EPA 600-1-81-006

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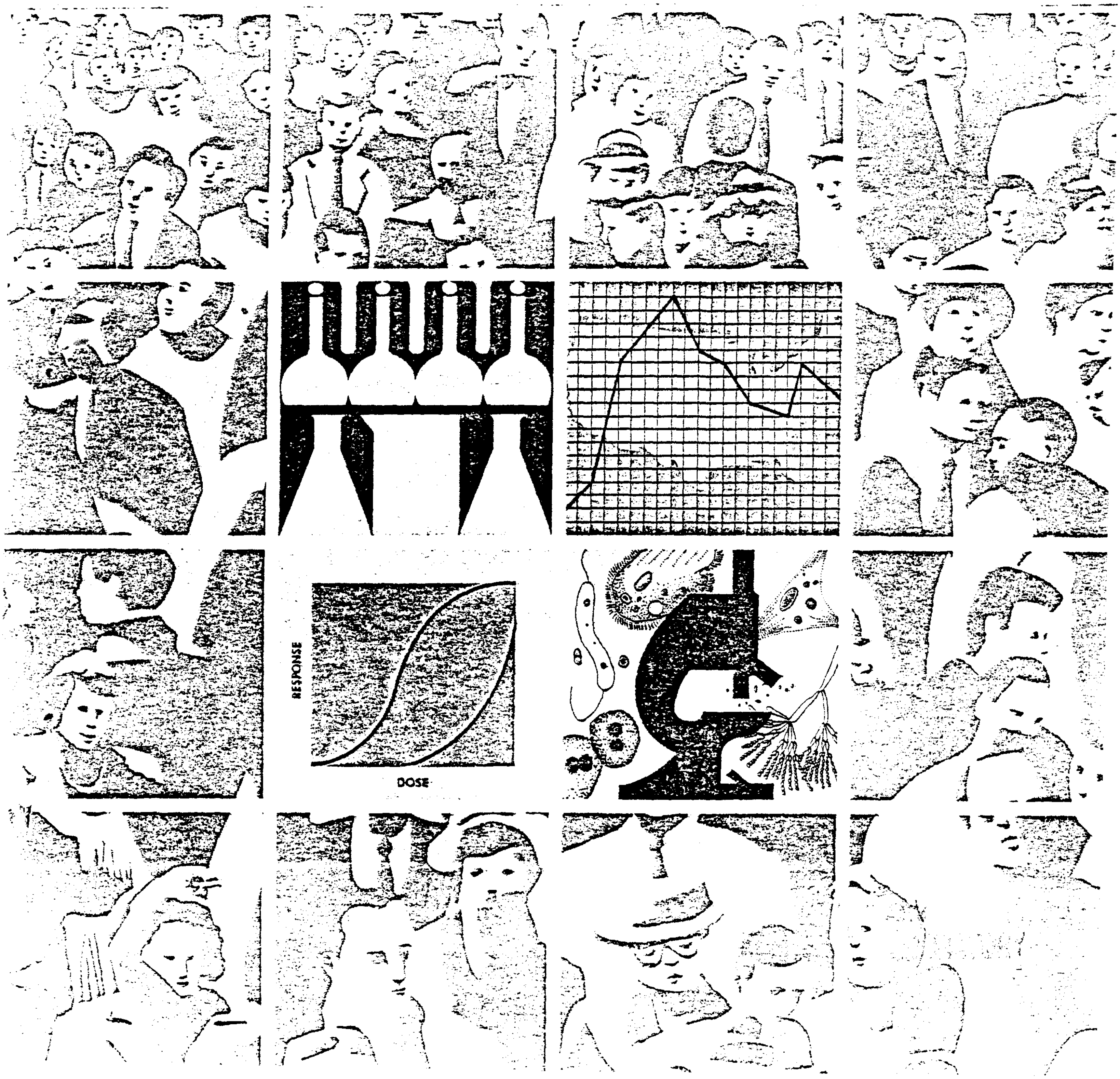
POTENTIAL HEALTH EFFECTS FROM VIABLE EMISSIONS AND TOXINS ASSOCIATED WITH WASTEWATER TREATMENT PLANTS AND LAND APPLICATION SITES



POTENTIAL HEALTH EFFECTS FROM VIABLE EMISSIONS AND TOXINS ASSOCIATED WITH WASTEWATER TREATMENT PLANTS AND LAND APPLICATION SITES

by

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Grant No. R-805445

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DISCLAIMER

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare to the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our national environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The primary mission of the Health Effects Research Laboratory in Cincinnati (HERL) is to provide a sound health effects data base in support of the regulatory activities of the EPA. To this end, HERL conducts a research program to identify, characterize, and quantitate harmful effects of pollutants that may result from exposure to chemical, physical, or biological agents found in the environment. In addition to the valuable health information generated by these activities, new research techniques and methods are being developed that contribute to a better understanding of human biochemical and physiological functions, and how these functions are altered by low-level insults.

This report presents an overview of the literature on potential health problems associated with microbiological contaminants during wastewater treatment or disposal. It is hoped that this review will provide a better understanding of the problem so that adequate measures may be taken to avoid disease.

R.J. Garner
Director
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ABSTRACT

This report summarizes the potential health effects from viable emissions and toxins associated with wastewater treatment plants and land application facilities to the workers and nearby populations. The different types of microorganisms present in wastewater and sludge and the effectiveness of the various treatment processes in their removal or inactivation is discussed briefly. The monitoring of microorganisms and toxins in aerosols generated at wastewater treatment plants and land application sites, the disadvantages in using coliform organisms as indicators to represent the actual levels of pathogenic microorganisms in aerosols, and the various mathematical models that are used to predict the microorganism levels in aerosols are also reviewed. The levels of microorganisms detected in aerosols at wastewater treatment plants and land application facilities from some of the recent studies are presented.

Diseases attributed to the pathogenic microorganisms are summarized. Results from several recent epidemiologic studies of workers at wastewater treatment plants and land application sites and on nearby residents are evaluated. The different methods that can be used to reduce the microorganism levels in aerosols and to suppress and/or to reduce the generation of aerosols are also discussed.

The review concludes that although pathogenic microorganisms have been detected in aerosols at wastewater treatment plants and land application facilities, the existing evidence from health effects studies does not indicate a significant health hazard to the workers from infectious disease agents and that a health risk to nearby populations has not been demonstrated. The fact that exposure to pathogenic microorgansims in wastewater aerosols is not a unique way of initiating enteric infections, makes it difficult to detect the effect, if any, of a wastewater facility. The report also concludes that the mathematical models that are used to predict the microorganism levels in aerosols are not perfected enough to replace actual field monitoring. Recommendations are made concerning suitable microorganisms other than coliform organisms as indicators of pathogen levels in aerosols and regarding monitoring requirements of water samples at land application facilites for microorganisms. Recommendations are also made concerning guidelines (minimum treatment requirements) for land application and buffer or safety zones.

This report was submitted in partial fulfillment of Grant No. R805445 by the Department of Environmental Health, University of Cincinnati, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period February 22, 1978 to May 21, 1980.

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ACKNOWLEDGMENTS

Mr. A. Komrichwarakool, Ms. H. K. Weir, and Mr. A. I. Carson, graduate students in the Department of Environmental Health, University of Cincinnati, provided assistance in searching and partial evaluation of the literature pertaining to this report.

Ms. K. Brenner, Ms. W. Davis-Hoover, and Dr. P. V. Scarpino of the Department of Civil and Environmental Engineering, University of Cincinnati, prepared the material from which Section 6 on predictive models was adapted. Mr. T. L. Huge, Biostatistician, Department of Environmental Health, University of Cincinnati, helped provide an understanding of the basic principles and limitations of the predictive models.

The assistance provided by Ms. M. J. Onslow and Ms. S. F. Humiston, Department of Environmental Health, University of Cincinnati, in preparing and providing editorial assistance for the manuscript, respectively, is gratefully acknowledged.

The comments and suggestions provided by Dr. R. L. Ward of the Sandia Laboratories, Albuquerque, New Mexico, and Dr. J. J. Bertucci, of the Metropolitan Sanitary District of Greater Chicago, in their reviews of this document are sincerely appreciated.

We are also thankful to the Health Effects Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, for providing financial support for this work.

SECTION 1

INTRODUCTION

A large variety of potential disease-causing microorganisms and viruses are present in municipal wastewaters. The workers at the wastewater treatment plants are potentially exposed to these pathogenic microorganisms and viruses through ingestion as well as inhalation of the aerosolized pathogens. Furthermore, the populations living in the vicinity of the wastewater treatment plants may be exposed to low densities of these pathogenic microorganisms and viruses that are airborne.

As a result of legislative actions, such as the 1972 Clean Water Act and its 1977 amendments, land application of wastewater and sludge is gaining renewed interest as an alternative means to the more conventionally used disposal methods, such as ocean and surface water dumping, and incineration. Land application represents a recycling process in which water and plant nutrients are returned to the soil. However, wastewater treatment does not completely remove pathogens and many become concentrated in the sludge.

The potential health effects on workers from exposure to airborne pathogens and toxins at wastewater treatment plants and land application sites, and on the populations living in the vicinity of the treatment plants and land application sites, will be discussed in this report. Also, recommendations regarding methods to control human exposure will be made.

Information regarding human health risks resulting from contact with wastewater and sludge brought about by occupational exposure or by residing near wastewater treatment plants and/or land application facilities, is limited. Several health effects studies have been initiated in the past few years on the health risks of pathogens in wastewater and aerosols generated at the wastewater treatment plants.

The reports of Hickey and Reist (1), Sepp (2), Parsons et al. (3), Clark et al. (4), the Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges (5), the International Symposium on the State of Knowledge in Land Treatment of Wastewater (6), SCS Engineers report (7) and the State of California's report on State-of-the-Art Review of Health Aspects of Wastewater Reclamation for Groundwater Recharge (8), all form the background material for parts of this report.

In order to assess the potential health risks from exposure to viable and nonviable pathogens in aerosols generated at wastewater treatment plants and land application sites, three topics are first discussed.

Occurrence and persistence of microorganisms and toxins in wastewater and sludge (Section 4).

Microorganisms and toxins in aerosols generated at wastewater treatment plants and land application sites (Section 5).

Models for predicting microorganism and virus levels in aerosols (Section 6).

Following this background, diseases attributed to pathogens for wastewater and sludge are discussed along with the results of several recent epidemiologic studies of populations with wastewater exposure in a section entitled:

Effects of pathogenic microorganisms and viruses present in wastewater and wastewater aerosols (Section 7).

The final section of the report addresses the need for the control of aerosols and methods applicable to their control (Section 8).

SECTION 2

CONCLUSIONS

Members of each group of the microorganisms - bacteria, protozoa, helminths, and viruses survive standard wastewater treatment processes, although in reduced numbers, and are concentrated in sludge.

Pathogenic bacteria are present in aerosols in detectable levels at wastewater treatment plants and spray application facilities, and inhalation is a possible route of exposure. Animal viruses have been detected, but only by sampling relatively large volumes of air.

Coliform organisms do not survive wastewater aerosolization as well as the other microorganisms such as Streptococcus faecalis and, therefore, have limited usefulness as indicators of pathogens in aerosols. The use of coliform organisms as indicators would tend to underestimate the potential effect on workers as well as nearby populations.

Because of the lack of a standard method for viral monitoring, comparison of data from two or more laboratories must consider differences in sample handling, concentration, and method of measurement. Because of the difficulties involved in routinely detecting airborne viruses at wastewater treatment plants and spray irrigation facilities, it is presently not possible to validate atmospheric dispersion models for their prediction.

For bacteria the models appear to have some usefulness, but have not been perfected enough to replace the field monitoring.

Information is not available on minimum infective dose of airborne microorganism levels for the inhalation route.

A number of epidemiological studies have recently been performed on workers at wastewater treatment plants and spray irrigation facilities and on populations living adjacent to these sites who would generally be exposed to lower levels of the pathogens. Data on health effects from the existing epidemiological studies do not show any correlation between the airborne pathogenic microorganism levels at wastewater treatment plants and incidence of disease in treatment plant workers or in nearby populations. However, the worst case of exposure of either the workers or the nearby populations has probably not yet been investigated. No adverse health effects have been reported in workers or in nearby populations at wastewater spray application facilities. From the data on health effects from the existing epidemiological studies, it is concluded that exposure to pathogenic microorganisms in wastewater aerosols is not a unique way of initiating enteric infections. The existence of the other possible pathways of infection could tend to make more difficult the detection of a wastewater facility effect if indeed one exists.

Studies reported from Sweden attribute responses such as elevated immunoglobulins and excess gastrointestinal symptoms in workers at conventional wastewater treatment plants to the effects of exposure to endotoxins.

Investigators in Copenhagen, Denmark, showed that sewer workers had elevated levels of immunoglobulin, IgG and hepatitis A antibodies compared to a control group.

Buffer zones, vegetative barriers, design of spray equipment, use.of subsurface injection, covering aeration tanks, etc. can suppress or reduce the aerosols and/or the levels of microorganisms in aerosols. These measures could serve to control the exposure of nearby populations, and in some cases, but to a lesser extent, that of the workers.

Data from viral and bacterial monitoring of wastewater and aerosols indicate that buffer or safety zones may not be necessary between wastewater treatment plants or spray application facilities and the surrounding population centers.

SECTION 3

RECOMMENDATIONS

POLICY/GUIDELINES

1. For aesthetic reasons, a minimum vegetative barrier or buffer zone is recommended around wastewater treatment plants and spray irrigation facilities to control the possible release of foam and water droplets.

2. For spray application, low pressure downward spray equipment is generally preferred instead of high pressure upward spray equipment. Ridge and furrow irrigation or subsurface injection should be practiced whenever possible, instead of spray application.

3. Spray application of wastewater without appropriate prior treatment is not recommended under conditions which increase the viability of airborne microorganisms such as very high relative humidity, night-time or at other times when there is no solar radiation, winter months in colder regions, etc.

4. Only stabilized sludge should be permitted to be applied on land.

5. Wastewater must be pretreated prior to application on land. The pretreatment requirements should be based on the type of land use, type of crops grown, etc. as shown:

   (a) A minimum of primary treatment should be required for the irrigation of forest land, sod farms, fodder crops, pasture land and other non-food crops, and for irrigation of lands that are remote from and not easily accessible to the general public.

   (b) A minimum of secondary treatment or sufficient elapsed time for microorganism die-off should be required for agricultural irrigation of food crops processed for human consumption.

   (c) A minimum of secondary treatment followed by disinfection should be required for the irrigation of public areas such as golf courses and public parks.

6. Water samples (leachates and runoff) at land application facilities should be monitored for microorganisms to ensure protection of ground and surface waters.

7. Resistant microorganisms such as Streptococcus faecalis should be used as indicators of pathogen levels in ambient air.

FURTHER RESEARCH

A standard method should be developed for the concentration and detection of viruses in wastewater and in aerosols to facilitate virus monitoring and to enable comparison of results obtained in different laboratories.

Epidemiology of health effects of workers involved in worst-case sewer activities and wastewater and sludge treatment operations should be conducted.

Existing covers on aeration basins used to control odors should be evaluated for their usefulness in suppression of aerosols.

SECTION 4

OCCURRENCE AND PERSISTENCE OF MICROORGANISMS AND TOXINS IN WASTEWATER AND SLUDGE

Microorganisms present in wastewater and sludge and their survival during treatment have been discussed thoroughly recently by several authors (9-16) and, therefore, will only be summarized here briefly.

MICROORGANISMS AND TOXINS PRESENT IN WASTEWATER AND SLUDGE

Microorganisms

The major groups of microorganisms present in municipal wastewater and sludge are bacteria, viruses, protozoa and helminths. Some of these microorganisms, the diseases that are attributed to them, and known reservoirs of infection are shown in Table 1 (9).

Bacteria. The enteric bacteria are the most common microorganisms present in wastewater. Escherichia coli frequently are present at a concentration of about 10^9/liter and streptococcus faecalis, at about 10^8/liter of wastewater. Salmonella are the most prevalent pathogenic bacterial species present in wastewater and densities of 5000/liter have been reported in raw wastewater (11). Shigella and pathogenic strains of E. coli also occur in wastewater.

Protozoa. The protozoan agents present in wastewater are in the form of cysts which are excreted in large numbers of the feces. The most pathogenic of these is Entamoeba histolytica. Balantidium coli and Giardia lamblia are also found in wastewater. It is estimated that protozoan cysts in wastewater do not exceed 5000/liter (17).

Helminths. A large number of parasitic helminths are present in wastewater in the form of eggs. The helminths are of major public health concern because of the extreme persistence of the eggs to a wide range of environmental conditions. The various parasitic ova most commonly found in wastewater are Ascaris lumbricoides, Trichuris trichiura, Hymenolepis species, Taenia saginata, Enterobius vermicularis, and Necator americanus. Levels of parasitic eggs have been predicted to be about 62/liter of raw wastewater in the U.S. (18). Since a significant amount of animal wastes reach municipal wastewater, the parasites of animal origin are also of concern.

TABLE 1. MAJOR ORGANISMS OF HEALTH CONCERN THAT MAY BE PRESENT IN SEWAGE FROM U.S. COMMUNITITES (9)

Organisms	Disease	Reservoir(s)
I. Bacteria		
Salmonellae (Approx. 1700 types)	Typhoid fever Salmonellosis	Man, domestic and wild animals and birds
Shigellae (4 spp.)	Shigellosis (bacillary dysentary)	Man
Escherichia coli (enteropathogenic types)	Gastroenteritis	Man, domestic animals
II. Enteric viruses		
Enteroviruses (67 types)	Gastroenteritis, heart anomalies, meningitis, others	Man, possibly lower animals
Rotavirus	Gastroenteritis	Man, domestic animals
Parvovirus-like agents (at least 2 types)	Gastroenteritis	Man
Hepatitis A virus	Infectious hepatitis	Man, other primates
Adenoviruses (31 types)	Respiratory disease, conjunctivities, other	Man
III. Protozoan		
Balantidium coli	Balantidiasis	Man, swine
Entamoeba histolytica	Amebiasis	Man
Giardia lamblia	Giardiasis	Man, domestic and wild animals?
IV. Helminths		
Nematodes (roundworms)		
Ascaris lumbricoides	Ascariasis	Man, swine?
Ancylostoma duodenale	Ancylostomiasis	Man

(continued)

TABLE 1 (continued)

Organisms	Disease	Reservoir(s)
Necator americanus	Necatoriasis	Man
Ancylostoma braziliense (cat hookworm)	Cutaneous larva migrans	Cat
Ancylostoma caninum (dog hookworm)	Cutaneous larva migrams	Dog
Enterobius vermicularis (pinworm)	Enterobiasis	Man
Strongyloides stercoralis (threadworm)	Strongyloidiasis	Man, dog
Toxocara cati (cat roundworm)	Visceral larva migrams	Carnivores
Toxocara canis (dog roundworm)	Visceral larva migrams	Carnivores
Trichuris trichiura (whipworm)	Trichuriasis	Man
Cestodes (tapeworms)		
Taenia saginata (beef tapeworm)	Taeniasis	Man
Taenia solium (pork tapeworm)	Taeniasis	Man
Hymenolepis nana (dwarf tapeworm)	Taeniasis	Man, rat
Echinococcus granulosue (dog tapeworm)	Unilocular echinococcosis	Dog
*Echinococcus multiloculari*e	Alveolar hydratid disease	Dog, carnivore

Reprinted from "Health Hazards Associated with Wastewater Effluents and Sludge: Microbiological Considerations" by Akin et al. In: Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. A. Sorber, eds., University of Texas at San Antonio, San Antonio, Texas, 1978, pp. 9-26, with permission of the editors.

