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An Approach for Comparing Health Risks of Wastewater Treatment Alternatives

A Limited Comparison of Health Risks Between Slow Rate Land Treatment and Activited Sludge Treatment and Discharge

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Technical Report

AN APPROACH FOR COMPARING HEALTH RISKS OF WASTEWATER TREATMENT ALTERNATIVES

A Limited Comparison of Health Risks Between Slow Rate Land Treatment and Activated Sludge Treatment and Discharge

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FOREWORD

The objective of this report is to develop an approach for comparing the health effects of land treatment and conventional treatment and discharge systems. Because a great deal of information is available and a large number of studies are currently underway, this is necessarily a limited comparison. The methodology is presented, however, for a more complete and detailed comparison as more data are generated.

The risk of human exposure to pathogens is as low with land treatment as it is with conventional treatment and discharge. There are, however, more concerns voiced about the health effects of land treatment. It is in the interest of the public and the engineering profession to know the relative health risks of each system. When these risks are understood more clearly, state regulatory authorities and public health officials should be able to assess the standards that are needed in their communities.

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INTRODUCTION

Land treatment of municipal wastewater has been practiced at various locations in the United States for over 100 years. Recently the passage of PL 92-500, with its emphasis on land treatment and recycling of resources, has renewed interest in land treatment. In addition, guidelines promulgated by the Environmental Protection Agency (EPA) require evaluation of such systems in all facilities plans.

There is, however, a general reluctance to equate land treatment of municipal wastewater with conventional treatment systems because of either real or speculative public health impacts. The impacts most often cited are (1) the transmission of pathogens, including virus, into the groundwater with the percolate; (2) the pathogens associated with livestock feed; (3) the potential passage of certain organics through the soil column and into potable water aquifers; (4) the introduction of certain heavy metals directly into the human food chain via vegetable crops or indirectly through the animals fed on the crops; and (5) the aerosol transmission of pathogens.

Most of the research findings to date deal with the impact of pathogen transmission in groundwater and soils. This report will concentrate on these findings and the related transmission of inorganic constituents into groundwater or surface water. Because the major studies on aerosols have not been concluded, aerosols will not be assessed in this report.

Several research projects in the United States and other countries are studying the public health implications of treatment systems. Most of these research programs are new, however, and conclusions will not be made for several years. Nevertheless, there is an increasing amount of information that, when coupled with engineering and scientific logic, makes a comparison of the public health implications for land treatment systems and more conventional treatment systems possible.

PUBLIC HEALTH

The proper collection, transport, treatment, and disposal of wastewater before it is discharged into the environment has been a major factor in the maintenance and upgrading of public health in the United States. Increasing demands on the use of available water resources and demands of an enlightened public have resulted in the need for stringent controls on effluent discharges into the environment, hence minimizing the potential for waterborne transmission of constituents adverse to public health.

Many wastewater constituents, such as infectious agents and inorganic and organic chemical compounds, can produce adverse health effects. Health problems arise when a particular sequence of events takes place (e.g.. allowing a susceptible host to encounter an infective dose). Many factors influence this sequence, so a health problem occurs only if all the necessary conditions are present. Consequently, sanitation practices and public health engineering have concentrated on removing the links or interrupting the sequence of events that will allow a susceptible host to encounter a sufficient dose of a chemical or infectious agent to result in illness.

The maintenance of public health is predicated on the concepts of (1) interrupting the agent-host cycle of transmission as much as possible, (2) reducing the quantity of adverse agents, and (3) limiting the potential for public contact or ingestion. Each of these three protective steps is accomplished to a lesser or greater degree by various wastewater management systems. For example, modern wastewater sewer systems maintain a distance between waterborne agents and the public. Modern wastewater treatment facilities, including the use of disinfection, reduce the number of adverse agents. The third step may be accomplished by limiting water-oriented recreation such as swimming and boating in an area near a wastewater discharge.

PURPOSE

The purpose of this report is to present an approach to comparing some of the health factors associated with both land treatment and conventional treatment systems. The report is intended to provide an approach or framework so that more objective comparisons can be made as more data become available.

This approach must consider many factors relevant to the wastewater management systems. Discussing each of these factors and comparing them collectively should help both the design engineer and the regulatory or public health official to understand the strengths and weaknesses of both land treatment and conventional treatment systems, thereby helping to ensure the best possible decisions in future wastewater management planning.

BASIS OF COMPARISON

Modern wastewater treatment technology offers a wide variety of approaches to the treatment and management of municipal wastewater. An assessment that considers every wastewater treatment alternative would be voluminous, and is beyond the scope of this report. Therefore, for purposes of this report, conventional treatment will be limited to a standard rate activated sludge plant with discharge to surface waters. Land treatment systems usually include one or more of three basic treatment processes: slow rate, rapid infiltration, and overland flow. A slow rate system will be used for the example assessment, because it is the most common land treatment option.

Generally, conventional wastewater treatment systems are designed to discharge effluents into a receiving water. Land treatment systems, on the other hand, can be designed to discharge all or a portion of the percolating effluent into the underlying groundwater aquifer. To reduce the dissimilarities between conventional and land treatment systems, the comparison will be made using a slow rate land treatment system with effluent recovery and discharge into a receiving water.

APPROACH

In this report, the approach to health risk assessment has five major steps:

1. Adequately determine and define the limits within which the relative assessment would be made and the assumptions required to simplify the approach to manageable levels.

2. Find available information useful in evaluating public health risks.

3. Detail the assessment method to facilitate its subsequent use.

4. Illustrate the assessment method by use of an example assessment.

5. Discuss the variations and implications of the assessment example.

The structure of the report follows the steps developed for the assessment procedure.

Chapter 3	Identify wastewater constituents affecting health, both quantity and nature of organisms and diseases
Chapter 4	Describe the dose-response and probable risks associated with wastewater constituents
Chapter 5	Describe and quantify the removal mechanisms for wastewater constituents in conventional treatment and land treatment systems
Chapter 6	Describe the assessment technique and steps
Chapter 7	Illustrate by example a. Define areas of probable contact (1) Site workers (2) Public at large b. Prepare a table of comparable effluent qualities c. Compare qualitative results and implications
Chapter 8	Discuss the variations in health effects for the different types of land treatment systems
Chapter 9	Provide a glossary of public health terms
Chapter 10	Provide a bibliography of cited references

Chapter 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

An example assessment between activated sludge and slow rate land treatment of wastewater was presented based on the following assumptions:

- Flow of 3 Mgal/d of domestic wastewater.
- Activated sludge flowsheet with (1) disinfection and (2) surface water discharge.
- Slow rate land treatment flowsheet with (1) aerated lagoon preapplication treatment, (2) storage, (3) no disinfection, and (4) percolate water recovery by underdrains and surface water discharge.

The following conclusions on the relative health risks were reached.

1. The qualitative results indicate that both conventional and land treatment systems, which are well-maintained and have good operating conditions, provide a large measure of safety for public health. Land treatment systems that involve slow infiltration offer greater protection against parasites and viruses, trace metals, nitrate, trace organics, and halogenated organics.

2. Adequate removals of parasitic eggs and cysts require positive measures, such as filtration, or long detention times in ponds or storage lagoons. As such, the land treatment alternative offers greater protection from health risks. The levels of parasites are very low in the United States, so neither discharge practice appears to be a significant health risk.

3. The land treatment system removes viruses to a higher degree than conventional treatment and disinfection systems. Treatment processes with longer detention times, such as in ponds and storage lagoons, have better removals than conventional activated sludge treatment.

4. The health hazard to site workers is slightly greater than to the general public. The contact by site workers is generally limited to occasional direct contact.

5. The use of wastewater for irrigation of food crops may provide a greater risk than irrigation of nonfood crops, since the agent-host transmission cycle will be shorter and positive removals by soil are not used. Die-away varies according to type of crop and infectious agent. However, present application rates of wastewater to crops, as suggested in California regulations, provides a safety factor of 10^8 to 10^{13} over the last reported incidents of disease transmittal using "night soil" on food crops.

6. Intake of trace metals by water sources should not pose problems because the typically low values in municipal wastewaters are generally reduced to below drinking water standards by wastewater treatment.

7. No estimation can be made of the health hazards resulting from low level exposure to trace organics. The dose response and health effects are unknown at this time.

RECOMMENDATIONS

Conduct research to resolve the questions on health effects in the following areas. Definitive conclusions from this research would improve the prospects for a complete risk assessment.

1. Potential for disease transmission from passage of bacterial and viral pathogens through a soil profile to groundwater supplies, from aerosols, or from direct application of wastewater and sludge to crops consumed by humans.

2. The health hazard from persistent organic compounds in wastewater that may resist biodegradation during land treatment.

3. Health hazards from human consumption of cadmium as a result of cadmium uptake by crops.

Chapter 3

WASTEWATER CONSTITUENTS AFFECTING HEALTH

Domestic wastewater is known to contain a number of infectious agents whose source is primarily the excrement of man. In addition, toxic inorganic and organic chemicals may be present from sources in both industrial and household activities, the former usually being the major contributor. Each of these categories of constituents is described and discussed in the following paragraphs.

INFECTIOUS AGENTS

The infectious agents include various bacteria, viruses, and parasites. The concern about infectious agents present in wastewater is due to their waterborne transmission and potential for causing disease. An important source of data on disease incidents in the United States is the United States Public Health Service (USPHS) Center for Disease Control, Atlanta, Georgia. Using data from the USPHS, waterborne disease cases for selected infectious agents are compared with total disease cases in Figure 1 using a log scale.

The waterborne disease cases include any incident in which it was shown that the infectious agent was transferred by water used for domestic purposes. The overall waterborne transmission of disease is low, with reported values ranging from 0 for amoebiasis to 11.5% for salmonella (typhoid). However, salmonella had the fewest number of total reported cases of disease. The cases where waterborne transmission had been identified included (1) deficiencies in water treatment, (2) deficiencies in distribution systems, (3) use of untreated surface water, and (4) use of untreated groundwater. No reported cases resulted directly from inadequate operation of a municipal wastewater treatment system.

Disease incidents related to (1) raw wastewater contamination of water supplies; (2) abuse of commonly accepted wastewater management practices; and (3) contamination of food crops to be eaten raw by untreated or partially treated wastewater have occurred historically and have been summarized by Sepp [1] and Bryan [2]. Because this study is intended to compare health factors associated with modern treatment practices, these incidents of contamination are not discussed here.

In the United States, the pathogenic bacteria that have the greatest health impacts and have been identified in wastewater include members of the genera *Shigella*, *Salmonella*, and *Escherichia*. Viruses and parasites have also been recognized

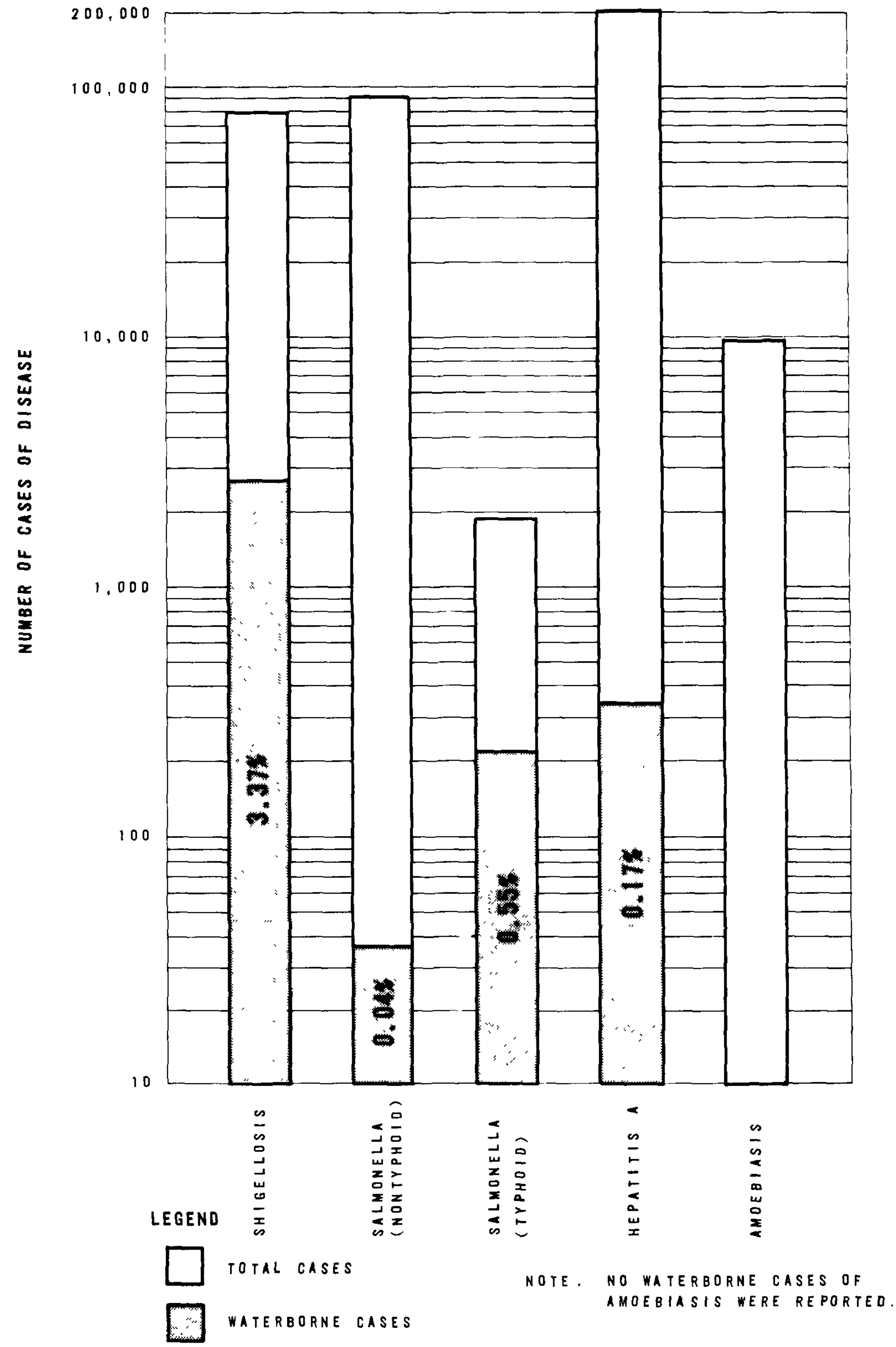

FIGURE 1

RELATIONSHIP BETWEEN WATERBORNE DISEASE CASES AND TOTAL DISEASE CASES (1971-1974) as important within the United States. Hepatitis is the virus of greatest concern because it has the greatest disease effect, although numerous other viruses have been reported or are present in untreated wastewater. Parasites of significance in the United States include *Giardia lamblia* and *Entamoeba histolytica*. A summary of available information on the reported diseases is presented in Table 1.

