APPENDIX 1

BACTERIA AND VIRUS SURVIVAL AND TRANSPORT IN SOIL AND GROUNDWATER

AN ANNOTATED BIBLIOGRAPHY

Excerpted from

Survival and Transport of Enteric Bacteria and Viruses in the Nearshore Marine Environment:

An Annotated Bibliography
by
George R. Heufelder and Susan K. Rask

Reproduced as Part of a Training Course on Title 5

MODULE 2

VERTICAL SEPARATION TO GROUNDWATER

Course compiled by
Barnstable County Department of Health and the Environment

Allen, M. J. 1981. Microbiology of ground water. JWPCF 53:1107-1109.

Literature summary on the entrainment of pathogens and indicator organisms in groundwater. 23 refs.

Asano, T., ed. 1985. Artificial Recharge of Groundwater Butterworth Publishing, Boston.

Berg, G.,ed. 1983. Viral Pollution of the Environment CRC Press, Boca Raton, FL

Bitton, G. *1975.* Adsorption of viruses onto surfaces in soil and water. Water Research 9:473-484.

Literature review. Viruses act as electrically charged colloidal particles which may adsorb to surfaces outside the host cells. The adsorptive interactions between viruses and surfaces influence the behavior of viruses in soil and other environments. 8 figs.

Bouwer, S., S. C. Lance, and M. S. Riggs. 1974. High-rate land treatment II: water quality and economic aspects of the Flushing Meadows project. JWPCF 46:844

Most fecal coliform were removed in the first 2 ft (60 cm) of soil. Infiltration of fecal coliforms was slightly higher when initial flooding followed a dry period.

Brown, K. W., H. W. Wolf, K. C. Donnelly, and S. F. Slowey. 1979. The movement of fecal coliforms and coliphages below septic lines. J. Environ. Qual. 8:121-125.

Septic effluent was applied to subsurface to three soil types of 80, 41 and 7.6 % sand content. Applied effluent averaged 1.108 x 106 plus or minus I x 10^4 FC/100 ml. Fecal coliform were present in leachate collected 120 cm below septic lines only on a few occasions. Coliphages also showed limited mobility. 7 figs., 13 refs.

Burge, W. D. and N. K. Enkiri. 1978. Virus adsorption by five soils. J. Environ. Qual. 7:73-76.

Adsorption rate of virus to soil was correlated with cation exchange capacity, specific surface areas, organic content and p14 of soil. Soil which did not adsorb virus had coarsest texture and highest pH. High negative correlation with pH is due to the amphoteric nature of virus coats; lowering soil pH increases the postive charge on the virus particle making it more likely to adsorb to soil surface. 7 figs., 14 refs.

Cogger, C. G., L. M. Hajjar, C. L. Moe, and M. D. Sobsey. 1988. Septic system performance on a coastal barrier island. J. Environ. Qual. 17:40 1-408.

Evaluated effect of loading rate and water table depth on wastewater treatment from septic absorption fields in sandy soil. When soil under the leach fields remained aerobic, almost complete nitrification occurred and fecal coliform counts were reduced to an average of 60 MIPN per liter. However, when water tables were closer to the leach fields, soils underneath became anaerobic and nitrogen was found predominantly as ammonia while FC averaged over 25,000 MIPN per liter. Loading rate had a significant effect on all constituents, but was secondary to water table level.

Dizer, H., A. Nasser, and J. M. Lopez. 1984. Penetration of different human pathogenic viruses into sand columns percolated with distilled water, groundwater, or wastewater. Appl. Environ. Microbiol. 47:409-415.

Enteroviruses and rotavirus SAl I were applied to 80 cm sand columns at a number of infiltration velocities. Tertiary treated effluent showed best adsorption; adsorption was poor for secondary effluent, probably due to increased organic content. Presence of surfactants significantly reduced adsorption. Results indicate that sand, even of low clay content, and at infiltration velocities of 0.5 to *5* in/day, is an excellent material for the elimination of viruses from contaminated waters. 7 figs., 22 refs.