Viruses--

About 100 different enteric virus species are associated with human waste. About 80% of the viruses isolated from wastewater are enteroviruses. Other groups found include adenovirus, rotavirus, reovirus, parvovirus-like agents, and hepatitis A virus. The numbers of viruses isolated from wastewater are undoubtedly lower than the actual levels due to the limited sensitivity of detection methods. The average enteric virus density in the United States has been estimated to be about 7000 viruses per liter of raw wastewater (19) and most reports indicate virus levels of 1 to 2000 per liter in secondary treated wastewater.

Bertucci et al. (20) studied the relationship between confirmed virus plaques and unconfirmed plaques in primary and secondary wastewater effluent samples from three midwestern U.S. cities. They found that the virus concentrations for individual samples ranged from 0-80.0 pfu per liter of wastewater and that infective viruses were present in 16.5% of the plaques. The authors believe that failure to confirm plaques as being virus induced may result in overestimation of virus content of wastewater samples. Since Bertucci et al. (20) confirmed 16.5% of all plaques, they would have overestimated the virus content of wastewater samples by an average factor of six if they had not confirmed the plaques.

Toxins

The dust generated at the wastewater treatment plants during sludge heat-treatment operations and at land application sites may contain significant quantities of toxins which may represent a potential health risk to the workers. The toxins of concern are endotoxins derived from bacteria and mycotoxins produced by the fungi. Endotoxins are derived from viable and nonviable gram-negative bacteria which are present in wastewater and sludges. They are the lipopolysaccharide component of the bacterial cell wall and are usually known as the lipopolysaccharides (LPS). Endotoxins are released when the cell wall is disrupted. Acute and chronic inflammation observed in workers exposed to dust generated at a sewage treatment plant in Gothenburg, Sweden, were attributed to exposure to endotoxins in sewage dust by Rylander et al. (21,22).

Among the mycotoxins, aflatoxin produced by the fungus Aspergillus flavus a known human carcinogen, may be of concern for workers involved in sludge composting operations. Composting is a thermophilic process which encourages proliferation of thermophilic fungi. Detroy et al. (23) have shown that the optimal conditions that favor aflatoxin production (i.e., moisture content, humidity, temperature, incubation time, aeration, and nitrogen and carbohydrate content) parallel the conditions present in sludge composting operations. They have also shown that aflatoxin is not destroyed by temperatures of 60-80°C and therefore would not be detoxified by the temperatures generated during composting (40-60°C).

MICROORGANISMS AND TOXIN PERSISTENCE DURING WASTEWATER AND SLUDGE TREATMENT

Wastewater

Several factors affect microorganism survival during wastewater treatment-pH, operating temperature, oxygen demand, ammonia concentration, etc.

Primary Treatment. Primary treatment involves physical processes such as screening, grit removal and sedimentation. The microorganisms may settle out by their density or by being adsorbed to solids. Because of their relatively small size, viruses are less easily removed from wastewater than bacteria, protozoa or helminths. Viruses do not settle out unless adsorbed to solids. The removal of parasitic ova and protozoan cysts during primary treatment is usually not very efficient due to their low specific densities (11). An exception are *Ascaris* ova which have been reported to be up to 100% removed by primary wastewater treatment (24). The percentage of efficiency of removal of some of the microorganisms during primary treatment is about 50% (7,12,13).

Secondary Treatment. Secondary treatment is a biological degradation process. Activated sludge treatment, trickling filters, aerated lagoons and ponding are some of the secondary treatment processes. Each of these processes requires subsequent sedimentation which may be incorporated within the latter two methods. The percentage of efficiency of removal of some of the microorganisms during secondary treatment is about 90% (7,12-14).

Tertiary Treatment. Chemical treatment, filtration, adsorption, ion exchange, nitrogen removal, etc. are tertiary treatment processes. There is not very much information available on the survival of microorganisms in the various tertiary treatment processes. Available information indicates that microorganisms are not completely removed from wastewater by tertiary treatment (7).

Disinfection. Chlorination and ozonation are two of the methods used for the disinfection of wastewater effluents. Chlorination is most commonly used (7,15). Disinfection is very effective in achieving a decrease of up to three orders of magnitude in the number of bacteria and viruses (25). The effectiveness of disinfection by chlorine is dependent on the concentration of the chlorine used, free chlorine residual, pH, time, temperature, the microorganisms under consideration, and the presence of particulate material. Viruses are not inactivated as fast as bacteria and require free chlorine residuals (7,15). The efficiency of chlorine disinfection in inactivating the microorganisms and viruses in wastewater is shown in Table 2 (7,14). Some pathogens such as amoebic cysts, helminth ova, and some viruses, are considerably more resistant to chlorination than coliforms or total aerobic bacteria.

TABLE 2. REMOVAL OF MICROORGANISMS FROM WASTEWATER BY DISINFECTION WITH CHLORINE (7,14)

Group	Organism	Chlorine residual (mg/l)	Time min.	Efficiency
Virus	Infectious hepatitis	1	30	Survived
		15	30	Inactivated
	Coxsackie	5	2.5	Survived
	Coxsackie	1.0	3	99.6% Inactivated
	Echo	1.95	6.5	Survived
	Poliovirus I	0.53	14	Survived
	Coliphage B	0.03	10	20% Survival
	Theiler phage	0.03	10	Inactivated
Bacteria	*M. tuberculosis*	1-5	120	99% Killed
		2	30	99% Killed
		1	30	Destroyed
	E. coli	0.14	3	99.9% Killed
	Coliforms	0.03	10	52% Killed
		1-1.2	15	99% Killed
	Total count	Some	15	98-99% Killed
Nematodes	Diplogaster	2.5-3	120	Survived and
	Cheilobus	15-45	1	Mobile
Others	*S. mansoni* (ova and miracidia)	0.2-0.6	30	Killed
	S. japonicum (ova and miracidia)	0.2-0.6	30	Killed

Sludge

Each of the sedimentation processes described earlier produces a sludge. The microorganisms that survive the various stages of the treatment may accumulate in these sludges and if so, are present in much higher concentration than in wastewater (26). Bacteria (27) and viruses (28,29) adsorb to particulate materials and remain infectious. The activated sludge process sequesters a major portion of the viruses in the sludge (30). Poliovirus in wastewater are mostly associated with the sludge and their presence in wastewater effluents is inversely proportional to the solid content in wastewater (31). Considerable quantities of Mycobacterium may occur in primary sludge. Tubercle bacilli showed a 67-fold increase in concentration in primary sludge as compared to influent wastewater (32). The range of protozoan cysts in sludge is estimated to be about 310-410/liter (18).

Stabilization of sludge by treatment prior to land application is usually necessary to reduce the levels of pathogenic microorganisms and putrescible organic matter. Anaerobic digestion, aerobic digestion, chemical treatment, heat-drying, and composting are some of the methods that can be used to stabilize the sludge.

Anaerobic digestion is the biological decomposition in the absence of free oxygen. Sufficient inactivation of microorganisms including enteroviruses may be obtained in anaerobic digestion depending on the temperature and retention time (16,33,34). The efficiency of inactivation of some of the microorganisms and viruses present in sludge by anaerobic digestion is shown in Table 3 (15,35-38). Virus inactivation by anaerobic digestion is dependent on temperature and retention time. Fenters et al. (39) showed that virus inactivation rates varied in proportion to temperature over a range of 20-35^{o}C. They also showed that among the components of anaerobically digested sludge, sludge supernatant had the greater impact on virus inactivation.

Aerobic digestion process is a biochemical oxidative stabilization of sludge. Pathogen inactivation by aerobic digestion is less efficient under normal design conditions but 100% pathogen destruction can be achieved under auto-heated design conditions (33). Although heat drying is generally regarded as an effective sludge stabilization method, high concentrations of viable airborne bacteria have been measured in a sludge heat-drying facility indicating the potential for pathogen survival (40). These bacteria must have been released from the sludge stream before or without heating since the temperatures reached in the heat drying units are adequate to kill bacteria.

Composting is a thermophilic aerobic decomposition process. Two types of composting processes are generally in use in the U.S.A. -- windrow and forced aeration pile system (33,41). The windrow system consists of long, low piles which are turned periodically. Forced aeration pile system consists of a stationary compost pile constructed over an aeration system. A blower is used to draw air through the pile. Temperatures in the range of 55^{o}-65^{o}C are usually attained during the composting process (33). One of the most important objectives of composting is to obtain high, uniform temperatures throughout the system for sufficient duration so as to penetrate the entire

TABLE 3. INACTIVATION OF MICROORGANISMS BY ANAEROBIC DIGESTION[a]

Organism	Temperature (°C)	Time (Days)	System	% Inactivation	Reference
Virus					
Coxsackie A9	35	1	Bench	97.6	35
Coxsackie A9	35	2	Bench	99.7	35
Echo 11	35	1	Bench	54.5	35
Echo 11	35	2	Bench	92.5	35
Coxsackie B4	35	1	Bench	91.25	35
Coxsackie B4	35	2	Bench	98.99	35
Bacteria					
Tubercle bacilli	Not given	35	Plant and Bench	70-85	36
Salmonella	Not given	60-90	Plant	25	37
Helminths					
Taenia saginata eggs (beef tapeworm)	85	180	Bench	50+	38

a. Adapted from O. J. Sproul "The Efficiency of Wastewater Unit Processes in Risk Reduction." IN: Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. A. Sorber, eds. University of Texas at San Antonio, San Antonio, Texas, 1978. pp. 282-296 mass. A well-run composting process can inactivate the microorganisms including viruses provided the mixing or aeration is efficient. However, windrow or aerated pile operations have not achieved a sufficiently uniform internal temperature to inactivate all microorganisms (33). Burge et al. (42) showed that windrow system was less effective than the aeration pile system in destroying pathogenic microorganisms. This was attributed to the greater probability of non-uniform heat within the windrow where mixing moves the material from outside of the mound to the center and also possibly due to the potential regrowth of bacteria in the cooler portion of the windrows.

Toxins

As mentioned before, endotoxins are derived from the lipopolysaccharide component of the bacterial cell wall. Any treatment process that results in destruction of bacteria in wastewater and sludge is expected to result in increased amounts of endotoxin. Similarly, the conditions present in sludge composting, a thermophilic process, are believed to be conducive to the production of aflatoxin, a mycotoxin, from the fungus *Aspergillus flavus*.

SUMMARY

In conclusion, the existing data indicate that some of the microorganisms survive during wastewater and sludge treatment; and that the amount of endotoxins may increase during treatment processes that result in destruction of bacteria. Workers at wastewater treatment plants and land application sites will, therefore, be potentially at risk of exposure to pathogenic bacteria, viruses and endotoxins.

SECTION 5

MICROORGANISMS AND TOXINS IN AEROSOLS GENERATED AT WASTEWATER TREATMENT PLANTS AND LAND APPLICATION SITES

AEROSOLS

Some of the microorganisms present in wastewater and sludge, especially bacteria and viruses, can become airborne (43). Major sources of the aerosols are the aeration basins of the activated sludge treatment units, trickling filters, and land application sites that use spray irrigation. Aerosols are particulate materials in either solid or liquid form and may also include gases and vapors that are adsorbed or contained in airborne particles or liquid droplets. Inhalation is a possible route of infection because the viruses and most pathogenic bacteria are in the respirable size range. The health hazard posed by aerosolized particles depends on their ability to deposit in the lungs. The most important factor in lung deposition is the size of the particle.

The particle size is usually expressed as mass median or aerodynamic diameter. The aerodynamic diameter is a function of both the physical diameter and the density of the particle. It is defined as the diameter of a unit density sphere having the same settling velocity as the particle in question of whatever shape and density. Figure 1 shows the deposition pattern in the various regions of the respiratory system by different sized particles (44,45). Particles with an aerodynamic diameter greater than 30 µm do not enter the nasal passage, those with an aerodynamic diameter ranging from 5-30 µm are deposited in the naso-pharyngeal region. Particles ranging in aerodynamic diameter from 1-5 µm are usually deposited in the tracheobronchial region by sedimentation. Particles less than 1 µm in aerodynamic diameter are deposited in the pulmonary or alveolar region by diffusion. It is the last category of particles that may constitute a health hazard by inhalation. Particles deposited in the tracheobronchial region can be removed by mucociliary action (spiral movement of the mucus by ciliated epithelium) toward the trachea and pharynx where the material is swallowed or expectorated. The swallowed particles then pose a health hazard via ingestion by exposing the gastrointestinal tract to the pathogens.

Bacteria and viruses may be concentrated in the aerosolized droplet. The concentration of *Escherichia coli* and bacteriophage were found to be 30 and 50 times, respectively, greater in the aerosols than in the suspending fluid (46).

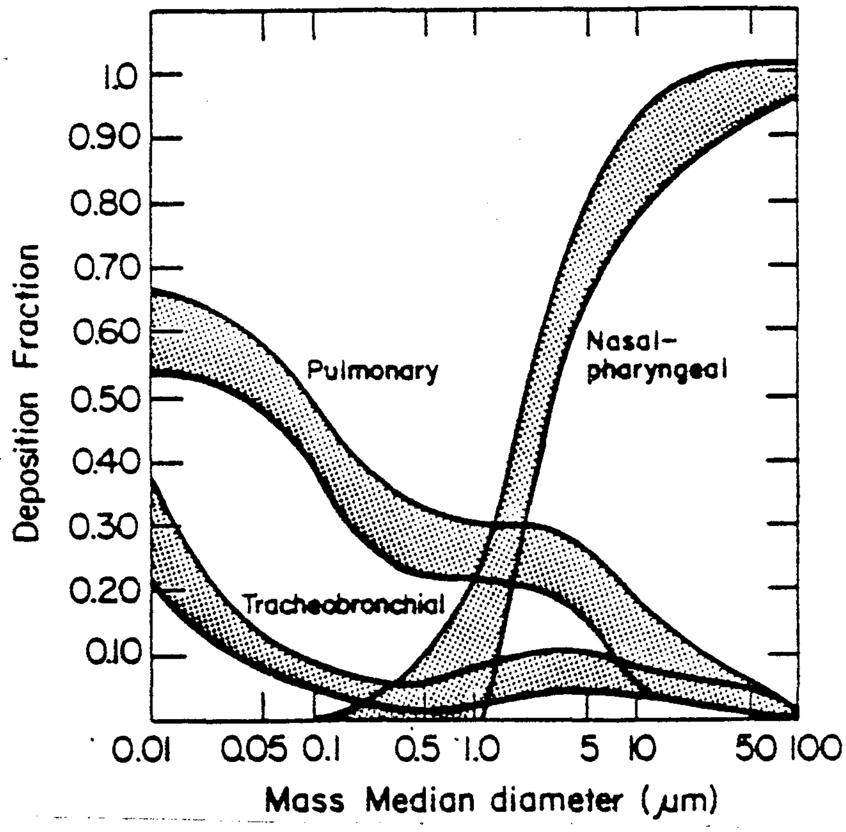

Figure 1. Variability of deposition of particles in the respiratory tract (44,45).

Each shaded area (envelope) indicates the variability of deposition for a given mass median (aerodynamic) diameter (μm) in each compartment when the distribution parameter varies from 1.2 to 4.5 and the tidal volume is 1450 ml, and at the rate of 15 respirations per minute.

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MICROORGANISM MONITORING IN AEROSOLS

Sampling of Microorganisms in Aerosols

Airborne microorganisms are usually collected by the Andersen air sampler (47,48), all glass impinger (47,49), or high volume air sampler (47,50). The Andersen air sampler collects and separates particles into different size ranges and thus provides a good size distribution of the particles. The Andersen sampler is good only when particle concentrations are high, since it has a limited sampling rate of 28.3 liters/min. It also requires a large number of plates. The all glass impinger also has a low sampling rate (6- 12.5 liters/min) and, therefore, is not well adapted to low concentrations of microbial particles. The high volume air sampler can sample large quantities of air with a high collection efficiency for all particle sizes, but it does not provide a size distribution of the particles.

Viruses in aerosols are less well studied than bacteria mainly due to technical limitations in sampling and in obtaining accurate measurement of viruses in air. Large volumes of air must be sampled for virus monitoring in aerosols because of low levels of viruses present in wastewater and wastewater aerosols. For the low levels of viruses present in wastewater, Johnson et al. (51,52) believe that monitoring of viruses in air near wastewater treatment plants and spray irrigation sites is not feasible except by using extraordinary methods. They suggest that "a more practical approach would be to measure the levels in wastewater and then to utilize a predictive model to estimate their concentrations in the air at various distances."

Moore et al. (53) showed that in order to detect aerosolized viruses, extremely large air volumes have to be sampled, and additional concentration of aerosol sample collection fluids was also found to be necessary. For example, Moore et al. (53) sampled 1440 m^3 (4716 ml of collection fluid) and 2340 m^3 (7820 ml of collection fluid) of air to detect significant numbers of viruses in aerosols at a spray irrigation site in Pleasanton, California. In order to be able to collect such large volumes of air, eight high volume samplers close to each other at the appropriate downwind distance were used The samples were operated simultaneously for six to eight consecutive 30-minute periods.

The techniques used for concentrating and quantifying bacteria may be found in Standard Methods for Analysis of Water and Wastewater (54). Bacterial cell count is usually performed by determining the number of cells in the sample capable of forming colonies on a suitable agar medium. It is reported either as standard plate count or colony forming units (cfu). Viruses are usually replicated in suitable tissue cell monolayer and are quantified as plaque forming units (pfu). Viruses are also reported in terms of endpoint dilution such as most probable number (MPN). As mentioned in an earlier section, Bertucci et al. (20) studied the relationship between virus levels as measured by the plaque assay and actual virus populations in wastewater samples from three midwestern areas. Although virus populations in excess of 10^4 pfu/liter have been reported in untreated municipal wastewater, Bertucci et al. (20) found infective viruses in only 16.5% of the plaques. The authors agree that all viruses which are present in an environmental sample will not be detected by any one particular assay system and that plaque lesions or cytopathic effects may be induced by agents other than viruses. Bertucci et al. (20) conclude that virus populations reported only in terms of pfu without plaque confirmation may be grossly overestimated.

