APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Jan. 1981, p. 139-147
0099-2240/81/010139-09$02.00/0
Vol. 41, No. 1

Virus Removal During Groundwater Recharge: Effects of Infiltration Rate on Adsorption of Poliovirus to Soil

JAMES M. VAUGHN,* EDWARD F. LANDRY, CHERYL A. BECKWITH, AND McHARRELL Z. THOMAS

Department of Energy and Environment, Brookhaven National Laboratory, Upton, New York 11973

Studies were conducted to determine the influence of infiltration rate on poliovirus removal during groundwater recharge with tertiary-treated wastewater effluents. Experiments were conducted at a uniquely designed, field-situated test recharge basin facility through which some 62,000 m^3 of sewage had been previously applied. Recharge at high infiltration rates (75 to 100 cm/h) resulted in the movement of considerable numbers of seeded poliovirus to the groundwater. Moderately reduced infiltration rates (6 cm/h) affected significantly improved virus removal. Very low infiltration rates (0.5 to 1.0 cm/h), achieved by partial clogging of the test basin, yielded the greatest virus removal efficiencies.

Several laboratory-scale studies have identified factors contributing to the removal of human enteric viruses during the renovation of domestic wastewater via passage through soils. Drewry and Eliassen (7) reported that adsorption rather than filtration was the major mechanism of removal during sand or soil percolation. Gerba et al. (10) later indicated that adsorption was influenced by a number of factors including the pH of recharged water, the chemical composition and moisture content of the soil, and the infiltration rate through the soil. Attachment of virus to soil has also been shown to be related to the ionic strength of the adsorbing material (8, 15, 23). Clean, dry sand has been shown to have little virus-adsorbing capacity (2), whereas previously moistened sand has demonstrated improved removal efficiencies (19). Soils containing clays were reported to have the greatest virus-adsorbing capacity (7), due primarily to their large surface area (4).

Comparatively few reports have characterized naturally occurring virus populations in wastewater-recharged groundwater. Wellings et al. (23) described the isolation of polioviruses and coxsackieviruses from an aquifer directly beneath a cypress dome used for the recharge of secondarily treated effluent. Schaub and Sorber (21) also reported sporadic enterovirus occurrence in recharged groundwater, whereas Gilbert et al. (11) were unable to detect viruses in groundwater samples taken at the Flushing Meadows recharge project. More recently, Vaughn et al. (22) reported the recovery of various enteroviruses from groundwater at three separate recharge sites located on Long Island.

Most of the above field studies were conducted at recharge sites receiving secondarily treated sewage. The present report relates the results of experimentation carried out at a uniquely designed recharge installation which received tertiary-treated effluent. The major emphasis of the study was the identification of the influence of infiltration rate on virus-soil interactions during normal recharge operations.

MATERIALS AND METHODS

Experimental site. The study site was located at the 12-Pines treatment facility in Medford, Suffolk County, N.Y. The treatment plant (Fig. 1) was designed to accommodate a population of 12,400 and has the capacity to treat 1.2 million gal (4.7 million liters) of wastewater per day. Throughout the duration of the studies reported here, the treatment plant was operating at approximately one-half capacity. The treatment sequence (Fig. 2) combined conventional primary and secondary treatment processes with a denitrification step. After final clarification, effluents were passed through filters composed of garnet, quartz, and anthracite; they were then disinfected by chlorination. Treated effluents were then either pumped to a series of recharge basins (seven basins, 2.5 total acres) or diverted to the experimental basin. The typical physical and chemical characteristics of the tertiary effluent and the renovated wastewater (i.e., groundwater beneath the recharge basin) are given in Table 1.

The experimental facility used in this study, constructed and operated by the U.S. Geological Survey, was located in the northeast corner of the site (Fig. 3). The structure was a miniaturized version of the adjacent recharge basins, consisting of a circular test basin 6.09 m in diameter (25 m^2), whose surface was approximately 7.62 m above the static water level. A concrete-walled manhole had been carefully constructed through the center of the basin to a depth of 6.4 m, within which gravity samplers (38.7-cm^2 capture area) were constructed at depths of 0.75, 2.25, and 5.34 m. Each sampler extended 0.9 m into the surrounding basin. Platforms were installed at the 2.5- and 4.9-m marks within the manhole to provide working levels.

