7

Regulations Governing Agricultural Use of Municipal Wastewater and Sludge

Government regulations at both the federal and state levels develop within a complex set of circumstances. To fully understand them, regulations must be examined in terms of the regulatory approach taken, the underlying scientific principles that are applied, the objectives of the regulation, and the effectiveness of implementation. The following section begins with a discussion of the regulatory background for agricultural use of municipal wastewater and sludge. Current federal standards for control of pathogens and toxic chemicals in sludge use are then described and evaluated. Finally, state regulations and United States Environmental Pro-tection Agency (EPA) guidelines for agricultural irrigation with treated effluents are discussed.

The implementation of wastewater and sludge reuse programs also involves other reg-ulatory components, including program management, surveillance, and enforcement. Economic considerations, liability issues, and public concerns will likewise play a role. These imple-mentation issues are considered in Chapter 8.

REGULATORY BACKGROUND

Agricultural Irrigation With Wastewater

Irrigation of crops with treated effluent and farmland application of sewage sludge have been conducted without federal regulations for decades in the United States. Early regulations by states addressed infectious disease transmission and the reduction of odor. Wastewater irrigation continues to be regulated at the state level, and those states (such as Arizona, Cal-ifornia, Florida, Hawaii, and Texas) that have active water reuse programs have developed comprehensive, numerical water quality criteria for different water uses, including crop irrigation. Pathogen reduction continues to be the major concern, and microbiological limits for treated effluents are based largely on practical experience within the public health community, and on the expected performance of wastewater treatment processes. There have been no reports of infectious disease associated with agricultural reuse projects, and existing criteria are con-sidered to be adequate (see Chapter 5). Most states distinguish between produce (or crops that can be eaten raw) from crops that are commercially processed or cooked prior to consumption, and require more stringent water quality levels for produce crops.

Nevertheless, states differ in the manner in which wastewater irrigation can be imple-mented. For example, California, with the longest history of regulating reclaimed wastewater for agricultural use, permits high-quality effluents to be used on produce crops. Florida normally restricts the agricultural use of reclaimed water to those food crops that are skinned, cooked, or thermally processed before consumption (EPA, 1992).

Chemical pollutants in treated municipal wastewater have not been targeted by state regulations for reclaimed water. This is because the concentrations of these pollutants in effluents that receive a minimum of secondary treatment are comparable to those in conventional sources of irrigation water, and the reclaimed water generally meets current irrigation water quality criteria (e.g., Wescot and Ayers, 1985) for chemicals that are potentially harmful to crop production or to ground water contamination (see Chapters 2 and 4 for further discussion). Source control of industrial inputs, conventional secondary treatment, and advanced treatment are relied upon to reduce effluent concentrations of chemical pollutants to levels that do not impact the particular end use.

Agricultural Use of Sewage Sludge

Sewage sludges are recognized as potentially harmful because of the chemical pollutants and the disease-causing agents they may contain. Prior to the early 1970s, there was no direct legislative authority for any federal agency to regulate sludge disposal. In 1972, Congress directed EPA to regulate the disposal of sludge entering navigable waters through Section 405(a) of the Federal Water Pollution Control Act. The Resource Conservation and Recovery Act (RCRA) of 1976 (P.L. 95-512) exempts sewage sludge from hazardous waste management regulation in cases where industrial discharges to the publicly owned treatment plant (POTW) are already regulated under EPA-approved pretreatment programs. In 1977, Congress amended section 405 of the Federal Water Pollution Control Act to add a new section, 405(d), that required EPA to develop regulations containing guidelines for the use and disposal of sewage sludge on land as well as in water. These guidelines were to (1) identify alternatives for sludge use and disposal; (2) specify what factors must be accounted for in determining the methods and practices applicable to each of the identified uses; and (3) identify concentrations of pollutants that would interfere with each use. Federal criteria (40 CFR Part 257) identifying "acceptable solid waste disposal practices—including landfill and land application—were issued in 1979 under the joint authority of RCRA (Subtitle D) and the Clean Water Act (Section 405). These criteria specified limits on cadmium in sludge and soil pH levels, limited the soil incorporation of sludges with greater than 10 mg/PCB/kg, and contained criteria for pathogen reduction. How-ever, these criteria for sludge use and disposal were not widely used.

In 1987, Congress once again amended Section 405 to establish a timetable for developing technical standards for sewage sludge use and disposal (Water Quality Act of 1987, P.L. 100-4). Congress directed EPA to identify toxic pollutants that may be present in sewage sludge in concentrations that may affect public health and the environment, and to specify acceptable management practices and numerical limits for sludge that contain these pollutants. These regulations were to be "adequate to protect the human health and the environment from any reasonably anticipated adverse effect of each pollutant." (Section 405(d)(2)(D)). Section 405 was also amended to specify that technical standards for sludge use and disposal be included in any permit issued to a POTW or other treatment works. The final "Standards for the Use and Disposal of Sewage Sludge" were promulgated in 1993 by the EPA (40 CFR 503, EPA, 1993a) and are referred to as the "Part 503 Sludge Rule" in this report.

FEDERAL STANDARDS FOR THE CONTROL OF PATHOGENS IN SEWAGE SLUDGE

Standards and management practices for the reduction of pathogens to acceptable levels prior to human or animal contact and vector attraction reduction are major aspects of the Part 503 Sludge Rule. Based upon pathogen reduction criteria, the Rule divides sludge into two categories, Class A (safe for direct contact) and Class B (land and crop use restriction supply). Class A sewage sludge can be used in an unrestricted manner. Class A pathogen requirements (shown in Table 7.1) must be met by one of six alternatives and use of either the fecal coliform or salmonella tests as described below.

In Part 503, all Class A sludges must meet either a fecal coliform limit of less than 1,000 fecal coliform/g dry weight of solids or a measure of less than 3 salmonella/4 g dry weight of solids (EPA, 1993a). As discussed in Chapter 5, the threshold of 1,000 fecal coliform/g dry weight appears reasonable given that all evidence points to equal or greater resistance of fecal coliforms in comparison to other common bacterial pathogens such as salmonella. When the numbers of fecal coliforms in raw sludge are in the range of 10,000,000/g, then the reduction to 1,000/g would indicate a similar rate of reduction in bacterial pathogen numbers. For example, the concentration of salmonella in raw sludge is estimated to be 2,000/g of solids; thus, a five $\log^{10}$ reduction would reduce the salmonella level to approximately 2/100 g of solids. In a comparison of the relationship between fecal coliform and salmonella numbers, Yanko (1988) described this same relationship.

Because of the small sample size and interference by large numbers of nonsalmonella bacteria, the method prescribed for salmonella in Part 503 is apt to underestimate the number present in any given sludge sample (also see Yanko et al., 1995). The chances of finding 3 salmonella in 4 g of sludge is much less than those of finding 1,000 fecal coliforms in 1 g. This may be of some concern when the salmonella determination is used in lieu of the fecal coliform assay. As stated in the Rule, to be classified as Class A, all sludges must meet either the fecal coliform or the salmonella requirement. Because standard salmonella determination methods as now practiced are not precise, there may be a temptation to use the salmonella test in lieu of the coliform test, regardless of the regrowth potential in the sludge.

In certain Class A processed sludges, fecal coliform regrowth may occur, in which case the sludge might not meet the fecal coliform requirement, but the sanitary significance of the numbers would be unclear. In this instance the Part 503 Sludge Rule allows for the direct determination of salmonella, and if their concentration is less than 3 salmonella/4 g dry weight of sludge, the Class A classification would hold. Until such time as more accurate salmonella detection methods are developed, it would be expedient to use the salmonella test only after coli-

TABLE 7.1 Summary of Part 503 Sludge Rule Pathogen Limits For Class A Sludge

All Class A sludges must meet:	fecal coliform density of <1,000 MPN[a]/gram total solids.[b] or *Salmonella* sp. density of <3 MPN/4 grams total solids.
Plus one of 6 alternatives:	
#1	Time and temperature requirements specified, depending on solids content of sludge.
#2	Alkaline and temperature treatment requirements: pH >12 for at least 72 hours. Temperature >52°C for at least 12 hours, then air dry sludge to ≥50% total solids.
#3	Level of enteric virus and helminth ova prior to pathogen treatment are <1 PFU[c]/4 grams total solids for virus and < 1 viable ova/4 grams total solids for helminth ova. or If levels of enteric virus and/or helminth ova prior to pathogen treatment are ≥1 PFU or if viable ova are present, then test after treatment. Document process operating parameters to achieve <1 PFU/4 grams total solids for virus and <1 viable ova/4 grams total solids for helminth ova.
#4	Levels of enteric virus and helminth ova after treatment and when ready to distribute are <1 PFU/4 grams total solids for virus and <1 viable ova/4 grams total solids for helminth ova.
#5	Use of *Process to Further Reduce Pathogens* (PFRP). See requirements for composting, heat drying, heat treatment, thermophilic aerobic digestion, beta ray irradiation, gamma ray irradiation, and pasteurization.
#6	Treat equivalent to PFRP requirements. Determined by the permitting authority.

