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Removal of micro-organisms upon basin recharge, deep well injection and river bank filtration in the Netherlands

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ABSTRACT: River Bank Filtration (RBF), artificial recharge (AR) using basins and AR by deep well injection are applied in the Netherlands to cover 19% of the drinking water needs. The recharged aquifers are composed of unconsolidated Quarternary sands or gravels. Field studies (with or without seeding of micro-organisms in feed water) and column studies were carried out to quantify the relation between travel time/distance and micro-organism removal (primarily MS2 and PRD1 phages, *Clostridium* spores and *E.coli*), and to determine the factors that influence this relation. All studies showed that sandy soils pose a very effective barrier to all micro-organisms. The first 1-6 m of soil passage, in the field, removed all micro-organisms most effectively, probably due to a raised sorption capacity by deep bed filtration of fine particles close to the recharge means. In case of deep well injection oxidation of pyrite into ferri-hydroxides, which sorb micro-organisms, offers an additional explanation. Critical situations may arise during flood events where RBF systems draw from gravel aquifers; and where the recollection system is subject to short-circuiting or contamination of the abstraction systems (wells, drains) by animal life or infiltration of contaminated water.

1 INTRODUCTION

Soil or aquifer passage is applied in many surface water treatment systems for drinking water supply. In The Netherlands, River Bank Filtration (RBF) covers 5% of the needs, artificial recharge (AR) using basins 13% and AR using deep well injection 1%. During the past 110 years of application of RBF and 60 years of AR, in the Netherlands, no outbreaks of waterborne diseases have been associated with these systems, notwithstanding high loads of microbial pathogens in the surface waters used. This can be attributed to the sufficiently long detention times (>60 days) and travel distances (>50 m) in the fine-grained aquifers, and the additional purification processes before (AR only) and after aquifer passage. Little quantitative information was available, however, about the relation between travel time or distance in the aquifer and the removal of micro-organisms.

Current developments call for more knowledge in this regard. The first is the accepted philosophy to minimise disinfection of the recollected water in order to reduce toxic disinfection by-products. The second is the desire, in densely populated areas where space is scarce, to make AR systems using basins more compact, by raising the infiltration intensity and reducing the distance between basins and the recollection system. Another drive is new legislation regarding hygienic safety. The new Drinking Water Decree requires an assessment of the risk of infection, which in case of AR and RBF should be based on concentrations in the infiltration water and the effectiveness of aquifer passage. These developments stimulated quantitative studies into the relationship between travel time/distance and micro-organism removal (primarily MS2 and PRD1 phages, anaerobic spores and *E.coli*), and to determine the factors that influence this relationship. This was done in field studies and column studies in sandy soils in various AR and RBF systems during the past years. This paper summarises their results.

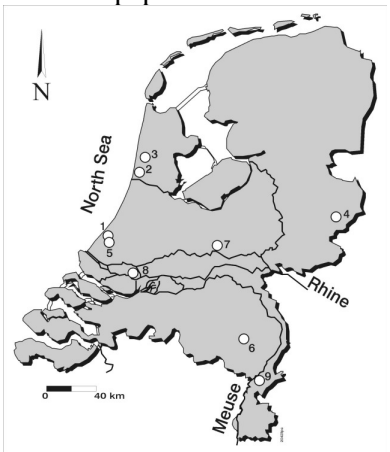

Figure 1. Location of the 9 study sites, the numbering of which corresponds with Table 1.