The viable aerosol sampling protocol should take into consideration several meteorological factors such as air temperature, relative humidity, solar radiation, wind velocity, wind direction, evaporation, precipitation, time of day, etc. since microbial survival is dependent on these factors. It is recommended, in general, that sampling be done under stable atmospheric conditions (55). Schaub et al. (56) recommend that simultaneous, continuous meteorological information is required to insure valid sampling and also for predictive mathematical aerosol modeling.

Indicator Organisms

Coliform bacteria and coliphage viruses are generally used as indicators of fecal contamination in water, because they are considered to reflect pathogen levels. Coliform is a general term used to describe the non-spore forming facultative anaerobic gram-negative rods which ferment lactose. These bacteria inhabit the intestinal tract of humans and other animals. The coliform group includes Escherichia, Klebsiella, Enterobacter and Citrobacter. The use of coliform organisms as indicators meets many if not all of the requirements for drinking water standards (57). Usually laboratory cultures are seeded as indicator organisms. Selection of the indicator organism depends on the prevalence of the organism in the substrate, availability of methods for quantifying the organism, and resistance of the organism relative to other organisms in the group it represents. Conditions that may destroy a laboratory strain may not harm a naturally occurring strain.

Coliform organisms are also used as indicators of pathogen levels in the monitoring of aerosols. The absence of coliform organisms is often interpreted as meaning that the specific environment or medium under consideration is free of pathogens. This practice is being questioned in the recent years as to its accuracy. It is believed that the traditional coliform indicators for water pollution are very poor models for the evaluation of microbial transport in wastewater aerosols (58). For instance, it has been shown that the disinfection by chlorination is often more effective in reducing the levels of coliform organisms than the viruses and certain other bacteria (59-62). It has also been shown that pathogens such as fecal streptococci, Pseudomonas, and Clostridium perfringens survive longer in aerosols (59-62) than E. coli which has an extremely short life span in the aerosolized form (60,63,64).

From extensive environmental monitoring studies conducted at a spray irrigation site in Pleasanton, California, Johnson et al. (51) have shown that the indicator microorganisms, especially total coliforms and fecal coliforms die-off more rapidly with aerosol age than do the pathogenic bacteria. They also found that coliphage levels, which are used as indicators of airborne animal and human viruses, tend to decay much faster than the hardier human viruses in the aerosol state. Johnson et al. (51) concluded that the use of the traditional coliform organisms as indicators of pathogenic microorganism levels in aerosols results in an extreme underestimation of actual pathogen levels.

Monitoring for total airborne bacteria instead of only for coliform organisms has been suggested by several workers as a faster and a more reliable method of indicating pathogen levels in aerosols because coliform organisms such as Escherichia, Klebsiella, and Enterobacter species accounted for only 5% of the total aerosolized bacterial population (65,66). Monitoring of total bacterial count has the advantage of not having to preselect the indicator organism in wastewater, but it may not be representative of the pathogenicity of the aerosol. Encapsulated organisms such as Klebsiella have been shown to survive longer in aerosol state than noncapsulated organisms such as E. coli (67). Johnson et al. (51) recommend that fecal streptococci would be a more suitable indicator than coliform organisms because of the relative ease of the assay, the levels found in wastewater, its relative hardiness during aerosolization, and its relatively low viability decay rate.

The hardiness of viruses is shown in studies where they were detectable in a primary effluent containing 3 mg/liter of chlorine as a disinfectant (68). Coliphages have been suggested as indicators of airborne animal viral contamination (68), and they are also more stable than coliform bacteria in the airborne state. The human enteric viruses are hardier than coliphages; however, the monitoring of these viruses is not very practical because large volumes of air ($> 300\ m^3$) must be sampled and monitoring cannot be done at a distance greater than 100 m from the source in the case of spray irrigation facilities (51,52).

MONITORING ENDOTOXINS IN DUST AND AEROSOLS

One of the limitations to the accurate monitoring of endotoxin levels in environmental samples is the lack of a sensitive and specific assay for endotoxins. Assay methods currently available include the rabbit pyrogenicity assay (69), tumor necrosis assay (69), and the mouse lethality or the Limulus lysate assay (70). All these assays require endotoxin to be pure and free from contaminants which may give false positive reactions. Endotoxins in dust or aerosol samples are usually extracted and purified by Westphal's method (71). However, the yield of endotoxin extracted by this method is only about 1% based on the dry weight of bacteria or cell walls extracted.

Rylander et al. (72) have reported detecting endotoxins in aerosols at conventional wastewater treatment plants in Sweden. Samples for endotoxin analysis were collected from air on Millipore filters using personal air samplers, which were carried by workers over a four-hour period while performing routine work. Levels of endotoxins were determined using the Limulus lysate assay method (70). Values of endotoxins found ranged from 0 to 0.2 $\mu g/m^3$ (73).

MICROORGANISMS IN AEROSOLS AT WASTEWATER TREATMENT PLANTS AND VICINITY

As indicated before, two of the secondary treatment processes - activated sludge treatment units and trickling filters are shown to be the main sources of aerosols at most wastewater treatment plants (74) and about 50% of the particles generated are found to be 5 μm in diameter (67). Hickey and Reist (1) have made an extensive survey of the microorganisms emitted at wastewater treatment plants as well as spray irrigation sites. SCS Engineers (7) also reviewed the microorganism emissions at wastewater treatment plants and spray irrigation facilities.

For lack of standardized sampling methods and suitable indicator organisms, it is difficult to interpret the literature on airborne levels of microorganisms. Most researchers to date, have relied upon coliforms as indicator organisms. Because of the many variables involved, quantitative results among the various investigations may be compared only in general terms.

The bacteria and virus concentrations in aerosols generated from some activated sludge units and trickling filters are listed in Table 4. Aerosol sampling protocols generally included collection of air samples at or near the source and sometimes also at specified downwind distances. Samples collected upwind were used as controls.

Some of the factors affecting the emission of viable aerosols besides aeration from wastewater are shown to be aeration bubble size, microorganism concentration in wastewater, total solid content in the aerated liquid droplet and wind velocity. Smaller aeration bubble size, increased microorganism concentration in wastewater, increase in total solid content in the aerated liquid droplets and higher wind velocity have all been shown to increase emission of viable aerosols (1,43,75-78). Blanchard et al. (79) report that in the process of droplet formation at the surface of aerated liquids, the droplet scavenges organic material and microorganisms, with the result that the aerosol particles may contain a bacterial or virus concentration 100 or more times greater than that of the ambient water. This suggests that bubbles formed during aeration processes of sewage treatment such as the activated sludge method may lead to the formation of droplets containing very much higher concentrations of pathogens than the wastewater itself (16).

The recovery of microorganisms in air samples was dependent upon aerosol die-off, deposition, diffusion between the source and the sampling location, wind velocity, relative humidity, solar radiation, air temperature, etc. (65,76-78, 80). The pattern of recovery of microorganisms was found to be similar with all studies. The concentrations of the microorganisms per unit volume of air were relatively high at or near the source and much lower

TABLE 4. BACTERIA CONCENTRATIONS IN AEROSOLS AT SPECIFIED DISTANCES FROM TRICKLING FILTERS AND ACTIVATED SLUDGE UNITS

Aerosol source	Sampling distance downwind	Micro-organism sampled	Concentration in the aerosol	Comments	Ref.
Trickling Filter	≤5 m	Coliphage Virus	$0.32/m^3$	Average most probable number. Only coliforms show a statistically significant decrease with distance.	68
	≥5 m		$0.24/m^3$		
	≤5 m	Coliphage Virus	$0.25/m^3$		
	≥5 m		$0.16/m^3$		
	≤5 m	Coliphage Bacteria	$210/m^3$		
	≥5 m		$14/m^3$		
Activated Sludge	Near the source	Total Bacteria	$30,700/m^3$	Andersen Sampler	1,7,
			$1,170/m^3$	All-glass impinger	80
		Klebsiella, Aerobacter, Proteus	10.5% of total bacteria	Known respiratory tract pathogens	
Activated Sludge	45 m	Total Bacteria	$106/m^3$	Same as concentration 45 m upwind. No observable effect at >45 m downwind.	1,7, 65
Activated Sludge	0 m	Coliform	$99; 770/m^3$	50% particles <5 μm in diameter	7,67
	45 m		$7; 1088/m^3$		
Trickling Filter	0 m	Coliform	$106; 1053/m^3$		
	45 m		$7; 141/m^3$		
Activated Sludge	On-plant site	Total Viable Particles	$376/m^3$	Mean concentration	83
	800 m		$198/m^3$		
	On-plant site	Total Coliforms	$6.87/m^3$	Mean concentration	
	800 m		$1.15/m^3$		

(continued)

TABLE 4 (continued)

Aerosol source	Sampling distance downwind	Micro-organism sampled	Concentration in the aerosol	Comments	Ref.
Activated Sludge	30- 50 m	Total Coliform	5.8 cfu/m^3	Geometric mean concentration	85
		Pseudomonas	7.0 cfu/m^3		
		Coliphage	0.7 pfu/m^3		
		Enterovirus	$<9.0 \times 10^{-4}$ pfu/m^3		
		Fecal Streptococcus	2.0 cfu/m^3		
		Mycobacterium	9.1 cfu/m^3		
Activated Sludge	20- 25 m	Proteus	<17 cfu/m^3	High volume air sampler. Maximum concentrations at the distance indicated.	84
		Fecal Streptococcus	<17 cfu/m^3		
		Salmonella	<17 cfu/m^3		
		Shigella	<17 cfu/m^3		
		Klebsiella	Possibly isolated		
		Enterovirus	<0.7 pfu/m^3	5-day plaques	
	250-300 m	Proteus	<15 cfu/m^3		
		Fecal Streptcoccus	<15 cfu/m^3		
		Salmonella	<15 cfu/m^3		
		Shigella	<15 cfu/m^3		
		Klebsiella	Isolated		
		Enterovirus	<0.76 pfu/m^3	5-day plaques	
	1000-2000 m	Proteus	<17 cfu/m^3		
		Fecal Streptococcus	<17 cfu/m^3		
		Salmonella	<17 cfu/m^3		
		Shigella	<17 cfu/m^3		
		Klebsiella	Not isolated		
		Enterovirus	<0.47 pfu/m^3	5-day plaques	

(continued)

TABLE 4 (continued)

Aerosol source	Sampling distance downwind	Micro-organism sampled	Concentration in the aerosol	Comments	Ref.
Activated sludge	on-plant site	Standard plate count	812/m^3	Geometric mean concentrations at the aeration basins	86
		Total coliform	8/m^3		
		Fecal coliform	1/m^3		
		Fecal streptococci	2/m^3		
Activated sludge	on-plant site	Standard plate count	253/m^3	Geometric mean concentrations at the aeration basins	86
		Total coliform	13/m^3		
		Fecal coliform	6/m^3		
		Fecal streptococci	2/m^3		
Activated sludge	on-plant site	Standard plate count	292/m^3	Geometric mean concentrations at the aeration basins	86
		Total coliform	4/m^3		
		Fecal coliform	3/m^3		
		Fecal streptococci	2/m^3		
Activated sludge	on-plant site	Standard plate count	735/m^3	Geometric mean concentrations at the aeration basins	86
		Total coliform	43/m^3		
		Fecal coliform	12/m^3		
		Fecal streptococci	55/m^3		
Activated sludge	on-plant site	Standard plate count	583/m^3	Geometric mean concentrations at the aeration basins	86
		Total coliform	68/m^3		
		Fecal coliform	45/m^3		
		Fecal streptococci	66/m^3		

as the downwind sampling distance increased. Hickey and Reist (1) noted that the downwind viable aerosol concentrations generally diminished to upwind concentrations within a few meters of the source, although coliforms have been reported to have been recovered 1.29 Km downwind from a trickling filter (78). They attributed such recoveries at greater downwind distances to normal sampling variations. Hickey and Reist (1) as well as SCS Engineers (7) concluded that the activated sludge and trickling filter generate microorganisms, some of which are pathogenic, in aerosols and that the aerosols may also contain low levels of animal viruses. Fannin et al. (81) and Slote (82) also concluded, from independent investigations, that the aerosols emitted from activated sludge units and trickling filters are continuous sources of low levels of animal viruses. Some of the recent studies that have been reported since the reviews of Hickey and Reist (1) and the SCS Engineers (7) are discussed below.

The activated sludge unit of the wastewater treatment plant in Skokie, Illinois was shown to be a source of aerobic bacteria containing particles and total coliforms at the treatment plant and in the vicinity by Carnow et al. (83). The concentration of the microorganisms decreased with downwind distance from the plant. At 0.8 Km downwind, the concentration of total viable particles was found to be 45% greater than that at a similar location upwind.

Aerosol monitoring conducted at and in the vicinity of wastewater treatment plant near Chicago, Illinois, by Johnson et al. (84) showed that the aeration basin is probably the source of airborne indicator bacteria, coliphage, pathogenic bacteria, and enteroviruses. However, in the neighboring residential areas at a distance of 400 meters, microorganism levels in air, soil and water samples were found to be indistinguishable from the background levels. Johnson et al. (85) also measured the microorganism levels in aerosols at the aeration and surge basins at the Durham advanced treatment plant in Tigard, Oregon. They found that the microorganism levels in aerosols were higher at the aeration basin than at the surge basin. The aeration basin and the surge basin were located within 400 m of the classroom area and 50 m of the school playground, respectively, from an elementary school. The daily peak dose to which the school children may be exposed on any one school day per year was estimated to be about 9 cfu of mycobacteria and 3.5 cfu of fecal streptococci.

The airborne microorganism levels measured by Clark et al. (86) at the center of aeration tanks at treatment plants in three midwestern U.S. cities are listed in Table 4.

MICROORGANISMS IN AEROSOLS AT WASTEWATER LAND APPLICATION SITES AND VICINITY

Wastewater application methods (87,88) play an important role in the emission of aerosols at land application sites. The choice of the method depends on the individual land application facility, geographic location and climate. Of the various methods of land application, spray or sprinkler irrigation is believed to generate the maximum amount of aerosols.

The type of spray equipment and type and spacing of nozzles would also affect the emission of aerosols at spray irrigation sites. Between 0.1% and 1% of the wastewater sprayed is transformed into aerosol depending on the type of spray device, the pressure and the wind speed. Increased pressure is reported to increase the emission of smaller particles (89). The concentration of microorganisms in aerosols, as has been shown before, is directly proportional to the concentration in the wastewater. Airborne E. coli were detected only when the effluent concentration was 10^4 organisms/ml or greater (90).

The concentration of microorganisms in aerosols at spray irrigation sites would also depend on the degree of treatment received by the wastewater or the sludge. Microbial concentration in aerosols decreases as the treatment process received by the wastewater increases. The experience of European countries with raw or partially treated wastewater supports this statement (2). The coliform organisms generated in aerosols from the use of raw wastewater could be detected at 400 m downwind, when the wind velocity was 16-32 kilometers per hour (Kph) (91). Under favorable meteorological conditions such as high humidity and wind and little or no sunlight, coliform organisms were found to be dispersed as far as 1200 m from the source when settled raw sewage was used (92). The bacteria and virus concentrations in aerosols generated at some wastewater spray irrigation sites are shown in Table 5.

Katzenelson et al. (90,93) reported that coliform bacteria were found in the air 350 m downwind from the wastewater spray sprinklers. They also reported detecting a colony of Salmonella in one sample, a known human pathogen, 60 m downwind from the spray source. The authors calculated that at a distance of 100 m downwind from this wastewater sprinkler, a person may inhale about 36 coliform organisms in 10 minutes. It must be emphasized that the effluent sprayed on these fields was from partially-treated undisinfected municipal wastewater and levels of coliform bacteria in the effluent were approximately the same as those seen in raw wastewater present in the United States, and raw wastewater is not sprayed in the United States.

Sorber et al. (25) and Bausum et al. (94,95) conducted two field studies at Ft. Huachuca, Arizona where chlorinated secondary municipal effluent was used to irrigate a golf course. Field testing was also conducted with unchlorinated effluent to determine the effect of chlorine disinfection on the levels of microorganisms in wastewater aerosols. In the first study (25), bacterial aerosol levels that were significantly above background levels were measured out to 200 m downwind of the spray line, the greatest distance tested. Klebsiella was the most commonly found pathogen. Bacteriophage was used as a tracer in the second study conducted at Ft. Huachuca (94,95). The study showed that bacteriophage can be recovered at a distance of 562 m downwind from the spray nozzle. The study also showed that total aerobic bacteria reached levels in excess of $10,000/m^3$ at 46 m downwind and that Klebsiella formed a large part of coliform population at 46 m downwind from the source when unchlorinated effluent was used. The concentration of the microorganisms in aerosols from the two studies at Ft. Huachuca are listed in Table 5.

TABLE 5. BACTERIA AND VIRUS CONCENTRATIONS IN AEROSOLS AT SPECIFIED DISTANCES FROM WASTEWATER SPRAY IRRIGATION SITES

Concentration in wastewater	Sampling distance downwind	Micro-organism sampled	Concentration in the aerosol	Comments	Ref.
3.7×10^5/ml[a]	47 m 152 m	Aerobic bacteria	1630/m^3 100/m^3		25
1.4×10^5/ml[a]	47 m 152 m	Coliform-like bacteria	330/m^3 30/m^3		
$2\text{-}4 \times 10^5$/ml[a]	46 m	Aerobic bacteria Klebsiella	>10^4/m^3 ~50/m^3		94,95
2.5×10^5/ml[b,c]	563 m	Tracer bacteriophage	Recovered, concentrations not indicated		
$10^5\text{-}10^6$/ml[d]	10 m 70 m	Total coliform Total coliform	425/m^3 102/m^3	All glass impinger Maximum concentrations	93
	10 m 100 m 400 m 60 m	Total coliform Total coliform Total coliform Salmonella	496/m^3 88/m^3 4/m^3 1 colony found	Andersen sampler Maximum concentrations	
$10^4\text{-}10^5$/ml[e]	30 m 100 m 200 m	Total coliform Total coliform Total coliform	452/m^3 5/m^3 4/m^3	Andersen sampler Maximum concentrations	93
$5.8 \times 10^3 - 6.6 \times 10^4$/ml[f]	30 m 50 m 100 m	Standard plate count	485 cfu/m^3 417 cfu/m^3 37 cfu/m^3	75% particles < 5 μm in diameter Mean value for airborne bacteria bearing particles above background	97

(continued)

TABLE 5 (continued)

Concentration in wastewater	Sampling distance downwind	Micro-organism sampled	Concentration in the aerosol	Comments	Ref.
699,000/ml[a]	5- 20 m 100-200 m	Standard plate count	2570/m^3 880/m^3	Geometric mean concentrations	51,52
7500/ml[a]	5- 20 m 100-200 m	Total coliform	5.7 MFC/m^3 1.2 MFC/m^3		
800/ml[a]	5- 20 m 100-200 m	Fecal coliform	1.0 MFC/m^3 $<$0.3 MFC/m^3		
220/ml[a]	5- 20 m 100-200 m	Coliphage	0.34 pfu/m^3 0.18 pfu/m^3		
67/ml[a]	5- 20 m 100-200 m	Fecal streptococci	1.4 cfu/m^3 1.9 cfu/m^3		
1050/ml[a]	5- 20 m 100-200 m	*Pseudomonas*	72 cfu/m^3 43 cfu/m^3		
390/ml[a]	5- 20 m 100-200 m	*Klebsiella*	$<$5 cfu/m^3 $<$5 cfu/m^3		
54/ml[a]	5- 20 m 100-200 m	*Clostridium perfringens*	1.5 cfu/m^3 1.1 cfu/m^3		
46/ml[a]	50 m 100 m	Mycobacteria	0.80 cfu/m^3 0.82 cfu/m^3		
0.12/ml[a]	50 m 100 m	Enteroviruses (3 and 5 day)	0.014 pfu/m^3		

a. Secondary treated wastewater
b. Lagoon effluent, unchlorinated
c. Tracer bateriophage concentration at the spray nozzle
d. Untreated wastewater
e. Aerated ponds
f. Ponded, chlorinated wastewater

Sorber et al. (25) and Bausum et al. (94,95) also showed that disinfection of the effluent by terminal chlorination was effective in reducing the bacterial concentration in aerosols to near background levels, but was much less effective in reducing the dissemination of the bacteriophage. The studies also showed that under nighttime conditions, characterized by lower wind speeds and increased atmospheric stability, microorganism levels in aerosols were slightly greater than under daytime conditions.