[a] MPN: Most Probable Number
[b] all weights are dry weights
[c] PFU: Plaque Forming Units

SOURCE: EPA, 1993b

form regrowth or regrowth potential has been determined, and not as an alternative to the fecal coliform method for determining pathogen levels in all sludges.

In addition to the fecal coliform or salmonella test, there are six alternative requirements for achieving a Class A sludge status (Table 7.1). These can be summarized as: (1) use of specified application of time and temperature; (2) use of heat and elevated pH; (3) and (4) the demonstration of the absence of viable helminth ova and enteric viruses either before or after some form of treatment; and,(5) and (6) an accepted process to further reduce pathogens (PFRP) or equivalent. The Part 503 Sludge Rule states that all the alternatives are of equal value in that they will meet, as a minimum, the pathogen standard set forth in alternatives (3) and (4).

At the present state of our knowledge, Class A microbial standards or process standards for sludge appear to be adequate for public health protection. However, when relying on the direct measurement of pathogens, one should be aware of the accuracy and precision of the methods that are presently available. The standard may be quite adequate but the method used to determine if the standard has been met can be questionable (Cooper and Riggs, 1994).

Part 503 describes "Class B" as sludge having lesser sanitary quality than Class A at the time of application. This class of sludge is applied to land under a variety of restrictions. There are three alternative requirements that must be met to qualify a sludge as Class B. The first alternative requires a domestic sludge to contain a geometric average fecal coliform level of less than 2,000,000 bacteria most probable number (MPN)/g dry weight based on seven samples. Most wastewater and sludge treatment practices can attain this fecal coliform level. A second alternative for meeting Class B requirements is to use designated sludge treatment processes to significantly reduce pathogens (PSRP). Processes that meet PSRP criteria will, as a minimum, meet the coliform requirement of 2,000,000/g.

In addition to the above quality or process requirements, land use restrictions are also required for the application of Class B sludge. These restrictions are summarized in Table 7.2, and their rational is based on the time required to significantly reduce the number of helminth ova. Helminth ova are among the most environmentally resistant of the infectious agents, and the time required for their reduction would be more than sufficient for the reduction of bacterial and viral pathogens. The Part 503 Sludge Rule requires a 20-month time period to elapse prior to harvesting root crops and a 14-month time period before harvest of other crops that touch the ground. These criteria are based on data developed by the EPA (EPA, 1993b) that indicate a "relatively high rate of die-off of helminth ova on the soil surface" within these time periods. Lawn turf is land with a high potential for human contact, and Feachem et al. (1983) consider a year to be a sufficient waiting period to provide adequate protection to the public from ascaris infection in this context. The 30-day restriction for nonroot or aboveground crops, feed, and fodder was considered to be adequate for the protection of public and animal health.

The analysis for the Part 503 Sludge Rule predicts greater risks to those exposed to runoff water (e.g., from swimming) than for other pathways. Because of this concern, Part 503 urges that drainage be carefully managed. The model also predicted a greater risk to onsite workers during the initial time period of application. The greatest onsite risk calculated was 0.02 infections per 100,000 (EPA, 1993b). It should be kept in mind that the number of individuals exposed onsite is relatively small and thus the occurrence of infection would be limited.

The beef tapeworm, *Taenia sarginata*, and the pork tapeworm, *T. solium*, are the primary human pathogens of concern in the application of Class B sludge to fodder or grazing land. According to Feachem et al., (1983) and the EPA model, 30 days should be a sufficient period of time for destruction of these ova; however, a more recent investigation in Denmark (Ilsole et al., 1991) indicated that a small proportion of the ova remained viable for 5 to 6 months and were nonviable by the end of 8 to 10 months of soil exposure.

The pathogen criteria for the application of Class B sludge to land is based on information from the available literature and, with the exception of the waiting time criteria for fields to be used for fodder and grazing, appear to conform to that literature. Although concern is based only on a single report (Ilsole et al., 1991), it does create a reservation that should be

TABLE 7.2 Class B Sludge Application-Land Use Restrictions

Food crops that touch sludge or soil	Harvest after 14 mos. of sludge application
Root crops	Harvest after 20 mos. if 4 mos. elapse prior to planting
Other food, feed or fodder	Harvest after 30 days of sludge application
Grazing	No grazing prior to 30 days after sludge application
Lawn turf	Harvest after one year of sludge application
Public access to land - high access potential	one year waiting period prior to access
Public access to land - low access potential	30 day waiting period prior to access

addressed. In this country, we depend on consumer cooking of meat to destroy any helminth cysts, including trichina worms in pork. Managing the disposal of human waste to grazing land and meat inspections provide additional controls. Generally, the fewer viable eggs of *Taenia* species allowed on grazing land, the better; however, the actual risk of a too short waiting period may not be measurable.

As stated previously, the reliability of any sludge treatment process in reducing path-ogens to acceptable levels is paramount for public health protection. There are many variables, such as pH, moisture, sunlight, temperature, and indigenous microflora, that are involved in the decay of pathogens in the soil environment. Class B applications rely on these natural processes for public health protection. Because of the number of uncontrollable variables, one might assume less reliability in pathogen reduction than in the case of most Class A sludge appli-cations. In this regard the use of Class B solids on fields used to grow for crops for human consumption, particularly those eaten raw, may present a greater risk than does the use of Class A materials. The absolute degree and impact of this increased risk on public health cannot be determined but, at the present state of our knowledge and experience, the difference in infectious disease risk appears to be imperceptible.

A second public health aspect of sewage sludge management is the potential for vector attraction, although this aspect of the Part 503 Sludge Rule has not been evaluated in this study. Vectors are animals involved in the transmission of infectious diseases to humans. In the case of sludge disposal, there is particular concern with insect vectors that might be attracted to the disposal site as a result of management practices. The Part 503 Sludge Rule recognizes this potential and has made provisions for vector attraction and nuisance reduction.

APPROACHES TO TOXIC CHEMICAL REGULATION IN SLUDGE AND WASTEWATER LAND APPLICATION

Philosophically, pollutant inputs to soils through land application of wastewater and sewage sludge may be regulated through two approaches (Chang et al. 1993). One approach is to prevent toxic chemical pollutants from accumulating above natural background levels in the soils. Another approach is to allow pollutants to accumulate so long as the soil capacity for assimilating, attenuating, and detoxifying the pollutants is adequate to minimize the risk to humans, agricultural crops, and the environment.

The Part 503 Sludge Rule is based on the second approach, whereas regulations in several European nations, such as Holland and Norway, are based upon the first. McGrath et al. (1994) reviewed regulations controlling pollutant inputs via land application of municipal sludges in the United States and in Western Europe and compared the benefits and disadvantages of each approach. While the scientific principles of these two approaches are both valid, the numerical limits on toxic chemicals derived from each approach may vary by orders of magni-tude.

Preventing Toxic Chemical Pollutant Accumulation in Soils

The underlying objective of this approach is to preserve a soil's current condition and to avoid an accumulation of pollutants from long-term applications of sludge and wastewater. This approach aims to prevent an increase in the concentration of pollutants based on the assumption that any increase in pollutants would compromise the soil's ability to support a productive microbial and botanical population and limit its potential use. A land application regulation based on this approach strives to prevent pollutant accumulation in the soil from exceeding levels that exist before sludge or wastewater effluent is applied.

To meet this objective, pollutant input from applications of wastewater or sludge and other sources must be balanced by pollutant output via surface runoff, leaching, atmospheric loss, and plant uptake followed by removal. In soils, pollutant output is typically very low. Consequently, the pollutant loading from all sources including land application of wastewater and sewage sludge must also be very low in order to maintain the balance and prevent any net accumulation. Regulations and guidelines that employ this principle must set very stringent toxic chemical pollutant loading limits for soils that can only be met by preventing all toxic chemical pollutants from entering wastewater collection and treatment systems, or by requiring the use of advanced levels of treatment to physically strip pollutants out of the effluent or sludge prior to land application. Otherwise, the sludges or effluents have to be applied at very low rates to prevent no net change in the pollutant concentration in the soil.