Table 1. Characteristics of the 9 study sites

Study site	Water Supply Company	Source water ##	Experiments @	Research Period	Aquifer				Further data in §
					Type	grain size µm	Redox Environment	pH	
BASIN RECHARGE									
1. Scheveningen Pond 13.1	DZH	M^P	F	1980-83	Dune sand	200	Suboxic	7.7	A
2. Wijk aan Zee	PWN	Y^P	F	1992[2]	Dune sand	200	Suboxic	7.8	B, A
3. Castricum, basin 5	PWN	Y^P	F(S)+C	1997	Dune sand	200	Suboxic	7.8	C, I, K
4. Enschede Basin 13	Vitens	$C1^P$	F	2001	Fluvial sand[1]	460[1]	Suboxic	7.0	D
DEEP WELL INJECTION									
5. Scheveningen, FLIP-FLOP	DZH	M^P	F	1984-87	Fluvial sand	350	Anoxic	7.5	E
6. Someren, DIZON	WML, BW	$C2^P$	F(s)	1998-99	Fluvial sand	300	Deep anoxic	6.6	F, J
RIVER BANK FILTRATION									
7. Remmerden, well 1	Hydron	R	F	1986-87	Fluvial sand	400	Suboxic	7.7	G
8. Zwijndrecht, wells 7+19	Hydron	R	F	1986-87	Fluvial sand	300	Deep anoxic	7.4	G
9. Roosteren, well XI	WML	M	F + C	1997-99	Fluvial gravel	20000	Suboxic	6.5	H, K

1 = below a 1 m thick loam layer, which needs to be passed first; 2 = also in 1980-1981 (Hoekstra, 1984).
##: C1 = Twente Canal; C2 = Zuidwillems Canal; M = River Meuse; R = River Rhine; Y = Lake Yssel; ^{P} = pretreated.
@: F = Field study; F(S) = Field study with oganisms seeded into feed water; C = Column study;
§: A = Hoekstra, 1984; B = Schijven *et al*., 1998; C = Peters *et al*., 1998; D = Joziasse *et al*., 2002; E = Rutte, 1990; F = Schijven *et al.,* 2000; G = Van Olphen *et al.,* 1993; H = Medema *et al*., 2001; I = Schijven, 2001; J = Stuyfzand *et al.,* 2002; K = Hijnen *et al.,* 2000.

2 SITES AND METHODS

The studies were carried out on 9 sites in 3 environments (Fig.1): the coastal dunes (1-3, 5), Rhine fluvial plain (7-8), and Pleistocene hills (4, 6, 9). General characteristics of these sites, the experiments, source water and aquifer characteristics are given in Table 1. In all cases of basin recharge and RBF no unsaturated zone was observed in between the surface water body and the infiltrated groundwater. The AR systems used continuous recharge schemes with only incidental stops, mainly to remove clogging material. The RBF systems 7 and 9 created induced recharge, because the river is exfiltrating otherwise. RBF 8 is situated along an already infiltrating Rhine tributary (for centuries).

In all field studies due attention was paid to initially disinfect the observation and pumping wells, and to flush the well screen, riser, pump, tubes and vessels at least 3 times prior to sampling. At field sites 3, 6 and 9 the groundwater (infiltrate) was continuously pumped from the observation wells (screen length 0.25-2 m) at a low rate and sampled at intervals. This was done to avoid any mobilisation of particles from the aquifer, which normally contain higher amounts of micro-organisms than the water (Hofmann & Schöttler, 1998). The expected low concentrations in the infiltrated water required the sampling of large volumes (10-1000 litres), and the concentration of these larger samples by filtration. Samples were kept cool (4°C) in the dark, during transport and storage, until processing within 18 hours.

Prior to or during all studies the travel time of water and longitudinal dispersion were determined by monitoring the delay and dampening of chloride fluctuations in the infiltration water. For details on analytical methods reference is made to the literature cited in Table 1.

In field studies (and column studies), multiple samples were taken of the feed water and of water from observation or pumping wells. In seeded field studies, the feed water was seeded with high concentrations of lab-grown micro-organisms for a short time-period. This resulted in a pulse-challenge and the pulse and breakthrough curves were monitored extensively to determine transport of micro-organisms.

The Decimal Elimination Capacity (DEC) is used to express the removal capacity of aquifer passage:

$$DEC = \log_{10} \{C_{IN} / C_{OUT}\} \quad (1)$$

with: C_{IN} = mean concentration in the infiltration water just before percolation [n/L]; C_{OUT} = mean concentration in the infiltrate somewhere in the aquifer [n/L]. In studies where micro-organisms were seeded into the water, the maximum observed concentration in the breakthrough curve (C_{MAX}) was taken for C_{OUT}.

