Chapter 9

HEALTH AND ENVIRONMENTAL EFFECTS

9.1 Introduction

Wastewater constituents that are of major concern for health or environmental reasons are:

- Nitrogen
- Phosphorus
- Dissolved solids
- Trace elements
- Microorganisms
- Trace organics

Potential effects of these constituents vary among the three major types of land treatment, as shown in Table 9-1. The relationship of wastewater constituents to health effects is presented in Table 9-2.

In general, constituent removals are greatest for SR systems. Health and environmental effects of RI systems depend on site selection and design factors such as hydraulic loading rate and length of application and resting cycles. Overland flow has the fewest potential impacts on ground water because very little water penetrates below the soil surface. However, renovated water from OF systems is normally discharged to local surface waters as a point source, and, therefore, can affect surface water quality.

Recently, the EPA has funded extensive studies at several operating land treatment systems to evaluate potential long-term health and environmental effects. The ten study sites are presented in Table 9-3. Results from these and other studies are included in this chapter.

TABLE 9-1
LAND TREATMENT METHODS AND CONCERNS [1]

Potential Concerns	SR	RI	OF
Nitrogen			
Health: drinking water aquifers	X	X	--
Environment: eutrophication	X	X	X
crops	X	--	--
Phosphorus			
Environment: eutrophication	X	X	X
Dissolved solids			
Health: drinking water aquifers	X	X	--
Environment: soils	X	X	X
crops	X	--	X
ground water	X	X	--
Trace elements			
Health: drinking water aquifers	X	X	--
crops	X	--	X
Environment: crops	X	--	--
animals	X	--	X
Microorganisms			
Health: drinking water aquifers	X	X	--
crops	X	--	X
aerosols	X	--	X
Environment: animals	X	--	X
Trace organics			
Health: drinking water aquifers	X	X	--
crops	X	--	--

Note: An X in the matrix indicates the possibility for concern. The magnitude of the impact is not considered.

TABLE 9-2
RELATIONSHIP OF POLLUTANTS TO HEALTH EFFECTS[a]

Pollutant (agent)	Principal health effect
Nitrate nitrogen	Methemoglobinemia
Sodium	Cardiovascular
Trace elements	Toxicity
Microorganisms	Infection, disease
Bacteria	
Virus	
Protozoa	
Helminths	
Trace organics	Toxicity, carcinogenesis

a. Adapted from reference [2].

TABLE 9-3
EPA LONG-TERM EFFECTS STUDIES

Location	Date operation started	Flow during study, m^3/s	Level of preapplication treatment	Crops	Hydraulic loading rate, m/yr
Slow rate systems					
Camarillo, California [3]	1966	0.130	Secondary (activated sludge) with disinfection	Tomatoes, broccoli	1.6
Dickinson, North Dakota [4]	1959	0.044	Secondary (aerated ponds) with disinfection	Forage grasses	1.4
Mesa, Arizona [5]	1950	0.208	Secondary (trickling filters)	Grain, corn, barley	4-8.6
Roswell, New Mexico [6]	1944	0.175	Secondary (trickling filters followed by oxidation ditch) with disinfection	Corn, alfalfa, sorghum	0.8
San Angelo, Texas [7]	1959	0.241	Primary	Forage grasses, pasture	2.9
Tooele, Utah [8]	1967	0.061	Secondary (trickling filters) with disinfection	Forage grasses, alfalfa. Test plots of beans, carrots, lettuce, peas, radishes, sweet corn, wheat	0.6
Rapid infiltration systems					
Hollister, California [9]	1945	0.044	Primary	--	15
Lake George, New York [10]	1939	0.058	Secondary (trickling filters)	--	43
Milton, Wisconsin [11]	1957	0.013	Secondary (activated sludge)	--	224
Vineland, New Jersey [12]	1926	0.215	Primary	--	19

Note: See Appendix G for metric conversions.

9.2 Nitrogen

Both nitrates and ammonia are of concern in land treatment systems. Other nitrogen compounds either are harmless or are degraded during land treatment.

Storage ponds can be used in conjunction with land treatment to achieve high nitrogen removals. Although such ponds work well for SR and OF systems, the resulting algal growth may cause soil clogging at RI systems. The use of storage ponds for nitrogen removal is described in greater detail in Section 4.4.1.

9.2.1 Crops

In the general case, nitrogen is beneficial for crops, increasing yields and quality. However, uptake of excess nitrogen in some crops can increase succulence beyond desirable levels causing lodging in grain crops and reduced sugar content in beets and cane, for example. High levels of nitrogen or application beyond seasonal needs may induce more vegetative than fruit growth, and also delay ripening. High nitrate content in forages can be a concern if these are the principal ration for livestock. Cattle can also suffer from grass tetany, which is related to an imbalance of nitrogen, potassium, and magnesium in pasture grasses. These potential nitrogen related crop effects are not expected with typical municipal wastewaters applied to properly designed and well managed land treatment systems.

9.2.2 Ground Water

As indicated in previous chapters, EPA guidance requires a maximum contaminant level (MCL) of 10 mg/L nitrate as nitrogen at the land treatment boundary. This is to avoid the potential of methemoglobinemia in very young infants using the water supply. As a result, nitrogen is often the limiting parameter for land treatment design. Methods to satisfy this requirement are described in the design chapters (Sections 4.5.2 and 5.4.3.1).

9.2.3 Surface Water

Un-ionized ammonia is toxic to several species of young freshwater fish. The oxygen carrying capacity of certain fish can be impaired at concentrations as low as 0.3 mg/L un-ionized ammonia (approximately 2.5 mg/L total ammonia nitrogen at normal pH values) [13]. For this reason, many land treatment systems that discharge to surface waters are designed to provide nitrification. Using normal application rates, OF and SR systems produce a well nitrified effluent. Renovated water from RI systems contains very little ammonia nitrogen if relatively short application periods are alternated with somewhat longer drying periods (Table 5-13).