Sorber et al. (61) calculated predicted levels of bacteria and viruses downwind of spray irrigation sites using modification of the Turner's atmospheric dispersion model. They determined that an individual working 200 m downwind from a center pivot spray rig with a 300 m radius could inhale as many as 20 infectious airborne viruses in 10 minutes. Teltsch and Katzenelson (96) recovered Echovirus 7 in 4 out of 12 air samples taken at 40 m downwind from the source at a spray irrigation site in Israel. As mentioned before, the microbial content of effluents sprayed in Israel is approximately the same as that found in raw wastewater and the case in Israel is not representative of situations in the United States since raw wastewater is not sprayed in the United States.

Bausum et al. (97) monitored the bacterial levels in aerosols generated at a spray irrigation site at Deer Creek Lake, Ohio, a demonstration land wastewater treatment site for U.S. Army Corps of Engineers recreational areas. They observed a mean value of 485 cfu/m^3 for standard plate count at 30 m downwind. This value was reduced by 15% and 92% at 50 m and 200 m, respectively. The median diameter of the bacteria - bearing particles was found to be 2.6 μm at 30 m downwind, and 75% of these particles had a diameter that ranged from 1-5 μm. A number of spray heads were used in this study compared to only a single spray head or a line source used, in general, in their previous studies (25,94,95).

Johnson et al. (51,52) conducted extensive monitoring of the aerosols generated at a spray irrigation facility in Pleasanton, California, for microorganism levels at the downwind edge of the spray irrigation site and at several downwind locations. The levels of microorganisms in aerosols at 100-200 m downwind are, as expected, found to be lower than at the downwind edge of the spray irrigation site. Aerosols sampling was performed out to 600 meters downwind of the spray fields, extending into the populated areas. Detectable levels above background were noted for standard plate count, fecal streptococci, and mycobacteria. Microbial levels observed in the aerosols at night were twice those seen in the daytime. The levels found in aerosols of a number of microorganisms, standard bacterial plate count, total coliform, fecal coliform, fecal streptococci, Pseudomonas, Klebsiella, Clostridium perfringens, coliphages, and enteroviruses, are shown in Table 5. Based on the reported enterovirus density, a worker on duty 8 hours per day at 50 meters would inhale only one enterovirus each nine days.

Baubinas and Vlodavets (98) have reported recovering enteric pathogens from grass and aerosols at a distance of 200, 250, and 400 meters from a spray irrigation site in Russia.

Brenner et al. (99) and Davis-Hoover et al. (100) have carried out environmental monitoring for airborne animal viruses and pathogenic bacteria at the spray irrigation facility of the Muskegon Wastewater Management System 1 in Michigan. The Muskegon County Wastewater Management System is an aeration, lagoon impoundment, and spray irrigation facility which treats about 102,000 cubic meters of wastewater per day and irrigates 2160 hectares of corn land. During the growing season, wastewater is applied using center-pivot irrigation rigs. Although viruses were present in the raw influent wastewater and sometimes in the storage lagoon, no animal viruses were detected either in the lagoon wastewater just prior to spray application or in the aerosol samples collected at the aeration basin. Enterobacter cloacae, Klebsiella pneumoniae and aerogenes were some of the bacteria isolated in the air samples collected at the facility. Klebsiella was found to be the most predominant of the gram-negative rod pathogens. The numbers of bacteria isolated adjacent to the spray irrigation rigs as well as aeration basins were found to be higher than those found upwind. Their findings also showed that the number of bacteria isolated adjacent to the aeration basins were higher than those found adjacent to the spray irrigation rigs. The bacterial levels found upwind of the aeration basin appeared to be about the same as those detected 18 m downwind of spray irrigation rigs. The authors calculated that an average adult breathing 500 ml of air per breath and 20 breaths per minute, standing downwind of the aeration basin would inhale about 10 total bacteria colony forming units (cfu) per minute.

In summary, the available data indicate that the microorganisms in aerosols generated at spray irrigation sites may remain viable and be dispersed for several hundred meters from the spray source.

SURVIVAL AND DISPERSION OF MICROORGANISMS IN AEROSOLS

Some of the variables that affect the survival and dispersion of microorganisms in aerosols are die-off, deposition, and diffusion (65,66), and have been discussed in detail recently (1,101,102) and, therefore, will only be summarized briefly. In general, a higher viable aerosol decay rate was observed initially followed by a much lower decay rate. The high initial decay rate of microorganisms in aerosols was attributed to organism die-off from the stress of droplet evaporation. Die-off, deposition, and diffusion of the microorganisms in aerosols are affected by the following environmental factors.

Relative Humidity: Microorganisms in aerosols survive longer at high relative humidities such as those occurring at night. High relative humidity delays droplet evaporation and retards organism die-off (101).

Wind Velocity: The dispersion of microorganisms in aerosols is directly proportional to wind velocity (101).

Sunlight: Sunlight promotes decay of airborne microorganisms. It has been shown that the concentration of the microorganisms in air samples taken at nighttime were generally higher than those taken during the daytime (51).

Temperature: Increased temperature reduces the viability of microorganisms in aerosols. The effect of the temperature is not usually apparent until it is 80°F or more. Increased temperature also increases droplet evaporation (102).

Open Air: Airborne microorganisms are shown to be inactivated more rapidly in the actual field conditions compared to those generated under controlled conditions in the laboratory (102).

Continuous emission from the source, so that diffusion in the direction of transport may be neglected.

The material was a stable gas or aerosol (less than 20 microns in diameter) which remained suspended in the air over long periods of time.

None of the material emitted was removed from the plume as it was moved downwind, and there was complete reflection at the ground, thus no deposition or chemical/biological reactions.

The mean wind direction specified the X-axis, and a mean wind speed representative of the diffusing layer was chosen.

Except where mentioned, the plume constituents were distributed normally in both the vertical and cross wind directions.

The model held for ten minute intervals.

These equations were to be used when the mean wind speed and direction could be determined, but when the measurements of turbulence were not available. If these were available, then Pasquill's equations would be more accurate.

These equations should be used for only sources of ground level to 20 meters in height.

Turner's equations were used by Katzenelson et. al (90, 93) directly without any modification and by Kenline et. al (65, 66), Sorber et. al (25, 61), Bausum et. al (97) and Johnson et. al (107) with modifications to determine the concentration of microorganisms in aerosols at wastewater treatment plants and wastewater spray irrigation facilities.

The work of Katzenelson, et al. (90,93) was based on Turner's equations. Air samples were taken in the field of Kibbutz Tsorah and near the agricultural school at En Kerem, using Andersen six-stage cascade impactor and AGI-30 impingers. The equation used was Turner's (104) line source equation, derived from Sutton (109). The assumptions were the same as in Turner's work with one additional assumption, that the quantity of aerosols was 1% of the total output of the sprinkler for all meteorological conditions. There was no modification of the equation to make it applicable to viable particles (that is, to account for die-off) or to account for relative humidity which is thought to be critical for viable particle survival. The authors believed that the difference in the observed and predicted values was probably due to these factors.

Turner's equations were modified by Kenline and Scarpino (65, 66). They tried to account for the deficiencies in Turner's equations, such as deposition and die-off, and derived a new equation, using many ideas from Sutton (109) and Chamberlain (110). Their equation for an area source (an aeration basin at a conventional secondary sewage treatment plant) was achieved by summing Sutton's line source equation. They included a term for microbial deposition and die-off, atmospheric diffusion and height above the ground. By exposing petri dishes containing solid media at ground level adjacent to the Andersen sampler, they were able to calculate the velocity of deposition. Although Kenline felt that relative humidity was important in the survival of bacteria, this was not taken into account directly in the equation. Kenline's equation assumes Turner's stability class B (104) and a mean wind speed of 2 m/sec. He found that while diffusion and die-off were dependent on distance, deposition was not. With a limited number of samples, there is a good correlation between the predicted values and measured values. Kenline felt that his average vertical difference of 10%, with a range of 1 to 21%, and an average horizontal difference of 13%, with a range of 1 to 25%, was within the acceptable ranges of sampling error.

Work done by Sorber, Schaub, and Bausum (61) eventually led to the development of Camann's early model (25). This study used Turner's equations without any measured aerosol data. The study was done on aerosolization produced by center pivot rigs and was admittedly a "gross approximation". Preliminary data suggested that the aerosolization efficiency was 0.1 to 1%. The authors stated that the achievement of more than a 3 log reduction in viruses by filtration and disinfection is superior, in protecting the environment, to a buffer zone of 800m which only achieves a 2 log reduction.

The next application of Turner's equations by Sorber, Bausum and Schaub (95) was used in a study of the Ft. Huachuca Golf Course, which was irrigated with secondary treated domestic sewage. They used f_2 phage as a tracer, a questionable procedure as other phage in the wastewater can grow in the host and give a positive result in the f_2 test, thus leading to possibly misleading elevated results. Andersen six-stage samplers with disposable plastic petri dishes were used to collect total aerobic bacteria and coliphage, and high volume air samplers were also used to determine total viable bacteria. All measurements were taken at five foot elevation for 30 to 40 minutes. When the wastewater was chlorinated, they found a lowering of viable counts by three and a half orders of magnitude (a factor of 10^{OMD}, where OMD = the numbers of orders of magnitude, in this case $10^{3.5}$) for total aerobic bacteria and one order of magnitude for the f_2 phage.

The equations used by Sorber et al. (95) assume 100% aerosolization, 100% sampler efficiency, and zero decay. Thus, they accurately predicted that the computed values would usually be higher than the actual values. The predicted to observed ratios ranged from 0/1 to 9750/1. Using a dye as a tracer, they found that about 0.32% of wastewater solids escaped the wetted zone as an aerosol.

The model developed by Sorber et. al (25) in their later work was based on Turner's adaptation (104) of Pasquill's diffusion equation (103). The equation used specific wind velocities instead of the mean wind velocity and incorporated separate calculations of concentrations of microorganisms in the atmosphere for each one minute interval throughout the sampling period. These concentrations were then summed and used in a new multiplicative equation to find the adjusted sampler recovery. Variables considered were the summed model prediction from Turner's equation, efficiency of aerosolization and sampler collection, a decay factor, and a "factor of fit." Using this model, estimates of the buffer zone required to reduce the total aerobic bacterial aerosol population to 5 organisms/m^3 above background were made. A study of terminal disinfection showed that the reduction in aerosol bacterial levels was somewhat less than the reduction in wastewater bacterial levels, but the authors (25) felt that terminal chlorination would probably be a more practical and economical measure than buffer zones.

The next development was seen in the first phase of the Pleasanton study by Johnson et al. (108). The assumptions were the same as Turner's assumptions with one addition, that measurements must be made on a level terrain. Johnson et al. (108) explained that the estimates would be greater than the observed values, as the assumption of no deposition was probably invalid. The wastewater dye source strength and the percent aerosolization were calculated. The latter ranged from 0.43 to 0.75%. There were no data to show how close the observed values were to the estimated values. A second model was proposed for Andersen samplers, using bacterial survival factors, such as temperature, relative humidity, solar radiation, and sampling period, as variables, but there was no data showing how these estimated results related to the observed results.

CAMANN'S MODEL

A dispersion model based on an extensive aerosol monitoring study (51) at the City of Pleasanton, California, spray irrigation site using all glass impingers, LEAP and Litton M Large-Volume air samplers, and Rotorod samplers, was developed by Camann (51, 52, 56, 58, 106, 111). The study consisted of two phases: phase I (108) was designed to select a suitable site and to develop optimum methods for sampling and analysis of wastewater and aerosol samples; Phase II (51) was designed to perform extensive environmental monitoring and to develop a dispersion model that could be applied to other wastewater spray irrigation sites.

Camann's dispersion model (57) incorporated three parameters, partially developed in the earlier multiplicative model of Sorber et al. (25). These parameters are (1) a site specific parameter for aerosolization efficiency, i.e., the fraction of the sprayed wastewater that is aerosolized during a run, (2) a microbiological impact factor, i.e., the proportion of the aerosolized microorganisms of a group that remain viable at some downwind distance, and (3) a microbiological age decay rate, i.e., the rate at which microorganisms of a group die-off with aerosol age.

Several assumptions were made in the development of this model. First, the major biological and physical processes affecting microorganism levels in aerosols from spray irrigated wastewater were adequately represented by the multiplicative dispersion model. Second, aerosol microorganism die-off was caused by factors such as meteorological conditions that have the same effect at any spray irrigation site. Last, the microbiological aerosol concentrations from field studies vary with the sampling, shipping and assay procedures used. Hence, the aerosol concentrations predicted by the model assume the use of the Pleasanton procedures.

Camann found that the preponderance of model predictions were within one order of magnitude of the net measured values, and most were within a factor of 5. This model was developed from selected Pleasanton data and was validated for indicator organisms with the remaining data and data from additional studies at a Ft. Huachuca, Arizona, golf course spray irrigation site (25,95) and the Deer Creek Lake State Park, Ohio, campground spray fields (97). Camann suggested that the use of limited sampling and the predictions from this microbiological dispersion model may be a preferable alternative to extensive field sampling when sprayed wastewater was not chlorinated.

Sorber and Sagik (58) suggested that the model developed at Pleasanton (51) may be used to estimate the level or dose of aerosolized pathogens to which treatment plant workers and nearby residents may be exposed. They point out, however, that it cannot be used to determine the threshold levels of pathogens in aerosols and is not predictive of the health risks associated with spray irrigation.

Schaub et. al (56), in detailed discussion of the methodology of aerosol monitoring, suggested that a major limitation in verifying Camann's model has been the lack of reliable methods for obtaining microorganism concentrations in effluent and aerosol samples. They suggested that refinements in the model may be needed to separate the individual components of the microbiological impact factor. In addition, standard indicator organisms, used in the development of the model, were not representative indicators of the pathogen content of the wastewater aerosols.

In aerosol studies (85) conducted at the Durham Advanced Wastewater Treatment Plant in Tigard, Oregon, using Litton Model M Large Volume air samplers, Camann's model was used to predict the daily dose of aerosolized mycobacteria and fecal streptococci received by Durham elementary school children. In order to use the model, the authors assumed that the wastewater quality and meteorological conditions during the week of aerosol sampling were representative of both the mean levels and the variability occurring over the two school years of interest and that the extrapolation procedure used was valid. Examination of the school attendance records revealed no adverse effects from the operation of the treatment facility, located adjacent to the school. However, it was suggested that the students may have received a peak daily dose of 9 cfu of mycobacteria and 3.5 cfu of fecal streptococci about one day per year. These values exceed the usual seven-hour outdoor background dose by two orders of magnitude for fecal streptococci and by three or more orders of magnitude for mycobacteria. The authors admitted that the extrapolation procedure used may have caused uncertainty in the predicted microorganism concentrations of one or more orders of magnitude.

CONCLUSIONS

To date, dispersion models have limited usefulness in the prediction of aerosol concentrations of microorganisms for various reasons. Some of the limitations of dispersion models are the following:

(1) Models make assumptions in their development which may, in reality, be only partially valid or may only be valid for a specific site and set of conditions.

(2) Models may contain considerable error or imprecision due to extrapolations, interpolations, partially valid or invalid assumptions, and the inadequacies of the measurement of various equation parameters.

(3) Models may not incorporate all factors necessary for the determination of the actual microorganism concentration in aerosols, such as aerosolization efficiency, deposition, die-off, relative humidity, and solar radiation.

(4) Models may be used for purposes not originally intended at the time of their development.

(5) Models may not be sufficiently validated.

(6) Insufficient or inappropriate techniques may be used in the mathematical or other types of analysis of the model.

(7) Models are based on and validated by data collected using sampling methods limited by the current state-of-the-art.

The predictions of microorganism concentration in aerosols by the present models contain one of more of the limitations listed above. However, for bacteria the models appear to have some usefulness but have not been developed enough to replace actual field monitoring. More research is needed to test and improve present models or to develop new ones.

SECTION 7

EFFECTS OF PATHOGENIC MICROORGANISMS PRESENT IN WASTEWATER AND WASTEWATER AEROSOLS

Details about the pathogenic microorganisms present in wastewater that have adverse effects on human health, the various routes of their infection, the relative risk associated with each potential mechanism, sewage-related diseases of concern, their symptoms and severity, current incidence, etc. have been discussed extensively recently and will only be summarized here (1,4,7,9,112-114). Disease incidents related to contamination of water supplies by untreated wastewater and abuse of commonly accepted wastewater management practices have been summarized by Sepp (2) and Bryan (13) and, therefore, will not be discussed here.

DISEASES ATTRIBUTED TO PATHOGENIC MICROORGANISMS PRESENT IN WASTEWATER AND AEROSOLS

Pathogenic microorganisms generated at wastewater treatment plants and land application sites can be transmitted via inhalation, skin contact, and ingestion via poor hygiene. Infection may result in disease depending on the degree of exposure as well as other factors such as pathogen density minimum infective dose, virulence of the organism, and susceptibility of the exposed individual.

