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CHAPTER 19

Virus Survival and Transport in Groundwater

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Almost half of all documented outbreaks of water-borne disease in the United States result from contaminated groundwater. Many of these outbreaks are known to be caused by viral agents. An understanding of factors that control virus migration through subsurface soil systems is necessary for the management of septic tank and wastewater land-treatment systems. The effectiveness of virus removal during land application of wastes is determined by their survival in the subsurface and their retention by soil particles. Both survival and retention are largely determined by (1) climate; (2) nature of the soil; and (3) nature of the microorganisms. Climate influences subsurface temperature which is probably the single most important factor in survival of viruses. Viruses are removed from groundwater by adsorption which is controlled by various characteristics of soil and the type and strain of virus. Both electrostatic and hydrophobic effects are now believed to be involved in virus adsorption.

INTRODUCTION

The fate and transport of pathogenic microorganisms is an area of major public health concern. Almost half of the outbreaks of water-borne diseases each year in the United States are caused by contaminated groundwater (Craun 1979). Overflow from septic tanks and cesspools was believed responsible for 42% of outbreaks, and 71% of illness in nonmunicipal systems. In one of the largest documented outbreaks of water-borne diseases in recent years, an estimated 8,000 persons developed gastroenteritis from the consumption of contaminated groundwater (Hejkal et al. 1982). Furthermore, 65% of the documented outbreaks of water-borne disease from 1946 through 1977 can be attributed to illness of probable viral etiology (i.e., Norwalk agent). This number probably represents only a fraction of the actual number of virus-caused outbreaks because of the difficulties involved in proving a viral etiology of a water-borne outbreak. Recent research indicates that the Norwalk agent (a virus which causes gastroenteritis in man) is a major cause of outbreaks of water-borne disease in the United States (Kaplan et al. 1982).

The occurrence of human enteric viruses in groundwater in locations near surface waste discharges has been well documented (Keswick and Gerba 1980). Most of these studies were conducted beneath areas where the land application of domestic sewage was being practiced, although some data does exist on viral contamination of drinking-water wells (Keswick and Gerba 1980; Hejkal et al. 1982). These studies indicate that viruses can travel to depths as great as 64 m and distances as great as 408 m under certain conditions. Unfortunately, few studies have been done on viral contamination of groundwater near septic tanks, which are believed to be responsible for most of the outbreaks of groundwater diseases.

Two principal factors control virus contamination of groundwater, i.e., their survival in the subsurface and their retention by soil particles. The longer a virus survives, the greater the chance that an event will occur that may promote its migration through the subsurface. Based on laboratory studies and field observations, survival and retention appear to be determined largely by the three factors listed in Table 1.

TABLE 1. *Virus fate in soil*

Effectiveness of virus removal is determined by:

1. Survival
2. Retention

which are largely determined by:

1. Climate
2. Nature of the soil
3. Nature of the microorganism

Climate will control two important factors in determining viral survival. These two factors are temperature and rainfall. The survival of viruses is greatly prolonged at low temperatures; below 4 C, they can survive for months or even years (Gerba et al. 1975). At higher temperatures, inactivation or die-off is fairly rapid. Survival of viruses near the surface would be expected to be more limited since drying adversely affects survival of viruses.

The nature of the soil will play a major role in determining survival. Soil properties influence moisture-holding capacity, pH, and organic matter, all of which will control the survival of viruses in the soil. We have conducted studies recently on the effect of soil properties on survival of viruses (Hurst et al. 1980). The results indicated that adsorption of viruses to the soil particles offers protection against factors responsible for viral inactivation in soil. Soil-saturated pH, exchangeable aluminum, and resin-extractable phosphorus can be correlated with virus survival, but all of these factors appear to be related to the degree of virus adsorption. Using these factors, it was possible to develop a linear regression equation for comparing survival of viruses among different soil types (Hurst et al. 1980).