Duboise, S. M., B. E. Moore, C. A. Sorber, and B. P. Sagik. 1979. Viruses in Soil Systems. CRC Critical Reviews in Microbiology 9:245-285.

Extensive literature review of behavior of viruses in soils. Summary discussion points out the need for site-specific data to predict viral behavior. 9 figs., 301 refs.

Duboise, S. M., B. E. Moore, and B. P. Sagik. 1976. Poliovirus survival and movement in a sandy forest soil. April. Environ. Microbiol. 31:536-543.

Ionic strength and pH of soil water greatly affect poliovirus adsorption to soil. Cycles of rainfall and effluent application, resulting in ionic gradients, caused viral elution off soils. Poliovirus survived in soil at 4 C to 20 C for up to 84 days. 9 figs., 21 refs.

Duda, A. M., and K. D. Cromartie. 1982. Coastal pollution from septic tank drainflelds. J. Environ. Eng. Div.. Amer. Soc. Civil Eng. 108:1265-1279.

Septic tank drainflelds installed in unsuitable soils were implicated as a major source of coliform contamination of coastal waters. Higher levels of indicator bacteria were found in catchments with greater number of septic systems, in both wet and dry conditions. Authors calculate that densities of more than 0.15 septic drainflelds per acre (equals one septic drainfleld per 7 acres watershed) result in bacterial levels high enough to cause shellfish closure. 8 figs., 17 refs.

Edniond, R. *L*. 1976. Survival of coliform bacteria in sewage sludge applied to a forest clearcut and potential movement into groundwater. Appl. Environ. Microbiol. 32:537-546.

Fecal colifonn applied to soil persisted for at least 204 days. In summer, aftergrowth of low numbers of fecal coliforms was noted. Die off rates were highest in winter. Both total and fecal coliforms migrated to soil beneath surface, but few moved more than *5* cm. 10 figs., 12 refs.

Farrah, S. R., G. Bitton, E. M. Hoffmann, 0. Lanni, 0. C. Pancorho, M. D. Lutrick, and .1. F. Bertrand. 1981. Survival of enteroviruses and coliform bacteria in a sludge lagoon. AmA. Environ. Microbiol. 41:459-465.

Enteroviruses are efficiently retained by sludge-soil mixtures; viruses were not detected in 40-60 foot wells monitored at the site. 6 figs., 17 refs.

Funderburg, S. W., B. F. Moore, B. P. Sagik and C. A. Sorber. 1981. Viral transport through soil columns under conditions of saturated flow. Water Research 15:703-711.

Movement of poliovirus 1, reovirus 3 and bacteriophage 0X174 was studied in 8 different soils. Adsorption and entrainment were related to soil cation exchange capacity (CEC), organic content, percent clay, pH, and specific surface area. Poliovirus recovery was correlated with low CEC and high organic carbon and clay content. Recovery of 0X174 was related to low CEC and low organic carbon. Soil CEC values of 23 meq/ 100 g were sufficient to remove at least 99% of poliovirus within 33 cm. 6 figs., 22 refs.

Gerba, C. P., C. Wallis, J. L. Melnick. 1975. Fate of wastewater bacteria and viruses in soil. J. of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 101:157-175.

Literature summary. Soil moisture content, temperature, PH, availability of nutrients and antagonism are the principle factors influencing the survival of enteric bacteria in soils. The amount of information on virus survival in soil is very limited, but viruses appear to survive at least as long, if not longer than enteric bacteria. S figs., 63 refs.

Gerba, C. P., and J. C. Lance. 1978. Poliovirus removal from primary and secondary sewage effluent by soil filtration. AmA. Environ. Microbiol.. 36:247-251.

Primary and secondary sewage effluent applied to 240 cm soil column, using loamy sand. Adsorption of virus to soil, and desorption by distilled water were similar for both effluents. The greater concentration of organics in primary effluent did not appreciably affect the removal of poliovirus by the soil. 5 figs., 22 refs.