Land treatment systems that discharge to surface waters in which nitrogen is the limiting nutrient are designed to achieve nitrogen removal to avoid algal blooms and increased rates of eutrophication. Methods for achieving nitrogen removal are described in Sections 4.5.2, 5.4.3.1, and 6.5.2.

9.3 Phosphorus

Phosphorus is not known to cause adverse health effects. Like nitrogen, it is an important nutrient for crops. Because there are no drinking or irrigation water standards, the principal concern is that phosphorus can be the limiting nutrient that controls eutrophication of surface waters.

9.3.1 Soils

The principal phosphorus removal mechanisms at SR and RI systems are soil adsorption and precipitation. Removals achieved at operating SR and RI systems are shown in Tables 4-3 and 5-3.

9.3.2 Crops

Normal crop uptake of phosphorus occurs in both SR and OF systems with loadings far in excess of crop needs. No adverse effects on crops from phosphorus have been reported.

9.3.3 Ground Water

Phosphorus concentrations found in percolates from SR and RI systems are presented in Tables 4-3 and 5-3. As shown in these two tables, percolate phosphorus concentrations are reduced substantially within relatively short travel distances.

9.3.4 Surface Water

Because phosphorus concentrations in SR and RI percolates generally are quite low (less than 1 mg/L), adequate phosphorus removal usually occurs before any percolate intercepts surface water. At OF systems, where phosphorus removal averages 50 to 60%, additional treatment may be necessary if phosphorus is limited by the discharge permit.

9.4 Dissolved Solids

Salt concentrations in domestic wastewater vary widely, according to the salinity of the local water source and the chemicals added during preapplication treatment (if any). Depending on the salinity of the applied wastewater, soil properties, crops, and water for livestock and human consumption may be affected.

9.4.1 Soils

High concentrations of sodium in applied wastewater can cause substitution of sodium ions for other cations in the soil.

This substitution tends to disperse clay particles within the soil, leading to decreased permeability, lowered shear strength, and increased compressibility [14]. Wastewater with an SAR of less than 4 has caused no changes in these properties [8]. No adverse soil impacts are expected unless the SAR exceeds 9.

9.4.2 Crops

Salinity, as measured by the electrical conductivity of the water, can cause yield reductions in crops. Crops vary widely in tolerance to salinity. The salinity tolerances and leaching requirements of several field and forage crops are given in Table 9-4. Salinity effects are generally only of concern in arid regions where accumulated salts are not flushed from the soil profile by natural precipitation. No salinity problems have been reported at the systems listed in Table 9-3.

Boron toxicity can occur because this element tends to be unaffected by most preapplication treatment processes. Fruit and citrus trees are affected at 0.5 to 1.0 mg/L; field crops can be affected at 1.0 to 2.0 mg/L; and most grasses are relatively tolerant at 2.0 to 10.0 mg/L.

Sodium and chloride ions are usually present together in wastewaters. Most tree crops are sensitive to sodium and chloride taken up by the roots. Leaves of many crops may show leaf—burn due to excessive sodium or chloride adsorption or bicarbonate deposition under low-humidity, high—evaporation conditions. Irrigating at night or increasing the rotation speed of sprinkler heads can help avoid these problems.

9.4.3 Ground Water

The salinity of percolate from some systems may limit the potential for reuse of renovated water. National drinking water standards recommend that finished potable water contains less than 500 mg/L total dissolved solids (TDS), but more saline waters have been used without ill effects. Excessive TDS can cause poor taste in drinking water, may have laxative effects on consumers, and may corrode equipment in water distribution systems. Salinity restrictions on water for livestock uses are not as stringent as for drinking water. In general, a TDS of 10,000 mg/L is the upper limit for healthy larger animals such as cows and sheep; a limit of 5,000 mg/L TDS should be used for smaller animals (including poultry), lactating animals, and young animals [13].

TABLE 9-4
TOLERANCE OF SELECTED CROPS TO SALINITY IN IRRIGATION WATER [15]

	Yield decrement to be expected due to salinity of irrigation water						
	0%			50%			
	EC_e, mmho/cm	EC_w, mmho/cm	LR, %	EC_e, mmho/cm	EC_w, mmho/cm	LR, %	Maximum EC_{dw}, mmho/cm
Field crops							
Barley	8	5.3	12	18	12	27	24
Sugarbeets	6.7[a]	4.5	11	16	10.7	26	42
Cotton	6.7	4.5	11	16	10.7	26	42
Safflower	5.3	3.5	12.5	14	8	28.5	28
Wheat	4.7[a]	3.1	8	14	9.3	23	40
Sorghum	4	2.7	7.4	12	8	22	36
Soybean	3.7	2.5	10	9	6	23	26
Rice (paddy)	3.3	2.2	9	8	5.3	22	24
Corn	3.3	2.2	12	7	4.7	26	18
Sesbania	2.7	1.8	7	9	6	23	26
Broadbean	2.3	1.5	8	6.5	4.3	24	18
Flax	2	1.3	7	6.5	4.3	24	18
Beans (field)	1	0.7	6	3.5	2.3	19	12
Forage crops							
Bermudagrass	8.7	5.8	13	18	12	27	44
Tall wheatgrass	7.3	4.9	11	18	12	27	44
Crested wheatgrass	4	2.7	6	18	12	27	44
Tall fescue	4.7	3.1	8	14.5	9.7	24	40
Barley (hay)	5.3	3.5	10	13.5	9	25	36
Perennial rye	5.3	3.5	10	13	8.7	24	36
Harding grass	5.3	3.5	10	13	8.7	24	36
Birdsfoot trefoil	4	2.7	10	10	6.7	24	28
Beardless wild rye	2.7	1.8	6	11	7.3	26	28
Alfalfa	2	1.3	5	8	5.3	19	28
Orchardgrass	1.7	1.1	4	8	5.3	20	26
Meadow foxtail	1.3	0.9	4	6.5	4.3	18	24
Clover	1.3	0.9	6	4	2.7	19	14

Notes:

EC_e = electrical conductivity of saturation extract.

