CHAPTER 13

FATE OF WASTEWATER CONSTITUENTS IN SOIL AND GROUNDWATER: TRACE ELEMENTS

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INTRODUCTION

The term trace element is used to denote a group of otherwise unrelated chemical elements present in the natural environment in low concentrations. In small quantities, many elements (e.g, F, Si, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Se, Mo, Sn, I, Cl, B) are essential to biological growth. At a slightly higher concentration, many elements may become toxic to plants and/or animals. There are also elements (e.g., As, Cd, Pb, Hg) that have no known physiological function and are always considered biologically harmful.

In the soil, uncontrolled trace-element inputs are undesirable, because once accumulated in the soil, these substances are in most cases practically impossible to remove and subsequently may lead to (1) toxicity to plants grown on the affected soils, (2) absorption by crops, resulting in trace-element levels in the plant tissue considered harmful to the health of humans or animals who consume the crops, and (3) transport from soils to underground or surface water, thereby rendering the water unfit for its intended use.

Wastewaters always contain trace elements. Here we review the fate of trace elements applied to soil during wastewater irrigation. Our analysis is based upon the quantity of irrigation water that would commonly be applied to irrigate crops in arid and semi-arid regions, which is 4 ft/year (1.2 m/year).

TRACE ELEMENTS IN WASTEWATER

The occurrence of trace elements in the wastewater is related to the source water and activities in the urban environment. Trace elements are widely used in industrial processing and in manufacturing consumer goods [1]. Even when they are not used, trace elements may occur as contaminants in many products used in manufacturing. The deterioration of storage and transmission equipment in the community water supply system and the wear of household plumbing fixtures also contribute to their presence in the water. For these reasons, small amounts of trace elements are always found in domestic wastewater [2]. Many publicly owned treatment works (POTWS) also receive industrial waste discharge, and a consistently high concentration of trace elements usually is an indication of industrial waste inputs. The actual concentration of trace elements in the wastewater, however, may vary considerably with time within a particular treatment plant as well as among treatment plants in various communities [3,4]. Experimental data also demonstrate that most trace elements in the wastewater (except boron) are adsorbed onto the organic or inorganic solids or form sparingly soluble inorganic precipitates.

Although a conventional wastewater treatment system is not designed to remove the trace elements because they are adsorbed on or precipitated by suspended solids, they are effectively removed from the wastewater by removal of suspended solids. Under the normal operating conditions, trace-element concentrations of primary effluents are reduced by 70% to 90% through secondary treatment [5]. Typical concentration ranges for trace elements in wastewater effluents are summarized in Table 13-1. A comparison of the median concentrations for trace elements in wastewater effluents listed in Table 13-1 with the irrigation water-quality criteria established by U.S. Environmental Protection Agency in 1973 [6] shows that the trace-element concentration (except boron) in at least half of the POTWS surveyed will meet the trace-element requirements of irrigation water. Since the trace-element threshold limits of the irrigation-water-quality criteria were intended to protect even the most sensitive plants from harmful effects, wastewaters from the other half of the POTWS may be suitable for irrigation if their use is carefully planned and managed.

EFFECTS OF TRACE ELEMENTS ON PLANT GROWTH

Among the trace elements commonly found in the wastewater, B, Cd, Cu, Mo, Ni, and Zn are considered to present a potentially serious hazard if they are introduced into the cropland soils in an uncontrolled manner [7]. The potential hazards associated with other trace elements in the soil are ruled out by their attenuated chemical

Table 13-1. Concentrations of trace elements in wastewater from municipal treatment plants (mg/L).[a]

Element	Primary effluent Range	Primary effluent Median	Secondary effluent Range	Secondary effluent Median	Water-quality criteria for irrigation[b] Long term	Water-quality criteria for irrigation[b] Short term
As	<0.005 -0.03	<0.005	<0.005 -0.023	<0.005	0.10	10
B	<0.01 -2.5	1.0	<0.1 -2.5	0.7	0.75	2
Cd	<0.02 -6.4	<0.02	<0.005 -0.15	<0.005	0.01	0.05
Cr	<0.05 -6.8	<0.05	<0.005 -1.2	0.02	0.10	20.0
Cu	<0.02 -5.9	0.10	<0.006 -1.3	0.04	0.20	5.0
Hg	<0.0001-0.125	0.0009	<0.0002-0.001	0.0005	--	--
Mo	<0.001 -0.02	0.008	0.001 -0.018	0.007	0.01	0.05
Ni	<0.1 -1.5	0.1	0.003 -0.6	0.004	0.2	2.0
Pb	<0.2 -6.0	<0.2	0.003 -0.35	0.008	5.0	20.0
Se	<0.005 -0.02	<0.005	<0.005 -0.02	<0.005	0.02	0.05
Zn	<0.02 -2.0	0.12	0.004 -1.2	0.04	2.0	10.0

a. Based upon information presented by Bouwer and Chaney [24] and accumulated by the authors from a number of sources.

b. From U.S. Environmental Protection Agency [6].

activities in the soil or by their infrequent occurrence and exceptionally low concentration in the wastewater. Following the common crop production practice, Mn, Fe, Al, Cr, As, Se, Sb, Pb, and Hg inputs through application of treated wastewater to land should not result in phytotoxicity or expose consumers to potentially hazardous trace-element levels. Concentrations of selected trace elements normally found in the soil and plant tissue and their effects on crop growth are summarized in Table 13-2. At these reported levels, trace elements do not appear to cause any serious concern.

Among those elements that may limit the use of wastewater for irrigation, Cd, Cu, Ni, and Zn are singled out for their potential phytotoxic effects. Assuming that a wastewater with typical trace-element concentration is applied at 4 ft/year (1.2 m/year), the annual inputs of Cu, Ni, and Zn will be 1.2, 0.24, and 1.8 kg/ha, respectively. For Cu and Zn, these input levels are far below the amounts routinely used to correct trace-element deficiencies in the soil. Even if the concentrations of Cu and Zn in the wastewater are one order of magnitude higher, their inputs to the soil are still in line with the recommended fertilization practice. It is unlikely that short-term use of wastewater for crop irrigation could result in crop injuries due to Cu, Ni, or Zn. Since these elements may accumulate in the soil, the long-term toxic effects require further examination.

To safeguard plants from possible detrimental effects of sludge-borne trace-elements in cropland sludge applications, the U.S. Environmental Protection Agency has recommended that the cumulative total loading of Cd, Cu, Ni, Zn, and Pb during the land application of sludges be limited according to the cation exchange capacity (CEC) of the receiving soil [8,9]. In the absence of any trace-element input criteria--specifically for wastewater irrigation--the EPA-suggested limits for trace elements through sludge application to agricultural land can be used as a point of reference. Given trace-element concentrations in wastewater for sludge loading criteria and annual water application rate, one may calculate the time required for a soil to reach the loading limits of metals in the water (Table 13-3).

Table 13-2. Concentrations of selected trace elements normally found in soil and plant tissue (μg/g) and their impact on plant growth.

Element	Soil concentration[a] Range	Soil concentration[a] Typical	Typical concentration in plant tissue Range	Impact on plant growth[b]
As	0.1 -40	6	0.1 -5	Not required
B	2 -200	10	5 -30	Required, wide species differences
Be	1 -40	6	--	Not required: toxic
Bi	--	--	--	Not required: toxic
Cd	0.01-7	0.06	0.2 -0.8	Not required: toxic
Cr	5 -3000	100	0.2 -1.0	Not required: low toxicity
Co	1 -40	8	0.05-015	Required by legume at <0.2 ppm
Cu	2 -100	20	2 -15	Required at 2-4 ppm: toxic at >20 ppm
Pb	2 -200	10	0.1 -10	Not required: low toxicity
Mn	100 -400	850	15 -100	Required: toxicity depends on Fe/Mn ratio
Mo	0.2 -5	2	1 -100	Required at <0.1 ppm: low toxicity
Ni	10 -1000	40	1 -10	Not required: toxic at >50 ppm
Se	0.1 -2.0	0.5	0.02-2.0	Not required: toxic at >50 ppm
V	20 -500	100	0.1 -10	Required by some algae: toxic at >10 ppm
Zn	10 -300	50	15 -200	Required: toxic at >200 ppm

a. Derived from data published by Bowen [25], Allaway [12], Lisk [26], Page [27] and Chapman [28].

b. Concentration listed for plant tissue are on a dry-weight (70 C) basis.

Table 13-3. Calculated length of time for wastewater-irrigated agricultural soils to reach heavy-metal loading limits.

Element	Typical concentration (mg/L)	Annual input (@1.2 m/yr water depth)	Suggested loading (kg/ha) at soil CEC[a]			Time (in yrs) to reach soil loading limit at CEC[a]		
			<5	5-15	>15	<5	5-15	>15
Cd	0.005	0.06	5	10	20	82	167	333
Cu	0.10	1.2	125	250	500	104	208	416
Ni	0.02	0.24	125	250	500	521	1042	2083
Zn	0.15	1.8	250	500	1000	139	278	556
Pb	0.05	0.60	500	1000	2000	833	1667	3333

a. Cation exchange capacity expressed in units of meq/100g soil.

When a wastewater with typical trace-element concentrations is applied at 4 ft/year (1.2 m/yr) the time required for a trace-element to reach its limit in the soil varies from 82 years (for Cd on soil with CEC less than 5 meq/100 g) to more than 3000 years (for Pb on soil with CEC greater than 15 meq/100 g). Since the limits of metal input are specified for soils of pH > 6.5, the pH of the metal-affected soils to which the metals are applied must be maintained above 6.5.

Unlike Cu, Ni, and Zn, cadmium is not an essential element for crop growth. In the soil, the problems associated with the additions of Cd are twofold. Cadmium is usually phytotoxic at low concentrations, yet even before any phytotoxic symptom is detected, the Cd added to the soil may drastically elevate the Cd level in the affected plant tissue. However, the tolerance of plant species to levels of Cd added to the soil is highly variable; Table 13-4 summarizes the tolerance of selected crop species to Cd in the soil. The annual input limit (<0.5 kg/ha) suggested by the U.S. Environmental Protection Agency for cropland receiving sludge was intended to protect against the possibility of accelerated entry of Cd into the human food chain. At the irrigation rate of 1.2 m/year, the concentration of Cd in the applied wastewater could reach 0.04 mg/L before this limit is exceeded. It is conceivable that the annual Cd input may become a factor limiting the application of some wastewaters to land.

The role of B in the land application of wastewater is somewhat unusual. In wastewater, boron probably occurs in the form of undissociated boric acid. It is not removed very effectively during wastewater treatment. Being uncharged, B also passes through soils much more rapidly than the other trace elements. Although B is essential for crop growth, the margin between levels considered essential to plant growth and those considered phytotoxic is extremely narrow. Plants grown on soils whose water-extractable boron (soil saturation extract) is less than 0.04 mg/L often exhibit symptoms of B deficiencies, whereas at concentrations in excess of 1.0 mg/L, B is toxic to many boron-sensitive crop species [10]. Unlike other elements (e.g., Cd, Cu, Ni, Zn, Pb, Cr, Fe, Mn, Se, Mo, As, Hg, Sb and Al) that tend to deposit near the ground surface following the application, B is only weakly adsorbed and may rapidly pass through

Table 13-4. Relative tolerance of plant species to various levels of cadmium added to soil.[a]

Range of soil-Cd addition (μg/g)	Plant species showing 50% yield reduction
10-50	Spinach (*Spinacia oleracca* L.), soybean (*Glycine max* Meer.), curlycress (*Lepidium sativa* L.), sweet corn (*Zea mays* L.), upland rice (*Oryza sativa* L.)
50-100	Sudangrass (*Sorghum halepense* Perse. var. *sudanense* Hitche), carrot (*Daucus carota* L. var. *sativa* D.C.), field bean (*Phaseolus vulgaris* L.), wheat (*Triticum aestivum* L.)
100-300	White clover (*Trifolium repens* L.), table beet (*Beta vulgaris* L.), alfalfa (*Medicago sativa* L.), radish *Raphanus sativus* L.), zucchini squash (*Curcurbita pepo* L. var. *Medullosa* Alef.)
>300	Swiss chard (*Beta vulgaris* L. var. *cicla* L.), tall fescue (*Festuca elatior* L.), cabbage (*Brassica oleracca* L. var. *capitata* L.), bermudagrass (*Cynodon dactylon* Pers.), tomato (*Lycopersicon esculentum* Mil.), paddy rice (*Oryza sativa* L)

a. Adapted from Bingham et al. [29,30]. Plant response observed for one particular kind of soil, and as such it is not necessarily applicable to all soils.

the soil with leaching water. For this reason, the boron concentrations may have a more immediate effect on restricting the use of wastewater for irrigation, and cumulative effects commonly important to other trace elements do not apply to B.

Large quantities of Mo may be added to the soil with little effect on crop growth [11]. However, Mo applied to the soil is readily absorbed by crops. The availability of Mo to crops increases with the soil pH. As a micronutrient element, Mo is required in small amounts by plants and is also essential, at low concentrations, in the diet of animals; for some livestock animals (particularly ruminant animals), however, Mo concentration as low as 5 mg/kg in the feed may be toxic [12]. Molybdenum toxicity and its severity are directly related to the amount of Mo ingested relative to that of Cu and SO_4. High Mo and low Cu levels in forage constitute the worst possible situation. Since more than 50% of the effluents from POTW may have Mo concentrations exceeding the upper limit of the irrigation-water-quality criteria, the potential hazard associated with Mo accumulation in plant tissue should be carefully evaluated when wastewater is to be used for irrigating forage crops or grazing pastures.

BEHAVIOR OF WASTEWATER-BORNE TRACE ELEMENTS IN THE SOIL

Passage of wastewater through the complex soil matrix induces a variety of physical and chemical reactions that influence the capacity of soil to renovate the wastewater. The mechanism of removal depends on the characteristics of trace elements in the wastewater. Trace elements present in the wastewater in suspended forms are removed primarily through filtration [13]. For all practical purposes, the suspended solids are expected to be deposited near the surface of the soil profile during irrigation with wastewater.

For trace elements present in the wastewater in the dissolved state, filtering would have no effect on their removal from the water. Instead, chemical reactions such as ion exchange, precipitation, surface adsorption, and organic complexing are important. Unless the equilibrium constants of each reaction are known, and the reaction kinetics in the soil are clearly defined, the outcome is unpredictable. Factors that influence the transformation of trace elements in the soil are illustrated in Figure 13-1.

The principal mechanisms that immobilize dissolved trace elements in the wastewater within the soil appear to be adsorption and precipitation. Recent studies have demonstrated that most soils have a high capacity to retain most trace elements [14-21].

At Pb application rates up to 3200 kg/ha [as $Pb(OAc)_2$], Stevenson and Welch [22] observed the downward movement of Pb in a midwestern soil to a depth not greater than 0.9 m. Doner [18] leached a Hanford soil with solutions containing 10 mg/L of Cd, Cu, or Ni and found that the soil had the capacity to attenuate 506, 558, and 1480 kg/ha of Cd, Cu, and Ni, respectively, before a breakthrough took place at the 30-cm depth.

Factors that affect the retention of trace elements by soils include soil texture, pH, soil organic matter, and contents of amorphous oxides of Fe, Al, and Mn. Fuller and co-workers [19,20,21], in a study of trace-element attenuation in a variety of soils found that all soils studied showed high capacity to attenuate the concentration of Cu and Pb in the soil solution. The retention of other trace elements studied was best correlated with the clay content and free iron oxide content of the soil. Capacities for attenuating the cationic trace elements (Cu, Pb, Be, Zn, Cd, Ni, and Hg) in soils tended to increase with their clay and iron oxide contents. For the anionic trace elements (SeO_3, VO_3, AsO_4, CrO_4), retention in the soil also increased with increasing clay and iron oxide content of the soils. Similar observations have been reported by other researchers [23]. In general, the solubility of cationic trace-element species increases as the pH of the soil decreases. By contrast, the solubilities of anionic trace-element species in the soil tend to increase as the pH of the soil increases.

The amounts of trace elements removed by crops are small compared with the amounts applied to the soils through the application (at 4 ft/year) of a wastewater with typical trace-element concentrations (Table 13-5).

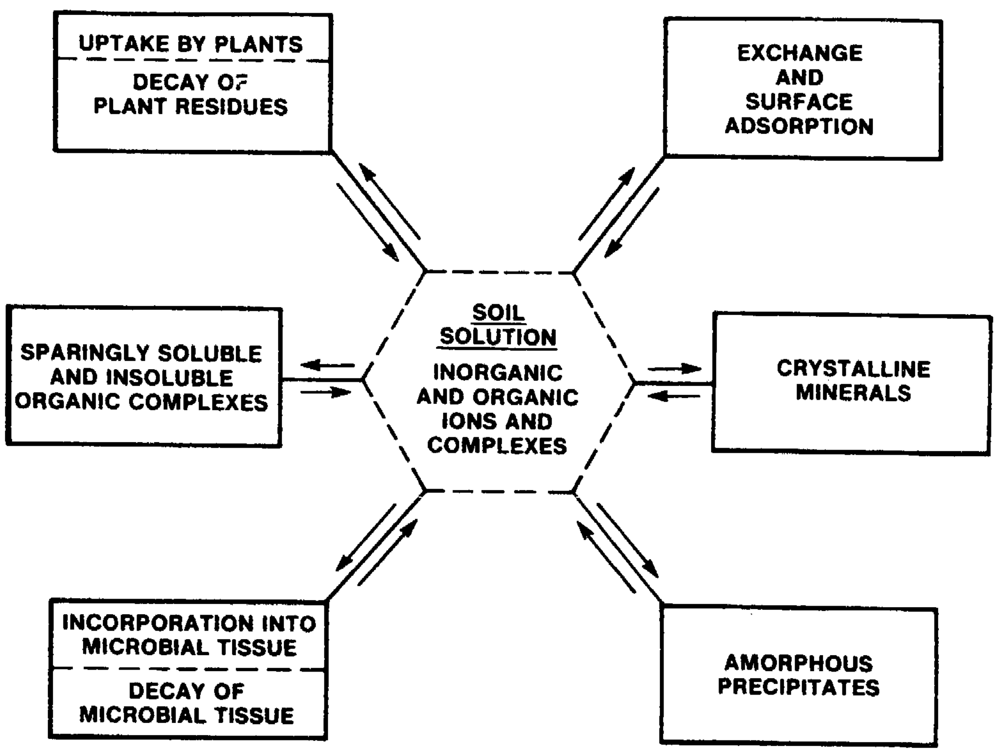

Figure 13-1. Schematic diagram showing possible pathways of trace elements in soils.