Gerba, C. P., and S. M. Goyal. 1985. Pathogen removal from wastewater during groundwater recharge. pp 283-317 in T. Asano, ed. Artificial Recharge of Groundwater, Butterworth Publishing, Boston, *1985.*

Review of recent information on variables affecting microorganism survival and movement through soil, and fate of pathogens in subsurface waters, including results of field studies. 12 *figs.*, 99 refs.

Gerba,C. P., and S. F. McNabb. 1981. Microbial aspects of groundwater pollution. ASM News 47:326-329.

Overview of the problems associated with groundwater microbiology. Cites studies documenting coliform travel in groundwater a distance of 900 m from site of application and viral travel to 408 m. 21 refs.

Gilbert, R. G., C. P. Gerba, R. C. Rice, H. Bouwer, C. Wallis, and S. L. Melnick. 1976. Virus and bacteria removal from wastewater by land treatment. AunI. Environ. Microbiol. 32:333-338.

Secondary sewage effluent was land-applied. After percolation through 9 meters of sandy loam soil no viruses or Salmonella spp. were detected in well samples, and the number of fecal coliform, fecal streptococci and total bacteria were decreased by 99.9%. 6 figs., l9refs.

Goyal, S. M. and C. P. Gerba. 1979. Comparative adsorption of human enteroviruses, simian rotavirus, and selected bacteriophages to soils. Appi. Environ. Microbiol. 3 8:241-247.

Viral adsorption to soil shows high variability among viral types, and among different strains of the same virus. Adsorption was also influenced by soil type and soil pH; soils with pH less than *5* were generally good adsorbers. Results emphasize that no one virus or soil can be used as sole model for predicting viral adsorption. 6 figs., 30 refs.

Hagedorn, C., D. T. Hansen and G. H. Simonson. 1978. Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. J. Environ. Quality. *7:55-59.*

E. coli and Streptococcus faecalis survived in groundwater to 32 days. Neither bacteria was detected in wells 30 in distance on day 32, but sufficient time may not have elapsed for travel in groundwater to this distance. Rainfall caused a peak in the bacterial numbers in wells. *5* figs., 8 refs.

Harvey, R. W., L. H. George, R. L. Smith, and D. R. LeBlane. 1989. Transport of microspheres and indigenous bacteria through a sandy aquifer:results of natural and forced-gradient tracer experiments. Environ. Sci. Technol. *23:51-56.*

Fluorochrome stained bacteria, conservative tracers (Br or Cl) and bacteria-sized (0.2-1.3 micron) microspheres having carboxylated, carbonyl or neutral surfaces were injected into a sandy aquifer. In natural-gradient test, surface characteristics had greatest effect on attenuation while particle size had a secondary effect. In forced-gradient experiment, stained bacteria showed breakout well before conservative tracer, and transport of bacteria was different from that of carboxylated microspheres of same size. 5 figs., 20 refs.

Hunt, C. S., C. P. Gerba and I. Cech. 1980. Effects of environmental variables and soil characteristics on virus survival in soil. Appi. Environ. Microbiol. 40:1067-1079.

Primary factors affecting virus survival in soils were temperature and viral adsorption to soil. Viral survival was also dependent on soil moisture, presence of aerobic microorganisms, soil levels of resin-extractable phosphorus, exchangable aluminum, and soil pH. 12 figs., 18 refs.

Hunt, C. S., C. P. Gerba, S. C. Lance, and R. C. Rice. 1980. Survival of enteroviruses in rapid-infiltration basins during the land application of wastewater. Anni. Environ. Microbiol. 40:192-200.

Poliovirus type 1 and Echovirus 1. Viruses exhibited a differential downward migration; 100 times more poliovirus than echovirus migrated 5-10 cm. after 5 days. Results indicate that the rate of virus inactivation was dependent on rate of soil moisture loss; drying cycles during the land application of wastewater enhance virus inactivation in soils. Maximum survival measured was 60 cm. 9 figs., 25 refs.