EC_w = electrical conductivity of irrigation water.

LR = leaching requirement: that fraction of the irrigation water that must be leached through the active root zone to control soil salinity at the tolerance level. This is in addition to the irrigation water taken up by the plants. $LR = EC_w \times 100/EC_{dw}$. (For an approximate conversion to TDS, mg/L, or ppm, multiply mmho/cm by 640.)

EC_{dw} = maximum concentration of salts in drainage water that can be tolerated by crop. At 100% efficiency, applied water (needed to satisfy ET + LR) is equal to ET/(1 - LR).

Conversion from EC_w to EC_e assumes that irrigation water salts increase three fold in salinity in becoming soil water salts (EC_{sw}). This occurs in the more active part of the root zone due to ET. ($EC_w \times 3 = EC_{sw}$; $EC_{sw} \div 2 = EC_e$)

a. Tolerance during germination (beets) or early seedling stage (wheat, barley) is limited to EC_e = about 4 mmho/cm in the upper soil area where germination and early growth take place.

If the salinity of a community*s wastewater is significantly higher than the salinity of the ground water, land treatment may be limited to processes that discharge to surface waters or renovated water recovery may be required to protect ground water quality. This condition occurs most frequently in the arid western states where water resources are limited and protection of ground water from increasing salinity is a major concern.

9.5 Trace Elements

Trace elements (heavy metals) in municipal wastewaters are contributed by both domestic and industrial dischargers; contributions vary widely with industry. Frequently, trace element concentrations in municipal wastewaters are lower than the limits established for drinking water. Therefore, in most communities, land treatment is unlikely to cause direct adverse health or environmental effects [16].

The fate of trace elements during land treatment is a concern primarily for two reasons:

- Trace elements, particularly cadmium, can accumulate in the food chain.
- Trace elements can move through soil and enter ground water.

9.5.1 Soils

Movement of trace elements into and through the soil may occur during wastewater application or after land treatment operations have ceased. For this reason, it is important to understand removal mechanisms and the conditions that influence retention in and transport through the soil (see Sections 4.2.4 and 5.2.4).

Concentrations of trace elements retained in the soil profile at SR and RI sites are highest near the soil surface and decrease with depth [17]. Removal efficiencies at selected systems are presented in Tables 4-4 and 5-4. Soils can retain a finite amount of trace elements; the capacity or design life for metals removal is at least the same order of magnitude as for phosphorus. For example, in typical New England soils, the design life for copper and cadmium based only on ion exchange capacity could be several hundred years using an SR system and seasonal wastewater application [l].

At OF systems, trace elements are adsorbed at the soil surface in the organic layer of decomposing organic material and plant roots. Because adsorption occurs as the applied wastewater flows across the soil surface, metals tend to accumulate near the point of wastewater application. In pilot studies near Utica, Mississippi, approximately 50% of the monitored trace elements (cadmium, copper, nickel, and zinc) was removed on the upper third of the treatment slope [18]. Data from the same pilot studies, presented in Table 9-5, indicate that most of the trace elements entering this system are retained near the soil surface. The system has not approached its full capacity for trace element removal.

TABLE 9-5
MASS BALANCE OF TRACE ELEMENTS IN OF SYSTEM AT UTICA, MISSISSIPPI [18]

Metal	Component	Grams	Percent of applied
Cadmium	Applied	46.21	
	Grass	0.54	1.2
	Runoff	3.50	7.6
	Soil	42.14	91.2
Copper	Applied	90.39	
	Grass	3.59	4.0
	Runoff	13.13	14.5
	Soil	73.67	81.5
Nickel	Applied	110.11	
	Grass	1.50	1.4
	Runoff	5.20	4.7
	Soil	103.39	93.9
Zinc	Applied	264.05	
	Grass	20.03	7.6
	Runoff	32.06	12.1
	Soil	212.03	80.3

The results of one study on an abandoned RI basin are reported in Table 5-5. These data, collected approximately 1 year after the last wastewater application, indicate that relatively little leaching occurred both during the 33 years of operation and in the year following operation. Leaching should not be a problem provided a soil pH of at least 6.5 is maintained. At this pH, most trace elements are precipitated as insoluble compounds. Methods for adjusting soil pH are discussed in Section 4.9.1.3.

9.5.2 Crops

Bioconcentration of trace elements in the food chain is most likely to occur during the operational years of a land treatment system. Plant uptake of trace elements occurs when the elements are present in soluble or exchangeable form in the root zone. Generally, this occurs in increasing amounts as more adsorption sites are occupied and as the soil pH decreases. To minimize the plant uptake of trace elements, the soil pH should be maintained at 6.5 or above. The trace elements that are of greatest concern are cadmium, copper, molybdenum, nickel, and zinc.

With regard to health effects, nickel and zinc are of least concern because they cause visible adverse effects in plants before plant concentrations are high enough to be of concern to animals or man. Cadmium, copper, and molybdenum all may be harmful to animals at concentrations that are too low to visibly affect plants. Copper is not a health hazard to man or monogastric animals, but can be toxic to ruminants (cows and sheep). These animals* tolerance for copper increases as available molybdenum increases. Molybdenum itself may cause adverse effects in animals at 10 to 20 ppm in forage that is low in copper [13] . Cadmium is toxic to both man and animals in doses as low as 15 ppm, but ruminants absorb very small proportions of the cadmium they ingest. Once absorbed, however, this metal is stored in the kidneys and liver [19], so that most meat and milk products remain unaffected by high cadmium concentrations ingested by livestock [13].