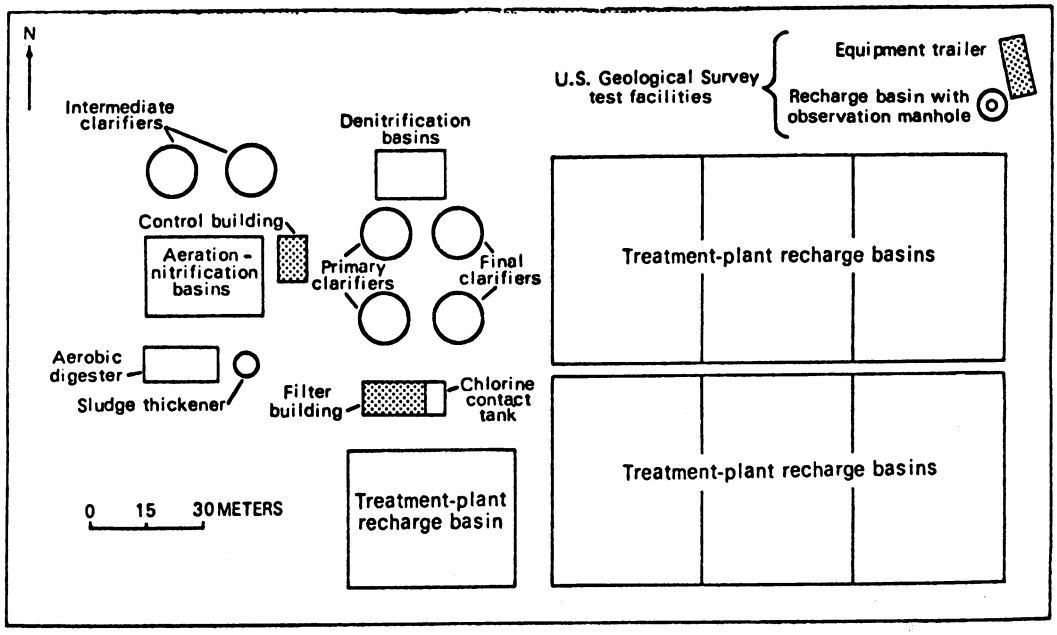

FIG. 1. *Schematic diagram of advanced wastewater treatment plant and U.S. Geological Survey testing Facility. Reprinted with permission of the authors (20).*

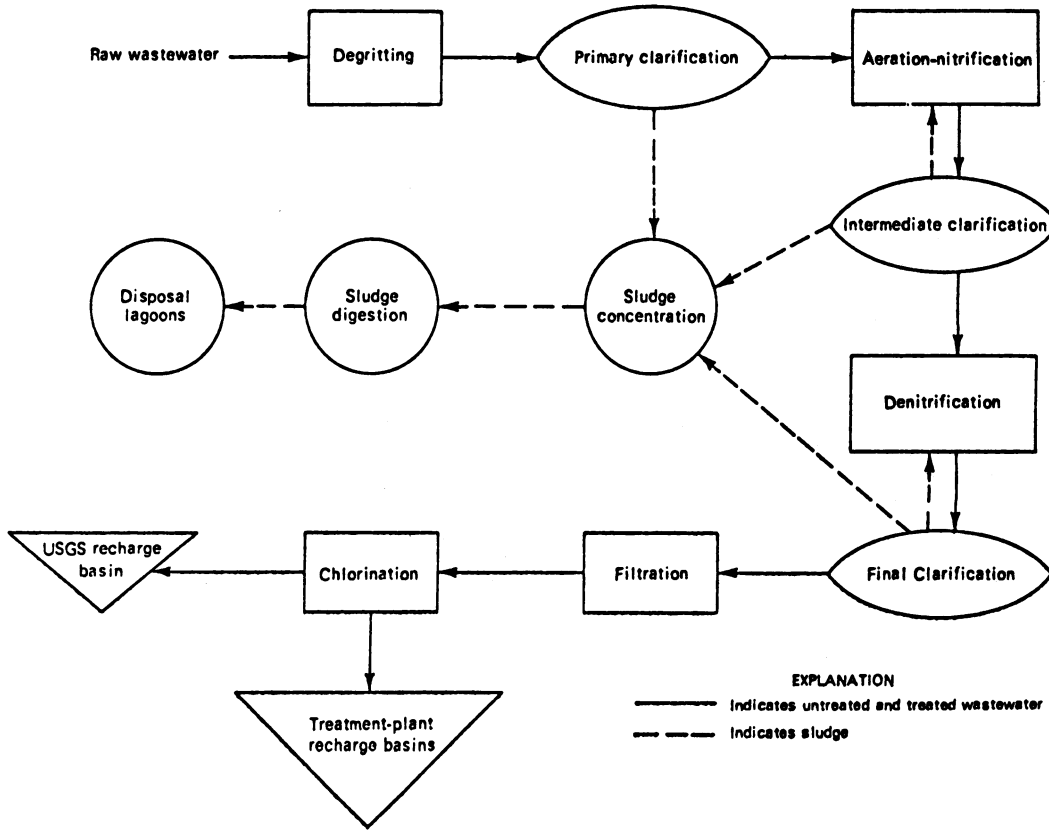

FIG. 2. *Major steps of the 12-Pines treatment process. Reprinted with permission of the authors (20).*

TABLE 1. *Chemical and physical characteristics of 12-Pines tertiary-treated sewage effluent and renovated water*