3 RESULTS & DISCUSSIONS

3.1 Basin Recharge

The main results obtained at the 4 study sites are listed in Table 2. In the recharge basins the pretreated surface water is in all cases re-infected by (abundant) animal life, leading to negative DEC values (-0.2 up to –1.5) for coliforms (COLI37 and COLI44), faecal streptococci (FSTREP), sulphite-reducing clostridia (SSRC) and colony counts (HPC).The passage through dune sand (sites 1-3) re-

duced the number of faecal bacteria, SSRC, bacteriophages and viruses (not shown in Table 2) by >3-4 log_{10}-units. The removal capacity is highest in the first 4 metres, as can be seen in Fig.2 (COLI44) and Fig.3 (phage MS2 and PRD1). These first 4 metres result in the following DECs: 3-4 for the two phages and FSTREP, 2-4 for COLI44, and about 2 for SSRC and colony counts.

Table 2. Mean results of microbiological analyses at basin recharge sites 1-4. Derived from the literature cited in Table 1.
X = travel distance in aquifer; t = travel time in recharge basin or aquifer (excl. time in basin).

Monitor-ingPoint	X	t	start date	end date	No-sam-n	HPC 22°C	HPC 37°C	Coli 37°C	Coli 44°C	E. coli	F. strep.	Clos-perfrin-	Clos-SSRC	Phage F-RNA	Phage MS2	Phage PRD1
	m	d				n/mL	n/mL	n/L	n/L	n/L	n/L	n/L	n/L	n/L	n/L	n/L
1. SCHEVENINGEN: FIELD EXPERIMENT																
infil.water	0	0	1/1/1981	31/12/1981	27	-	-	79	40	-	100	-	63	-	-	-
pond 13.1	0	1.5	1/1/1981	31/12/1981	27	31623	14125	631	316	-	251	-	251	-	-	-
wp.351	1.8	2	1/1/1981	31/12/1981	27	-	-	0.05	-	-	0.1	-	20	-	-	-
wp.195	10	8	1/1/1981	31/12/1981	27	25	4.5	<0.05	-	-	0.06	-	0.06	-	-	-
Rec. drain	65	70	1/1/1982	31/12/1982	52	-	-	1	0.8	-	16	-	0.1	-	-	-
2. WIJK AAN ZEE: FIELD EXPERIMENT																
infil.water	0	0	6/10/1980	15/6/1981	40	1390	5	130		-	13	-	10	-	-	-
pond 9	0	1	13/10/1980	15/6/1981	18	7350	85	200		-	20	-	300	-	-	-
M7	8	5.5	17/10/1980	12/6/1981	18	280	1	<5		-	<10	-	<5	-	-	-
M6	18	9.5	21/10/1980	16/6/1981	16	30	<1	<5		-	<10	-	<5	-	-	-
M5	23	25	6/11/1980	11/6/1981	11	75	<1	-<5		-	<10	-	<5	-	-	-
M4	29	27	7/11/1980	5/6/1981	10	45	2	<5		-	<10	-	<5	-	-	-
M3	33	40	26/2/1981	18/6/1981	9	15	<1	<5		-	<10	-	<5	-	-	-
M2	38	50	24/2/1981	9/6/1981	9	40	<1	<5		-	<10	-	<5	-	-	-
M1	44	60	11/3/1981	3/6/1981	7	<1	<1	<5		-	<10	-	<5	-	-	-
pond 9	0	1	11/12/1995	26/2/1996	4	-	-	89	28.3	-	3.75	-	91.5	58	-	-
WP.1	2	1	22/1/1996	26/2/1996	4	-	-	10.3	4.3	-	<1	-	3	0.017	-	-
WP.2	4	2	29/1/1996	26/2/1996	2	-	-	10	-0.5	-	<1	-	<1	0.0027	-	-
3. CASTRICUM: SEEDED FIELD EXPERIMENT																
Pond V	0	2	27/1/1997	6/2/1997	50	-	-	-	-	-	-	-	-	-	1.1E+8	1E+7
W.1	2.4	1.7	27/1/1997	27/5/1997	50	-	-	-	-	-	-	-	-	-	110000	6310
W.2	3.7	2.5	27/1/1997	27/5/1997	50	-	-	-	-	-	-	-	-	-	27631	5623
W.3	6.4	4.3	27/1/1997	27/5/1997	50	-	-	-	-	-	-	-	-	-	1385	631
W.4	10.2	7	27/1/1997	27/5/1997	50	-	-	-	-	-	-	-	-	-	276	200
W.5	17.1	12	27/1/1997	27/5/1997	50	-	-	-	-	-	-	-	-	-	68	2.2
W.6	30.1	26	27/1/1997	27/5/1997	50	-	-	-	-	-	-	-	-	-	0.83	0.06
4. ENSCHEDE: FIELD EXPERIMENT																
Basin 13	0	2	11/4/2001	11/4/2001	1	-	-	-	-	2.3	-	14	-	-	-	-
SKB.5-f1	0.3	?	11/4/2001	11/4/2001	1	-	-	-	-	<2.5	-	15	-	-	-	-
SKB.5-f2	2.5	?	11/4/2001	11/4/2001	1	-	-	-	-	<0.4	-	6.2	-	-	-	-
SKB.4-f2	6	?	11/4/2001	11/4/2001	1	-	-	-	-	1.5	-	13	-	-	-	-
SKB.3-m9	15	?	10/4/2001	10/4/2001	1	-	-	-	-	<0.16	-	5	-	-	-	-
SKB.2-m9	22	?	10/4/2001	10/4/2001	1	-	-	-	-	<0.1	-	<1.4	-	-	-	-
SKB.1-m9	30	?	10/4/2001	10/4/2001	1	-	-	-	-	-	-	2.1	-	-	-	-
Rec. well	35	?	10/4/2001	10/4/2001	1	-	-	-	-	0.32	-	5.5	-	-	-	-