Table 1. SUMMARY INFORMATION ON REPORTED WATERBORNE DISEASE IN THE UNITED STATES [3-7]

Wastewater constituent	Resulting disease	Disease incidents, 1961-1974: Reported no. of outbreaks	Disease incidents, 1961-1974: 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.

Cholera is a disease prevalent in other parts of the world. In 1959, 33,953 cases were reported in India and East Pakistan. Fortunately, cholera is not a problem in the United States; only two indigenous cases have been reported since 1911 [8, 9]. Most of the current cholera cases are reported in Asia and the Middle East [10].

Bacteria

The three most important classes of bacteria and their related diseases are discussed in the following paragraphs.

Shigella. There are six species of Shigella of which two, Shigella sonnei and S. flexneri are the most common. Sixty percent of the reported cases of shigellosis in the United States are caused by S. sonnei and 10% are caused by S. flexneri. Shigellosis, also known as bacillary dysentery, is an intestinal disease limited to man and higher apes. It spreads rapidly under improper sanitary conditions and primarily from person to person. However, contaminated water has occasionally been reported as the initiating source. The reported incidence of shigellosis in the United States in 1975 is presented in Table 2 [11]. It is estimated by the Center for Disease Control that this incidence probably accounts for only 5% of the infected population. Thus the actual number of infections may be almost 1,380 per million population. In 1974, 86 deaths out of 22,600 total waterborne and nonwaterborne cases were reported.

Table 2. WATERBORNE AND NONWATERBORNE MORBIDITY AND MORTALITY DATA FOR INFECTIOUS AGENTS [11, 12, 13]

MORBIDITY DATA

Disease	Reported incidence	Year	Remarks
Shigellosis	$90/10^6$ [a]	1973	Center for Disease Control estimates that reported values are only 5% of occurrences.
Shigellosis	$69.2/10^6$	1975	
Typhoid fever	$1.8/10^6$	1975	--
Salmonellosis	$106/10^6$	1975	--
Gastroenteritis by E. coli	Not known		Outbreaks have been reported.
Infectious hepatitis	$168.2/10^6$	1975	--
Poliomyelitis	$<8.1/10^6$	1973-1975	3-year period.
Amoebiasis	$13/10^6$	1975	--
Giardiasis	Not known	--	Only incomplete reporting available.

MORTALITY DATA

Disease	Reported deaths	Total reported cases	Year
Shigellosis	86	22,600	1974
Typhoid fever	3	437	1974
Salmonellosis (nontyphoid)	59	21,980	1974
Infectious hepatitis	36	$168.2/10^6$	1975

a. Cases per 10^6 total population.

Salmonella. The genus Salmonella contains a large number of species that are pathogenic to man. *S. typhi*, the causative agent of typhoid fever, is peculiar to man and causes a severe enteric fever. Fortunately, the incidence of this disease in the United States is quite low. In 1974, three deaths out of 437 total cases were reported. The incidence of salmonellosis (nontyphoid), in the United States has been greater than that for typhoid fever (Table 2). This disease can be caused by a large variety of species of *Salmonella* and is characterized by diarrhea, abdominal pain, and vomiting. Its predominant cause (29.4% of all cases) is due to *S. typhimurium*, the typical species isolated [14]. In 1974, 59 deaths out of 21,980 total cases were reported.

E. coli. Since the mid-1940s when *E.coli* was associated with diarrheal disease in nurseries, it has become increasingly clear that varieties of this bacteria known as enteropathogenic *E. coli* are involved in waterborne enteric disease [15]. These pathogenic strains produce mild to severe cholera-like symptoms in the small intestine and produce an endotoxin, or they may develop in the colon and penetrate the epithelial cells and produce shigellosis-like symptoms [16]. Enteropathogenic *E. coli* has been shown to be the cause of traveler's diarrhea [17] and waterborne epidemics of diarrhea, such as the occurrence in Crater Lake National Park in 1975 [18]. The morbidity of this disease in the United States is unknown because of lack of reporting.

Virus

More than 100 strains of viruses may be present in the intestines of man and animals and thus viruses find their way into wastewater. The most important of these, from the standpoint of the severity of disease produced, is the agent of infectious hepatitis. The morbidity and mortality of infectious hepatitis are presented in Table 2.

Before the successful vaccination campaign of the 1950s, the virus poliomyelitis would have been listed as an important disease. However, less than ten cases of poliomyelitis per 1,000,000 population were reported from 1973 to 1975 (Table 2) [19].

The other viruses found in wastewater would include members of the Coxsakie, the Echo, the Adeno, and Reovirus groups. These produce various diseases including aseptic meningitis, myocarditis, respiratory involvement, and gastrointestinal upset. Children of preschool age have the principal incidence of infection, and transmission is primarily by person-to-person contact. The role of water in the transmission of these agents is not clear and some authorities believe it is not important [20].

The water route of transmission has been implicated in several outbreaks of poliomyelitis. Outbreaks in Edmonton, Alberta (Canada), and Huskerville, Nebraska, were attributed to contaminated water but the evidence is not conclusive [21]. Most authorities agree that in developed countries, the transmission of poliomyelitis by water is, at most, a rare occurrence. In underdeveloped countries where sanitation is poor, however, the transmission of poliomyelitis and other enteric viruses by water may be a common occurrence.

Three outbreaks of pharyngoconjunctivitis caused by Adenovirus Type 3 and one of Type 7 have been attributed to contaminated swimming pools. Isolation of the virus from the pool water was either unsuccessful or not attempted, and the water route of transmission was implicated only on the basis of epidemiologic evidence [22].

In 1974, five children showed symptoms of a disease with similar clinical characteristics. The disease was positively diagnosed as caused by Coxsackie virus Type A16. In this instance, the infections were acquired while swimming in lake water that had relatively high fecal coliform counts. The specific virus was successfully isolated from the lake water. This is one of the first instances in which a Type A Coxsackie virus has been shown to be transmitted to bathers [23].

No other enteric viruses have been specifically implicated as causative agents in documented outbreaks of waterborne viral disease. However, a virus-like particle similar in appearance to the hepatitis "A" particle has been reported to be associated with an acute infectious nonbacterial gastroenteritis that occurred in Norwalk, Ohio [24].

Clemmer et al. [25] have carefully examined the spread of subclinical (no physical symptoms for diagnosis) Coxsackie virus B3 infection in 25 Louisiana families. One-half of the households (51 children) showed virus infection, which indicated interfamilial (vertical) spread, but horizontal transmission from family to family was more difficult to show [25]. No clinical disease was evidenced in any of the group. Lennette [20] points out that in an epidemic of Echo virus 30 in Seattle, there occurred many thousands of infections, more than half of which were subclinical, and only a few cases resulted in apparent disease. Thus, the disease produced by many of the enteric viruses is frequently subclinical, generally inapparent, and results from close person-to-person contact.

Parasites

There are a myriad of relatively large parasites associated with the waste discharge from man and animals. In the United States those commonly associated with waterborne disease are the amoeba, *Entamoeba histolytica* (amoebic dysentary), and the flagellated protozoan, *Giardia lamblia* (giardiasis) (Table 1).

In amoebiasis, the amoeba infects the human colon causing erosion of the superficial mucous membranes. It may eventually invade the tissue with consequent ulceration. In certain severe cases, the parasite may metastasize to other body organs. The parasite has the ability to encyst and these cysts subsequently enter the environment in infected feces. When the encysted amoeba reenters a susceptible host, usually in contaminated food or drink, it germinates in the gut and infects or reinfects. The morbidity of amoebiasis is shown in Table 2.

Giardiasis is an intestinal disease produced by infection of the gut by the protozoan *G. lamblia*. The disease ranges from subclinical to severe maladsorption. The parasite produces cysts that are passed with the stool and spread to other hosts through fecal contamination. This disease has only recently been recognized in the United States. In a number of instances it has been associated with drinking water contamination [12]. The total incidence of this disease in the United States is unreported.

CHEMICAL CONSTITUENTS

The chemical constituents, both inorganic and organic, form the second major category of wastewater constituents that may have an impact on human health. The numbers of different types of chemicals that may be present in water are unknown but it is certain that the numbers are very large. Their sources are both natural and from human activity. Health implications of their presence in water are known for only a few.

The inorganic chemicals that have an impact on human health are the best understood because the analytical technology is relatively well developed. There is also a longer history of recognizing the associated health problems. However, there are still many gaps in our knowledge particularly in connection with chronic diseases (e.g., the relationship between water hardness, sodium, cadmium, and lithium, and cardiovascular disease) [26].

Inorganic Chemicals

The inorganic chemicals found in water that appear to affect health are arsenic, cadmium, cyanide, fluoride, lead, mercury, nitrate, and selenium.

Arsenic is common in nature and is present in water in concentrations as high as 336 µg/L. The recommended level in acceptable drinking water should not exceed 50 µg/L. Hyperkeratosis and cancer of the skin can be caused by the injection of arsenic. The symptoms of chronic arsenic poisoning are fatigue and lack of energy.

Cadmium is normally present at very low levels in surface water and groundwater. If present, its concentration in water ranges from 1 to 20 µg/L with most waters containing less than 1 µg/L. The human intake of cadmium has been attributed to various ailments, including renal dysfunction and hypertension.

Cyanide is used in industrial activities and may enter surface water and groundwater. Hydrogen cyanide (HCN) is the most toxic species and is the most common form of cyanide at pH levels of surface water or groundwater. When ingested, cyanide interferes with the body's oxygen transport system causing illness or death.

Fluoride is a naturally occurring mineral in water. Excess fluoride can cause dental fluorosis (teeth mottling) and, in increased doses, can cause bone changes including crippling fluorosis. Fluoride is sometimes added to drinking water to prevent tooth decay. This practice has led to illnesses, including 351 reported cases of fluoride poisoning due to excess fluoride addition [12].

Lead occurs in water primarily from industrial and domestic activity. When present in U.S. waters it has been found in concentrations ranging from 2 to 140 µg/L. Lead poisoning is a chronic disease that can produce a variety of symptoms including anorexia, nausea, vomiting, paralysis, mental confusion, visual problems, and anemia. It has been suggested that drinking water not exceed a lead content of 50 µg/L [27].

Mercury levels in surface water rarely exceed 5 µg/L and usually are less than 1 µg/L. In groundwater, the level is generally less than 0.1 µg/L. Chronic poisoning with mercury is normally associated with industrial exposure particularly to mercury fumes. The organic mercurials, such as methylmercury, are more toxic in the natural environment. Mercury can accumulate in the body and chronic exposure can produce inflammation of the mouth and gums, swelling of salivary glands, loosening of teeth, kidney damage, and personality changes.

Nitrates may enter water from various sources: natural, agricultural, industrial, and domestic. Serious, sometimes fatal poisoning in infants has occurred following ingestion of water that contains nitrate. The disease in infants is called methemoglobinemia in which the nitrate is reduced to nitrite in the infant's stomach, which in turn seriously impairs the oxygen carrying capacity of the blood. Cases of methemoglobinemia due to nitrates in drinking water have not been reported recently; however, since 1945 approximately 2,000 cases of this disease have been reported in North America and Europe. Many water supplies in the United States exceed the recommended maximum level of 10 mg/L nitrate-nitrogen.

Selenium is highly insoluble in the unoxidized state and very little data concerning concentrations in U.S. waters are available. The suggested maximum level in drinking water is 10 µg/L. Selenium toxicity is similar to that of arsenic.

A number of other inorganic constitutents found in water may be associated with human disease, although a cause and effect relationship has not been demonstrated. These include the previously mentioned relationships between water hardness and heart disease, sodium and heart disease, and the suspect metalocarcinogens beryllium, chromium, nickel, and selenium. For more information on these and other inorganic chemicals in water the reader is referred to reference [28].

Organic Chemicals

Our knowledge about the presence of organic chemicals in water is limited; however, the identification of chemical species is increasing rapidly. In the early part of 1975, over 160 organic compounds had been identified in water [29]. The recognition of their presence in water raised questions concerning their impact on the health of the public, particularly in reference to cancer. Constituents found in U.S. water supplies, reported in an EPA study and selected for their potential hazard, are shown in Table 3. The concentration ranges of these compounds and the relative frequency in which they were found are indicated in this table. Chloroform and other halogenated methanes were found in all waters and were greater in concentration than the other selected organics. The chlorination of water has been assumed responsible for a good proportion of these compounds. For more information on these compounds, the reader should see references [26-29].

Table 3. THE AMOUNTS AND EXPECTED PERCENT DISTRIBUTION OF SELECTED CONSTITUENTS IN THE U.S. DRINKING WATER SUPPLIES [29].

