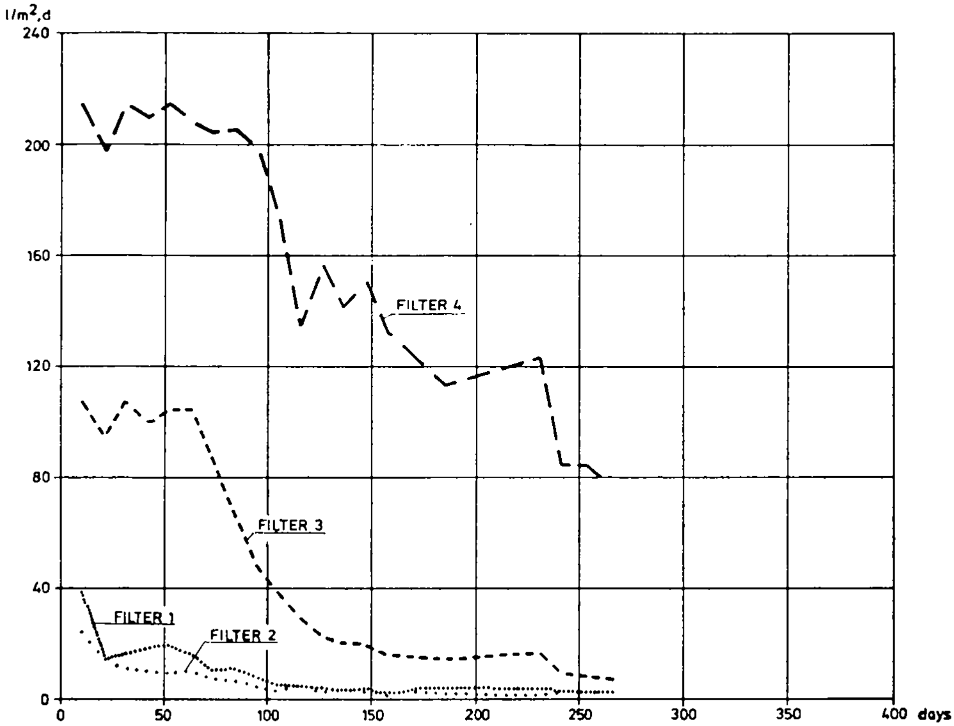


Fig. 3. *Column experiments 1975/76.* Hydraulic load, filter 1—4.

seemed to be established at 1—10 l/m²,d. It may be noted that the loads at the end of the testperiod were very small compared to the loads that infiltration systems normally are dimensioned for (10—100 l/m²,d).

Organic substance

The reduction of organic substance was high (85—90 %) in all filters, Table 2. Large variations in temperature (8—25°) and in the concentration of organic substance in the input water did not influence the reduction.

In order to evaluate the contents of organic substance in the filters COD-analyses were carried out on soil samples from different levels (Fig. 4). From the figure it can be seen that COD-contents are highest in the surface layers. The zone with raised COD-contents is thicker the coarser grained the filter is.

Table 2. *Column tests 1975/76.* COD-contents (mg/l), filter 1—4.

	Primary effluent	Output			
		Filter 1	Filter 2	Filter 3	Filter 4
COD Average	205	23	18	22	22
Range	165—395	12—30	13—48	13—51	17—36
Reduction % ...	—	89	91	89	89

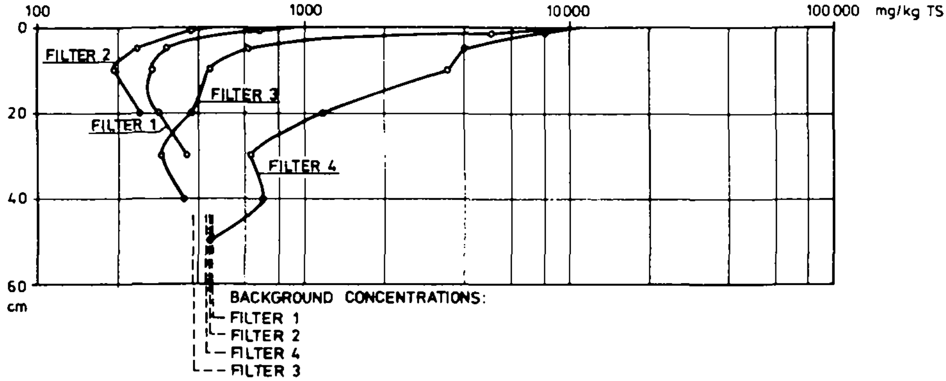


Fig. 4. *Column experiments 1975/76.* Contents of COD in soil samples, filter 1—4.

Microorganisms

On four occasions analyses of bacteria were carried out from the intake and output water. Minimum- and maximumvalues from the analyses are presented in Table 3.

The reduction of bacteria was high in all filters though it was highest in the finest-grained filter. This is especially evident with respect to the coliform bacteria. However, the total supply of bacteria was larger and the delay-time was shorter in the coarse-grained filters.

When the tests were over cores were taken out from the filters. The cores were examined with reference to microorganisms.

In filter 1 the biologically active zone was about 2 cm. It consisted of a differentiated organism society with bacteria, fungi, protozoa and round-worms (Nemathelminthes).

Filter 2 was somewhat more fine-grained than filter 1 and this caused the biozone to be thinner (1—2 cm). Moreover, some of the organisms from filter 1 were missing. The zone was dominated by protozoa and bacteria.

In filter 3 the biozone had a thickness of about 5 cm. The pore-size made it possible for larger organisms to colonize pores somewhat deeper in the filter.

The biozone was dominated by round-worms, protozoa and bacteria but crustaceans (Copepoda) also appeared.

Table 3. *Column tests 1975/76.* Bacterial counts (No/ml), filter 1—4.