Determination[a]	Sewage effluent	Renovated water
Turbidity (NTU)[b]	4.58 (1.2–9.0)[c]	7.2 (2.5–15)
Conductivity (μmho/cm)	439.50 (393–500)	459.0 (389–500)
pH	6.62 (6.10–7.20)	6.11 (5.2–7.1)
Total alkalinity	95.38 (48–115)	67.12 (31–98)
Chloride	54.13 (47–64)	53.5 (50–56)
Sulfate	35.63 (28–54)	36.0 (29–56)
Nitrate-nitrogen	3.38 (0.07–16.0)	7.54 (0.09–17)
Nitrite-nitrogen	0.11 (0.006–0.49)	0.026 (0.003–0.083)
Ammonia-nitrogen	5.34 (0.06–15)	0.38 (0.16–1.1)
Total Kjeldahl nitrogen	6.63 (0.9–17)	2.27 (0.6–10)
Orthophosphate	6.13 (4.8–6.8)	6.07 (4.8–7.0)
Iron	<0.05 (<0.05)	0.05 (<0.05–0.1)
Manganese	0.02 (0.01–0.03)	0.078 (0.02–0.15)
Magnesium	4.53 (2.7–7.8)	4.26 (2.6–7.0)
Calcium	19.0 (15–24)	21.37 (17–33)
Sodium	58.25 (54–68)	59.12 (54–68)
Potassium	12.25 (11–13)	12.87 (12–14)
Total suspended solids	5.00 (1–14)	NT[d]
Total organic carbon	15.13 (10–29)	NT

[a] Except for pH and where noted, all determinations are in milligrams per liter.
[b] NTU, Nephelometric turbidity units.
[c] Values in parentheses are ranges.
[d] NT, Not tested.

At the bottom of the manhole a 9-cm-diameter well had been sunk into the static water table (some 2 m below) to allow the sampling of waters which had percolated through the basin. The test basin was equipped with instrumentation for measuring water level, infiltration rate, temperature, and conductivity. The basin soil consisted primarily of coarse sand and fine gravel and contained an average of 1.12% silt and clay (Table 2). The study facility normally operated at a loading rate of 40,000 liters per day and provided the advantages of a large operating surface with the ability to control experimental variations which might be applied to the system. As of this writing, approximately 62,000 m^3 of tertiary sewage effluent had been applied to the test basin.

Viruses and host cells. Poliovirus type 1 LSc 2ab was provided by R. Reid (Carborundum Corp.). Poliovirus LScg^r-T, a spontaneous guanidine-resistant mutant of strain LSc 2ab, selected by multiple passage in host cells grown in guanidine-containing media (18), was a gift from Dr. R. Tershak (Pennsylvania State University).

Viruses were propagated on monolayers of low-passage Buffalo green monkey kidney cells (BGM, Microbiological Associates) grown in Eagle minimal essential medium (MEM) with Earle balanced salt solution supplemented with 10% fetal calf serum, glutamine, and antibiotics (penicillin, streptomycin, and gentamicin). Viruses were maintained in monodispersed stocks prepared by passage through serum-treated 50-nm filters (13).

Virus assay. Viral enumerations were carried out on monolayers of BGM cells which were propagated as described above. Sample volumes of 0.5 ml were placed on cell monolayers (25-cm^2 flasks) and incubated with rocking for 1 h to facilitate virus attachment. After decanting excess inoculum, infected monolayers were overlaid with minimal essential medium plaquing medium, incubated for 1 to 3 days (36°C), and then stained with a second agar overlay containing neutral red.

Other physical and chemical tests. Physicochemical testing of tertiary sewage effluent and renovated wastewater was carried out by the Suffolk County Department of Environmental Control. All determinations were made by appropriate standard techniques (1).

Field sampling. Large-volume samples were collected in 220-liter tanks (Plast-i-cube; Grief Brothers Corp., Staten Island, N.Y.) which had been sanitized with 0.12 N hydrochloric acid. Immediately before collection at each site, tanks and pumping equipment were rinsed with 40 to 80 liters of the various waters to be sampled. Small-volume samples (100 ml to 4 liters) were collected in sterile 4-liter containers.

Virus concentration procedures. Concentration of viruses from large volumes involved a filter adsorption-beef extract elution-organic flocculation method (17). Briefly, samples were acidified to pH 3.5, supplemented with $AlCl_3$ (0.5 mM), and passed through a virus-concentrating filter series consisting of a fiberglass depth cartridge filter (K-27) and a pleated cartridge filter (Duo-Fine; Filterite, Timonium, Md.). Viruses were eluted from filters with 1-liter volumes of 0.5 M tris(hydroxymethyl)aminomethane-buffered 3% beef extract (pH 9.5). Reconcentrations followed the technique of Katzenelson et al. (14). Eluate pH was adjusted to 3.5, causing the formation of a virus-adsorbing protein precipitate. After 30 min, the precipitate was collected by centrifugation (5,000 × *g* for 10 min), and the resulting pellets were dissolved in 20- to 25-ml volumes of 0.15 dibasic sodium phosphate (Na_2HPO_4, pH 9.0). Concentrates were neutralized to pH 7.2 and stored at −60°C to await assay.