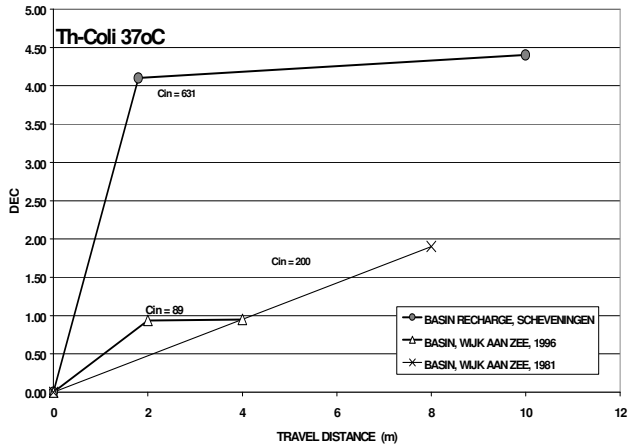

Fig.2. Decimal Elimination Capacity (DEC, Eq.1) of dune sand at basin recharge sites 1 and 2, for coliforms. Based on data in Hoekstra (1984) and Schijven *et al.* (1998).

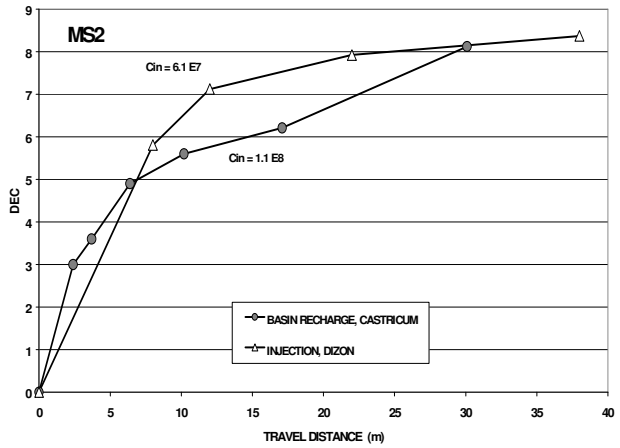

Fig.3. Decimal Elimination Capacity (DEC, Eq.1) of sandy aquifers at basin recharge site 3 and deep well injection site 6, for bacteriophage MS2. Based on data in Peters *et al.* (1998) and Schijven *et al.* (2000).

