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Project Summary

Development of a Qualitative Pathogen Risk Assessment Methodology for Municipal Sludge Landfilling

This report addresses potential risks from microbiological pathogens present in municipal sludge disposed of in landfills. Municipal sludge landfilling is defined for purposes of this assessment as the application of sludge to the land and subsequent internment by applying a layer of cover soil over the sludge that is thicker than the depth of the plow zone.

Municipal sludges contain a wide variety of bacteria, viruses, protozoa, helminths and fungi. Although humans may potentially be exposed to pathogens from municipal sludge via aerosols and direct contact, surface water and runoff, plants and animals, and ground water, proper landfill management techniques make transport of significant amounts of pathogenic microorganisms from landfilled sludge by the first three routes unlikely.

Survival characteristics of pathogens are critical factors in assessing the risks associated with potential transport of microorganisms from the sludge-soil matrix to the groundwater environment of landfills. Various models are discussed for predicting microbial die-off. The order of persistence in the environment from longest to shortest survival time appears to be the helminth eggs > viruses > bacteria > protozoan cysts.

Whether or not a pathogen reaches ground water and is transported to drinking-water wells depends on a number of factors, including initial concentration of the pathogen, survival of the pathogen, number of pathogens that reach the sludge-soil interface, degree of removal through the unsaturated and saturated soil zones, and the hydraulic gradient. The degree to which each of these factors will influence the probability of pathogens entering ground water cannot be determined precisely. Viruses, because of their small size, probably have the greatest potential of all the pathogens of actually reaching the ground water and being transported from the site. Laboratory studies suggest that at least 0.1-1% of the viruses present may be leached from a municipal sludge landfill.

Information on the fate of pathogens at existing landfills is sorely lacking. Additional laboratory and field studies are needed to determine the degree of pathogen leaching, survival and transport in ground water in order to estimate potential risks from pathogens at sludge landfills with reasonable validity.

This Project Summary was developed by EPA's Environmental Criteria and Assessment Office, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Municipal sludge landfilling is defined for purposes of this assessment as the burying of sludge (that is, the application of sludge to the land and subsequent treatment by applying a layer of cover soil over sludge). To be defined as a landfill, an area must have soil thicker than the depth of the plow zone (e.g., 15 cm). Several different methods of disposal are used at sludge-only landfills. The type of method utilized is dependent on the characteristics of the sludge and the nature of the site. The different methods of disposal may have different risks associated with them. The presence of infectious microorganisms in sludges necessitates the placement of certain constraints on landfilling of municipal sludge.

Sludge Characteristics and Landfilling Methods

Municipal sludge is a complex mixture of solids of biological and mineral origin that are removed from wastewater in sewage treatment plants. Sludge is a by-product of physical (primary treatment), biological (activated sludge, trickling filters) and physiochemical (precipitation with lime, ferric chloride or alum) treatment of wastewater. Many of the pathogenic microorganisms present in raw wastewaters will find their way into municipal sludges. Treatment of these sludges by anaerobic or aerobic digestion and/or dewatering will reduce the number of pathogens, but some numbers may remain. Only dewatered sludges with solids contents ≥15% are considered suitable for disposal in sludge-only landfills. The type of treatment will determine the concentration of pathogens and the relative risks of disposal. Stabilization of sludges may be accomplished by either aerobic or anaerobic digestion, lime addition, heat or wet oxidation. In general, only stabilized sludges are recommended for landfilling

Sludge is commonly landfilled either by subsurface excavation (trenches) or by area fill above the original ground surface. Because filling proceeds above the ground surface, liners can be installed more readily at area fill operations than at trench sites. With or without liners, surface runoff of moisture from the sludge and contaminated rainwater should be expected in relatively greater quantities at area fills. Diked containment area fill sites are relatively large, with typical dimensions of 50-100 ft (15-30 m) wide, 100-200 ft (30-60 m) long and 10-30 ft (3-9 m) deep. The depth of the fill in conjunction with the weight of the sludge and cover fill results in much of the sludge moisture being squeezed into the surrounding dikes and into the floor of the containment; thus, the potential for leachate emissions is present.