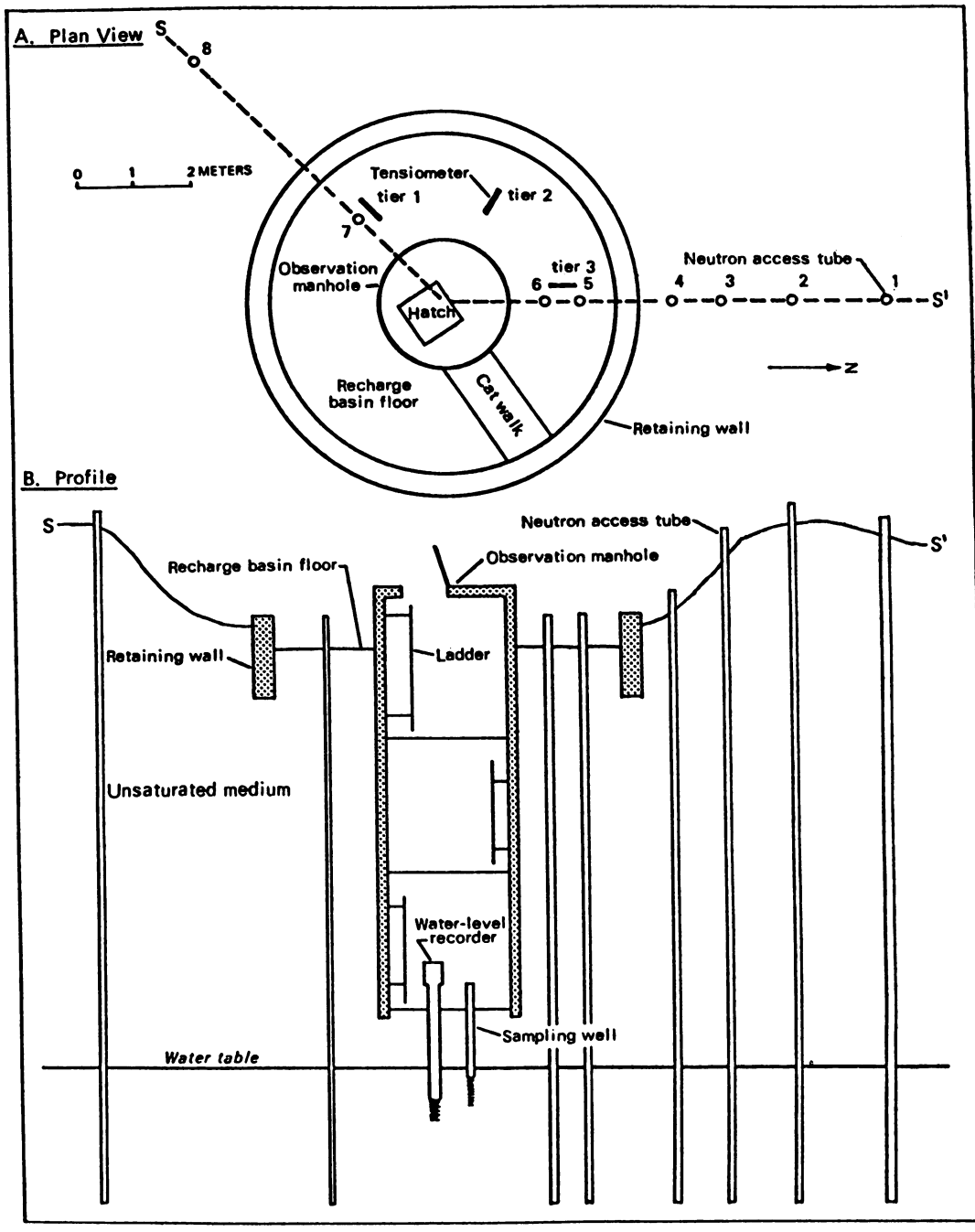

FIG. 3. *Schematic diagram of the U.S. Geological Survey test basin facility. Reprinted with permission of the authors (20).*

Small-volume samples of up to 4 liters were supplemented with 3% beef extract and then precipitated and processed as described above.

Test basin seeding experiments. Seeding experiments were conducted to assess the virus-removing capacity of the test basin when operated at various infiltration rates. All experiments used tertiary effluent which had been seeded with known numbers of poliovirus type 1 LSc 2ab or LScg^r-T.

(i) High-rate recharge. For several weeks preced-

TABLE 2. *Particle size analysis of test basin soil from unsaturated zone*

Particle diam (mm)	% Composition at depths below basin surface		
	0.75 m	2.25 m	5.34 m
Silt and clay, <0.0625	0.30	0.75	1.2
Sand			
0.0625–0.125	0.4	1.8	1.6
0.125–0.250	3.3	23.5	10.9
0.250–0.5	14.1	27.5	25.2
0.5–1	36.4	25.8	36.3
1–2	13.4	4.1	6.2
Gravel			
2–4	6.9	4.2	4.3
4–8	6.4	4.1	4.3
8–16	9.6	8.0	6.2
16–32	9.3	0.0	3.5
32–64	0.0	0.0	0.0

ing the high-infiltration-rate experiment, the test basin was allowed to dry. One week before the experiment, the top 2.5 cm of basin soil was removed and replaced with clean sand which had been excavated during construction of the basin. These manipulations resulted in an infiltration rate of 75 to 100 cm/h (as measured by neutron sampler). Monodispersed poliovirus LSc 2ab was added to 4,000 liters of unchlorinated tertiary effluent to a final concentration of 2.3×10^6 plaque-forming units PFU/liter. Seeded sewage was then rapidly pumped into the test basin (1,000 liters/min) and allowed to drain through the basin surface. Normal recharge was then resumed with the chlorinated tertiary effluent pumped from the nearby treatment plant. During passage of the seeded "front" of water through the basin, 1-liter samples were collected at timed intervals from the intermediate-level gravity samplers. After passage of this initial virus front, interval sampling was discontinued in lieu of composite (2 to 3 h) sample collection. Large-volume (380 liters) renovated water samples were collected at intervals from the groundwater observation well located beneath the basin.