The dose of a particular organism that is required to produce an infection or disease in a healthy individual is referred to as the minimum infective dose. It depends on the particular strain of the organism, its virulence under the conditions of exposure and the susceptibility of the individual. It is very difficult to define dose-response to low densities of pathogenic microorganisms. Low density refers to a density capable of causing disease in only a small fraction of the exposed population. Under special circumstances, an infection can develop from a single virus, protozoan or helminth. The minimum infective dose for bacteria ranges from 100 to 100 million, depending on species (13). While the 50 percent infective dose for *Giardia lamblia* is between 25 and 100 cysts (115). A summary of available information on the reported waterborne diseases in the U.S. is shown in Table 6 (114). A brief discussion of the diseases attributed to the pathogenic microorganisms present in wastewater and wastewater aerosols is presented below.

TABLE 6. SUMMARY INFORMATION ON REPORTED WATERBORNE DISEASES IN THE UNITED STATES (114)

Wastewater constituent	Resulting disease	Disease incidents 1961-1974 Reported no. of outbreaks	Reported no. of cases	Reported untreated wastewater concentration No./100 mL
Indicator organisms				
Total coliforms	NA	NA	NA	10^9
Fecal coliforms	NA	NA	NA	10^8
Bacteria				
Shigella sp	Shigellosis	32	4,413	ND
Salmonella typhi	Typhoid fever	18	326	10^6 to $4x10^3$
Salmonella sp[a]	Salmonellosis	11	16,743	600
Escherichia coli	--	4[b]	188	ND
Virus				
NS	NS	NA	NA	700 to 1,900
Hepatitis virus A	Hepatitis A	43	1,254	--
Parasites				
Entamoeba histolytica	Amoebiasis	3	39	$4x10^{-1}$
Giardia lamblia	Giardiasis	15[c]	5,303[c]	ND
Miscellaneous				
NS	Gastroenteritis[d]	85	34,538	ND
Chemical agents	Chemical poisoning	9[e]	474[e]	ND

Note: NA = not applicable; ND = no data; NS = not specified.

a. Excludes *S. typhi*.
b. None reported during 1971-1974.
c. Incomplete reporting for major incidents only.
d. May include other disease previously reported.
e. For the time interval 1971-1974.

Bacterial Diseases

The important classes of bacteria and the diseases attributed to them are shown below:

Agent	Disease
Shigella sp.	Shigellosis
Salmonella sp.	Salmonellosis
Vibrio cholerae	Cholera
Mycobacterium tuberculosis	Tuberculosis
Leptospira icterohemorrhagiae	Leptospirosis
Escherichia coli (enteropathogenic)	Gastroenteritis

Shigellosis. Shigellosis, also known as bacillary dysentery is an acute bacterial diarrheal disease and is caused by Shigella organisms. Shigellosis is an intestinal disese and is limited to man and higher apes. Infection is primarily due to ingestion and spreads rapidly under improper sanitary conditions. Waterborne spread of the organisms can cause outbreaks of shigellosis. Recovery is usually spontaneous. Most Shigella infections are subclinical with no manifested symptoms.

Salmonellosis. Salmonellosis is caused by a large variety of species of Salmonella and is characterized by diarrhea, abdominal cramps, fever, nausea and vomiting. The disease is usually mild and even asymptomatic. Infection usually occurs as a result of ingestion of contaminated food. Typhoid fever is usually obtained from drinking water or eating food contaminated with Salmonella typhi. The duration of the illness is about three weeks. In untreated cases, a mortality rate of 10% is observed (112,116). Salmonella typhi has been shown to be responsible for incidents of typhoid fever associated with wastewater contaminated drinking water (117). Other members of the Salmonella group are associated with paratyphoid fever and acute gastroenteritis.

Cholera. Cholera is caused by the bacterium Vibrio cholerae. It is a serious acute intestinal disease characterized by acute diarrhea, vomiting, dehydration, and lowered body temperature and blood pressure. Death can occur within a few hours of the onset of the disease. Infection can spread from person to person via contaminated food and water. Occurrence of cholera in Israel in 1970 was attributed to the practice of irrigating vegetable crops with untreated wastewater (118).

Tuberculosis. Tuberculosis is caused by the bacterium Mycobacterium tuberculosis. Infection is primarily due to inhalation of infective bacteria. Tuberculosis manifests itself in two forms, primary and post-primary. Primary tuberculosis is characterized by acute respiratory debilitation either healing or progressing to more serious illness and death. Post-primary tuberculosis is a chronic illness.

Leptospiroris. Leptospirosis, also known as Weil's disease is caused by the bacterium Leptospira icterohemorrhagiae and can be transmitted to man by rodents. Symptoms include chills, high fever, headache, photophobia and muscular pain. The infection is usually subclinical but, on occasion it can be fatal. Outbreaks of the disease have been linked to water contaminated by urine from humans, pet animals, and livestock.

Gastroenteritis. Gastroenteritis can be caused by a number of bacteria, in particular, by enteropathogenic strains of *Escherichia coli*. It is characterized by diarrhea, nausea, prostration, dehydration, and usually the lack of febrile response (119). In general, the illness is not severe and recovery is spontaneous. The disease can be spread via sewage-contamination of drinking water (120).

Viral Diseases

Viruses consist of a nucleic acid genome enclosed in a protective protein coat. Viruses that are shed in fecal matter, referred to as enteric viruses, are characterized by their ability to infect tissues in the throat and gastrointestinal (GI) tract. These viruses include the enteroviruses (polio-, echo-, and coxsackie viruses), reoviruses, adenoviruses and rotaviruses, as well as the agent of infectious hepatitis. They can cause a wide variety of diseases, such as paralysis, meningitis, respiratory illness, myocarditis, congenital heart anamolies, diarrhea, eye infections, liver disease and gastroenteritis. Almost all of these viruses also produce nonclinical infections thus making it difficult to recognize them as being waterborne. Known cases of waterborne viral diseases have largely been limited to infectious hepatitis. Some viral diseases that may be transmitted via wastewater and their etiologic agents are discussed below.

Infectious Hepatitis. Infectious hepatitis is caused by Hepatitis A virus and is a common viral disease transmissible via wastewater. Waterborne outbreaks of hepatitis are known to occur (117). Foodborne outbreaks from harvesting of sea food from sewage contaminated water have also been reported (121).

Poliomyelitis. Poliomyelitis is caused by poliovirus types 1, 2 and 3. It is a viral disease that affects the central nervous systems. Symptoms include fever, malaise, headache, etc. Paralysis of the voluntary muscles can occur in severe cases. Infection occurs following ingestion of viable virus particles.

Gastroenteritis. A number of viruses are known to cause gastroenteritis. Enteric viruses such as coxsackie, Echo and Hepatitis A viruses, parvovirus-like agent, rotavirus and adenovirus all cause gastroenteritis.

Gastroenteritis is a relatively mild illness, often subclinical, and of short duration. Rotavirus infection is of particular interest because of its prevalence in infants. It is often stated that a single virus particle is capable of initiating infection in a susceptible individual (122). Mininum infective dose for normal persons is in the range of 10 to 200 viruses. Since viruses do not replicate in the external environment, asymptomatic individuals can act as an important reservoir for viral replication and thus increase the likelihood of initiating disease in susceptible individuals.

Protozoan Diseases

Protozoans pathogenic to man and capable of transmission via wastewater are Entamoeba histolylica, which causes amebic dysentery or amoebiasis, and Giardia lamblia which causes giardiasis. These diseases can result from fecal contamination of drinking water. The organisms are obligate parasites and do not survive outside the human host.

Amebic Dysentery. Amebic dysentery is caused by the organism Entamoeba histolytica. The organism infects the human colon causing erosion of the superficial mucous membranes. It may eventually invade the tissue with subsequent ulceration. Symptoms include abdominal discomfort, diarrhea, nausea, and in some cases liver abscesses.

Giardiasis. Giardiasis is an intestinal disease caused by the infection of the gut by the protozoan Giardia lamblia. The disease ranges from subclinical to clinical malabsorption. Symptoms include abdominal pain, loss of appetite, apathy, headache and diarrhea alternating with constipation. Outbreaks of giardiasis due to consumption of contaminated drinking water have been reported (112).

Parasitic Diseases

The parasitic organisms of most concern are Ascaris lumbricoides, Necator americanus (hookworm), Trichuris trichiura (whipworm) and Taenia saginata (beef tapeworm). These parasitic organisms can cause infection via skin contact. The severity of infestation depends on the number of ingested eggs.

Ascariasis. Ascariasis results from ingestion of the eggs of A. lumbricoides. The larvae of this organism hatch in the small intestine and penetrate through the wall to infiltrate the blood stream. The symptoms are variable depending on the number of infecting organisms present. They include abdominal pain, acute colic pain, vomiting, diarrhea, and mild fever. The worms do not reproduce inside a human host and, therefore, the severity of symptoms is directly related to the number of eggs ingested. The infection is usually self limiting, but migration of the larvae in large numbers through the lung can cause hemorrhage and pneumonia.

Trichuriasis. Whipworm infestation is caused by Trichuris trichiura eggs. These eggs are not hardy and require special environmental conditions in order to mature to an infective stage (112,123).

Necatoriasis. Hookworm infestation is caused by skin penetration by the larvae of N. americanus. The eggs of this organism must hatch in the soil and develop to the third stage larvae in order to be infective to humans (112,123). The larvae penetrate the skin on contact and follow the cardiopulmonary pharyngeal route to the intestine. Hookworms cause malnutrition and anemia (119). Workers involved in the transportation of sludge and those at land application sites are potentially at risk to infection via skin penetration. The organism is not common in the U.S.

Taeniasis. Taeniasis is caused by Taenia saginata (Beef tapeworm) and/or Taenia solium (pork tapeworm). These helminths can be present in contaminated animal flesh and in water. The symptoms of taeniasis are abdominal pain, digestive disturbance and weight loss.

EPIDEMIOLOGY OF WASTEWATER TREATMENT PLANT WORKERS AND POPULATIONS LIVING IN THE VICINITY

Clark et al. (4) reviewed the literature concerning the possible health effects of workers exposed to municipal wastewater via physical and aerosol routes of exposure to pathogenic microorganisms. They stated that only a few studies to date (1975) had been conducted on the health status of wastewater workers. These studies were mostly retrospective in nature and, therefore, do not permit determination of whether the specific disease condition existed before exposure to wastewater. Also, most of the studies mentioned in their work were from outside of the United States. They found that no correlation had been made between specific microorganism levels and the incidence of selected disease. They concluded that in order to evaluate the disease risk associated with occupational exposure to wastewater, the disease incidence of the comparable general population group must be known as well as worker health status, and length and degree of exposure. They recommend that more definitive studies of occupational risks associated with sewage collection and treatment should be carried out.

A number of studies on the health effects of wastewater exposure have been initiated in recent years. The studies usually consisted of two general types --

(1) retrospective medical history questionnaire surveys or examination of medical records, and

(2) prospective clinical and laboratory evaluation of the health status of treatment plant workers and populations residing near treatment plants.

Some of the recent studies are discussed in this section.

Cincinnati, Ohio; Chicago, Illinois; and Memphis, Tennessee (86). A prospective seroepidemiological study of municipal wastewater workers with controls in three metropolitan areas -- Cincinnati, Ohio; Chicago, Illinois; and Memphis, Tennessee -- was carried out by Clark et al. (86). The study group consisted of more than 100 workers recruited when they began work at activated sludge treatment plants. In addition, in Cincinnati about 50 sewer maintenance workers and 50 primary wastewater treatment plant workers were also included in order to differentiate between aerosol exposure and exposure associated with primary wastewater treatment. The study involved quarterly collection of sera, throat and rectal swabs, annual multiphasic and physical examinations; monthly collection of illness information and environmental monitoring. Clinical illness surveys did not show an increase in respiratory, gastrointestinal or other illness in workers exposed to wastewater. Clinical laboratory examination showed no evidence of increased bacterial or parasitic infections in wastewater workers. Liver function tests and immunoglobulin determinations (IgA, IgG and IgM) also did not show consistent abnormalities in the wastewater workers. Although more enteroviruses were recovered from wastewater workers, the authors found that the recovery rates were not significantly different. Preliminary analysis of viral serology data also failed to show a significant difference in the prevalence of antibodies specific to viruses. However, in one of the cities in 1977, there were significantly more seroconversions in experienced wastewater treatment plant workers than in inexperienced workers and controls when the results of testing for 31 viruses were evaluated together. Viral serology of the family members of the study participants also did not reveal any significant differences between workers and family members. Additional testing for antibodies to Hepatitis A and Legionella pneumophila is planned. The study did show an increase in minor gastrointestinal illness in inexperienced wastewater workers compared to experienced workers and controls. However, these illnesses did not correspond to enteroviral infections.

Gartside and Clark et al. (124) carried out a mortality study of former employees of the Metropolitan Sanitation District of Greater Chicago (MSDGC). Preliminary analysis of about 400 death certificates showed no significant departures from expected death rates for several major disease groupings for the workers as a whole or for several employee subgroups, or the length of employment. They did not find any correlation between cause of death and exposure to wastewater.

Winnipeg, Manitoba, Canada (125). A prospective epidemiological study of wastewater treatment plant workers was conducted in Winnipeg, Manitoba by Sekla et al. (125). The study was initiated as a result of frequent complaints of headache, fatigue, lassitude, dysentery, and nausea by the workers. The symptoms were noted when workers were taken out of their work environment; thus illness was of short duration. Comprehensive hematological, biochemical, serological and immunological profiles of the workers were compared with those of suitable controls. The study concluded that clinical laboratory results obtained from the wastewater exposed workers did not differ from those of the controls. However, sinusitis was detected among the wastewater workers that started upon exposure to the work environment and diminished after leaving work. They suggest that an allergen might be involved. An excess of nasal disorders was also detected.

Gothenburg, Sweden (72). Rylander et al. (72) carried out a prospective epidemiological study of workers in conventional sewage treatment plant, at a plant where the sludge was heat-treated and at another plant where household waste and sewage sludge was composted. The study involved interviewing workers to determine the frequency of clinical symptoms and chemical and immunological evaluations of workers' sera. A high proportion of workers in conventional sewage treatment plants and in the compost plant had gastrointestinal symptoms. Workers exposed to sewage dust, especially at heat-treated sludge operations were found by Rylander and his co-workers (21) to suffer from acute episodes of fever and eye discharges. Sewage-exposed workers were found to have elevated levels of immunoglobulins (IgG, IgM and IgA), in addition to a higher percentage of elevated levels of C-reactive protein and fibrinogen degradation products. Rylander et al. (72) attribute the clinical symptoms as due to exposure to endotoxins present in the wastewater treatment process, especially the dust generated during the sludge-drying operations.

Copenhagen, Denmark (126,127). Investigators in Copenhagen conducted a health survey of Copenhagen sewer workers, who were noted to have a higher death rate than a comparable control population. The study was initiated at the request of the sewer workers and consisted of analysis of death statistics and sick leave records, administration of a health questionnaire, medical consultation, and blood and urine chemistry. The study showed that a high proportion of deaths occur within the year of retirement. The death rate was found to be greater in those working for 9-16 years than in those employed for less than nine years. A limitation of this study is that only 33 deaths were evaluated. Absenteeism was found to be significantly higher in workers over 50 years of age than in office workers of the same age. However, there is no difference in absenteeism rate in sewer workers when compared to other manual workers. The study also showed that sewer workers experience a high rate of acute gastrointestinal disorders including nausea, vomiting, and diarrhea. Clinical laboratory analyses showed that sewer workers have elevated levels of the immunoglobulin, IgG, but no other significant differences from control groups. Higher levels of antibodies to Hepatitis A were also reported in sewer workers but not to Hepatitis B. Hepatitis A results correlated better with age than with length of employment. Other investigators have shown that the presence of antibody to Hepatitis A increases with age (128).

Honolulu, Hawaii (129). A retrospective epidemiological study of the assessment of health risks to sewer workers was carried out by Root et al. (128). The study involved examination of medical and sick leave records of the workers for a two-year period. Analysis of individual sick leave records showed that total number of days lost in a year are 2.5 times greater for workers frequently exposed to raw wastewater than for those who were rarely exposed. Symptoms included colds, flu, stomach upsets, and a variety of aches and pains. A review of annual physical examination records showed no differences in the exposed and rarely exposed groups. Root et al. (129) state that from sick leave record analysis, it would appear that there is a significant relationship between frequency of exposure to sewage and number of sick days taken. They concede that their conclusions should be based on more than a two-year study and recommend that a more detailed analysis be carried out over a greater time period. They do, however, conclude that sewer workers were at no greater risk than the general population.

Egan Plant, Chicago, Illinois (84). A prospective epidemiological study of households within a 5 Km radius of a new wastewater reclamation plant located near Chicago, Illinois was carried out by Johnson et al. (84). The study consisted of environmental monitoring, household health survey to examine the incidence of respiratory and gastrointestinal diseases, and clinical evaluation of biological specimens to isolate pathogenic bacteria, viruses and parasites, and to determine viral antibody titers. The study showed that the microorganism and chemical levels in the air, water and soil samples in the neighborhood were not distinguishable from the background levels. The household health survey showed that there is an increased incidence of skin disease, nausea, vomiting, and diarrhea among residents living close to the wastewater treatment plant. The authors believe that these symptoms may be associated with the nearby operation of the wastewater treatment plant. However, they mention that the evidence obtained from the household health survey is non-medical and possibly subjective. Clinical laboratory evaluations did not show evidence of an adverse health effect from the wastewater treatment plant. They concluded that there is no public health hazard for populations living beyond 400 meters from the plant, this distance being the closest that any people resided. The authors, however, point out that the area surrounding the plant was developed further after their study started and that the new residents were not included in the study.

Skokie, Illinois (83). A prospective epidemiological health survey of a population living within 1.6 Km of an activated sludge treatment plant in Skokie, Illinois was carried out by Carnow et al. (83). The study consisted of collection of throat swabs, stool specimens, blood samples for pathogenic bacteria and virus analysis, immunological evaluation for viral antibodies; maintenance of health diaries, and environmental monitoring. The study included 269 households living at about 600-800 meters from the center of the wastewater treatment plant. The study failed to show a correlation between exposure and the rate of illnesses reported or of bacterial or viral infection rates, even though the plant has been shown to be a source of viable bacteria and viruses. They concluded that there are no adverse health effects on residents potentially exposed to viable aerosols. The authors, however, concede that only a very small number of people were exposed to the highest pollution levels and hence the results are not conclusive.

Tecumseh, Michigan (130). The potential health effects of an activated sludge treatment plant on residents of a community living within a series of 600 meter concentric rings from the plant were studied by a retrospective study by administering a questionnaire by Fannin et al. (130).

The objective of the study was to find the incidence of total, respiratory, and gastrointestinal illnesses. They found differences in disease incidence during the period May through October at varying distances from the wastewater treatment plant. Persons living within a 600 m radius were found to have a greater than expected risk to respiratory and gastrointestinal illnesses, when specified for income and education. The authors conclude that the higher illness rates may be related to higher densities of lower socioeconomic families than to the wastewater treatment plant. Persons living around a second 600 m concentric ring were used as controls.

