5

Public Health Concerns About Infectious Disease Agents

The infectious disease agents associated with municipal wastewater and sludge are those found in the domestic sanitary waste of the population and from industries that process meats, fish, and other food products. These microbial pathogens include a large number of bacteria, viruses, and parasites. Important examples are members of the bacterial genera *Salmonella* and *Shigella*; the infectious hepatitis, Rota and Norwalk viruses; and the parasites associated with giardiasis, cryptosporidiosis, taeniasis, and ascariasis (See Table 5.1 for a more complete list). It is reasonable to assume that any or all of these infectious agents might be present in the water and solids fractions of raw sewage.

INFECTIOUS DISEASE TRANSMISSION

Three conditions are necessary to produce infectious disease in a population: (1) the disease agent must be present, (2) it must be present in sufficient concentration to be infectious, and (3) susceptible individuals must come into contact with the agent in a manner that causes infection and disease. From a public health perspective, it is prudent to presume that raw sewage and sludge contain pathogenic organisms; thus, the first of the above criteria is always met. The concentration of these agents in sewage will be a function of the disease morbidity in the contributing population. An example of the number of pathogenic microorganisms found in raw sewage, treated effluent, and in raw and treated sludge is shown in Table 5.2.

The second of the above criteria—that the infectious agent be present in sufficient concentration—is fraught with uncertainty because available data on human dose response are very limited, particularly at the population level. Usually it takes more than a single organism to produce a detectable disease response in an individual in the exposed population. In many instances a lower dose of pathogens will produce infection but not disease. The limited human dose-response data that have been reported indicate much variation in the severity of sickness among those exposed to known dosages of pathogens (Bryan, 1974). Table 5.3 contains some examples of bacterial pathogen dose response.

TABLE 5.1 Examples of Pathogens Associated With Raw Domestic Sewage and Sewage Solids

Pathogen Class	Examples	Disease
Bacteria	*Shigella sp.*	Bacillary dysentery
	Salmonella sp.	Salmonellosis (gastroenteritis)
	Salmonella typhi	Typhoid fever
	Vibrio cholerae	Cholera
	Enteropathogenic- *Escherichia coli*	A variety of gastroenteric diseases
	Yersinia sp.	Yersiniosis (gastroenteritis)
	Campylobacter jejuni	Campylobacteriosis (gastroenteritis)
Viruses	Hepatitis A virus	Infectious hepatitis
	Norwalk viruses	Acute gastroenteritis
	Rotaviruses	Acute gastroenteritis
	Polioviruses	Poliomyelitis
	Coxsackie viruses	"flu-like" symptoms
	Echoviruses	"flu-like" symptoms
Protozoa	*Entamoeba histolytica*	Amebiasis (amoebic dysentery)
	Giardia lamblia	Giardiasis (gastroenteritis)
	Cryptosporidium sp.	Cryptosporidiosis (gastroenteritis)
	Balantidium coli	Balantidiasis (gastroenteritis)
Helminths	*Ascaris sp.*	Ascariasis (roundworm infection)
	Taenia sp.	Taeniasis (tapeworm infection)
	Necator americanus	Ancylostomiasis (hookworm infection)
	Trichuris trichuria	Trichuriasis (whipworm infection)

The final link in the infectious disease transmission chain is the exposure of the sus-ceptible human population to infectious agents. The primary route of exposure to wastewater-associated pathogens is by ingestion, although other routes, such as respiratory and ocular, can be involved. If reclaimed water and sludges are to be used in the production of human food crops, particularly those that are eaten raw, then there is a chance of exposure through ingestion. Consequently, there is a greater need to reduce pathogen numbers to low levels prior to soil application, or at least prior to crop harvesting or livestock exposure.

Available engineering knowledge and technology can produce reclaimed water of the desired quality for use in such activities as agriculture, landscape irrigation, and ground water recharge. Data in Table 5.2 are illustrative of the effect of tertiary (advanced) treatment of wastewater in the removal of pathogens. The technology has advanced such that, in a number of instances, the use of reclaimed water to augment of water sources for drinking water supplies is either being seriously proposed or is a reality (City of San Diego, 1992; Gunn and Reberger, 1980; James M. Montgomery, Inc., 1983; Lauer and Johns, 1990). Treatment processes are also available to effectively reduce the concentration of pathogens in sewage sludge to levels safe for direct contact. Some examples include lime treatment, heat treatment, drying and com-posting (EPA, 1992b).