Table 13-5. Expected trace-element removal by vegetation from wastewater-irrigated soils.

Element	Typical concentration in wastewater[a] (μg/ml)	Annual input[b] (g/ha)	Typical concentration in vegetation[c] (μg/g)	Annual removal[d] (g/ha)	Removal (%)
As	<0.005	<60	1	5	8.3
B	1.0	12,000	50	250	2.1
Cd	0.005	60	0.5	2.5	4.2
Cr	0.025	300	0.5	2.5	0.8
Cu	0.10	1,200	15	75	6.3
Hg	0.0009	11	0.02	0.1	0.9
Mo	0.005	60	1	5	8.3
Ni	0.02	240	5	25	10.4
Pb	0.05	600	2	10	1.7
Se	<0.005	<60	0.5	2.5	4.2
Zn	0.15	1,800	50	250	13.9

a. From Dowdy, et al. [31].

b. At an application rate of 1.2 m/yr.

c. Authors estimates based on data from Bowen [25], Allaway [12], Chapman [28] and Lists [26].

d. Assuming annual dry-matter yield of 5 t/ha, e.g., potatoes.

Generally, no more than 10% of the added trace elements is expected to appear in the harvested crops. Long-term use of wastewater for irrigation, therefore, will result in their gradual accumulation in the affected soils.

CONCLUSIONS

When wastewater effluents are used for crop irrigation, the concentration of trace elements in the water is not high enough to cause any short-term acute harmful effects. Since most trace elements tend to accumulate in the soil, the trace-element contents of the receiving soil could be substantially elevated by the long-term use of the wastewater. Therefore, the potential for harmful effects in the future should not be overlooked. A typical wastewater may be applied for almost 100 years before any trace-element accumulation in the soil may reach a currently proposed upper limit for trace-element soil deposition. Since trace-element concentrations of wastewater vary considerably, it is essential that cropland irrigation operations should be evaluated case by case.

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CHAPTER 14
FATE OF WASTEWATER CONSTITUENTS IN SOIL AND GROUNDWATER: PATHOGENS

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INTRODUCTION

One major concern in using wastewater for agricultural irrigation is the potential public health hazard resulting from exposure to pathogenic organisms. The term "pathogenic" is applied to those organisms that invariably cause infectious diseases. Pathogens that can survive modern wastewater treatments include bacteria, protozoa, helminths (parasitic worms), and viruses. Epidemiological studies show that direct contact with these agents increases the probability of encountering gastrointestinal and urogenital infections. However, transmission of most pathogenic diseases from wastewater requires the fecal-to-oral route. There is very little evidence indicating a potential health hazard (by dissemination of infectious agents) in handling disinfected wastewater for irrigation on agricultural land [1].

FACTORS AFFECTING PATHOGEN SURVIVAL IN SOIL

In most cases, the survival rates of pathogens in soil have been reported to vary from a few hours to several months. A summary of pathogen survival rates in soils compiled by Gerba et al. [2], Parsons et al. [3], and Burge and Marsh [1] is shown in Table 14-1. Streptococci were reported to be viable for 35 to 63 days when applied to soil. Leptospira had survival rates of 15 to 43 days. Cysts of the protozoa *Entamoeba histolytica* remained viable for 6 to 8 days, and the survival time for tubercle bacilli was reported to be more than 180 days. Salmonellae may survive as long as 70 days in moist soil irrigated with wastewater and for 35 days in dry soil during the summer [4]. Hookworm larvae and enteroviruses have been reported to survive in soil for 42 days and for 8 to 175 days, respectively. Wellings et al. [5] showed that the survival of polioviruses in a

Table 14-1. Survival of pathogens in soils.[a]

Organism	Survival time (days)
Coliforms	38
Streptococci	35 to 63
Fecal streptococci	26 to 77
Salmonellae	15 to > 280
Salmonella typhi	1 to 120
Tubercle bacilli	> 180
Leptospira	15 to 43
Entamoeba histolytica cysts	6 to 8
Enteroviruses	8 to 175
Ascaris ova	Up to 7 years
Hookworm larvae	42
Brucella abortus	30 to 125
Q-fever organisms	148

a. Adapted from Gerba et al. [2]; Parsons et al. [3]; Burge and Marsh [1].

Florida cypress dome used for sewage effluent discharge was evident for at least 28 days. Lefler and Kott [6] reported the survival of poliovirus type 1 in dry sterile sand for 77 days. Tate and Terry [7] found a 92% and 86% decline in fecal and total coliform populations, respectively, as early as two days after a soil was amended with sewage effluent. Usually 2 to 3 months is sufficient time to allow the numbers of most pathogens in untreated wastewater to decline to negligible levels in soil after application [2]. However, survival of enteric bacteria in soil is dependent on several factors, including soil moisture content, temperature, pH, season of the year, sunlight, organic matter content, and antagonistic organisms [8].

Several reports indicate that increased soil moisture content tends to increase the survival rate of enteric bacteria. Beard [9] reported that the survival of *Escherichia coli* and *Salmonella typhosa* were increased substantially in moist soils. Kibbey et al. [10] found that the survival rate of *Streptococcus faecalis* was greatest when the soil was saturated and lowest when soil was air-dried. Boyd et al. [11] reported a decrease in microbial survival rates with a decrease in moisture content from 50% to 10% in a fine sandy loam soil. Survival time is less in sandy soils than in soils with greater water-holding capacities [2].

Survival of bacteria in soils is favored by cold temperatures [2]. Beard [9] reported that *S. typhosa* could survive as long as two years under freezing conditions. By increasing the temperature, the survival rates of enteric bacteria in soil tend to decrease. With a compilation of pathogen survival data from the literature, Reddy et al. [12] reported that the die-off rates of pathogenic bacteria and indicator organisms approximately double with an 18°F (10°C) rise in temperature between 41 and 86°F (5-30°C). The alternate freezing and thawing periods in the winter months also affects the survival of pathogens in soil: Weiser and Osterud [13] reported that freezing and thawing promoted significant mortality of *E. coli*.

Extreme acidic and alkaline conditions (pH < 6.0 or > 8.0) tend to adversely affect most bacteria in soil. Generally, neutrality (pH 7.0) favors the growth and survival of enteric bacteria. The pathogens *Erysipelothrix, Salmonella, E. coli, S. faecalis,* and *Mycobacterium* survive best at a soil pH range of 6 to 7 [14]. Die-off rates of these pathogens were higher under acidic soil conditions.

The season of the year influences the viable population of pathogens in soil. Their survival rates appear to be related to fluctuations in moisture and temperature. Van Donsel et al. [15] studied the death rates of *E. coli* and *S. faecalis* subsp. *liquefaciens* in soil with seasonal changes. They found a 90% reduction rate in fecal coliforms after 3.3 days in the summer and 13.4 days in the autumn. Fecal coliforms survived slightly longer than the fecal streptococci in the summer, but the reverse was true in the spring and winter months. In the temperate regions, both the autumn and spring months favor the survival of fecal coliforms and fecal streptococci, whereas populations diminish in the dry summer months [2,15].

Sunlight exerts a lethal effect on all microorganisms located on the very surface of soil. This effect may be due to desiccation and/or ultraviolet (UV) irradiation. Tannock and Smith [16] studied the survival of *Salmonella typhimurium* and *Salmonella bovismorbificans* applied to pasture soils exposed to direct sunlight vs. shaded areas. Two outdoor plots were exposed to direct sunlight, while two others were enclosed on three sides by black polyethylene sheeting approximately 1 m in height. In general, survival of salmonellae was prolonged in the shaded areas when compared with the exposed plots. In the summer, survival of *S. bovismorbificans* was evident up to 6 weeks after inoculation in the shaded areas and up to only 2 weeks in the direct sunlight. Similar results were reported by Van Donsel et al. [15]. When *E. coli* and *S. faecalis* were added to soil plots, their die-off rates were much greater when exposed to direct sunlight than when in shaded areas. The die-off rates of *Leptospira, Brucella,* and *Mycobacterium* are also influenced by the intensity of sunlight [2].

Bacterial numbers are generally related to the organic matter content of soil. Since the enteric bacteria are heterotrophs, their only carbon supply would be the organic nutrients present in soil and suspended organic material added with the wastewater. Geldreich and co-workers [17] enumerated coli-aerogenes bacteria from 251 soil samples collected from 26 states and 3 foreign countries and found that fecal coli-aerogenes were usually absent or present in comparatively low numbers in undisturbed soils. Tannock and Smith [16] reported that when surface water was contaminated with feces and applied to soil, salmonellae numbers declined by 10,000-fold in about 10 weeks, but when the feces were absent, a 1 million-fold decrease was observed within 2 weeks. Although both *Shigella* and *Salmonella* are capable of utilizing the limited carbonaceous materials in soils, they are not able to compete with the indigenous soil microflora for the low available nutrient supply [2]. Enteric bacteria require simple sugars for a carbon source to synthesize amino acids, nucleic acids, and vitamins, but simple sugars rarely exist in soil in the free form. Instead, carbohydrates are often complexed as polymers.

Antagonistic microflora may also effect the survival of pathogens introduced to soil by the means of wastewater. The survival time for enteric bacteria inoculated into sterilized soil is longer than that in nonsterile soil [2]. Predation by protozoa and parasitism by *Bdellovibrio* (bacteria which are parasites on other bacteria) may play a role in regulating bacterial populations. Production of lytic enzymes and antibiotics by soil fungi and actinomycetes could suppress the growth of enterics. Bryanskaya [18] reported that the growth of *Salmonella* and dysentery bacilli were inhibited by the present of actinomycetes in soils.

There is very little information available on the survival of helminths and protozoa in soil. Helminth ova can appear in sewage sludge and treated wastewater after sewage treatment practices. According to Burge and Marsh [1], the ova of *Ascaris lumbricoides* (intestinal worm) may survive as long as 7 years in a garden soil (Table 14-1). The survival and persistence of protozoa in wastewater and soil is usually attributed to their ability to form cysts, which is an inactive metabolic state that can endure extreme environmental conditions such as high and low temperatures, drought, adverse pH, and low oxygen concentrations. Cysts of the protozoan *Entamoeba histolytica* have been reported to survive up to 8 days in soil and up to 3 days on plant surfaces (Table 14-1).

Many viruses survive modern wastewater-treatment practices, including chlorination [2]. When wastewater is applied to soil, viruses may survive a year or more. Most of the studies on virus survival or inactivation in wastewater and soil have been carried out with polioviruses and bacteriophages (viruses which infect bacteria).

Virus inactivation (loss of infectivity toward the host cell) appears to be affected by dispersion of viral aggregate clumps, presence of salts (particularly chloride anions), temperature, pH, virucidal chemical species, and the presence of suspended solids [19]. Virus inactivation rates tend to be much greater in wastewater and natural waters than in distilled water because of disaggregation of viral clumps. Dispersion of poliovirus type 1 was more complete in secondary sewage effluent than in distilled water [20]. Burge and Enkiri [21] reported that the inactivation rate for øx-174 phage in sterilized soil leachate was 24 times greater than that of poliovirus type 1 in distilled water.

The presence of salts (NaCl) increases virus inactivation relative to non-saline environments; however, this effect can be partially reduced by the presence of divalent cations such as Ca^{2+} and Mg^{2+}. These cations have a stabilizing effect on viruses that prevents inactivation, particularly at elevated temperatures (50°C).

Studies on inactivation of viruses in relation to temperature and pH demonstrate that virus inactivation increases with increasing temperature [19], and permanent inactivation of enteroviruses in solution is favored by alkaline pH [22].

Antagonistic microflora in soil may produce inactivating agents such as antiviral toxins. Also, sterilization or heat treatment of wastewater may drive off heat-labile virucidal chemical agents such as ammonia [23].

Suspended organic matter and clay are believed to have some protective effect on viruses in wastewater. Bitton and Mitchell [24] reported increased survival rates of T7 phage in seawater containing colloidal montmorillonite. Gerba and Schaiberger [25] showed that viruses adsorbed to kaolinite clay survived longer in seawater than unadsorbed viruses.

Although there is a voluminous amount of literature on the removal efficiency and movement of viruses in soil, there has been very little work on virus survival in field experiments. Wellings et al. [5] reported that virus survival in a Florida cypress dome used for sewage effluent discharge was evident for at least 28 days. Fujioka and Loh [26] reported that poliovirus type survived in field plots at least 32 days when irrigated with wastewater effluent. Depending on the nature of the soil, temperature, pH, and moisture content, enterovirus survival has been reported to vary between 25 to 170 days [2].

It should be emphasized that the disappearance of infectious viruses from percolating wastewater occurs mainly by sorption interactions, but, this mechanism does not eliminate infectivity for host cells. Schaub et al. [27] reported that viruses adsorbed to clay were just as infectious to mice as were the free entities. Further, Lefler and Kott [6] demonstrated that viruses adsorbed to sand are capable of infecting tissue cultures.

MOVEMENT OF BACTERIA IN SOIL

The migration of wastewater pathogens in soil involves transport by insects, birds, rodents, overland runoff, windblown soil, and percolation through the soil profile to ground water. Many insects, birds, and rodents can become carriers of fecal agents when in direct contact with wastewater. However, there is no evidence that suggests dissemination of infectious agents by such means should be of major concern. Retention of pathogenic organisms near the surface could be a potential problem because of contamination of surface runoff waters and windblown soil, but treated wastewater would probably be of little threat. These mechanisms of transport are more likely to be applicable to livestock grazing areas and feedlots, since they appear to be concentrated with fecal coliforms and streptococci [28, 29, 30].

The main factors limiting transport of bacteria, ova of intestinal worms, and cysts of protozoa through the soil matrix are straining, sedimentation, and adsorption. The soil acts as a filter, and as the soil aggregates become disturbed, structural breakdown gives rise to swelling, slaking, and dispersion of soil particles straining even finer particles. The removal of bacteria, ova, and cysts from percolating wastewater, through a given depth, is inversely proportional to the soil particle size [31].

The infiltration rates of wastewater in soil influences the removal efficiency of pathogenic bacteria. Low flow rates favor greater retention in soils. The flow rate is dependent on soil texture, structure, type of clays present, and nutrients supplied by the wastewater to the indigenous soil microflora [32]. If wastewater is continuously applied to the soil, the nutrients may support continuous growth of the microflora, resulting in biological clogging and alteration in pore configuration.

Adsorption also plays a role in retention of bacteria by soil, but probably to a lesser extent than the previous factors mentioned. Goldschmid [33] showed that tapwater increased the removal of coliforms through sand when compared with distilled water. The removal efficiency of bacteria was increased with increasing cation concentration, higher valence, and decreasing pH (below pH 7.0). A more detailed explanation on the mechanism of adsorption will be presented in the discussion of virus movement in soils.

Several studies have shown that as much as 90% to 95% of the fecal organisms are concentrated in the surface layers during the passage of wastewater through soil, and the remainder are concentrated in subsurface layers [34, 35, 36, 37]. Information on the movement of pathogenic bacteria through soil in relation to wastewater application has been compiled by Gerba et al. [2] and Hagedorn et al. [38] and is shown in Table 14-2.

The Sanitary Engineering Research Laboratory of the University of California at Berkeley initiated the first major field studies at Whittier and Azusa, California, on bacterial removal during wastewater percolation through soil. At the Whittier Narrows Recharge site, coliform densities in secondary sewage effluent were reduced from 110,000 to 40,000 per mL after percolating through infiltration basins with a 3-ft (0.9-m) depth in 12 days [39]. At Azusa, a depth of 2.5 to 7 ft (.8 to 2.1 m) of soil was required to reduce the density of 120,000/100 mL in treated sewage effluent to 6,000 organisms [40]. In Lodi, California, secondary sewage effluent was allowed to percolate

Table 14-2. Movement of bacteria through soils in relation to wastewater application.[a]

Nature of fluid	Organisms	Media	Maximum distance traveled (m)	Time of travel
Tertiary treated wastewater	Coliforms	Fine to medium sand	6.1	--
Secondary sewage effluent on percolation beds	Fecal coliforms	Fine loamy sand to gravel	9.1	--
Primary sewage in infiltration beds	Fecal streptococci	Silty sand and gravel	183	--
Inoculated water and diluted sewage injected subsurface	*Bacillus stearothermophilis*	Crystalline bedrock	28.7	24-30 hr
Sewage in buried latrine intersecting groundwater	*Bacillus coli*	Sand and sandy clay	10.7	8 weeks
Canal water in infiltration basins	*Escherichia coli*	Sand dunes	3.1	--

a. Adapted from Gerba et al. [2]; Hagedorn et al. [38].

through sandy loam soil for 2½ years. Results indicated that the most probable number of coliform bacteria was reduced from 10^5 to less than one per mL of effluent in 4 to 5 ft (1.2 to 1.5 m) of soil [41].