Tigard, Oregon (85). Johnson et al. (85) analyzed the attendance data at an elementary school that was located next to a wastewater treatment plant in Tigard, Oregon, as a part of the first phase of a potential health hazard evaluation. The aeration basin of the plant was located within 400 m of the classrooms and the surge basin was found to be located within 50 m of the school playground. The study also included environmental monitoring. Camaan et al. (111) using a model, calculated that the students would receive a peak dose of about 9 cfu of mycobacteria and 3.5 cfu of fecal streptococci. Small exposure levels would be encountered several dozen days per year. The study concluded that illness, as represented by school attendance, did not show evidence of adverse health effects from wastewater treatment plant operations at these exposure doses. The authors concede that the analysis of school attendance data was a relatively insensitive measure.

Summary

The following conclusions can be drawn from the epidemiology of workers at the wastewater treatment plants and populations living in the vicinity and are based mostly on the comments from the panel at the USEPA Symposium (131). The survival and dispersion of viable particles in aerosols are dependent on a variety of factors as mentioned earlier. Finding a correlation between airborne microorganism levels and incidence of disease in exposed workers or in nearby populations is rather difficult because of the complexity of the variables involved. Also, there is no information available on minimum infective dose of airborne microorganism levels for inhalation route. Although pathogenic microorganisms have been detected in aerosols and inhalation is a possible route of exposure, the health effects studies carried out so far do not indicate any increased health risk due to exposure to wastewater aerosols. However, in the words of Oliver "negative epidemiologic evidence is even less persuasive than most other kinds of negative evidence." Cliver recommends that "people should not venture closer than necessary to a source of wastewater aerosol." He also notes that people visiting sewage treatment plants regularly stand in the "aerosol cloud" of the activated sludge tanks without perceptible ill effects (132).

The panel at the USEPA symposium concluded that wastewater treatment plant workers' hazard, if any, is small from infectious disease agents, hazards to nearby residents is almost nonexistent and that the exposure to pathogenic microorganisms in aerosols is not a unique way of initiating enteric infections. The panel recognized, however, that the worst case exposure of either the worker or the populations has not yet been investigated (131).

The absence of a recognizable disease hazard due to exposure to wastewater aerosols in wastewater treatment plant workers may be explained as due to the possible immunity developed by being regularly exposed to low levels of viruses and pathogenic bacteria that can cause infection but not clinical illness (133).

EPIDEMIOLOGY OF WORKERS AT LAND APPLICATION SITES AND POPULATIONS LIVING IN THE VICINITY

There are only a limited number of studies on health effects of workers at land application sites and populations living in the vicinity, some of these studies are still being carried at present.

Israel (134). A retrospective epidemiological study was carried out in Israel by Katzenelson et al. (133). The incidence of enteric communicable disease in 77 kibbutzim (cooperative agricultural settlements) where crop irrigation was practiced with partially treated, nondisinfected wastewater, was compared with that of 130 kibbutzim not practicing such irrigation. The incidence of shigellosis, salmonellosis, typhoid fever, and infectious hepatitis was found to be 2-4 times higher in the kibbutzim practicing wastewater spray irrigation. The study populations lived from 100 to 3000 m from the spray irrigation fields. The study seemed to provide some evidence for an increased risk for enteric communicable disease among populations living near wastewater spray irrigation sites. The pathways of infection, that is, direct contact or aerosol exposure, are not clear. The study also did not directly relate spray irrigation with the elevated incidence of diseases. The authors concede that the study has serious methodology problems and that there were other sources of disease besides the wastewater pathogens.

A follow-up retrospective epidemiological study was carried out by Shuval et al. (135) in 83 kibbutzim. Preliminary analysis of data showed that there is no apparent difference in overall enteric disease incidence between kibbutzim practicing wastewater sprinkler irrigation and those that do not. In those kibbutzim which irrigated with wastewater for only two out of a four-year period, the study also showed no difference in enteric disease incidence for the period when wastewater irrigation was practiced compared to the period when they did not. Although these conclusions are based on preliminary analysis of data only, it appears that aerosols are probably not an important pathway of infection in the kubbutz populations. A prospective epidemiological study is planned which is aimed at further elucidation of the possible routes of transmission of pathogens from spray irrigation sites to the adjacent communities (135).

Melbourne, Victoria, Australia (136). Wastewater from the city of Melbourne has been applied to agricultural lands at the Melbourne and Metropolitan Board of Works Werribee Farm since 1896. Land filtration, grass filtration, and lagooning are some of the treatment processes used prior to land application of the raw wastewater, depending on the season.

The workers involved in the land application and the residents on the farm would be expected to be at risk from exposure to pathogens and chemicals in the wastewater. Even though the farm had been in operation for the past 80 years, according to an official of the farm, the health of the workers as well as the residents of the farm "has been as good as that of the community generally and no epidemics of diseases have occurred." It appears, in the absence of supporting evidence, that such a conclusion was a personal observation made by the official and was probably not based on an actual health effects study (health questionnaire survey or clinical investigation). No special precautions were taken during the whole of this period other than normal hygiene practices. There were, however, complaints of objectionable odor, but they report that the degree of offense or inconvenience has been minimal.

India (137). A prospective epidemiological study of the health status of sewage farm workers and a suitable control population was carried out in India by Krishnamoorthi et al. (137). The study consisted of a clinical evaluation and collection of stool specimens for the analysis of protozoan parasites, cysts, and helminthic eggs. *Ascaris lumbricoides* (round worm) and *Ancyloma duodenale* (hook worm) were the most dominant parasites while *Entamoeba histolytica* was the most dominant protozoan found among the sewage farm workers. The study results show that the incidence of infection was about 20-27% higher in the sewage farm workers compared to the control populations and the multiplicity and intensity of infection were found to be more predominant in sewage farm workers than the control population; thus indicating a clear health hazard to the workers involved in the land application of raw sewage. It must be emphasized that the experience in India involves land application of untreated sewage and, therefore, does not represent situations in the United States.

Ohio State Farm Bureau (138). A prospective epidemiological study of the health effects of farm families utilizing municipal sludge for land application is being carried out by Ohio Farm Bureau Federation and the United States Environmental Protection Agency in cooperation with the Ohio State University Research Foundation, the Ohio Agricultural Research and Development Center, the Ohio Cooperative Extension Service, the Ohio Department of Health and the Ohio Environmental Protection Agency (138, 139).

Muskegon, Michigan (140). A short-term prospective seroepidemiological study of the workers at a wastewater spray irrigation facility in Muskegon, Michigan is being carried out by Clark et al. (140).

Stanford et al. (141) carried out a study of morbidity risk factors from irrigation with treated wastewater. They found that no instance of disease was reported from the spray irrigation of chlorinated secondary effluents.

Summary

The following conclusions can be drawn from the limited information available on the epidemiology of workers and populations at land application sites. Although pathogenic microorganisms are present in aerosols in detectable levels, there is no recognized disease transmission that can be attributed to airborne pathogens to either workers or populations at land application facilities. It is believed that the health hazard from sprinkling wastewater is limited to direct contact with unevaporated droplets. There is, however, a potential for contamination of food crops grown on wastewater or sludge treated lands which should be taken into consideration when formulating guidelines or recommendations. It has been shown that viruses concentrate in sludge because of their tendency to adsorb to particulate material, which also prolongs their survival. Once crops are harvested, enteric viruses can survive for long periods during storage at low temperature. There is also a possibility that vegetables consumed after thorough cooking might have been infected by contact with kitchen surface, utensils and hands contaminated by raw crops.

SECTION 8

CONTROL OF AEROSOLS

Major sources of aerosols are, as has been mentioned earlier, aeration basins, trickling filters, and land application sites that practice spray application. Some of the factors that affect the microbial concentration in aerosols are:

-- viable microorganism levels in wastewater
-- aerosolization efficiency i.e., the proportion of wastewater that enters the aerosol state.
-- aerosol decay rate
-- volume of the wastewater sprayed per unit time
-- atmospheric stability and other meteorological parameters such as wind speed, relative humidity, solar radiation, temperature, etc.

Once aerosolized, the survival of airborne microorganisms is reduced by increased temperature, lower relative humidity, and solar radiation. Airborne microorganism levels are also reduced by diffusion by high wind speed. However, neither meteorlogical conditions nor diffusion by high wind speed would provide reliable reduction in airborne microorganism levels.

Some of the techniques which may be used to control or suppress aerosols and/or the levels of microorganisms in aerosols are:

-- use of vegetative barriers to intercept, filter, and disperse aerosols
-- use of suitable buffer/safety zones
-- disinfection of wastewater effluents and sludge prior to land application
-- selection of proper spray equipment
-- covering the aeration basins.

Adaptation of some or all or a combination of these techniques would help suppress the aerosols and/or microorganism levels in aerosols. The effectiveness of the various techniques is discussed below briefly.

Vegetative Barriers. The effectiveness of the vegetative barrier was evaluated by the Metropolitan Sanitary District of Greater Chicago (MSDGC) by using dense coniferous and deciduous vegetation (142,143). The extent of filtration as a function of vegetation density and wind velocity was studied in a low-speed wind tunnel. Filtration effectiveness was determined by reduction in the levels of *Bacillus subtilis*, var. *niger* and *E. coli* in aerosols. The study showed that the levels of microorganisms in aerosols were reduced by 50% and concluded that strategically-placed vegetation would effectively reduce aerosols generated at wastewater treatment plants. This would be expected to be true atspray irrigation facilities also.

Buffer/Safety Zones. A buffer or safety zone is a space between the wastewater treatment plant or the edge of the wetted area of spray irrigation site and adjacent land uses that ensures adequate protection of populations from potential health hazards or aesthetic insult of exposure to pathogenic microorganisms in aerosols, and water supplies from contamination with pathogenic microorganisms present in wastewater and sludge used for land application.

The buffer zones recommended by several states for safe land application of municipal wastewater and sludge are listed in Table 7. The distance recommended for human inhabitation ranged from about 61 meters (Iowa, surface spreading of stabilized sludge) to 400 meters (Minnesota and South Dakota, spray application of secondary wastewater). The data shown in Table 7 are compiled from information/literature received in response to a mail survey from states and U.S. territories. The guidelines established by some states for safe land application of wastewater and sludge are shown in Table 8. The data shown in Table 8 are obtained from the same source used for compiling the data in Table 7. As can be seen from Table 8, some states have adapted quite stringent requirements depending on the type of the use of the land. Although most states permitted grazing of pasture lands by dairy cows after a certain number of days following wastewater or sludge application, some states do not permit such use. As can be seen from Tables 7 and 8, none of the states permit land application of raw wastewater or unstabilized sludge. When queried regarding the basis for the guidelines, responses ranged from "none" to "intuition" to published literature, United States Department of Agriculture (USDA) studies and EPA Manuals. As can be seen from Table 8, the greater the potential hazard (i.e., the more intimate the public contact with the treated wastewater), the more stringent are the regulations. None of the states have based their guidelines on a health effects survey or on known health effects.

It was mentioned earlier that Sorber et al. (61) calculated predicted levels of bacteria and viruses downwind of spray irrigation sites using a modification of Turner's atmospheric dispersion model. They determined that an individual working 200 m downwind from a center pivot spray rig with a 300 m radius could inhale as many as 20 infectious airborne viruses in 10 minutes. From this, they estimated that an 800 m buffer zone should be used around a spray irrigation site as a safe distance for normal human inhabitation. Bertucci et al. (20) calculated that a total of about 1340 hectares (3348 acres) would be required to provide an 800 m buffer zone, as recommended by Sorber et al. (61), around a 400 hectare (100 acres) spray irrigation site. But based on the reported enterovirus density by Johnson et al. (51,52) at a spray irrigation site in Pleasanton, California, a worker on duty 8 hours per day at 50 meters would inhale only one enterovirus every nine days.

TABLE 7. BUFFER/SAFETY ZONES RECOMMENDED BY SOME STATES FOR SAFE APPLICATION OF WASTEWATER (W) AND/OR SLUDGE (S) TO LAND COMPILED FROM MAIL SURVEY[a] (METERS)

State	Minimum treatment required	Nearest water supply: Well	Nearest water supply: Surface	Nearest public road	Nearest inhabited area	Nearest residential development	Nearest property line
Florida[b] (S)	Stabilized	304	91.2	91.2	91.2	--	--
Florida (W)	Secondary & disinfection	60.8	60.8	--	--	--	--
Georgia (W)	Secondary	60.8	30.4	45.6	91.2	--	45.6
Idaho[b] (S)	Stabilized	152	91.2	15.2	91.2	--	--
Idaho[c] (S)	Stabilized	152	152	152	152	--	--
Illinois[b] (S)	Digested	45.6	60.8	6.08	60.8	--	--
Illinois[c,d] (S)	Digested	45.6	304	304	304	--	--
Illinois[c,e] (S)	Digested	45.6	60.8	60.8	60.8	--	--
Indiana[b] (S)	Stabilized	91.2	91.2	91.2	91.2	456	--
Iowa[b] (S)	Stabilized	152	--	--	60.8	--	--
Kansas[c] (W & S)	Secondary	60.8	60.8	--	--	152	30.4
Maine[b] (S)	Stabilized	30.4	30.4	--	--	--	--
Maine[b] (S)	Untreated	91.2	91.2	Reasonable Dist.	91.2	--	--
Michigan[b] (S)	Stabilized	60.8	60.8	60.8	152	152	7.6
Minnesota[b] (S)	Stabilized	60.8	60.8	7.6	60.8	182.4	--
Minnesota[c] (S))	Stabilized	60.8	91.2	91.2	395.2	790.4	--
Minnesota (W)	Secondary & disinfection	400	400	--	400	400	--
Nebraska (W)	Pretreatment[f]	91.2	15.2	15.2	364.8	364.8	--
Nebraska[b] (S)	Digested	60.8	60.8	--	--	--	--
New York[b] (S)	Untreated	--	60.8	--	304	--	--
New York[b] (S)	Digested	--	60.8	--	152	--	--
Ohio (S)	Digested or stabilized	--	91.2	--	--	--	--
Pennsylvania (S)	Digested	91.2	30.4	--	91.2	--	15.2

(continued)

TABLE 7 (continued)

State	Minimum treatment required	Nearest water supply		Nearest public road	Nearest inhabited area	Nearest residential development	Nearest property line
		Well	Surface				
S. Dakota (W)	Secondary	400	400	30.4	400	400	30.4
Tennessee[b] (S)	Stabilized	45.6[g] (Summer) 212.8 (Winter)	--	--	--	--	--
Texas (W)	Primary & disinfection	152	--	--	--	--	--
Utah[c] (W)	Secondary	--	--	--	304	304	--
Wisconsin[b] (S)	Digested	152	--	--	152	152	--
Wisconsin[c] (W)	--	76	76	--	152	152	--

S: Sludge; W: Wastewater; --: not indicated or specified.

a. Compiled from data/literature received in response to a mail survey from states and U.S. territories.
b. Surface spreading.
c. Spray application
d. High pressure spraying of liquid sludge.
e. Low pressure spraying of liquid sludge.
f. Lagoon storage for 120 days.
g. Variable with the slope of the site.

Number of states/U.S. territories that responded - 40
Number of states/U.S. territories with no requirements - 9

TABLE 8. GUIDELINES ESTABLISHED BY SOME STATES FOR SAFE LAND APPLICATION OF WASTEWATER (W) AND/OR SLUDGE (S) COMPILED FROM MAIL SURVEY[a]

State	Irrigation of sod farms, forests, fodder crops, etc.		Irrigation of pasture land		Irrigation of golf courses, and public parks	
	Minimum treatment required	Limit of coliforms/ 100 mL	Minimum treatment required	Limit on grazing	Minimum treatment required	Limit of coliforms/ 100 mL
Arizona (W)	Secondary	No limit	--	--		
	Secondary + disinfection (for processed food crops)	100 FC/100 ml (average)	--	--	Secondary + disinfection (non-residential areas)	--
	Tertiary + disinfection (for unprocessed food crops)	200 FC/100 ml (average)	--	--	Tertiary + disinfection (residential areas)	--
Arizona (S)	Stabilized	--	Stabilized	Grazing by dairy cattle not permitted	--	--
California (W)	Primary	--				
	Oxidized + disinfection (surface irrigation of food crops)	2.2 TC/100 ml (median)	Oxidized + disinfection	23 TC/ 100 ml	Oxidized + disinfection (golf courses, freeway landscapes, etc.)	23 TC/100 (median) 240 TC/ 100 ml (maximum)
	Oxidized coagulated, clarified, filtered & disinfected (spray irrigation of food crops)	2.2 TC/100 ml (median) 23 TC/100 ml (maximum)			Oxidized, coagulated, clarified, filtered & disinfected (public parks, playgrounds, etc.)	2.2 TC/ 100 ml (median) 23 TC/ 100 ml (maximum)

TABLE 8 (continued)

State	Irrigation of sod farms forest, fodder crops etc.		Irrigation of pasture land		Irrigation of golf courses, and public parks	
	Minimum treatment required	Limit of coliforms/ 100 mL	Minimum treatment required	Limit on grazing	Minimum treatment required	Limit of coliforms/ 100 mL
Florida (W)	Secondary + disinfection	23/100 ml[b] (median)	Secondary + disinfection	15 days (dairy cows)	Secondary + disinfection	2.2/100 ml[b] (median)
Florida (S)	--	--	Stabilized	60 days (diary cows)	--	--
Georgia (W)	Biological + disinfection (optional)	200 FC/100 ml (maximum)	Biological + disinfection (optional)	--	Biological + disinfection	30 FC/100 ml (maximum)
Idaho (S)	Stabilized	--	Stabilized	30 days (dairy cows) 15 days (other animals)	--	--
Illinois (S)	Digested	--	Digested	Sludge must have been washed off by precipitation	Digested	--
Indiana (S)	Stabilized	--	Stabilized	30 days (dairy cows)	Stabilized	--
Iowa (S)	Stabilized	--	Stabilized	--	Stabilized public access restricted for 60 days	--

(continued)

TABLE 8 (continued)

State	Irrigation of sod farms forest, fodder crops etc.		Irrigation of pasture land		Irrigation of golf courses and public pakks	
	Minimum treatment required	Limit of coliforms/ 100 mL	Minimum treatment required	LImit on grazing	Minimum treatment required	Limit of coliforms/ 100 mL
Kansas (W&S)	Secondary	--	Secondary	--	Secondary, filtration and disinfection	--
Maine (S)	Stabilized[c]	---	Stabilized	45 days	--	--
Maryland (S)	Stabilized[d]	--	Stabilized[d] (must be negative for _Salmonella_ and _Ascaris_)	Sludge must have been washed by precipitation	--	--
Michigan (S)	Digested	-- --	Digested	60 days (dairy cows)	--	--
Minnesota (W)	Secondary + dinsinfection	2000 FC/ 100 ml[e]	--	--	--	--
Minnesota (S)	Stabilized	--	Stabilized	15 days	Stabilized public access restricted for 15 days	--
Nebraska (W)	Lagoon storage for 120 days	--	Lagoon storage for 120 days	--	Lagoon storage for 120 days + disinfection	1000 FC/ 100 ml (geometric mean)

