Microbial Contamination of Groundwater by Landfills: Risk Assessment

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Introduction

Sanitary and sludge landfills are potential sources of large numbers of pathogenic microorganisms which may leach into the groundwater. It is essential that criteria be developed to assess the risks associated with the landfilling of domestic wastes and sludges so that proper design criteria and standards can be developed. A large variety of enteric pathogens may be found in human feces and sewage sludge. Many bacterial, viral, protozoan and helminth pathogens are able to survive sludge treatment and be present in sludge destined for landfills (Gerba, 1983). In sanitary landfills, disposable diapers and pet feces also contribute pathogenic microorganisms to the landfill.

Pathways of Microbial Transport

Possible pathways by which infectious microorganisms may come into contact with humans during landfill operations are shown in Figure 1. The consequence of exposure by one or more routes of transmission is dependent upon the likelihood of significant numbers of pathogenic microorganisms being present to result in infection. It is not inconceivable that some microorganisms as a result of landfilling follow all of the routes illustrated in Figure 1. However, it is unlikely that significant exposure occurs by all of the pathways.

Exposure to personnel may occur through direct contact with the waste or through exposure to aerosols generated during burial. Aerosols could also be transported downwind to expose areas distant from the disposal site. Aerosols containing viable microorganisms also represent a means of direct contamination of clothing and equipment. Microorganisms may leach from the buried sludge with infiltrating water to contaminate the groundwater. Exposure of the wastes to the surface would result in the generation of runoff which would transport waste materials to nearby surface waters. It is also possible that if the site becomes saturated with water, surface leachate contamination will occur. Burrowing animals could come into contact with the buried waste and birds would be exposed before burial. These animals could serve to transport contaminated waste material off-site or expose it to the surface. Translocation of viruses from the subsurface roots of plants to the aerial parts of the plants is another potential pathway.

However, of all the potential pathways, the contamination of groundwater and use of that groundwater for domestic purposes appears the most likely route of significant human exposure from sludge and domestic waste burial (Gerba, 1986). The only other significant pathway is that of surface exposure of the buried wastes and consequent surface runoff and contamination of surface waters. Many of the landfills in the United States are operated over aquifers that are used as potable sources. A review of landfill sites (EPA, 1978) indicates that many are constructed within a few meters of the groundwater table.

While domestic solid wastes may contain significant concentrations of pathogenic microorganisms, sewage sludges usually contain far higher concentrations (Table 1). All types of sewage sludges (primary, secondary, raw and digested) are currently disposed of in sludge only landfills or codisposed with domestic solid wastes (EPA, 1978). A major difficulty in assessing the risks of groundwater contamination by landfilling sludge is the near absence of any field or laboratory studies concerning the survival and transport of pathogens into groundwater by this practice. Previous studies on land application of sludge have only been concerned with its application to the soil surface or within a few centimeters of the soil surface. Application rates at such sites are in the order of 10 tons/acre vs. 10,000 tons/acre or more at sludge landfills (EPA, 1978; Sagik et al., 1980). Thus, the concentration of pathogens/acre is much greater at landfill sites.

A review of the literature would suggest that, in terms of risk, significant concentrations of human pathogens can be expected in the sludges that landfills receive (Table 1). Most of the methods used in pathogen detection are not 100% efficient (Gerba and Goyal, 1982). In addition, methods do not exist for the detection of all of the pathogens which may occur in sewage sludges. As an example, recent studies on the occurrence of rotaviruses in anaerobically digested sludges suggest they occur in concentrations at least equal to that observed for the enteroviruses (Badawy, 1986). It would not be unreasonable to suggest that the actual concentrations of enteric viruses are 10-100 times that observed experimentally (Gerba, 1986).

Pathogen Survival

Many pathogens found in sludge are capable of prolonged survival in sludges, especially at low temperatures and high moisture conditions (Feachem et al., 1983; Gerba, 1983; 1986). Indicator bacteria (coliforms and fecal coliforms) have been observed to survive for years in sludge only and codisposal landfills (Donnelly and Scarpino, 1984). The high level of organic matter probably results in the survival and growth of indicator bacteria. Bacterial pathogens such as Salmonella are also capable of growth in sterilized sludges (Ward et al., 1984), although this appears unlikely in digested sludges because of the large number of antagonistic bacteria. Under ideal conditions, viruses and parasites may be expected to survive for months to years, especially if subsurface temperatures approach 10°C (Jackson et al., 1977; Feachem et al., 1983; Gerba, 1983; Yates and Gerba, 1985).