Constituent(s)	Amounts, µg/L	Percent distribution[a]
Carbon tetrachloride	<2 - 3	10
Chloroform	<0.3 - 311	100
Other halogenated C_1 and C_2[b]	<0.3 - 229	100
Bis(2-chloroethyl)ether	0.02 - 0.12	Low
β-chloroethylmethylether	Unknown	Low
Acetylenedichloride	<1	Low
Hexachlorobutadiene	~0.2	Low
Benzene[c]	10	High
Octadecane	~0.1	High
C_8 - C_{30} hydrocarbons	<1	High
Phthalate esters	~1	50
Phthalic anhydride	<0.1	Low
Polynuclear aromatics[d]	0.001 - 1	High

a. 100% distribution means that tests of all drinking waters (24) showed the presence of the listed constituent(s). Percent values are rounded to the nearest 10%. Where insufficient sites have been sampled, low or high estimates have been made.

b. Includes summation of all C_1 and C_2 halogenated hydrocarbons except carbon tetrachloride and chloroform.

c. Whereas benzene has not been frequently reported, its distribution is probably widespread. The amount and distribution columns here refer to benzene and the alkylated benzenes up to C_6 which have been reported in many drinking waters.

d. The listed amounts are a summation of the concentrations of individual compounds.

Chapter 4

DOSE RESPONSE AND PROBABLE RISK

The evaluation of the health risks involved in the management of water and wastewater requires knowledge concerning: (1) the presence of agents that cause disease; (2) the dose response characteristics of the agents involved (i.e., the concentration of the agent and the concentration required to produce disease); and (3) how the agent might come into contact with susceptible individuals. Unfortunately, in many instances, data on one or more of the three criteria required for making risk assessments are not available.

INDICATOR ORGANISMS

Historically, the presence of infectious agents in water and wastewater has been estimated using the coliform test. Because of the myriad of microorganisms that may be present, it was practically and in some instances technically infeasible to determine the dose of each agent. Thus, the coliform bacteria group was chosen as an indicator of fecal contamination. If coliform bacteria were present, one could assume a probability that other pathogenic microorganisms of fecal origin might also be present.

DOSE RESPONSE - INFECTIOUS AGENTS

Information on human dose response (production of clinically recognizable disease) is available for typhoid fever, certain of the other salmonella, and some strains of *E. coli* and *Giardia lamblia*. There is a notable deficiency in dose response data involving enteric viruses. Bryan [2] has compiled a dose response listing for a variety of infectious agents and a summarized version of his data is shown in Table 4.

Table 4. DOSE RESPONSE FOR SELECTED ENTERIC MICROORGANISMS [2]

Microorganism	No. per dose[a]
Shigella sp.	10^2-10^3
S. typhi	10^4-10^7
Salmonella sp. (not *S. typhi*)	10^6-10^9
E. coli	10^6-10^{10}
Vibrio cholerae	10^3-10^8
G. Lamblia	10^1-10^6 (infection without illness)
Virus	Not known

a. Needed to produce illness in 25 to 75% of persons taking dose.

As shown in this table, the dose response varies from one organism to another. In the case of the bacterial diseases, it normally takes a considerable number of organisms to elicit a significant response in those challenged. In the case of the parasitical disease giardiasis, no clinical infections were seen with total doses as high as a million organisms; however, a dose as low as ten cysts produced infection in 100% of those challenged.

As stated previously, data for enteric virus dose response are not well established, although some believe that one enteric virus particle will be an effective dose. Others state that an effective dose requires a much greater number of virus. As Lennette writes [20],

> The contention that a single viral particle invariably or even frequently constitutes a minimal infective dose for man is simplistic and misleading. It fails to take into account the considerable amount of data from oral polio vaccine studies which are nonsupportive of this contention and ignores the manifold factors associated with the humoral and cellular immune responses of the animal as well as the chance factors--which under natural conditions surely must be enormous--that a single viral particle contained in a volume of food or drink will find its way through the mechanical barriers of saliva, mucus, gastric acid, etc.; encounter a susceptible cell; find the appropriate receptor site on that cell; and enter and replicate sufficiently to spread to other cells.

DOSE RESPONSE ANALYSIS - INFECTIOUS AGENTS

The relationship between the numbers of coliforms present in water and the numbers of enteric bacterial pathogens also present in water is of considerable importance since the former are used as indicators of the latter. Kehr and Butterfield [30] indirectly related the number of S. typhi per million coliforms to the morbidity of typhoid in the community. This relationship can be shown by the equation

$$y = ar^n$$

where y = number of S. typhi per million coliforms
a = a constant
r = the morbidity of the disease per 100,000
n = a constant

Since the present morbidity of typhoid fever in the United States is 0.18 per 100,000 (r = 0.18 from Table 2) and a = 3 and n = 0.46 [30], 1.4 typhoid bacilli per million coliforms (y = 1.4) would be estimated from this equation. Assuming the same relationship applies for salmonella and shigella, one would estimate 36 salmonella and 29 shigella organisms per million coliforms.

These numbers are based on the disease rate for the entire country; however, if there is a local epidemic, then the number of pathogens per million coliforms would be proportionately higher. When the dose response data for typhoid fever and for other salmonella are examined (Table 4) and evaluated using the Kehr and Butterfield relationship of pathogens to coliforms, the risk of contacting these diseases from water seems slight.

Dudley et al. [31] performed a sophisticated statistical analysis to determine indirectly the risk to swimmers of contracting typhoid or other salmonella from bathing water. They used the dose response data shown in Table 4 and assumed a swimmer would imbibe 10 mL of water. Using the equation and assuming the morbidity rate is 0.18 per 100,000 and that untreated wastewater contains 10^9 coliforms per 100 mL, then 1,300 typhoid bacilli should be present in 100 mL of untreated wastewater (13,000 organisms/L). If this number of typhoid bacilli were present in untreated wastewater and were imbibed by a population of swimmers, the rate of disease would be about 20 cases or less per 100,000 population as shown in Figure 2. In the case of other salmonella, the same activity would be estimated to produce only four cases in 100,000 people.

These predictions should be taken with reservation, because they assume that people will directly consume untreated wastewater. They also assume that the parameters used to determine coliform-to-typhoid ratios are realistic and that the dose response data are an accurate reflection of dose response in a large population. Kehr and Butterfield contended that one typhoid bacilli would cause disease in 1 to 1.5% of those exposed. This rate was in agreement with observations they made of actual epidemics.

The dose response data used (Table 4) in calculating the risk of illness when exposed to other species of salmonella did not include *S. typhimurium*, which is the major cause of waterborne salmonellosis. Perhaps the dose response to this microorganism is much more sensitive than for the type of salmonella used in the dose response studies. This might explain why *S. typhimurium* is so common a cause of intestinal illness.

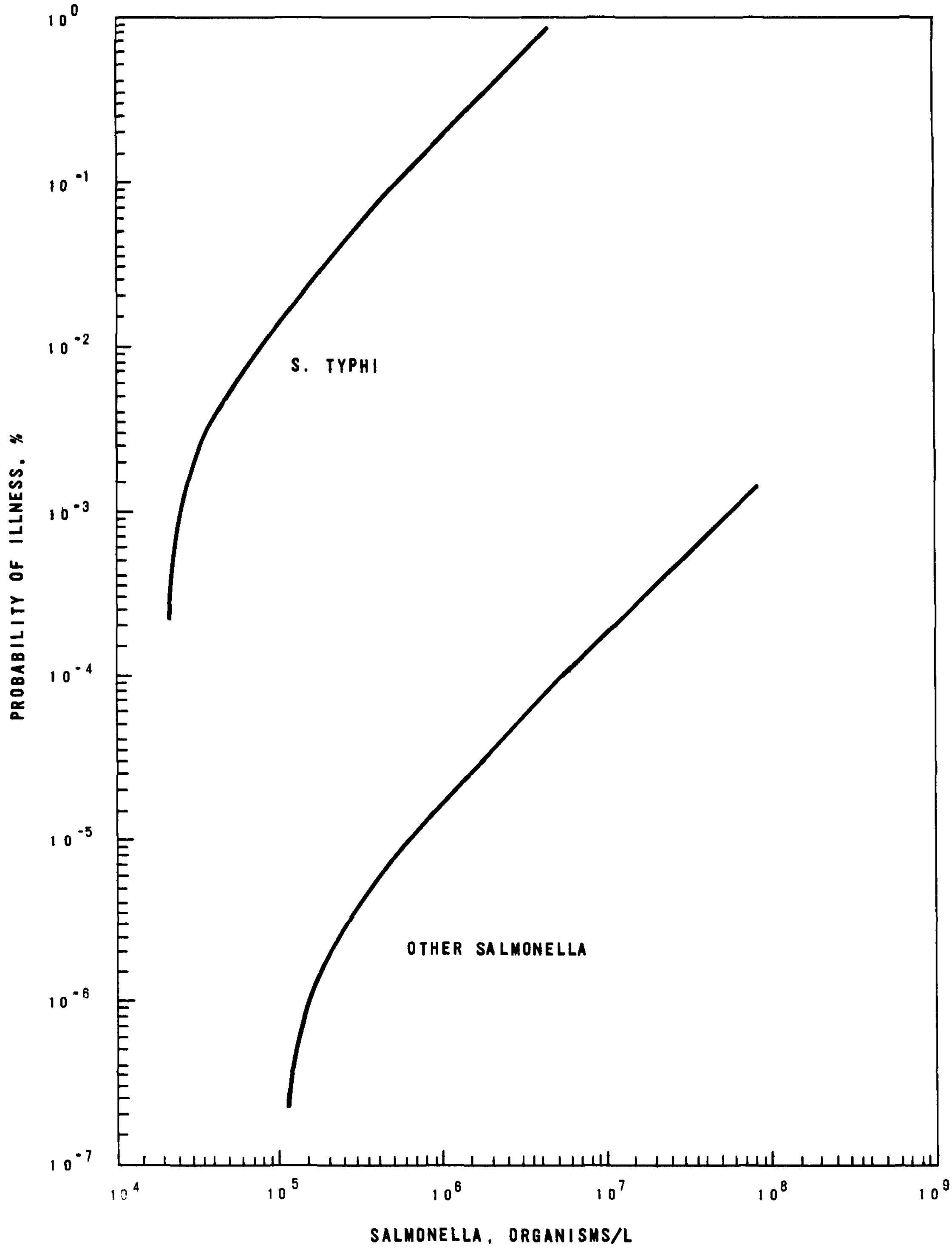

FIGURE 2

PROBABILITY OF DISEASE, AS RELATED TO EXPOSURE TO SALMONELLA sp, OCCURRING IN BATHERS [31]

To find the probability of swimmers contacting typhoid or other salmonella, the truth most probably lies in between the methods used by Kehr and Butterfield and Dudley, et al. From laboratory data, it is evident that a considerable number of salmonella are required to cause clinical disease and that infectivity of S. typhi is greater than the other tested salmonella. The relationship between the presence of coliforms and the presence of pathogenic bacteria discussed by Kehr and Butterfield is based on reasonable parameters, although the accuracy of the numbers involved may be questioned. It should be kept in mind that the data are only for certain salmonella and do not represent all pathogenic agents that might be present in contaminated water.

It should also be kept in mind that the presence of salmonella in wastewater will not be as consistent as will the coliforms that are shed continually by the entire population. The salmonella present would most probably not be evenly distributed in the water. Theoretically, if one assumes an even distribution of pathogens the chances of contacting salmonella while drinking water of poor bacteriological quality may be small.

In fact, however, a discontinuous distribution of salmonella may result in more effective (greater number of organisms) doses being delivered, by chance, to more individuals than one would predict. An example is the 1926 case in Detroit, Michigan, cited by Kehr and Butterfield. There were eight cases of typhoid fever and 45,000 cases of gastroenteritis transmitted by water that contained an average of 6.5 coliforms per 100 mL. The morbidity of typhoid in the area was estimated to be 27 per 100,000. The previously mentioned indirect methods would have underestimated this value.

DOSE RESPONSE - TOXIC CHEMICALS

Dose response to toxic chemicals is normally evaluated by using laboratory animals and the results reported as dose per animal weight or per body surface area. Estimates of human dose response relationships are made by extrapolating from data on animals. In many cases, there is a threshold concentration of a given chemical below which exposure does no harm and above which frequency of response increases with dose. Many of the values for the acceptable concentration of inorganic chemicals in water are based on these kinds of data. In developing such standards, the total intake from sources other than water was also estimated so that the water contribution will normally be insufficient to raise the total intake over the threshold value.

DOSE RESPONSE - CARCINOGENIC AGENTS

When carcinogens or suspected carcinogens are involved, the usefulness of a threshold level value may be questionable. The World Health Organization has identified other issues [32].

1. The self replicating nature of the cancer cell.
2. The possibility that the carcinogenic event is irreversible.
3. Certain evidence that tumor initiation may be caused by a single tumor initiating event.
4. The fact that cancer can occur in response to chemicals long after their disappearance from the body.

To evaluate the risk of developing cancer from exposure to water and wastewater, the first problem is to determine the presence of a carcinogenic or mutagenic agent. The second problem is to determine the risk to the human population from the presence of such an agent. The first problem is being vigorously attacked in many laboratories throughout the world with many promising results. These activities have been summarized by Drake et al. [33]. The second problem is more difficult to study because of the four issues listed.

ACCEPTABLE RISK

One approach to assess the health hazard of exposure to low doses of carcinogens has been suggested by Friedman [34], who used the method of Mantel and Bryan [35]. Because a no-response dose of carcinogenic may not exist, it is necessary to select some acceptable risk of contracting cancer (e.g., 1 in 100 million as suggested by Mantel and Bryan). From dose response information obtained when using high doses of material, Mantel and Bryan extrapolated the dose associated with the selected risk (i.e., 1 in 100 million).