One advantage of this approach is that detailed knowledge about the fate and transport of pollutants, exposure analysis, and dose-response relationships is not necessary. The numerical limits for pollutants may be calculated by simple mass balances (pollutants in sludge and/or wastewater=pollutants transported out of soil system via surface runoff, leaching, atmospheric loss and removal by harvested plants) and this relationship can be applied to any location. However, the disadvantages are twofold: (1) meeting the numerical limits can be very costly, and (2) the allowable application rates are too low to provide any nutrient value.

Allowing Pollutant Accumulation in the Soil

The premise of this approach is that advantage can be taken of the beneficial qualities (moisture, organic matter and nutrients) of sludges and wastewater and of the capacity of soil to attenuate toxic chemical pollutants present in the sludges or wastewater. Soil is a dynamic medium consisting of mineral fragments, organic matter, biota, water, and air. Pollutants introduced into soil are subject to physical, chemical and biological transformations. Con-sequently, pollutants introduced to soil in low amounts may not have an immediate deleterious effect. Over time, such pollutants will accumulate and when a specific concentration is reached, harmful effects can occur. This knowledge can be used to properly manage cropland application of treated effluents and treated sludge so that the accumulation of chemical pollutants in the soil does not reach levels that harm exposed individuals or the environment. Under this scenario, agronomic benefits of wastewater and sewage sludge may be realized without harming soil quality, public health, and the environment.

This approach entails developing maximum permissible pollutant loading limits and/or maximum permissible pollutant concentration for the soil. It necessitates a more complete understanding of pollutant chemistry, health hazards, pathways to exposure, and sophisticated modeling techniques.

DEVELOPMENT OF U.S. CHEMICAL POLLUTANT STANDARDS FOR AGRICULTURAL USE OF SEWAGE SLUDGE

The Part 503 Sludge Rule defines the domain within which sewage sludges may be safely disposed or beneficially used (EPA, 1993a). The sludge management options addressed by this regulation include agricultural land application, nonagricultural land application, sludge-only landfills, surface disposal, and incineration. This report is concerned with agricultural land application of sludge. For this use, the regulation sets numerical limits on cumulative loadings for certain pollutants, defines the sludge- processing requirements necessary to control pathogens and parasites, and outlines an implementation plan. Requirements for nonagricultural land ap-plication, including home or horticultural use, are derived from the requirements for agricultural land application.

EPA used a risk assessment approach to develop the standards for chemical pollutant limits in the Part 503 Sludge Rule. In performing the assessment, EPA followed a framework presented by the National Research Council (NRC, 1983). EPA's approach is premised on the condition that chemical pollutants will accumulate in the soil with each application of sludge. The risk assessment considers pollutant transport through various environmental exposure pathways, and has the objective of setting maximum pollutant loading limits and minimum sludge quality requirements for cropland application of sewage sludge. EPA's analysis focused on those chemicals that are resistant to degradation and may be incorporated into food crops, or animal feed, or ingested by grazing animals. EPA also considered human exposure that can occur through direct ingestion of sludge-amended soil. This last pathway was assessed by EPA based on the residential use of packaged sludge-derived material where infants may ingest the dirt, and it is outside the scope of this report. A general description of a risk assessment ap-proach is briefly presented below, after which EPA's specific approach is explained and evaluated.

General Approach to Risk Assessment

The method for performing a risk assessment, as outlined by the NRC (1983), consists of four steps: (1) hazard identification, (2) dose-response evaluation, (3) exposure evaluation, and (4) characterization of risks.

Hazard Identification

The first step in the risk assessment process—hazard identification—is to determine the nature of the effects that may be experienced by a human exposed to an identified pollutant and whether evidence of toxicity exists sufficient to warrant a quantitative risk assessment. Data are gathered on a specific pollutant and qualitatively evaluated based on the type of health effect produced, the conditions of exposure, and the metabolic processes that govern pollutant behavior within the human body or other organism studied. It may also be necessary to characterize the behavior of the pollutant in the environment. Thus, hazard identification helps to determine whether it is scientifically appropriate to infer that effects observed under one set of conditions (e.g., in experimental animals) are likely to occur in other settings (e.g., in human beings), and whether data are adequate to support a quantitative risk assessment. The following two sections discuss how such quantitative assessments are conducted.

Dose-Response Assessment

The second step in the risk assessment process is estimating or evaluating the dose-response relationships—what "dose" of a chemical produces a given "response"—for the pol-lutant under review. Evaluating dose-response data involves quantitatively characterizing the connection between exposure to a pollutant (measured in terms of quantity and duration) and the extent of toxic injury or disease. Most dose-response relationships estimates are based on animal studies, because even good epidemiological studies rarely have reliable information on human exposure. In this context, two general approaches to dose-response evaluation are used, depending on whether the health effects are based on threshold or nonthreshold characteristics of the pollutant. "Threshold" refers to exposure levels below which no adverse health effects are assumed to occur. Effects that involve altering genetic material (including carcinogenicity and mutagenicity) may take place at very low doses; therefore, they are modeled with no thresholds. For most other biological effects, it is usually, but not always, assumed that thresh-old levels exist.

Exposure Evaluation

Exposure evaluation estimates environmental concentrations of pollutants. The severity of the exposure is then assessed by evaluating the nature and size of the population exposed to the pollutant, the route of exposure (i.e., oral, inhalation, or dermal), the extent of exposure (concentration times duration), and the circumstances of exposure.

Risk Characterization

In the final phase of a risk assessment, the risk characterization, information on the range of exposures and risks and on all major uncertainties, along with their influence on the assess-ment, are presented.

EPA's Risk Assessment Approach

Hazard Identification

EPA initially developed environmental profiles and hazard indices on 50 pollutants that were selected by a group of experts convened by EPA in 1984 (EPA, 1993). Of those 50 pollutants, 22 (10 metals and 12 organics) were selected, through a screening process, for regulation in the 1989 proposed rule for land application (Federal Register, 1989). These 22 pollutants are listed in Table 7.3.

After the proposed rule was issued, EPA completed a National Sewage Sludge Survey (NSSS) (EPA, 1990). The NSSS sampled sludge from 209 sewage treatment plants throughout the country to produce national estimates of concentrations of toxic pollutants in sewage sludge.

Using the NSSS data and information from the risk assessment, EPA conducted a further screening analysis to eliminate from regulation any pollutant that was not present in con-centrations that posed a significant public health or environmental risk. Based on this screening analysis, 12 organic chemicals were deleted, leaving 10 inorganic chemicals for regulation by the Part 503 Sludge Rule. The criteria used to remove organic pollutants from the rule is discussed below.

Three screening criteria were used to assess the need for regulating the 12 organic pol-lutants that were part of the original 22 pollutants identified in the proposed rule. If a pollutant satisfied any one of the criteria below, it was exempted from regulation in Part 503. The three criteria were described as follows:

- The pollutant has been banned for use, has restricted use, or is no longer manufactured for use in the United States.
- The pollutant has a low frequency of detection in the sewage sludge (less than 5 percent), based on data from the NSSS.
- The concentration of the pollutant in sewage sludge is already low enough that the estimated annual loading to cropland soil would result in an annual pollutant loading rate within allowable risk-based levels.

Based on these criteria, EPA exempted all of the organic pollutants under consideration. The pollutant loading used for the third criterion is based on the quantity of sewage sludge that would be applied at agronomic rates and using the sludge pollutant concentration equal to the

TABLE 7.3 Pollutants Selected for Initial Hazard Identification Analysis

Inorganic Chemical Pollutants	Organic Chemical Pollutants
Arsenic	Aldrin/Dieldrin
Cadmium	Benzo(a)Pyrene
Chromium	Chlordane
Copper	DDT/DDD/DDE
Lead	Dimethyl nitrosamine
Mercury	Heptachlor
Molybdenum	Hexachlorobenzene
Nickel	Hexachlorobutadiene
Selenium	Lindane
Zinc	Polychlorinated biphenyls (PCBs)
	Toxaphene
	Trichloroethylene

SOURCE: EPA, 1993b.

99th percentile value of the NSSS (EPA, 1993b, Appendix B). Table 7.4 lists the criteria by which each pollutant was screened.

Exposure Assessment

The exposure assessment analyzed 14 pollutant transport pathways (Table 7.5) in agri-cultural land application of sewage sludge. Of primary relevance to the committee's assessment of human health impacts were the three pathways that involved crop consumption. The other pathways traced effects of digestion of soil on livestock, plants, soil biota, soil biota predators, and human-health. At the end of each pollutant transport pathway, there is an exposed subject who is the receptor of the pollutant. For each pathway, the exposed subject represents the segment of the exposed population that is most susceptible—the "highly exposed individual" (HEI).