Virus adsorption to soils and other solids (Gerba and Schaiberger 1975) acts to prolong survival of viruses as compared to freely suspended or unassociated virus. Thus, survival of unassociated virus in the groundwater is also important. Published studies are almost nonexistent on the survival of human enteric viruses in groundwater. Field studies by Wellings et al. (1975) suggest that viruses could survive for at least 28 d in groundwater. We recently have conducted a series of experiments on the comparative survival of enteric bacteria and viruses in groundwater (Keswick et al. 1982). In these studies the test organisms were contained in McFeters' type survival chambers (McFeters and Stuart 1972) and exposed to a continuous flow of groundwater from a 84-m deep domestic well. The rate of inactivation of each organism is indicated in Table 2. The survival of the test organisms ranked in order of increasing survival time were *Escherichia coli*, fecal streptococcus, f2 bacteriophage, SA-11 rotavirus, echovirus-1, coxsackievirus B3, and poliovirus-1. When compared to values previously reported (in which McFeters' type chambers were used), enteric viruses and bacteria survive longer in the groundwater used in this study than in surface waters (LaBelle and Gerba 1980; O'Brien and Newman 1977). This is probably attributable to a number of factors such as lower temperature, protection from sunlight, and lack of microbial antagonism. The fact that enteroviruses had lower inactivation rates than indicator bacteria is not surprising as this has been reported previously in surface waters (Berg and Metcalf 1978). It was further interesting that the f2 phage and *E. coli* appear to be poor indicators of the survival of the animal viruses. The choice of coliforms for viral pathogens is once again questioned by the data as *E. coli* had the fastest die-off rate of any of the organisms. The fecal streptococcus, on the other hand, was more indicative of virus survival.

TABLE 2. *Survival of enteric bacteria and virus in groundwater*

Organism	Days to One LRT[a]	Two LRT
Poliovirus type 1	8	10
Coxsackievirus type B3	4	11
Echovirus type 1	2	6
Rotavirus SA-11	2	5
Bacteriophage f2	2	3
Escherichia coli	2	3
Fecal streptococcus	2	5

[a] Log_{10} reduction in titer.

Retention of viruses by soil is, of course, a paramount consideration in protecting groundwater from contamination. Filtration plays a major role in bacterial removal although adsorption is also involved. Removal of viruses is believed to be almost totally dependent on adsorption (Keswick and Gerba 1980). The nature of the soil probably plays a major role in determining the degree of virus adsorption. Understanding the physical-chemical properties of the soil as related to virus adsorption has been seen as an aid in understanding the potential for groundwater contamination. Virus adsorption to soils is believed to be governed largely by electrostatic, double-layer interactions and Van der Waal's forces (Murray and Parks 1980). More recent work (Zerda and Gerba, unpubl. data) indicates that hydrophobic interactions also could play a significant role (Farrah et al. 1981).

A number of studies evaluating virus adsorption to soils using batch reactors has been conducted (Goyal and Gerba 1979; Moore et al. 1981). In these studies, a given amount of soil was mixed with virus suspended in a solution and adsorption determined after a given period of time. The results of such studies indicate that virus adsorption is related to cation exchange capacity, pH, surface area, and organic matter, but firm predictive correlations between virus adsorption and these factors have not been well established. Moore et al. (1981) recently found a strong negative correlation between poliovirus adsorption and the available negative surface charge on soils as determined by their capacities for adsorbing the cationic polyelectrolyte, polydiallyldimethylammonium chloride. It was suggested by the authors that the amount of polyelectrolyte adsorbed per area unit of soil surface could be used as an indicator of a given ability of soil to adsorb virus.

Establishment of predictive relationships between soil factors and virus adsorption is complicated further by genetic variability among the different types of viruses and strains. The isoelectric point of viruses varies among strains and types of viruses, and we have shown this to affect virus adsorption ot surfaces (Gerba et al. 1981; Zerda et al. 1981). The hydrophobicity of the virus also may be involved (S. Singh and C. P. Gerba, unpubl. data).

Batch studies have shown also that the pH of the suspending media, soluble organics, and the presence of cations will influence virus adsorption (Keswick and Gerba 1980). All of these factors act to influence the electrostatic potential between the virus and soil. Generally speaking, increasing cation concentration and decreasing pH and soluble organics tend to promote virus adsorption.

Unfortunately, viruses cannot be considered permanently immobilized after adsorption onto a soil particle. This became clear in the study of a land application site in Florida by Wellings et al. (1975). Viruses remained undetected in wells approximately 3 m (10 ft) and 6 m (20 ft) below the soil surface until after periods of high rainfall. Subsequent laboratory studies confirmed that viruses previously adsorbed near the soil surface desorb and migrate further through the soil column (Lance et al. 1976). The degree of elution which occurs during a rainfall event also appears to be dependent on both the type and specific strain of virus (Landry et al. 1979). Virus which eluted near the soil surface will eventually readsorb further down a soil column (Lance et al. 1976), but it has been speculated that viruses could travel vertically through the soil by a chromatograhic effect controlled by periodic rainfall events.