	Total bacteria	Coliform bacteria	
		35°C	44°C
Primary effluent	$2.0 \cdot 10^5$—$1.0 \cdot 10^6$	$2.0 \cdot 10^4$—$4.0 \cdot 10^4$	$1.0 \cdot 10^4$—$2.2 \cdot 10^4$
Output			
Filter 1	$5.0 \cdot 10^2$—$2.0 \cdot 10^5$	<1	<1
Filter 2	$3.0 \cdot 10^1$—$2.5 \cdot 10^2$	<1—$3.5 \cdot 10^1$	<1
Filter 3	$7.0 \cdot 10^3$—$8.5 \cdot 10^4$	5—$2.0 \cdot 10^2$	<1—5
Filter 4	$5.0 \cdot 10^2$—$1.5 \cdot 10^4$	$3.0 \cdot 10^2$—$2.0 \cdot 10^3$	$1.0 \cdot 10^1$—$5.0 \cdot 10^2$

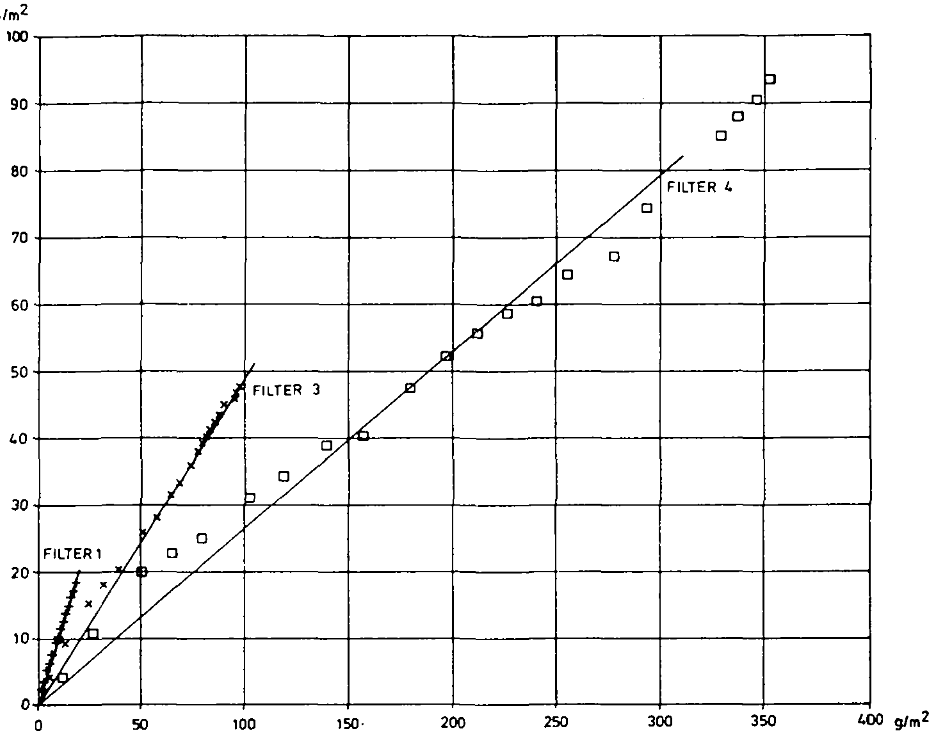


Fig. 5. *Column experiments 1975/76.* Sorbed phosphorus as a function of the phosphorus supply, filter 1, 3 and 4.

In filter 4 with the coarsest grained sand, the biozone was rather thick, 20—30 cm. Within the upper 10 cm a well differentiated society existed with not only one-celled species but also a significant population of higher organisms such as annulata, crustaceans and insects. Further down in the filter the fauna was impoverished mainly due to the reduced access to nutriment. At a depth of 10—30 cm bacteria and protozoa dominated.

In all filters aerobic organisms were found. From an ecological point of view the filters may be classified as isosaprobic systems. The distribution of microorganisms may be compared with the COD-contents in the filter material (Figure 4).

Nitrogen

In the input water about 75 % of the nitrogen appeared as ammonia and the rest as organic nitrogen. At the passage through the filters a mineralization occured whereby organic nitrogen was almost entirely converted into its inorganic form. Furthermore ammonia was substantially oxidized to nitrate.

In the fine-grained filters 1 and 2 the total nitrogen content was reduced to a considerable degree. The reduction, which in all probability was due to denitrification in anaerobic microenvironments, was more than 90 % at the end of the testperiod.

Phosphorus

Fig. 5 shows the amount of sorbed phosphorus as a function of the phosphorus supply to filter 1, 3 and 4 (for the sake of clarity filter 2 is excluded). The reduction, which in the diagram is represented by the inclination of the lines, was not changed during the testperiod.

The deviations from the straight lines are within the margin of error.

The reduction of phosporus was quite different in the different filters. In fine sand (filters 1 and 2) the reduction was more than 90 %, in medium-coarse sand 50 % (filter 3) and in coarse sand 20—25 % (filter 4).

Aerobic-anaerobic conditions

Apart from the four filters which were run under predominately aerobic conditions, one filter was loaded anaerobically. The material in this latter filter consisted of medium-coarse sand equal to filter 3.

In the long run there was no great difference in hydraulic capacity between filter 3 and the anaerobic filter.

Also the reduction of organic substance and bacteria was about the same.

While bacteria and protozoa dominated in the aerobic filters only bacteria and fungi were found in the anaerobic one.

In the anaerobic filter nitrification did not occur. Sulphate was more or less completely reduced to sulphides.

The phosphorus reduction averaged 70 % in the anaerobic filter and 50 % in the corresponding aerobic filter. Leakage of phosphorus was found upon changing from aerobic to anaerobic conditions.

Rock-fragment distribution

During the 1976/77 test runs the infiltration properties were studied in four filters with different rock-fragment distributions, but with similar texture (medium-coarse sand comparable to filter 3). The rock-fragment distribution is shown in Table 4.

No significant differences in the reduction of organic substance, bacteria or nitrogen were observed.

On the other hand, there were quite substantial differences in phosphorus reduction. In the two calcareous sands the reduction was higher than 90 %. In filter 7, con-

Table 4. *Column tests 1976/77.* Rock-fragment distribution, filter 7, 9, 11 and 12.