The maximum tolerable exposure for the HEI was set equal to the risk reference dose (RfD) corresponding to a risk level of 10^{-4} for known carcinogenic chemicals and equal to the recommended daily allowance (RDA) for non-carcinogenic chemicals. EPA traditionally establishes standards within a range of $1x10^{-7}$ to $1x10^{-4}$, depending on the statute, surrounding issues, uncertainties, and information bases. EPA chose a carcinogenic risk target of $1x10^{-4}$ for the use of sewage sludge in the production of agricultural crops because EPA's analysis did not indicate a significant aggregate populational carcinogenic risk from this practice, and because of the conservative assumptions built into the HEI approach (EPA, 1993a).

For the purposes of the Part 503 Sludge Rule, models were developed to determine the maximum amount of pollutant that could be added to the soil (otherwise known as a "pollutant loading") that would not cause undue risk. This analysis produced 14 pollutant loadings—one for each pathway—for each of the pollutants evaluated. The smallest value of all pathways was selected as the maximum permissible loading for each pollutant. This value, termed "cumulative

TABLE 7.4 Results of Screening Criteria for Organic Pollutants Considered for Part 503 Sludge Regulations

Pollutants	Pollutant is Banned in United States	Pollutant has < 5% Detection Frequency in the NSSS	Does Not Exceed Risk Assessment Criteria from 99th percentile in NSSS
Aldrin/Dieldrin (total)	x		x
Benzo(a)Pyrene		x	
Chlordane	x	x	x
DDT/DDE/DDD (total)	x	x	x
Heptachlor	x	x	x
Hexachlorobenzene		x	
Hexachlorobutadiene		x	x
Lindane	x	x	x
N-Nitroso dimethylamine	x	x	
PCBs	x		
Toxaphene	x	x	x
Trichloroethylene		x	x

pollutant loading rate," sets the total allowable level of sludge-borne pollutant that can be added to the soil and still maintain an acceptable level of exposure to the HEI from the most sensitive pathway. The analysis treats all pathways as equal so that adverse effects on livestock animals, plants, and soil biota are weighed equally to those on humans. In other words, if a limiting pathway for a pollutant is one in which the HEI is a plant, the numeric limit for the pollutant is more restrictive than necessary to protect a human because the plant is more sensitive than the human. The limiting pathway for each of the 10 pollutants regulated and their corresponding HEIs are listed in Table 7.6. It is important to note that none of the limiting pathways involve the human consumption of crops grown in sludge-amended soils.

TABLE 7.5 Exposure Assessment Pathways

Pathway Numbers	Pathway
1	Sludge-soil-plant-human
2	Sludge-soil-plant-home gardener
3	Sludge-soil-child
4	Sludge-soil-plant-animal-human
5	Sludge-soil-animal-human
6	Sludge-soil-plant-animal
7	Sludge-soil-animal
8	Sludge-soil-plant
9	Sludge-soil-soil biota
10	Sludge-soil-soil biota-predator of soil biota
11	Sludge-soil-airborne dust-human
12	Sludge-soil-surface water-fish-human
13	Sludge-soil-air-human
14	Sludge-soil-ground water-human

Risk Characterization

EPA established cumulative pollutant loading rates for 10 inorganic elements (Table 7.7). These rates represent the maximum amount of a pollutant that can be uniformly applied to a hectare of land and still provide acceptable protection to the HEI.

To provide flexibility in applying sludges and to expedite the use of sewage sludge in nonagricultural land application, several variations in pollutant loading limits were derived from the risk-based cumulative pollutant loading rates. These alternative limits are described below and include pollutant concentration limits, ceiling concentration limits for pollutants, and annual pollutant loading rates. Recordkeeping and management requirements for sludge will vary depending on which set of limits are used (in addition to any requirement based on the pathogen levels as earlier discussed).

TABLE 7.6 Most Limiting Pathway for Pollutants Regulated in CFR Title 40, Parts 503

Pollutant	Highly Exposed Individual (HEI)	Limiting Pathway Number
Arsenic	Sludge eaten by child	3
Cadmium	Sludge eaten by child	3
Chromium	Phytotoxicity	8
Copper	Phytotoxicity	8
Lead	Sludge eaten by child	3
Mercury	Sludge eaten by child	3
Molybdenum	Animal eating feed	6
Nickel	Phytotoxicity	8
Selenium	Sludge eaten by child	3
Zinc	Phytotoxicity	8

Pollutant Concentration Limits To derive pollutant concentration limits, EPA assumes that the life span of a land application site is no more than 100 years and that the annual sludge application rate is less than or equal to 10 metric tons/ha (an agronomic rate for a typical sludge that would provide adequate available nitrogen for a number of crops). In this case, the sludge application rate at a given site will not exceed 1,000 metric tons/ha. The risk-based, cumulative pollutant loading rate (kg of pollutant/ha for the life span of the application site) is then uniformly distributed among 1,000 metric tons of sludge/ha, and a maximum permissible pollutant concentration (in kg of pollutant/ton of sludge or in mg of pollutant/kg of sludge) was calculated. This value was then compared to the 99th percentile concentration value for the pollutant from the NSSS and the more stringent of the two was determined to be the pollutant concentration (EPA, 1993a) as shown in Table 7.8. Given these assumptions, the cumulative pollutant loading rates would not be exceeded in normal agricultural practices and there would be little need for oversight except to assure that the sludge quality meets the criteria prior to distribution or application.

In an effort to encourage the continued reduction of pollutant levels in the municipal wastewater stream, EPA developed the concept of "exceptional quality" sewage sludge. Under this classification, sludges with specified low levels of pollutants, termed "pollutant concentration limits" and Class A pathogen levels, can be applied to agricultural land with a minimum of regulation and oversight.

Ceiling Concentration Limits for Sewage Sludge According to EPA's risk assessment, any sewage sludge may be applied on cropland as long as the cumulative pollutant loading rates are not exceeded. However, some sewage sludges contain unusually high amounts of pollutants that are prone to cause harmful effects when applied on cropland. EPA established ceiling concentrations to prevent such sewage sludges from being applied on cropland. The ceiling concentration of a pollutant is set at the least stringent of: (1) the 99th percentile concentration

TABLE 7.7 Cumulative Pollutant Loading Rates

Pollutant	Cumulative Pollutant Loading Rate (kg/ha)
Arsenic	41
Cadmium	39
Chromium[1]	3,000
Copper	1,500
Lead	300
Mercury	17
Molybdenum[1]	18
Nickel	420
Selenium	100
Zinc	2,800

[1] Above limits have been deleted for chromium (since October 1995) and molybdenum (since February 1994) pending reconsideration by EPA.

Annual pollutant Loading Rates Annual Pollutant Loading Rates (APLR) are used as a management strategy to make sure that sludges sold or given away in bags do not exceed the risk-based cumulative pollutant loading rates. This applies to sewage sludges with concentrations that are less than, or equal to, the ceiling concentrations, but do not meet the pollutant concentrations. The APLR is calculated by assuming the cumulative pollutant loading rates are reached in 20 years of agricultural or residential land applications. These preset annual pollutant loading rates shown in Table 7.8 can not be exceeded.

EVALUATION OF FEDERAL STANDARDS FOR CHEMICAL POLLUTANTS IN SEWAGE SLUDGE

The objectives of the Part 503 Sludge Rule are to protect human health and the environment from reasonably anticipated adverse effect of pollutants in sewage sludge and to encourage the beneficial use of sewage sludge. If the regulation is viewed in this manner, the risk assessment approach used by EPA to establish the numerical limits (cumulative pollutant loading rate) is reasonable. The risk assessment is logical and the exposure analysis is conducted with the best available scientific data. Based on the principles and objectives of the regulation and the approach used for the rule development, the regulation appears to serve its purpose. The limits set on pollutants of concern are sufficient to prevent adverse effects on consumers from food crops or animal products exposed to sludge. This type of regulation provides flexibility for users to develop site-specific land application operations. If the nu-merical limits on pollutant loadings and associated management practices are followed, cropland application of sewage sludge can be practiced without causing harm to public health and the environment. Sludge generators, appliers, and regulatory agencies must ensure that agronomic rates are followed and that numerical limits are not exceeded.