These values are all arbitrary. However, they are conservative because the calculation method ignores other probabilities involved, such as (1) the probability that an individual will have a given exposure; (2) the probability that the individual involved will be overshadowed by some other competing risk; and (3) the age of the individual when the cancer will occur.

A major difficulty is to set the limit of acceptable risk. Friedman suggests that the risk level should be associated with everyday risks of cancer, such as eating a commonly accepted food with a known level of carcinogen (e.g., benzpyrene in broiled beef steak). Using an extrapolation, the risk of cancer from consuming 70 g of charcoal broiled steak is 8 in 10 million.

It is obvious that there is much to be determined before satisfactory dose-response-risk data will be available on disease agents in water and wastewater. It is probably utopian to assume that such data will ever be developed for all factors involved. However, information now available or presently being developed provides an insight into what factors are involved in the transmission and cause of environmentally associated disease. Present knowledge gives us some information about the magnitude of various problems. This knowledge coupled with observation (epidemiological evidence) helps in the assessment of health risks.

Chapter 5

REMOVAL MECHANISMS

The infectious organic and inorganic agents in wastewater are affected by numerous mechanisms that are used in wastewater treatment and disposal and that reduce health risks. Although the mechanisms lessen the numbers by removal as well as by dilution, the term removal mechanisms refers to both. In conventional treatment, mechanisms include disinfection, sedimentation, retention time in activated sludge treatment, and retention time in oxidation lagoons. In land treatment, mechanisms include filtration, desiccation by sunlight, and microbial antagonism by naturally occurring soil microorganisms.

INFECTIOUS AGENTS

The infectious agents in wastewater, which were discussed in Chapter 3, are reduced in numbers by various mechanisms during collection, treatment, and discharge. At the source, the number of pathogenic and indicator organisms is the largest. The comparison between "night soil," as is used by many lesser developed countries, and raw municipal sewage shows that dilution in a collection system may account for a pathogen reduction factor of 2×10^3 to 2×10^5 [36]. This reduction is important when extrapolating reported disease incidents resulting from use of "night soil" to use of treated effluents.

Although the presence of all infectious agents is assumed from a public health viewpoint, the removal mechanisms discussed in this report are limited to the most common agents, such as *Shigella*, *Salmonella*, *Escherichia coli*, infectious hepatitis, Coxsackie-, Echo- Adeno-, and Reo-viruses, and the parasites *Entamoeba hystolytica* and *Giardia lamblia*. The reductions of less prevalent agents should be similar to the behavior of these common agents. The study of indicator organisms has been greater than that of the infectious agents. In some instances, the behavior of the fecal and total coliforms may serve as guidelines, but caution over their use is expressed since major differences occur.

Conventional Treatment

Conventional treatment provides reductions in infectious agents by primary treatment (sedimentation), secondary treatment (aeration and sedimentation), chlorine disinfection, and dilution and die-off during surface water discharge. The reductions in the number of the infectious agents are presented in Table 5. Although the overall removals vary from negligible values to greater than 99% removal, highly effective mechanisms are required to produce the 4 to 8 log reductions in numbers that are needed to reduce pathogen counts to low numbers. Conventional wastewater treatment has relied heavily on chlorine disinfection to accomplish this die-off of infectious agents.

Table 5. ENTERIC MICROORGANISM REDUCTION BY CONVENTIONAL TREATMENT[a] [5, 28, 37, 38]

Microorganism	Primary treatment removal, %	Secondary treatment removal, %
Total coliforms	<10	90-99
Fecal coliforms	35	90-99
Shigella sp.	15	91-99
Salmonella sp.	15	96-99
Escherichia coli	15	90-99
Virus	<10	76-99
Entamoeba histolytica	10-50	10

a. Without disenfection.

The effectiveness of chlorination in the destruction of infectious agents in wastewater effluents varies depending on the type of infectious agent, the applied chlorine dose and contact time, and the quantity of interfering material, such as suspended solids and ammonium nitrogen. The resistance of various infectious agents to chlorination was described by Bauman and Ludwig (cited in [37]). They used a die-off coefficient, a K value, that was equal to the product of chlorine dose and contact time. K values for various waterborne microorganisms are presented in Table 6. E. coli had the most rapid die-off with a K value of 2 to 4, while E. histolytica was most resistant with a K value of 50 to 125.

Table 6. VALUE OF DISINFECTION CONSTANT K FOR VARIOUS WATERBORNE MICROORGANISMS [37]

Microorganism	pH range	K value
E. coli	7.0-8.5	2-4
Salmonella sp.	7.0	2-4
Poliovirus	6.8-9.3	6
Coxsackie A	7.0-9.0	6
Hepatitis	6.4	10
E. histolytica	7-8	50-125

Conventional wastewater treatment generally precedes discharge of the treated effluent into a surface water. Since these waters occasionally serve as recreation areas and as sources of potable water, the effects of the receiving waters on the infectious agents are important. The survival of enteric microorganisms is less favorable in environments other than the human body. The die-off mechanisms in surface waters combine with dilution to promote reduction in populations. Historical research has generally been focused on trying to define the die-off behavior of the indicator organisms (fecal and total coliforms). The die-off of microorganisms is generally accepted to occur as a first order decay relationship according to Chick's Law:

$$\ln C/C_o = -Kt$$

where C = concentration at time (t)
C_o = initial concentration
K = die-off coefficient, day^{-1}
t = time in the environment, day

Most of the research to determine the die-off coefficients has been conducted in rivers or laboratory studies. The results from studies of water quality models give a range of die-off values, as shown in Figure 3. The temperature of the experiments varied from 41 to 86°F (5 to 30°C).

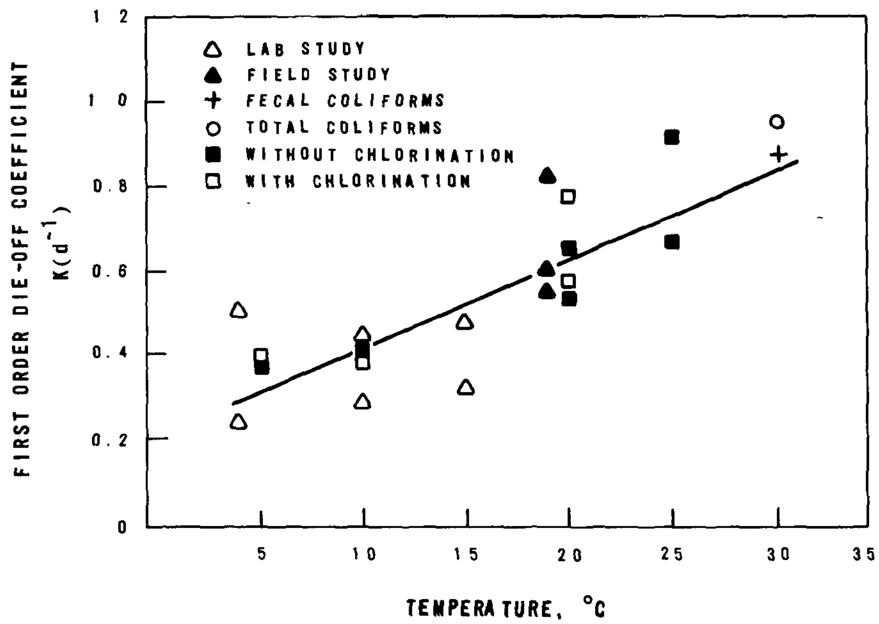

FIGURE 3

FIRST ORDER TOTAL COLIFORM DIE-OFF COEFFICIENT [39]

The die-off under *in situ* subartic river conditions was found to be 0.5 day^{-1} at a temperature of 32°F (0°C) [40]. A reportedly high die-off coefficient of 8.72 day^{-1} was found for *in situ* determinations in Lake Michigan at a water temperature of 63°F (17°C) [41]. It generally appears that *in situ* die-off coefficients are considerably higher than those observed in laboratory experiments. In addition to the survival of the indicator organisms in surface waters, limited information is available for the infectious agents themselves [42] as shown in Table 7.

Table 7. SURVIVAL OF INFECTIOUS AGENTS IN SURFACE WATERS [42]

Infectious agent	Time for 99.9% removal, d	Half-life, h	Removal after 2 d, %
E. coli	5-7	12-17	86-94
S. fecalis	8-18	19-43	54-83
Enterobacter aerogenes	8-18	19-43	54-83
Echo 7	7-16	17-39	59-86
Echo 12	5-12	12-29	68-94
Coxsackie A9	≤8	19	≥83
Polio I	13-20	31-48	50-65

Land Treatment

Land treatment systems substantially reduce the numbers of indicator organisms and infectious agents. The removals can be accomplished by various mechanisms within the treatment sequence. The treatment sequence can include primary treatment (reported previously in Table 5), aerated lagoon secondary treatment, storage, and application to the land. After the wastewater has been applied to the land, removal mechanisms include retention on soil surface, retention within the soil profile, die-off by predation, and dilution in groundwater or surface water. The land treatment processes (slow rate, overland flow, and rapid infiltration) rely on some or all of these mechanisms.

Aerated lagoons have been used more as preapplication treatment methods, because their capital and operating costs are low, and their low maintenance requirements are generally compatible with land treatment systems. Some reported maximum removal capabilities for indicator organisms and infectious agents are presented in Table 8. Adequate system operation and maintenance is required to maintain these removal capabilities.

Table 8. MAXIMUM REMOVAL OF ENTERIC MICROORGANISMS BY LAGOON SYSTEMS[a] [7, 37,43]

Enteric microorganism	Removal, %
Coliforms	60-99.99
Fecal coliforms	99.
Total bacteria	99.
<u>S. typhi</u>	99.5
Virus	99.99[b]
<u>P. aeruginosa</u>	99.69

a. Without disinfection.

b. Laboratory study.

Slow rate systems generally include storage facilities that act as treatment ponds. Predation by bacteria and adverse environmental factors, such as pH changes and ultraviolet radiation, should provide at least 99% removal during storage for most infectious agents.

The capabilities of the soil to remove infectious agents from solution have been investigated under many conditions for bacterial and viral pathogenic agents (Table 9). The removal of fecal coliform indicator organisms was reported to be essentially complete under many conditions.

Table 9. REMOVAL OF ENTERIC MICROORGANISMS BY SOIL SYSTEMS [44, 45]

Enteric microorganisms	Location	Removal, %	Observed concentration No./mL	Observation depth, ft
Fecal coliforms	Hanover, New Hampshire	Essentially complete	<1/100	5
Coliforms	Lodi, California	Essentially complete	1/100	4-7
Coliforms	Whittier Narrows, California	Complete	None	>4
Fecal streptococci	Santee, California	99.5	20/100	--[a]
Fecal streptococci	Santee, California	99.8	6.8/100	--[b]

a. 200 ft of lateral flow.

b. 1,500 ft of lateral flow.

The removal capabilities of full-scale systems were reported at Lodi, California, where coliform counts in effluent applied to a sandy loam soil were reduced to 1/100 mL between a 4 and 7 ft (1.2 to 2.1 m) soil depth [45]. At Whittier Narrows, California, applied coliform concentrations of 110,000/100 mL were reduced to 40,000/100 mL at a 3 ft (0.9 m) depth. None of the coliforms was detected at greater depths. Lateral flow through sand and gravel at Santee, California, removed fecal streptococci applied at a concentration of 4,500/100 mL to 20/100 mL at a 200 ft (61 m) distance, 48/100 mL at a 400 ft (122 m) distance, and 6.8/100 mL at an interceptor ditch.

The rapid infiltration system at Flushing Meadows, Arizona, has been studied to determine removals of bacteria and virus. The removal effectiveness depends on the rate of application. The fecal coliform reduction of applied effluent (10^6/100 mL) was reduced to values from 0 to 100/100 mL at a distance of 30 ft (9.2 m). With 2 to 3 days of continuous inundations, the total coliforms were reported to be 5/100 mL. As the rate of application increased, the inundations increased to 2 to 3 weeks; the reported total coliform concentrations after 30 ft (9.2 m) of travel were 200/100 mL.

After application of seeded virus to rapid infiltration soil columns at hydraulic rates of 22 and 6 in./d (55 and 15 cm/d), the detection of virus in the soil column was limited to the soil depths less than 69 in. (175 cm), as shown in Figure 4.

Virus removal in rapid sand filters for (potable) water treatment was reported to be greater than 99% at application rates of up to 36 in./d (91 cm/d) using a sand media [46]. Lesser application rates can be expected to produce greater removals. A summary of observed travel distance through soil for virus from wastewater effluents ranged from 8 to 46 in. (20 to 117 cm) [46].