Pathogens

Raw sewage may contain a wide variety of pathogenic microorganisms, including bacteria, viruses and parasites such as protozoa, helminths and fungi. All of these types of pathogens can be expected to be present in raw, primary and secondary sludges. Pathogens of primary concern and the associated diseases they can induce in humans are listed in Tables 1 and 2.

Salmonella bacteria are the most widely recognized enteric pathogens. Often associated with food and waterborne outbreaks of illness, *Salmonella* are responsible annually for 1-2 million human disease cases in the United States. *Shigella, Campylobacter, Vibrio cholerae, Yersinia enterocolitica* and even *Escherichia coli* have all been recognized as etiological agents of acute enteritis, but information is lacking on the concentrations of these organisms in sludge or their removal by sewage treatment processes.

The most commonly studied enteric viruses in sewage and sludge are the enteroviruses, which include polioviruses, coxsackie A and B viruses, echoviruses and hepatitis A virus. Much information is available on removal of enteroviruses by sewage treatment, and many studies have been conducted on their occurrence in sludges. Rotaviruses, Norwalk viruses and adenoviruses have also been associated with human gastroenteritis but little is known about the concentration in or removal of these viruses from sewage or sludge.

Of the common protozoa found in sewage, only *Entamoeba histolytica, Giardia lamblia, Balantidium coli* and *Cryptosporidium* sp. are believed to be of major significance for transmission of disease to humans (see Table 1). All four species have been linked to waterborne

Table 1. *Bacteria, Parasites and Fungi Pathogenic to Man That May Be Present in Sewage and Sludge*

Group	*Pathogen*	*Symptoms and/or Disease Caused*
Bacteria	Salmonella *(1700 types)*	*Typhoid, paratyphoid, salmonellosis*
	Shigella *(4 spp.)*	*Bacillary dysentery*
	Enteropathogenic Escherichia coli	*Gastroenteritis*
	Yersinia enterocolitica	*Gastroenteritis*
	Campylobacter jejuni	*Gastroenteritis*
	Vibrio cholerae	*Cholera*
	Leptospira	*Weil's disease*
Protozoa	Entamoeba histolytica	*Amoebic dysentery, liver abscess, colonic ulceration*
	Giardia lamblia	*Diarrhea, malabsorption*
	Balantidium coli	*Mild diarrhea, colonic ulceration*
	Cryptosporidium	*Diarrhea*
Helminths	Ascaris lumbricoides *(Roundworm)*	*Ascariasis*
	Ancyclostoma duodenale *(Hookworm)*	*Anemia*
	Necator americanus *(Hookworm)*	*Anemia*
	Taenia saginata *(Tapeworm)*	*Taeniasis*
	Trichuris *(Whipworm)*	*Abdominal pain, diarrhea*
	Toxocara *(Roundworm)*	*Fever, abdominal pain*
	Strongyloides (Threadworm)	*Abdominal pain, nausea, diarrhea*
Fungi	Aspergillus fumigatus	*Respiratory disease, otomycosis*
	Candida albicans	*Candidiasis*
	Cryptococcus neopormans	*Subacute chronic meningitis*
	Epidermophyton *spp. and* Tricophyton *spp.*	*Ringworm and athlete's foot*
	Trichosporon *spp.*	*Infection of hair follicles*
	Phialophora *spp.*	*Deep tissue infections*

Table 2. *Enteric Viruses That May Be Present in Sewage and Sludge*

Viruses	Type	Symptoms and/or Disease Caused
Enteroviruses.		
Poliovirus	3	*Meningitis, paralysis, fever*
Echovirus	31	*Meningitis, diarrhea, rash, fever, respiratory disease*
Coxsackievirus A	23	*Meningitis, herpangina, fever, respiratory disease*
Coxsackievirus B	6	*Myocarditis, congenital heart anomalies, pleurodynia, respiratory disease, fever, rash, meningitis*
New enteroviruses (Types 68-71)	4	*Meningitis, encephalitis, acute hemorrhagic conjunctivitis, fever, respiratory disease*
Hepatitis Type A (Enterovirus 72)	1	*Infectious hepatitis*
Norwalk virus	1	*Diarrhea, vomiting, fever*
Calicivirus	1	*Gastroenteritis*
Astrovirus	1	*Gastroenteritis*
Reovirus	3	*Not clearly established*
Rotavirus	2	*Diarrhea, vomiting*
Adenovirus	41	*Respiratory disease, eye infections, gastroenteritis*
Pararotavirus	*unknown*	*Gastroenteritis*
Snow Mountain Agent	*unknown*	*Gastroenteritis*
Epidemic non-A non-B hepatitis	*unknown*	*Hepatitis*

outbreaks of mild to severe diarrhea. Limited information is available on the occurrence of protozoa in sewage, and even less is known about their concentration in sludges.