TABLE 7.8 Ceiling Concentrations, Pollutant Concentration, and Annual Pollutant Loading Rates

Pollutant	Ceiling Concentration Limits (mg/kg)	Pollutant Concentration Limits (mg/kg)	Annual Pollutant Loading Rates (kg/ha/yr)
Arsenic	75	41	2.0
Cadmium	85	39	1.9
Chromium[1]	3,000	1,200	150.0
Copper	4,300	1,500	75.0
Lead	840	300	15.0
Mercury	57	17	0.85
Molybdenum[1]	75	18	0.90
Nickel	420	420	21.0
Selenium[1]	100	36	5.0
Zinc	7,500	2,800	140.0

[1] Above limits for chromium and molybdenum (except for ceiling concentration) have been deleted, and the pollutant concentration limits have been revised for selenium.

In the course of reviewing the rule-making process, the Committee noted some inconsistencies in how the numeric limits were developed. A discussion of these inconsistencies follows. While the inconsistencies do not affect food safety, they point to areas that need attention from EPA in its follow-up assessments to improve confidence in the regulation. EPA is scheduled to update Part 503 in the near future and will be addressing pollutants not currently regulated in "Round Two" of Part 503.

Justification for Exempting Organic Pollutants From Regulation Should Be Confirmed

Initially, EPA identified 12 organic pollutants for regulation in 1989. Following a review of public comments on the proposed rule, the Agency undertook a screening exercise to re-evaluate the need to regulate these 12 organic pollutants. The exercise resulted in no organic chemicals being regulated under the final rule promulgated in 1993. The application of the screening criteria, however, leads to concern with certain organic pollutants, whose concentration in sewage sludge may exceed the risk-based limits for these pollutants.

The screening criteria compared the APLR, based upon the NSSS's 99th percentile concentration of each pollutant, to the annual pollutant loading concentration calculated by the Part 503 exposure assessment. If the 99th percentile concentration of a pollutant resulted in an annual pollutant loading rate less than the loading calculated through the risk-based exposure assessment, EPA saw little justification in regulating the pollutant.

However, there are four pollutants (PCBs, benzo(a)pyrene, hexachlorobenzene and N-Nitrosodimethylamine) whose 99th percentile concentrations resulted in calculated APLRs higher than those calculated by the exposure assessment. When calculating the APLR, EPA used 7 metric tons as the annual whole sludge application rate for agricultural land. However, in its development of the APLR for trace elements, 10 metric tons was used. The rationale for using a lower application for calculating trace organic loading rates is based on their decomposition in the soil.

Table 7.9 shows how various percentile concentrations of pollutants from the NSSS compare to the concentrations of pollutants that would have been allowed using the EPA's exposure assessment. This table shows that the 99th percentile concentration of benzo(a)pyrene, hexachlorobenzene, N-Nitrosodimethylamine and PCBs are higher than the concentrations that would have been allowed by the APLR determined through the risk assessment. In other words, should these pollutants be detected in sludges at levels approaching the 99th percentile, they could pose more of a risk than the exposure assessment would have considered acceptable. For the three pollutants other than PCBs, this may be a rare occurrence considering that the NSSS detected these pollutants in less than 5 percent of the sludges sampled. But 19 percent of the sludges had detectable levels of PCBs; thus, those sludges with particularly high concentrations of PCBs may be posing some risk that the risk assessment would consider unacceptable.

However, at the 90th and 50th percentile concentrations of PCBs, few sludges should have total PCB concentrations above the exposure assessment value of 4.6 mg/kg (see Table 7.9). The 90th percentile concentration is 1.2 mg/kg and the 50th percentile concentration is 0.2 mg/kg (the 98th percentile concentration, not shown, is 2.8 mg/kg). Therefore, it is unlikely that most sludges would have levels above 4.6 mg/kg. The concern is then limited to sludges that might have concentrations of total PCBs higher than 4.6 mg/kg; this should be a small percentage of all sludges in the United States.

For N-Nitrosodimethylamine the APLR calculation using the 50th percentile concentration is above the exposure assessment APLR. This pollutant was eliminated because it was detected in less than 5 percent of the samples. However, in those samples where it was detected, the concentrations may be high enough to be of concern.

This entire analysis on organic chemicals depends on the integrity of the NSSS. One criticism of the NSSS was its use of wet weight detection methods and conversion of these to dry weight concentrations. Because of this inconsistency in sampling, the limits of detection may vary by as much as two or more orders of magnitude for the same chemical among sludges from different POTWs. As a result, the frequency of a chemical's detection may be un-derestimated. When the limit of detection value is used in determining the mean and standard deviation of a chemical's concentration, these measures may become unreliable. This is more of a problem for toxic organic chemicals than for trace elements because many of the toxic organic chemicals occur infrequently and near detection limits in sewage sludge, whereas trace elements are almost always detected. To improve the quality of the data set, EPA plans to repeat the Survey in the near future. A second NSSS is needed to provide more definitive doc-

umentation to show whether or not concentrations of organic chemicals are within the range of concentrations that do not pose a risk to human health or the environment. If the NSSS does not support this conclusion, EPA should develop limits for those organics which exceed safe levels.

APLRs May Cause Maximum Permissible Loading Limits to be Exceeded

Sewage sludges that are marketed and distributed in bags are used primarily as soil amendments in landscaping or home gardening. Although "bagged" sludge products are not used routinely for this purpose, the amount of sewage sludge applied each time they are used could be large. In the rule-making process, EPA justified allowing sludges that exceeded the "exceptional quality" criteria of the lowest pollutant concentration limits (see table 7.8) to qualify for marketing and distribution. EPA argued that this approach is justified because pollutant inputs exceeding the calculated annual pollutant loading rate (APLR), should they ever occur, would result in little additional pollutant uptake by plants (Chaney and Ryan, 1992). While this may be an adequate technical justification for agricultural use, allowing sludge of less than the highest quality to be used by the general public opens the door for exceeding regulatory limits, and may undermine the intent of the Part 503 Sludge Rule and public confidence in the law.

Food Safety Is Not Likely to be Affected by the Regulations

In the risk assessment conducted by EPA, 14 exposure pathways were employed. Among them, nine pathways involve human HEI (pathways 1, 2, 3, 4, 5, 11, 12, 13, and 14 in Table 7.5), three of which are directly related to production of human food crops on sludge-amended agricultural land. These are "sludge-soil-plant-human" (pathways 1), "sludge-soil-plant-animal-human" (pathway 4), and "sludge-soil-animal-human" (pathway 5). In the Part 503 Sludge Rule, the final numerical limit of a pollutant is the lowest cumulative pollutant loading of all 14 exposure pathways. Because other, nonfood-chain pathways resulted in lower pollutant limits, the final cumulative pollutant loading for 10 chemical pollutants currently being regulated are all significantly lower than any of the limits that would be derived from the human food-chain exposure pathways. Table 7.10 shows the final cumulative pollutant loading rates in kg/ha for the 10 regulated pollutants and what the limits would have been if they were based on the food-chain exposure pathways.

In some cases, the food crop production pathway limits were not determined because the oral reference dose (RfD) or the recommended dietary allowance (RDA) for that pollutant did not exist owing to the fact that uptake of the particular constituent is inconsequential, or because the food exposure pathway is extremely small compared to exposure from other sources. In this comparison, the margin of safety provided by the current regulation ranges from 6 to over 1,700 times greater than the final cumulative pollutant loading adopted by EPA.

Table 7.11 shows a corresponding comparison for organic pollutants that were not regulated. In this case, the results have all been converted to annual pollutant loading rates (kg/ha/yr) rather than the cumulative pollutant loading rates shown in Table 7.10 for trace ele-

TABLE 7.10 Final Cumulative Pollutant Loading Rates vs. the Maximum Pollutant Loading Rate Calculated from Food-Chain Exposure Pathways

Pollutant	Cumulative Pollutant Loading Rate (kg/ha)	Maximum Permissible Pollutant Loading Rate (kg/ha)		
		Pathway 1	Pathway 4	Pathway 5
Arsenic	41	6,700	NA*	NA
Cadmium	39	610	1,600	68,000
Chromium	3,000	NA	NA	NA
Copper	1,500	NA	NA	NA
Lead	300	NA	NA	NA
Mercury	17	180	1,500	24,000
Molybdenum	18	NA	NA	NA
Nickel	420	63,000	NA	NA
Selenium	100	14,000	15,000	13,000
Zinc	2,800	16,000	150,000	2,200,000

*NA: not applicable because (1) plant uptake is inconsequential, or (2) food exposure route to humans is extremely small compared to exposure from other sources.