	Filter 7 Baskarp	Filter 9 Benestad	Filter 11 Vånga	Filter 12 Fjälkinge
Archean %	98.5	67	99	40
Shale %	0.5	13	1	—
Sandstone %	1	—	—	—
Limestone Ordovician %	—	15	—	—
Limestone and sandstone Cretaceous %	—	5	—	60
Number of examined particles (1—2 mm)	214	116	203	549
Lime content (according to Passon) %	0.0	22	0.0	20

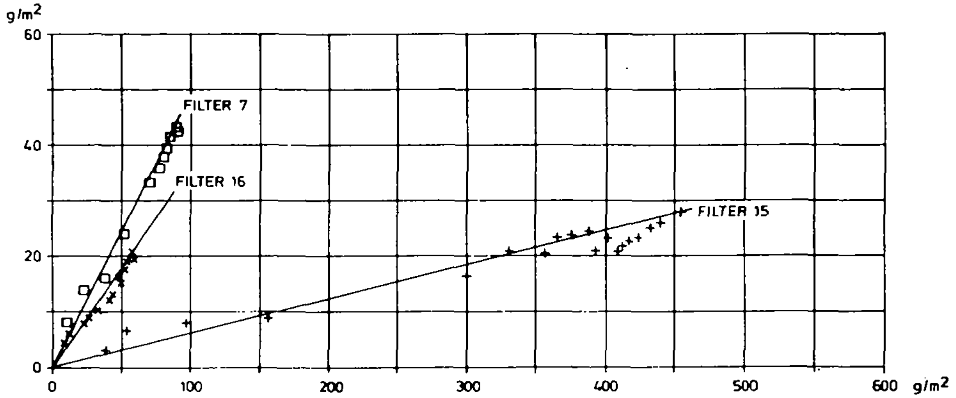


Fig. 6. *Column experiments 1976/77.* Sorbed phosphorus as a function of the phosphorus supply, filter 7, 15 and 16.

taining Archean sand the reduction was 50 % and in filter 11, containing another Archean sand with a higher proportion of basic material, it was approximately 90 %. A closer investigation has not been conducted with regard to which components of the filter material are responsible for the reduction of phosphorus. However, the bond is probably made primarily to calcium in the calcareous sands and to aluminium and iron compounds in the Archean rock material.

Pretreatment of wastewater

During the 1976/77 test runs two filters (15 and 16) were loaded with biologically respectively bio-chemically treated sewage. Filter material and method of loading were the same as for filters 3 and 7 above.

Also with secondary and tertiary effluent the hydraulic capacity dropped towards very low values, which were on a level with those obtained with primary effluent (Figure 3).

During infiltration of secondary or tertiary effluent a further small reduction of organic substance and bacteria occured. The biological activity in the filters was also probably limited by the small supply of organic substance. With reference to nitrogen no significant changes occured (the main part of the nitrogen in the input water existed as nitrate).

Fig. 6 illustrates the amount of sorbed phosphorus per square unit as a function of the total phosphorus supply.

In filter 7, loaded with primary effluent the reduction was about 50 %. The contents in the output water which varied considerably had an average of 5—6 mg/l.

In filter 15, loaded with secondary effluent (activated sludge) the phosphorus reduction was only 5—10 %. The output water contained 6—7 mg/l and the amount of sorbed phosphorus was distinctly lower than in filter 7. Also during earlier column-tests we have observed a smaller reduction of phosphorus when infiltrating secondary sewage effluent (VIAK AB, 1973). However, the reason for this has not been elucidated more closely.

In filter 16, which was loaded with tertiary sewage effluent (activated sludge and precipitation with alum), the reduction was 30—40 % of the total supply. In the output water the contents averaged 0.4—0.5 mg/l. An essential part of the reduction is supposed to depend upon filtration of chemical flocs that have not been removed in the settling basin.

Summary

During the column experiments we have studied how the infiltration capacity and the treatment effects are affected by:

— Texture and rock-fragment distribution of the filter medium

— Pretreatment of the wastewater (primary, secondary and tertiary sewage effluent)

— Loading conditions (aerobic/anaerobic conditions and intermittence)

The investigations were mainly concerned with analysis of intake and output water in the columns. The parameters studied were primarily organic substance, bacteria, nitrogen and phosphorus.

The experiments have shown that:

1) During infiltration in an unsaturated system — aerobic or anaerobic — the reduction of organic substance and bacteria can be considerable. The reduction occurs in a biologically active zone which developes at the infiltration-surface. This zone has a great influence on the hydraulic capacity and the treatment effects.

2) Phosphorus is sorbed to a varying degree, primarily depending upon the texture and the rock-fragment distribution of the filter medium.

3) The reduction of nitrogen is usually low to moderate. However, under favourable conditions there can be a considerable reduction. This reduction may in many cases be explained by denitrification in anaerobic microenvironments in an otherwise aerobic soil.

Sammanfattning

Vid kolonnförsöken har undersökts hur infiltrationskapacitet och behandlingseffekter påverkas av:

— Kornfördelning och bergartssammansättning hos filtermaterialet

— Förbehandling hos avloppsvattnet (mekanisk, biologisk och biologisk-kemisk behandling)

— Belastningsförhållandena (aeroba/anaeroba förhållanden och intermittens)

Undersökningarna har i första hand omfattat analys på inkommande och utgående vatten i kolonnerna. De parametrar som främst studerats har varit organisk substans, bakterier, kväve och fosfor.

Försöken har bl.a. visat:

1) Under infiltration i ett omättat system — aerobt eller anaerobt — kan reduktionen av organisk substans vara betydande. Reduktionen inträffar i en biologiskt aktiv zon som utvecklas vid infiltrationsytan. Denna zon har stor inverkan på den hydrauliska kapaciteten och behandlingseffekterna.

2) Fosfor fastlägges i varierande utsträckning, främst beroende på kornfördelning och bergartssammansättning i filtermaterialet.