Low-rate recharge. The first low-infiltration-rate experiment was conducted after a prolonged period of sewage recharge (6 weeks) which resulted in sufficient basin clogging to produce a stable 6-cm/h infiltration rate. Poliovirus type 1 LSc 2ab, prepared as previously described, was seeded into 8,500 liters of unchlorinated tertiary sewage effluent to a final concentration of $\sim 7 \times 10^4$ PFU/liter. Seeded waters were then applied to the basin and allowed to drain through its surface. Normal tertiary effluent recharge was then resumed. Composite samples of 1 to 2 liters were collected from gravity samplers over a period of several days. The reduced infiltration rate of this experiment produced significantly smaller sample volumes per unit time at each sampler than did the previous high-rate experiment. Large-volume samples (400 liters) were collected over the same interval from the groundwater observation well. Samples were processed and analyzed for virus by the previously described methods.

Very low rate recharge. To obtain infiltration rates of a lower order than in the preceding experiment, it was necessary to further clog the surface of the test basin. This was done by suspending the settled solids in the treatment plant chlorine-contact chamber by manual mixing. The particulate-laden effluent was then pumped into the test basin and allowed to clog its surface. With this method, stable infiltration rates of 0.5 to 2.0 cm/h could be produced.

Two separate experiments were conducted at these lowered infiltration rates. The first of these was carried out at an infiltration rate of 1 cm/h. The test basin was challenged with 4,000 liters of tertiary effluent containing approximately 7.8×10^5 PFU of poliovirus LSc 2ab per liter. Complete infiltration of this volume through the basin surface required some 36 h. Normal recharge was then resumed. Composite samples were collected from each gravity sampler level over an 8-day period. Sample volumes varied from 0.17 to 809 liters, depending on the location of the sampler and the experimental stage at which samples were collected.

An additional experiment was conducted at 0.5 cm/h with a guanidine-resistant strain of poliovirus type 1 (LSc 2abg^r-T), the adsorption-desorption profile of which has been shown to be more consistent with that of other enterovirus types (16). The experimental procedure was as described in the previous study except that samples were collected over a 16-day period. The initial virus concentration in the seeded effluent was 1.92×10^6 PFU/liter.

RESULTS AND DISCUSSION

Currently practiced sewage treatment methods generally cannot ensure the removal of all human viruses from treated wastewater (5, 6, 22). The presence of these organisms has been viewed as a potential hazard to wastewater reuse operations, especially those involving aquifer supplementation by recharge (2, 3, 12). Although the precise health hazard posed by the groundwater contamination with these agents cannot be accurately assessed due to the lack of epidemiological evidence, the optimization of land treatment systems for their removal appears to be a reasonable and prudent goal. To date, no attempts have been made to control virus penetration in operating recharge basins, and the 12-Pines test recharge basin facility offers a unique opportunity to initiate such a study.

Virus migration during high-rate recharge (75 to 100 cm/h). Initial experiments were designed to determine the extent of virus migration through the test basin during normal recharge operations. Since most of the recharge basins on Long Island are composed of coarse, sandy soils, the infiltration rates which normally occur during recharge are quite high (50 to 75 cm/h), with little or no ponding of wastewater in the basins (should ponding occur, basins are immediately dried and scarified to allow resumption of high-rate discharge). Such high infiltration rates do not appear to be necessary for

disposal of wastewater generated by the various plants, as most basins are designed to handle recharge at a much slower rate (5 gal/day per ft^2, or 0.8 cm/h). However, as local practices involved recharge at high rate, this condition was chosen as a starting point for our experiments. The results (Table 3) indicated extremely poor virus retention at this rate with high concentrations of viruses detected at all sampling levels. The seeded effluent apparently moved through the first level (0.75 m) in a sharply defined band (samples 1 through 3), with decreasing numbers of viruses observed after the passage of the sewage front (samples 4 through 9) through this area. By the time the band had reached level 2 (2.25 m), it had been rendered less compact by diffusion within the soil column. Fewer viruses were isolated at this level, indicating that some virus adsorption had occurred between the first and second levels. The high virus numbers detected in the initial sample from level 3 (5.34 m) may have been the result of channeling through some portions of the basin (this early arrival of virus was not consistent with prior estimates of the lead water travel time). The band of water containing the highest viral concentrations appeared to pass the third sampler during the 2.8 to 3.0-h interval. Reduced numbers of viruses were recovered from the acquifer located 7.6 m below the floor of the recharge basin. This reduction was likely the result of the dilution of the virus-containing water after entrance into the groundwater table.