Keswick, B. H. and C. P. Gerba. 1980. Viruses in Groundwater. Environmental Science & Technology 14:1290-1297.

Literature summary with many useful charts for entrainment of viruses in groundwater, including the effects of various parameters on entrainment. 7 figs., 56 refs.

Kibbey, H. S., C. Hagedorn, and E. L. McCoy. 1978. Use of fecal streptococci as indicators of pollution in soil. Appl. Environ. Microbiol. 35:711-717.

Streptococcus faecalis survived up to 12 weeks in soil under cool, moist conditions (4 and 10 C). Freeze-thaw cycles killed the bacteria. Bacteria exhibited variation in die-off among soil types. 8 figs., 15 refs.

Lance, S. C., C. P. Gerba, and S. L. Melnick. 1976. Virus movement in soil columns flooded with secondary sewage effluent. AmA. Environ. Microbiol. 32:520-526.

Poliovirus i in sewage effluent traveled a maximum of 160 cm through a 250 cm column packed with calcareous sand. Most viruses were adsorbed in the top 5 cm of soil. Flooding with deionized water caused desorption from the soil and increased virus movement in the soils. 99.99 % or more removal of virus would be expected after passage of secondary effluent though 250 cm of calcareous sand unless heavy rains fell within 1 day of application. 9 figs., 16 refs.

Lance, J. C., C. P. Gerha and S. S. Wang. 1982. Comparative movement of different enteroviruses in soil columns. J. Environ. Qual. 11:347-351.

Travel of Echo 1, Echo 29, and Polio 1 viruses through 250 m soil columns. Greater than 99.9% of viruses were removed by 160 cm. Virus movement thru loamy sand roughly parallels travel of fecal coliform. 8 figs., 15 refs.

Lance, S. C. and C. P. Gerba. 1984. Virus movement in soil during saturated and unsaturated flow. April. Environ. Microbiol. 47:335-337.

Movement of poliovims during unsaturated flow of sewage thru 250 cm. soil columns was much less than during saturated flow. Vimses moved 160 cm under saturated flow, vs. 40 cm during unsaturated flow. 4 figs., 13 refs.

Landry, E. F., S. M. Vaughn, M. I Thomas and C. A. Beckwith. 1979. Adsorption of enteroviruses to soil cores and their subsequent elution by artificial rainwater. Arrnl. Environ. Microbiol. 38:680-687.

Lo, S. H., and 0. 5. Sproul 1977. Polio-virus adsorption from water onto silicate minerals. Water Research ll:653-658.

The presence of proteinaceous materials decreased the ability of silicate minerals to adsorb virus; extraneous organic material not only competed for adsorption sites but also desorbed the virus from the minerals. Organics in treated wastewater reduced the total adsorption capacity and rate of adsorption. 6 figs., 18 refs.

Mack, W. N., Vue-Shoung Lu, D. B. Coohon. 1972. Isolation of poliomyditis virus from a contaminated well. Health Services Reports 87:271-274.

Poliovirus was isolated from drinking water from a well located more than 300 feet from the edge of a sewage drainfleld. However, the well casing was in limestone so that percolation through soil may not have been involved. Actual source of virus in the well water was not determined. 2 figs., 4 refs.

Mallmann, W. L., and W. Litsky. 1951. Survival of selected enteric organisms in various types of soil. American J. of Public Health 41:38-44.

The longevity of coliform organisms, typhoid bacilli and enterococci in soil was prolonged with an increase in the organic content of the soil. Coliforms were found to persist in soil for long periods, while enterococci died out rapidly. 5 figs., 13 refs.

Marzouk, V., S. M. Goyal, and C. P. Gerba. 1980. Relationship of viruses and indicator bacteria in water and wastewater of Isreal. Water Research. 14:1585-1590.