With regard to effects on crops, trace elements have not caused any adverse effects on any of the crops grown at the SR systems listed in Table 9-3. Similarly, analyses of forage crops grown at the Melbourne, Australia, system, which has operated since 1896, show relatively little increase in trace element uptake over forage crops irrigated with potable water [20]. Typical trace element concentrations in forage grasses are presented in Table 9-6 with concentrations in forage crops grown at selected SR sites.

At the OF site near Utica, trace elements have had no adverse effects on the grasses grown. As with the soil in this system, grass uptake of trace elements is greatest near the point of wastewater application and decreases with distance down the treatment slope. Grass uptake accounted for only 1.2, 1.4, 4.0, and 7.6% of the applied cadmium, nickel, copper, and zinc, respectively [18]. If trace element uptake is a concern, the use of Festuca rubia (red fescue) at OF systems is recommended because trace element uptake by this plant is approximately a third the trace element uptake of most grasses [18].

TABLE 9-6
TRACE ELEMENT CONTENT OF FORAGE GRASSES AT
SELECTED SR SYSTEMS [4, 7, 21]
ppm

		Melbourne, Australia		Dickinson, North Dakota		San Angelo, Texas
Trace element	Typical range	Control site	Wastewater irrigated forage	Control site	Wastewater irrigated forage	Wastewater irrigated forage
Boron	1.0-80	NT[a]	NT	14.1	19.6	NT
Cadmium	0.2-0.8	0.77	0.64-1.28	<5	<5	0.2-0.5
Chromium	0.1-0.5	6.9	6.9-28	2	<5	<0.5-1.5
Cobalt	0.05-0.5	<0.64	<0.64-1.28	<1	<1	NT
Copper	2.0-15	6.5	11-19	7.4	6.8	3.8-9.1
Iron	250-600	970	361-987	NT	NT	NT
Lead	0.1-10	<2.5	<2.5	<5	<5	NT
Manganese	15-200	149	44-54	53	78	NT
Molybdenum	0.1-4.0	NT	NT	<0.05	<0.05	NT
Nickel	0.1-3.5	2.7	2.7-9.1	<0.5	<0.5	1.2-4.0
Zinc	8.0-60	50	58-150	22	37	10-61

a. Not tested.

9.5.3 Ground Water

Trace elements in ground water can limit its use for drinking or irrigation purposes. For this reason, the potential for trace element contamination of ground water is a concern at SR and RI systems overlying potable aquifers or aquifers that can be used as irrigation water supplies. Drinking and irrigation water standards are presented in Table 9-7.

The most toxic metals to man--cadmium, lead, and mercury-were demonstratably absent in the percolate at five of the six SR sites listed in Table 9-3; the sixth site gave inconclusive data because fallout from nearby smelters contaminated the soils. Concentrations of the metals have not approached toxic levels in any of the sites studied after up to 50 years of operation.

Cadmium, lead, and mercury concentrations in shallow ground water were comparable to concentrations in control wells at two of the three RI sites where trace metals were monitored [17] . At Hollister, shallow ground water concentrations of cadmium and lead were only slightly higher than control well concentrations and were well within drinking water standards. At the sites studied, trace element contamination of ground water has not been a problem. As long as the soil pH is maintained at 6.5 or higher, ground water contamination is likely to remain nonexistent.

TABLE 9-7
TRACE ELEMENT DRINKING AND IRRIGATION WATER STANDARDS [8, 13, 22-27]
mg/L

	Drinking water	Irrigation water		
		For fine textured soils[a]	For any soil[b]	For livestock
Aluminum (Al)	--	20[c]	--	5[c]
Antimony (Sb)	0.145[d]	--	--	--
Arsenic (As)	0.05[e]	2[c]	0.1[c]	0.2[c]
Barium (Ba)	1.0[e]	--	--	--
Beryllium (Be)	--	0.5[c]	0.1[c]	--
Boron (B)	--	0.75[c]	2[c]	5.0[c]
Cadmium (Cd)	0.01[e]	0.05[c]	0.01[c]	0.05[c]
Chromium (Cr^{+6})	0.05[e]	1.0[c]	0.1[c]	1.0[c]
Cobalt (Co)	--	5[c]	0.5[c]	1.0[c]
Copper (Cu)	1.0[f]	5[c]	0.2[c]	0.5[c]
Iron (Fe)	0.3[f]	20[c]	5[c]	--
Lead (Pb)	0.05[e]	10[c]	5.0[c]	0.1[c]
Manganese (Mn)	0.05[f]	10.0[c]	0.02[c]	--
Mercury (Hg)	0.002[e]	--	--	0.01[c]
Molybdenum (Mo)	--	0.05[c]	0.01[c]	--
Nickel (Ni)	--	2.0[c]	0.2[c]	--
Selenium (Se)	0.01[e]	0.02[c]	0.02[c]	0.05[c]
Silver (Ag)	0.05[e]	4-8[g]	--	--
Thallium (Tl)	0.004[d]	--	--	--
Vanadium (V)	--	1.0[c]	0.1[c]	0.1[c]
Zinc (Zn)	5[f]	10[c]	2[c]	25[c]

a. Normal irrigation practice for 20 years.
b. Normal irrigation practice, no time limit.
c. Recommended Water Quality Standards, 1972 Report to EPA on Water Quality Criteria.
d. EPA Toxic Pollutants Standards for Human Health.
e. EPA Primary Drinking Water Standards.
f. EPA Secondary Drinking Water Standards.
g. EPA Recommended Irrigation Water Standards.