TABLE 3. *Movement of poliovirus LSc 2ab through a recharge basin during high-rate recharge (75 to 100 cm/h)*

Depth below surface of basin floor (m)	Sample no.	Time after seeding (h)	Virus recovered (PFU/liter × 10^4)
0.75 (level 1)	1	0.60–0.81	78.00
	2	0.86–0.91	97.50
	3	1.03–1.06	26.50
	4	1.20–1.23	1.46
	5	1.41–1.45	1.94
	6	1.58–1.61	1.22
	7	1.75–1.78	0.79
	8	2.00–2.03	0.90
	9	2.41–2.45	0.03
2.25 (level 2)	1	1.20–1.30	2.44
	2	1.41–1.50	8.58
	3	1.58–1.63	6.70
	4	1.75–1.81	5.40
	5	2.00–2.08	1.81
	6	2.25–2.31	1.38
	7	2.50–2.56	0.31
	8	2.58–3.86	0.05
5.34 (level 3)	1	1.78–2.15	8.82
	2	2.16–2.28	0.54
	3	2.33–2.41	0.27
	4	2.50–2.55	1.81
	5	2.81–2.85	10.10
	6	3.00–3.03	9.80
	7	3.28–3.31	3.32
	8	3.50–3.53	1.96
	9	3.53–4.03	0.12
7.62 (level 4)	1	2.50–2.66	0.11
	2	4.66–4.83	0.001

The data indicated that significant numbers of virus could move appreciable vertical distances during high-rate recharge. It is important to note that the virus type used in this study, poliovirus LSc 2ab, had previously been shown to absorb to basin soils more efficiently than other enterovirus types (16). This suggested that viruses which normally absorb poorly to Long Island soils (e.g., coxsackievirus B3) might move in greater concentrations and to greater depths than the experimental strain. This selective adsorption might explain the isolation of certain virus types (e.g., echovirus and coxsackievirus) and not others (poliovirus) from aquifers beneath field recharge basins noted during a previously reported study (21).

Virus migration during low-rate recharge. The first low-rate experiment was conducted by using a basin surface which had become clogged during prolonged recharge (~6 weeks). Throughout the experiment, an infiltration rate of 6 cm/h was maintained. Data resulting from the experiment (Table 4) indicated that a significant reduction in viral numbers had occurred during passage through the test basin. Peak virus concentrations in the 0.75-m sampler were noted between 4 and 10 h after basin seeding, but these levels (16 to 20 PFU/liter) were significantly lower than input values (7×10^4 PFU/liter). Samples collected on the following day yielded even fewer isolates, suggesting that significant adsorption had occurred within the top 0.75 m of soil. Low concentrations of viruses were recovered from most of the samples collected at level 2, with a concentration peak occurring at 11 h. No viruses were recovered during passage of the lead band of water through the 5.3-m sampler level. A spot check of this sampler on the following day, however, indicated that viruses were moving through this area. Extensive sampling of the observation well over a 3-day period indicated that few viruses were able to travel through the entire 7.6 m of soil. The peak concentration of viruses in the groundwater observation well (0.35 PFU/liter) was noted at 24 h. These results represented a significant improvement in virus removal when compared with data obtained during the previous high-rate recharge.

Although a substantial number of viruses were

TABLE 4. *Movement of poliovirus LSc 2ab through a recharge basin during low-rate recharge (6 cm/h)*

Depth below surface of basin floor (m)	Sample no.	Time after seeding (h)	Virus recovered (PFU/liter)
0.75 (level 1)	1	1.45–2.25	0
	2	2.25–3.00	0
	3	3.00–4.63	7.90
	4	4.63–6.66	16.90
	5	6.66–8.53	20.00
	6	8.53–9.25	17.70
	7	9.25–10.08	25.25
	8	23.63–24.25	1.90
	9	28.81–29.33	3.70
2.25 (level 2)	1	2.26–2.91	5.45
	2	2.91–3.61	0
	3	3.61–5.26	3.18
	4	5.26–7.66	3.60
	5	7.66–10.08	11.60
	6	10.08–11.16	2.20
	7	11.16–11.91	23.30
	8	23.68–24.33	1.59
	9	28.78–29.41	19.50
5.34 (level 3)	1	6.83–9.41	0
	2	9.41–11.91	0
	3	23.83–25.08	38.20
	4	28.75–29.83	0
7.62 (level 4)	1	0	0
	2	12	0
	3	24	0.35
	4	30	0
	5	48	0
	6	54	0.08
	7	72	0.07

retained by the soil during recharge at 6 cm/h, a portion of the population was able to move through the entire unsaturated zone. To determine whether such movement could be completely eliminated, experiments were conducted at even lower infiltration rates (0.5 to 1 cm/h).

The results of one such experiment are presented in Table 5. Significant virus removal was observed during recharge at an infiltration rate of 1 cm/h. Viruses were not detected at the 0.75-m level until 24 to 48 h after inoculation of the basin, and then only at greatly reduced concentrations. Subsequent sampling at this level revealed a consistent decrease in virus concentrations with time. Samples from levels 2 and 3 also yielded low concentrations of viruses. It appeared that the initial band of virus-containing water (level 1, 24 to 48 h) retained the same concentration of viruses as it moved through level 2 (48 to 97 h). Data from large-volume samples (400 to 800 liters) collected from the observation well (level 4) revealed that few viruses were able to completely penetrate the length of the basin.