Pathogen Transport

Transport of pathogens from the sludge to the groundwater is more difficult to assess. The nature of the underlying soil is probably the most significant factor in controlling pathogen movement (Gerba et al., 1975). In clayey soils or clay lined landfills, no movement of pathogens from the site probably occurs. However, in larger grained soils, at least some movement of pathogens could probably be assumed. No data base appears to exist to estimate the numbers of pathogens which could be leached from sludge landfills. The concentration of fecal coliform bacteria in sludge-only landfills has been reported to range from 2400-24,000/100 ml, and that of fecal streptococcus from 2100-240,000/100 ml (EPA, 1978). This suggests that significant leaching of pathogenic bacteria and viruses can occur. The chemical constituents of the leachate and its pH would be expected to have an influence on pathogen survival and transport (Gerba and Bitton, 1984). The high organic content of the leachate (total organic carbon reported to be 100-15,000 mg/l) could reduce viral and bacterial retention by soil particles as well as enhancing survival (EPA, 1978). Bacteria and viruses probably have the greatest chance of being leached from landfills. The amount of rainfall would probably be a major factor in microbial release from the sludge (Gerba and Bitton, 1984; Jorgensen, 1985). In addition, the water content and weight of the sludge in landfills can be expected to increase water infiltration. Infiltration is also increased since the sludge provides greater pore space and decreases the potential of surface sealing (Epstein, 1973). Sludges with a pH >7.0 would be expected to bind viruses less and greater mobilization of viruses may occur. Studies with surface applied sludges suggest that at least 0.1-1% of the viruses applied are released from the sludge (Ait et al., 1984). Numbers released may actually be greater since viral inactivation could be expected to be greater in surface applied sludges because of drying and higher temperatures.

Any organisms released from the sludge would usually have to travel through an unsaturated zone before reaching the groundwater table. Removal of microorganisms in this zone is greater than the saturated zone (Lance and Gerba, 1984; Gerba, 1986). Rainfall may play a significant role in the pentration of this barrier by microorganisms. Most of the landfills described in the U.S. EPA's Process Design Manual for Municipal Sludge Landfills (EPA, 1978) are constructed such that they are within 3 m of groundwater. While laboratory studies suggest substantial removal of microorganisms through the unsaturated zone, field studies indicate that penetration of enteric bacteria and viruses is possible (Keswick and Gerba, 1980). The degree of microbial removal will depend greatly upon the soil type with little occurring through fine grained soil types. However, quantitative information on pathogen removal through the unsaturated zone is almost nonexistent.

Less removal of microorganisms can be expected once they have entered the groundwater. Under saturated flow, viruses can travel long distances in sandy soils (Keswick and Gerba, 1980). The degree of removal is determined by the composition of the substrata. High removals can be expected in clay soils while little removal probably occurs in fractured substrata or karst terrain (Gerba and Bitton, 1984). The rate of virus removal through soil observed in the laboratory seems to be at variance to that observed in the field (Gerba, 1986). Laboratory studies with poliovirus and echovirus would suggest that 1-3 logs of virus removal would occur per meter of travel through sandy saturated loam soils (Gerba et al., 1975; Lance and Gerba, 1984). However, in field studies observed removals are usually <0.1 log/m. In one recent study, Stramer (1984) observed <0.05 log/m removal of poliovirus through silty loam soil under saturated flow conditions. The virus traveled over 46 m to contaminate a nearby lake. These results suggest that laboratory grown viruses or laboratory experimental designs do not actually reflect virus transport through the subsurface in the field.

Bacteria and protozoa also appear capable of being transported several meters through sandy soils (Gerba, 1986). Giardia can penetrate at least a meter of fine sand (Logsdon et al., 1984). Helminth eggs, because of their larger size, are unlikely to travel a few centimeters unless fractures in the substrata exist. Bacteria and protozoa cysts would not be expected to travel as great a distance in the subsurface as viruses.

Characteristics of Best and Worst Case Landfills

Based on this review of the literature, the best and worst landfill sites as potential risks for contamination of groundwater are shown in Table 2. The ideal site would utilize digested secondary sludge with a solids content of ≥20%. The substrata would be a clayey soil with a deep groundwater table and in an area of low rainfall. With a clayish soil and a clay lining, no enteric pathogens would be expected to contaminate groundwater. A worst case landfill would dispose of raw or primary sludge with a solids content of <15%, lay within 1 m of the groundwater table, be unlined with a sand to gravel substrata, and in an area of high rainfall.

Also presented in Table 2 are representative conditions present at 15 sludge landfill sites reviewed in the U.S. EPA's Process Design Manual on Municipal Sludge Landfills (EPA, 1978). A review of the characteristics of these sites suggests that both raw and stabilized sludges are disposed, that the depth to groundwater is often within 1 m, clay to gravel substrata, and rainfalls >30 inches/year. Some sites are clay lined.