The Santee Water Reclamation Project near San Diego, California, involved the application of tertiary treated sewage effluent through percolation beds consisting of a shallow stratum of sand and gravel [42]. Analysis of total coliforms, fecal coliforms, and fecal streptococci in water samples was performed on sample well sites 200 ft (61 m) and 400 ft downstream from the percolation beds and 1500 ft (457 m) downstream in a collection ditch. Most of the bacteria were removed within the first 200 ft of travel. Fecal streptococci densities were reduced from 4,500/mL in the sewage effluent to 20, 48, and 7/mL when sampled downstream in the 200-ft and 400-ft wells and the collection ditch, respectively.

The Flushing Meadows Wastewater Renovation Project near Phoenix, Arizona, has been recharging groundwater since 1967 with an activated-sludge-type secondary sewage effluent and has proved to be highly successful in obtaining favorable bacterial quality in the renovated water [43]. The effluent was allowed to infiltrate into six parallel horizontal basins (6 m by 210 m, 6 m apart) consisting of 6 to 9 m of fine loamy sand underlaid by a succession of coarse sand and gravel layers to a depth of 75 m. The infiltration rate was approximately 330 ft (100 m) of wastewater per year. Renovated well water samples contained no human viral pathogens nor salmonellae, and the numbers of fecal coliforms, fecal streptococci, and total bacteria were reduced by 99% after the wastewater was filtered through approximately 30 ft (9 m) of soil.

MOVEMENT OF VIRUSES IN SOIL

Virus removal from percolating wastewater is almost totally dependent on adsorption to various soil components. Excerpts from the literature on the movement of viruses through various soil systems is shown in Table 14-3.

Drewey and Eliassen [44] conducted experiments on virus migration with bacteriophages T1, T2, and f2 through nine California soils varying widely in chemical and physical properties. Batch tests

Table 14-3. Movement of viruses through soil.[a]

Virus type	Nature of fluid	Nature of medium	Flow rate	Distance of travel	Percentage of removal
T1, T2, f2	Distilled water with added salts	9 types of soils from California	0.078 mL/min to 0.313 mL/min	45 to 50 cm	> 99
Poliovirus 1	Distilled water, 10^{-5} $\underline{N}$ Ca and Mg salts	Dune sand	1 mL/min to 2 mL/min	20 cm	99.8 to 99.9
Poliovirus 2	Distilled water	Low humic latersols	100 gal/day·ft^2 to 140 gal/day·ft^2	1.5 to 6 inch	96 to 99.3
Poliovirus 2	Secondary effluent	Sandy gravel	--	60 m	100
Coxsackie	Spring water	Garden soils	--	36 inch	50
T4	Distilled water	Low humic latersols	100 gal/day·ft^2 to 140 gal/day·ft^2	1.5 to 6 inch	100
T7	Secondary treated	Sandy forest	--	19.5 cm	99.6
Indigenous enteric viruses	Secondary effluent	Loamy sand soil	Intermittent avg: 0.02 cm/min	3 to 9 m	100

a. Adapted from Bitton [52]; Gerba et al. [2]; Vilker [19].

revealed that T2 and f2 followed typical Freundlich isotherms, indicating physical adsorption. In column experiments, viruses were suspended in distilled water and passed through sterile soil columns. Over 99% of virus removal was demonstrated with radioactive tagging (P-32), indicating that most of the viruses were retained in the upper 0.8 inch (2 cm) of the columns.

Robeck et al. [45] conducted studies on poliovirus removal through 2 ft (0.6 m) of California dune sand at application rates of approximately 20 to 40 gal/ft^2·day (0.8 to 1.6 m/day). Results indicated that the sand was capable of removing 99% of the viruses in 98 days. At the Santee Project (near San Diego), high concentrations of attenuated (reduced virulence) polioviruses were applied to percolation beds consisting of sand and gravel. Poliovirus could not be detected downstream in sample wells 200 ft (61 m) from the application site.

In 1974, at the Flushing Meadows Project, secondary sewage effluent and renovated water from four well sites were assayed for viruses periodically every two months [43, 46]. Virus doses in the sewage effluent ranged from 158 to 7,475 plaque-forming units (PFU) per 100 L with seven different types of viruses identified. Wastewater viruses did not move through the soil infiltration system into the groundwater and were adsorbed by 9.8 to 29.5 ft (3 to 9 m) of basin soil with a 99.99% removal efficiency.

Lance et al. [47] studied virus movement in 250-cm columns packed with calcareous sand flooded with secondary sewage effluent containing about 3 x 10^4 PFU of poliovirus type 1 (LSc) per mL. The viruses were suspended in dechlorinated secondary sewage effluent and applied to soil columns on a schedule of 9 days of flooding alternated by 5 days of drying. Movement through the soil reduced the virus concentration to about 1% of the initial level during the first 2 cm of travel and to 0.1% after 38 cm of travel. Viruses were not detected in 1-ml extracts from columns below 160 cm.

Landry et al. [48] studied adsorption and elution of human enteroviruses in permeable sandy soil cores (43 by 125 mm) collected from an operating recharge basin on Long Island. The viruses studied included field strains and reference strains of poliovirus types 1 and

3, coxsackie virus B3, and echovirus types 1 and 6. The viruses were suspended in treated sewage effluent and allowed to percolate through soil cores. Infiltration rates for all cores were rapid, averaging 83 cm/hr. Column effluents were collected and assayed for total virus PFU. All the polioviruses tested (including field and reference strains) and coxsackie B3 were adsorbed extremely well. Echovirus 1 exhibited the greatest soil affinity (over 99%), whereas echovirus 6 showed the least affinity with 78% of virus adsorption.

Wang et al. [49] recently conducted laboratory experiments on the effects of soil permeability on virus removal through soil columns. Unchlorinated secondary sewage effluent seeded with poliovirus type 1 or echovirus type 1 was continuously applied to 100-cm soil columns for 3 to 4 days at various hydraulic flow rates. Column effluents at various depths were assayed for virus PFU. The effectiveness of virus removal was influenced by the soil types and the hydraulic flow rates. Their results indicated that virus removal was very effective at a flow rate of 13 inches/day (33 cm/day). A soil depth of 2.8 inches (7 cm) was sufficient to remove these two viruses in a sandy loam soil, whereas 47 and 67 cm were required to remove more than 98% of the seeded viruses from Flushing Meadows and Pomello sands, respectively.

FACTORS AFFECTING VIRUS REMOVAL BY SOIL

The mobility of viruses in soil is related to the properties of the viral protein coat; to the cation exchange capacity, pH, hydraulic conductivity, surface area, organic matter content, and texture of the soil; and to the pH, the ionic strength, and the flow rate of the percolating fluid. Viruses are colloidal-size particles (10-300 nm) that possess a nucleic acid core encapsulated by a shell or capsid (sometimes the capsid is enclosed by an envelope). The morphological feature of the protein coat (which includes the capsid and lipoprotein envelope) is characterized by being amphoteric. Soil organic matter and clay are generally negatively charged and readily adsorb the positively charged reactive groups of the viral protein coat below its isoelectric point (the pH in which there is no electrical charge on the particle). Cookson [50, 51] studied the mechanism of adsorption of bacteriophage T4 to activated carbon and found that the adsorption process was reversible and obeyed linear adsorption isotherms. The mechanism of adsorption was believed to involve the positively charged amino groups of the T4 phage and the negatively charged carboxyl groups of the activated carbon particles. When the pH of the medium was lowered, the carboxyl groups became protonated and desorption was evident.

Bitton [52] reviewed the mechanism of sorption between viruses and surface particles and reported that the presence of cations in the medium greatly influences the adsorption process. Cations of various salts neutralize the repulsive electrostatic potential of excess negative charges of the virus and soil colloids. Lefler and Kott [6] reported that the retention of poliovirus type 1 in sterile sand columns was increased in the presence of 0.5 N NaCl. Divalent cations are much more effective for the adsorption of viruses to surface particles when compared with monovalent cations [53, 54].

Gerba and co-workers [2] reviewed two theories on the mechanism of virus adsorption to soil. One theory involves the virus-cation-clay bridge, in which the cation links the two negatively charged particles. Reactive groups of viral proteins such as charged carboxyl, sulfhydryl, and phenolic OH groups are responsible for the electrostatic attraction between the viruses and the adsorbed cations held by micelles (minute colloidal particles) in the cation exchange sites of soils. If the concentration of cations in solution is reduced, the bridging effect breaks down and the virus is eluted. The other theory involves the fixation of cations onto ionizable groups of the viral particles, reducing the net electric charge and allowing an interaction with surface particles by Van der Waals forces.

Until recently, most of the literature reported on virus removal in soil was on a limited number of virus types. Goyal and Gerba [55] compared adsorption of 27 different types and strains of human enteroviruses and bacteriophages to nine different soil types using a 30-min batch adsorption procedure. Virus adsorption to soil was highly strain-dependent. Of all the viruses tested, poliovirus type 1 and coliphage T4 were adsorbed most readily to the nine soils. Echovirus type 1 and coliphage f2 were adsorbed the least. The work showed that no single enterovirus or coliphage should be used to model virus adsorption behavior to soils. Differing adsorption patterns for various virus strains appears to be due to their characteristic viral capsid protein affecting the viral isoelectric point and electronegative charge [48].

There have been many attempts to predict the ability of a soil to adsorb virus particles based on the chemical and physical properties of the soil (Table 14-4). Virus adsorption is generally enhanced with increasing clay and organic matter content because of their surface area and greater number of active sites for adsorption compared with silt and sand. Burge and Enkiri [21] found that, of all the soil properties which show general trends to increasing levels of adsorption (pH, cation exchange capacity, surface area, glycerol-retention capacity, and organic matter content), only pH was significantly correlated with the rate of virus adsorption. However, Gerba and Lance [56] reported that virus adsorption was highly dependent on the CEC and exchangeable aluminum content of soils.

Virus adsorption is generally favored at pH values below 7.0 and is less effective at higher pH values [44]. Landry and co-workers [48] reported that a soil pH below 5.0 seems to be the best for adsorbing a wide variety of enteroviruses. In general, viruses are negatively charged at a pH above their isoelectric point, behaving as an anion and repelling the negatively charged soil particles. At a pH below the viral isoelectric point, the virus would behave as a cation with greater attraction to the negative micelles. The isoelectric point for most enteric viruses is below pH 5.0 [2]. However, a low pH may not favor best wastewater irrigation practice, since inactivation of enteroviruses is favored by alkaline pH [22].

Evidently, organic compounds are able to compete with viruses for adsorption sites on soil colloids [53]. Schaub et al. [57] reported that when soils were treated with wastewater containing low cation and high soluble organic concentrations, viruses were not adsorbed effectively because of the electronegative charges on both the viruses and low-molecular-weight organic material. Consequently, viruses remaining in primary sewage effluent are poorly held by soil compared with those in secondary effluent [47].

Table 14-4. Factors affecting virus removal by soil.

Factors	Remarks
pH	Low pH favors virus adsorption; however, high pH favors virus inactivation.
Cations	Cations neutralize or reduce the repulsive electrostatic potential (negative charge) of virus particles and soil components, favoring adsorption.
Clays	Enhances virus adsorption.
Organic matter content	Enhances virus adsorption.
Cation exchange capacity	High cation exchange capacity promotes virus adsorption.
Flow rate	Low flow rates (<0.6 m/day) favor virus removal.
Suspended solids	Soluble organic matter competes with viruses for adsorption sites on soil colloids and hinders viral inactivation in wastewater.
Rainwater	Promotes desorption of viruses.

Lance and Gerba [58] reported that the velocity of wastewater movement through soil is an important factor affecting virus distribution with depth. They found that when flow rates of secondary sewage effluent seeded with poliovirus type 1 were increased from 0.6 to 1.2 m/day, more virus movement occurred through the soil. Flow rates less than 0.6 m/day were the most effective for virus removal. At the Flushing Meadows field site, 90% to 99% of the applied poliovirus type 1 in secondary sewage effluent was removed in the upper 2 to 4 inches (5 to 10 cm) of soil at infiltration rates of 6 to 22 inches/day (15 to 55 cm/day) [47]. Robeck et al. [45] reported that virus removal in coarse sands was more than 90% when flow rates were less than 3 ft/day (0.9 m/day). More virus breakthrough was observed as the rate was increased, reaching 80% to 90% elution at flow rates above 192 ft/day (59 m/day).

Mobilization of viruses in soil is affected not only by the flow rate of wastewater but also by the ionic strength of the percolating fluid. Viruses are slightly negatively charged at the pH often encountered in wastewater [19]. The presence of cations will neutralize the repulsive interaction between the viral particles and soil colloids. The divalent cations (Ca^{2+} and Mg^{2+}) appear to be more effective than monovalent cations (Na^+, K^+), and trivalent cations (Al^{3+}, Fe^{3+}) are even more efficient in forming a virus-cation-clay bridge. Goyal and Gerba [55] found that adsorption of coxsackie virus strains were enhanced to the Flushing Meadow soil by the presence of 10 mM Ca^{2+}. Lance and Gerba [58] observed complete adsorption of poliovirus type 1 (LSc) in the top 5 cm of soil when 5 mM of $CaCl_2$ was added.

Intermittent loading of wastewater to soil tends to enhance virus immobilization over continuous loading. Lance et al. [47] found that drying the soil for one day between virus loading and flooding with deionized water reduced migration of viruses through soil columns. Upon flooding, elution of viral particles was not observed after a 5-day drying period. Furthermore, wetting and drying cycles of 14 days at the Flushing Meadows project site resulted in very high virus retention in soils. There appears to be no conclusive reports on how wetting and drying affects virus inactivation.

Virus desorption can be demonstrated when the ionic strength of the percolation fluid is lowered. Duboise and his associates [59] reported adsorption of poliovirus in soil columns when sewage effluent was applied, but the addition of distilled water caused the release and migration of the virus through the columns. Roper and Marshall [60] showed similar findings when a bacteriophage from marine sediments was rapidly desorbed following decreasing salinity with successive washings of the samples. Lance et al. [47] reported that when deionized water was applied 2 hours after a sewage-water-poliovirus 1 mixture was added to soil columns, desorption of viruses eluting down to 5.2-ft (160-cm) depths was evident. Increased virus elution from soil cores often coincides with low electrical conductivity levels of column effluents [59]. In the field, heavy rainfall could cause desorption of viruses and promote their downward migration to the groundwater. Wellings et al. [5] observed a burst of enteric viruses in 3-m sampling wells following a period of heavy rainfall.

SUMMARY

The survival rates of pathogenic bacteria in soil normally vary from one day to several months. Many factors affect the survival of enteric bacteria in soil. Increased soil moisture content, cooler temperatures, and higher organic matter content tend to favor longer survival, but extremely acidic or alkaline conditions, sunlight, and antagonistic microflora are opposing factors to survival. Protozoa and helminths appear to survive as long as enteric bacteria in soil, although ascaris ova may remain viable much longer. Depending on the nature of the soil, temperature, pH, and moisture content, enterovirus survival has been reported to vary from 25 to 170 days. Virus inactivation is promoted by dissaggregation of viral clumps, presence of chloride salts, high temperature and pH, and virucidal chemical species such as ammonia. Suspended organic matter in wastewater (virus-solid association) is believed to have some protective effect on virus survival.

The movement of pathogens in soil involves transport by insects, birds, rodents, windblown soil, overland runoff, and percolation through the soil profile to groundwater. Continuous application of wastewater could result in accumulation of pathogens at the soil surface. Pathogen movement in surface runoff water may be a greater hazard for disseminating diseases than pathogen elution to groundwater. The main factors that govern the transport of bacteria, ova of intestinal worms, and cysts of protozoa through the soil matrix are straining, sedimentation, and adsorption. Most studies show that bacteria are confined to the upper few centimeters of soil and never reach the groundwater unless the soil has large cracks or channels.

The literature indicates excellent removal of viruses through soil columns and adsorption in batch studies. It is evident that viruses differ quite markedly in their survival and removal during percolation through soil. The mobility of viruses in soil is related to viral properties; to the pH, cation exchange capacity, surface area, organic matter content, and texture of the soil; and to the pH, ionic strength, and flow rate of the percolating fluid.

Adsorption is the primary mechanism for viral retention in soil and is favored by low flow rates, intermittent loading, high cation exchange capacity, high clay content, high organic matter content, and low pH. Desorption is promoted by percolating fluids with low ionic strength through soil. Wastewater application to soil appears to be very effective in pathogen immobilization and inactivation.

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CHAPTER 15

FATE OF WASTEWATER CONSTITUENTS IN SOIL AND GROUNDWATER: TRACE ORGANICS

A. C. Chang and A. L. Page

INTRODUCTION

Organic matter content of wastewater and its treated effluents is customarily expressed in terms of the biochemical oxygen demand, the chemical oxygen demand, and the total organic carbon. Although these measurements have been effective in estimating the pollutional strength of the water and evaluating the performance of wastewater treatment processes, they neither indicate the composition of organic matter nor identify any toxic organic substance. It is quite conceivable that two waters of identical total organic carbon contents may be composed of entirely different organic compounds. In the toxicological assessment of the water quality, it is essential that toxic organic substances in the water be positively identified and their concentrations determined.

Analytical techniques now permit the identification and detection of organic chemicals in the water at concentrations near the level of one part per billion [1,2]. Although these methods are rather cumbersome for routine water-quality monitoring, they have been helpful in understanding the chemical nature of organic substances in the water. When these improved analytical procedure are used, a wide spectrum of organic chemicals in minute quantities are isolated from surface water bodies, ground water, and drinking water [3,4]. The majority of the organic residues found in the water are naturally occurring. But many synthetic organic compounds also are known to be toxic or are suspected of causing cancer on the basis of short-term laboratory tests. The concentrations of these substances in the water, except in rare instances, are always below levels at which adverse responses have been reported. Their presence in the water, nevertheless, raises the possibility that the long-term low-level exposure to potentially harmful organic substances through the use of water may become a human health hazard. In municipal wastewater, organic chemicals similar to those present in natural water systems have been found even more frequently.