9.6 Microorganisms

Three classes of microorganisms can be pathogenic to man and animals:

- Bacteria
- Viruses
- Parasitic protozoa and helminths

Several approaches have been used at land treatment systems to minimize the public health impacts of pathogens. Many SR and RI systems use primary sedimentation prior to land treatment, thereby removing most helminths. Holding ponds also can be used before land treatment to inactivate most pathogens. Generally, a long detention time (about 30 days) and moderate temperatures are required for effective pathogen removal (Section 4.4.1). Many SR and RI. systems rely on the filtering capacity of the soil to remove bacteria, helminths, and protozoa, and on soil adsorption for virus removal.

There are five potential pathways for pathogen transport from land treatment systems:

- Soils
- Crops
- Ground water
- Surface waters
- Aerosols

9.6.1 Soils

Straining and microbiological activity are the primary mechanisms for bacterial removal as wastewater passes through soil. Finer soils, of course, tend to have higher capacity for pathogen removal. Depending on the particular system design, there will be either a mat on top of or a zone within the soil where intense microbiological activity occurs. Here, bacteria, protozoa, and helminths and their eggs are removed by straining and the predations of other organisms, which consume the dead organisms along with the BOD in the applied wastewater and convert them primarily to carbon dioxide and ammonia. No lasting adverse effects to soil have been noted that result from these organisms.

Bacteria removal in the finer textured soils commonly encountered at SR systems is usually quite high (as shown in Table 4-6). Research has shown that complete bacteria removal generally occurs within the top 1.5 m (5 ft) of the soil profile [28] . Similar research has indicated that die-off occurs in two phases: during the first 48 hours following wastewater application, 90% of the bacteria died; the remainder of the bacteria died during the following 2 weeks [29].

Removal efficiencies at selected RI systems are presented in Table 5-6. As indicated by this table, effective bacteria removals are achieved at RI sites when adequate soil travel distance is provided.

At OF sites, bacteria are removed near the soil surface by filtration, biological predation, and ultraviolet radiation. Fecal coliform removals in excess of 95% can be obtained by maximizing the OF residence time (increasing the removal of suspended solids) and applying wastewater at a slow and relatively continuous rate [30]. For example, daily application of wastewater for extended periods (12 to 18 hours) results in better removal efficiency than shorter application periods (6 hours) alternated with weekend drying.

Adsorption is the primary mechanism for virus removal at land treatment systems. Virus removal at SR systems is quite effective. Virus removal at RI sites depends on initial concentration, hydraulic loading rate, soil type, and distance traveled through the soil. Virus transmission through soil at RI systems is presented in Table 9-8. Removal at OF sites is generally the same order of magnitude as virus removal during conventional secondary treatment.

It is possible for parasite eggs, such as Ascaris and helminths, to survive for months to years in soil. Although no conclusive evidence has been found to link transmission of parasitic infections to operating land treatment systems, vegetables that will be consumed raw should not be grown at land treatment sites for at least 1 to 2 years after land treatment operations are terminated.

9.6.2 Crops

In the United States, the use of wastewater for irrigation of crops that are eaten raw is not common. At present, crops usually grown include fiber, feed, fodder, and processed grains. No incidents of infection resulting from crops receiving wastewater have been identified in the United States. Sewage farms in Paris apply raw wastewater to fruit and vegetable crops (not eaten raw) which are approved for public consumption by the Ministry of Health, with no reported health problems.

Systemic uptake of pathogens by crops and subsequent transmission through the food chain is not a problem. When extremely high concentrations of viruses were applied to damaged roots and leaves, plants did take up organisms along with water and nutrients [31]. Several studies performed using typical wastewaters on undamaged crops show no pathogen uptake [4, 6].

TABLE 9-8
VIRUS TRANSMISSION THROUGH SOIL AT
RI SYSTEMS [1]

Location	Sampling distance, m	Virus concentration, PFU/L	
		At source	At sample point
Phoenix, Arizona (Jan-Dec 1974)	3-9	8	0
		27	0
		24	0
		2	0
		75	0
		11	0
Gainesville, Florida (Apr-Sep 1974)	7	0.14 (avg over study period)	0.005
		0.14 (avg over study period)	0
		0.14 (avg over study period)	0
		0.14 (avg over study period)	0
		0.14 (avg over study period)	0
		0.14 (avg over study period)	0
		0.14 (avg over study period)	0
		0.14 (avg over study period)	0
Santee, California (1966)	61	Concentrated type 3 polio	0
Ft. Devens, Massachusetts (1974)	17	Indigenous virus, 276 (avg)	8.3 (avg)
		f_2 bacteriophage seed, 2.2×10^5	1.3×10^5
Medford, New York (Nov 1976-Oct 1977)	0.75-8.34	Indigenous virus, 1.1-81.0	17 samples negative; 6 positive, at 0.47 (avg); range 0.14-0.66
	0.75	Polio virus seed, 7×10^4 (6 cm/h infiltration rate)	Range 0-25.5
	0.75	1.84×10^5 (100 cm/h infiltration rate)	Range 0.03×10^4 to 97.5×10^4
Vineland, New Jersey (Aug 1976-May 1977)	0.6-16.8	13 (avg over study period)	9 of 10 positive, 1.62 avg
		13 (avg over study period)	7 of 10 positive
		13 (avg over study period)	2 of 10 positive, 1.95 avg
		13 (avg over study period)	0 of 10 positive, 0.48 avg

When wastewater is applied by sprinklers, the potential exists for pathogens to survive on the surface of a plant. Sunlight is an effective disinfectant, killing pathogens in a few hours to a few days; but any place that stays warm, dark, and moist could harbor bacteria. For this reason, wastewater is not used to irrigate crops that are eaten raw unless a very high degree of preapplication treatment is provided. To protect livestock, grazing should not be allowed on pasture irrigated with disinfected pond or secondary effluent for 3 to 4 days following wastewater application. At least 1 week should be allowed between applications of primary effluent and grazing. Longer resting periods are recommended for cold, northern climates, particularly when forage crops such as Reed canarygrass, orchardgrass, and bromegrass are irrigated [29, 32].