TABLE 5.2 Typical Numbers of Microorganisms Found in Various Stages of Wastewater and Sludge Treatment

Microbe	Number Per 100 ml Of Effluent				Numbers Per Gram of Sludge	
	Raw Sewage	Primary Treatment	Secondary Treatment	Tertiary[a] Treatment	Raw	Digested[b]
Fecal coliform MPN[c]	1,000,000,000	10,000,000	1,000,000	<2	10,000,000	1,000,000
Salmonella MPN	8,000	800	8	<2	1,800	18
Shigella MPN	1,000	100	1	<2	220	3
Enteric virus PFU[d]	50,000	15,000	1,500	0.002	1,400	210
Helminth ova	800	80	0.08	<0.08	30	10
Giardia lamblia cysts	10,000	5,000	2,500	3	140	43

[a] Includes coagulation, sedimentation, filtration and disinfection
[b] Mesophilic anaerobic digestion.
[c] MPN = Most Probable Number
[d] PFU = Plaque-forming units

SOURCES: EPA, 1991 and 1992a; Dean and Smith, 1973; Feachem et al., 1980; Engineering Science, 1987; Gerba, 1983 and Logsdon et al., 1985.

Thus, the technical knowledge is available for the design of processes that can adequately reduce the number of infectious agents present in raw wastewater and solids to safe levels. The important public health concern lies in the ability of these processes to reliably produce an acceptable product. Such reliability must be a critical element in the design and operation of wastewater treatment plants or other facilities producing these materials.

In California, treatment processes specified by the Water Reclamation Criteria (California Water Code, 1994) can achieve a 5 orders of magnitude reduction *in situ* of viruses. This level of reduction produces effluent that is accepted as being "free" of viruses. In the Monterey Wastewater Reclamation Study for Agriculture (Sheikh et al., 1990), tests conducted over a 5-year period of over 80,000 gal of reclaimed water that met Title 22 requirements found no viruses (Engineering Science, 1987). Virus seeding studies were conducted that verified the 5-log reduction in viruses from the treatment process. Additionally, a 99 percent natural die-off rate over 5 days was demonstrated under both field and laboratory conditions for the virus T99. A rough calculation illustrates the very low level of viruses to be expected after irrigation with reclaimed water of this quality on food crops. In the Monterey study, the median number of viruses detected in the raw wastewater influent was 8 plaque-forming units (pfu) in 67 samples, so that even without treatment, the number of viruses that might remain following irrigation is very small. To illustrate, reclaimed water is typically applied to the crop in an "irrigation set" of 2 in. of water. In California, crops cannot be harvested for two weeks following a reclaimed water irrigation set. If a plant occupies 2 square feet, it would receive about 2.4 gal of water. Even if the treatment plant failed completely, and assuming all the viruses in that volume of untreated wastewater stuck to the edible part of the plant, one would expect approximately 10^{-3} pfu per plant. With treatment, the number of viruses remaining on the plant is essentially zero. The study also found that a five-log reduction in viruses occurred in soil after ten days.

TABLE 5.3 Dose Required for a 25 to 75 Percent Disease Response in Humans

Number of Bacteria	Bacterial Species
100 - 1,000	*Shigella* sp.
1,000 - 10,000,000	*Salmonella typhi* (Typhoid fever)
100,000 - 1,000,000,000	*Salmonella* sp. (Gastroenteritis)
1,000 - 100,000,000	*Vibrio cholerae* (Cholera)

SOURCE: Bryan, 1974.

While the use of essentially pathogen-free sewage sludge or effluent would be ideal, materials of lesser sanitary quality (less treatment) can be applied in cases where direct human exposure to applied sludge or effluent is minimal. In these instances natural decay processes in the soil would be relied on to reduce the number of pathogenic agents to safe levels. Site restrictions would be required to limit public access and to allow adequate time for pathogen reduction prior to crop planting, harvesting, or domestic animal grazing.