Slow sand filters with application rates of 15.7 to 39 ft/d (4.8 to 12 m/d) exhibited virus removal from 98.25 to 99.997% [47]. At a rapid infiltration site at Santee, California, 3.2 gal (12 L) of concentrated polio vaccine virus was applied to sand and gravel. None was detected by the gauze pad technique after travel through 200 ft (61 m) of soil [45]. At Whittier Narrows, California, a massive community inoculation with the Sabine oral vaccine occurred during the rapid infiltration studies. No vaccine viruses were detected in the treated wastewater after passage through a collection system, treatment plant, and travel through 2 ft (0.6 m) of soil, but the detection limit of the method used was estimated to be 5 to 10 PFU/100 mL [45]. In contrast to these results, a virus was isolated in sandy soils (with no silt or clay) using

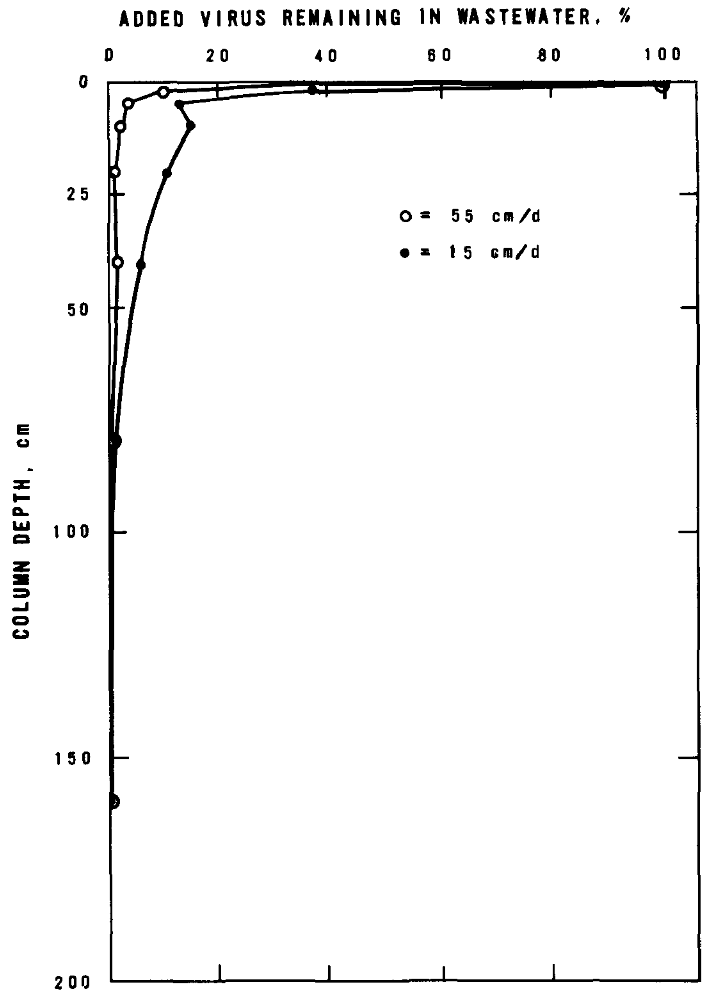

FIGURE 4

REMOVAL OF POLIOVIRUS FROM WASTEWATER BY SOIL COLUMNS WITH DIFFERENT INFILTRATION RATES. ADDED CONCENTRATION OF VIRUS WAS 3 TO 5 x 10^4 PFU/mL [48] improved techniques, and a concentration method for using as much as 150 gal (570 L) of sample (cited in [46]). They surmised that an extremely heavy rainfall caused virus to be released from the soil by elution during these singular events.

The observed survival times of the retained virus in a soil column was reported to be less than 8 days on bare lysimeters and up to 32 days on the soil surface of a sod covered lysimeter, as shown in Figure 5 [4].

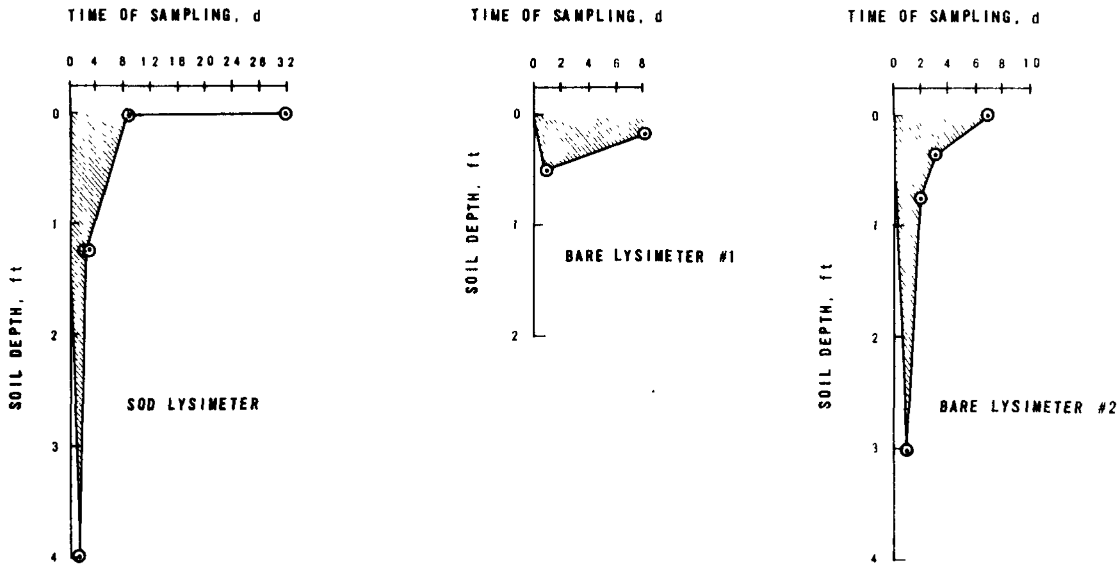

FIGURE 5

SEEDED VIRUS SURVIVAL IN SOIL [4]

The capabilities of overland flow to reduce total and fecal coliforms were reported [6]. The results show (Table 10) that before discharge of the treated runoff water, the effluent may require additional treatment for pathogen removal. Chlorine disinfection should require lesser doses for an overland flow effluent than for a conventional secondary treatment process due to a low total nitrogen (less than 6 mg/L) and low BOD and SS values.

Table 10. REDUCTIONS OF INDICATOR ORGANISMS BY OVERLAND FLOW TREATMENT [6]

Indicator organisms	Raw wastewater applied concentration	Added aluminum sulfate[a] None	14 mg/L	20 mg/L
Total coliforms	7.2×10^6	0.3×10^6	0.2×10^6	0.2×10^6
Fecal coliforms	1.0×10^6	0.09×10^6	0.03×10^6	0.02×10^6

a. Aluminum sulfate added to enhance phosphorus removal.

Although it is expected that very low infectious agent concentrations will pass into groundwater from a well-designed land treatment system, additional reductions do occur in groundwater movement. The survival of infectious agents in well water was reported and the results are presented in Table 11 [49]. Times for 99.9% removal varied from 2 days for S. bovis to 11 days for Sh. flexneri.

Table 11. SURVIVAL TIMES OF ENTERIC MICROORGANISMS IN WELL WATER [49]

Enteric microorganism	Time for 99.9% removal, d	Half-life, h	Removal after 4 d, %
Coliforms	7	17	98.1
Sh. dysenteriae	9	22	95.2
Sh. flexneri	11	27	91.7
Sh. sonnei	10	25	93.7
S. typhi	3	6	99.99
S. equinus	4	10	99.9
S. bovis	2	4	99.9999
Enterococci	9	22	95.2
V. cholera	3	7	99.99

The die-off of wastewater microorganisms when applied to the soil surface or vegetation is of interest due to potential vector transport, site worker contact, or survival on harvested crops used for food. Microorganism die-off occurs due to sunlight effects of desiccation and ultraviolet radiation. Some values reported in the literature are summarized in Table 12.

Table 12. SURVIVAL TIMES OF ENTERIC MICROORGANISMS ON SOILS AND VEGETATION [1, 50]

Enteric microorganisms	Environment	Survival time, d	Estimated die-off after 7 d, %[a]
Coliforms	Fodder	6-34	98
	Vegetables	35	90
	Soil surface	38	88
Shigella sp.	Fodder	<2	Below detection
	Leaf vegetables	2-7	Below detection
	Orchard crops	6	Below detection
Salmonella sp.	Fodder	12-<42	94
	Soil surface	15-46	93
	Leaf vegetables	1-40	98
	Orchard crops	0.75-<2	Below detection
Enterovirus	Leaf vegetables	15-60	89
E. histolytica	Leaf vegetables	2	Below detection

a. Calculated from median survival time.

INORGANIC CONSTITUENTS

Nitrogen

Nitrogen occurs in wastewater at concentrations ranging from 20 to 80 mg/L as total nitrogen. Discharge of treated wastewater to potable water sources from which a concentration greater than 10 mg/L can be withdrawn should be avoided. Control of nitrogen discharge to groundwater from land treatment systems can be accomplished by appropriate design [51].

Nitrogen removal occurs by crop uptake and denitrification in slow rate and overland flow systems and by denitrification in rapid infiltration systems. The final effluent discharge for overland flow systems is generally to surface water bodies. Other systems may discharge to either groundwater or surface water bodies.

Conventional activated sludge treatment does not remove nitrogen, but modifications of the process can result in nitrification. Nitrate concentrations meeting drinking water standards are usually achieved by dilution in the receiving surface water.

Trace Metals

The concentrations of trace metals in municipal wastewater only are usually low, because industrial inputs are generally the major source of trace metals. As shown in Table 13, the concentrations in untreated municipal wastewater are, at times, less than the EPA drinking water standard. The removals from solution by primary and secondary conventional treatment, as well as the removals by the three land treatment types, are also presented in Table 13. Land treatment reduces concentrations to low values, and these values are usually less than drinking water standards [51].

Table 13. SUMMARY OF TRACE METAL INFORMATION, CONCENTRATIONS, AND REMOVALS [44, 51-53]

Component	EPA drinking water standard, mg/L	Raw municipal wastewater concentration, mg/L	Primary treatment removal, %	Secondary treatment removal, %	Mass removal by land treatment, %[a]	
					Slow rate	Rapid infiltration
Arsenic	0.05	0.003	--	--	<drinking water standards	--
Cadmium	0.01	0.004-0.14	30	60	≤drinking water standards	<10
Chromium	0.05	0.02-0.7	40	40-80	<drinking water standards	--
Copper	1.0	0.02-3.4	40	60-70	<drinking water standards	90
Fluoride	1.4-2.4[b]	--	--	--	--	--
Iron	0.3	0.9-3.5	60	50	--	--
Lead	0.05	0.05-1.3	50	50-60	≤drinking water standards	20
Manganese	0.05	0.11-0.14	30	20	--	--
Mercury	0.002	0.002-0.05	--	70-80	<drinking water standards	30-40
Selenium	0.01	--	--	--	--	--
Silver	0.05	0.05-0.60	50	70	<drinking water standards	--
Zinc	5.0	0.03-8.3	50	60	<drinking water standards	40-80

a. Insufficient data available on overland flow.

b. Dependent on temperature; higher limits for lower temperature.

Chapter 6

RISK ASSESSMENT

The task of assessing health risks involves many factors of which the existing body of scientific knowledge varies from essentially zero (speculative) to well-established facts. Municipal wastewater contains constituents for which current knowledge spans this entire range. For example, known relationships exist for challenge (direct) doses of Salmonella sp., although the dose reponse of virus is not defined, and the health effects of trace organics are speculative at this point.

In 1973, Benarde reviewed the health effects literature on land treatment [54]. He concluded that "from a communicable disease viewpoint, land disposal is far less hazardous than disposal into rivers and streams" [54].

More recently risk assessment was the subject of a conference and Barth presented current EPA research on the subject [55]. Llewellyn concluded that from an epidemiologist's point of view "the best that science and public health practice and engineering techniques presently have to offer cannot provide the policy maker with the data for a clear decision regarding risks of wastewater application or of standards for this application" [56]. Dorcey, on the other hand, found that it is "reasonable to expect that the increased consideration being given by municipalities to options for application of municipal wastewaters and sludges to the land will lead to improvements in the analysis of alternatives and their consequences." He also indicated that the "decision maker's ideal would be to have quantitative information on the cost of reducing risk and uncertainty as part of a systematic analysis of the costs and benefits of alternative plans..." [57].

The risk assessment approach presented in this report is semi-quantitative. It relies on known public health, sanitary engineering, and scientific information that describes health-related problems. The public health information generally describes the health-related constituents, the available information on minimum infective dose, requirements for asymptomatic infection, and symptoms from clinical infection. In addition, the available morbidity (illness) data provide information on the waterborne occurrences of the disease in relation to total public incidents.

The sanitary engineering information describes the controls exercised by wastewater treatment systems and planned environmental discharges to maintain and upgrade public health objectives. Scientific principles provide assessment methodology and information on physical behavior in cases where general behavior is known, but specific case study information is lacking.

A second level of refinement would include weighting of the relative health effects. For example, a greater loss value would be assigned for a disease such as hepatitis than for salmonellosis. Such an assessment would include a comparison of the severity of potential diseases and of the number of cases of a single disease. Weighting factors needed for this level of assessment should be based on arbitrary or combined expert evaluation.

A relative health risk assessment is based on an evaluation of the known principles and tabulations of known data. The proposed steps for making the relative assessment of health risks are as follows:

1. List wastewater constituents of concern from known information about nationwide occurrences of disease, or from local information obtained from a public health official.

2. List alternative treatment sequences. Identify points of contact and assign contact intensity factors. Estimate contact duration factors based on staffing requirements or potential public contact.

3. Describe the reduction of health affecting constituents in the wastewater treatment sequence. Assign initial concentrations in wastewater and compute concentrations after each subsequent step.

4. Prepare a summary tabulation of the three factors at agent-host contact points:

    a. Expected concentration of each constituent

    b. Contact duration factor

    c. Contact intensity factor

5. Compare expected concentrations, contact duration, and contact intensity of each individual constituent within the alternative treatment sequences. From these comparisons, draw conclusions on the major differences and prepare a statement as to relative risks.

Chapter 7

EXAMPLE ASSESSMENT

The purpose of the example assessment is to illustrate the procedure set forth in Chapter 6 by comparing the relative health impacts of land treatment and activated sludge treatment systems. This same procedure can be followed to make other comparisons. Since a large number of variations in treatment processes exist, the most commonly used treatment sequence was used to provide the reference and basis for comparison.

Although activated sludge and slow rate were considered equivalent treatment systems in the example assessment, a slow rate system will produce a higher quality effluent with lower BOD values and an increased removal of nitrogen and phosphorus.

In the following paragraphs, assumed characteristics of each treatment system will be presented followed by a stepwise description of the assessment process.

LAND TREATMENT SYSTEM

The land treatment system objectives vary considerably depending on local conditions. The typical systems assumed for this report were based on a recent study of wastewater reclamation facilities in California that listed reuse objectives and the number of systems employing them (Table 14) [58].