A wide variety of helminths and their eggs may occur in domestic sludges. Those of primary concern include nematodes (roundworms) such as *Ascaris lumbricoides* and *Toxocara* cestodes (tapeworms) such as *Taenia saginata*, as well as hookworms, whipworms and threadworms (see Table 1) Helminth eggs have been found in municipal wastewater sludge in the southeastern and northern United States. Many common helminths are pathogenic to domestic animals (e.g., cats and dogs) but cause only mild or asymptomatic infections in humans.

Fungi are usually considered to be of minimal health risk in the application of municipal sludge, although yeasts (*Candida albicans*, *Cryptococcus neopormans* and *Trichosporon* spp.) and filamentous molds *Aspergillus fumigatus*, *Epidermophoyton* spp., *Phialophora* spp. and *Trichophyton* spp.) have been reported to be present in sewage and in all stages of sludge treatment.

Exposure Pathways

Possible exposure pathways by which infectious microorganisms may come into contact with humans during the operation of sludge landfills are shown in Figure 1. Exposure to personnel may occur through direct contact with the sludge or through exposure to aerosols generated during burial. Aerosols containing viable microorganisms could also be transported downwind to exposure areas distant from the disposal site. Pathogens may leach from the buried sludge with infiltrating water to contaminate the ground water. Surface runoff could also contaminate nearby bodies of water Burrowing animals or birds could serve to transport exposed sludge offsite before burial.

Aerosols of enteric pathogens are generated during sewage treatment and during the spraying of sewage effluents and sludges onto land. The microorganisms in such aerosols can be transmitted by inhalation or through the settling of the organisms onto surfaces that come into contact with humans. The greatest chance for transport of aerosols offsite could be expected to occur with area fill operations involving primary sludges However, through proper landfill management and the use of a buffer zone, significant microbial aerosols are not expected to occur offsite.

Based on the assumption of good operating practices involving the use of drainage ditches at sludge landfills, surface runoff becomes a part of the groundwater pathway or is eliminated. Transport of significant amounts of pathogenic microorganisms from landfill sites by plants and animals also appears unlikely.

Contamination of ground water that is used for domestic purposes appears be the most likely route of significant human exposure to pathogens from sludge burial. The risk assessment methodology developed in this report considers the ground-water contamination pathway in the greatest detail

Expected Concentrations of Pathogens in Sludge

Concentrations and types of pathogens in sludges depend on the incidence of infection within a community and the type of treatment the sludge receives. Various sludge treatment processes, such as anaerobic digestion and dewatering, reduce the numbers of some pathogens initially present

Primary sludge, obtained after gravity sedimentation of solids in raw wastewater, has remaining ~60% of the total suspended solids from sewage. Primary sludge is a semisolid substance that typically contains ~5% solids by weight and has a pH of ~6

Secondary sludges are obtained from wastewater treated by the activated sludge process, trickling filters or rotating biological contactors Secondary sludges obtained following such biological treatment commonly have low percentages of solids and may be thickened by flotation, centrifugation or other means. Before disposal, both primary and secondary sludges must be stabilized and dewatered to reduce volatile solids

Most pathogens contained in raw sewage are concentrated in sludge during primary sedimentation. Microbial densities range from $10\text{-}10^3$/g dry

