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

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MODULE 2

VERTICAL SEPARATION TO GROUNDWATER

Course compiled by

Barnstable County Department of Health and the Environment

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


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.


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.


Septic effluent was applied to subsurface to three soil types of 80, 41 and 7.6 % sand content. Applied effluent averaged 1.108 x 10^6 plus or minus 1 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.


Adsorption rate of virus to soil was correlated with cation exchange capacity, specific surface areas, organic content and pH 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 positive charge on the virus particle making it more likely to adsorb to soil surface. 7 figs., 14 refs.

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.


Enteroviruses and rotavirus SA1-1 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.


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.


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.


Septic tank drainfields 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 drainfields per acre (equals one septic drainfield per 7 acres watershed) result in bacterial levels high enough to cause shellfish closure. 8 figs., 17 refs.

Fecal coliform 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.


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.


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.


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. 5 figs., 63 refs.


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.


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.

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.


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., 19 refs.


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.


*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.


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.


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, exchangeable aluminum, and soil pH. 12 figs., 18 refs.

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.


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


*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.


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.


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.


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.


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.


Poliovirus was isolated from drinking water from a well located more than 300 feet from the edge of a sewage drainfield. 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.


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.


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.


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.


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.

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


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.


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


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 pH were not strongly correlated with viral adsorption. 11 figs., 44 refs.


Found coliform multiplication in wells. High coliform 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.


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.


Wastewater applied to plots of unconsolidated silty sand and gravel. Indigenous
enteroviruses and coliphage 12 tracer were sporadically detected in groundwater to
horizontal distances of 600 ft 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.

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.

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.


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.


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
coli 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
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.


Authors show persistence of fecal bacterial viability in feces to at least 8 weeks ($10^6$ reduced to $10^3$ or $10^5$) under field conditions during a snow free period.


This publication outlines a rating system developed for use as a tool in siting septic systems to minimize microorganismal 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.


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.


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


Tertiary-treated effluent was applied to recharge basins. High infiltration rates (75-100 cm/hr) 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.

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.


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.


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.


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


Secondary effluent was discharged to a cypress dome; underlying soil strata was organic matter, sand and relatively impermeable sandclay 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.


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, poliovirus survived 3-5 days before a 1 LTR took place. 3 figs., 19 refs.