SOURCE: EPA, 1993b

ments (see footnote, p. 140). Table 7.11 shows that the most limiting, risk-based pollutant rate used by EPA to screen these chemicals was, in most cases, based on the risk of consuming animal products from animals directly grazing on sludge-amended fields (pathway 5). As discussed in Chapter 6, organic pollutants in sludge are not readily absorbed by plants. To be of significance to humans consuming crops grown with sludge, the soil concentrations of organic pollutants would have to be orders of magnitude higher than those for the grazing animal pathways. Consuming the meat of animals grazed on sludge-amended fields is a potential concern because animals may accumulate certain pollutants in the kidneys and liver (as discussed in Chapter 6). As discussed earlier and shown in Table 7.9, four organic pollutants are of potential concern because their 99th percentile concentration in the NSSS exceeded the risk-based limits for the pollutant. Of these four, the grazing animal pathway was used to set the risk-based limit for hexachlorobenzene and PCBs. Hexachlorobenzene occurred at low (less than 5 percent) frequency in the survey, but PCBs had a detection level of 19 percent; however, the concern is limited to sludges that might have total concentrations of PCBs higher than 4.6 mg/kg, which should also be a small percentage of all sludges in the United States. (see Table 7.12 for a listing of the limiting pathways).

REGULATIONS AND GUIDANCE FOR AGRICULTURAL USE OF MUNICIPAL WASTEWATER

In the United States, there is a long history of using municipal wastewater for crop ir-

TABLE 7.11 Maximum Permissible Organic Pollutant Loading Rates Calculated from Food-Chain Exposure Pathways

Pollutant	Most Limiting Pollutant Rate (kg/ha/yr)	Maximum Permissible Pollutant Loading Rate (kg/ha/yr)		
		Pathway 1	Pathway 4	Pathway 5[b]
Aldrin/Dieldrin	0.03 (5)	2.8[a]	0.2[a]	0.03
Benzo(a)Pyrene	0.15 (3)	23	NA[c]	NA
Chlorodane	0.9 (3)	34	360[a]	23
DDT/DDD/DDE	1.2 (12)	560	48	1.5
Dimethylnitrosoamine	0.02 (3)	87	NA	NA
Heptachlor	0.7 (5)	990	110	0.07
Hexachlorobenzene	0.3 (5)	320	48	0.3
Hexachlorobutadiene	6 (3)	43,30	NA	6
Lindane	0.8 (3)	0	1,500	1.4
PCBs	0.05 (5)	2,300	4.3	0.05
Toxaphene	0.10 (5)	37	120	0.1
Trichloroethylene	100 (3)	2,800	NA	NA
		220,0		
		00		

[a] Values shown for the Most Limiting Pollutant Rate are obtained from EPA, 1993b in Table 5.4-5.6, pp. 5-436, of the Technical Support Document of the Part 503 Regulation. These values represent the smallest of the reference annual pollutant application rates (or "RPa" measured in kg/ha/yr) for the organic pollutant. Where an RPa was not directly available, it was derived from the reference cumulative application rates (or "RPc" measured in kg/ha, which are used in Table 7-10) by assuming a life span of the application site of 100 years. Therefore, the RPa would be 1/100th of RPc. Alternately, an RPa was derived from the reference concentration of a pollutant in sewage sludge (or "RSC" measured in µg/g) by assuming an annual sewage sludge application rate of 10 metric tons/ha. The number in parenthesis indicates the pathway from which the most limiting pollutant rate is derived.

[b] All values converted from concentration of pollutant in sewage sludge (mg/kg) with the assumption of sewage sludge application rate at 10 metric tons/ha/yr.

[c] NA: not applicable because (1) plant uptake is inconsequential, or (2) food exposure route to humans is extremely small compared to exposure from other sources.

SOURCE: EPA, 1993b

rigation. Although the practice has not been extensive, reclaiming municipal wastewater for crop irrigation is well-established in some parts of the country. Over the years, federal agencies have not exercised direct regulatory authority over either wastewater irrigation or other type of effluent reuse, except through provisions in the National Pollutant Discharge Elimination System permit system which regulates the discharge of treated wastewater effluents. In practice, wastewater irrigation is normally treated as a community-wide environmental sanitation and public work improvement project that should undergo rigorous facility planning and engineering evaluation (EPA, 1981). The technical merit, market feasibility, and public health risks of each potential project should be carefully reviewed by many agencies before it is implemented. This

TABLE 7.12 Limiting Pathways for Organic Chemical Pollutants Evaluated in the Development of The Part 503 Sludge Rule

Pollutant	Highly Exposed Individual (HEI)	Limiting Pathway Number
Aldrin	Eating animal fat/milk	5
Dieldrin	Eating animal fat/milk	5
Benzo(a)Pyrene	Sludge eaten by child	3
Chlordane	Sludge eaten by child	3
DDT/DDD/DDE	Eating fish	12
Dimethylnitrosamine	Sludge eaten by child	3
Heptachlor	Eating animal fat/milk	5
Hexachlorobenzene	Eating animal fat/milk	5
Hexachlorobutadiene	Eating animal fat/milk	5
Lindane	Sludge eaten by child	3
PCBs	Eating animal fat/milk	5
Toxaphene	Eating animal fat/milk	5
Trichlororethylene	Sludge eaten by child	3

is usually done and there have been no reported incidents in the United States of food contamination and/or water pollution caused by applying treated wastewater effluents to cropland.

The public health is protected by adequate and reliable treatment of the reclaimed water as well as site restrictions associated with the degree of treatment. In the United States, both the level of wastewater treatment and the microbiological requirements for agricultural reuse vary from state to state. By 1992, at least 19 States had set regulations or guidelines for the use of reclaimed water on food crops.

Recently the EPA published guidelines for the reuse of wastewater in a number of applications, including use in agriculture (EPA, 1992a). Those recommended criteria that are pertinent to infectious disease transmission through agricultural application are summarized in Table 7.13. Reclaimed water applied to most food crops, particularly those that can be eaten uncooked, should be processed at least through secondary treatment followed by filtration and adequate disinfection.

Evolution of Regulations Governing Irrigation with Treated Municipal Wastewater

In many respects, California has been a pioneer in reclaiming and reuse of municipal wastewater. The wastewater irrigation-related regulations in California can therefore be used as a model for examining regulatory development. The California Water Code (State of California, 1987) declares that "the people of the state have a primary interest in the development of facilities to reclaim water containing waste to supplement existing surface and underground water supplies and to assist in meeting the future water requirement of the state" (Cal. Water Code, Section 13510). The statute further declares that "the use of potable domestic water for nonpotable uses, including, but not limited to, cemeteries, golf courses, parks, highway land-

TABLE 7.13 Summary of EPA Guidelines for Reclaimed Water Reuse in Agriculture

Type of reuse	Treatment Required	Water quality
Food crops not commercially processed	Secondary Filtration Disinfection	<2.2 fecal Coliform/100mL 1mg/L Cl_2 residual after 30 min. contact time (minimum) Turbidity ≤ 2NTU ≤ 10mg/L BOD
Food crops commercially processed including orchards and vineyards	Secondary Disinfection	≤200 fecal coliform/100mL 1mg/L Cl_2 residual after 30 min. contact time (minimum) ≤ 30mg/L BOD ≤ 30mg/L SS
Nonfood crops pasture, fodder, fiber and seed	Secondary Disinfection	≤ 200 fecal coliform/100mL 1mg/L Cl_2 residual after 30 min. contact time (minimum) ≤ 30mg/L BOD ≤ 30mg/L SS

scaped areas, and industrial and irrigation uses, is a waste or an unreasonable use of the water within the meaning of .... the California Constitution if reclaimed water is available....." (Cal. Water Code, Section 13550). These policy declarations culminated in a mandate that "the State Department of Health Services shall establish statewide reclamation criteria for each type of use of reclaimed water where such use involves the protection of public health" (Cal. Water Code, Section 13521). In California, wastewater reclamation and reuse is an integral part of the water resource management plan. The provisions of Reclamation Criteria of California (Department of Health Services, 1993) reflect the legislative intent. They are conducive to water reuse and are enacted to protect public health when reclaimed water is used.

Long before the statutes were official, domestic wastewater was used in crop irrigation (Ward and Ongerth, 1970). In 1910, at least 35 communities in California operated sewage farms to dispose of raw sewage or septic tank effluents. In 1918, the California Board of Health adopted regulations governing the use of sewage for irrigation purposes. It prohibited the use of raw sewage, septic tank effluents, and other similar wastewater for irrigation of vegetables that would be consumed uncooked by people. The regulation permitted the use of untreated wastewater for irrigating crops that would be cooked before consumption, provided that a 30-day or longer waiting period was observed prior to harvest. It also permitted the use of reclaimed water for fruit and nut trees and melon crops if the products did not come into direct contact with the wastewater. For the next 75 years, the regulations continued to evolve in re-sponse to new experience in wastewater use, new wastewater treatment technology, and as the demand for reclaimed wastewater rose.