Table 14. TYPES OF REUSE OBJECTIVES IN CALIFORNIA SYSTEMS USING LAND TREATMENT [58]

Reuse objectives	No. of systems
Fodder, fiber, seed crop irrigation	139
Landscape irrigation	44
Orchard and vineyard irrigation	16
Processed food crop irrigation	14
Groundwater recharge	8
Industrial uses	8
Food crop irrigation (not processed)	6
Others, including nonrestricted and restricted recreational impoundments, landscape impoundments, and pasture for milking animals	12

Additional information on a typical land treatment system was compiled in a nationwide survey [59]. This information is summarized below:

1. Secondary preapplication treatment, usually including lagoons
2. Operation - 7 d/wk
3. Application to sand, loam, or silt
4. Sprinkler application (humid areas)
5. Surface application (arid areas)
6. Farming zone locations
7. 73% of flows less than 5 Mgal/d
8. No collection of treated water
9. 76% of systems do not have disinfection before application
10. Application less than 2 in./wk (5 cm/wk)

BASIS OF COMPARISON

A schematic flow diagram for the activated sludge and the land treatment system used is presented in Figure 6. A population of 30,000 and a wastewater flow of 3 Mgal/d (0.13 m^3/s) is assumed. Industrial toxicants are assumed to be largely removed by pretreatment.

Land treatment is preceded by aerated lagoon treatment with winter storage. The activated sludge treatment sequence consists of grit removal, primary sedimentation, aeration, secondary sedimentation, chlorination, and surface water discharge (Figure 6).

Staffing requirements were estimated for the alternative systems to determine degree of worker exposure to health affecting components. According to the methods published by the EPA [60] and an assumed flow of 3 Mgal/d, both systems (slow rate and activated sludge) would require staffing of about 6 men per year (approximately 9,000 man-hours). Sludge handling and disposal was not included in the activated sludge alternative, nor was vegetation planting and harvest included with the land treatment options.

Planting, harvest, and vegetation management would apply to the slow rate and overland flow systems. A rapid infiltration system would require the least staffing with an estimated 3 men (approximately 4,500 man-hours). Overland flow would require an estimated staff of 6 men (approximately 9,000 man-hours).

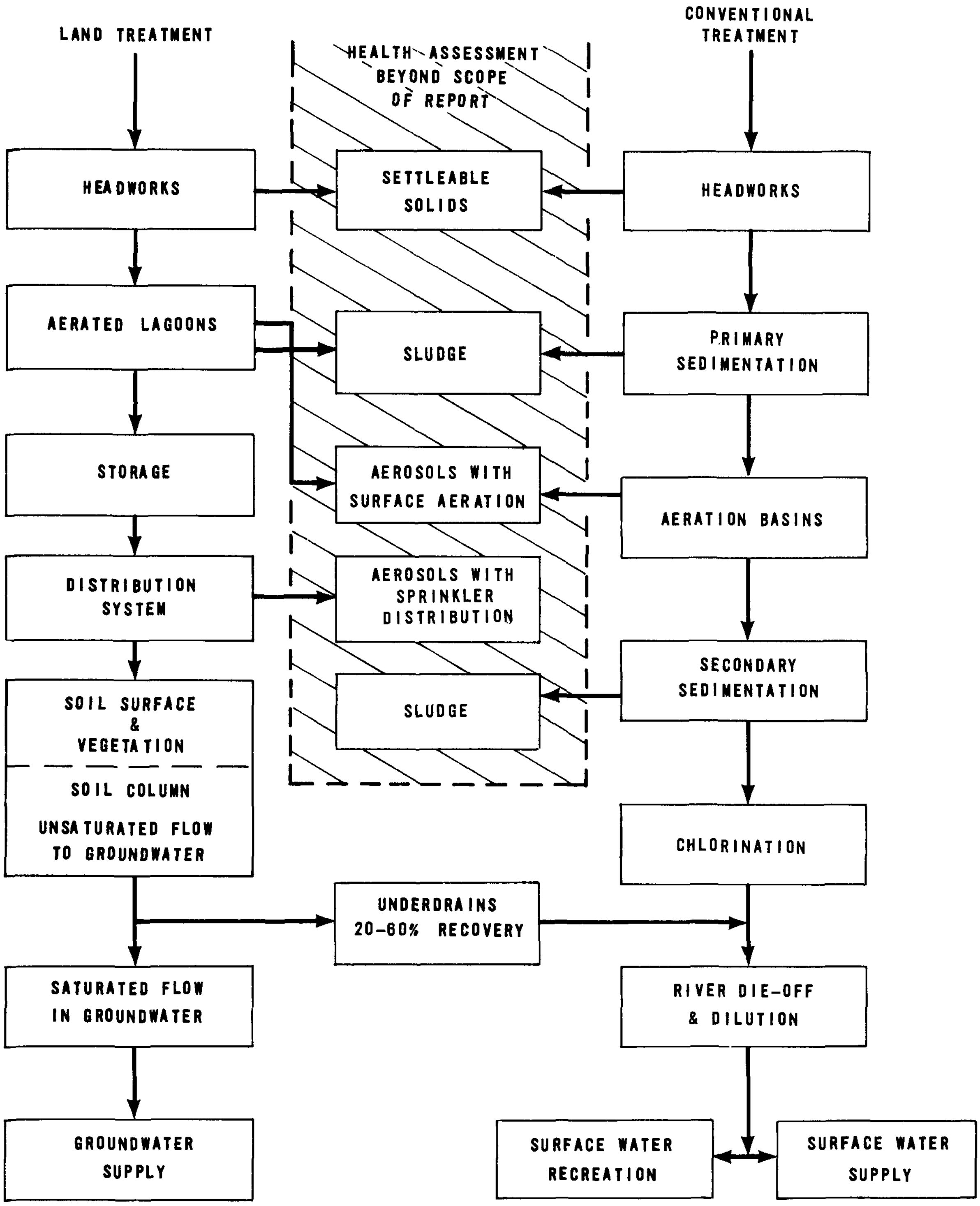

FIGURE 6

TREATMENT FLOW SEQUENCES USED IN EXAMPLE COMPARISON

ASSESSMENT

Identify Wastewater Constituents

The initial step is to identify the significant wastewater constituents affecting health. General information for the United States (Chapter 3) shows that the infectious agents of concern are *Salmonella* sp., *Shigella* sp., parasites, *Escherichia coli*, and viruses. Fecal and total coliforms are included since they are generally accepted for use as indicator organisms. Principal inorganic chemicals of concern are nitrates and trace metals. The list of trace organic chemicals known or suspected to cause adverse health effects includes hundreds of compounds. Some were listed in Table 3.

Overall, these components comprise the major health risk in most areas. However, in cases where additional infectious agents are endemic, or as additional or higher concentrations of chemicals occur, the health risk assessment should be expanded to comply with local conditions.

Concentrations of Wastewater Constituents

The process steps for each treatment sequence should be identified as to their potential to remove a wastewater constituent from solution, concentrate a wastewater constituent, or provide an opportunity for contact in the agent-host transmission cycle. Discussions of each of these process steps are given for removal, concentration, or host contact.

No removals of health-related constituents are assumed during wastewater collection. The headworks in both treatment systems provide removal of large solids and opportunities for wastewater contact by site workers, although reduction of wastewater constituents is negligible. Various removal capabilities occur in aerated lagoons, storage lagoons, primary and secondary sedimentation, and aeration basins.

Disinfection can provide high removals of infectious agents. In addition, discharge of effluents to surface waters provides reductions by dilution and die-off. Retention on the soil surface allows infectious agent die-off by environmental exposure, while travel through the soil column provides excellent removals of many constituents. Transport with groundwater also provides dilution and die-off.

An estimate was made for the percent removal during each treatment sequence based on available data, which were summarized in Chapter 5. Data are not always available, so extrapolation between similar organisms such as Salmonella sp. and Shigella sp. was used when necessary. Some treatment systems report a single removal, so this was used without change. When a range of values were reported, both were used, with the high removals used consistently to give one end of expected range and the low removals used to estimate the other end.

Agent-Host Transmission Cycle

Opportunities for contact with a host exist at many points within a treatment sequence. The initial wastewater collection provides the greatest risk of exposure; however, in this example, the contact is assumed equal for both treatment systems and is not discussed. Site operation and maintenance provides worker exposure at levels that can be estimated based on staffing requirements. The use of surface aeration in lagoons and aeration basins provides opportunities for contact with aerosol droplets. The disinfection process provides little opportunity for contact, although discharge to surface waters provides contact from incidental events, recreational use, and, at times, potable water supply.

Wastewater application to the land provides opportunities for incidental contact on the soil surface, and, if sprinkler applied, aerosol contact. Retention of wastewater constituents provides contact opportunities on vegetation, but contact is nil for retention within the soil profile. Passage to groundwater provides an opportunity for contact through withdrawal from wells and seeps.

The assessment of health risks requires quantification of the wastewater constituents and the transmission cycle to a susceptible host. The wastewater constituents were described previously, and the relative numbers were presented. The transmission cycle is not easily quantified, so the following method is presented based on contact intensity factors and contact duration factors. Contact intensity describes the relative potential of a contact producing illness. Contact duration estimates the frequency of these contacts based on annual exposure. The two factors are chosen to illustrate the difference between low and high intensity of contact and long and short durations of contact. At present, no method exists that allows comparison between a long duration, low-intensity contact and a short duration, high-intensity contact.

Contact Intensity

Contact intensity factors are defined in four categories to describe the point of transmission between an infectious agent and a susceptible host.

Incidental physical contact is the potential physical contact between a host body and an object that has been contacted by wastewater or the wastewater itself. This does not assume direct intake into the body, but rather makes the assumption that it can occur. This contact is the least likely to cause infection or illness.

Accidental ingestion is the small volume potential ingestion from being in the water, as typified by recreational activities, such as swimming, boating, and water skiing. This category would also include the incidental occurrence of using surface water for potable purposes, such as one-time consumption of waters.

Potable ingestion is the ingestion of domestic water, which includes the daily ingestion for drinking, as well as food preparation, bathing, and other uses. Although not specifically addressed in this report, the water ingested for potable purposes would undergo additional treatment by at least chlorine disinfection in essentially all municipal and many private water supply systems drawing from surface water or groundwater sources. This contact has the greatest potential to produce infection or illness based on contact factors alone.

Contact Duration

Contact duration factors are used to assess the exposure of the total population to various contact opportunities with the health affecting constituents of wastewater. This method is a compromise between estimating ingested volume of treated or untreated water, and incidental contact. For this report, the contact duration is considered to be the total annual man-hours of exposure. During the treatment sequence, the man-hours of contact are estimated from staffing requirements for operation and maintenance (Table 15). For general public contact through recreation, municipal surface and subsurface water supply, and private subsurface water supply, the following annual estimates were made.

Municipal water supply:

$$\frac{1\ h}{d} \times \frac{365\ d}{yr} \times 30{,}000 \text{ persons} = 1.1 \times 10^7, \text{ say } 10^7 \text{ h/yr.}$$

This example assumes that the entire community (30,000 persons) has contact through the municipal supply.

Private water supply (adjacent owners to land treatment):

$\frac{1\ h}{d} \times \frac{365\ d}{yr} \times 20$ persons $= 7.3 \times 10^3$, say 10^4 h/yr.

This example assumes that 5 families (4 persons each) have contact from private wells.

Table 15. ESTIMATED CONTACT DURATION FACTORS
Annual Man-Hours [60]

	Activated sludge		Land treatment	
Process step	Process	Contact duration	Process	Contact duration
0	Collection	Negligible	Collection	Negligible
1	Headworks	2×10^2	Headworks	2×10^2
2	Primary sedimentation	6×10^2	Aerated lagoon	2×10^3
3	Aeration and sedimentation	3×10^3	Storage lagoon	6×10^2
4	Disinfection	2×10^2	Field distribution	2×10^3
5	River die-off	Negligible[a]	Soil surface	5×10^2
6	River dilution	Negligible[a]	Soil column	Negligible
7	Recreation	10^5	Groundwater flow	Negligible
8	Municipal water supply	10^7	Private water supply	10^4
			Municipal water supply	10^7

a. All river contact assumed to occur during recreation.

The activated sludge treatment generally uses chlorine disinfection to reduce the number of infectious agents. Since the susceptibility of various microorganisms varies according to the relationship given in Table 6, the percent die-off will vary for a given chlorine dose and contact time. For the purposes of the example assessment, the estimated removals of other wastewater microorganisms based on a 99.99% die-off for E. coli and K values (Table 6) are given below:

Agent	Percent die-off at fixed contact time and dose
E. coli	99.99 (assumed by design)
Salmonella sp.	99.99
Poliovirus	99
Coxsackie virus	99
Hepatitis virus	94
E. histolytica	20-45

RESULTS OF EXAMPLE ASSESSMENT

Infectious Agents

The results of the example assessment for land treatment and activated sludge and river discharge are presented for infectious agents in tabular form in Tables 16 and 17. As shown in these tables, there is a dramatic decrease in the number of water borne infectious agents. Thus, the incidence of disease because of waterborne infectious agents is almost nonexistent.

Nitrate Nitrogen

For activated sludge and discharge, nitrate reduction will occur as a result of dilution. For slow rate, removal of nitrate can be adequately controlled during system design.

Trace Metals

Trace metals should pose no health concerns in the effluent portions of the wastewater under the assumed conditions. Since typical values in untreated wastewater are low, the removals by either treatment method should produce concentrations less than drinking water standards. The retention of metals within the soil profile requires assessment to ensure that the mass accumulation remains below recommended limits to prevent plant inhibitory effects.