The National Technical Advisory Committee on Water Quality advises a standard of.1,000 fecal coliforms/100 mL for water used in agriculture [20]. Even lower fecal coliform concentrations can be achieved, without disinfection, by settling and storing the effluent before application (Section 4.4.1).

9.6.3 Ground Water

Because viruses can survive outside an animal host for longer periods of time than bacteria and other pathogens, and because ingestion of only a few viruses may cause disease, virus transmission is the primary concern when evaluating the ground water pathway. Other pathogens are removed largely by filtration or natural die-off before they have an opportunity to migrate into ground water. Although no viral standards have been established, SR and RI systems that discharge to potable aquifers are designed to meet the bacterial standard listed in Table 2-4. The intent of this standard is to ensure that renovated water is essentially bacteria- and virus-free.

As indicated in Section 9.6.1, virus removal at SR systems is quite effective, mainly due to the adsorptive capacity of soils used for SR systems. Thus, most research on virus transmission has been focused on RI systems and coarser textured soils, such as the studies summarized in Table 9-8. As indicated in this table, viruses can enter ground water, particularly when large virus concentrations are applied at high loading rates to very permeable soils. However, the number of viruses that are transmitted is low, and the risk to potential consumers is minimal provided adequate distance between the treatment site and any ground water wells is maintained.

Coliform levels found in ground water underlying SR and RI systems are shown in Tables 4-6 and 5-6. These tables indicate that over 99% of the applied coliforms is removed within short travel distances. Provided adequate distance is allowed, it is possible for any well-operated SR or RI system to meet the coliform standard for drinking waters.

9.6.4 Surface Water

Land treatment systems that discharge to surface waters used for drinking, irrigation, or recreation must meet local discharge standards for microorganisms. As mentioned previously, SR and RI systems should have no problems meeting discharge standards. The microbiological quality of renovated water from OF systems generally is comparable to effluent from conventional secondary treatment systems without chlorination. Bacteria removals of 90 to 95% or higher and virus removals of 70 to 90% are typical at OF systems (Section 6.2.6).

9.6.5 Aerosols

Aerosols are very small airborne droplets, less than 20 microns in diameter, that may be carried beyond the range of discernible droplets from sprinklers. Sprinkler generated aerosols are slightly smaller than ambient aerosols; two-thirds to three-fourths of the sprinkler generated aerosols are in the potentially respirable size range of 1 to 5 microns [33]. Aerosols may carry bacteria and viruses, but do not normally contain pathogenic protozoa or helminths and their eggs. Aerosols may come from sources other than wastewater treatment sites, such as cooling towers and public facilities. As a result of these other sources, ambient bacterial concentrations in the air of some cities are comparable to the concentrations found near land treatment sprinkler zones.

As aerosols are generated, they are immediately subjected to an "impact factor" that may reduce bacteria concentrations by 90% and virus concentrations by 70% within seconds [2]. Further reduction may be caused by desiccation, temperature, deposition, and solar radiation. Aerosol dispersion, influenced by wind speed, air turbulence, and local topography, occurs concurrently.

The concentration of bacteria and viruses in aerosols is a function of their concentration in the applied wastewater and the aerosolization efficiency of the spray process. The latter of these factors depends on nozzle size, pressure, angle of spray trajectory, angle of spray entry into the wind, and impact devices [34]. Studies have shown that approximately 0.32% of the liquid leaving the nozzle is aerosolized [35].

Bacteria cannot be detected in aerosols at distances of even 10 m (33 ft) from sprinklers unless the bacteria concentrations in the applied wastewater are at least 103 to 10^4/mL, [36]. When undisinfected wastewater is sprinkler applied, aerosol bacteria have been found to travel a maximum distance of 400 m (1,312 ft) from a sprinkler line [37]. Under some conditions, viruses have been detected at distances of up to 100 m (328 ft) [2]. Concentrations of bacteria and enteroviruses that have been detected near various SR land treatment sites are shown in Tables 9-9 and 9-10.

TABLE 9-9
AEROSOL BACTERIA AT LAND
TREATMENT SITES [2]

Wastewater type	Location	Distance downwind from site, m	Bacteria	Density range[a], No./m^3	
Raw or primary	Germany	90-160[b]	Coliforms	--	
	Germany	63-400[b,c]	Coliforms	--	
	California	32[b]	Coliforms	--	
	Kibbutz Tzora, Israel	10	Coliforms	11-496	
		10	Fecal coliforms	35-86	
		20	Coliforms	0-480	
		60	Coliforms	0-501	
		70	*Salmonella*		
		100	Coliforms	30-102	
		150	Coliforms	0-88	
		200	Coliforms	4-32	
		250	Coliforms	0-17	
		300	Coliforms	0-21	
		350	Coliforms	0-7	
		400	Coliforms	0-4	
Ponded, chlorinated	Deer Creek, Ohio	Control value	Standard plate count	23-403	(111)
		21-30	Standard plate count	46-1,582[d]	(485)
		41-50	Standard plate count	0-1,429[d]	(417)
		200	Standard plate count	<0-223[d]	(37)
Secondary, nondisinfected	Ft. Huachuca, Arizona	Control value	Standard plate count	12-170	(28)
		Control value	Coliforms	0-58	(2.4)
		45-49[c]	Standard plate count	430-1,400	(day)
				560-6,300	(night)
			Klebsiella	1-23	
		120-152[c]	Standard plate count	86-130	(day)
				170-410	(night)
	Pleasanton, California	Control value	Standard plate count	300-805	
		30-50	Standard plate count	450-1,560	
			Total coliforms	2.4-2.5	
			Fecal coliforms	0.4	
			Fecal streptococci	0.3-1.7	
			Pseudomonas	34	
			Klebsiella	<5	
			Clostridium perfringens	0.9	
			Mycobacterium	0.8	
		100-200	Standard plate count	330-880	
			Total coliforms	0.6-1.2	
			Fecal coliforms	<0.3	
			Fecal streptococci	0.3-1.9	
			Pseudomonas	43	
			Klebsiella	<5	
			Clostridium perfringens	1.1	
			Mycobacterium	0.8	

a. Numbers in parentheses indicate mean values.

b. Distance quoted is maximum distance at which coliforms were detected.

c. Upper values occurred during night hours.

d. Corrected for upwind background value.