(continued)

TABLE 8 (continued)

State	Irrigation of sod farms forest, fodder crops etc.		Irrigation of pasture land		Irrigation of golf courses and public parks	
	Minimum treatment required	Limit of coliforms/ 100 mL	Minimum treatment required	Limit on grazing	Minimum treatment required	Limit of coliforms/ 100 mL
Nebraska (S)	Digested	--	Digested	60 days (dairy cows) 15 days (other animals)	Digested	--
New Hampshire (W)	Secondary + disinfection	--	Secondary + disinfection	--	Secondary + disinfection	--
New Jersey (S)	Stabilized (recommend subsurface application)	--	Digested and composted	30 days (dairy cows) 15 days (other animals)	--	--
New York (S)	Digested	--	Digested	--	Digested	--
Ohio (S)	Digested or stabilized	--	Digested or stabilized	Grazing by dairy cows not permitted	Digested or stabilized	--
Pennsylvania (S)	Digested or chemically stabilized	--	Digested or chemically stabilized	60 days (dairy cows)	Digested or chemically stabilized	--
South Dakota (W)	Secondary	--	Secondary	--	Secondary	--

(continued)

TABLE 8 (continued)

State	Irrigation of sod farms forest, fodder crops etc.		Irrigation of pasture land		Irrigation of golf courses and public parks	
	Minimum treatment required	Limit of coliforms/ 100 mL	Minimum treatment required	LImit on grazing	Minimum treatment required	Limit of coliforms/ 100 mL
Tennessee (S)	Stabilized	--	Stabilized	60 days (dairy cows)	--	--
Texas (W)	Primary	50/100 ml[j,m]	--	--	Secondary	--
Texas (S)	Digested	-	Digested	Grazing by dairy cows not permitted	Aerobic stabilized sludge only	--
Utah (W)	Secondary	--	Secondary	Grazing by dairy cows not permitted	Advanced treatment	3 TC/100 ml (maximum)
Utah (S)	Heat-treated sludge only	--	Heat-treated sludge only	--	Heat-treated sludge only	--
Vermont (S)	Stabilized	--	--	--	--	--
Wisconsin (S)	Digested	--	Digested	60 days (dairy cows) 15 days (other animals)	--	--

a. Compiled from information/literature received in response to a mail survey.
b. Not specified whether total or fecal coliforms.
c. Sludge that is not stabilized is permitted on forest land.
d. Sludge must be negative for Salmonella and Ascaris ova for unprocessed food crops ~~and for grazing of dairy~~ cows.
e. Not specified whether average, median or maximum.

W: Wastewater S: Sludge
-- Not specified or not applicable.
TC: Total coliform FC: Fecal coliform

Bertucci et al. (20) examined the recommendation of Sorber et al. and suggested that no buffer zones are required around wastewater treatment plants based on their study of the relationship between confirmed virus plaques and unconfirmed plaques in primary and secondary wastewater. Bertucci et al. (20) suggest that other agents present in wastewater might mimic the effects of virus in such assays resulting in an overestimation. They found that in recent literature, a consistent ratio of confirmed virus colonies to pfu has not been established. Because of the very low average ratios found, they concluded that no buffer zones would be necessary between wastewater treatment plants or spray irrigation sites and the surrounding population centers. The health effects studies described in Section 7 also seem to lend support to such a conclusion.

In Russia, buffer/sanitary protection zones of 100-1000 meters are required around agricultural fields that are irrigated by spray application of wastewater (98).

Disinfection. It was discussed earlier that disinfection of wastewater effluents is very effective in reducing the levels of microorganisms in wastewater by 2-3 orders of magnitude. The levels of airborne microorganisms are directly proportional to their levels in wastewater. Sorber et al. (25) and Johnson et al. (51,52) have shown that disinfection of wastewater prior to spray application reduced the levels of airborne microorganisms to nondetectable levels.

Spray Equipment. The type of spray equipment and type and spacing of nozzles affect the emission of aerosols at spray irrigation sites. Selection of proper spray equipment can be employed to effectively reduce the generation of aerosols. This was demonstrated in a Russian study in which bacterial aerosols have been found to spread up to 250 m when short spray equipment was used compared to 450 m and 600 m when medium and far spray equipment, respectively, were used (98). In the United States, the spray technology is changing in the past five years from the use of high pressure upward spray to low pressure downward spray equipemnt and more recently to subsurface injection.

Covering Aeration Basins. Removable covers installed on top of the aeration basins would suppress aerosols as well as control odors. Existing covers used for the suppression of odors should be examined for their utility in suppressing aerosols.

Summary

In conclusion, adaptation of any or all or a combination of these techniques would help suppress the aerosols and/or microorganism levels in aerosols. But care must be taken in the examination of the various techniques for aerosols control or suppression to insure that workers are not subjected to undue safety risks as well as other hazards.

REFERENCES

1. Hickey, J. L. S. and, P. C. Reist. Health Significance of Airborne Microorganisms from Wastewater Treatment Processes. Part I and Part II. J. Water Poll. Control Fed., 47(12):2741-2773, 1975.

2. Sepp, E. The Use of Sewage for Irrigation, A Literature Review. California Department of Public Health, Revised 1971. 40 pp.

3. Parsons D. et al. Health Aspects of Sewage Effluent Irrigation. British Columbia Water Resources Service, Pollution Control Branch, 1975. 75 pp.

4. Clark, C. S., E. J. Cleary, G. M. Schiff, C. C. Linnemann, Jr., J. P. Phair, and T. M. Briggs. Disease Risks of Occupational Exposure to Sewage. Jour. Environ. Eng. Div. of Am. Soc. of Civil Eng., 102(EE2): 375-388, 1976.

5. Proceedings of Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. A. Sorber, eds. Center for Applied Research and Technology, The University of Texas at San Antonio, San Antonio, Texas, 1978. 329 pp.

6. International Symposium on State of Knowledge in Land Treatment of Wastewater. Vol. 1 and 2, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, August 20-25, 1978.

7. SCS Engineers. Health Effects Associated With Wastewater Treatment and Disposal Systems. State-of-the-Art Review, Vol. 1. EPA-600/1-79-016a, 1979. 672 pp.

8. Cooper, R. C. Wastewater Contaminants and Their Effect on Public Health. In: A "State-of-the-Art" Review of Health Aspects of Wastewater Reclamation for Groundwater Recharge. Department of Health, State of California, November 1975. pp. 33-82.

9. Akin, E. W., W. Jakubowski, J. B. Lucas, and H. R. Pahren. Health Hazards Associated With Wastewater Effluents and Sludge: Microbiological Considerations. In: Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. A. Sorber, eds. University of Texas at San Antonio, San Antonio, Texas, 1978. pp. 9-26.

10. Larkin, E. P., J. T. Tierney, J. Lovett, D. Van Donsel, and D. W. Francis. Land Application of Sewage Wastes: Potential for Contamination of Foodstuffs and Agricultural Soils by Viruses, Bacterial Pathogens and Parasites. In: International Symposium on State of Knowledge in Land Treatment of Wastewater, Vol. 2, CRREL, Hanover, New Hampshire, August 20-25, 1978. pp. 215-223.

11. Foster, D. H., and R. S. Engelbrecht. Microbial Hazards of Disposing of Wastewater on Soil. In: Recycling Treated Municipal Wastewater and Sludge Through Forest and Crop Land, W. E. Sopper and L. T. Kardos eds. Pennsylvania State University Press, 1973. pp. 247-270.

12. Foster, D. H., and R. S. Engelbrecht. Microbial Hazards in Disposing of Wastewater in Soil. In: Conference on Recycling Treated Municipal Wastewater Through Forest and Cropland, W. E. Sopper and L. T. Kardos, eds. EPA-660/2-74-003, Pennsylvania State University, University Park, Institute for Research on Land and Water Resources, March 1974. pp. 217-241.

13. Bryan, F. L. Diseases Transmitted by Foods Contaminated by Wastewater. In: Wastewater Use in the Production of Food and Fiber-Proceedings. EPA-660/2-74-041, U.S. Environmental Protection Agency, Cincinnati, Ohio, Office of Research and Development, June 1974. pp. 16-45.

14. Hunter, J. V., and T. A. Kotalik. Chemical and Biological Quality of Sewage Effluents. In: Conference on Recycling Treated Municipal Wastewater Through Forest and Cropland, W. E. Sopper and L. T. Kardos, eds. EPA-660/2-74-003, Pennsylvania State University, University Park, Institute for Research on Land and Water Resources, March 1974. pp. 6-27.

15. Sproul, O. J. The Efficiency of Wastewater Unit Processes in Risk Reduction. In: Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. a. Sorber, eds. University of Texas at San Antonio, San Antonio, Texas, 1978. pp. 282-296.

16. World Health Organization (WHO). Human Viruses in Water, Wastewater and Soil. WHO Technical Report Series 639, Geneva, Switzerland, 1979.

17. Chang, S. L., and P. W. Kabler. Detection of Entamoeba histolytica in Tap Water by Use of Membrane Filter. Amer. Jour. Hyg., 64:170-180, 1956.

18. Hays, B. D. Potential for Parasitic Disease Transmission With Land Application of Sewage Plant Effluents and Sludges. Water Research, 11:583-595, 1977.

19. Melnick, J. L., G. P. Gerba, and C. Wallis. Viruses in Water. Bulletin of the World Health Organization, 56(4):499-508, 1978.

20. Bertucci, J. J., S. H. Abid, C. Lue-Hing, C. S. Clark, J. D. Fenders, and K. F. Fannin. Relationship Between Confirmed Virus Plaques and Unconfirmed Plaques Isolated From Sewage. Presented at 51st Water Pollution Control Federation Meeting, Anaheim, California, October 1-6, 1978.

21. Rylander, R., K. Andersson, C. Belin, G. Berglund, R. Bergstrom, C. Hanson, M. Lundholm, and I. Mattsby. Sewage Worker's Syndrome. Lancet, 28:478-479, 1976.

22. Mattsby, I., and R. Rylander. Clinical and Immunological Findings in Workers Exposed to Sewage Dust. Jour. of Occup. Med., 20(10):690-692, 1978.

23. Detroy, R. W. et al. Aflatoxin and Related Compounds. In: Microbial Toxins: A Comprehensive Treatise, Vol. VI, Fungal Toxins, A. Ciegler, S. Kadis, and S. J. Ajl, eds. Academic Press, New York, 1971.

24. Cram, E. B. The Effect of Various Treatment Processes on the Survival of Helminth Ova and Protozoan Cysts in Sewage. Sewage Works Jour., 15(6):1119-1138, 1943.

25. Sorber, C. A., H. T. Bausum, S. A. Schaub, and M. J. Small. A Study of Bacterial Aerosols at a Wastewater Irrigation Site. Jour. WPCF, 48(10): 2367-2379, 1976.

26. Kabler, P. Removal of Pathogenic Microorganisms by Sewage Treatment Processes. Sewage and Indus. Wastes, 31(12):1373-1382, 1959.

27. Marshall, K. C. Interaction Between Colloidal, Montmorillonite and Cells of Rhizobium Species With Inorganic Surfaces. Biochem. Biophys. Acta, 156:179-186, 1968.

28. Moore, B. E., B. P. Sagik, and J. F. Malina, Jr. Viral Association With Suspended Solids. Water Research, 9:197-203, 1975.

29. Schaub, S. A., and B. P. Sagik. Association of Enteroviruses With Natural and Artifically Introduced Colloidal Solids in Water and Infectivity of Solids-Associated Virions. Appl. Microbiol, 30: 212-222, 1975.

30. Moore, B. E., B. P. Sagik, and C. A. Sorber. Land Application of Sludges: Minimizing the Impact of Viruses on Water Resources. In: Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. A. Sorber eds. University of Texas at San Antonio, San Antonio, Texas, 1978. pp. 154-166.

31. Malina, J. F., K. R. Ranganathan, B. P. Sagik, and B. E. Moore. Poliovirus Inactivation by Activated Sludge. Journal WPCF, 47(8):2178-2183, 1975.

32. Pramer, D., H. Heukelekian, and R. A. Ragotzkie. Survival of Tubercle Bacilli in Various Sewage Treatment Processes. 1. Development of a Method for the Quantitative Recovery of Mycobacteria From Sewage. Public Health Reports, 65:851-859, 1950.

33. U.S. Environmental Protection Agency (EPA). Process Design Manual - Sludge Treatment and Disposal, EPA 625/1-79-011, USEPA, Cincinnati, Ohio, 1979.

34. National Research Council. Multimedium Management of Municipal Sludge. National academy of sciences, Analytical Studies for the U.S. Environmental Protection Agency, Volume IX, Chap. 3, 1978.

35. Bertucci, J. J., C. Lue-Hing, D. Zenz, and S. J. Sedita. Inactivation of Viruses During Anaerobic Sludge Digestion. JWPCF, 49:1642-1651, 1977.

36. Heukelekian, H., and M. Albanese. Enumeration and Survival of Human Tubercule Bacilli in Polluted Waters. II. Effect of Sewage Treatment and Natural Purification. Sewage and Indust. Wastes, 28:1094-1102, 1956.

37. Leclerc, H., A. Perchet, C. Savage, S. Andrieu, and R. Nguematcha. Microbiological Aspects of Sewage Treatment, in S. H. Jenkins (ed.) Advances in Water Pollution Research, Proceedings of 5th International Conference on Water Pollution Research, Pergamon Press, Oxford, 1971.

38. Newton, W. L., H. J. Bennet, and W. d. Figgat. Observations on the Effects of Various Sewage Treatment Processes Upon Eggs of Taenia Saginata. Am. Jour. Hyg., 49:166-175, 1949.

39. Fenters, J., J. Reed, C. Lue-Hing, and J. Bertucci. Inactivation of Viruses by Digested Sludge Components. JWPCF, 51(4):689-694, 1979.

40. Clark, C. S. et al. Health Risks of Human Exposure to Wastewater. Final Report, Health Effects Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980.

41. Epstein, E. Technical aspects of composting as a Disinfection Process: An Overview. In: Workshop on the Health and Legal Implications of Sewage Sludge Composting. Volume 2, Chap. 1, Energy Resources Company, December 18-20, 1978, Cambridge, Mass.

42. Burge, W. D., W. N. Cramer, and E. Epstein. Destruction of Pathogens in Sewage Sludge Composting. Trans. Amer. Soc. for Agricultural Engineering, 21:510-4, 1978.

43. Smith, B. M. A Study of the Mechanism by Which Bioaerosols are Generated When Liquids Containing Microorganisms are Aerated. Ph.D. Dissertation. Georgia Institute of Technology, Atlanta, Georgia, 1968.

44. Clayton, G. D., and F. L. Clayton, eds. Patty's Industrial Hygiene and Toxicology. Vol. 1, 3rd Edition, Chapter 6, John Wiley, New York, 1978.

45. Task Group on Lung Dynamics. International Commission on Radiologic Protection. Health Physics, 12:173-207, 1966.

46. Baylor, E. R., V. Peters, and M. B. Baylor. Water-to-Air Transfer of Virus. Science, 197:763-764, 1977.

47. Air Sampling Instruments for Evaluation of Atmospheric Contaminants. 4th Edition, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1972.

48. Andersen, A. A. New Sampler for the Collection, Sizing and Enumeration of Viable Airborne Particles. Jour. Bacteriol., 76(5):471-484, 1958.

49. Tyler, M. E., and E. L. Shipe. Bacterial Aerosol Samplers. I. Development and Evaluation of the All-glass Impinger. Appl. Microbiol., 7:337-349, 1959.

50. Decker, H. M., D. E. Frisque, B. M. Roberts, and L. H. Graf. Large-volume Air Samplers for Collecting and Concentrating Microorganisms. Technical Memorandum No. 172, U.S. Army, Fort Detrick, Maryland, 1969.

51. Johnson, D. E., D. E. Camann, J. W. Register, R. E. Thomas, C. A. Sorber, M. N. Guentzel, J. M. Taylor, and H. J. Harding. The Evaluation of Microbiological Aerosols Associated With the Application of Wastewater to Land: Pleasanton, California. EPA-600/1-80-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980, 191 pp.

52. Johnson, D. E. et al. Aerosol Monitoring for Microbiological Organisms Near a Spray Irrigation Site. In: Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, B. P. Sagik and C. A. Sorber, eds. University of Texas at San Antonio, San Antonio, Texas, 1978. pp. 231-239.

53. Moore, B.E., B. P. Sagik, and C. A. Sorber. Procedure for the Recovery of Airborne Human Enteric Viruses During Spray Irrigation of Treated Wastewater. Appl. Env. Microbiology, 38(4):688-693, 1979.

54. Standard Methods for the Examination of Water and Wastewater. 14th Edition, American Public Health Association, Washington, D.C., 1975.

55. Dimmick, R. L., and A. B. Akers, eds. An Introduction to Experimental Aerobiology, John Wiley, New York, New York, 1969.

56. Schaub, S. A., J. P. Glennon, and H. T. Bausum. Monitoring of Microbiological Aerosols at Wastewater Sprinkler Irrigation Sites. In: International Symposium on State of Knowledge in Land Treatment of Wastewater, Vol. 1, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, August 20-25, 1978. pp. 377-388.

57. Microbiology of Drinking Water. In: Drinking Water and Health, Chapter III. Safe Drinking Water Committee, National Academy of Sciences, Washington, D.C., 1977.

58. Sorber, C. A., and B. P. Sagik. Wastewater Aerosol Stirs Controversy. Water and Sewage Works, pp. 56-57, February 1979.

59. Sorber, C. A. Progress of Aerosol Studies - Land Application of Wastewater. Presented at Research Workshop on Wastewater Management via Land Treatment. U.S. Army Cold Regions Research Engineering Laboratory, Hanover, New Hampshire, September 24-25, 1973.

60. Sorber, C. A., S. A. Schaub, and K, M. Guter. Problem Definition Study: Evaluation of Health and Hygiene Aspects of Land Disposal of Wastewater at Military Installations. U.S. Army Medical Environmental Engineering Research Unit, Edgewood Arsenal, Maryland, 1972. 32 pp.

61. Sorber, C. A., S. A. Schaub, and H. T. Bausum. An Assessment of Potential Virus Hazard Associated With Spray Irrigation of Domestic Wastewaters. In: Virus Survival in Water and Wastewater Systems, J. F. Malina, Jr. and B. P. Sagik, eds. University of Texas at Austin, Center for Research in Water Resources, 1974. pp. 241-52.