In 1933, the regulation was revised to allow the use of well-oxidized, nonputrescible, and reliably disinfected or filtered effluents for irrigation of vegetable crops for raw consumption.

Requirements were established for the finished water's coliform counts and the treatment plant operations. Subsequently, a more comprehensive regulation for the use of reclaimed water for irrigation and recreational impoundments was adopted in 1968 to accommodate the increasing population and volume of reclaimed water available for reuse. The new standards specified levels of wastewater treatment required and coliform density of finished water for various type of uses. The need to insure wastewater treatment reliability and to limit public access to the application site was documented based on the data of several field investigations. In 1975, regulatory provisions were added to guarantee wastewater treatment reliability and to limit public access to the application site. Since it inception, the Reclamation Criteria (California De-partment of Health Services, 1993) has been revised several times. However, the technical requirements for crop irrigation remained the same as written in 1975.

General Description of the State Regulations

As the demand for reclaimed wastewater for crop irrigation spread across the nation, many states enacted regulations or developed guidelines to govern its use. Recently, EPA (1992a) published guidelines for water reuse including the use of reclaimed water in agriculture in the United States. The conditions for use of reclaimed water for irrigating food and nonfood crops in 18 and 35 states, respectively were summarized.

The Reclamation Criteria of California (California Department of Public Health Services, 1993) have been a model for reclaimed water regulations for many states. The primary health concerns targeted have been the risk of pathogen and chemical pollutant exposure to workers involved in irrigation projects, to residents near a wastewater irrigation site, and to consumers of food produced from wastewater-irrigated fields. Regulations have focused on infectious disease risks by establishing the following:

- the level of wastewater treatment required (primary treatment, secondary treatment, oxidized, filtered, coagulated, disinfected, etc.);
- the upper limits for selected water quality parameters to insure wastewater treat-ment reliability (maximum BOD, total suspended solids, chlorine residual, turbidity, indicator organisms concentrations permitted, and pH range, etc.), and on-line chlorine residual and turbidity;
- treatment reliability provisions;
- site management practices that prevent workers and residents from being exposed to applied water and contaminated soils at the application site (providing setback distance, limiting public and worker access, posting warning signs, cross-connection prevention, hydraulic loading rate, etc.); and
- water management practices that minimize contamination of crops (specifying method of irrigation and/or types of crops permitted, requiring waiting period for crop harvesting or animal grazing, maximum water application rate, etc.)

Regulations define the conditions necessary to minimize human exposure to pathogens. This is accomplished by specifying the degree of treatment the wastewater receives, by speci- fying time and environmental conditions to reduce pathogen survival prior to human contact, and by restricting certain food crops depending on the level of reclaimed water quality. There are usually backup technical requirements in these state regulations such as simultaneous specification of wastewater treatment levels to minimize presence of pathogens, provision of setback distance to prevent direct contact with pathogens, and waiting period requirement after irrigation to reduce pathogen survival.

Five of the 18 states that permit reclaimed water for irrigation of produce crops require advanced wastewater treatment (e.g., oxidation, clarification, coagulation, filtration, and dis-infection). To ensure the consistency of treatment performance, the total coliform (or fecal coliform) density of finished water is required to be less than or equal to 2.2 per 100 milliliters. Under such a circumstance, the reclaimed water is considered to be essentially free of pathogens for nonpotable reuse purposes. Other requirements such as setback distance, waiting period, and restricted site access are, in this case, not necessary.

At the other end of the spectrum, primary effluents may be permitted to irrigate food crops for processing if requirements are met to protect workers and nearby residents and to prevent water pollution. Human exposure to pathogens is controlled by factors other than pathogen density in the wastewater effluents. The deficiency in one factor may be mitigated by more stringent requirements of other factors. For example, in Utah, food crops may be irrigated by secondary effluents with total coliform density up to 2000/100 ml (30-day average), provided spray irrigation is not used. In this case, the risk of exposure to pathogens is reduced by preventing the water from coming into direct contact with the food crop.

If reclaimed water is used to irrigate nonfood crops or animal food crops, the risk of exposure to pathogens is considerably smaller than with vegetables produced for raw con-sumption by humans. Therefore, restrictions on wastewater treatment levels and operational reliability usually are more relaxed for nonfood crops than are those required for irrigating human-consumed food crops. Effluents from oxidation ponds, primary treatment, and secondary treatment are all acceptable under various circumstances. But the other requirements such as setback distance and site access usually remained the same or become more stringent for the protection of workers and nearby residents. Many states (15 of the 35 states that permitted reclaimed wastewater for nonfood crop irrigation in 1992) either: (1) ban the used of lower-quality treated wastewater on pasture, (2) require disinfection when irrigating pastures for milking animals, or (3) require an extended waiting period before animals are allowed on fields irrigated with lower-quality wastewater effluents.

So far, trace chemical contaminants in treated municipal wastewater have not been targeted by State regulations or EPA guidelines for reclaimed water because their concentrations in wastewater receiving a minimum of secondary treatment are comparable to conventional sources of irrigation water (see Chapter 4). Source control of industrial inputs, conventional secondary treatment, and advanced treatment are relied on to reduce effluent concentrations of chemical pollutants to levels that meet current irrigation water quality criteria (e.g., Wescot and Ayers, 1985) for chemicals that are potentially harmful to crop production or to ground water contamination. This assumption appears justified if industrial pretreatment programs are rigor-ously enforced by municipalities and wastewater is properly treated. In such case, it is possible to produce reclaimed wastewater that meets the highest required water quality standard for irrigation of food crops and with trace element and organic chemical concentrations that are lower than the maximum contamination levels of the National Primary Drinking Water Standard (Crook et al., 1990). If the concentrations of chemical pollutants tabulated in Table 7.14 are typical for reclaimed water, the annual pollutant inputs to the soil through reclaimed water irrigation will be small and will be balanced or out-balanced by the output through crop absorption (see Chapter 4 for details). In this manner, toxic chemicals and trace elements are not expected to accumulate in soils irrigated with reclaimed water to levels that are harmful to humans.

Adequacy of Current Regulations for Reclaimed Water

California's Water Code defines the Reclamation Criteria as "levels of constituents of reclaimed water, which will result in reclaimed water safe from the standpoint of public health, for the uses to be made" (Cal. Water Code, Section 13520). Early on, state regulatory agencies recognized that numerous pollutants are present in reclaimed water, and it is impractical, if not impossible, to track all of them. Besides, there is little epidemiological data to define the dose-response relationships. Defining "levels of constituents of reclaimed wastewater" suitable for various uses is difficult if the epidemiological data for quantitative dose-response evaluation are not available. As a result, regulations for reclaimed wastewater irrigation always rely on the capability of wastewater treatment and site management to accomplish the goal of public health protection.

While the public health safety record for reclaimed water irrigation has been excellent, there are little epidemiological data to support or refute the currently regulated levels (Crook, 1978; 1982). For developing countries, recent research in epidemiology indicates that the public health risks resulting from crop irrigation with treated municipal wastewater are overestimated, and that the United States guideline may be "unjustifiably restrictive, particularly with respect of bacterial pathogens" (World Health Organization, 1989).

Are current regulations for reclaimed water adequate to protect human health? The answer to this question does not lie in the regulations alone. Over the past century, the en-vironmental sanitation practice of collecting, treating, and disposing municipal wastewater has been instrumental in improving the public health. Over time, an integrated infrastructure has evolved to regulate, plan, and implement the monumental task of handling municipal wastewater day-in and day-out. This system is vertically integrated with the environmental protection and pollution control authorities at the federal level, water quality and public health authorities at the state level, and the environmental sanitation authorities at the local level. The nation is also horizontally connected across political boundaries by special service agencies that have re-sponsibilities for collecting, treating and disposing wastewater. Within the framework of this infrastructure, policies are made; funds are generated and appropriated, regulations are enacted;and physical plants are planned, built, and maintained. The common objective cutting across the entire infrastructure are to safeguard public health and to prevent environmental pollution.