3) Reduktionen av kväve är vanligtvis låg—måttlig. Under gynnsamma betingelser kan emellertid reduktionen vara betydande. Denna reduktion torde i många fall förklaras av denitrifikation i anaeroba mikromiljöer i en i övrigt aerob jordprofil.

Acknowledgements

The authors are indebted to Mr R Corner for correcting the language in this paper.

References

VIAK AB (1973): Avloppsinfiltration. Undersökningar utförda 1970—1973 av anläggningar i Eggby, Långstorp, S. Sandby, Bjärnum, Karlshamn. — Utredning utförd på uppdrag av SNV, VIAK AB, Malmö.

Nilsson, K. & Englöv, P. (1979): Avloppsinfiltration. — VIAK AB, Malmö.

RAPID INFILTRATION OF WASTEWATER

Case studies of full-scale systems (subsurface sand filters and infiltration plants)

by KAJ NILSSON and PETER ENGLÖV, VIAK AB, Krusegränd 42 C, S-212 25 Malmö, Sweden

Introduction

In an earlier paper we have reported on column experiments carried out within a research project on rapid infiltration of wastewater (Nilsson & Englöv 1979 b). The purpose of these experiments was to study filter clogging and certain physical, chemical and biological processes during infiltration.

Besides the column tests, the function of five subsurface sand filters and five infiltration plants have been studied. The goal has been to obtain a connection between the column test results and treatment effects obtained during full-scale operation.

The investigations, in both model-scale and full-scale, have mainly included a study of hydraulic load and changes as regards to organic substance, bacteria, nitrogen and phosphorus.

Subsurface sand filters

The design principles of the examined filters are shown in Figure 1. The wastewater was spread from distribution pipes in macadam over a sand or gravel filter usually 0.7—1.0 m thick. After percolation through the filter the wastewater gathered in a drainage layer and discharged into a recipient.

The function studies of the sand filters were carried out during 1975—1977 on the sites presented in Table 1.

All filters were loaded with primary sewage effluent. However, three of the filters (Färna bruk, Grönbo and Ändesta) have occasionally been charged with considerable quantities of drainage and storm water.

Below results are presented from the Solbacken filter where function and management are best known.

Table 1. *Subsurface sand filters.*

Plant	Community	Filter area (m^2)	In operation	No of samplings
Solbacken	Hedemora	790	May 1975	21
Färna bruk	Skinnskatteberg	990	Dec 1975	17
Grönbo	Lindesberg	250	Sept 1975	15
Ändesta	Västerås	520	July 1974	26
Kullagården	Höganäs	240	1974	6

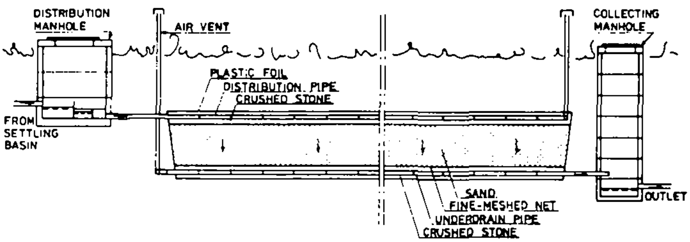


Fig. 1. *Subsurface sand-filter. Section.*

The Solbacken sand filter

The sand filter serves the Solbacken nursing home which is organized for long-term therapy for about 80 patients. The sewage plant which was taken into operation in May 1975, has been dimensioned on the following assumptions:

Connected persons	130 pe
Waste water flow	39 m^3/d
Drainage water flow	11 m^3/d
Dry weather flow, average	50 m^3/d

The sewage effluent from the nursing home, as well as wastewater, drainage water and storm water from a personnel household, was conveyed by way of a three-compartment septic tank to a pumping station. From this station the water was pumped to distribution manholes connected to slotted pipes over the sand filter.

The treated wastewater was collected in a collecting manhole before outlet in a ditch.

Design data

The design data for the sand filter were as follows:

Area	792 m^2
Distribution layer, crushed stone 8—16 mm	0.4 m
Sand filter	0.8 m
Drainage layer, crushed stone 8—16 mm	0.4 m

The sand filter was separated into two parts which were loaded alternately, Figure 2.

Investigations

During the period June 1975—June 1978 water samples have been taken on 21 occasions. Pumping control has been achieved via the pump which delivers the wastewater to the filter.

The sampling of intake water has been carried out proportionally to flow over a period of 24 hours. The samples have been taken from the distribution manholes with the help of a tubing pump.

Composite samples were taken from the output water. These consisted of a series of smaller samples collected at constant intervals over a period of 24 hours. For

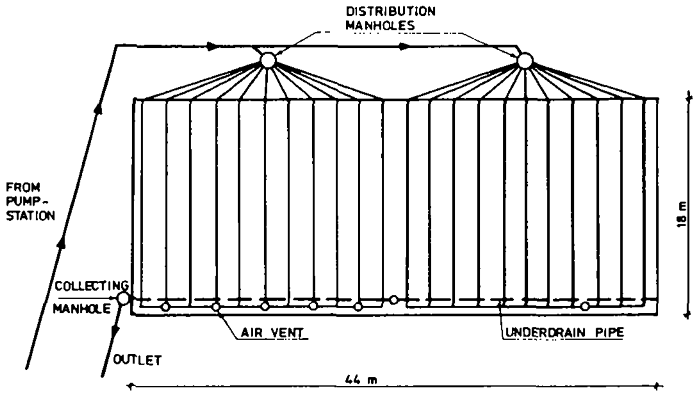


Fig. 2. *Solbacken. Plan.*

economical reasons sampling proportional to flow has not been performed since this had required the installation of a flow control. Furthermore the necessity of this kind of sampling is probably less from the output water since a considerable compensation of flow and water-quality variations is to be expected over the filter.

Hydraulic load

The wastewater load varied between 15 and 20 m^3/d, corresponding to an average surface-load (over the entire filter) within the order of 20—25 $l/m^2 \cdot d$.