Trace Organics

Trace organics can only be described in general terms since quantitative data are mostly absent. The removal of trace organics in activated sludge treatment is slight. The major reduction would be due to dilution with the river water (assumed 20:1 for this example) and adsorption on settleable particles. Land treatment provides considerable contact with soil particles and opportunities for adsorption. The soil microorganisms provide further opportunities for microbial breakdown.

The use of chlorine disinfection can form halogenated organic compounds, some of which are thought to be carcinogenic. The capabilities of land treatment to provide high levels of removal without a (chlorine) disinfection step are noteworthy. The elimination of a chlorine disinfection step with conventional treatment and discharge would generally not be accomplished without an increase in health risks.

Table 16. LAND TREATMENT - ESTIMATES OF INFECTIOUS AGENT DOSE

Process step	Fecal and total coliforms Reduction[a]	Fecal and total coliforms Dose[b]	*Salmonella* sp. Reduction[a]	*Salmonella* sp. Dose[b]	*Shigella* sp. Reduction[a]	*Shigella* sp. Dose[b]	Virus Reduction[a]	Virus Dose[b]	Parasites Reduction[a]	Parasites Dose[b]
Wastewater collection	Initial conc.	$3x10^7$	Initial conc.	$4x10^3$	Initial conc.	$4x10^3$	Initial conc.	$1.9x10^3$	Initial conc.	$1x10^3$ [c]
Headworks	None	$3x10^7$	None	$4x10^3$	None	$4x10^3$	None	$1.9x10^3$	None	$1x10^3$
Aerated lagoon	99	$3x10^5$	99.5	20	99.5	20	99.9	1.9	99.7	3
Storage lagoon	99	$3x10^3$	99	0.2	99	0.2	99	$1.9x10^{-2}$	99	$3x10^{-2}$
Field distribution	None	$3x10^3$	None	0.2	None	0.2	None	$1.9x10^{-2}$	None	$3x10^{-2}$
Soil surface [d]	88-98	60-360	93-94	$(1.2-1.4)x10^{-2}$	Essentially complete on fodder	Below detection	89 on leaf vegetables	$2.1x10^{-3}$	Essentially complete (*E. histolytica*)	Below detection
Soil column	99.9999	$3.0x10^{-2}$	99.99	$2.0x10^{-5}$	99.99	$2x10^{-5}$	99.99	$1.9x10^{-6}$	99.9999	$3x10^{-7}$
Groundwater option										
Groundwater[e]	98	$6x10^{-4}$	99	$2.0x10^{-7}$	92-95	$(1.0-1.6)x10^{-6}$	99[f]	$1.9x10^{-8}$	99[f]	$3x10^{-9}$
Groundwater supply	None[g]	$6x10^{-4}$	None[g]	$2.0x10^{-7}$	None[g]	$(1.0-1.6)x10^{-6}$	None	$1.9x10^{-8}$	None	$3x10^{-9}$
Surface water option										
Underdrain recovery (50% recovery)[h]	50	$1.5x10^{-3}$	50	$1.0x10^{-5}$	50	$1.0x10^{-5}$	50	$1.0x10^{-6}$	50	$1.5x10^{-7}$
River dilution	95	$7.5x10^{-5}$	95	$5x10^{-7}$	95	$5x10^{-7}$	95	$5x10^{-8}$	95	$7.5x10^{-9}$
River die-off	90	$7.5x10^{-6}$	70	$1.5x10^{-7}$	70	$1.5x10^{-7}$	70	$1.5x10^{-8}$	70	$2x10^{-9}$
Surface water supply or recreation	--	$7.5x10^{-6}$	--	$1.5x10^{-7}$	--	$1.5x10^{-7}$	--	$1.5x10^{-8}$	--	$2x10^{-9}$

a. .Expressed as % removal for each process step.

b. Expressed as No./100 mL.

c. Uses a high literature value; most report less than 50 organisms/100 mL.

d. Estimated after 7 days exposure on soil surface or fodder crop, respectively.

e. Assumes 4 days travel before removal in wells.

f. Assumed value based on estimated behavior, not correlated to actual field measurements.

g. A municipal water supply would normally employ chlorination prior to distribution, although it is not shown here.

h. Recovery assumes 50% by mass basis, but considered as concentration. A river dilution would produce equal concentrations for 50% reduction by mass or concentration.

Table 17. ACTIVATED SLUDGE AND RIVER DISCHARGE ESTIMATES OF INFECTIOUS AGENT DOSE

	Fecal and total coliforms		*Salmonella* sp.		*Shigella* sp.		Virus		Parasites	
Process step	Reduction[a]	Dose[b]	Reduction[a]	Dose[b]	Reduction[a]	Dose[b]	Reduction[a]	Dose[b]	Reduction[a]	Dose[b]
Sewage collection	Initial conc.	$3x10^7$	Initial conc.	$4x10^3$	Initial conc.	$4x10^3$	Initial conc.	$1.9x10^3$	Initial conc.	$1x10^3$[c]
Headworks	None	$3x10^7$	None	$4x10^3$	None	$4x10^3$	None	$1.9x10^3$	None	$1x10^3$
Primary treatment	10-35	$(2.0-2.7)x10^7$	15	$3.4x10^3$	15	$3.4x10^3$	10-15	$(9.5-17)x10^2$	10-50	500-900
Secondary treatment	90-99	$(2.0-27)x10^5$	96-99	34-140	91-99	34-310	76-99	9.5-410	10	450-810
Disinfection (chlorine)	99.99	20-270	99.99	$(3.4-14)x10^{-3}$	99.99	$(3.4-31)x10^{-3}$	94-99	0.09-25	20-45	250-650
Dilution in recieving water	95	1-13.5	95	$(1.7-7)x10^{-4}$	95	$(1.7-15)x10^{-4}$	95	$(4.5-1250)x10^{-3}$	95	12.5-32.5
Die-off in receiving water	90	0.1-1.4	70	$(0.5-2)x10^{-4}$	70	$(0.5-4.5)x10^{-4}$	70	$(1-400)x10^{-3}$	70	4-10
Surface water supply or recreation	None[d]	0.1-1.4	None[d]	$(0.5-2)x10^{-4}$	None[d]	$(0.5-4.5)x10^{-4}$	None[d]	$(1-400)x10^{-3}$	None[d]	4-10

a. Expressed as % removal for each process.

b. Expressed as No. organisms/100 mL.

c. Uses a high literature value; most report less than 50 organisms/100 mL.

d. A municipal water supply would normally employ chlorination prior to distribution, although it is not shown here.

RISK EVALUATION

Site Workers

The health risk to site workers from either a slow rate land treatment system or an activated sludge system depends on three factors: (1) the type of contact (contact intensity); (2) the length of contact (contact duration); and (3) the concentration of wastewater constituents at the time of contact. There is no method at present that relates these factors, so only a qualitative assessment is presented.

The annual man-hours of worker contact are estimated to be greater for a slow rate system than an activated sludge system (Table 15). It cannot be said that this is a direct indication of increased risk, because wastewater concentrations vary throughout the process steps. In addition, although both contact intensities are limited to incidental and aerosol contacts only, the onsite conditions change within each type, so comparisons are difficult to make. In general, the health risks are considered to be equal, with neither producing a notable health risk. This is substantiated by a lack of any reports indicating increased health risk from occupational exposure by a wastewater treatment plant worker within the United States.

General Public

The relative health risk to the general public after the treated wastewater effluent is discharged to surface water or groundwater is shown in Table 18. The basis for comparison is the estimated concentrations for an activated sludge discharge (with chlorination) to surface water, and land treatment discharge to groundwater or withdrawal and discharge to surface water. Based on the estimated concentrations of infectious agents, the land treatment system decreased the relative health risk potential by providing greater removals.

A summary comparison of the removal mechanisms for slow rate and activated sludge systems is provided in Table 19. The decreased risk with slow rate land treatment from infectious agents was shown in comparing estimated concentrations as discussed previously. The slow rate land treatment removal mechanisms provide removals of nitrates, trace elements, and possibly trace organics. An overall decreased relative health risk occurs under these conditions.

Table 18. SUMMARY COMPARISON OF HEALTH RISK POTENTIALS
No. Organisms/100 mL

	Relative concentration at contact points			
	Surface water supply[a]		Groundwater supply	
Wastewater agent	Land treatment	Activated sludge	Land treatment	Activated sludge[b]
Coliforms	$7.5x10^{-6}$	0.1-1.4	$6x10^{-4}$	--
Salmonella sp.	$1.5x10^{-7}$	$0.5-2x10^{-4}$	$2x10^{-7}$	--
Shigella sp.	$1.5x10^{-7}$	$0.5-4.5x10^{-4}$	$(1.0-1.6)x10^{-6}$	--
Virus	$1.5x10^{-8}$	$1-400x10^{-3}$	$1.9x10^{-8}$	--
Parasites	$2x10^{-9}$	4-10	$3x10^{-9}$	--

a. Provides water for municipal supply as well as recreation. Health risk potentials are different due to different contact intensity and contact duration.

b. An activated sludge system discharging to surface water would impact groundwater only if streambed outflow were significantly large.

Table 19. SUMMARY COMPARISON OF REMOVAL MECHANISMS

Wastewater constituent	Slow rate land treatment	Activated sludge treatment
Bacteria		
Salmonella sp.	+	+
Shigella sp	+	+
E. coli	+	+
Virus, in general	+	-
Parasites		
E. histolytica	+	-
G. lamblia	+	-
Nitrate	+	-
Trace elements	+	+
Trace organics	0 to +	0

Note: Comparisons based on the following notations:

+ Positive removals with little remaining.
- Minor removals.
0 Behavior unknown, but partial removals have occurred.

Chapter 8

DISCUSSION OF THE EXAMPLE

The example assessment was developed to illustrate the suggested approach to qualitative assessment of public health factors for activated sludge and land treatment systems. The example, as would any approach to this type of assessment, includes assumptions to simplify the approach. In the assessment, some factors were assumed to be constant although they change and can influence the assessment; these factors include:

1. Fail-safe aspects
2. Food crops
3. Perspective with non-United States conditions
4. Alternative systems: rapid infiltration and overland flow
5. Site management and design changes

A discussion of these factors is presented to show the differences that can occur for the various land treatment options. The assessment method is presented for the slow rate example and can be used to assess other land treatment options.

FAIL-SAFE ASPECTS

The example assessment showed that well-maintained and operated treatment systems greatly decrease health risks. The concentration of infectious agents may be reduced as much as 12 orders of magnitude between collection at a plant and potable reuse. Inclusion of dilution during collection brings the total reductions to as high as 17 orders of magnitude. These reductions are optimistic at times, but the reduction of health risk is presently occurring under much less favorable conditions.

When consideration is given to existing primary, secondary, and miscellaneous discharge of erratically operated (at times) treatment systems without the demonstration of adverse health aspects, implicitly it must be agreed that some truth lies within the example. This does not, however, mean that standards should change radically or different treatment policies advocated. As populations and water use increase, the cycle between wastewater treatment and discharge, and potable reuse, becomes shorter. The maintenance of public health requires consideration of this shorter cycle.

The reliability of the unit processes in conventional treatment gives an indication of the fail-safe aspects. Mechanical equipment, such as pumps, feeders, and mixers, provide continuous and adequate performance only if maintained and operated properly. Smaller systems generally do not provide continuous staffing. System upsets are more apt to occur. The resulting inefficiency depends on engineering design, but may result in minor or major contamination of receiving water. Disinfection processes are equally subject to upset, with results ranging from over-chlorination with potential halogenated organic and chlorine toxicity, to under chlorination with insufficient pathogen die-off.

Land treatment systems are also subject to short circuiting in the preapplication treatment such as in the aerated or storage lagoons. However, the overall treatment process, including passage through the soil column, is relatively unaffected by applied wastewater concentrations. In addition, a slow rate system is fail-safe (i.e., if too much water is applied, the soil will not take the water).

The water must also pass through the soil to reach to groundwater or the underdrains (assuming no fractured rock for direct transmission). A properly designed land treatment system should provide reliable treatment greater than that provided by a well-designed activated sludge plant. Many additional factors should be considered in overall assessment. Although not included in the discussion, consideration should be given to:

1. Storm flow bypasses in conventional treatment
2. Rainfall runoff on land treatment sites
3. Daily and weekly flow variations in conventional treatment
4. Extreme climatic considerations in land treatment

Both land treatment and conventional treatment exhibit a range of values for process performance under good operating conditions. Although little data are available, the variations in performance would be valuable in assessing overall reliability.

FOOD CROPS

Although the production of food crops for human consumption without processing is rare for wastewater irrigation, its consideration raises much concern. Historically, disease outbreaks have been attributed to the use of "night soil" on vegetables that were consumed raw. A comparison shows that the concentration of infectious agents that came into contact with the food was probably 10^3 to 10^5 greater than present in untreated (collected) wastewater now. For example, California regulations require that only oxidized, coagulated, filtered, and disinfected wastewater be allowed for sprinkler irrigation of human food crops to be eaten raw. The further reduction in concentration probably varies by a factor of 10^5 to 10^8. As such, the combined difference in infectious agent concentration between the past reported disease outbreaks and present practices amounts to a factor as much as 10^8 to 10^{13}. Although adverse health effects could occur (as with any wastewater use), the risk is minimal and is probably similar to the risk of everyday activities.

COMPARISON TO NON-UNITED STATES CONDITIONS

The health risks from wastewater treatment and discharge vary considerably according to local conditions. In the United States, the reported morbidity levels are low and concentrations of infectious agents are also low. The artificial and natural mitigation mechanisms provide considerable removals. The agent-host transmission cycle is quite large, so the combined factors make the documentation of a wastewater treatment and discharge related disease incident a rare event.