The passage through fluvial sand at site 4 resulted in an irregular relationship between removal of *Escherichia coli* and *Clostridium perfringens* and travel distance(Fig.4), with overall substantially less removal than in sites 1-3. These irregular results could be caused by suspended fines in the sampled groundwater, aquifer heterogeneity (larger than dune sand). The fact that *E. coli* and *C. perfringens* spores showed a similar pattern points to soil heterogeneity.

In several cases, like on sites 1 and 4, the benefits of aquifer passage are partly undone in the recollection system. This is due to: (a) short circuiting by pipe leakage, aquifer heterogeneity, or spots where aquifer passage is too short; and (b) imperfections in an air and water tight construction of the recovery bore, allowing access of animal life or water from above.

3.2 Deep Well Injection

The main results obtained at the 2 study sites are listed in Table 3. The intensive pre-treatment at site 5 resulted in a very low input of micro-organisms. Nevertheless relatively high colony counts and numbers of coliphages were observed. This is probably connected with the unwanted contribution of suspended fines from the aquifer, and relatively high MDLs. Aeromonades and Pseudomonades are clearly removed by 1.8-1.9 $\log_{10}$ units, the bulk of which occurs during the first 14 metres. Their removal rate did not change during the experiment, when redox conditions gradually changed from anoxic into suboxic (Rutte, 1990).

The field study at site 6, with micro-organisms seeded into the feed water, showed (very) high DEC values for *E. coli* (7.6), *Clostridium bifermentans* (5.3) and bacteriophages MS2 (8.4) and PRD1 (7.1). The first 8 metres were most effective (see MS2 in Fig.3), yielding DEC values of 5-7.6. *Clostridium bifermentans* was hardly removed any further beyond 8 metres of aquifer passage.

Inactivation was far to slow to explain the high removal rates in the first meters (Medema *et al.*, 2000), and attachment was the primary process that governed removal (Schijven *et al.*, 2000). The greater attachment in the first 8 m around the well is explained by: (1) the localised oxidation of pyrite into iron(hydr)oxides which, by their positive charge at pH 6.5-6.8, are capable of sorbing negatively charged micro-organisms. This pyrite weathering has progressed most in the close vicinity of the injection well (<8 m), which delivers the necessary oxidants O_2 and NO_3^-.

Comparison of the peak migration downgradient of the salt tracer and the micro-organism cocktail (Fig.5), yields 3 additional important facts: (a) part of the micro-organisms migrated at about the same velocity in the aquifer as the salt, without retardation; (b) the long tail after breakthrough suggests that another part does sorb and desorb; and (c) the juttering (reduction of the water table in the well by aire pressure and sudden release of pressure to induce rapid water flows) during well regeneration 5 (on day 34 in Fig.5) clearly re-mobilised MS2 phages, which were transported and observed further downstream.

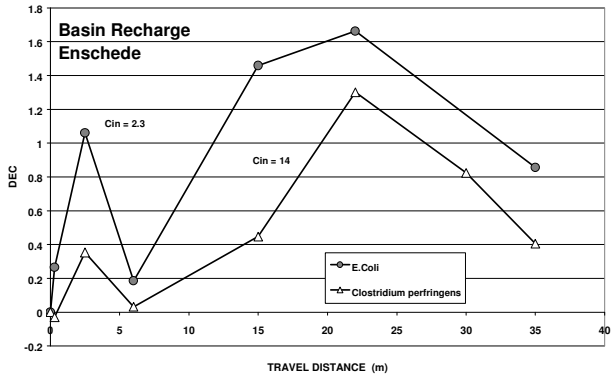

Fig.4. Decimal Elimination Capacity (DEC, Eq.1) of fluvial sand at basin recharge site 4, for *Escherichia coli* and *Clostridium perfringens*. Based on data in Joziasse *et al.,* 2002.