The chloride analyses indicated that a certain dilution from drainage — or ground water might have occurred in the filter, Figure 3. This contribution was estimated to 10—20 %.

Organic substance

The COD-demand in intake and output water to the filter is shown in Figure 4.

The COD-content averaged 265 mg/l in the intake water and 44 mg/l in the output water.

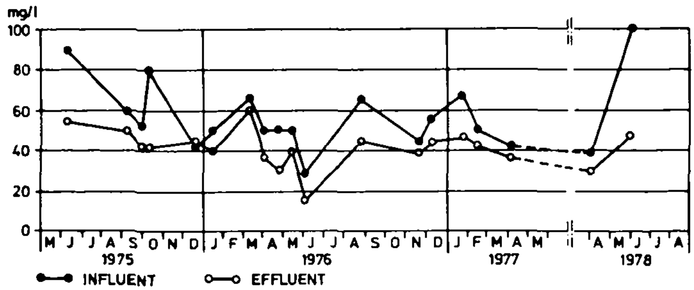


Fig. 3. *Solbacken. Chloride concentrations.*

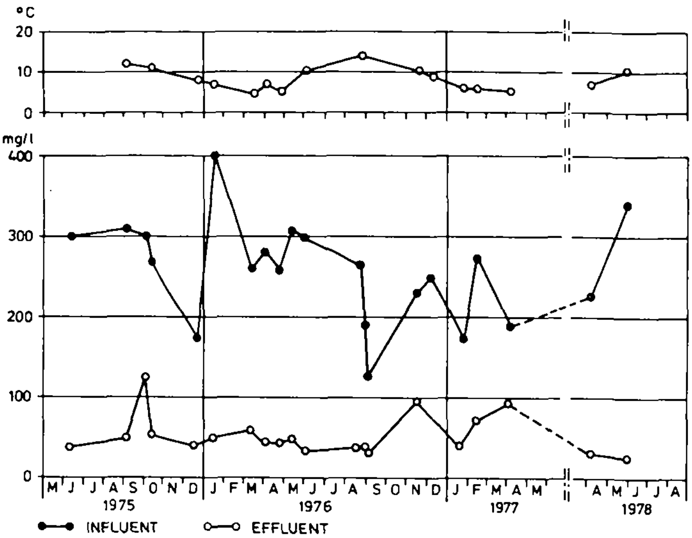


Fig. 4. *Solbacken. COD-concentrations and temperature.*

This means that the COD-reduction was about 83 %. No difference in treatment effect has been observed between the two parts of the filter.

The COD-reduction has in all respects been high (more than 80 %) also in the other studied sand filters. The COD-contents in the output water have on the whole been stable and have not been influenced by the large variations in hydraulic load and temperature.

Bacteria

From Table 2 it is evident that a considerable reduction of bacteria has occured in the filter. The amount of coliform bacteria has on average been reduced to one thousandth.

Nitrogen

In the influent the nitrogen content has averaged 53 mg/l of which about 70 % was ammonia and the rest organically bound nitrogen, Figure 5.

Table 2. *Solbacken. Bacterial counts* (No/ml).

		Influent	Effluent
Total bacteria	median	$1.2 \cdot 10^7$	$5.0 \cdot 10^5$
	min-max	$2.8 \cdot 10^6$—$1.6 \cdot 10^8$	$1.4 \cdot 10^4$—$5.5 \cdot 10^6$
Coliform bacteria 35°	median	$1.8 \cdot 10^6$	$1.3 \cdot 10^3$
	min-max	$9.4 \cdot 10^4$—$5.4 \cdot 10^7$	8—$1.3 \cdot 10^5$
Coliform bacteria 44°	median	$1.3 \cdot 10^5$	$1.0 \cdot 10^2$
	min-max	$2.6 \cdot 10^4$—$> 2.5 \cdot 10^7$	1—$1.3 \cdot 10^4$

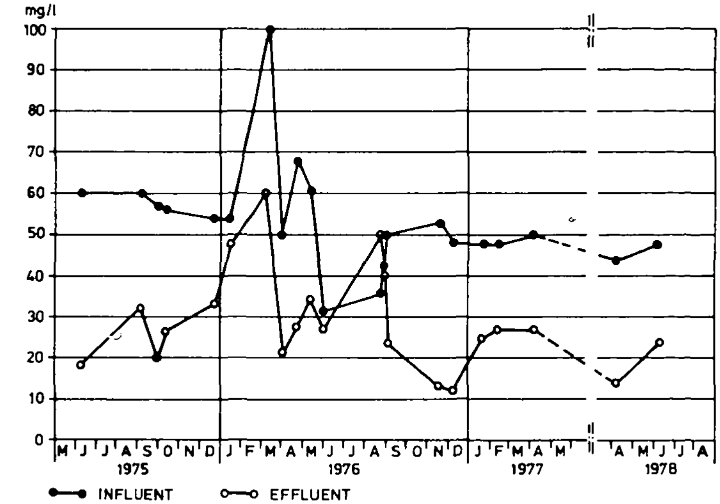


Fig. 5. *Solbacken. Total nitrogen concentrations.*

In the output water the nitrogen content averaged 27 mg/l. This means that the reduction in the filter was about 50 %. The distribution between ammonia — and nitrate — nitrogen has varied. On certain occasions one of the substances dominated, while the other dominated on other occasions.

Phosphorus

The concentration of phosphorus in the intake water has varied between 6 and 12 mg/l and the median value was 8.8 mg/l, Figure 6. About 85 % appeared as phosphate.

In the beginning the phosphorus contents were low (< 1 mg/l) in the output water. After 8—9 months a sudden increase up to 2—6 mg/l occured. The median value during this latter part of the test period was 3.1 mg/l.

In the other filter beds a high reduction of phosphorus was also observed in the beginning. After some time the reduction seemed to stabilize within the interval 30—60 %.