INFECTIOUS DISEASE RISK

Where wastewater or sludge treatment is the primary mechanism to protect the public from infectious disease, acceptable microbiological quality standards must be developed. In the case of treated effluents used for crop irrigation, these values have developed over time and are based upon the use of standard water quality bacterial indicator microorganisms (e.g., coliform group or fecal coliform bacteria). More recently, specific treatment processes have been relied on to effect a significant reduction in the numbers of viruses and parasites (i.e. a process standard rather than a strict microbiological standard). For example, the Water Reclamation Criteria of California, which has been a model of reclaimed water regulations for many states (see Chapter 7), has established process standards for crop irrigation to ensure that the reclaimed water has a concentration of total coliform (or fecal coliform) less than or equal to 2.2 per 100 ml. This criteria is considered safe for human contact, and is based on past experience of health professionals and on a lack of detectable health problems associated with agricultural irrigation with treated effluent that meet this microbiological quality criteria. Thus, the microbiological quality values are not based on a formal risk assessment but rather on experience and the knowledge that accepted treatment processes can effectively reduce pathogen numbers.

There is, in the United States, less public health experience with sludge application than there is with wastewater reuse. EPA has established microbial quality criteria for sewage sludge that is to be applied to land in the Part 503 Sludge Rule (EPA, 1993). As with reclaimed water, the microbiological standards for sludge in the Part 503 Sludge Rule (discussed in more detail in Chapter 7) are also set primarily on the basis of experience, and expected efficiency of treatment processes to reduce pathogens.

There is a desire among regulators, producers, and users to develop and evaluate standards based on a more defined framework for risk assessment. This desire is generating interest in the use of mathematical models to predict the risk of infectious disease among those exposed to domestic waste-associated materials. Mathematical modeling makes assumptions explicit and is useful in organizing data and assumptions into a framework that leads to quantitative predictions. Models should, however, be used with caution. The model itself brings no new data or information to the process, and careful interpretation of modeling results is required; a numerical result of a model has human health significance only in the context of the model's assumptions. The mathematical format and numerical output of these models can lead to overconfidence in their results. There is the danger that inaccurate parameter estimates can lead to unrealistic risk forecasts.

Attempts to provide a quantitative model for the assessment of human health risks associated with the ingestion of waterborne pathogens have generally focused on estimating the probability of an individual infection resulting from a single exposure event. Most models described in the literature are of the same generic form (Fuhs, 1975; Dudley et al., 1976; Hass, 1983; Payment, 1984; Asano and Sakaji, 1990 and Rose and Gerba, 1991). They give a single value estimate of the probability of a particular exposure leading to infection or disease in a single individual and, except for Dudley's work, provide little or no information on the uncertainty or variability in this estimate.

A different approach to infectious disease risk assessment modeling starts from a population perspective and carries the analysis beyond the simple individual risk of infection or disease by estimating the probability distribution of the number of infected or diseased people in the exposed population (Cooper et al., 1986; Olivieri et al., 1986, 1989). This type of dynamic model allows for the evaluation of the sensitivity of the risk distribution to varying the dose and to varying the dose-response assumptions. Ideally the dynamic risk model should include the size of the exposed population, the immune status of the population, and other relevant demographic factors. The strength of this modeling approach is that it overtly acknowledges both uncertainty and variability in parameter values in a structured fashion that helps avoid unrealistic worst-case analysis results. Presently, it would be premature to give too much weight to the results of any of the existing models. It is anticipated that the development of the more sophisticated dynamic models will eventually enable risk managers to better understand the uncertainties involved and more realistically evaluate risk estimates.

MONITORING INFECTIOUS DISEASE POTENTIAL

Many of the variables associated with the transmission of infectious disease from wastewater and sludge are either not well understood or are unpredictable. Thus, it is essential that the dose of infectious agents in these materials be reduced to numbers that minimize the risk of disease transmission. This implies that a treatment process, including site restrictions, be applied that will *reliably* reduce the concentration of pathogens to an acceptable level prior to human or animal contact.