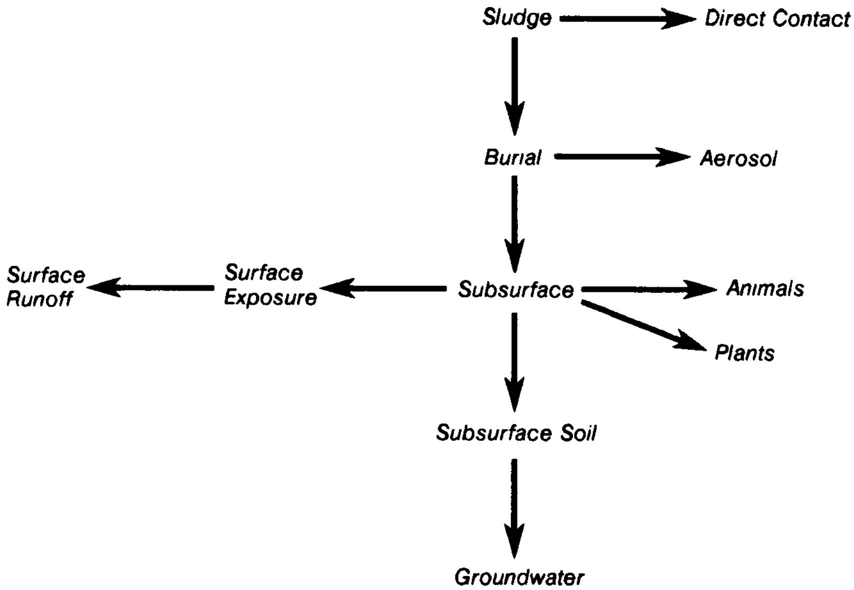

Figure 1. *Pathways of microbial transport from sludge landfills.*

weight primary sludge for parasites to 10^6-10^7 for coliform bacteria. Viral and bacterial pathogens have been shown to be reduced in concentration by activated-sludge treatment, but microbial densities in most secondary sludges still range from 10-10^3/g dry weight for typical parasites to 8×10^6-7×10^8 for coliforms.

Reductions in microbial concentrations of sludge after stabilization, dewatering and disinfection are estimated to range from 0-3 orders of magnitude.

Survival Characteristics of Pathogens

Although most pathogenic microorganisms have a finite lifetime in the environment once they have left the host organism, under the proper conditions microbes may actually increase in numbers. To determine risks of disease associated with landfilling of sludge, it is necessary to be able to predict the persistence of pathogens in the soil-sludge and ground-water environments.

Field data on pathogen survival in sludge landfills and leachate are virtually nonexistent; however, laboratory lysimeter studies suggest that total coliforms may persist for at least 100 weeks in buried sewage sludge. A review of the literature on pathogen survival in water, sludge and soil was undertaken to ascertain significant factors controlling microbial survival and to aid in developing mathematical models for predicting pathogen die-off or inactivation.

Temperature, pH, moisture and nutrient supply (except for viruses) are key factors governing the survival of microorganisms in the sludge landfill environment. Acidic conditions can greatly increase bacterial die-off rates. While more resistant to inactivation under acidic conditions, both viruses and parasites are inactivated at extremes of pH. Survival times of all enteric pathogens are increased at lower temperatures. Although freezing temperatures may kill bacteria and protozoa, they have little effect on viruses and may actually increase their survival. Low nutrient availability will decrease bacterial persistence.

In soil flooded with inoculated sewage sludge, poliovirus 1 was found to survive for at least 96 days during the winter and 36 days during the summer, but in a study using seeded effluent applied to soil columns, a 99% die-off of poliovirus 1 occurred in clay soil after 10 days at 30°C. At 4°C, a comparable die-off did not occur even after 134 days Hepatitis A virus (HAV) appears to be more resistant than other enteroviruses to thermal inactivation in sewage effluents and soils

Bacterial die-off approximately doubles with each 10° rise in temperature between 5 and 30°C. *Salmonella* applied to arid land in summer persisted for 6-7 weeks, while *Salmonella* on grass treated with sludge sur-vived for ≤16 months in Switzerland. Organic content present in sludge is thought to enhance bacterial survival *Vibrio cholerae* appears capable of surviving for 4-10 days in soils moistened with sewage at 20-28°C. No studies could be located on survival of *Shigella* in soils or sludge, but a literature review suggests that at temperatures <30°C, *Shigella* survival is less than that of *Salmonella*

Protozoan cysts are more susceptible to adverse environmental effects, such as drying and elevated temperatures, than are eggs of helminths. *Entamoeba histolytica* cysts died within 5 minutes after drying in the laboratory, but under agricultural field conditions they survived 42 hours in wet soil and 18 hours in dry soil. *Ascaris* (roundworm) eggs have survived ≤4 years in soil, and *Trichuris* (whipworm) eggs may remain viable on soil for 6 years In a U S EPA-sponsored study on the presence of parasites in land-applied sludges at 12 sites nationwide, 8 sites reported *Ascaris, Toxocara, Trichuris* or hookworms present in soil or sludge samples.