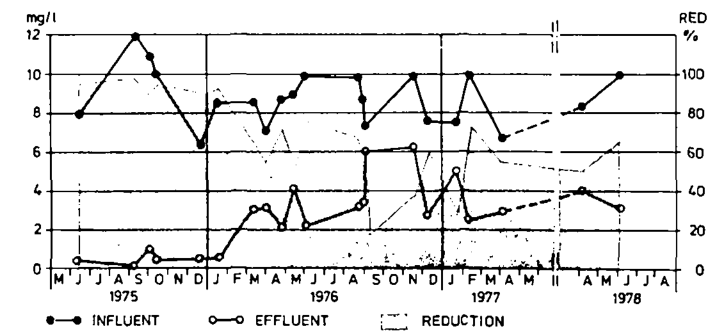


Fig. 6. *Solbacken. Total phosphorus concentrations.*

Table 3. *Subsurface infiltration plants.*

Plant	Community	Infiltration bottom area (m^2)	In operation	No of sampling tubes
Eggby	Skara	870	1963	8
Jära	Nässjö	224	1973	7
Rödån	Habo	780	1973	2
Skämningsfors	Habo	260	1974	1
V Torup	Hässleholm	400	1973	3

Subsurface infiltration plants

In order to study waste water influence and spreading in the ground water five infiltration plants have been followed up more closely. The plants which were studied in 1976/77 are listed in Table 3.

The investigations have included measurement of water flows as well as sampling and analyses of wastewater and ground water. At three of the plants (Rödån, Skämningsfors and Västra Torup) sampling has only been carried out directly under the plants, while more extensive tests on the spreading were performed at Eggby and Jära.

The plants were constructed with separate infiltration trenches according to Figure 7.

All plants were loaded with primary sewage effluent. Considerable quantities of drainage and storm water have also entered the plants at Rödån, Skämningsfors and V. Torup.

Only results from the Eggby-plant are presented below. The reason for this is that the data from this plant were most complete, and that the plant was the oldest one studied.

The infiltration plant at Eggby

The plant, in operation from 1963, was designed according to the following assumptions:

Connected persons	150	pe
Waste water flow	63	m^3/d
Drainage water flow	31	m^3/d
Dry weather flow, average	94	m^3/d

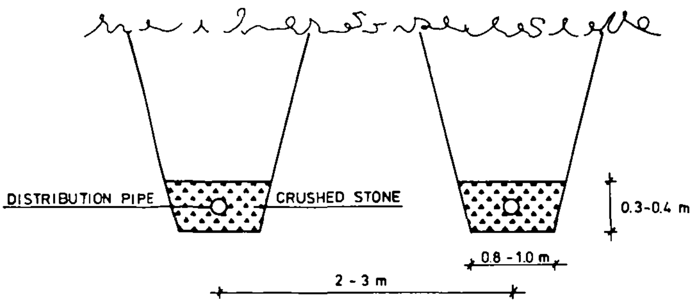


Fig. 7. *Disposal trenches. Section.*

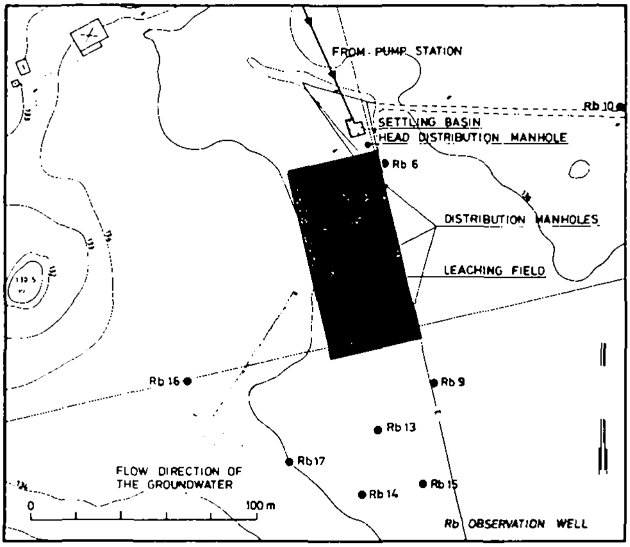


Fig. 8. *Eggby. Detail map.*

Hydrogeology

The plant was situated in an area with vast glacio-fluvial sediments west of the mount Billingen "Valle härad". The sediment thickness at the plant was more than 9 m. The sampling wells Rb 6—17 have been driven to this depth without reaching the bottom level of the sediments. The sediments consisted mainly of sand and gravel but also considerable amounts of silt were present. Thus, the sediments may be classified as poorly sorted. The rock-fragment distribution was dominated by Cambro-Silurian rocks (limestone and shales) from mount Billingen.

The ground water table in the area was at a depth of 5.5—7 m below the ground surface. The water table sloped gently (hydraulic gradient < 1 ‰) towards SW, Figure 8.

Design data

The plant was comprised of three parts with 10 separate infiltration trenches each.

The total length of the trenches was 1080 m and corresponded to a total infiltration area (bottom area of the trenches) of 870 m^2.

The infiltration trenches consisted of ϕ 100 tiles in a bed of crushed stone, 80 cm broad and 40 cm thick. The end points of the trenches were connected to ventilation pipes.

Investigations

The Eggby plant was studied earlier (VIAK AB 1973) with respect to
— Operating conditions
— Bacteria and organic substance in soil and ground water
— Ground-water quality
— Chemical composition of the sediments

The studies in the present investigation have mainly included sampling and analyses of wastewater and ground water. The observation net was completed by more sampling wells. All wells consisted of 50 mm steel-pipes perforated at the bottom (8 mm holes at a length of 1 m). The perforation was located to a depth of 1—2 m below the ground-water table.

Sampling was carried out on four occasions during the test period (June, September and December 1976 and April 1977). The samples of ground water were collected with the help of a pneumatic pump with a capacity of 1—2 l/min. The samples were taken out after pumping for 20—30 minutes. Samples of wastewater were taken from the main distribution manhole. These samples were grouped together from about ten samples taken at intervals of 0.5 hours.