There is a great diversity of pathogenic agents involved in the fecal-oral exposure route, and an equal diversity of dose-response relationships. Monitoring for all of these agents is impractical; therefore, the use of indicator organisms has been the traditional approach to estimating sanitary quality. Coliform bacteria have been the most used in this regard. Their presence in the environment, particularly the fecal coliforms, is an indication of the presence of animal and human fecal matter, and thus the possible presence of many associated pathogens. Intestinal bacterial pathogens will react to environmental phenomena in much the same manner as coliforms, so the rates of removal of coliforms during water reclamation or sludge processing should reflect a similar reduction in pathogenic bacteria. Coliform bacteria determinations, in themselves, may not adequately predict the presence of viruses, protozoa or helminths. Many enteric viruses, for example, have a greater resistance to chemical disinfection and irradiation than do most bacterial indicators.

There are instances in sludge processing, such as composting, in which the coliform levels cannot be satisfactorily reduced even though there is reason to believe that the sanitary quality of the material is otherwise acceptable (EPA, 1992b; Skanavis and Yanko, 1994). In this situation, when the coliform numbers remain high, one should directly monitor for species of *Salmonella* to demonstrate the absence of this common bacterial pathogen.

Many of the parasites of concern exist in the encysted stage outside of the human or animal intestinal track, and are quite resistant to chemical and physical disinfection in this form. Wastewater reclamation practice relies on the treatment process to control these parasites. Parasite ova and cysts concentrate in sewage sludge and thus are of most concern for land application of sludge. Helminth ova are very resistant to those environmental factors that reduce the numbers of bacterial indicators or animal viruses in sludge. Because of its particular resistance, the presence or absence of viable helminth ova is being used as a criterion for monitoring for the presence of helminths in sludge to be applied to land (EPA, 1993).

As previously explained, there in no general agreement on the numerical values used in setting microbiological standards. They vary from region to region, both domestically and internationally. The standards are based on expected performance of wastewater treatment processes and on past experience with land application rather than on predictive science.

Because coliform bacteria are not always reliable indicators of the sanitary quality of reclaimed water or of sludge, there is a continuing search for substitute indicator organisms or for methods for directly measuring pathogens. The bacterium *Clostridium perfringens* is an example. Because of its presence in large numbers in wastewater, ease and speed of detection and the resistance of its spores to disinfection, this bacterium is considered by some to be a good indicator of how effective a treatment process has been. The evaluation of such potential pro-cess monitoring indicators should be encouraged.

Applications of immunological and molecular biological methods to environmental microbiology are evolving and offer the possibility for low levels of pathogenic microbes to be detected directly from environmental materials such as water and soil. Fluorescent antibody (FA) methods are available that are both qualitative and quantitative for specific microbial pathogens such as *Giardia* and *Cryptosporidium*. Gene probes have equal or greater specificity for species of microorganisms as FA, but at the present time are less suitable for rapid quan-tification. The application of polymerase chain reaction (PCR) methodology has the potential to detect very low levels of specific pathogen nucleic acid and, by inference, the presence of pathogenic microbes. While the application of these sensitive detection methods could result in more definitive monitoring, questions remain about the viability of the microbes detected and about the public health significance detecting very low numbers of these agents in water and sludge that are applied to land.

PUBLIC HEALTH EXPERIENCE WITH THE USE OF RECLAIMED WATER AND SLUDGE

There is an extensive literature on the public health (infectious disease) experience with wastewater reclamation and reuse (EPA, 1992a). This is not the case for the application of treated sludge onto land. There have been no reported outbreaks of infectious disease associated with a population's exposure—either directly or through food consumption pathways—to adequately treated and properly distributed reclaimed water or sludge applied to agricultural land.

Reports of the occurrence of infectious disease transmission linked to the irrigation of food crops with wastewater are associated with *untreated* sewage or treated wastewater of questionable quality. A recent epidemiological review of disease transmission from irrigation with reclaimed water (Shuval, 1990) also concludes that only untreated wastewater has been implicated in the transmission of infectious disease. Except for the use of raw sewage or primary effluent on sewage farms in the late 19th century, there have not been any documented cases of infectious disease resulting from reclaimed water use in the United States (EPA, 1992a, Water Pollution Control Federation, 1989).