TABLE 7.14 Concentration of Trace Elements and Toxic Organic Chemicals in Selected Treated Effluents in California

Pollutant	Unit	San Jose Creek	Whittier Narrow	Pomona	NPDWS[a]
Arsenic	mg/l	0.005	0.004	<0.004	0.05
Aluminum	mg/l	<0.06	<00	<0.08	1.0
Barium	mg/l	0.06	0.04	0.04	1.0
Cadmium	mg/l	ND[b]	ND	ND	0.01
Chromium	mg/l	<0.02	<0.03	<0.03	0.05
Lead	mg/l	ND	ND	<0.05	0.05
Manganese	mg/l	<0.02	<0.01	<0.01	0.05
Mercury	mg/l	<0.0003	ND	<0.0001	0.002
Selenium	mg/l	<0.001	0.007	<0.004	0.01
Silver	mg/l	<0.005	ND	<0.005	0.05
Lindane	µg/l	ND	ND	ND	4
Endrin	µg/l	ND	ND	ND	0.2
Toxaphene	µg/l	ND	ND	ND	5
Methoxychlor	µg/l	ND	ND	ND	100
2,4-D	µg/l	ND	ND	ND	100
2,4,5-D	µg/l	<01	ND	ND	10
Turbidity	NTU[b] (silica scale)	1.6	1.6	1.0	2
Total Coliform	No./100 ml	<1	<1	<1	2.2

[a] National Primary drinking water standards

[b] ND denotes the constituent was not detected in the specimen.

SOURCE: Crook et al., 1990.

The interdependency and interlinking of the components provide check-and-balance and technical redundancy to ensure that integrity will not be breached and that the well-being of the public is not threatened by pollutants and pathogens in the wastewater (see additional discussion in Chapter 8 on Other Government Regulations).

When viewed in this manner, the practice of irrigation with reclaimed water is not a monolithic event. Instead, it is merely one component of this integrated wastewater handling, treatment, and disposal infrastructure erected to protect public health and prevent environmental pollution. Whether crop irrigation can be safely administered is therefore interdependent on whether other components of the system are performing up to expectation. The current re-claimed wastewater irrigation regulations take full advantage of the advances in wastewater treatment technology to deliver water of appropriate quality. Again, the record has been a successful one.

If the integrity of the infrastructure is maintained, it is reasonable to assume that re-clamation of wastewater for food crop irrigation will continue to be practiced safely. Because of the checks and balances and technical redundancy offered by the system, the likelihood of failure is small and, if failure occurs, it is likely to be promptly detected and corrected. Although the risk from trace chemical contaminants in reclaimed water applied to food crops has not been quantified, it is likely that such use presents little additional risk since the levels of trace chemical contaminants in reclaimed water are normally within accepted guidelines that have been developed for irrigation with conventional sources of irrigation water.

SUMMARY

Pathogen Regulations for Sludge

In the United States, the Part 503 Sludge Rule is the current management strategy for the application of sludge to land. At the present state of our knowledge, this rule appears to be, with one possible exception, adequate for the protection of the public from the transmission of waste associated pathogens. The possible exception is the potential that the prescribed waiting period between the application of Class B sludge and animal grazing may not be adequate to prevent the transmission of tapeworm to grazing cattle.

Toxic Chemicals Regulations for Sludge

The Part 503 Sludge Rule was developed with the intent to encourage beneficial use of sewage sludge. Using risk-assessment-based calculations, the regulation specifies numerical limits for chemical pollutant loading rates within which the sewage sludge may be safely applied on cropland. The regulation has a sound conceptual basis for protecting public health and encouraging beneficial use of sewage sludge.

In terms of trace elements, sewage sludge that is applied according to the pollutant loading rates specified in Part 503 should not affect the safety of the nation's food supply. The pollutant loading rates are set by the maximum permissible loading rates of nonfood-chain pathways, which are 6 to 1,700 times smaller than the maximum permissible pollutant rates ac-cording to food-chain related exposure pathways.

No organics are currently regulated by Part 503. Most toxic organic compounds found in municipal sewage sludges exist at concentrations well below those considered to pose a risk to human health or the environment. However, benzo(a)pyrene, hexachlorobenzene, and N-nitrosodimethylamine, detected in less than 5 percent of the sludge samples analyzed in the NSSS, occurred at concentrations above the 99th percentile ceiling concentration used by EPA in setting an acceptable risk. Total PCBs may be of concern because they occurred at a higher frequency of detection (19 percent), but only a small fraction is expected to exceed risk-based limits. Some of the sample preparation and analytical methods used in the NSSS for measuring concentration of toxic organic compounds in sludge were not sufficiently sensitive to show whether or not toxic organic compounds were present sludges at levels that would pose a threat to human and animal health. Therefore, a second survey should be conducted with better sampling methods to determine concentrations of toxic organic compounds, and those which exceed risk-based limits should be regulated.

Sludges allowed for marketing and distribution to the public have the potential to cause maximum permissible pollutant limits to be exceeded. While not a food safety issue, this has the potential to undermine the intent of Part 503.

Regulations for Effluent Irrigation

State regulations governing reclaimed wastewater for crop irrigation rely on wastewater treatment and site management to (1) minimize the presence of pathogens, (2) prevent workers, residents, and consumers from direct contact with wastewater or wastewater-contaminated soils and crops, and (3) minimize the opportunity for pathogen survival after water application. They do not address trace chemical contaminants. The requirements stipulated in these regulations, such as type of wastewater treatment, set-back distance, waiting period, coliform density of finished water, etc., vary considerably. The variation is caused by the many factors that control the risk of exposure. The deficiency in one factor is often offset by more stringent requirements for other factors.

The current requirements of reclaimed wastewater for crop irrigation were not derived by risk-based analysis and are not supported or refuted by actual epidemiological data. They are based on experience in wastewater treatment and reclaimed wastewater crop irrigation operations. The checks and balances and technical redundancies provided by today's wastewater treatment infrastructure seem to provide an ample margin of safety.

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TABLE 7.9 Comparison of NSSS Percentile Concentrations of Pollutants to Concentrations Using EPAs Risk Assessment for the Part 503 Sludge Rule

Pollutant	Exposure kg/ha/yr[a]	Exposure mg/kg[b]	99th kg/ha/yr[c]	99th mg/kg[d]	90th kg/ha/yr[e]	90th mg/kg[f]	50th kg/ha/yr[g]	50th mg/kg[h]
Aldrin/Dieldrin	0.027	2.7	0.00074	0.074	0.0001	0.01	1.0000E-05	0.001
Benzo(a)pyrene	0.15	15.0	0.43	43.0	0.286	28.6	0.047	4.7
zChlordane	0.86	86.0	0.18	1.8	0.005	0.5	0.0024	0.24
DDT/DDE/DDD	1.2	120.0	0.0014	0.14	0.00041	0.041	0.00009	0.009
Heptachlor	0.074	7.4	0.0014	0.14	0.0003	0.03	0.0001	0.01
Hexachlorobenzene	0.29	29.0	0.43	43.0	0.286	28.6	0.045	4.5
Hexachlorobutadiene	6.0	600.0	0.43	43.0	0.286	28.6	0.045	4.5
Lindane	0.84	84.0	0.0018	0.18	0.0005	0.05	0.0002	0.02
N-Nitrosodimethylamine	0.021	2.1	2.1	210.0	1.43	143.0	0.228	22.8
PCBs	0.046	4.6	0.06	6.0	0.012	1.2	0.002	0.2
Toxaphene	0.1	10.0	0.074	7.4	0.02	2.0	0.0096	0.96
Trichloroethylene	100.0	10,000.0	0.07	7.0	0.02	2.0	0.0035	0.35

[a] The APLR from the 503 Risk Assessment (provided in Table 6, Appendix B) EPA, 1993b

[b] The concentration of pollutants in sludge necessary to meet the APLR from the Part 503 Risk Assessment, EPA, 1993b with an Annual Whole Sludge Application Rate of 10 metric tons/ha/yr.

[c] The APLR derived from using the 99th percentile concentration of the pollutant

[d] The 99th percentile concentration of pollutants in sludge from 1988 NSSS (provided in Table 4, Appendix B, EPA, 1993b, except for PCBs, which is based on weighted nonparametric substitution method stratum estimate, SM-COM. see p. 7-58 EPA, 1992b)

[e] The APLR derived from using the 90th percentile concentration of the pollutant

[f] The 90th percentile concentration of pollutants in sludge from the 1988 NSSS (provided in Table 7-11, EPA, 1992b)

[g] The APLR derived by using the 50th percentile concentration of the pollutant

[h] The 50th percentile concentration of pollutants in sludge from the 1988 NSSS (provided in Table 7-11, EPA, 1992b)