The order of pathogen persistence in the sludge landfill environment from longest to shortest survival time appears to be as follows: helminth eggs > viruses > bacteria > protozoan cysts Quantitative models based on first-order reaction kinetics have been attempted for predicting viral and bacterial decay rates in water and soil; however, insufficient information is available at present to develop models for predicting survival of helminths and protozoan cysts. Temperature is by far the most useful factor for mathematical prediction of pathogen survival time. In studies of viral decay in ground water, 77.5% of the variation in decay rates among samples could be explained by temperature. As groundwater temperatures approach -8°C, viral decay becomes negligible.

Insufficient data are currently available on viral and bacterial decay in sludges at different temperatures to be used in a predictive model. With additional data, models could be developed for pathogen decay in sludge landfills, soil and ground water. Microbial survival times could be predicted on the basis of sludge-soil type, pH, temperature and moisture.

Transport of Pathogens in the Subsurface

In conjunction with pathogen survival rates, knowledge of microbial movement through the sludge-soil matrix is critical for assessing potential risks posed by microorganisms at sludge landfills. Microbial movement in soil is governed in part by physical characteristics of the soil, such as texture, particle size, clay content, organic matter content, pH, cation exchange capacity and pore size distribution. Environmental and chemical factors related to the soil, such as temperature, moisture content, water flux, ionic content, and microbial density and dimensions, are also important factors affecting movement of pathogens through the subsurface.

Retention by soil particles is great for soils with a high clay content, and movement of pathogens through the soil matrix is substantially reduced so that ground-water contamination is not considered a major exposure route with clay soil unless cracks or fissures are present. Conversely, sand and gravel permit greater and more rapid microbial movement. Size of the microbes themselves, however, is probably the most important factor. In most soils, viruses could be expected to travel the greatest distances because of their small size (0.02-0.08μm), while the movement of protozoa and helminths would be limited because of their large size (5-38 μm).

Published data indicate that viruses can travel at least 67 m vertically and 408 m laterally in soil. In gravel and karst substrata, viruses have been observed to travel as far as 1600 m at ≤1000 m/hour. Removal of viruses from soil is primarily by adsorption to soil particles, whereas bacteria, protozoa and helminths are removed mainly by filtration and straining. Poliovirus type 1 and coxsackievirus B3 appear to adsorb to a much greater degree on sludge and soils than many of the other enteroviruses. Viral binding to sludge is also significantly influenced by pH. Binding of poliovirus is ~42% at pH 5-7 but decreases rapidly at pH >7.0 and is <10% at pH >9. Thus, when high pH sludges are disposed of, viruses may be more mobile.

Viral transport in the subsurface has been modeled assuming instantaneous equilibrium between suspended and adsorbed virus concentrations and assuming a mass-transfer or "rate-controlled" model to account for distribution of viruses between the fluid and solid phases. In both cases, the model formulation leads to linear partial differential equations that can be solved by a variety of methods depending upon the problem domain, heterogeneities in aquifer properties and boundary conditions. The mathematical capabilities of the methods far exceed current basic understanding of the behavior of viruses in soil and ground-water systems, and further laboratory experimentation and field verification with different substrata are needed to validate the usefulness of the models. A comparison of previous field and laboratory studies suggests that laboratory evaluations tend to overestimate virus removal, possibly because they do not adequately take into account soil inhomogeneities and rainfall in the field.