One of the most important routes for chronic exposure to trace quantities of hazardous organic chemical (--the direct ingestion of the substance through drinking water--) was examined by a panel of experts assembled in 1976 by the National Academy of Sciences and National Academy of Engineers [5]. They reviewed the existing scientific literature for information relevant to the occurrence, metabolism and toxicology of each potentially hazardous water-borne organic substance. There is a serious deficiency of toxicological data for organic compounds and a great deal of uncertainty associated with extrapolating those data to assess the risk of low-level chronic exposure. However, they found no evidence that trace amounts of toxic organic substances in drinking water have caused cancer or increased the incidences of cancer. Since the no-response threshold concentration cannot be clearly established, the risk of disease as a result of long-term exposure cannot be completely ruled out.

In wastewater irrigation, the route of exposure to water-borne trace organics will not be direct ingestion. Instead, trace organics are deposited in the soil, subjected to attenuation by physical, chemical, and biological reactions in the soil, and translocated into plant tissue before they may enter the human food chain. Through the soil matrix, trace organics introduced by irrigation may also become contaminants of groundwater. It is essential that the fate of trace organic substances introduced into the soil through irrigation be determined.

OCCURRENCE OF TRACE ORGANICS IN WASTEWATER

In the current literature, the term "trace organics" is not clearly defined. Generally, the term is used to characterize those organic substances that are present in seemingly uncontaminated water or treated wastewater effluents in extremely low concentrations. Most of the constituents detected are perhaps naturally occurring, At the concentration levels in which they appear in water, none of them seriously interferes with use of the water. However, there are also many potentially toxic synthetic organic chemicals. Although there are thousands of synthetic chemicals, not all of them have found their way into the water. Some chemicals occur in water more frequently than others. The trace organic composition of any two streams of water are not likely to be the same. For the purpose of this discussion, only the potentially hazardous trace organics of the water will be considered.

Recently, the occurrence of priority pollutants in the influents of four publicly owned treatment works (Cincinnati, Ohio; Atlanta, Georgia; St. Louis, Missouri; and Hartford, Conn.) was surveyed [6]. "Priority pollutants" are toxic pollutants regulated under section 307 of the Federal Water Pollution Control Act, (see 95th Congress Committee Print 95-30 Data relating to H.R. 3199, U.S. Government Printing Office, 1977). Among them, 77 were never detected during the 3-month sampling period, and another 20 were detected less than 10% of the time. Of the 56 frequently found priority pollutants, 43 were organic substances. Many were found in extremely low concentrations. Table 15-1 summarizes the detection frequency, the range and the average concentrations of each organic priority pollutant. Since their concentrations in wastewater were low, it was often difficult to pinpoint their source. Although they were found in wastewater from both residential and industrial sectors of the urban community, the wastewater flow from the industrial area contributed significantly greater amounts to the total trace organic load [7]. However, it is not certain that the pattern developed from the wastewater of these communities could be extrapolated to represent the distribution pattern of trace organics in the 13,000 publicly owned treatment works in the United States; nevertheless, this represents the best available data.

Processes commonly engaged in the treatment of the municipal wastewater are designed to remove suspended solids, biochemical oxygen demand, and bacteria from the incoming wastewater. Studies show that conventional wastewater treatment is also effective in reducing the level of trace organics [7]. The removal of trace organics occurs almost entirely during biological treatment. Chlorination of wastewater effluent often yields additional halogenated hydrocarbons [8,9]. Although rapid sand filtration has little effect on the

Table 15-1. Priority pollutants in influents from publicly owned treatment works[a].

Priority pollutant	Frequency of detection	Concentration (μg/L) Range	Mean
Trichlorofluoromethane	6	--	--
Acrylonitrile	6	--	--
1,1-Dichloroethylene	17	0- 8.6	2.4
1,1-Dichloroethane	6	0- 0.3	0.1
trans-1,2-Dichloroethylene	28	0- 18.6	4.8
Chloroform	100	3.6- 7.1	4.9
1,2-Dichloroethane	11	0- 0.4	0.2
1,1,1-Trichloroethane	78	0.3- 95.9	28.9
Bromodichloromethane	11	0- 0.7	0.2
Trichloroethylene	67	0- 164.9	50.5
Benzene	67	0- 7.0	2.7
Dibromochloromethane	22	0- 1.0	0.2
1,1,2,2,-Tetrachloroethane	6	--	--
1,1,2,2-Tetrachloroethylene	83	1.1- 239.4	77.9
Toluene	78	1.6- 60.2	25.8
Chlorobenzene	6	0- 0.2	0
Ethylbenzene	67	0- 48.7	16.3
Phenol	33	0- 18.8	7.3
2,4-Dimethylphenol	11	0- 9.9	2.5
p-Chloro-m-cresol	6	--	--
Pentachlorophenol	22	0- 19.2	5.7
Dichlorobenzene	56	0- 92.7	33.1
Napthalene	44	0- 32.9	11.6
Diethylphthalate	50	3.6- 11.6	6.8
Di-n-butylphthalate	67	4.2- 15.8	9.3
Butylbenzylphthalate	44	0- 77.3	22.2
Bis(2-ethylhexyl)/ di-n-octylphthalate	22	0- 4.5	2.2
Heptachlor	6	--	--

a. Derived from Levins et al. [6].

concentrations of trace organics in the water, lime coagulation is an effective unit process for reducing the concentration of trace organics during tertiary treatment. However, even with activated carbon adsorption and reverse osmosis, a wastewater effluent is not rendered completely free of trace organics [10]. In one study, the concentrations of trace organics in a treated wastewater effluent usually followed a log-normal distribution. Table 15-2 summarizes the concentrations of trace organics of the secondary effluent at the Orange County Water District's wastewater treatment plant from 1976 to 1978 [10].

BEHAVIOR OF TRACE ORGANICS IN THE SOIL

Soils are porous media consisting of weathered mineral fragments, organic matter, microorganisms, water, and air. They are chemically and biologically complex. For the purpose of describing the behavior of trace organic substances in the soil environment, the physical features of a soil may be divided into four components:atmospheric, aqueous, solid, and biotic. The fate of a trace organic compounds during the passage of wastewater through the soil matrix is dependent on the partitioning of the introduced chemical among these four components. The mechanisms that are responsible for the attenuation of trace organics are essentially identical to those in other segments of the environment. However, the reaction kinetics that determine the mass transfer may be different from those in the aqueous or the atmospheric system. Experiences indicate that rate constants for the transport process in the soil are influenced by the properties of the soil and the nature of the chemical compound.

Among the processes that may affect the transformation of trace organic substances during wastewater irrigation, adsorption, volatilization, and biodegradation are considered most important. At present, there are few experimental data that would permit a comprehensive evaluation of the fate of trace organics in the soil. In the following discussion, one approach to assessing the behavior of trace organics in the soil is presented.

Table 15-2. Trace organics (μg/L) in secondary effluents--Orange County Water District.

Compound	Jan. 1976 - Sept. 1976[a] No. of samples	Range	Geometric mean	Mar. 1978 - Oct. 1978[b] No. of samples	Range	Geometric mean
Trihalomethane						
Chloroform	52	0.2 -3.9	1.6	28	0.8-17	2.9
Bromodichloromethane	42	<0.1 -1.1	0.09	27	0.2-3.2	0.6
Dibromochloromethane	35	<0.1- 10	0.15	28	0.2-1.8	0.71
Bromoform	24	<0.1- 3	0.12	23	0.1-6.4	0.37
Other volatile organics						
Carbon tetrachloride	--	---	--	28	<0.1-0.1	<0.1
Methylene chloride	41	1.7-74	17.0	--	---	--
1,1,1-Trichloroethane	50	<0.3-38	4.7	28	0.3-15	2.9
Trichloroethylene	46	<0.1-12	0.9	--	---	--
Tetrachloroethylene	39	<0.1-15	0.6	28	0.2-9.5	1.5
Chlorobenzenes						
Chlorobenzene	14	0.2 -9.4	2.5	27	<0.02-1.1	0.11
1,2-Dichlorobenzene	15	0.3 -8.9	2.4	27	0.07-13	0.63
1,3-Dichlorobenzene	15	0.2 -1.7	0.68	26	<0.02-5.4	0.17
1,4-Dichlorobenzene	15	0.8 -9.2	2.1	26	0.07-15	1.9
1,3,4-Trichlorobenzene	15	<0.02-4.1	0.46	27	<0.02-3.1	0.18
Aromatic hydrocarbons						
Ethylbenzene	13	0.2 -8.7	1.4	25	<0.02-0.5	0.039
m-Xylene	--	---	--	24	<0.02-0.2	0.027
p-Xylene	--	---	--	24	<0.02-0.04	0.016
Naphthalene	16	0.1 -4.1	0.57	27	<0.02-0.54	0.065
1-Methylnaphthalene	11	0.1 -3.9	0.86	27	<0.02-0.89	0.004
2-Methylnaphthalene	10	0.4 -2.6	1.0	27	<0.02-0.18	0.018
Solvent extractables[b]						
Dimethylphthalate	3	14.7-18.7	0.6	25	0.8-14	5.4
Diethylphthalate	11	<2	<2.0	25	<0.3-12	<0.3
Di-n-butylphthalate	3	<0.5- 0.5	<0.5	24	<0.5-3.4	0.75
Di-isobutylphthalate	11	<0.3-16	2.9	25	<1-10	4.4
Bis-[2-ethylhexyl]phthalate	11	15 -65	28.0	25	<4-62	9.3
PCB (as Aroclor 1242)	11	2 - 7.6	3.3	25	<0.3-1.3	0.47
Lindane	10	<0.1- 0.6	0.19	25	0.09-0.19	0.15

a. Period from Oct. 1976 to Mar. 1978 trickling filter effluent, period from Mar. 1978 to Oct. 1978 activated sludge treatement with segregation of wastewaters to reduce industrial inputs.

b. One liter of sample extracted with 2 x 15 mL of hexane, dried with sodium sulfate, concentrated to 2 mL, and cleaned on a Florisil column before analysis.

Adsorption

In the soil, adsorption is a process that describes the migration of chemical constituents from the aqueous phase to the surface of soil particles. As the solutes are temporarily or permanently immobilized into the stationary phase, the concentration of potentially hazardous trace organic substances in the soil solution will be reduced. Although a variety of intermolecular electrostatic forces are known to cause adsorption in soils, it is not always possible to measure the relative contribution of each interacting component in an adsorption process. As a result, the soil adsorption is always measured as the sum of contributing processes.

The distribution of a solute between the aqueous phase and the solid phase at equilibrium can be mathematically described by the Langmuir or the Freundlich adsorption isotherm. The experimentally obtained data may also be fitted into a simple proportionality equation [11]:

$$\frac{X}{M_s} = K_d \times C \qquad [15\text{-}1]$$

where X is the amount of solute adsorbed (μg), M_s is the amount of soil (g), C is the equilibrium solute concentration (μg/mL), and K_d is the soil adsorption constant (mL/g).

In this equation, the value of K_d, which indicates the relative magnitude of the adsorption, is specific for the soil and the chemical involved. For non-polar hydrophobic organic substances, their adsorption can be positively correlated to the organic matter content of the soil [12,13]. Therefore, Equation 15-1 may be written to express the influence of soil organic matter so that:

$$\frac{X}{M_{oc}} = \frac{K_d}{f_{oc}} \times C = K_{oc} \times C \qquad [15\text{-}2]$$

where f_{oc} is the soil organic matter expressed in weight fraction, M_{oc} is the amount of soil organic matter (g) that equals M_s multiplied by the fraction of soil organic matter (f_{oc}), and K_{oc} is the soil adsorption constant in terms of the soil organic matter (mL/g).

Under a given circumstance, the K_d is experimentally determined. The value of K_{oc} for a given organic substance, however, remains fairly constant and is independent of the soil type. Despite the importance of the adsorption constants in predicting the transport of organic solute in the soil, only a few K_{oc} and K_d values of trace organic substances (except for pesticide residues) have been determined.

More recent studies showed that the K_{oc} of an organic substance may be estimated from the octanol-water partition coefficient (K_{ow}) of the compound [14]. Several equations that may be used to empirically estimate the K_{oc} of trace organic substances are listed as follows:

$$K_{oc} = 0.63 \times K_{ow} \text{ [12]} \qquad [15\text{-}3]$$

$$\log K_{oc} = 0.72 \log K_{ow} + 0.49 \text{ [15]} \qquad [15\text{-}4]$$

$$\log K_{oc} = 0.544 \log K_{ow} + 1.377 \text{ [16]} \qquad [15\text{-}5]$$

The octanol-water partition coefficient (K_{ow}) describes the hydrophobicity of an organic compound by partitioning it between the aqueous phase and a phase (octanol) in which lipids are soluble [17]. It has been used extensively in predicting the chemical behavior of organic compounds in water and soil. Besides its usefulness in predicting the K_{oc}, the K_{ow} of a compound may also indicate the bioaccumulation potential in the aquatic environment. It appears that octanol is similar in polarity characteristics to the glyceryl esters that comprise the principal components of the cell membrane. More important, the K_{ow} of organic compounds are extensively tabulated. They may also be estimated from the molecular structure of the compound. The availability of K_{ow} in the published literature provided the basis for calculating the K_{oc} of selected trace organic substances of treated wastewater effluent shown in Table 15-3 [17,18,19]. The K_{oc} values of selected trace organic substances varied from 70 for bromodichloromethane to more than 30,000 for PCB. The strong adsorption of PCB by earth materials is well established [20]. Compounds with a K_{oc} of 200-300 or higher are expected to be effectively immobilized in the soil under most irrigation schedules (3 to 4 ft/year or 91-122 cm/year) [21,22].

Volatilization

In a moist soil, volatilization from the dilute aqueous solution is determined by the partitioning coefficient (K_w) between the water and the air [11,23]. The K_w of an organic chemical is defined as the ratio of the equilibrium concentration in water (µg/mL) to the corresponding concentration in the air (µg/mL) at 77°F (25°C). This parameter provides a comparative measurement of the ability of a chemical to partition between the water and the air. A lower numerical value of K_w indicates a greater tendency for the compound to become volatilized. Since a steady-state equilibrium is seldom reached in the soil, the partitioning coefficient of a compound between the water and the air in a soil is best determined experimentally.

If experimental data are not available, the partitioning coefficient may be estimated. Mathematically, the value of K_w for an organic chemical equals the inverse of the Henry's Law constant and can be approximated by dividing the water solubility (S in µg/mL) by the saturated vapor concentration (i.e., amount of the chemical in vapor phase [µg]/volume of gas [cm³]). Using the perfect gas law to evaluate the saturated vapor concentration, the K_w may be expressed as [11]:

$$K_w = [S \times 0.062366 \times (273.15 + T)]/[V_T \times M] \qquad [15\text{-}6]$$

where S is the water solubility of the organic chemical (µg/mL), T is the temperature (°C) at which the water solubility was measured, V_T is the saturated vapor pressure at T (mmHg), and M is the molecular weight of the chemical.

Trace organics in treated wastewater effluents consist primarily of low-molecular-weight, nonpolar organic substances whose high vapor pressure and relatively low solubility in water are especially conducive to rapid volatilization. At the concentrations at which they are present in the water, even a slight volatilization could be significant in solute transport. As the molecular weight of the organic substances increases, the saturated vapor pressure and the solubility frequently decrease to levels difficult to measure accurately. For a high-molecular-weight organic substance, it is essential that K_w be determined from actual experimental data [24].

Table 15-3 summarizes the K_w for selected trace organics of wastewater effluents calculated by equation 15-6. Except for phthalate esters, all other trace organic chemicals listed in Table 15-3 should be subject to rapid volatilization in soil solution.

In the soil, the mass transfer through volatilization depends not only on the partition of a chemical between the water and the air but also on movement of the chemical to the soil surface and its dispersion in the air. Consequently, the actual volatilization loss of trace organics from the soil will depend on factors affecting the movement of chemicals to the soil surface and of volatilized compounds away from the water/air interface [25].

The values of K_{oc} and K_w tabulated in Table 15-3 describe the relative importance of soil adsorption and volatilization among a group of selected trace organic substances. In order to assess the fate of a chemical in soil, it is essential to compare the properties of the substance in question with organic substances whose environmental behavior is well understood. By assuming that (1) the rate of leaching is proportional to the amount of the trace organic substance in the aqueous phase of the soil system and (2) the rate of volatilization is proportional to the amount of the trace organic substance in the atmospheric phase of the soil system, Laskowski et al. [11] derived the following mathematical expressions for leaching potential and volatilization potential of an organic substance:

$$\text{Leaching Potential} = S_{25}/(V_p \times K_{oc}) \qquad [15\text{-}7]$$

$$\text{Volatilization Potential} = V_p/(S_{25} \times K_{oc}) \qquad [15\text{-}8]$$

where S_{25} is water solubility of the substance at 25°C (ppm), and V_p is the saturated vapor pressure of the substance at 25°C. Table 15-4 summarizes the calculated leaching potential and volatilization potential of selected trace organic substances found in treated wastewater effluents. They are compared with the leaching and volatilization potentials of four pesticide residues (2,4-D, malathion, lindane and DDT) whose behavior in the soil has been studied extensively. It is obvious that trace organic substances in wastewater effluent have a leaching potential similar to DDT the soil. However, most trace organic substances are far more likely to volatilize from the soil than DDT.