Hydraulic load

The plant has been functioning sufficiently since it was taken into operation in 1963. The maintenance of the plant, however, was scanty during the first years and for this reason the hydraulic load was irregular from time to time. In spite of this, clogging tendencies were not observed.

No measurement of wastewater flows was carried out. However, a certain degree of information about wastewater flow was given by the water consumption. During 1975—76 this was on average 34—35 m^3/d. Since no contribution of storm water or drainage water occurred it seems reasonable to assume that the wastewater flow was about the same as the water consumption, that is 30—40 m^3/d. This means an average load of 35—45 $l/m^2 \cdot d$ at the bottom of the trenches.

Influence on ground-water quality

The ionic distribution in waste water and in the sampling wells is shown in Figure 9.

The diagrams are based on analyses from sampling in September 6th, 1976.

From Figure 9 it can be seen that Rb 8 and 12 are strongly influenced by the infiltration of wastewater. The ground water at these wells consisted mainly of wastewater. A certain influence is also apparent in Rb 13, 16 and 17. Rb 6 and 9 are slightly influenced.

Based on the chloride contents the sampling wells can be grouped according to what degree they were influenced by the wastewater infiltration, Table 4. The wells were influenced differently on different occasions. The reason for this is that the dispersion pattern varied because the plant was loaded intermittently (1/3 of the plant was always out of operation).

From Table 4 it is apparent that the salt concentrations were highest in September 1976 and lowest in April 1977. The variation was a seasonal phenomenon depending upon the natural ground-water recharge. During the winter, and especially during the spring, there was a contribution of water with low salinity from precipitation. Therefore, the highest salt concentrations are to be expected during the late summer when ground water is normally not recharged.

Ground-water hardness also increased due to the infiltration of wastewater. In some cases a hardness of 50°dH was found. The reason for the increased hardness is that carbon dioxide emanating from the oxidation of organic substances dissolves calcium carbonate from the limey sediments.

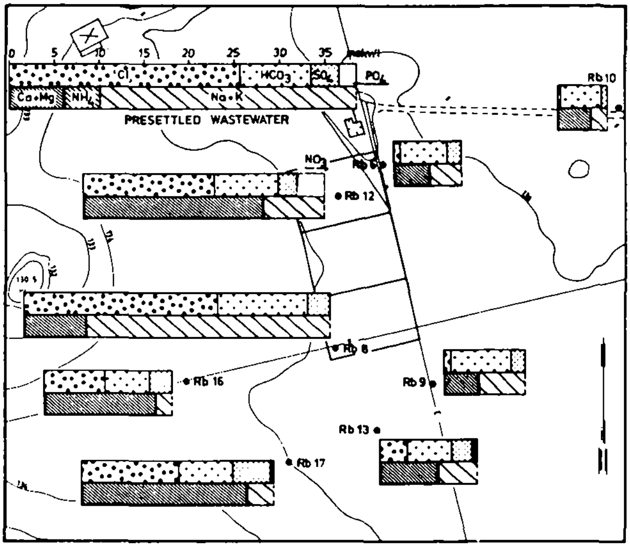


Fig. 9. *Eggby. Ionic distribution.*

Table 4. *Eggby. Chemical analyses.*

Waste-water influence	Sampling point	Cl (mg/l)	COD (mg/l)	NH_4-N (mg/l)	NO_3-N (mg/l)	Tot-N (mg/l)	PO_4-P (mg/l)	Date
Waste-water	Intake	910	480	53	0.02	50	20	760907
		810	600	55	0.02	75	19	761216
		840	460	61	0.02	110	19	770405
Strong influence	Rb 8	760	< 10	0.12	0.11	0.51	0.025	760907
		630	25	0.11	23	25	0.005	761216
		360	< 10	0.35	32	32	0.003	770405
	Rb 12	510	< 10	0.16	40	40	0.007	760907
		340	11	0.03	28	29	0.007	761216
		380	16	0.17	10	10	0.003	770405
Influence decreasing ↓	Rb 17	380	12	< 0.02	3.0	3.1	0.029	760907
		300	22	0.02	0.47	1.1	0.076	761216
		260	24	2.1	10	12	0.022	770405
	Rb 16	240	21	< 0.02	< 0.02	0.21	0.50	760907
		260	24	0.02	0.05	0.24	0.20	761216
		85	24	0.10	0.05	0.15	0.002	770405
	Rb 13	110	14	0.13	6.2	6.6	0.15	760907
		70	20	< 0.02	2.7	2.4	0.083	761216
		58	12	0.29	6.8	7.5	0.003	770405
	Rb 9	23	< 10	0.17	< 0.02	0.21	0.006	760907
		16	< 10	0.02	< 0.02	0.18	0.010	761216
		21	< 10	0.16	0.07	0.39	0.004	770405
	Rb 6	24	< 10	0.09	2.1	2.4	0.020	760907
		13	< 10	0.07	2.0	3.0	0.007	761216
		41	< 10	0.42	3.8	4.2	0.004	770405
Natural ground-water	Rb 10	10	< 10	0.02	< 0.02	0.24	0.009	760907
		13	< 10	< 0.02	< 0.02	0.15	0.063	761216
		13	12	0.13	0.02	0.39	0.019	770405

Table 5. *Eggby. Bacterial counts.*

Wastewater influence	Sampling point	No of total bacteria/ml	No of coliform bacteria/100 ml	
			35°	44°
Strong influence	Rb 8	20 000	23	<2
	Rb 12	1 000	<2	<2
Influence decreasing ↓	Rb 17	40	<2	<2
	Rb 16	70	13	<2
	Rb 13	20 000	5	<2
	Rb 9	10	<2	<2
	Rb 6	10	<2	<2
Natural ground water	Rb 10	4	<2	<2

Organic substance

The COD-contents are shown in Table 4. High contents were found the wastewater, indicating that dilution with drainage water did not occur.

The natural ground water (Rb 10) contained small amounts of organic substance. Approximately the same organic substance contents were found in the sampling wells (Rb 8 and 12) directly under the plant. Since the water samples from these wells to more than 50 % consisted of wastewater, it is evident that the decomposition of organic substance was nearly complete.