62. Riley, R. L., and F. O'Grady. Airborne Infection: Transmission and Control. Macmillan Co., New York, New York, 1961.

63. Poon, C. P. C. Studies on the Instantaneous Death of Airborne Escherichia coli. Am. Jour. Epidemiol., 84(1):1-19, 1966.

64. Sorber, C. A., H. T. Bausum, and S. A. Schaub. Bacterial Aerosols Created by Spray Irrigation of Wastewater. Presented at the 1975 Sprinkler Irrigation Association Technical Conference, Atlanta, Georgia, February 1975.

65. Kenline, P. A. The Emission, Identification and Fate of Bacteria Airborne From Activated Sludge and Extended Aeration Sewage Treatment Plants. Ph.D. Dissertation. University of Cincinnati, Cincinnati, Ohio, 1968.

66. Kenline, P. A., and P. V. Scarpino. Bacterial Air Pollution From Sewage Treatment Plants. Am. Ind. Hyg. Assoc. Jour., 33(5):346-52, 1972.

67. Ledbetter, J., and C. W. Randall. Bacterial Emissions From Activated Sludge Units. Ind. Med. Surg., 34(5):130-133, 1965.

68. Fannin, K. F., J. J. Gannon, K. W. Cochran, and J. C. Spendlove. Field Studies on Coliphages and Coliforms as Indicators of Airborne Animal Viral Contamination From Wastewater Treatment Facilities. Water Research, 11:181-188, 1977.

69. Cooper, J. F., J. Levin, and H. N. Wagner, Jr. Quantitative Comparison of In Vitro and In Vivo Methods for the Detection of Endotoxin. J. Laboratory and Clinical Medicine, 78:138-148, 1971.

70. Rojas-Gorona, R. R., R. Skarnes, S. Tamakuma and J. Fine. The Limulus Coagulation Test for Endotoxin. A Comparison with Other Assay Methods. Proceedings of the Society of Experimental Biology and Medicine, 32:599-601, 1969.

71. Westphal, O., and K. Jans. In: Methods of Carbohydrage Chemistry, R. L. Whistler and M. L. Wolfrom, eds. Academic Press, New York, New York, 5:83-91, 1965.

72. Rylander, R.; and M.Lundholm. Responses to Wastewater Exposure With Reference to Endotoxins. In: Symposium on Wastewater Aerosols and Disease, U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

73. Rylander, R. Personal Communication.

74. Napolitano, P. J., and D. R. Rowe. Microbial Content of Air Near Sewage Treatment Plants. Water and Sewage Works, 113(12):480-483, 1966.

75. Higgins, F. B. Bacterial Aerosols From Bursting Bubbles. Ph.D. Dissertation. Georgia Institute of Technology, Atlanta, Georgia, 1964.

76. Albrecht, C. R. Bacterial Air Pollution Associated With the Sewage Treatment Process. M.S. Thesis. University of Florida, Gainesville, Florida, 1958.

77. Ladd, F. C. Airborne Bacteria From Liquid Waste Treatment Units. M.S. Thesis. Oklahoma State University, Stillwater, Oklahoma, 1966.

78. Adams, A. P., and J. C. Spendlove. Coliform Aerosols Emitted by Sewage Treatment Plants. Science, 169(3951):1218-20, 1970.

79. Blanchard, D. C., and L. D. Syzdek. Importance of Bubble Scavenging in the Water-to-Air Transfer of Organic Material and Bacteria. Journal de Recherches Atmospheriques, 8:529-540, 1974.

80. Randall, C. W., and J. O. Ledbetter. Bacterial Air Pollution From Activated Sludge Units. Am. Ind. Hyg. Assoc. Jour., 27:506-519, 1976.

81. Fannin, K. F., J. C. Spendlove, K. W. Cochran, and J. J. Gannon. Airborne Coliphages From Wastewater Treatment Facilities. Appl. and Environ. Microbiol., 31(5):705-710, 1976.

82. Slote, L. Viral Aerosols. Jour. Environ. Health, 38(5):310-314, 1976.

83. Carnow, B., R. Northrop, R. Wadden, S. Rosenberg, J. Holden, A. Neal, L. Sheaff, P. Scheffi, and S. Meyer. Health Effects of Aerosols Emitted From an Activated Sludge Plant. EPA-600/1-79-019, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 215 pp.

84. Johnson, D. E., D. E. Camann, J. W. Register, R. J. Prevost, J. B. Tillery, R. E. Thomas, J. M. Taylor, and J. M. Hosenfeld. Health Implications of Sewage Treatment Facilities. EPA-600/1-78-032, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 361 pp.

85. Johnson, D. E., D. E. Camann, H. J. Harding, and C. A. Sorber. Environmental Monitoring of a Wastewater Treatment Plant. EPA-600/1-79-027, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979. 125 pp.

86. Clark, C. S., G. L. Van Meer, C. C. Linnemann, Jr., A. B. Bjornson, P. S. Gartside, G. M. Schiff, S. E. Trimble, D. L. Alexander, E. J. Cleary, and J. P. Phair. Health Effects of Occupational Exposure to Wastewater. In: Symposium on Wastewater Aerosols and Disease, U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

87. Multimedium Management of Municipal Sludge. Vol. IX, National Research Council, National Academy of Sciences, 1978. pp. 72-73.

88. Ragnor, G. S., and J. V. Hayes. Aerosol Production by Irrigation Equipment Used for Land Application of Wastewater. Am. Ind. Hyg. Assoc. Jour., 37(9):526-536, 1976.

89. Sorber, C. A., and K. J. Guter. Health and Hygiene Aspects of Spray Irrigation. Am. Jour. Public Health, 65:47-51, 1975.

90. Katzenelson, E., and B. Teltsch. Dispersion of Enteric Bacteria by Spray Irrigation. Journal WPCF, 48(4):710-716, 1976.

91. Reploh, H., and H. Handloser. Investigations on the Spread of Bacteria Caused by Irrigation With Wastewater. Arch. Hyg. Berl., 141:632, 1957; Water Poll. Abs., 33(3):100, March 1960.

92. Bringmann, G., and G. Trolldenier. Distance of Coliform Transport by Agricultural Sewage Spraying in Relation to Wind Velocity, Air Humidity, and Ultraviolet Radiation. Gesundheitsing, 81:268, 1960.

93. Katzenelson, E., B. Teltsch, and H. I. Shuval. Spray Irrigation With Wastewater: The Problem of Aerosolization and Dispersion of Enteric Microorganisms. Prog. Water Tech., 9:1-11, 1977.

94. Bausum, H. T., S. A. Schaub, M. J. Small, J. A. Highfill, and C. A. Sorber. Bacterial Aerosols Resulting From Spray Irrigation With Wastewater. Technical Report 7602, U.S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, Frederick, Maryland, 1976.

95. Bausum, H. T., S. A. Schaub, and C. A. Sorber. Viral and Bacterial Aerosols at a Wastewater Spray Irrigation Site. Technical Report 7804, U.S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, Frederick, Maryland, 1978.

96. Teltsch, B., and E. Katzenelson. Airborne Enteric Bacteria and Viruses From Spray Irrigation With Wastewater. Appl. and Environ. Microbiol., 35(2):290-296, 1978.

97. Bausum, H. T., B. E. Brockett, P. W. Schumacher, S. A. Schaub, H. T. McKim, and R. Bates. Microbiological Aerosols From a Field Source During Sprinkler Irrigation With Wastewater. In: International Symposium on State-of-Knowledge in Land Treatment of Wastewater, Vol. 2, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, August 20-25, 1978. pp. 273-280.

98. Baubinas, A. K., and V. V. Vlodavets. Hygiene Assessment of the Method of Sewage Spraying for Agricultural Irrigation. Gigiena i Sanitariya, 4:18-21, 1979 (Translated from Russian by I. Kukainis).

99. Brenner, K., P. V. Scarpino, and C. S. Clark. Examination of Aerosols at a Wastewater Sprinkler Irrigation Site for the Presence of Animal Viruses by the Use of Tissue Cultures. Presented at the Poster Session give by the Ohio Valley Branch of the Tissue Culture Association at Hueston Woods, Oxford, Ohio, November 2, 1979.

100. Davis-Hoover, W. J., P. V. Scarpino, and K. Brenner. Bacterial Enumeration and Identification of Aerosol Samples at a Wastewater Treatment Plant. Presented at American Society for Microbiology, Indiana-Ohio Branch, Hueston Woods, Oxford, Ohio, October 5, 1979.

101. Goff, G. D. et al. Emission of Microbial Aerosols From Sewate Treatment Plants That Use Trickling Filters. Health Services Reports, 88(7):640-652, 1973.

102. U.S. Environmental Protection Agency. Process Design Manual for Land Treatment of Municipal Wastewater. Appendix D, EPA 625/1-77-008, October, 1977.

103. Pasquill, F. The Estimation of the Dispersion of Windborne Material. The Meteorological Magazine, 90(1063):33-49, 1961.

104. Turner, D. B. Workbook of Atmospheric Dispersion Estimates, Publication No. AP-26, USEPA, Research Triangle Park, North Carolina, 1970, 84 pp.

105. Turner, D. B. Atmospheric Dispersion Modeling. A Critical Review. J. Air Poll. Cont. Association, 29(5):502-519, 1979.

106. Camann, D. E. et al. A Model for Predicting Pathogenic Concentrations in Wastewater Aerosols. In: Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges. B. P. Sagik and C. A. Sorber, eds., University of Texas, San Antonio, Texas, 1978. pp. 240-271.

107. Lighthart, B., and A. S. Frisch. Estimation of Viable Airborne Microbes Downwind from a Point Source. Appl. and Environ. Microbiol. 31(5):700-704, 1976.

108. Johnson, D. E., J. W. Register, D. E. Camann, C. H. Millstein, and J. L. Gulinson. Evaluation of Health Effects Associated with the Application of Wastewater to Land. Phase I Report by Southwest Research Institute to U.S. Army Medical Research and Development Command, Fort Detrick, Maryland, December, 1975.

109. Sutton, O. G. A Theory of Eddy Diffusion in the Atmosphere. Proc. Royal Society, A(135):143-165, 1932.

110. Chamberlain, A. C. Aspects of Travel and Deposition of Aerosols and Vapor Clouds. Atomic Energy Research Establishment Report HP/R 1261, H.M.S.O., London, 1956.

111. Camann, D. E. A Model for Predicting Dispersion of Microorganisms in Wastewater Aerosols. In: USEPA Symposium on Wastewater Aerosols and Disease, Cincinnati, Ohio, September 19-21, 1979.

112. Taffel, W. Health Risks Assessment. In: Workshop on Health and Legal Implications of Sewage Sludge Composting. Energy Resources Company, Cambridge, Massachusetts, Chap. 2, December 18-20, 1978.

113. Pahren, H. R., J. B. Lucas, J. A. Ryan, and G. K. Dotson. Health Risks Associated With Land Application of Municipal Sludge. Journal WPCF, 51(11):2588-2601, 1979.

114. Crites, R. W., and A. Uiga. An Approach for Comparing Health Risks of Wastewater Treatment Alternatives. U.S. Environmental Protection Agency, Office of Water Program Operations, EPA 430/9-79-009, Washington, D.C., 1979. 66 pp.

115. Rendtorff, R. L. The Experimental Transmission of Protozoan Parasites II. Giardia lamblia cysts in Capsules. Am. J. Hygiene, 59:209, 1954.

116. Morgan, H. R. The Enteric Bacteria, Dubos and Hirsch, eds., 1965. p. 610.

117. Craun, G. F., and L. J. McCabe. Waterborne Disease Outbreaks in the U.S., 1971-1974. Journal AWWA, 68:420-424, 1976.

118. Cohen, J., T. Schwartz, R. Klasmer, H. Ghalayini, D. Pridan, and A. M. Davies. Epidemiological Aspects of Cholera: El Tor Outbreak in a Non-epidemic Area. Lancet, 2:86-89, 1971.

119. Geldrich, E. E. Waterborne Pathogens. In: Water Pollution Microbiology, R. Mitchell, ed., Wiley-Interscience, New York, 1972.

120. Browning, G. E., and J. O. Mankin. Gastroenteritis Epidemic Owing to Sewage Contamination of Public Water Supply. Journal AWWA, 58:1465-70, 1966.

121. Bryan, F. L. Status of Foodborne Disease in the United States. Jour. Environ. Health, 38(2):74-84, 1975.

122. Westwood, J. C. N., and S. A. Sattar. The Minimal Infective Dose. In: Viruses in Water, edited by G. Berg et al. American Public Health Association, 1976.

123. Chandler, A. C., and C. P. Read. Introduction to Parasitology. John Wiley and Sons, New York, 1962.

124. Gartside, P. S., B. Specker, P. E. Harlow, and C. S. Clark. Interim Report on a Mortality Study of Former Employees of the Metropolitan Sanitary District of Greater Chicago. In: Symposium on Wastewater Aerosols and Disease. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

125. Sekla, L., D. Gemmill, J. Manfreda, and M. Lysyk, et al. Sewage Treatment Plant Workers and Their Environment: A Health Study Conducted in Manitoba. In: Symposium on Wastewater Aerosols and Disease. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

126. Dean, R. B. Assessment of Disease Rates Among Sewer Workers in Copenhagen, Denmark. EPA-600/1-78-007, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 10 pp.

127. Dean, R. B. Disease Rates Among Copenhagen Sewer Workers. In: Symposium on Wastewater Aerosols and Disease. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

128. Skinhøj, P., F. B. Hollinger, K. Hovind-Hougen, and P. Lous. Infectious Liver Diseases in Three Groups of Copenhagen Workers: Correlation of Hepatitis A Infection to Sewage Exposure. Accepted for Publication in Archives of Env. Health, 1980.

129. Root, B., K. Y. Kim, N. Cronin, and M. Goshima. An Investigation of the Health, Safety and Working Conditions of Honolulu Sewer Workers. State of Hawaii Department of Labor and Industrial Relations, Division of Occupational Safety and Health, Honolulu, November 1977.

130. Fannin, K, F., K. W. Cochran, H. Ross, and A. S. Monto. Health Effects of a Wastewater Treatment System. EPA-600/1-78-062, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 56 pp.

131. U.S. EPA Symposium, Wastewater Aerosols and Disease, Panel Discussion, September 19-21, 1979, Cincinnati, Ohio.

132. Cliver, D. O. Infection with Minimal Quantities of Pathogens from Wastewater Aerosols. In: USEPA Symposium on Wastewater Aerosols and Disease, Cincinnati, Ohio, September 19-21, 1979.

133. Dowling, H. F. Airborne Infection - The Past and the Future. Bacterialogical Rev., 30(3):485-487, 1966.

134. Katzenelson, E., I. Buium, and H. I. Shuval. Risk of Communicable Disease Infection Associated With Wastewater Irrigation in Agricultural Settlements. Science, 194(4268):944-946, 1976.

135. Shuval, H. I., and B. Fattal. Retrospective Epidemiological Study of Wastewater Irrigation in Israel. In: Symposium on Wastewater Aerosols and Disease. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

136. McPherson, J. B. Renovation of Wastewater by Land Treatment at Melbourne Board of Works Farm, Werribee, Victoria, Australia. In: International Symposium on State-of-Knowledge in Land Treatment of Wastewater. Vol. 1, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, August 20-25, 1979. pp. 210-212.

137. Krishnamoorthi, K. P., M. K. Abdulappa, and A. K. Ankiwar. Intestinal Parasitic Infections Associated With Sewage Farm Workers With Special Reference to Helminths and Protozoa. Proc. Symp. on Environ. Pollution, 1973. pp. 347-355.

138. Epidemiological Study of Farm Families Utilizing Municipal Sludge, Ohio Farm Bureau. U.S. Environmental Protection Agency, Quarterly Report, Cincinnati, Ohio, January-March 1979. p. 7.

139. Eichman, M. J. Wastewater Sludge Demonstration Project Underway in Springfield, Ohio. Buckeye Bulletin, 53(N1):14, 1980.

140. Clark, C. S. et al. Evaluation of the Health Risks Associated with the Treatment and Disposal of Municipal Wastewater and Sludge. U.S. Environmental Protection Agency Grant No. R 805445-01, Work in Progress. Department of Environmental Health, University of Cincinnati, Cincinnati, Ohio.

141. Stanford, G. B., and R. Tuburan. Morbidity Risk Factors from Spray Irrigation with Treated Wastewaters. In: Wastewater Use in the Production of Food and Fiber - Proceedings. EPA-660/2-74-041, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, June 1974. pp. 56-64.

142. Lue-Hing, C., J. O. Ledbetter, S. J. Sedita, B. M. Sawyer, and D. R. Zenz. Suppression of Aerosols at a Wastewater Reclamation Plant. In: Symposium on Wastewater Aerosols and Disease. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

143. Spendlove, J. C., R. Anderson, S. J. Sedita, P. O'Brien, B. Sawyer, and C. Lue-Hing. Effectiveness of Aerosol Suppression by Vegetative Barriers. In: Symposium on Wastewater Aerosols and Disease. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 19-21, 1979.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Potential Health Effects from Viable Emissions and Toxins Associated with Wastewater Treatment Plants and Land Application Sites

5. REPORT DATE
September 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Vimala A. Majeti and C. Scott Clark

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Department of Environmental Health
University of Cincinnati Medical Center
Cincinnati, Ohio 45267

10. PROGRAM ELEMENT NO.
C27B1A

11. CONTRACT/GRANT NO.
R805445

12. SPONSORING AGENCY NAME AND ADDRESS
Health Effects Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final, Feb. 1978 to May 1980

14. SPONSORING AGENCY CODE
EPA/600/10

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report summarizes the potential health effects from viable emissions and toxins associated with wastewater treatment plants and land application facilities to the workers and nearby populations. The different types of microorganisms present in wastewater and sludge and the effectiveness of the various treatment processes in their removal or inactivation is discussed briefly. The monitoring of microorganisms and toxins in aerosols generated at wastewater treatment plants and land application sites, the disadvantages in using coliform organisms as indicators to represent the actual levels of pathogenic microorganisms in aerosols, and the various mathematical models that are used to predict the microorganism levels in aerosols are also reviewed. The levels of microorganisms detected in aerosols at wastewater treatment plants and land application facilities from some of the recent studies are presented.

PB81-145260 PC A05/MF A01
Health Effects Research Lab., Cincinnati, OH.
Potential Health Effects from Viable Emissions and Toxins Associated with Wastewater Treatment Plants and Land Application Sites.
Final rept. Feb 78-May 80,
Cincinnati Univ. Medical Center, OH.
Vimala A. Majeti, and C. Scott Clak. Jan 81, 84p*
EPA-600/1-81-006
Grant EPA-R-805445

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Public health, waste water, aerosols, microorganisms, mathematical models, waste treatme t	irrigation, endotoxins	57U 68D

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