No correlation was found between indicator bacteria and the presence of viruses in groundwater. Suggests that the expected movement of viruses vs. bacteria in groundwater should be different. 5 figs., 33 refs.

McConnell, L. K., R. C. Sims, and B. B. Barnett. 1984. Reovirus removal and inactivation by slow-rate sand filtration. Aypl. Environ. Microbiol. 48:818-825.

Greatest removal of reovirus occurred in the top few centimeters of a slow sand filtration bed. No virus was found in effluent after it passed through 1.2 m of sand medium (99.9 % sand, 0.1 % clay). 11 figs., 38 refs.

McFeters, G. A., G. K. Bissonnette, J. J. .Jezeski, C. A. Thomson, and It G. Stuart. 1974. Comparative survival of indicator bacteria and enteric pathogens in well water. A~pl. Microbiol. 27:823-829

Comparative survival of various bacteria in flowing well water was as follows: Aeromonas sp. > the shigellae > fecal streptococci> coliforms = some salmonellae > Streptococcus equinus> Vibrio cholerae> Salmonella typhi> Streptococcus bovis> Salmonella enteritidis. 6 figs., 21 refs.

Melnick, S. L., and C. P. Gerba. 1980. The Ecology of Enteroviruses in Natural Waters. Critical Rev. Environ. Control. 10:65-93.

Extensive literature review. Topics include occurrence of enteroviruses in surface, marine, and groundwaters, mechanisms of viral transport, ral survival in natural waters. 11 figs., 146 refs.

Moore, B. E., B. P. Sagik, and C. A. Sorber. 1981. Viral transport to ground water at a wastewater land application site. JWPCF 53:1492-1502.

Sewage effluent was applied to calcereous well-drained soils with moderate permeability *(1.5-5.1* cm/h), soil pH of 7.7-9.0, and CEC of *25-50* meq/100 g. Fecal coliform and fecal streptococci were reduced by 90% with 0.46 m. infiltration depth. Enteric viruses were found to travel to a depth of at least 1.37 m. 9 Figs., 13 refs.

Moore, S. A. and G. R. Beehier. 1984. A study of the pollution potential of land-spread septage. J. Environ. Health 46:17 1-175.

Saturated flow conditions in sandy soil resulted in movement of fecal coliforms to shallow (3 meter) water table. 2 figs., 14 refs.

Moore, R. S., D. II. Taylor, L. S. Sturman, M. M. Reddy, and G.W. Fuhs. 1981. Poliovirus Adsorption by 34 Minerals and Soils. April. Environ. Microbiol. *42:963-975.*

A strong negative correlation was found between poliovirus adsorption and both the content of organic matter and the available negative surface charge on the substrates. The effects of surface area and p11 were not strongly correlated with viral adsorption. 11 figs., 44 refs.

Rebhun, M., and J. Schwartz. 1968. Clogging and contamination processes in recharge wells. Water Resources Research. 4:1207- 1217.

Found coliform multiplication in wells. High cofiform counts found in the repumped water were result of bacterial multiplication (growth) on the accumulated organic matter (consisting mostly of algal cells) which serves as a nutrient. 12 figs., 7 refs.

Renean, R. B., and D. E. Pettry. *1975.* Movements of coliform bacteria from septic tank effluent though selected coastal plain soils of Virginia. J. Environ. Qual. 4:41-44.

Coastal plains soils considered “marginally conducive” for sanitary disposal, due to seasonally fluctuating water tables and/or restricting layers, were investigated. Lateral movement of fecal coliform to at least 13.5 meters was observed, but fecal coliform did not penetrate confining layers to reach groundwater. 4 figs., 18 refs.

Schaub, S. A., and C. A. Sorber. 1977. Virus and bacteria removal from wastewater by rapid infiltration though soil. AmA. Environ. Microbiol. 33:609-619.