Filtration is the key mechanism for bacterial removal from soil, although adsorption also plays a role. Bacterial movement appears to be limited to depths of 10-50 cm in most soils, but travel distances of 3-122 m have been observed in sandy soils, and bacterial transport as great as 920 m has been reported for gravel. Rainfall can have a major effect on bacterial migration through the unsaturated zone by lowering ionic concentration and increasing infiltration rates. If bacteria are able to penetrate to the saturated zone, they appear capable of being transmitted significant distances in sandy and gravel soils. Rate of water flowing through the soil is highly correlated (r = 0.88) with the degree of removal of both bacteria and viruses

Because of their large size, protozoan cysts and helminth eggs are expected to exhibit even less movement through sludge than bacteria. Limited laboratory and field studies involving *Ascaris*, hookworm and *Taenia saginata* eggs and *Entamoeba histolytica* cysts have confirmed <2 cm of vertical movement through soil, but *Giardia* cysts have been reported to penetrate a sand column to a depth of 96 cm at operational flow rates of 0.04-0.4 m/hour. No studies could be found on the expected removal of parasites by soils.

None of the several models developed for predicting microbial transport through the saturated zone has been verified by laboratory or field studies. A comparison of field and laboratory studies on viral and bacterial movement through solids suggests that travel of microorganisms in the subsurface is greater in the field than laboratory studies indicate. Only through field studies at actual sludge landfills will the real potential for transport of pathogens be fully revealed.

Infective Dose and Risk of Disease from Microorganisms

Estimation of minimum infectious doses (MIDs) for various pathogens is difficult because of uncertainties in immune status of host, assay technique, sensitivity of host, virulence of pathogen, use of upper 95% confidence limit, route of exposure, choice of dose-response model, synergism/antagonism, dietary considerations and distribution of subjects among doses and number used.

In many studies, small numbers of viruses (as few as 1 or 2 tissue culture plaque-forming units), primarily vaccine strains, have produced infection in human subjects The infective dose of protozoan cysts such as *Giardia lamblia* and *Entamoeba* by the oral route appears to be as low as between 1 and 10 cysts Essentially one helminth egg can be considered to be infectious, although symptoms may be dose-related.

MIDs for bacteria are generally higher than those for viruses and parasites. The number of ingested bacteria required to cause illness appears to range from 10^2-10^5 although recent studies suggest that during outbreaks the infective dose for *Salmonella* may be <10 organisms. Virulence of the particular type and strain of microorganism and host factors may play roles in determining the actual number of microbes required to cause infection.

Individuals who do not actually consume or come into contact with contaminated water or sludge are also potentially at risk, because microorganisms may be spread by person-to-person contact or by subsequent contamination of other materials with which noninfected individuals may come into contact. Conversely, not everyone who may become infected with enteric viruses or parasites will become clinically ill. Asymptomatic infections are particularly common with some of the enteroviruses. The development of clinical illness depends on many factors, including the immune status and age of the host; virulence, type and strain of the microorganisms; and route of infection. For hepatitis A virus, the percentage of individuals with clinically observed illness is low for children (usually <5%) but increases greatly with age. In contrast, the frequency of clinical symptoms for rotavirus is greatest in childhood and lowest in adulthood. Frequency of clinical hepatitis A virus in adults is estimated at 75%, but during waterborne outbreaks it has been observed as high as 97%

Ground-water Pathway Risk Assessment Methodology

A major difficulty in assessing risks of ground-water contamination from municipal sludge landfills is the absence of any field or laboratory studies concerning survival of microorganisms and transport of pathogens into ground water from disposal sites. Previous studies on land application of sludge have concerned only its application to the soil surface or within several centimeters of the soil surface. Application rates at such sites are on the order of 22 metric tons/hectare. Disposal rates at sludge landfills range upwards of 22,000 metric tons/hectare, generating a much larger concentration of pathogens

A literature review suggests that significant concentrations of pathogens can be expected in the sludges that landfills receive. Many pathogens are capable of prolonged survival in sludges, especially at low temperatures under high moisture conditions. Coliforms have been observed to survive for years in sludge and codisposal landfills. Under ideal conditions, viruses and parasites may be expected to survive for months to years, especially if subsurface temperatures approach 10°C

Transport of pathogens from sludge landfills to ground water is more difficult to assess, but experimental results suggest that significant leaching of pathogenic bacteria and viruses can occur The amount of rainfall is probably a major factor governing microbial release from sludge Most of the landfills described in the U.S. EPA's Process Design Manual for Municipal Sludge Landfills are situated within 3 m of ground water, and although laboratory studies suggest substantial removal of microorganisms through the unsaturated zone, field studies indicate that penetration of enteric bacteria and viruses is possible. Quantitative information on pathogen removal through the unsaturated zone is almost nonexistent.