TABLE 9-10
AEROSOL ENTEROVIRUSES AT LAND
TREATMENT SITES [2]

Wastewater type	Location	Distance downwind from sprinkler, m	Wastewater enteroviruses, PFU/L		Aerosol enteroviruses, PFU/m³	
			Range	Mean	Range	Mean
Nondisinfected secondary effluent	Pleasanton, California	50	45-330	188	0.011-0.017	0.014
Raw wastewater	Kibbutz Tzora, Israel	36-42	0-650	125	0-0.82	0.015
		50	--	650	--	0.14
		70	170-13,000	6,585	0-0.026	0.013
		100	0-82,000	16,466	0-0.10	0.038

The data in Tables 9-9 and 9-10 can be used to estimate human exposure to aerosol bacteria and enteroviruses. For example, a reasonable estimate may be obtained by using data from Pleasanton, California. At a distance of 50 m (164 ft) downwind from a sprinkler, an adult male engaged in light work and breathing at a rate of 1.2 m^3/h (42 ft^3/h) would inhale an average of 1 plaque-forming unit (PFU) of enterovirus after 59 hours of exposure. Although this represents an extremely low rate of potential viral exposure, methods for recovering enteric viruses currently are not entirely efficient and actual viral exposure may be somewhat higher [38].

As shown by the data in Table 9-11, aerosol fecal coliform concentrations are lower at SR systems than at activated sludge facilities. Thus, the risk of disease transfer from SR sites should be no greater than from activated sludge facilities. For this reason, epidemiological studies of the health effects of aerosols from activated sludge plants may be used to conservatively estimate the health effects of SR facility aerosols.

Epidemiological studies of activated sludge plants indicate that there is no significant disease rate increase for nearby populations [39-44]. Based on these studies, it does not appear that land treatment system employees or people living near sprinkler irrigation sites should anticipate a risk of disease due to aerosols.

TABLE 9-11
COMPARISON OF COLIFORM LEVELS
IN AEROSOLS AT ACTIVATED SLUDGE AND
SLOW RATE LAND TREATMENT FACILITIES [37, 45]

	Maximum	Median	Minimum
Activated sludge[a]			
Aerosols, No./m^3			
Upwind	28	0	0
Over basins	146	14	0
Downwind[a]	141	7	0
Wastewater, No./100 mL	8×10^7	1.6×10^6	1.1×10^4
Aerated pond[b]			
Aerosols, No./m^3			
Downwind			
30 m	452	--	4
100 m	5	--	1
150 m	4	--	--
200 m	5	--	0
250 m	4	--	0
Wastewater, No./100 mL	10^5	--	10^4
Slow rate land treatment[a]			
Aerosols, No./m^3			
Upwind	1.0	BD[c]	BD
Downwind[d]	12.2	1.0	BD
Wastewater, No./100 mL	1.86×10^5	8.1×10^4	2.4×10^4

a. Fecal coliform levels reported.
b. Total coliform levels reported.
c. Below detection.
d. Up to 30 m (98 ft) downwind.

If necessary, several measures can be used to further reduce bacterial and viral exposure through aerosols. First, operating sprinklers during daylight hours increases the number of microorganisms killed by ultraviolet radiation [2]. Sprinkling during early morning hours is preferable in arid or semiarid areas for water conservation purposes. Second, the use of downward-directed, low pressure sprinklers results in fewer aerosols than upwarddirected high pressure sprinklers. Ridge-and-furrow irrigation or surface flooding are recommended when these application techniques are feasible [2]. Third, when public residences are near the sprinkler system, buffer zones may be used to separate the spray source and the general public. In general, public access to the irrigation site should be limited. Finally, planting vegetation around the site can reduce the aerosol concentrations leaving the site [46]. Coniferous or deciduous vegetation have achieved up to 50% aerosol removal by filtration. Planted as a barrier, these types of vegetation should be able to reduce aerosol concentrations several orders of magnitude through vertical dispersion and dilution.

9.7 Trace Organics

Concern over trace organics arose when chlorinated hydrocarbons and other trace organics were found in potable water supplies. At land treatment sites, the concern is that trace organics may travel through the soil profile and enter drinking water aquifers or accumulate in the soil profile and be taken up by plants.

9.7.1 Soils

Many trace organics are adsorbed as they move through the soil profile at SR and RI systems. Chloroform is one such compound, as indicated in Table 4-7; other chlorinated hydrocarbons behave similarly. Although the adsorptive capacity of a soil is limited, once trace organics have been adsorbed they may be biodegraded or volatilized and released to the atmosphere. In either case, the adsorption site becomes available for adsorption of additional organic molecules.

The amount of trace organics that can be removed during movement through the soil is not well understood. Some research has been conducted in West Germany using natural sand beds to filter contaminated river water. The river water contains high concentrations of trace organics, particularly chlorinated hydrocarbons. The observed removal efficiencies are presented in Table 9-12. As shown in this table, trace organics removal can be highly effective, even in coarser soils.