Table 3. Mean results of microbiological analyses at deep well injection sites 5-6. Derived from the literature cited in Table 1. X = travel distance in aquifer; t = travel time in aquifer. Clos bif. = *Clostridium bifermentans*.

Monitoring Point	X m	t d	start date	end date	No samples n	HPC 22°C n/mL	HPC 37°C n/mL	*E.coli* WR1 n/L	Clostrid-bif (R5) n/L	Aeromo-nades n/L	Pseudo-monads n/L	Coli phages n/L	Phage MS2 n/L	Phage PRD1 n/L
5. SCHEVENINGEN FLIP-FLOP: FIELD EXPERIMENT														
Inj. water FLIP	0	0	9/7/84	16/12/86	26	78	6.5	-	-	256	1300	2.9	-	-
WA-32	14	6	9/7/84	16/12/86	29	151	33	-	-	<10	260	3.5	-	-
WB-32	20	13	9/7/84	16/12/86	29	43	10	-	-	<10	40	3.4	-	-
WC-32	25	18	9/7/84	16/12/86	29	104	5.7	-	-	<10	50	3.3	-	-
WD-32	36	51	9/7/84	16/12/86	28	82	14.5	-	-	<10	130	3.5	-	-
Recovery	76.5	100	9/7/84	16/12/86	28	101	11.5	-	-	3	20	4.1	-	-
6. SOMEREN, DIZON: SEEDED FIELD EXPERIMENT														
Inj. water IP.2	0	0	12/10/98	30/12/98	17	-	-	1200000	30000	-	-	-	6.1E+07	510000
WP.3-f2	8	2.4	12/10/98	30/12/98	18	-	-	0.03	0.29	-	-	-	95	0.89
WP.2-f2	12	6.1	12/10/98	30/12/98	11	-	-	-	0.7	-	-	-	4.6	0.038
WP.4-f2	22	25	12/10/98	30/12/98	10	-	-	-	0.1	-	-	-	0.73	-
WP.1-f2	38	38	12/10/98	30/12/98	6	-	-	-	0.16	-	-	-	0.26	-

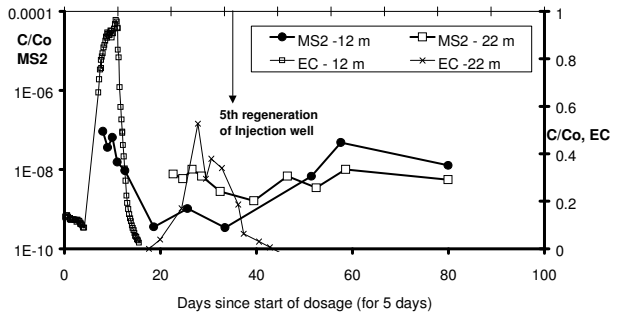

Fig.5. Propagation of a 5 days pulse in NaCl (measured by electrical conductivity EC) and MS2 phages, as monitored in WP2-f2 (12 m) and WP.4-f2 (22 m). Based on Someren data in Schijven *et al.,* 2000. C/C_0 = measured concentration or EC/ pulse input.