Conditions outside of the United States are generally worse, especially in less developed and highly populated countries. There have been few reports of infectious disease associated with irrigation systems using wastewater. Recently Katzenelson, et al. [61] reported the differences in disease rates between kibbutzim in Israel in which one group (a total of 77) used wastewater irrigation and the other (130) did not. The wastewater used was partially treated, nondisinfected oxidation pond effluent of poor quality. The incidence of shigellosis, salmonellosis, typhoid fever, and infectious hepatitis was 2 to 4 times higher in the kibbutzim using wastewater. The incidence of influenza-like disease was also twice as high in the groups using wastewater irrigation. The latter may have been due to enteric viruses such as Echo and Coxsackie [61].

Several important changes exist in the agent-host transmission cycle that are typically uncommon in the United States. The quality of applied wastewater was poor. Although some treatment was given, the concentrations of constituents in the wastewater applied to the land were greater than those of raw wastewater in the United States. The typical United States removals by aerated and storage lagoons did not occur so wastewater concentrations during application (sprinkling and flooding) and on soil and vegetation surfaces should have been greater by a factor of 10^3 to 10^4.

The higher concentrations provided an increased risk from incidental and aerosol contact. The contact duration is much greater in the kibbutzim than in United States systems. The Israeli kibbutzim rely to a greater degree on field workers rather than equipment for field management. Although an estimate was made for staffing requirements for United States on site management, a similar estimate would be difficult without guidance by the kibbutzim.

Onsite observers have stated that onsite hygiene is poor by United States standards and that mid-day meals are eaten in communal dining areas by field workers and other kibbutzim members. The agent-host transmission cycle between wastewater applied to fields, site workers, and communal dining areas is very short. The increased incidence of disease in wastewater irrigation kibbutzim comes as no surprise because of the much greater number of risk opportunities. The relevance to United States conditions is closer to "night soil" irrigation at the turn of the century, than to present United States land treatment practices.

ALTERNATIVE LAND TREATMENT SYSTEMS AND MANAGEMENT

In the example assessment the slow rate process of wastewater treatment was used. Rapid infiltration and overland flow are additional alternatives that require evaluation. Briefly described, rapid infiltration treats wastewater by percolation through more permeable soil horizons. Vegetation is not usually present and the distribution occurs principally by flooding. Overland flow treats wastewater during surface flow over graded terraces. Water-tolerant vegetation, microbial activity, and physical processes on the soil surface are the principal treatment mechanisms before collection and discharge of the treated wastewater.

Rapid Infiltration

Rapid infiltration systems show significant differences from slow rate systems. Application rates are considerably greater, so total land requirement is diminished. Daily operations apply treated wastewater by flooding to diked basins, so aerosol contact is minimal and surface runoff from basins is nonexistent. Site maintenance is limited to annual maintenance of basin surfaces and flow diversions to maintain applications cycles, so overall contact by site workers is lessened.

The removals of infectious agents, and inorganic and organic chemicals are slightly less than for a slow rate system, with the greatest differences occuring during infiltration through coarse sands and gravels. Nitrate removals have been demonstrated to be a function of application cycle and infiltration rates, so operation becomes more important for consistent removal [52]. Percolation of treated wastewater to a nonpotable aquifer would remove concern over potable consumption in water supplies, so the overall system would offer a lesser risk because of (1) limited worker contact, (2) negligible aerosol contact, and (3) decreased land area for incidental contact. Percolation to a potable aquifer would be a greater risk to health. Site specific conditions would be required to compare the risks of a rapid infiltration system with a slow rate system.

Overland Flow

Overland flow systems use the soil surface to treat wastewater; however, the slightly permeable or impermeable soils needed to prevent percolation require that the collected effluent be discharged to surface water or by other methods that do not rely on soil percolation [51]. Overland flow system is evaluated as a land treatment system from the site contact considerations, but as a treatment and discharge system for considerations of health risks from the water supply.

A comparison of the land application portion with slow rate systems shows that greater and lesser risks occur. Worker contact duration is increased because applications occur in each terrace 5 to 7 d/wk. The smoothly graded, 2 to 8% slopes require additional maintenance time to prevent erosion and short circuiting. Aerosol transport would be minimal with bubbling orifice distribution, although sprinkler distribution is also employed. Human food crops would not be a concern since the continuously wetted surface conditions require water tolerant grasses.

The overland flow discharge to surface waters should be compared with activated sludge treatment. The removal of chemical constituents, especially nitrogen, is considerably higher for overland flow than for activated sludge treatment. The removal of infectious agents for overland flow is comparable to activated sludge systems. The chlorine dose to achieve adequate disinfection can be substantially less following overland flow due to nitrogen removal, so disinfection can be improved and the potential formation of halogenated organic compounds is lessened.

Site Management and Design Changes

The design of land treatment systems offers options that may change the overall public health risks. In many instances, the changes are minor and may not constitute a major impact on overall health risk. In high population density areas, public health concerns may be a major consideration, so design considerations may be worthy of inclusion.

Site Location. Site location is a major option in planning and design considerations. Within reasonable distances, higher and lower population densities are usually available. Site choice can reflect predominate wind direction or groundwater flow, so potential for adjacent residential contact can be lessened.

Distribution System. Distribution systems offer some flexibility within the range of local topography [51]. Surface distribution systems are favored in many cases because aerosol contact becomes negligible. When sprinkler systems are used, options such as downward sprays and low pressure systems may limit aerosol formation.

Application Rates and Schedules. Application rates and schedules are design options based on pumping equipment capacity and staff requirements. Less applications per week favor less site worker contact, and allow a greater infectious agent die-off between application cycles.

Chapter 9

GLOSSARY

Case--A reported incident of disease involving a single person.

Clinical--Type of symptoms of disease that can be diagnosed by apparent effects, such as fever, or other physical effects.

Communicable disease--An illness due to a specific infectious agent or its toxic products which arises through transmission of that agent or its products from a reservoir to a susceptible host, either directly, as from an infected person or animal, or indirectly, through an intermediate plant or animal host, vector, or the inanimate environment.

Contact--A person or animal that has been in such association with an infected person or animal or a contaminated environment as to have had opportunity to acquire the infection.

Contamination--The presence of an infectious agent on a body surface; also on or in clothes, bedding, toys, surgical instruments or dressings, or other inanimate articles or substances including water, milk and food. Pollution is distinct from contamination and implies the presence of offensive, but not necessarily infectious matter, in the environment. Contamination on a body surface does not imply a carrier state.

Cyst--A sporelike cell with a resistant, protective wall.

Disinfection--Killing of infectious agents outside the body by chemical or physical means, directly applied. Concurrent disinfection is the application of disinfective measures as soon as possible after the discharge of infectious material from the body of an infected person, or after the soiling of articles with such infectious discharges, all personal contact with such discharges or articles being minimized prior to such disinfection.

Dose response--The number of human hosts exhibiting clinically recognizable symptoms from an infectious agent dose of known concentration.

Encyst--To enclose or become enclosed in a cyst.

Endemic--The constant presence of a disease or infectious agent within a given geographic area; may also refer to the usual prevalence of a given disease within such area. Hyperendemic expresses a persistent intense transmission, e.g., malaria.

Endotoxin--The toxic protoplasm liberated when a microorganism dies and disintegrates.

Enteric--Of or pertaining to the alimentary canal, extending from the mouth to the anus.

Epidemic--The occurrence in a community or region of cases of an illness (or an outbreak) clearly in excess of normal expectancy and derived from a common or a propagated source. The number of cases indicating presence of an epidemic will vary according to the infectious agent, size and type of population exposed, previous experience or lack of exposure to the disease, and time and place of occurrence; epidemicity is thus relative to usual frequency of the disease in the same area, among the specified population, at the same season of the year.

Gastrointestinal--Refers to stomach and intestines.

Host--A man or other living animal, including birds and arthropods, which affords subsistence or lodgment to an infectious agent under natural conditions. Some protozoa and helminths pass successive stages in alternative hosts of different species. Hosts in which the parasite attains maturity or passes its sexual stage are primary or definitive hosts; those in which the parasite is in a larval or asexual state are secondary or intermediate hosts. A transport host is a carrier in which the organism remains alive but does not undergo development.

Hyperkeratosis--A thickening of the horny layer of skin.

Illness--Synonymous with infection with manifest (visible) symptoms.

Immune person--A person (or animal) that possesses specific protective antibodies or cellular immunity as a result of previous infection or immunization, or is so conditioned by such previous specific experience as to respond adequately with production of antibodies sufficient to prevent clinical illness following exposure to the specific infectious agent of the disease. Immunity is relative; an ordinarily effective protection may be overwhelmed by an excessive dose of the infectious agent or via an unusual portal of entry; may also be impaired by immuno-suppressive drug therapy or concurrent disease.

Inapparent infection--The presence of infection in a host without occurrence of recognizable clinical signs or symptoms. Inapparent infections are only identifiable by laboratory means. Synonym: subclinical infection.

Incidence rate--A quotient (rate), with the number of cases of a specified disease diagnosed or reported during a defined period of time as the numerator, and the number of persons in the population in which they occurred as the denominator. This is usually expressed as cases per 1,000 or 100,000 per annum.

Indigenous (endemic)--Originating in and characterizing a particular region or country.

Infected person--A person who harbors an infectious agent and who has either manifest disease or inapparent infection. An infectious person is one from whom the infectious agent can be naturally acquired.

Infection--The entry and development or multiplication of an infectious agent in the body of man or animals. Infection is not synonymous with infectious disease; the result may be inapparent or manifest. The presence of living infectious agents on exterior surfaces of the body, or upon articles of apparel or soiled articles, is not infection, but contamination of such surfaces and articles.

Infectious agent--An organism, chiefly a microorganism but including helminths, that is capable of producing infection or infectious disease.

Infectious disease--A disease of man or animals resulting from an infection.

Metastasize--Transmission of disease from an original site to one or more sites elsewhere in the body, as in tuberculosis or cancer.

Morbidity rate--An incidence rate used to include all persons in the population under consideration who become ill during the period of time stated.

Occurrence--A reporting of the number of disease cases for a specified area by number of cases as a portion of 100,000 population. See epidemic.

Outbreak--A number of occurrences resulting from a single source, see Epidemic.

Pathogenicity--The capability of an infectious agent to cause disease in a susceptible host.

Report of a disease--An official report notifying appropriate authority of the occurrence of a specified communicable or other disease in man. Diseases in man are reported to the local health authority. Some few diseases in animals, also transmissible to man, are reportable. Each health jurisdiction declares a list of reportable diseases appropriate to its particular needs. Reports also list suspect cases of diseases of particular public health importance, ordinarily those requiring epidemiologic investigation or initiation of special control measures.

When a person is infected in one health jurisdiction and the case is reported from another, the authority receiving the report should notify the other jurisdiction, especially when the disease requires examination of contacts for infection, or if food or water or other common vehicles of infection may be involved. In addition to routine report of cases of specified diseases, special notification is required of all epidemics or outbreaks of disease, including diseases not on the list declared reportable.

Resistance--The sum total of body mechanisms which interpose barriers to the progress of invasion or multiplication of infectious agents or to damage by their toxic products.

a. Immunity--That resistance usually associated with possession of antibodies having a specific action on the microorganism concerned with a particular infectious disease or on its toxin.

b. Inherent resistance--An ability to resist disease independent of antibodies or of specifically developed tissue response; it commonly resides in anatomic or physiologic characteristics of the host and may be genetic or acquired, permanent or temporary. Synonym: nonspecific immunity.

Subclinical--See inapparent infection.

Susceptible--A person or animal presumably not possessing sufficient resistance against a particular pathogenic agent to prevent contracting a disease if or when exposed to the agent.

Transmission of infectious agents--Any mechanism by which a susceptible human host is exposed to an infectious agent. These mechanisms are:

a. Direct transmission--Direct and essentially immediate transfer of infectious agents (other than from an arthropod in which the organisms has undergone essential multiplication or development) to a receptive portal of entry through which infection of man may take place.

b. Indirect transmission--

(1) Vehicle-borne. Contaminated materials or objects such as toys, handkerchiefs, soiled clothes, bedding, cooking or eating utensils, surgical instruments or dressings (indirect contact); water, food, milk, biological products including serum and plasma; or any substance serving as an intermediate means by which an infectious agent is transported and introduced into a susceptible host through a suitable portal of entry. The agent may or may not have multiplied or developed in or on the vehicle before being introduced into man.

(2) Vector-borne. (a) Mechanical: includes simple mechanical carriage by a crawling or flying insect through soiling of its feet or proboscis, or by passage of organisms through its gastrointestinal tract. (b) Biological: propagation (multiplication), cyclic development, or a combination of these (cyclopropagation) is required before the arthropod can transmit the infective form of the agent to man.

(3) Airborne. The dissemination of microbial aerosols to a suitable portal of entry, usually the respiratory tract. Microbial aerosols are suspensions in the air of particles consisting partially or wholly of microorganisms. Particles in the 1 to 5 micron range are easily drawn into the alveoli of the lungs and may be retained there; many are exhaled from the alveoli without deposition. They may remain suspended in the air for long periods of time, some retaining and others losing infectivity or virulence. Not considered as airborne are droplets and other large particles which promptly settle out. The following are airborne and their mode of transmission is direct: (a) Droplet nuclei: usually the small residues which result from evaporation of fluid from droplets emitted by an infected host. Droplet nuclei also may be created purposely by a variety of atomizing devices, or

accidentally as in microbiology laboratories or in abattoirs, rendering plants or autopsy rooms. They usually remain suspended in the air for long periods of time. (b) Dust: the small particles of widely varying size which may arise from soil (as for example fungus spores separated from dry soil by wind or mechanical agitation), clothes, bedding, or contaminated floors.

(4) Waterborne. Communicated by water.

Toxic--Pertaining to, affected with, or caused by a toxin or poison; or acting as, or having the effect of a poison.

Chapter 10

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