From the foregoing discussion, it is apparent that many factors control the removal of pathogenic viruses during the movement of wastewater through the soil. Although the presence of viruses in groundwater has been demonstrated during land disposal of sewage, it would appear that with proper site selection and management the presence of viruses could be minimized or eliminated. The key is to define further the processes involved in the survival and transport of viruses in groundwater.

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LITERATURE CITED

Berg, G., and T. G. Metcalf. 1978. Indicators of viruses in water. Pages 267-296 *in* G. Berg, ed. *Indicators of Viruses in Water and Food.* Ann Arbor Science Publishers, Ann Arbor, MI.

Craun, G. F. 1979. Waterborne diseases - a status report emphasizing outbreaks in groundwater systems. *Ground Water* 17:183-191.

Farrah, S. R., D. O. Shah, and L. O. Ingram. 1981. Effects of chaotropic and antichaotropic agents on elution of poliovirus adsorbed on membrane filters. *Proc. Natl. Acad. Sci. USA* 78:1229-1232.

Gerba, C. P., and G. E. Schaiberger. 1975. Effect of particulates on the survival of virus in seawater. *J. Water Pollut. Control Fed.* 47:93-103.

Gerba, C. P., C. Wallis, and J. L. Melnick. 1975. Fate of wastewater bacteria and viruses in soil. *J. Irrig. Drain. Div. ASCE* 101:154-174.

Gerba, C. P., S. N. Goyal, I. Cech, and G. F. Bogdan. 1981. Quantitative assessment of the adsorptive behavior of viruses to soils. *Environ. Sci. Technol.* 15:940-944.

Goyal, S. M., and C. P. Gerba. 1979. Comparative adsorption of human enterviruses, simian rotavirus, and selected bacteriophages to soils. *Appl. Environ. Microbiol.* 38:241-247.

Hejkal, R. W., B. Keswick, R. L. LaBelle, C. P. Gerba, Y. Sanchez, G. Dreesman, B. Hafkin, and J. L. Melnick. 1982. Viruses in a community water supply assoicated with an outbreak of gastroenteritis and infectious hepatitis. *J. Am. Water Works Assoc.* 74:318-321.

Hurst, C. J., C. P. Gerba, and I. Cech. 1980. Effects of environmental variables and soil characteristics on virus survival in soil. *Appl. Environ. Microbiol.* 40:1067-1079.

Kaplan, J. E., G. W. Gary, Jr., and H. B. Greenberg. 1982. The role of Norwalk virus in outbreaks of acute nonbacterial gastroenteritis. Abs. Annu. Mtg. Am. Soc. Microbiol., p. 290.

Keswick, B. H., and C. P. Gerba. 1980. Viruses in ground water. *Environ. Sci. Technol.* 14:1290-1297.

Keswick, B. H., C. P. Gerba, S. L. Secor, and I. Cech. 1982. Survival of enteric viruses and indicator bacteria in groundwater. *J. Environ. Sci. Health* A17:903-912.

LaBelle, R. L., and C. P. Gerba. 1980. Influence of estuarine sediment on virus survival under field conditions. *Appl. Environ. Microbiol.* 39:749-755.

Lance, J. C., C. P. Gerba, and J. L. Melnick. 1976. Virus movement in soil columns flooded with secondary sewage effluent. *Appl. Environ. Microboil.* 32:520-526.

Landry, E. F., J. M. Vaughn, M. Z. Thomas, and C. A. Beckwith. 1979. Adorption of enteroviruses to soil cores and their subsequent elution by artificial rainwater. *Appl. Environ. Microbiol.* 38:680-687.

McFeters, G. A., and D. G. Stuart. 1972. Survival of coliform bacteria in natural waters: Field and laboratory studies with membrane-filter chambers. *Appl. Microbiol.* 24:805-811.

Moore, R. S., D. H. Taylor, L. S. Sturman, M. M. Reddy, and G. W. Fuhs. 1981. Poliovirus adsorption by 34 minerals and soils. *Appl. Environ. Microbiol.* 42:963-975.

Murray, J. P., and G. A. Parks. 1980. Poliovirus adsorption on oxide surfaces - correspondence with the DLVO-Lifshitz theory of colloid stability. *Adv. Chem. Ser.* 189:97-133.

O'Brien, R. T., and J. S. Newman. 1977. Inactivation of polioviruses and coxsackiebiruses in surface water. *Appl. Environ. Microbiol.* 33:334-340.

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.

Zerda, K., K. C. Hou, and C. P. Gerba. 1981. Adorption of viruses to charge-modified silica. Abs. Annu. Mtg. Am. Soc. Microbiol. p. 219.