Previous data (16) had indicated that virus interactions with soil often varied with virus type. Whereas poliovirus LSc 2ab absorbed extremely well to soil, other virus types absorbed with varied efficiency. Since all basin-seeding experiments had to be conducted with the LSc strain (because of potential hazards associated with the seeding of environmental systems with virulent strains), it is possible that data generated during the above experiments are inappropriate for extrapolation to other enterovirus types. An earlier report (16) had indicated that the soil interactions of guanidine-resistant strains of poliovirus LSc 2ab were more consistent with those of other enteroviruses. This virus was chosen for use in an additional low-infiltration-rate study (0.5 cm/h). The results of this experiment (Table 6) demonstrated a dramatic decrease in virus migration at all levels. A significant reduction in virus concentration was noted at the 0.75-m level, indicating considerable adsorption above this point. Few viruses were detected in samples from the groundwater observation well, with recoveries occurring in only two of the nine samples assayed.

The extensive virus adsorption seen in this experiment (as compared with the previous experiments) could be attributed to one or all of

TABLE 5. *Movement of poliovirus LSc 2ab through a recharge basin during very low rate recharge (1 cm/h)*

Depth below surface of basin floor (m)	Sample no.	Time after seeding (h)	Virus recovered (PFU/liter)
0.75 (level 1)	1	8–24	0
	2	24–48	4.07×10^2
	3	48–72	2.29×10^2
	4	72–98	2.09×10^1
	5	98–118	2.09×10^1
2.25 (level 2)	1	34–48	0
	2	48–72	4.13×10^2
	3	72–97	5.71×10^2
	4	97–120	0
	5	120–168	2.47×10^1
5.34 (level 3)	1	74–99	0
	2	99–122	0
	3	122–144	8.15×10^1
	4	144–170	1.94×10^2
7.62 (level 4)	1	73	0
	2	98	0
	3	121	0
	4	143	4.21
	5	170	1.37×10^{-2}
	6	194	6.63×10^{-2}
	7	218	1.24×10^{-1}

TABLE 6. *Movement of poliovirus LSc 2abg^r in a recharge basin during low-rate recharge (0.5 cm/h)*

Depth below surface of basin floor (m)	Sample no.	Time after seeding (h)	Virus recovered (PFU/liter)
0.75 (level 1)	1	8–23	0
	2	23–47	0
	3	47–71	0
	4	71–95	14.0
	5	95–119	15.3
	6	119–168	0
	7	168–213	13.6
2.25 (level 2)	1	9–40	0
	2	40–64	0
	3	64–88	14.4
	4	88–112	0
	5	112–161	Toxic
	6	161–206	0
5.34 (level 3)	1	73–143	0
	2	143–194	0
	3	194–242	175.2
	4	242–290	0
	5	290–338	0
	6	338–386	159.2
7.62 (level 4)	1	97	0
	2	121	0.001
	3	144	0.032
	4	170	0
	5	194	0
	6	242	0
	7	290	0
	8	338	0
	9	386	0

the following factors: (i) the different soil adsorption characteristics and soil extraction efficiencies of the guanidine-resistant and the parent LSc strain; (ii) the further decrease in infiltration rate (0.5 cm/h); and (ii) the increased amount of suspended solids deposited on the basin surface to obtain the reduced infiltration rate. It is unlikely that virus strain differences contributed to the increased retention, since previous laboratory experiments had shown the guanidine-resistant strain to be adsorbed less efficiently to soils than LSc 2ab (16). It follows, therefore, that the mutant viruses should have migrated to greater soil depths during the experiment. It is not known whether the surface mat created by the settling of the added suspended solids significantly contributed to the increased adsorption of viruses. Given the available data, it would be difficult to independently analyze the adsorption effects of the mat versus the likely influence of the resulting reduced infiltration rate. Although the addition of suspended solids might change the composition of the soil, making it more favorable to virus adsorption at the surface, it would have no effect on adsorption to the underlying soils. An analysis of the relative rates of virus removal at each level (at low infiltration rate) with high and low suspended solid content may provide the answer. Virus inactivation, although not directly assessed during the experiments, may have significantly contributed to the observations made during the low-infiltration-rate studies. In addition, the presence of residual chlorine in the "chase" waters may have enhanced the observed virus removal. Regardless of the exact removal mechanism, the data indicated that proper basin control could virtually eliminate poliovirus migration to the aquifer during recharge through soils which would normally be considered to be poor virus adsorbers (9).

The preceding experiments indicate the importance of basin management during groundwater recharge with treated domestic wastewater. Recharge may be used for both rapid water disposal (assuming that high-quality wastewater is being used) and additional treatment of lesser-quality effluents. For sewage treatment plants which ordinarily produce good-quality effluent (e.g., low virus recoveries), basin control (i.e., lowering infiltration rates) may not be indicated. Such plants would be appropriate for rapid, large-volume water disposal. However, in the case of plants producing lower-quality effluents (e.g., secondary treatment plants), basin control becomes a crucial method for further treatment. Several such treatment plants have been identified on Long Island (22), and basin control should be an important aspect of their treatment scheme.

The present study indicates that the high infiltration rates which normally occur during the initial phases of sewage recharge in this region may facilitate the movement of viruses into the groundwater aquifer. By allowing infiltration rates to be reduced by continual recharge, the potential for viral contamination of groundwater would be minimized.

It should be noted that the findings presented herein pertain only to the soil type described in Table 2 and may not be directly applicable to regions containing significantly different soil compositions.

ACKNOWLEDGMENTS

This project was supported by the U.S. Environmental Protection Agency under contract 804776-01.