Table 15-3. Soil adsorption constant (K_{oc}), water-air partitioning coefficient (K_w), and octanol-water partitioning coefficient (K_{ow}) of selected trace organic substances.[a]

Compounds	K_{oc}	K_w	K_{ow}
Chloroform	81	8.3	93
Bromodichloromethane	70	--	76
Dibromochloromethane	99	--	123
Bromoform	140	--	200
Carbon tetrachloride	246	1.0	437
Methyl chloride	129	--	178
1,1,1-Trichloroethane	113	0.7-6.4	148
Tetrachloroethylene	230	--	398
Chlorobenzene	343	6.9-9.2	692
1,2-Dichlorobenzene	839	12.2	2,399
1,3-Dichlorobenzene	838	6.8	2,398
1,4-Dichlorobenzene	853	7.5	2,455
1,2,4-Trichlorobenzene	3,607	7.3	18,197
Ethylbenzene	573	3.74	1,413
m-Xylene	622	--	1,585
p-Xylene	573	--	1,413
Napthalene	825	--	2,344
Dimethyl phthalate	104	47,076	132
Diethyl phthalate	643	--	1,660
Di-n-butyl phthalate	17,140	--	158,489
Bis-[2-ethyl hexyl]phthalate	20,230	--	199,526
PCB (Aroclor 1242)	32,181	40.5	380,189
Lindane	1,474	1,047	5,248

a. K_{ow} values were from Callahan et al. [18,19]; K_{oc} and K_w of each compound are calculated by Equation 15-4 and Equation 15-6, respectively.

Table 15-4. Relative risk of trace organic substances leaching through the soil and volatilizing from the soil as compared with selected pesticide residues in soil.

Compounds	Volatilization[a] potential	Leaching[a] potential
Chloroform	2.3×10^{-4}	1.9×10^{-1}
Carbon tetrachloride	4.8×10^{-4}	1.3×10^{-2}
Methyl chloride	1.8×10^{-4}	4.0×10^{-1}
1,1,1-Trichloroethane	1.7×10^{-3}-1.9×10^{-4}	4.5×10^{-2}-4.2×10^{-1}
Chlorobenzene	1.5×10^{-4}	1.5×10^{-1}
1,3-Dichlorobenzene	1.2×10^{-5}	1.2×10^{-1}
1,3-Dichlorobenzene	2.2×10^{-5}	6.5×10^{-2}
1,4-Dichlorobenzene	1.7×10^{-5}	7.8×10^{-2}
1,2,4-Trichlorobenzene	3.8×10^{-6}	1.9×10^{-2}
Ethylbenzene	8.0×10^{-5}	3.9×10^{-1}
Dimethyl phthalate	1.9×10^{-8}	34.6
2,4-D	1.1×10^{-11}	2.5×10^{7}
Malathion	2.9×10^{-10}	4.0×10^{3}
Lindane	1.6×10^{-7}	3.6
DDT	4.7×10^{-10}	3.7×10^{-2}

a. Leaching potential and volatilization potential of each substance are calculated according to Equations 15-7 and 15-8. Compounds with higher values are more likely to volatilize or be leached in the soil.

Biodegradation

In the soil, trace organic substances may be removed from the applied wastewater effluent by adsorption or volatilization, wherein the chemical structure of the compounds are not altered in the processes. There are experimental data that demonstrate the rapid desorption of the adsorbed trace organics when the soil is leached with a trace-organics-free water [15]. This reversal of the adsorption process releases the potentially hazardous chemicals to the aqueous phase.

Biodegradation is an enzyme-activated biochemical reaction whereby organic substances are effectively decomposed. Bacteria, actinomycetes, and fungi are the soil micro organisms most important in the decomposition of organic substances in the soil. Although the biochemical pathway responsible for breaking down trace organic substances is not entirely known, the microbial metabolisms are well understood. Biochemical reactions such as β-oxidation, cleavage of ether linkage, ring hydroxylation, ring cleavage, ester hydrolysis, dehalogenation, and n-dealkylation are all common to the degradation of pesticide residues in the soil [26]. However, enzymes responsible for the reactions may have to be induced. The same biochemical mechanisms are applicable to the degradation of trace organic substances introduced into the soil by wastewater irrigation. Biodegradation thus offers the means to detoxify trace organics retained by the soil.

The rate of biodegradation in soils is influenced by the type of microorganism, the characteristics of the soil, and the molecular structure of the compound [27]. The degradation processes of poorly adsorbed water-soluble trace organics may be described by the Michaelis-Menten reaction kinetics. At high substrate concentrations (>2.5 μg/mL), the rate of degradation appears to be independent of the substrate concentration (zero-order reaction). At low substrate concentrations, the decomposition becomes a first-order reaction. However, it is essential that reaction kinetics and breakdown in the soil be properly defined.

Following an extensive review of the literature, Callahan et al. [19] concluded that the biodegradation pathway of organic priority pollutants may be developed on a theoretical basis or extrapolated from experiments of compounds with similar chemical structures. Few experimental data are available to confirm the speculation. Tabak et al. [28] studied the biodegradability of 96 organic priority pollutants using the static-culture flask screening procedure developed by Bunch and Chambers [29] at 5 mg/L and 10 mg/L substrate concentrations. Their results are summarized in Table 15-5. Except for chlorodibromomethane and heptachlor, organic priority pollutants found in the influents from publicly owned treatment works (Table 15-1) can be biologically degraded. At the concentrations in which they are present in the wastewater effluent, it is questionable whether a viable microbial population will be maintained with trace organic substances as the sole carbon source. Reaction rates are expected to be considerably lower at low substrate concentrations [30]. Experimental results have demonstrated that significantly higher levels of trace organic reductions may be achieved when they are used as the secondary substrate. Therefore, the presence of readily available organic carbon sources in the soil would undoubtedly enhance the degradation of trace organics. Because adsorbed trace organics generally will not be subject to microbial attack, the rate of biodegradation for trace organics in the soil may also be slowed by adsorption.

Bioaccumulation

In this discussion, the possibility of trace organic substances being absorbed by crops has not been raised. Examples from the study of pesticide residues and polynuclear aromatic hydrocarbons in the soil show that some degree of plant absorption of trace organic substances will occur (magnitude lower than that of pesticides) [31]. Since there are no known physiological pathways for plants to absorb trace organics, the most likley mechanism would be by mass flow. Once the trace organics are adsorbed by the soil, the amounts available for plant uptake become limited. Because of their hydrophobic nature, trace organic compounds of high K_{ow} are expected, upon entering the plants, to be deposited primarily in the plant roots [32,33]. The lower-molecular-weight trace organic compounds that are gradually assimilated by plant tissue should not exhibit symptoms of

Table 15-5. Summary of biodegradability of organic priority pollutants derived from data in Tabak et al. [28].

Tested Compounds[b]	Biodegradability[a] Significantly Degraded	Significantly Degraded After Acclimation	Slowly to Moderately Degraded	Very Slowly Degraded	Significant Degradation With Subsequent Toxicity	Not Significantly Degraded
Phenolic compounds	Phenol 2-Chlorophenol 2,4 Dichlorophenol 2,4-6 Trichlorophenol 2,4-Dimethylphenol P-Chloro-m-cresol 2-Nitrophenol 4-Nitrophenol 2,4 Dinitrophenol	Pentachlorophenol				4,6-Dinitro-o-phenol
Phthalate esters	Dimethylphthalate Diethylphthalate Butylbenzylphthalate	Bis-(2-ethyl hexyl)phthalate Di-n-octylphthalate				
Naphthalenes	Nathalene 2-Chloronaphalene Acenapthene Acenaphthylene					
Monocyclic aromatic hydrocarbons	Benzene Chlorobenzene[c] Nitrobenzene Ethylbenzene Toluene	Chlorobenzene[c] Ethylbenzene[c]			1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene 1,2,4-Trichlorobenzene 2,4-Dinitrolene 2,6-Dinitrolene	Hexachlorobenzene
Polycyclic aromatic hydrocarbons	Phenanthrene Pyrene[d]	Anthracene Fluorene Fluoranthene[d] Chrysene[d]				Fluoranthene[d] Chrysene[d] Pyrene[d] 1,2-Benzanthrancene
Halogenated ethers	Bis-(2-Chloroethyl)ether 2-Chloroethyl vinylether Bis-(2-Chloroisopropyl)ether					4-Chlorodiphenylether 4-Bromophenylether Bis-(2-Chloroethoxy)ether
Polychlorinated byphenyls	PCB-1221 PCB-1232					PCB-1016 PCB-1242 PCB-1248 PCB-1254 PCB-1260
Nitrogenous organics	N-Nitrosodiphenylamine[c] Isophorone Acrylonitrile Acrolein				1,2-Diphenylhydrazine	N-Nitroso-di-N-propylamine
Halogenated aliphatic hydrocarbons	Hexachloroethane Methylene chloride Bromochloromethane Carbon tetrachloride Hexachloro-1,3-butadiene Hexachloro-cyclopentadiene	1,1-Dichloroethane Chloroform Dichlorobromomethane Bromoform 1,1-Dichloroethylene Trichloroethylene Tetrachloroethylene 1,2-Dichloropropane 1,3-Dichloropropylene	1,2-Dichloroethane 1,1,1-Trichloroethane 1,2-Dichloroethylene-cis 1,2-Dichloroethylene-trans	1,1,2-trichloroethane		Chlorodibromomethane Trichlorofluoromethane
Organichlorine pesticides						Aldrinane Dieldrine Chlordane DDT DDE DDD α-Endosulfan β-Endosulfan Endosulfan sulfate Endrin Heptachlor Heptachlorepoxide Hexachlorocyclohexane

a Biodegradability of organic priority pollutants were tested by batch culture procedure with microbial inoculum from a settled sewage at 25°C for 7 days. Significantly degraded: substrate concentration less than 0.1 ml/l at the end of the testing period. Significantly degraded after acclimation: significant degradation after 1-3 weeks of microbial adaptation. Significantly degraded with subsequent toxicity: degradation exhibited initially was lost due to loss of the metabolically efficient microbial population or gradual buildup of toxicity. Slowly to moderately degraded: total loss of the substrate compounds in 7 days incubation time less than 95% with significant amounts caused by volatilization. Very slowly degradable: substrate degradation less than 50% even with long microbial adaptation period. Not significantly degraded: substrates are not significantly degraded under the test conditions and/or precluded by extensive rate of volatilization.

b Priority pollutant compounds not texted are Benzo(a)-pyrene, 2,4-Benzofluoranthene, Benzo(k)-fluoranthene, Benzo(g,h)perylene, Dibenzo(a,h)anthracene, Indeno(1,2,3-cd)pyrene, Toxaphene, Bioxin, Endrin aldehyde, Benzidine, 3,3'-Dichlorobenzidine, Bis-(2-chlorometyl)ether, N-nitrosodimethylamine, Vinyl chloride, Chloroethane, Methylchloride, Methylbromide, and Dichlorodifluoromethane.

c Compounds significantly degraded at low substrate concentration (5 mg/l) and required microbial adaptation before significant degradation took place at a high substrate concentration.

d Biological degradation of the compound was not observed at high substrate concentration (10 mg/l).

bioaccumulation. Unless there are data to indicate otherwise, accumulation of trace organics in the plant tissue through root absorption is not expected to be significant.

CONCLUSION

Trace organic substances are a group of newly discovered contaminants of water supplies. Since their discovery, several hundred potentially hazardous organic chemicals have been found in natural water, wastewater, and drinking water. Because of the inherent toxic effects associated with many trace organic substances, their presence in the water (even at low concentrations) has caused great concern.

Although conventional wastewater treatment processes are not designed for trace-organic removal, such processes can greatly reduce the number and concentrations of trace organics. For this reason, the environmental risk associated with using the treated wastewater for irrigation should not be greater than that associated with using other sources of water, which may also contain trace organics.

When trace organics are introduced into the soil through wastewater irrigation, the most effective mechanisms of attenuation are expected to be adsorption, volatilization, and biodegradation. Because there are few data to quantitatively describe the fate of trace organics in soil, the soil adsorption coefficient (K_{oc}), water-air partition coefficient (K_w), and octanol-water partition coefficient (K_{ow}) of selected trace organics of the treated wastewater effluent provide useful indexes of the behavior of trace organics. When they are compared with several pesticides whose environmental fate and transport in the soil are well defined, it becomes obvious that most trace organics of the wastewater will be attenuated in the soil in a manner similar to attenuation of pesticide residues. Because the inputs of trace organic matter through irrigation are usually smaller than the application of pesticides, the environmental impact associated with their presence in wastewater effluents is not expected to be very significant.

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APPENDIX A

SELECTED MUNICIPAL WASTEWATER IRRIGATION PROJECTS IN CALIFORNIA

INTRODUCTION

This appendix contains descriptions of 17 municipal wastewater irrigation projects in California (Figure A-1). These descriptions were prepared by Boyle Engineering Corporation in March 1983. An earlier version of these descriptions was published in 1981 [1].

BAKERSFIELD

Bakersfield, located at the southern end of the San Joaquin Valley, has used wastewater to irrigate croplands for more than 60 years.

The treatment plant effluent is used to irrigate approximately 5,100 acres that the city owns and leases to a farmer. The city's lease with the farmer is quite specific about his responsibilities. He is required to take all of the wastewater produced by the treatment plant and use it for irrigation on those crops that meet State Health Department and California Regional Water Quality Control Board (CRWQCB) requirements. The annual cost to the lessee for the leased land and water is $80 per acre. The lease is for 14 years beginning in 1979.

The city owns a total of 5,770 acres. More than half of this land was recently purchased from the railroad, and it was poor agricultural ground with soils high in salinity and alkalinity.

The city has completed a land reclamation program including leveling, ripping, and applying gypsum at a rate of 10 tons/acre. Indications are that the land reclamation program is successful. The project is designed to provide waste treatment using the reclaimed water to irrigate the city-owned acreage through 1996. By that time, approximately 54 inches of reclaimed water per year will be applied to the 5,100 acres.

Many agricultural crops are grown in the Bakersfield area, including orchard, row, and field crops. Crops grown in the area

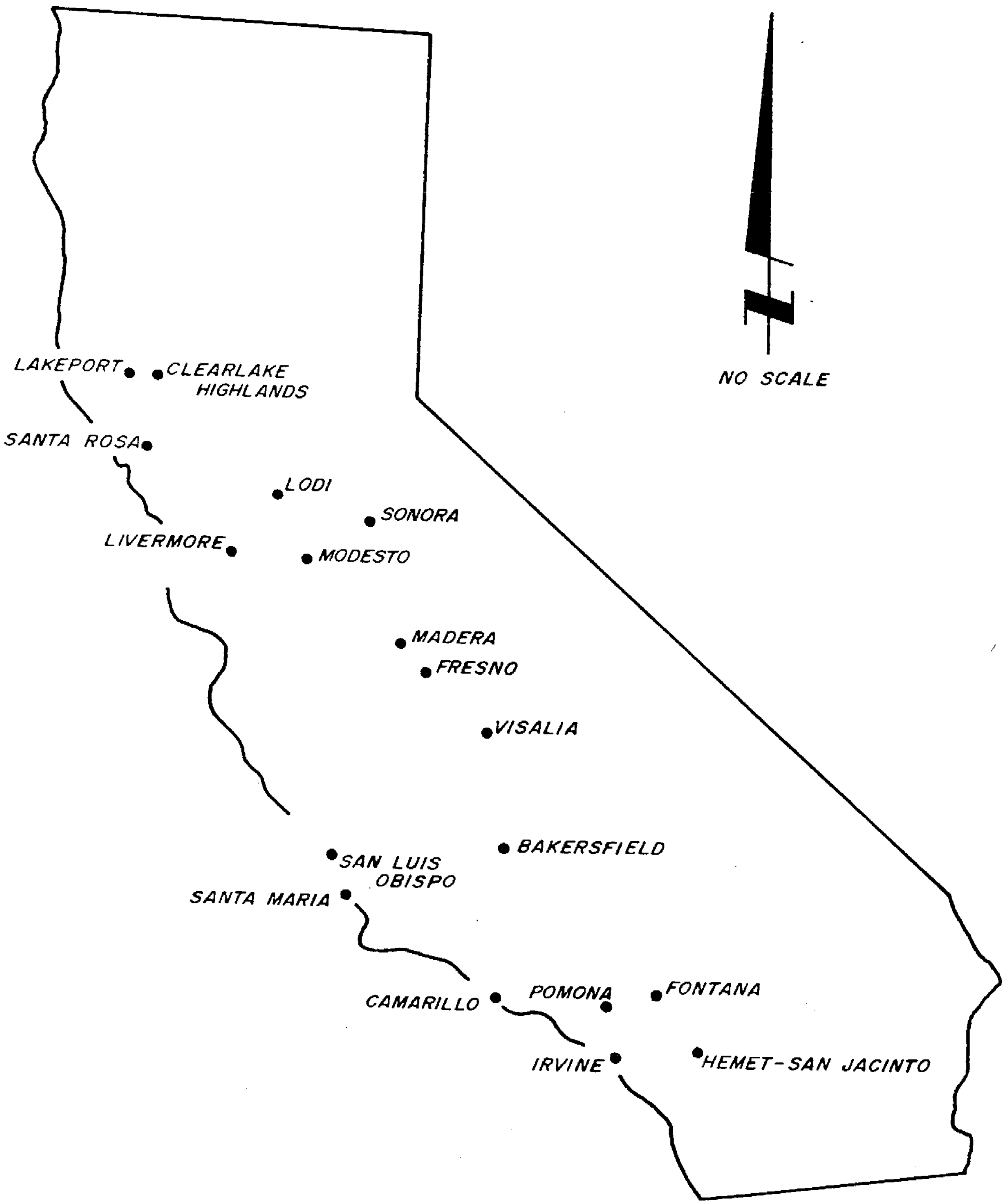

Figure A-1. Reviewed reclamation projects.

surrounding the city farm are cotton, corn, barley, alfalfa, sorghum, wheat, and permanent pasture. The city's tenant is growing barley, corn, cotton, alfalfa, sorghum, and permanent pasture.