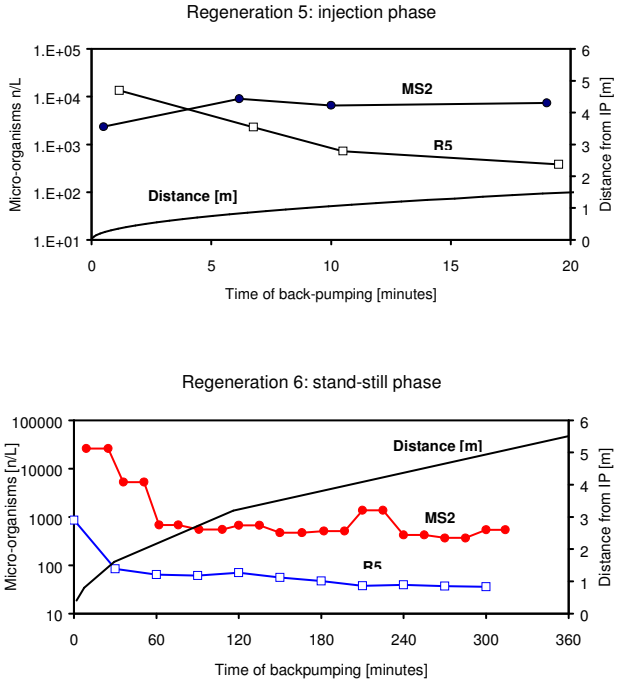

Fig.6. Concentration of MS2 phages and spores of *Clostridium bifermentans* (R5) in backpumped water of regenerations 5 (during the injection phase; 34 days after their addition) and 6 (after 108 days of stand-still; 217 days after their addition). Based on Someren data in Schijven *et al.,* 2000.

The back-pumped water from declogging 6 (after 108 days of stand-still; 217 days after their addition) contained, according to Fig.6, even higher concentrations of MS2 than the back-pumped water of declogging 5 (during the injection phase; 34 days after their addition). This is probably connected with the strong dissolution of iron(hydr)oxides in the immediate surroundings of the injection well (Stuyfzand *et al.,* 2002) which captured MS2, and the long survival of MS2 in an anoxic environment. R5 spores were also detected in raised concentrations, however at a lower level during regeneration 6 than 5. This difference cannot be due to a shorter half-life of R5 in an anoxic environment (these spores are very resistant in anoxic environments), but could be related to their larger size (R5 = 1 µm, MS2 = 0.026 µm).

3.3 River bank filtration

The main results obtained at the 3 study sites are listed in Table 4. Along the River Rhine, at sites 7 and 8, bacteria and viruses were effectively removed in sand and clayey river deposits, by >4 $\log_{10}$ units during a 1 year period.

Along the River Meuse similar removal rates were observed in gravel. During extreme flood peaks in winter, however, (very) low numbers of coliforms, SSRC and coliphages reached the pumping well (Medema *et al.,* 2002).

This is explained by low temperatures (reducing inactivation), but primarily by the short travel times in the gravel aquifer during these conditions, being 10-14 days instead of 45-65 days. The latter is caused by a >20% shortening of the travel distance and a >400% steepening of the hydraulic gradient. As elsewhere, the removal rates were highest during the first 7 metres (Table 4).

Table 4. Mean results of microbiological analyses at river bank filtration sites 7-9. Derived from the literature cited in Table 1. X = travel distance in aquifer; t = travel time in aquifer. Clos bif. = *Clostridium bifermentans*.

Monitoring Point	X m	t d	start date	end date	No samples	HPC 22°C n/mL	HPC 37°C n/mL	Coli 37°C n/L	Coli 44°C n/L	FSTREP n/L	SSRC n/L	Aeromonas n/L	Somatic coliphages n/L	Enterovirus n/L	F-RNA phages n/L	Cryptosporidium n/L	Giardia n/L
7. REMMERDEN: FIELD EXPERIMENT																	
River Rhine	0	0	8/10/86	20/5/87	11	2200	390	94000	17000	2700	1500	480000	-	9.7	7300	-	-
Pump well 1	30	14	5/11/86	3/6/87	11	1	0.072	<1	<1	<1	<1	3	-	<0.001	<0.005	-	-
8. ZWIJNDRECHT: FIELD EXPERIMENT																	
River Rhine	0	0	15/10/86	13/5/87	11	4900	850	130000	20000	4700	5600	700000	-	8.7	3600	-	-
Pump. well 7	25	-35	29/10/86	10/6/87	11	0.048	0.018	<1	<1	<1	<1	<1	-	-	<0.005	-	-
Pump. well 19	30	-35	29/10/86	10/6/87	11	0.086	0.019	<1	<1	<1	<1	<1	-	-	<0.005	-	-
9. ROOSTEREN: FIELD EXPERIMENT																	
River Meuse	0	0	19/11/98	16/4/99	7	-	-	280000	93300	11333	8600	1.01 E6	43900	0.52	10600	140	95
WP.41-f2	22	7	19/11/98	16/4/99	7	-	-	103	6.1		2.4	-	3.4	<0.01	1.5	<0.01	0.02
WP.42-f2	33	18	19/11/98	16/4/99	7	-	-	10	1.7		1.3	-	0.4	-	0.01	-	-
Pump. well 11	138	43	19/11/98	16/4/99	7	-	-	-	0.06	<3	0.11	<1	0.002	-	<0.01	-	-