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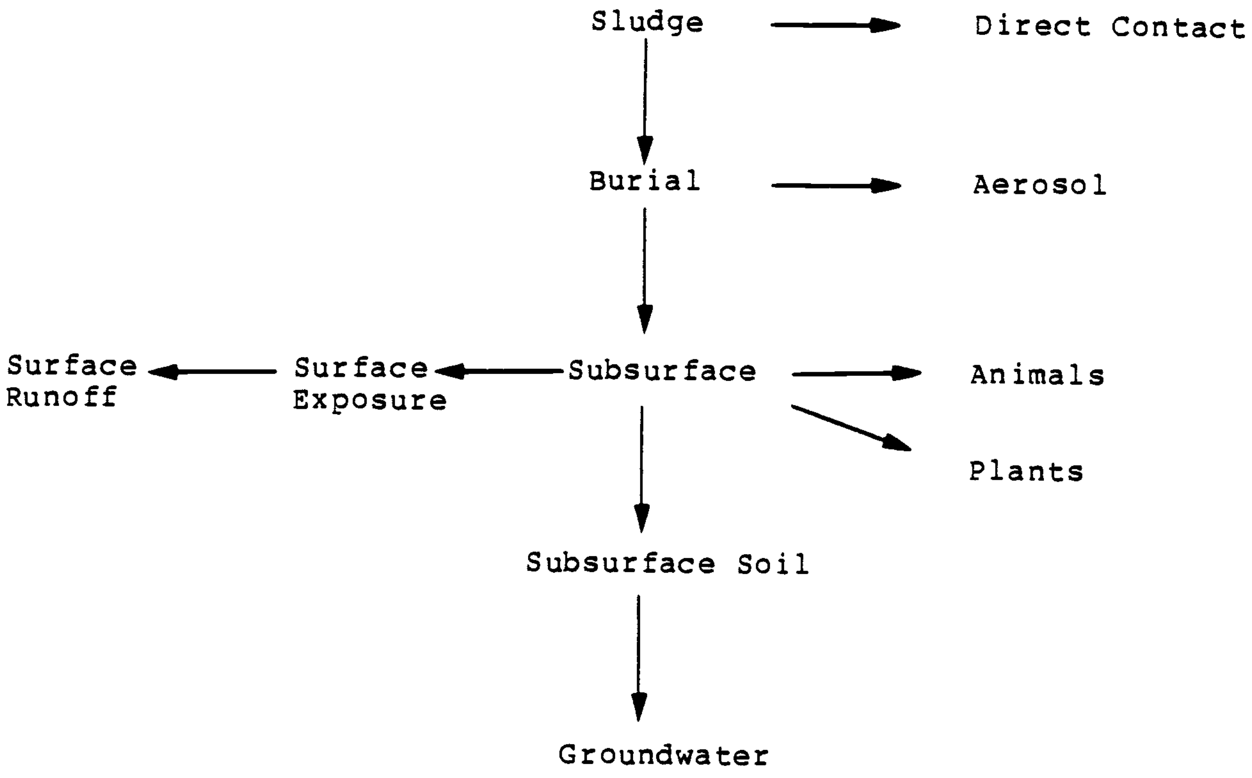

Figure 1. Pathways of Microbial Transport from Sludge Landfills

Table 1. Densities of Microbial Pathogens and Indicators in Primary and Digested Sewage Sludges*

		Concentration (number/g dry weight)	
Type	Organism	Primary	Anaerobically Digested
Virus	Enteroviruses	10^2-10^4	0.2-210
Bacteria	Fecal Coliforms	10^7-10^8	10^2-10^6
	Salmonella sp.	10^2-10^3	3-10^3
Parasite	*Ascaris* sp. (hookworm)	10^2-10^3	--
	Trichuris (whipworm)	10^2	--

*Compiled from Gerba, 1986.

Table 2. Characteristics of Best, Worst and Average Operated Sludge Landfills

	Sludge Characteristics			Site Characteristics				
Example	Treatment	Percent Solids	Sludge to Groundwater (ft)	Groundwater Flow (ft/day)	Nature of Soil	Rainfall (inches)	Groundwater Temperature (°C)	Other
Best	stabilized, anaerobic digestion, lime dewatered	20	≥100	1	clay	20	30	clay lined area fill
Operated landfills*	stabilized to raw anaerobic digested dewatered	3-28	22	--	clay to gravel	10-40	3-17	clay lined to unlined
Worst	unstabilized, raw	15	≤3	≥10	gravel-sand	40	10	unlined

*Source: EPA, 1978