The soils in the area consist of Bishop clay loams, Cajon fine sandy loams, Foster fine sandy loams, Hesperia-Cajon complex, and Traver fine sandy loams. All of these soils are affected by salt and alkali in their virgin state. The soils generally are extremely saline and alkali and in some areas contain high boron. Drainage and permeability of soils vary: the Cajon and Foster series have fairly good drainage, the Traver has fair drainage, the Hesperia-Cajon complex has fair to poor, and the Bishop series has poor drainage. Groundwater in the area varies from 4 ft to more than 15 ft in depth from the surface.

Before soil reclamation was initiated, many parcels had soil electrical conductivities of more than 16 mmho/cm with the exchangeable sodium percentage exceeding 60%. The soil reclamation program implemented in 1977-78 consisted of ripping to a depth of 30 inches, followed by land leveling to permit flood or furrow irrigation. Then after the ground was disked smooth and temporary irrigation borders were made, the field was irrigated. Ten tons of 60% gypsum were then disked and cross-disked into the top 6 inches of soil. Barley was planted in the fall of the first year and was irrigated during the winter and early spring to keep the crop growing. In those areas with poor growth, another 10 tons/acre of 60% gypsum were applied, and in the summer the areas were planted to a crop of Sudan grass or grain sorghum using border strip irrigation. After this crop was harvested, soil was analyzed to determine whether additional gypsum should be applied. In the late summer, the field was planted in pasture or alfalfa and border-irrigated, and the soil conditions were monitored until salinity levels reached a safe level at which furrow irrigation could be used.

The estimated amount of nitrogen (N) in the water is about 60 lbs/acre-ft. This amount will satisfy the nitrogen fertilizer requirements of most crops. Past tenants had problems growing cotton: vegetation was excessive, and the cotton bolls did not set. This is probably due to the presence of nitrogen in the water during the

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latter part of the growing season. To correct this problem, the present tenant uses reclaimed water in the early part of the season and switches to well or canal water in the latter part of the season.

CAMARILLO

Camarillo is located approximately 50 miles northwest of Los Angeles. The treatment plant has secondary treatment consisting of activated sludge, followed by chlorination and dechlorination. When irrigation water is not required, the Sanitation District has a NPDES permit to discharge into Conejo Creek adjacent to the treatment plant. Because of the permitted creek discharge, there are no restrictions on the discharge of irrigation tailwater into Conejo Creek. The treatment plant has recently been expanded from a capacity of 4.75 mgd to 6 mgd.

Since construction of the treatment plant in the late 1950s, approximately 400 acres of land adjacent to the treatment plant have been irrigated with reclaimed water. This land is now leased by a farmer who has been farming the land for 18 years. He receives the reclaimed water as part of his lease with the owner and uses the water at his own risk.

Agricultural commodities grown in the Camarillo area include strawberries, broccoli, cauliflower, tomatoes, various other truck crops, citrus, avocados, and turf sod. The farmer leasing the land adjacent to the plant is using reclaimed wastewater to furrow-irrigate beans, chili peppers, tomatoes, and broccoli. Alternative irrigation water sources include surface water from the California Water Project, with an agricultural water cost of about $122/acre-ft, or well water, with an average cost of $56/acre-ft. The cost of the reclaimed water is incorporated into the lease.

The use of reclaimed water appears to be well accepted in the farming community around Camarillo. The farmer leasing the land next to the plant indicates that production is equal to or higher than that in other areas he farms within the Oxnard Plain using fresh water. Flies, odor, and other vector problems were not detected on or around the 400-acre farming site, and no health problems related to the use of reclaimed water at this location have been reported.

FONTANA

The Fontana Wastewater Reclamation Plant is located in the City of Fontana at the north end of the Chino Basin and is operated by the Chino Basin Municipal Water District. The plant provides only primary treatment for an average daily flow of 3 mgd. Since construction of the plant in the 1950's, a portion of the reclaimed water has been used to irrigate adjacent orchards and vineyards. The primary method of ultimate disposal has been via percolation ponds at the plant site. The ponds serve both as disposal through evaporation and percolation and as storage for agricultural irrigation. The plant is operated under an order issued by the CRWQCB, Santa Ana Region. The operator states that the treatment facility operates with a high level of dependability and reliability.

FRESNO

The Fresno Wastewater Treatment Facilities consist of two separate plants with a combined average daily flow of 43 mgd. Both plant treatment processes include prechlorination for odor control as well as preliminary, primary, and secondary treatment. Plant #1 is the larger facility and utilizes activated sludge for its secondary treatment. Plant #2 utilizes trickling filters for its secondary treatment. Although Plant #2 effluent may go directly to the percolation ponds, better overall effluent quality is obtained by diverting it through the aeration basins for additional secondary treatment.

The city has a separate industrial waste sewer and disposal facility to handle winery stillage wastes, which would upset biological treatment of the domestic sewage.

The municipality owns 2,000 acres at the treatment plant site, of which 1,500 acres are divided into 93 separate percolation beds. If necessary, all of the wastewater from the treatment facility can be disposed of in the percolation beds. At present, about 600 acres of the percolation beds are leased to a farmer who is producing cotton and silage corn within the beds. Pipes and open channels provide reclaimed water to neighboring farmers along the perimeter of the 1,500 acres. In 1979, approximately 2,960 acres of private land adjacent to the treatment facility were irrigated with reclaimed water, and approximately 600 acres were farmed within the percolation beds.

Strategically spaced throughout the infiltration beds are 21 separate extraction wells, each with a capacity of up to 1,200 gpm. The extraction wells are approximately 250 to 300 ft deep and pump into a common pipeline, which discharges either into Dry Creek Canal, which passes through the 1,500-acre site, or into the Houghton Canal. Both canals serve as part of the Fresno Irrigation District's agricultural water supply system. By percolating the reclaimed water through the soil profile and extracting it with these reclamation wells, a form of tertiary treatment is accomplished at a very low cost.

The treatment facility is operated under a waste discharge permit from the CRWQCB, Central Valley Region. The six farmers using reclaimed water have reclamation permits from the CRWQCB that require them to report on a monthly basis the quantity of reclaimed water used and the crops irrigated with it. Each farmer has a written agreement with the city that requires them to use the reclaimed water in accordance with state regulations.

Numerous crops are grown in the surrounding area. Those crops grown and irrigated with reclaimed water include cotton, barley, alfalfa, grapes, silage corn, oats, wheat, and sorghum. The reclaimed water is available to the adjacent farmers at several points along the perimeter of the treatment facility and is supplied free of charge. The farmers must provide their own transmission and distribution system from the perimeter of the treatment facility. Reclaimed water has been used for more than 30 years to irrigate crops in the area. Through September of the 1979 irrigation season, more than 7,000 acre-ft of reclaimed water were used for crop irrigation within the percolation beds and the surrounding private land. Within the same period, more than 18,000 acre-ft were extracted from the 21 reclamation wells and exported to the Fresno Irrigation District.

The soils in the area around the reclamation facility are typically sandy loam. The farmer leasing the 600 acres within the percolation beds has observed infiltration problems that are probably related to the water and soil chemistry. He indicated that the percolation ponds being farmed have consistently had water ponded in them, are extremely sandy, and do not have the water soaking or retention capability that they originally did. This farmer and two others indicated that they apply little or no chemical fertilizers to their crops because of the nitrogen contained in the reclaimed water. Also, they feel the water is of high quality, thus requiring little leaching for salt control.

They have not experienced health problems associated with the reclaimed water, nor have they noticed health problems with their employees.

HEMET-SAN JACINTO WATER RECLAMATION FACILITY

The Hemet-San Jacinto Valley is located in Riverside County southwest of Mount San Jacinto. The Eastern Municipal Water District operates and maintains the Hemet-San Jacinto Water Reclamation Facility. The treatment plant is being expanded from 5.0 to 7.5 mgd and is currently operating at 5 mgd. Treatment consists of primary and secondary treatment (conventional activated sludge type). The solids removed in the process are treated by anaerobic digestion, and the secondary effluent can be disinfected through the use of "on site" chlorination.

The District has seven existing agreements with reclaimed water users for the total amount of water produced by the treatment plant. Two of the users are duck clubs, which require the reclaimed water to be chlorinated in order to meet State Health and Regional Water Quality Board requirements during the duck-hunting season (October 15 through January 15). The agreements with the users commonly provide for a minimum of 5 lbs/in^2 discharge pressure at the individual meters. The District has approximately 522 acre-ft of storage capacity that can be used during wet weather periods. The users purchase reclaimed water at the present (1983) rate of approximately $13.00/acre-ft. The water cost for the duck clubs during those periods requiring chlorinated water is approximately $30.00/acre-ft. This price is adjusted annually as necessary, to account for operational labor, energy, and related expenses.

IRVINE

The Irvine Ranch Water District (IRWD) is located in southern Orange County, which at one time was a large agricultural area but is now rapidly being urbanized. The water district operates the Michelson Water Reclamation Plant, which provides primary, secondary, and advanced treatment. The secondary treatment process is activated sludge, followed by dual media sand filtration and extended chlorination. The plant is operating at an average daily flow of approximately 8.2 mgd and has a design capacity of 15 mgd.

The IRWD has an extensive irrigation water distribution system, and its primary source of water is reclaimed water from the Michigan Water Reclamation Plant. The irrigation system supplies water for both landscape and agricultural irrigation. The principal agricultural irrigation water user is The Irvine Company, which has irrigated with reclaimed water since the mid 1960's and annually uses more than 6,000 acre-ft on various fruit trees and row crops. The Irvine Company uses the reclaimed water under a reclamation permit issued by the CRWQCB, Santa Ana Region, that requires them to submit monthly reports identifying the method of irrigation, crops, and quantity of water used. The district owns and operates two storage facilities: Rattlesnake Reservoir, with an available capacity of 1100 acre-ft, and Sand Canyon Reservoir, with an available capacity of 450 acre-ft. These are storage facilities principally for reclaimed water. Reclaimed water is distributed directly from the plant or impounded within the reservoirs, refiltered, and distributed as necessary. The water leaving the reservoirs for landscape use must be filtered to remove particulate matter and aquatic plant growth that occurs in the reservoirs. This is necessary to prevent plugging of the various components within the landscape irrigation system. The irrigation water is sold according to a district rate schedule.

Storage of reclaimed water during the winter months is one of the district's major reclamation problems. This has been an especially difficult problem during 1978-1980 because of the large amount of rainfall received in Orange County and the low irrigation demands during the winter months. Seasonal storage of the reclaimed water is required, as is storage of the surface runoff that also flows into the reservoirs. The district is not permitted to discharge into local drainage water courses. However, for the winter of 1979-1980, the district was granted an emergency discharge permit that allowed them to discharge from the reservoir into San Diego Creek when the reservoirs were full and had the potential of discharging over their spillways.

There are no formal contracts between the farmers and the district governing the use of reclaimed water. Generally, the CRWQCB issues reclamation permits individually to the users.

Reclaimed water quality from the IRWD is typical of that of other reclamation projects in Southern California. The water is high in total dissolved salts (800 to 1,000 mg/L) and boron (0.4 to 0.8 mg/L). There was one case in 1975 when sprinkler-irrigated crops were damaged by an excess amount of residual chlorine at a level of approximately 100 mg/L in the reclaimed water. The IRWD voluntarily reimbursed the farmer for the damage.

The Irvine Company is very concerned about the high concentrations of boron and other components in the reclaimed water and its effect on the citrus and other boron-sensitive crops. Since the early 1970's, soil samples from the various orchards and fields where reclaimed water is used have been taken to determine whether concentrations of these components are approaching toxic levels. Samples are taken at the beginning and at the end of the irrigation season to detect any buildup of toxic material during the season. It has been observed that TDS, boron, and other materials do tend to concentrate in the root zone during the irrigation season, and the normal rainfall during the winter months appears to leach them through the root zone. Over the last 10 years, boron levels in the reclaimed water have been as high as 1.25 mg/L, with no observed toxic effect on the citrus; an average level is about 0.06 mg/L. Crop nutrition programs at The Irvine Company are based on plant tissue analysis; fertilizers are used to supply those nutrients not present in the soil and reclaimed water in adequate amounts.

Exposed water conveyance facilities such as standpipes are marked with a notice that they contain reclaimed water. Reclaimed water usage is in accordance with DOHS guidelines and is monitored by the

CRWQCB. When the reclamation program was in its infancy during the late 1960's and early 1970's, there were problems with solids in the water that were plugging sprinklers and even gated pipe. These problems have been solved, and reclaimed water is a dependable irrigation water source in the Irvine area.

LAKE COUNTY

The Clear Lake area is located approximately 100 miles northeast of San Francisco in Lake County. Two reclamation projects are operated by the Lake County Sanitation District, one located north of Lakeport at the north end of Clear Lake, and the other at Clearlake Highlands near the south end of Clear Lake.

Treatment Plant No. 3, located near Lakeport, was recently constructed and put into operation. It has a design capacity of 2.1 mgd, with an average dry-weather flow of 0.7 mgd and wet-weather flow of 1.7 mgd. Wet-weather flows are high because of extensive groundwater infiltration inflow into the sewers during winter. The plant has secondary treatment followed by chlorination. An extended aeration racetrack provides secondary treatment. The effluent is used to irrigate permanent pasture located adjacent to the plant and owned by the sanitation district. The district owns approximately 1000 acres, of which 240 acres is irrigated pasture and 300 acres is dry farm pasture; the latter will be available for irrigation in the future as plant production increases. Irrigation is by solid-set sprinklers with wide spacing. The district also maintains an 800 acre-ft reservoir used to contain treatment plant flows during the winter.

The district operates under a reclamation permit issued by the CRWQCB that prohibits runoff from the irrigation site during the irrigation season. At the low end of the irrigated area, a recapture reservoir collects irrigation runoff for recycling into the irrigation system or for storage in the large reservoir. The reclamation permit requires the district to catch the runoff from the first winter storm and return it to the large storage reservoir. After the first winter storm, runoff can be discharged through the recapture reservoir and into Clear Lake. The only water-quality requirement specified in the reclamation permit is that suspended solids be 40 mg/L or less and biochemical oxygen demand (BOD) be 30 mg/L or less.

The Lake County Sanitation District Plant No. 1 at Clearlake Highlands is identical to Plant No. 3 in treatment processes and general operation. In the latter part of 1979, the plant had a capacity of 1.75 mgd, with a dry-weather flow of 0.6 mgd and a wet-weather flow of 1.3 mgd. The plant has a 240 acre-ft storage reservoir, which will be expanded to 470 acre-ft over the next few years. There are 280 acres of irrigated permanent pasture. The recapture reservoir and plant are operated the same as those in Plant No. 3.

The sprinkler system at reclamation Plant No. 3 near Lakeport consists of aluminum surface pipe and risers. The system at Clearlake Highlands consists of a totally buried main and submain system, using both PVC and asbestos-cement pipe with heavy galvanized iron risers. This system has been in service since 1975. The sprinkler spacing at both operations does not provide for any overlap. This maximizes the amount of area for reclaimed water disposal with a minimum amount of irrigation equipment. Each irrigation system has a full-time operator responsible for both the operation and maintenance of the system.

Irrigation systems at both reclamation projects are relatively new. They are located in very rural areas and have not presented nuisance problems to the surrounding communities. The Air Pollution Control Board has expressed some concern over bacteria in spray drift from the facilities but has taken no action.

LIVERMORE

The city of Livermore is located in Alameda County approximately 20 miles east of Oakland and 35 miles west of Stockton. The water reclamation plant is located adjacent to the Livermore Municipal Airport, South of Highway 580.

Approximately 150 acres of city-owned land are irrigated with reclaimed water from the reclamation plant. Water is distributed to this land by buried pipelines. The method of irrigation is fixed sprinkler. Approximately 15% to 20% of the treated wastewater is reclaimed for irrigation. The remainder is discharged into

San Francisco Bay through facilities completed in 1980. Excess water is transported from the plant through a buried pipeline owned by the Livermore-Amador Valley Water Management Agency to facilities located near the treatment plant at Dublin-San Ramon. At this point, it is pumped over a hill through facilities owned by the East Bay Discharge Authority and discharged into the bay.

Treatment processes used at the plant include primary sedimentation, activated sludge, coagulation, direct filtration, and chlorination. Plant capacity is 6.25 mgd. Average daily dry-weather flow is 4.4 mgd, and maximum daily flow may be as high as 5.0 mgd. The plant has an average of two shutdowns per year due to system failure. When this occurs, wastewater influent is stored in a lined reservoir until the plant is repaired.

The farmed acreage in the Livermore area has been reduced rapidly because of urban encroachment. Reclaimed water is used for irrigation of an 18-hole golf course and will be used soon for landscape irrigation along the Highway 580 right-of-way. Nearby agricultural lands that have been irrigated with reclaimed water have been sold for light industrial use. The use of reclaimed water for landscape irrigation on these lands, once they are developed, is being considered.

LODI

The city of Lodi is located in the delta area of central California between Stockton and Sacramento. The sewage treatment facility is about 5 miles west of the city. Both industrial and domestic wastes were treated at the plant, but in 1981 direct irrigation with cannery wastewater began. Domestic waste is treated, chlorinated and dechlorinated, and discharged into White Slough, which eventually discharges into San Francisco Bay. Industrial waste influent is discharged directly into an aeration pond without being treated in the plant. After aeration, it is pumped into a settling pond and then into one of two storage reservoirs. Detention time in the reservoirs ranges from 20 to 30 days, depending on the time of year. The industrial effluent is used for irrigation of agricultural crops; domestic effluent supplements it in the summertime. In general, during the summer all of the water is used for irrigation, but in the winter only the industrial effluent is reclaimed and the domestic effluent is discharged into the slough. The maximum discharge time into White Slough is approximately 150 days/yr.

Industrial effluent is not chlorinated when it is discharged into the storage reservoirs and used for irrigation. It consists of wastewater from several canneries in the area, a chrome-plating operation, and other minor industrial contributors. Water is distributed from the two storage reservoirs in concrete-lined canals, but field ditches are generally unlined. All of the irrigation tailwater is collected in unlined tailwater ditches. This tailwater drains into a buried pipeline through a surface grate. It is then recirculated either into an equalization pond or to the storage reservoir.