Wastewater applied to plots of unconsolidated silty sand and gravel. Indigeneous enteroviruses and coliphage 12 tracer were sporadically detected in groundwater to horizontal distances of 600 fl from the application zone. Fecal strep which penetrated the surface layer also travelled this distance. Enteric indicator bacteria were concentrated on soil surface by filtration on soil surface mat. 12 figs., 15 refs.

Schaub, S. A., and B. P. Sagik. *1975.* Association of enteroviruses with natural and artificially introduced colloidal solids in water and infectivity of solids-associated viions. April. Microbiol. 30:212-222.

Encephalomyocarditis viruses adsorb to introduced organic and inorganic material over a wide range of pH and with various concentrations of metal cations. Clay-adsorbed viruses maintained their infectivity. 9 figs., 41 refs.

Schenerman, P. R., G. Bitton, A. R. Overman, and G. E. Gifford. 1979. Transport of viruses through organic soils and sediments. Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers 105:629-641.

Wetland organic soils (cypress domes) appear not to be suitable for application of wastewater for treatment. The presence of humic substances originating from these black organic sediments was shown to interfere with the sorptive capacity of soils and sediments toward viruses. 10 figs., 14 refs.

Sinton, L. W. 1986. Microbial contamination of alluvial gravel aquifers by septic tank effluent. Water, Air, and Soil Pollution 28:407-425.

Fecal coliform were shown to travel 9 m from a *5.5* m deep soakage pit in an unconfined aquifer, and 42 m from an 18 m deep injection bore in a confined aquifer. Fecal coliform levels were reduced by factor of 3 within the septic tank. 10 figs.,26 refs.

Sobsey, M. D., C. H. Dean, M. E. Knuckles and R. A. Wagner. 1980. Interactions and survival of enteric viruses in soil materials. April. Environ. Microbiol. 40:92-101.

Clayey soils efficiently adsorbed poliovirus and reovirus from wastewater over a range of pH and total dissolved solids levels. Sands and organic materials were relatively poor adsorbents, though in some cases their ability to adsorb increased at low pH and with the addition of total dissolved solids or divalent cations; however, they did give> *95%* virus removal from intermittently applied, unsaturated flow wastewater. Simulated rainfall through columns easily eluted viruses off sandy soils, but did not elute viruses from clayey soils. 10 figs., 24 refs.

Stiles, C. W., and H. R. Crohurst. 1923. The principles underlying the movement of Bacillus coil in ground-water, with resulting pollution of wells. Public Health Report 38:1350-1353.

B. coli was found to travel up to 65 feet after being added to the saturated zone in fine sand (effective grain size of 0.13 mm)

Tate, R. L., III. 1978. Cultural and environmental factors affecting the longevity of Escherichia coli in histosols. Appl. Environ. Microbiol. 35:925-929.

The number of viable B. coil cells found in Pahokee Muck was approximately threefold greater than that found in Pompano fine sand after 8 days incubation. Greatest coliform survival was seen under anaerobic conditions. Coliform die-off appears to be controlled by biotic factors, including protozoa. Increased coliform survival in histosol compared to mineral soil was due to the higher organic content of the histosoL 6 figs., 15 refs.

Temple. K. L., A. K. Camper, and G. A. McFeters. 1980. Survival of two enterobacteria in feces buried in soil under field conditions. AppI. Environ. Microbiol. 40:794-797.

Authors show persistence of fecal bacterial viability in feces to at least 8 weeks (10^6 reduced to 10^3 or 10^3) under field conditions during a snow free period.

U.S. EPA. 1987. Septic tank siting to minimize the contamination of ground water by microorganisms. U. S. EPA Office of Groundwater Protection, Washington, D. C.

This publication outlines a rating system developed for use as a tool in siting septic systems to minimize microrganismal contamination of groundwater. Eight factors were used in the rating system: depth to water, net recharge, hydraulic conductivity, temperature, soil texture, aquifer medium, application rate, and distance to point of water use. Factors are then rated, weighted, and summed to indicate relative potential for groundwater contamination. Extensive references. 122 refs.