3.4 Column Studies

Column studies were carried out with basin bed, river bed and aquifer cores from sites 3 (AR, dune sand) and 9 (RBF, gravel). Schijven (2001) studied dune sand at 2-8°C, and concluded that virus removal was in the order of poliovirus 1 > phage ϕX174 > Coxsackie virus B4 ≈ PRD1 ≈ MS2. Bacteriophages MS2 and PRD1 can thus be considered as relatively conservative tracers for virus transport in saturated sandy soils (pH 6-8, temp. < 8°C, organic carbon content of sand 0.1-1 % d.w.).

Hijnen *et al.* (2000) tested dune sand (site 3) and gravel (site 9) at 16°C, using 0.5 m long columns. The resulting DEC values for phage MS2, *E.coli*, *Clostridium* spores (SCP), and (oo)cysts of *Cryptosporidium parvum* (CP) and *Giardia lamblia* (GL) are listed in Table 5, both for natural loadings with F-RNA phages, SSRC and COLI44 from their respective infiltration waters, and for a high experimental dosage with lab-grown micro-organisms. The results show that DEC increased when the infiltration rates decreased. The latter could be due to coagulation of particles at higher concentrations. The order of removal efficiency was: GL >> COLI44 ≥ SSRC > MS2. *C. parvum* oocysts were removed effectively in the gravel/sand columns, but were much less effectively removed in the sandy columns.

Table 5. Mean results for the column studies on dune sand from AR site 3, and on gravel from RBF site 9 (after Hijnen *et al.*, 2000). Input concentrations (in n/L) are given in the grey rows, other rows give DEC values. CP = *Cryptosporidium parvum*; GL = *Giardia lamblia*.

	F-RNA	COLI44	SSRC		
NATURAL	<100	6	34	-	-
Sand, 0.5 m/d	-	>0.6	0.6	-	-
Sand, 0.9 m/d	-	>0.6	0.4	-	-
	F-RNA	COLI44	SSRC		
NATURAL	850	2800	4600	-	-
Gravel, 0.9 m/d	>1.3	2.8	1.2	-	-
Gravel, 2.5 m/d	>1.3	1.5	1.6	-	-
	MS2	*E.coli*	SCP	CP	GL
DOSAGE	$2.3\ 10^9$	$2.3\ 10^6$	$7.2\ 10^5$	$2\ 10^6$	$2\ 10^6$
Sand, 0.5 m/d	2.2	4.5	≥4.3	3.6	6.7
Sand, 0.9 m/d	0.9	4.4	≥3.7	3.2	>6.9
	MS2	*E.coli*	SCP	CP	GL
DOSAGE	$2.4\ 10^9$	$1.2\ 10^6$	$6.5\ 10^5$	$1.8\ 10^6$	$1.7\ 10^6$
Gravel, 0.9 m/d	3	4	≥2.5	>7.2	>7.4
Gravel, 2.5 m/d	1.4	3.2	≥2.5	>6.7	>6.8

4 CONCLUSIONS

Aquifer passage in our AR or RBF systems results in hygienically safe water for drinking water supply. Soil passage is a very effective barrier against micro-organisms. From the spectrum of micro-organisms in surface water, viruses may be transported most readily through the soils, but also their concentrations are very significantly reduced. The first meters of soil passage are the most effective

Critical situations may arise, however, in the following cases: (a) where infiltration intensities are extremely high and travel times short, like in RBF systems drawing from gravel aquifers during flood events; and (b) where the recollection system may receive inputs through short circuits or imperfections in an air and water tight construction, allowing access of animal life or water from above. Further research should focus on the influence of suspended fines in groundwater, and on the relation between DEC and input concentration.

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