Treatment processes used at the plant include primary sedimentation, activated sludge, chlorination for domestic influent, and oxidation and settling ponds for industrial influent. The plant design capacity is 9.6 mgd but is operated with an average dry-weather flow of 7 mgd and a maximum daily flow as high as 12 mgd. Plant reliability has been excellent, and shutdowns due to system failure or other problems have generally been nonexistent. However, if problems occur, holding ponds are available to retain influent flows during repair operations.

Reclaimed water is used at the site to irrigate pasture, alfalfa, and a small test plot of eucalyptus trees.

An area farmer said that he gets better growth early and late in the season because of the warm temperature of the reclaimed water. He also feels that his pasture is as good as any in the area, even though he does not apply fertilizer.

The chrome-plating operation could be a source of toxic concentrations of chromium and zinc. Water-quality data are not available to support this hypothesis, and problems with crop or animal toxicity attributable to heavy metals have not been reported. There is no evidence to indicate degradation of soil or groundwater quality due to irrigation with reclaimed water. However, odor problems have occurred during the summer when the plant is receiving cannery wastewater.

MADERA

The city of Madera is located in the central San Joaquin Valley 20 miles north of Fresno. The sewage treatment plant is 50 miles west of the city.

The city of Madera owns approximately 320 acres of farmland that is leased to a grower and irrigated with reclaimed water. The reclaimed water may in some instances be supplemented with well or ditch water. The farming site consists of twelve 20-acre ponds and one 80-acre field. The ponds are used for water storage, percolation, and balancing irrigation water flows. In general, 4-6 ponds are used for storage each year; however, under conditions of abnormally high winter precipitation, more ponds may be required. All of the crops at the site are flood- or furrow-irrigated. Sludge is generally pumped to an adjacent field and incorporated by disking or plowing. In some instances, sludge may be mixed with reclaimed water before irrigation. No reclaimed water or sludge leaves the site.

Treatment processes used at the plant include primary sedimentation and trickling filters. The reclaimed water is not chlorinated before irrigation. The treatment plant design capacity is 7 mgd with an average annual flow of 3 mgd. Generally, the treatment plant's reliability has been excellent.

The crops currently grown with reclaimed water at the site include cereal grains, cotton, and Sudan grass.

MODESTO

The city of Modesto is located about 30 miles south of Stockton in the San Joaquin Valley. The sewage treatment plant is in the southwest portion of the city.

Primary treated effluent is pumped from the treatment plant through a 60-inch buried transmission pipeline for approximately 8 to 10 miles to an aeration storage basin. The aeration basin covers about 843 acres and has a storage capacity of about 1.3 billion gallons (3,990 acre-ft). Water is circulated through the basin at a rate of about 220 mgd. From this facility, water can be chlorinated and discharged into the San Joaquin River or pumped into transmission facilities for irrigation of adjacent lands. The water can be chlorinated before irrigation use, but this is generally not done. Approximately 775 acres of adjacent land are irrigated with reclaimed water. Although the grower receiving this water has a contract to take as much as 9,500 acre-ft per year, annual reclaimed water use is generally much less than this.

Reclaimed water is applied to irrigated permanent pasture, alfalfa, and forage crops, such as silage oats and silage corn. These crops are used to feed replacement heifers.

Treatment processes include primary sedimentation, oxidation ponds, and chlorination. The plant capacity is 60 mgd. Average daily dry-weather flow is approximately 44.7 mgd (August and September 1982), and maximum daily flow may be as high as 51.6 mgd. The city of Modesto anticipates that starting in 1986, excess reclaimed water that is not utilized on land adjacent to the storage facility will be pumped into irrigation district facilities west of the site. This will virtually eliminate discharges into the San Joaquin River with the exception of periodic winter releases. Treatment plant reliability has been excellent. Storage basins are available at the primary plant site in case of plant shutdown. BOD and total suspended solids are monitored daily for both effluent discharges into the San Joaquin River and reclaimed water used for irrigation.

The farmer has not encountered problems using reclaimed water. The grower does not rely on the nutrient content of the reclaimed water to meet crop requirements: he applies sufficient fertilizer to satisfy crop requirements. Water quality can vary during the season as a result of discharges from canneries. During periods of cannery discharge, solids and BOD loadings increase.

POMONA

The city of Pomona is located on the east side of Los Angeles County. The Pomona Water Reclamation Plant is owned and operated by the Los Angeles County Sanitation District. The City of Pomona has an exclusive contract with the District for the purchase and marketing of reclaimed water within their service area. The city distributes the water for both agricultural and landscape irrigation, and the major agricultural user is the California State Polytechnic University. At present, the city sells approximately 5,100 acre-ft of reclaimed water to nine users on an interruptible basis.

Chlorinated irrigation water is being supplied by the District, which helps prevent growth of bacterial slimes and algae within the transmission and distribution system. The average flow during 1982 was 9.26 mgd.

Nearby California State Polytechnic University has expanded its utilization of reclaimed water to approximately 1,200 acre-ft/year, which is used to irrigate approximately 200 acres of agricultural land and 150 acres of ornamental shrubbery.

Reclaimed water is used to irrigate permanent pasture, alfalfa, various citrus and deciduous orchard crops, grapes, and some row crops, that require processing before being eaten. The irrigation methods are sprinkler, furrow, or drip irrigation, depending on the type of crop.

The majority of the reclaimed water users are irrigating landscapes such as parks and cemeteries. The City of Pomona has two industrial users of reclaimed water, both manufacturing paper products. Although the reclaimed water supply is reasonably reliable, all of the users have alternate water supplies.

The University has instituted a formal program to monitor the effects of reclaimed water on soils, and it is scheduled to be implemented in mid 1983. There is no formal program to monitor the effects on irrigated crops. Fields and orchards irrigated with reclaimed water have been observed to require less chemical fertilizer for good plant growth; however, on citrus, the reclaimed water does supply abundant amounts of nutrients at times when not required by the citrus crop.

SAN LUIS OBISPO

The city of San Luis Obispo is located about 10 miles inland from the Pacific Ocean. The biofiltration plant is located south of the city.

Reclaimed water from the treatment facility is discharged either into a pasture for direct irrigation or into a storage pond. Approximately 45 acres of permanent pasture at the site are flood-irrigated and used for grazing beef cattle and horses. Tailwater is collected at the lower end of the field and transported by an open, unlined surface ditch to the storage facility. Reclaimed water is not chlorinated before irrigation or storage in the pond. Tailwater and reclaimed water not used for irrigation is chlorinated and discharged into San Luis Obispo Creek. San Luis Obispo Creek discharges into San Luis Bay at Avila Beach. A substantial amount of acreage along San Luis Obispo Creek is irrigated with runoff water and reclaimed water that flows down the creek. In the summer, these areas are irrigated entirely with reclaimed water.

Wastewater treatment processes include primary sedimentation, trickling filters, oxidation ponds, and chlorination before discharge. The present plant capacity is 5 mgd. The average daily dry-weather flow is 3.5 mgd, and maximum daily flows may be as high as 7.0 mgd. Additional wastewater treatment facilities are now being constructed. New facilities will include advanced levels of treatment. When this system is installed and operating, excess reclaimed water will be discharged into Laguna Lake, a recreational facility. Reclaimed water will still be used for irrigating the 45 acres of pasture at the plant site, and additional minor landscape irrigation will take place adjacent to Laguna Lake. When the new facilities are operating, the water will no longer be discharged into San Luis Obispo Creek.

The plant is shut down twice a year, on an average, as a result of system failure. Problems that cause shutdowns may include power shortages, pump problems, and plugging. When these problems occur, ponds located at the treatment site are used for retention of sewage while the problem is resolved.

Reclaimed water is applied to pasture at the site and is also applied to pasture downstream from the biofiltration plant by pumping from San Luis Obispo Creek. At Avila Beach, just before being discharged into the Pacific Ocean at San Luis Bay, water is drawn from the creek and used for irrigating an 18-hole golf course.

The farmers in the area readily accept the use of reclaimed water primarily because of its price, availability, reliability, and nutrient content. The farmer managing the pasture at the plant site irrigated with reclaimed water believes the pasture is better in quality than the pasture in the surrounding agricultural area. This is attributed to the nutrient content of the reclaimed water. A San Luis Obispo County farm adviser said that the farmers who use reclaimed water are not applying commercial fertilizer. In his opinion, the pasture in the area where reclaimed water is applied is superior to other pasture areas in the county not irrigated with reclaimed water.

The grower that farms the 45 acres of pasture at the plant site pays essentially nothing for the reclaimed water, since the cost is included in the land lease. Growers downstream who withdraw water from San Luis Obispo Creek pay no water costs other than power for pumping. Irrigation water wells were not observed in the area downstream from the treatment facility; however, pumping installations were observed drawing water directly from San Luis Obispo Creek.

No health or disease problems, with either animals or workers, have been observed in areas where reclaimed water is applied. No odor problems have occurred at the site or downstream from it. The irrigated area at the treatment plant site is fenced and marked with signs; however, no signs were evident downstream where reclaimed water is applied to the pastures and golf course.

SANTA MARIA

The city of Santa Maria is located on the California coast about 10 miles inland from the Pacific Ocean and 30 miles south of San Luis Obispo. The wastewater treatment facility is located about 2 miles west of the city.

Secondary treated, unchlorinated wastewater from the sewage treatment plant is discharged into percolation ponds. The facility has about 40 acres of irrigated pasture and 60 acres of percolation ponds, which also serve to balance irrigation flows. Reclaimed water is applied by flood irrigation; irrigation sets are operated on about a 24-hour cycle.

The city owns about 40 acres of irrigated land. The 40 acres will be leased to a farmer to raise beef cattle. There are private individuals interested in leasing land around the plant for raising Christmas trees and using effluent for irrigation.

Treatment processes used at the plant include primary sedimentation and trickling filters. Plant capacity is 7.8 mgd. The average daily dry-weather flow is 4.2 mgd, and the maximum daily flow may be as high as 5.2 mgd.

Reduction of flow is the result of two large industries leaving the area. The plant superintendent indicated that plant shutdown due to power failure occurred on an average of less than once per year. No alternate pond storage facilities are available in case of plant breakdown; primary treated water is discharged into the treated percolation ponds. There is no method of crop protection in case of treatment plant breakdowns, and no alternate source of irrigation water is available. A private laboratory performs heavy metal analyses of the reclaimed water, and results are reported to the CRWQCB.

The cropping pattern in the area surrounding the treatment plant consists primarily of strawberries and vegetable crops grown for both fresh consumption and processing.

SANTA ROSA

The city of Santa Rosa is located in the center of Sonoma County, about 50 miles north of San Francisco. The city operates an extensive wastewater reclamation project that consists of two treatment plants and an irrigation system. The West College Treatment Plant has a designed capacity of 5 mgd and an average flow of 5 mgd. The plant provides secondary treatment plus chlorination. The recently completed Laguna Wastewater Reclamation Plant is located approximately 5 miles south of the College Park plant, has a design capacity of 15 mgd, and is currently operating with an average flow of 9 mgd. The Laguna plant provides activated sludge, secondary treatment, and chlorination. The city operates a reclaimed water irrigation system and has a pipeline connecting the two treatment plants.

There are 21 individual farmers using the reclaimed wastewater to irrigate approximately 3,400 acres of land. Water is distributed from the treatment plants into storage reservoirs, which can contain at least 60 days worth of treatment plant flow. From the storage reservoirs, the city operates an extensive pressurized irrigation distribution system, which includes storage or peaking reservoirs. The system is operated and maintained by the city, and the farmers take water on demand from the system.

The city's operating permit requires the farmers to dispose of the reclaimed water on land from May 15 to September 30. After September 30, the city can discharge into the Russian River if the flow is above 1000 ft^3/sec, and it can discharge a volume no more than 1% of the river flow. When the flows drop below 1000 ft^3/sec, the reclaimed water must be either disposed of through irrigation or stored in ponds.

The city owns 1,100 acres of land for effluent disposal with approximately 900 acres of permanent set sprinklers. The area is fenced and posted, and the site is used solely for disposal of reclaimed water and growing of cattle feed crops. The land is laid out with tailwater return systems so that no runoff leaves the city property. The city is leasing some of the ground for farming or grazing of sheep. The city's irrigation system is totally automatic, using irrigation controllers and solenoid valves. There are reclaimed-water-balancing reservoirs located throughout the project that have observation wells along their banks for monitoring percolation into the groundwater.

Although the farmers are not issued reclamation permits from the CRWQCB, they have a contract with the city that requires them to use the water according to SCDHS guidelines and to contain tailwater. The city does patrol and check the different users to see that the reclaimed water is being used according to state requirements.

The crops being irrigated with reclaimed water include field corn, Sudan grass, oats, and turnips, which are used as winter feed for sheep.

The farmers in the area growing feed crops for their dairy animals feel that the reclaimed water supplies approximately two-thirds of the nutrients required by their crop. At least one farmer is applying an additional 100 lb N/acre·year on approximately 230 acres of permanent pasture, where he is grazing about 2,000 head of sheep. This farmer has retained the services of an agronomist, who routinely reviews the irrigation water quality, cropping pattern, and soil chemistry and makes recommendations on nutrient requirements.

SONORA

Sonora is a small community located in the Sierra Nevada foothills about 50 miles east of Modesto. The Tuolumne County Water District No. 2 Water Treatment Facility is located southwest of the city.

The treatment plant collects wastewater from Sonora and several surrounding communities. The reclaimed water is discharged from the treatment plant into two ponds that primarily balance irrigation flows. After chlorination, the reclaimed water flows by gravity through several miles of pipeline to a 1,500-acre-ft storage reservoir. Turnouts along the pipeline are available for irrigation of forage crops, small pastures, and landscape areas. Water stored in the reservoir is distributed to other growers further downslope by another buried transmission pipeline.

Many farmers have signed up to use the reclaimed water, and at present, 1,129 acres are potentially available for irrigation. However, many of these areas are too steep to irrigate, which substantially reduces the potential acreage.

The treatment processes used at the plant include primary sedimentation, trickling filters, and chlorination. The plant capacity is 2.6 mgd. Average daily dry-weather flow averages 0.5 mgd, and maximum daily flow may be as high as 3.5 mgd in the winter and 1.0 mgd in the summer. The treatment plant has been in operation for only 8 years, and the long-term plant reliability has been found to be very good. No problems with reliability have been encountered yet. In case of treatment plant breakdown, a 14-day storage capacity is available.

The farmers in the area are satisfied with the reclaimed water, particularly because now that reclaimed water is available, small acreages that were previously not economical to farm are being developed into permanent pasture areas.

A few farmers have installed tailwater return systems to control runoff. As more areas are developed and the use of reclaimed water increases, tailwater return systems should be more common.

The use of reclaimed water for agricultural irrigation has solved a pollution problem. In the past, effluent was discharged into Woods

Creek, which flows into Don Pedro Reservoir. The reclaimed water was considered a source of pollution for the reservoir. With the construction of this project and the total usage of reclaimed water for irrigation, it is anticipated that no further degradation of water resources in Don Pedro Reservoir will occur.

VISALIA

The city of Visalia operates a wastewater reclamation plant that uses primary and secondary treatment. Secondary treatment consists of trickling filters, followed by activated sludge and chlorination. The treatment plant has a design capacity of 12.5 mgd, with an average flow of 7.6 mgd and a peak flow of 12 mgd. After the effluent leaves the chlorine contact chambers, it goes into large evaporation/percolation ponds, which also serve as reservoirs. The effluent is discharged into Mill Creek, which is adjacent to the treatment plant. The city operates the treatment plant and discharges effluent under an NPDES permit that requires secondary treatment and chlorination before discharge.

Mill Creek is part of the Kaweah Delta Water Conservation District, which is the principal irrigation water purveyor for the area. The irrigation water in Mill Creek and other facilities served from Mill Creek is used as needed by the farmers. Farmers being served from the irrigation facility are not necessarily aware when reclaimed water is present, and some may not know that it is there at all. Irrigation water from this facility is used by the farmers to irrigate forage and fodder crops and landscape.

The agricultural community of the surrounding area is made up of both large and small farms. The crops grown in the area generally include milo, cotton, field corn, and alfalfa and are irrigated either from the Mill Creek canal system or from groundwater.

Some farmers along Mill Creek are using the effluent blended with their own well water at a ratio of about 1 to 1. Approximately 8 to 10 farmers regularly use water from Mill Creek. Under normal operation, the city sends water down the canal and diverts it into spreading basins within the watershed. The growers in the area have the ditch company's permission to change the head gates and bring the flow to their farm at any time.

The reclaimed water discharged into Mill Creek offers the farmers an alternate irrigation water source to the groundwater normally used for irrigation. The only cost in using this water is the cost of pumping it from the canal to their fields. Compared with the cost of pumping groundwater at a substantially high lift, the pumping cost could be significantly less when the use of reclaimed water in the Visalia area is viewed by the community as a water conservation measure and as an overall benefit to the community.

REFERENCES

1. Boyle Engineering Corporation. 1981. Evaluation of agricultural irrigation projects using reclaimed water. Prepared for California State Water Resources Control Board, Sacramento, Calif.