TABLE 9-12
TRACE ORGANICS REMOVALS DURING
SAND FILTRATION [47]

Constituent	% removal
Chlorobenzene	96
Dichlorobenzene	45
Trichlorobenzene	12
Chlorotoluene	94
Dichlorotoluene	62
Dissolved organic chlorides	38
Dissolved nonpolar organic chlorides	73
Dissolved organic carbon	68
Benzene	80
Toluene	95

9.7.2 Crops

Plants can absorb many organic pesticides and some organophosphate insecticides through their roots, with subsequent translocation to plant foliage. Uptake of these organics is affected by the solubility, size, concentration, and polarity of the organic molecules; the organic content, pH, and microbial activity of the soil; and the climate [48]. However, a recent study on health risks associated with land application of sludge has found that the level of pesticide and herbicide absorption is quite low; not more than 3% of the molecules that were in the soil passed into plant foliage [48] . Most trace organics are too large to pass through the semipermeable membrane of plant roots. Thus, it is unlikely that crop uptake of trace organics during land treatment is significant enough to be harmful to man or animals.

9.7.3 Ground Water

As mentioned in Section 9.7.1, soil adsorption of trace organics at SR and RI sites can be an effective removal mechanism. For this reason, only low levels of trace organics would be expected to migrate to underlying ground water. The results of studies at two SR systems (Table 9-13) and two RI systems (Table 5-8) indicate that significant removals do occur at these systems with the exception of the Milton RI site which was operated at continuous (no drying) extremely high wastewater loadings. At the Milton site, high removals are achieved by the time ground water travels a distance of 45 m (160 ft) downgradient. Endrin, methoxychlor, and toxaphene were not detectable in the wastewaters of any of the four communities, and the concentrations of lindane, 2,4-D, and 2,4,5-TP silvex were all well below drinking water limits in the ground waters underlying the land treatment sites (Table 2-4).

Recent research at the Phoenix RI site has examined the removal of refractory volatile organics during RI using secondary effluent [54] . The results are presented in Table 9-14. As shown by this table, fairly high removal efficiencies were obtained (70 to 100%).

Similar research conducted at the Fort Devens RI site indicated that 80 to 100% of the applied refractory organics is removed during RI; average removal of trace organics was 96% (501. Based on the results of these studies, it does not appear that normal concentrations of trace organics in applied wastewaters would cause problem levels in ground waters underlying SR and RI sites. Detailed studies on the fate of trace organics during land treatment are underway at the Muskegon SR site; these studies should provide additional insight into the potential risk of ground water contamination.

TABLE 9-13
TRACE ORGANICS REMOVALS AT SELECTED SR SITES [4, 6]
ng/L

	Roswell, New Mexico		Dickinson, North Dakota	
	Wastewater	Ground water	Wastewater	Ground water
Endrin	<0.03	<0.03	<0.03	<0.03
Lindane	560	74.3	397	53.6
Methoxychlor	<0.01	<0.01	<0.01	<0.01
Toxaphene	<0.1	<0.1	<0.1	<0.1
2,4-D	29.0	10.4	17.0	6.2
2,4,5-TP silvex	28.0	25.8	93	47.1

TABLE 9-14
REMOVAL OF REFRACTORY VOLATILE ORGANICS
BY CLASS AT PHOENIX RI SITE [49]

Class (typical example)	Removal, %
Chloroalkanes (tetrachloroethylene)	70
Chloroaromatics (p-dichlorobenzene)	94
Alkyabenzenes (o-xylene)	98
Alkyaphenols (p-isopropylphenol)	85
Alkylnaphthalenes (2-methylnapthalene)	100
Alkanes (hexatriacontane)	71
Alcohols (2,4-dimethl-3-hexanol)	95
Ketones (2,6-d-t-butyl-p-benzoquinone)	98
Indoles, Indenes (IH-indole)	96
Amides (N-[3-methylphenyl] acetamide)	74
Alkoxyaromatics (butoxymethylbenzene)	91
Weighted average	92

9.7.4 Surface Water

Discharge from the OF process will directly impact surface water in most cases. The effectiveness of trace organics removal during OF has been studied at a pilot system in Hanover, New Hampshire. Chlorinated primary effluent was used in these studies; this effluent contained 6.7 to 17.8

μg/L chloroform, 10.2 to 33.1 μg/L toluene, and lesser amounts of bromodichloromethane, 1,1,1-trichloroethane, tetrachloroethylene, and carbon tetrachloride [51]. Using a 30.5 m (100 ft) long slope with a 5% grade, chloroform and toluene removals were as presented in Table 9-15. These efficient removal rates are thought to result from volatilization as the wastewater flows over the slope or sorption near the soil surface followed by either microbial degradation or volatilization. Based on these results, it appears that volatile trace organics contamination of surface waters by renovated water from OF systems should not be a problem unless initial concentrations are excessive. Studies are underway on the removal of nonvolatile organic compounds.

TABLE 9-15
CHLOROFORM AND TOLUENE REMOVAL
DURING OF [51]

Application rate, cm/h	Concentration at various travel distances, μg/L						Total removal, %
	Wastewater	3.8 m	7.6 m	15.7 m	22.9 m	Runoff	
Chloroform							
0.40	17.8	12.4	6.9	3.1	--	0.3	98.3
0.60	6.7	5.7	3.8	2.1	0.9	0.5	92.5
0.80	13.2	6.4	5.9	3.7	1.5	0.8	93.9
1.05	6.7	--	5.9	4.1	--	1.1	83.6
1.32	9.0	7.8	6.8	6.1	1.4	1.9	78.9
Toluene							
0.40	33.1	20.7	4.9	BD[a]	--	BD	100.0
0.60	10.2	6.2	2.4	0.5	BD	BD	100.0
0.80	28.7	10.0	7.8	3.9	BD	BD	100.0
1.05	21.5	--	9.8	7.4	--	0.7	96.7
1.32	18.8	9.9	7.7	6.3	1.4	0.8	95.7

a. BD - concentration was below a detection limit estimated at 0.01 μg/L.

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