During the studies in 1970 analyses were carried out on the organic substance contents of soil samples taken under the infiltration trenches and samples taken from outside the plant. The analyses indicated incresaed contents down to a depth of 0.5—1 m below the infiltration level. Further down the organic substance content was about the same as outside the plant.

Bacteria

Analyses of bacteria were carried out on water samples in September 1976, Table 5. No thermo-stable coliform bacteria were found in any of the samples. Usually the total amount of coliform bacteria was also low. Increased values were found in Rb 8, 13 and 16. These values were probably due to a somewhat unsatisfactory sampling technic.

A very high reduction of bacteria was also found during earlier investigations. Coliform bacteria were not found in any of the sampling wells (Rb 8, 7 and 10). Analyses on soil samples indicated that the coliform bacteria were eliminated at about the same depth as organic substance, that is 0.5—1 m below the infiltration level.

Nitrogen

The nitrogen contents have varied strongly between different sampling points and on various occasions, Table 4. The manuring of arable land does not seem to have influenced the nitrogen content in the ground water. For instance, the contents in Rb 9 and 16 (located in cultivated land) were constantly low and were at the same level as in Rb 10, where no manuring took place.

Directly under the plant (Rb 8 and 12) there were large variations in nitrogen contents. Occasionally the nitrogen values in ground water were at the same level as in wastewater (if dilution is considered), while very low contents were found on other occasions.

The nitrogen contents were generally very low in Rb 16 and 17, in spite of the fact that these wells were influenced by infiltration (20—40 % wastewater according to the chloride analyses). Thus, the nitrogen analyses indicate a considerable nitrogen reduction in the ground-water zone.

In Rb 6 and 13, which were less influenced by wastewater infiltration than Rb 16 and 17, the nitrogen contents were considerable. From the present analyses it is not possible to judge whether infiltration has contributed to the nitrogen contents.

Both nitrate and ammonia were found in the ground water. When higher contents (> 1 mg/l) appear the nitrogen was mainly bound as nitrate. In natural ground water with low nitrogen contents, ammonia mainly appeared due to the reductive environment (iron and maganese were present). The reductive conditions favoured nitrogen reduction by denitrification.

Phosphorus

The phosphate concentrations are presented in Table 4. In wastewater the phosphorus contents were 15—20 mg/l and consisted mainly of phosphate.

In the sampling wells phosphate contents varied considerably at different times. This is in all probability due to sampling technic and methods for sample treatment. The water samples were preserved with sulphuric acid, and this may have caused solution of phosphate from the soil particles. Some of the water samples were very turbid and in these cases notable phosphorus values have appeared.

However, it may be noted that the phosphate contents in Rb 8 and 12, directly underneath the plant, were very low (in the order of some μg/l). Approximately the same values were obtained from sampling wells which were not or only slightly influenced by wastewater infiltration.

The conclusion is that the reduction of phosphorus has been practically complete and that no measurable influence has occured on the phosphorus content in the ground water.

This is well in accordance with the results from 1970 when it was established that phosphorus sorption may have occured 0—0.6 m below the infiltration level.

Summary

The case studies of full-scale systems have included five subsurface sand filters and five infiltration plants. The plants which were constructed for wastewater flows on 15—65 m³/d respectively 30—100 m³/d have been loaded with sewage effluent from settling tanks.

The investigations have mainly been concerned with studies of hydraulic load and changes in organic substance, bacteria, nitrogen and phosphorus.

In the sand filters the reduction of organic substance has been high (COD > 80 %) in spite of great variations in hydraulic and pollution load. Under normal load conditions also the bacteria reduction has been considerable (> 99.9 %). The reduc-

tion of nitrogen has usually been low to moderate. The phosphorus sorption has been high in the beginning. After some time the reduction has decreased to 30—60 %.

In the infiltration plants higher treatment effects have been observed than in the sand filters, especially for phosphorus which was sorbed almost completly in the studied infiltration plants.

In all essentials the results from the case studies are in accordance with those obtained in the column experiments.

Sammanfattning

Undersökningarna av fullskaleanläggningar har omfattat fem filterbäddar och fem infiltrationsanläggningar. Anläggningarna som har dimensionerats för avloppsvattenmängder på 15—65 m^3/d respektive 30—100 m^3/d, belastas med försedimenterat hushållsspillvatten.

Uppföljningarna har främst inriktats på studier av hydraulisk belastning samt förändringar med avseende på organisk substans, bakterier, kväve och fosfor.

Vid filterbäddarna har reduktionen av organisk substans varit hög (COD $>$ 80 %) trots stora variationer i hydraulisk belastning och föroreningsmängd. Under normala belastningsförhållanden har även bakteriereduktionen varit ansenlig ($>$ 99.9 %). Reduktionen av kväve har vanligtvis varit låg till måttlig. Fastläggningen av fosfor har varit hög närmast efter det att anläggningarna tagits i drift. Därefter har reduktionen minskats till 30—60 %.

Vid infiltrationsanläggningarna har behandlingseffekterna varit högre än i filterbäddarna. Särskilt gäller detta fosfor, som fastlagts i det närmaste fullständigt i de studerade infiltrationsanläggningarna.

I allt väsentligt överensstämmer resultaten från fullskaleanläggningarna med de resultat som erhållits vid kolonnförsöken.

Acknowledgements

The authors are indebted to Mr R Corner for correcting the language in this paper.

References

VIAK AB (1973): Avloppsinfiltration. Undersökningar utförda 1970—1973 av anläggningar i Eggby, Långstorp, S Sandby, Bjärnum, Karlshamn — Utredning utförd på uppdrag av SNV, VIAK AB, Malmö.

Nilsson, K. & Englöv, P. (1979 a): Avloppsinfiltration — VIAK AB, Malmö.

Nilsson, K. & Englöv, P. (1979 b): Rapid infiltration of wastewater — Vatten 3: 212—221.