U.S. EPA. 1987. Ground water quality protection: state and local strategies. EPA/600/55-86/00l January 1987.

Summaries are presented often state and three local programs for groundwater protection. A variety of technical and institutional approaches for information management, classification, standards, source control and implementation are presented.

Vaughn, James M. and E. Landry. 1983. Viruses in soil and groundwater. Chapter 9 in G. Berg (Ed.) Viral Pollution of the Environment CRC Press, Boca Raton, Florida.

A comprehensive review of the literature on the subject. Useful summary tables presented. 3 figs, 182 refs.

Vaughn, J. M., E. F. Landry, C. A. Beckwith and M. Z. Thomas. 1981. Virus removal during groundwater recharge: effects of infiltration rate on adsorption of poliovirus to soil. Appl. Environ. Microbiol. 41:139-147.

Tertiary-treated effluent was applied to recharge basins. High infiltration rates (75-100 cmlhr) resulted in movement of substantial numbers of poliovirus to groundwater. Infiltration rates of 6 cm/hr. significantly improved virus removal; highest viral removal efficiency was seen at very low infiltration rates of 0.5-1.0 cm/hr. 9 figs., 23 refs.

Vaughn, J. M., E. F. Landry and M. Z. Thomas. 1983. Entrainment of viruses from septic tank leach fields through a shallow, sandy soil aquifer. Appl. Environ. Microbiol. 45:1474-1480.

Authors document travel of human enteroviruses from a subsurface wastewater disposal system in an area of sandy unconsolidated soil with a shallow aquifer. Enteroviruses were detected at a lateral distance of 67.05 m and at aquifer depths of 18 m. Virus occurrence was not correlated with total or fecal coliform numbers. S figs., 25 refs.

Vaughn, J. M., E. F. Landry, L. S. Baranosky, C. A. Beckwith, M. C. DahI, N. C. Delihas. 1978. Survey of human virus occurrence in wastewater recharged groundwater on Long Island. AppL Environ. Microbiol. 36: 47-51.

Secondary- and tertiary-treated effluent was applied to recharge basins in sandy unconsolidated soil. Viruses were detected in groundwater where the recharge basins were located less than 35 feet (10.6 m) above the aquifer. Lateral entrainment of viruses to 45.7 m was noted at one site. 9 figs., 22 refs.

Wang, D-S, C. P. Gerba, and S. C. Lance. 1981. Effect of soil permeability on vims removal through soil columns. Appl. Environ. Microbiol. 42:83-88.

Secondarily treated wastewater was applied to 100 cm soil columns. Viral removal was primarily determined by flow rate. At 33 cm/day sandy loam removed 99% seeded poliovirus in first 7 cm. At 300 cm/day rubicon sand removed less than 90% in 100 cm. This study suggests that the rate of water flow thru the soil may be the most important factor in predicting viral movement into the groundwater. 9 figs., 23 refs.

Wellings, F. M., A. L. Lewis, C. W. Mountain, and L. M. Stark. 1975. Virus consideration in land disposal of sewage effluents and sludge. Florida Scientist 38:202-207.

Virus was shown to survive in groundwater for at least 28 days.3 figs., 11 refs.

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.

Secondary effluent was discharged to a cypress dome; underlying soil strata was organic matter, sand and relatively impermeable sandlclay layers. Study found viral percolation to 3.05 m depth, and 7 m subsurface lateral movement of virus. Virus survived at least 28 days in groundwater. 4 figs., 20 refs.

V., C. P. Gerba, and L. M. KeIley. 1985. Virus persistence in groundwater. Appl. Environ. Microbiol. 49:778-781.

Temperature was found to be the single best predictor of virus persistence in groundwater. At lower temperatures (approx. 4 C) both poliovirus 1 and echovirus 1 persisted for up to 28.8 days before a 1 LTR (log titre reduction) took place. At 26 C, pollovirus survived 3-5 days before a 1 LTR took place. 3 figs., 19 refs.