We acknowledge the assistance of L. Baranosky, M. Dahl, N. Delihas, and E. Arndt, of the Brookhaven Virology Group, and R. Prill, E. Oaksford, and J. Potorti, of the U.S. Geological

Survey. Chemical analyses were performed by the Suffolk County Department of Environmental Control.

LITERATURE CITED

1. **American Public Health Association.** 1976. Standard methods for the examination of water and wastewater, 14th ed. American Public Health Association, Inc., Washington, D.C.
2. **Berg, G.** 1973. Reassessment of the virus problem in sewage and in surface and renovated waters. Prog. Water Technol. **3**:87–94.
3. **Bernard, M. A.** 1973. Land disposal and sewage effluent: appraisal of health effects of pathogenic organisms. J. Am. Water Works Assoc. **65**:432–440.
4. **Bitton, G.** 1975. Adsorption of viruses onto surfaces in soil and water. Water Res. **9**:473–484.
5. **Buras, N.** 1976. Concentration of enteric viruses in wastewater and effluent: a two-year survey. Water Res. **10**: 295–298.
6. **Clark, E. M., O. S. Knowles, F. T. Shimada, A. J. Rhodes, R. C. Ritchie, and W. L. Donahue.** 1951. Coxsackie virus in urban sewage. Can. J. Public Health **42**:103.
7. **Drewry, W. A., and R. Eliassen.** 1968. Virus movement in groundwater. J. Water Pollut. Control Fed. **40**:R257–R271.
8. **Duboise, S. M., B. E. Moore, and B. P. Sagik.** 1976. Poliovirus survival and movement in a sandy forest soil. Appl. Environ. Microbiol. **31**:536–543.
9. **Gerba, C. P., and S. M. Goyal.** 1978. Adsorption of selected enteroviruses to soil, p. 225–234. *In* H. L. McKim (ed.), State of knowledge in land treatment of wastewater. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, N.H.
10. **Gerba, C. P., C. Wallis, and J. L. Melnick.** 1975. Fate of wastewater bacteria and viruses in soil. J. Irrig. Drain Div. Am. Soc. Civ. Eng. **101**:157–174.
11. **Gilbert, R. S., C. P. Gerba, R. C. Rice, H. Bouwer, C. Wallis, and J. L. Melnick.** 1976. Virus and bacteria removal from wastewater by land treatment. Appl. Environ. Microbiol. **32**:333–338.
12. **Hori, D. H., N. C. Burbank, R. H. Young, L. S. Law, and H. W. Klemmer.** 1970. Migration of poliovirus type 2 in percolating water through selected Oahu soils. Tech. Rep. no. 36. Water Resources Center, University of Hawaii, Honolulu.
13. **Jakubowski, W., W. F. Hill, Jr., and N. A. Clarke.** 1975. Comparative study of four microporous filters for concentrating viruses from drinking water. Appl. Microbiol. **30**:58–65.
14. **Katzenelson, E., B. Fattal, and T. Hostovesky.** 1976. Organic flocculation: an efficient second-step concentration method for the detection of viruses in tap water. Appl. Environ. Microbiol. **32**:638–639.
15. **Lance, J. C., C. P. Gerba, and J. L. Melnick.** 1976. Virus movement in soil columns flooded with secondary sewage effluent. Appl. Environ. Microbiol. **32**:520–526.
16. **Landry, E. F., J. M. Vaughn, M. Z. Thomas, and C. A. Beckwith.** 1979. Adsorption of enteroviruses to soil cores and their subsequent elution by artificial rainwater. Appl. Environ. Microbiol. **38**:680–687.
17. **Landry, E. F., J. M. Vaughn, M. Z. Thomas, and T. J. Vicale.** 1978. Efficiency of beef extract for the recovery of poliovirus from wastewater effluents. Appl. Environ. Microbiol. **36**:544–548.
18. **Melnick, J. L., D. Crowther, and J. Barrera-Ovo.** 1961. Rapid development of drug resistant mutants of poliovirus. Science **134**:557.
19. **Nestor, I., and L. Costin.** 1971. The removal of Coxsackie virus from water by sand obtained from the rapid sand filters of water plants. J. Hyg. Epidemiol. Microbiol. Immunol. **15**:129–136.
20. **Prill, R. C., E. T. Oaksford, and J. E. Potorti.** 1979. A facility designed to monitor the unsaturated zone during infiltration of tertiary-treated sewage, Long Island, New York. U.S. Geol. Surv. Water Resour. Invest., p. 79.
21. **Schaub, S. A., and C. A. Sorber.** 1977. Virus and bacteria: removal from wastewater by rapid infiltration through soil. Appl. Environ. Microbiol. **33**:609–619.
22. **Vaughn, J. M., E. F. Landry, L. J. Baranosky, C. A. Beckwith, M. C. Dahl, and N. C. Delihas.** 1978. Survey of human virus occurrence in wastewater-recharged groundwater on Long Island. Appl. Environ. Microbiol. **36**:47–51.
23. **Wellings, F. M., A. L. Lewis, C. W. Mountain, and L. V. Pierce.** 1975. Demonstration of virus in groundwater after effluent discharge onto soil. Appl. Microbiol. **29**: 751–757.