Based on a review of the literature, an ideal landfill site (i.e., one that poses a minimum risk of ground-water contamination) would utilize digested secondary sludge with a solids content of ≤20% The substrata would be a clayey soil with a deep ground-water table in an area of low rainfall With a clayish soil and a clay lining, no enteric pathogens would be expected to leach into the ground water. A worst-case landfill would dispose of raw or primary sludge with a solids content of 15%. The site would lay within 1 m of the ground-water table, be unlined with sand or gravel substrata and would experience high rainfall.

Two example sludge landfill sites with characteristics shown in Table 3 were evaluated by the micro-DRASTIC rating system to assess the likelihood of ground-water contamination It was determined that microbial contamination was probable directly beneath site A and possible beneath site B. At both sites, contamination was judged to be possible at distances of 100 and 200 m. Although the rating system has not been verified in the field, it provides a mechanism for evaluating the many interacting factors that control microbial survival and transport in the subsurface Micro-DRASTIC could potentially be used as a first step in evaluating the potential for microbial contamination at a particular site, based upon hydrogeologic settings

Other approaches to determine the likelihood of ground-water contamination have been based on estimating the leaching of pathogens from sludge landfill and plotting the concentrations of microorganisms at various distances from a given site. From this information, it is possible to estimate the risk of illness from using the ground water for drinking Of course, whether or not a pathogen reaches ground water and is transported to drinking-water wells depends on many factors, including initial concentration of the pathogens, survival of the microbes, number of pathogens that reach the sludge-soil interface, degree of removal through the unsaturated and saturated soil zones, and the hydraulic gradient. Under most favorable conditions, it is estimated that no more than 0.1% of viruses are released from sludge; for most probable conditions, 1% is estimated; and under worst possible conditions, a 10% release is estimated

Recommendations

It is clear that information on the fate of pathogens at existing landfills is essentially nonexistent. Laboratory and field studies are needed to determine the degree of pathogen leaching, survival and transport to ground water Approaches are available to estimate potential risks from pathogens at sludge landfills, but without adequate information, the reliability of the conclusions is weakened The availability of necessary information to perform a risk assessment and research needs are shown in Table 4.

Table 3 *Characteristics of Selected Municipal Sludge Landfills*

Site	Depth to Water (m)	Net Recharge (m)	Hydraulic Conductivity (ℓ /d-m^2)	Temperature (°C)	Soil Type Medium	Aquifer Type	Sludge
A	*3-4*	*0-1*	*0.35*	*10*	*clay, sand, and gravel*	*silt loam*	*secondary*
B	*10-12*	*7-8*	*0.35-0 035*	*14*	*silty clay*	*silty*	*primary*

Table 4. *Status of Information for Ground-water Risk Assessment and Research Needs*

Item	Adequate Data to Make a Risk Assessment: Bacteria	Viruses	Protozoan Cysts	Helminth Eggs	Research Needs
Concentration in sludge	yes	yes	yes	yes	Data for emerging pathogens and better detection methods needed
Concentration of organisms leached	limited	no	no	no	No data on pathogens. Field and laboratory studies needed
Survival (decay rate) in leachate	no	no	no	no	No data on pathogens
Survival (decay rate) in ground water	yes	yes	limited	limited	Data for emerging pathogens would be useful
Transport through unsaturated zone	limited	limited	limited	limited	Limited data available. Information on effect of rainfall needed
Transport through saturated zone	yes	limited	limited	yes	Proposed models need laboratory and field verification
Risk of illness	yes	yes	yes	yes	Data needed on nature of distribution of pathogens in water

Larry Fradkin is the EPA Project Officer (see below).

The complete report, entitled "Development of a Qualitative Pathogen Risk Assessment Methodology for Municipal Sludge Landfilling," (Order No. PB 88-198 544/AS; Cost: $19.95, subject to change) will be available only from:

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