In California, as a result of the Monterey study and others (Sheikh et al., 1990), a treatment process for reclaimed water has been approved by the state for any nonpotable purpose, including application to crops eaten raw. State health officials are convinced that specific treatment processes can be used to reduce the levels of pathogens such that treated wastewater is "safe to use." California standards for reclaimed water tend to lead the way in the United States, and are compatible with those developed by EPA in their *Guidelines for Water Reuse* (EPA, 1992a). See Chapter 7 for a discussion of the regulations governing pathogen control in reclaimed water and sludge.

The most extensive literature on human exposure to wastewater is concerned with the infectious disease risk to wastewater treatment plant operators and maintenance personnel. A review of the literature indicates that the occurrence of clinical disease associated with occupational exposure among these workers is rarely reported (Cooper, 1991a,b). From these observations it is not unreasonable to assume that exposure of agricultural workers to reclaimed water used in irrigation would result in an even lower risk of infectious disease than that to sewage plant operators.

Because of the intense public concern over AIDS, sewage treatment plant operators and others who come in close contact with wastewater and sludges have questioned their risk of infection with the HIV virus. All evidence indicates that there is no cause for alarm since the HIV virus does not survive in water; its transmission requires intimate contact with infected blood or body fluids (Moore, 1993; Riggs, 1989).

There have been a limited number of reports concerning an allergic response in sewage treatment plant workers exposed to species of *Aspergillus* fungi in the dust associated with the composting of sewage sludge (Clark et al., 1984; Epstein, 1994). In this instance the fungi source is not wastewater but growth of this common fungi as part of the composting process. The potential effects of aerosols generated by wastewater treatment plants on the sur-rounding community have been the subject of much speculation. To date, the information collected by multiple investigators indicates that no health problems have been demonstrated to be associated with these aerosols. This issue was thoroughly documented in the proceedings of an EPA symposium on wastewater aerosols and disease (Pharen, 1979). From these ob-servations, one could assume that the risk of contracting infectious disease from exposure to aerosols of reclaimed irrigation water is also negligible. No adverse health effects have ever been reported from the irrigation of median strips, parks, or private residences irrigated with properly treated reclaimed wastewater.

The limited number of epidemiological studies that have been conducted in the United States on treatment plant workers exposed to municipal wastewater or sludge or populations exposed to reclaimed water or treated sludge land application projects indicate that exposure to these materials was not a significant risk factor. However, the value of prospective epidemiological studies on reclaimed water or sludge use is limited because of a number of factors, including a low illness rate—if any—documented as resulting from these reuse practices, insufficient sensitivity of current epidemiological techniques to detect low-level disease transmission, population mobility, and difficulty in assessing actual levels of exposure.

Infectious diseases of the types that could be associated with municipal wastewater are under-reported and exposures are scattered, so that effects may well go unrecorded. From a public health point of view, the major microbiological considerations for evaluating any reuse management scheme are the ability to effectively monitor for treatment efficacy and the reliability of the process used to effect pathogen reduction.

One must keep in mind that there are a great many sources of these infectious disease agents other than reuse of wastewater or sludge, such as prepared food and person-to-person contact. Therefore, the potential added increment of pathogen exposure from the proper reuse of reclaimed water or sludge is minuscule compared to our everyday exposure to pathogens from other sources.

SUMMARY

Pathogenic microbes are inherent to domestic sewage and sewage solids. Because of the potential for the transmission of these infectious disease agents to humans and animals, use of these effluents on crops and grazing land must employ management strategies that protect the public's health. The main thrust of any management strategy is reduction of concentrations of pathogens to acceptable levels. This reduction can be achieved by treatment prior to land application or, as an alternative scheme in the case of sludge and reclaimed water of lower sanitary quality, crop restrictions and management of the application site to restrict human and grazing animal contact during the time required for pathogens to decay to acceptable levels. Two prime considerations in evaluating any management scheme are the ability to effectively monitor for treatment efficacy and the reliability of the process used to effect pathogen re-duction.

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