APPENDIX B

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

DIVISION OF WATER RIGHTS

PETITION FOR CHANGE

(FOR OWNERS OF WASTE WATER TREATMENT PLANTS ONLY)

PETITION FOR CHANGE OF ☐ POINT OF DISCHARGE OF TREATED WASTE WATER
☐ PURPOSE OF USE OF TREATED WASTE WATER
☐ PLACE OF USE OF TREATED WASTE WATER

State Water Resources Control Board
Division of Water Rights
P.O. Box 2000
Sacramento CA 95810

I HEREBY PETITION FOR CHANGES NOTED ABOVE AND SHOWN ON THE ACCOMPANYING MAP AND DESCRIBED AS FOLLOWS:

____
(Give tie by bearing and distance or by coordinate distances from some

____
government corner and the 40-acre subdivisions in which the new point

____
of discharge lies or acreage to be irrigated within each 40-acre tract).

GIVE REASON FOR PROPOSED CHANGE: ______________________________

____

WASTE WATER WILL BE USED FOR ______________________ *PURPOSES.*

I have access to the proposed new point of discharge or control the place of use proposed by virtue of

____
(ownership, lease, verbal, or written agreement)

____
(If by lease or agreement, state name and address of party or parties from whom access has been obtained.)

Are there any persons taking water from the stream between the old point of discharge and the new point of discharge _____ *yes* _____ *no*

Give names and adress, if answered yes, as well as other persons known to you who may be affected by the proposed change on the reverse side of this form or on an attached sheet.

This change does not involve water provided by a water service contract which prohibits my exclusive right to this treated waste water

_____ *yes* _____ *no*

No legal use of the discharge treated waste water will be affected

____ yes   ____ no

I declare under penalty of perjury that the above is true and correct to the best of my knowledge and belief.

Dated: ______________, 19 ___, at __________________________, California.

____

NOTE: Section 1547 of the Water Code requires a $10 filing fee with petitions for changes.

WR 22WW (4/14/83)

MINIMUM FILING FEE: $10:00
FILE ORIGINAL & ONE COPY
TYPE OR PRINT IN INK

STATE OF CALIFORNIA

State Water Resources Control Board
DIVISION OF WATER RIGHTS
901 P Street, Sacramento
P. O. Box 2000, Sacramento, CA 95810

APPLICATION to APPROPRIATE WATER

(For explanation of entries required, see booklet "How to File an Application to Appropriate Water in California")

Application No. ____________________

1. APPLICANT

I, ____
(Name of Applicant)

____
(Telephone Number where you may be reached between 8 a.m. and 5 p.m.—include area code)

____
(Address) (City or Town) (State) (Zip Code)

do hereby make application for a permit to appropriate the following described waters of the State of California, SUBJECT TO VESTED RIGHTS

2. SOURCE

a. The name of the source at the point of diversion is ____________________
(If unnamed, state nature of source and that it IS unnamed)

tributary to ____________________

b. In a normal year does the stream dry up at any point downstream from your project? YES ☐ NO ☐. If Yes, during what months is it usually dry? ____________________

3. POINT of DIVERSION and REDIVERSION

a. The point of diversion will be in the County of ____________________

b.

List all points giving coordinate distances from section corner or other tie as allowed by Board regulations	Point is within (40-acre Subdivision)	Section	Township	Range	Base and Meridan
	¼ of ¼				
	¼ of ¼				
	¼ of ¼				

c. Does applicant own the land at the point of diversion? YES ☐ NO ☐.

d. If applicant does not own land at point of diversion, state name and address of owner and state what steps have been taken to obtain right of access: ____________________

4. PURPOSE of USE, AMOUNT and SEASON

a. State the purpose(s) for which water is to be appropriated, the amounts of water for each purpose and dates between which diversions will be made in the table below. Use gallons per day if rate is less than 0.025 cubic feet per second (approximately 16,000 gallons per day).

PURPOSE OF USE	DIRECT DIVERSION				STORAGE		
	AMOUNT		SEASON OF DIVERSION		AMOUNT	COLLECTION SEASON	
	RATE (Cubic feet per second or gallons per day)	Acre-feet per year	Beginning Date (Mo. & Day)	Ending Date (Mo. & Day)	Acre-feet per year	Beginning Date (Mo. & Day)	Ending Date (Mo. & Day)
Irrigation							
Domestic							
	________ (TOTAL)				________ (TOTAL)		

b. Total combined amount taken by direct diversion and storage during any one year will be __________ acre-feet.

WR 1 (3 '84)

5. JUSTIFICATION OF AMOUNT

a. IRRIGATION: Maximum acreage to be irrigated in any one year will be ______________ acres.

CROP	ACRES	METHOD OF IRRIGATION (Sprinklers, flooding, etc.)	ACRE-FEET (per year)	NORMAL SEASON	
				Beginning Date	Ending Date

b. DOMESTIC: The number of residences to be served ________. Separately owned: YES ☐ NO ☐

The total number of people to be served ________. Estimated daily use per person ________________ (gallons per day).

The total area of domestic lawns and gardens ____________ (square feet).

Miscellaneous domestic uses ______________________________ (Dust control area, Number and kind of domestic animals, etc.)

c. STOCKWATERING: Kind of Stock ____________. Maximum Number ________. Describe type of operation (feed lot, dairy, range, etc.)

____

d. RECREATIONAL: Type of recreation: Fishing ☐, Swimming ☐, Boating ☐, Other ☐.

(Submit "Supplement to Application", form SWRCB 1–1, for justification of amount for uses not listed above.)

6. DIVERSION WORK

a. Diversion will be by pumping from ______________________ (sump, offset well, channel, reservoir, etc.). Pump discharge rate ____________ (cfs/gpd). Horsepower ________.

b. Diversion will be by gravity by means of ______________________________ (pipe in unobstructed channel, pipe through dam, siphon, gate, etc.).

c. Estimated total cost of the diversion works proposed is ______________________________ (Give only cost of intake, or headworks, pumps, storage reservoirs, and main conduits.)

d. Main conduit from diversion point to first lateral or offstream storage reservoir:

CONDUIT (Pipe or channel)	MATERIAL (Kind of Pipe or channel lining)	CROSS SECTIONAL DIMENSION (Pipe diameter or ditch depth and top and bottom width	LENGTH (feet)	TOTAL LIFT OR FALL		CAPACITY (estimated)
				(feet)	(+ or –)	

e. The following applies to storage reservoirs: (For reservoirs having a capacity of 25 acre-feet or more, complete supplemental form SWRCB 1–1,

Name or number of reservoir, if any	DAM				RESERVOIR		
	Height of dam from streambed to spillway level (ft.)	Material construction	Dam Length (ft.)	Freeboard Dam height above spillway crest (ft.)	Approximate surface area when full (acres)	Approximate capacity (acre-feet)	Max. water depth

f. If water will be stored and the reservoir is not at the diversion point, the maximum rate of diversion to offstream storage will be ______ cfs.

Diversion to offstream storage will be ande by pumping ☐: gravity ☐.

7. PLACE OF USE

a. Applicant owns the land where the water will be used: YES ☐ NO ☐. Land is in joint ownership: YES ☐ NO ☐.

All joint owners should include their names as applicants and sign the application. If applicant does not own land where the water will be used; give name and address of owner and state what arrangements have been made with the owner.

____

____

USE IS WITHIN (40-acre Subdivision)	SECTION	TOWNSHIP	RANGE	BASE AND MERIDIAN	IF IRRIGATION	
					State Number of Acres	Presently cultivated (Yes or No)
¼ of ¼						
¼ of ¼						
¼ of ¼						
¼ of ¼						
¼ of ¼						
¼ of ¼						

If area is unsurveyed, state the location as if lines of the public land survey were projected. If space does not permit listing all 40-acre tracts, include on another sheet or state sections, townships and ranges, and show detail on map. For public districts or other extremely large areas, see Page 16 of instruction booklet "How to File and Application to Appropriate Water in California".

8. COMPLETION SCHEDULE

a. What year will work start ____________________? b. What year will work be completed ____________________?

c. What year will water be used to the full extent intended ______________? d. If complete, year of completion ____________?

(ATTACH SUPPLEMENTAL SHEETS HERE)

9. GENERAL

a. What is the name of the post office most used by those living near the proposed point of diversion? ______

b. Does any part of the place of use comprise a subdivision on file with the State Department of Real Estate? YES ☐ NO ☐. If Yes, state name of subdivision ______ If No, is subdivision of these lands contemplated? YES ☐ NO ☐.
Is it planned to individually meter each service connection? YES ☐ NO ☐. If Yes, when? ______

c. Have you consulted the California Department of Fish and Game concerning this proposed project? YES ☐ NO ☐. If Yes, state the Department's opinion concerning the potential effects of your proposed project on fish and other wildlife and state measures required for mitigation ______

If No, state the effects on fish and other wildlife you foresee as potentially arising from your proposed project. ______

d. Please name other public agencies, if any, from which you have obtained or are required to obtain approvals regarding this project: ______

e. What are the names and addresses of diverters of water from the source of supply downstream from the proposed point of diversion? ______

f. Is the source used for navigation, including use by pleasure boats, for a significant part of each year at the point of diversion, or does the source substantially contribute to a waterway which is used for navigation, including use by pleasure boats? ______

10. EXISTING WATER RIGHT

Do you claim an existing right for the use of all or part of the water sought by this application? YES ☐ NO ☐
If yes, complete table below

Nature of Rights (riparian, appropriative, groundwater.)	Year of First Use	Purpose of use made in recent years including amount, if known	Season of Use	Source	Location of Point of Diversion

11. AUTHORIZED AGENT (Optional)

With respect to: ☐ All matters concerning this water right application, ☐ those matters designated as follows: ______

Name ______ Address ______
______ Zip Code: ______
is authorized to act on my behalf as my agent. (Telephone No. of agent between 8 a.m. and 5 p.m.)

12. SIGNATURE of APPLICANT

I (we) declare under penalty of perjury that the above is true and correct to the best of my (our) knowledge and belief.

Dated ______ 19 ____, at ______, California

Ms. Mr.
Miss, Mrs. ______
(Signature of applicant) (Refer to Section 671 of the Board's regulations)

If applicants are members of the same family (i.e., husband, wife, mother, father, son, brother, sister, etc.) or reside at the same address, please indicate their relationship:

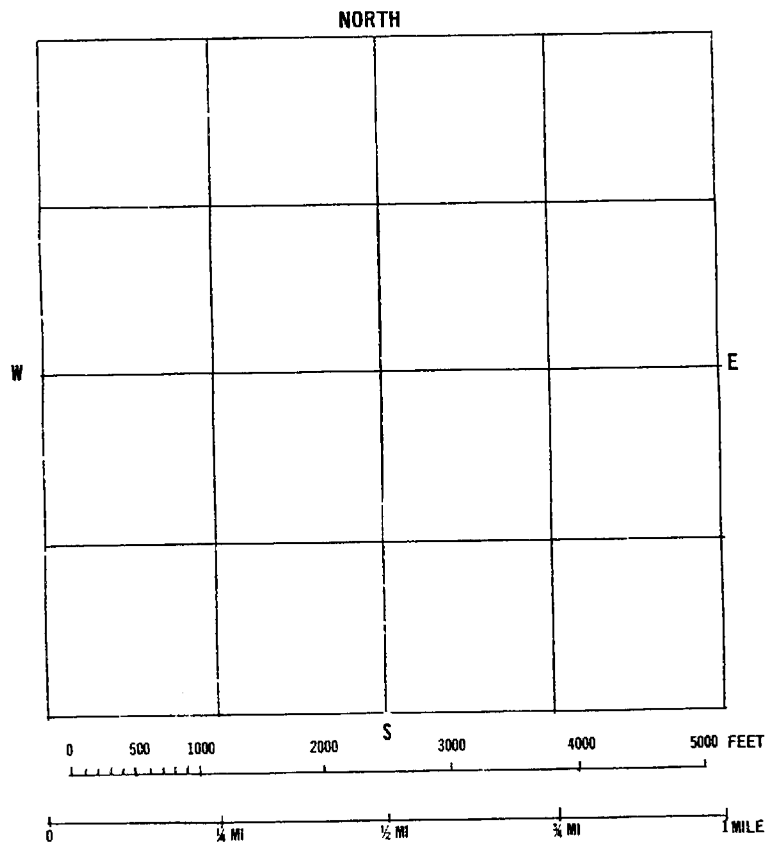
Ms. Mr.
Miss, Mrs. ______
(Signature of applicant) (Refer to Section 671 of the Board's regulations)

Additional information needed for preparation of this application may be found in the leaflet entitled "HOW TO FILE AN APPLICATION TO APPROPRIATE WATER IN CALIFORNIA". If there is insufficient space for answers in this form, attach extra sheets. Please cross reference all remarks to the numbered item to which they may refer. Send application in duplicate to the STATE WATER RESOURCES CONTROL BOARD, DIVISION OF WATER RIGHTS, P. O. Box 2000, Sacramento, CA 95810, with $10 minimum filing fee.

13. Application Map

(Please complete legibly, with as much detail as possible)
(See example in instruction booklet)

SECTION(S) ______________ TOWNSHIP __________; RANGE ______; ______ B&M



(1) Show location of the spring or stream, and give name,
(2) Show location of the main ditch or pipe line.
(3) Indicate clearly the proposed place of use of the water.
(4) Locate and describe the point of diversion (i.e., the point at which water is to be taken from the stream or spring) in the following way: Begin at the most convenient known corner of the public land survey, such as a section or quarter section corner (if on unsurveyed land more than two miles from a section corner, begin at a mark or some natural object or permanent monument that can be readily found and recognized) and measure directly north or south until opposite the point which it is desired to locate; then measure directly east or west to the desired point. Show these distances in figures on the map as shown in the instructions.

14. Environmental Information

An Environmental Information form provided by the State Water Resources Control Board should be completed and attached to this application.

APPENDIX D

MEMORANDUM OF UNDERSTANDING BETWEEN THE WALNUT VALLEY WATER DISTRICT (WALNUT) AND THE ROWLAND AREA COUNTY WATER DISTRICT (ROWLAND) RELATING TO THE TERMS AND CONDITIONS OF RECLAIMED WATER SERVICE FOR EXISTING AND FUTURE CUSTOMERS WITHIN THE ROWLAND SERVICE AREA

This is to outline the concepts and considerations under which Rowland will sell reclaimed water to customers within their service area and under which Walnut will provide Rowland with reclaimed water.

1. Walnut is providing, by separate agreement, a commitment from the City of Pomona for the supply of tertiary treated effluent. The quality, quantity and reliability of that supply are determined within that agreement. Walnut will receive reclaimed water from the City of Pomona at a point of delivery as provided within their agreement. This point of delivery will be the western terminus of the North Side line, approximately at its intersection with Grand Avenue.

2. Reclaimed water at the point of delivery to Walnut shall be at hydrostatic pressure which is available. Static head at the point of delivery is 144 feet, which is the difference in elevation between the effluent structure at the Pomona Water Renovation Plant and the point of delivery to Walnut.

3. Walnut agrees to supply reclaimed water from the Pomona WRP to Rowland for use by its customers.

4. Walnut agrees to supply reclaimed water to Rowland at a wholesale price. The difference between the wholesale price paid by Rowland and the retail price paid by customers shall be at least sufficient to fund Rowland's costs for meter reading, customer billing and meter maintenance and replacement.

5. Walnut agrees to provide said reclaimed water to Rowland and Rowland agrees to purchase said reclaimed water from Walnut for a term not less than 15 years.

6. Walnut agrees to provide reclaimed water to Rowland at such time as Walnut completes construction of all facilities required for the delivery of reclaimed water to the end use customers. Walnut shall coordinate its construction schedule with Rowland to provide reasonable notice of its intent to deliver reclaimed water.

7. Walnut agrees to responsibility for the provision of design, construction and financing for a complete reclaimed water system inclusive of transmission, distribution and appurtenant facilities as required, exclusive of service meters, and piping to customer's property.

8. Rowland agrees to responsibility for customer meter reading and collection of charges from said Rowland customers. Rowland agrees to fund and provide for meter and service installation and maintenance and replacement of customer meters.

9. Walnut agrees to fund and provide for operation, maintenance and replacement of transmission, distribution and appurtenant facilities except for customer meters.

APPENDIX E

SAMPLE CLAUSES LIMITING AND INDEMNIFYING SUPPLIER LIABILITY

A WORD OF CAUTION:

The following warranty, disclaimer, remedy limitation, and indemnity clauses are technically sufficient under the Uniform Commercial Code and the California Commercial Code. They are modeled on language that has been tested and upheld in litigation concerning other commercial ventures. There has been no courtroom test of such clauses in wastewater supply contracts, however. The author (C. S. Richardson) therefore DISCLAIMS ANY IMPLIED WARRANTY OF FITNESS FOR THE PARTICULAR PURPOSE OF WASTEWATER SUPPLY CONTRACTS.

SAMPLE CLAUSES LIMITING AND INDEMNIFYING SUPPLIER LIABILITY:

SECTION ______: LIABILITY AND INSURANCE

A. WARRANTY AND DISCLAIMER AGREEMENTS

1. LIMITED WARRANTY OF WASTEWATER QUALITY

(name of supplier) warrants that the wastewater delivered under this contract will comply with the physical and bacteriological requirements for the land disposition of treated wastewater imposed now and in the future by the California State Department of Health Services, the __________________ Regional Water Quality Control Board, and any agency having jurisdiction over such requirements during the term of this contract.

2. DISCLAIMER OF ALL OTHER WARRANTIES

The water quality warranty set forth above is the SOLE WARRANTY extended by the Supplier for wastewater delivered under this contract. ORAL STATEMENTS BY THE PERSONNEL OF THE SUPPLIER DO NOT CONSTITUTE WARRANTIES. The supplier's agents and employees are not authorized to make warranties about the wastewater delivered under this contract. The buyer will not rely on any oral statements or written documents not expressly incorporated into this written contract. The entire contract is embodied in this writing and NO WARRANTIES ARE GIVEN beyond those set forth in this contract at Section ____.A.1.

The Supplier EXPRESSLY DISCLAIMS ANY IMPLIED WARRANTY OF MERCHANTABILITY AND ANY IMPLIED WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE AND ALL OTHER EXPRESS AND IMPLIED WARRANTIES.

_______ (Buyer should initial this section)

B. LIMITATION OF REMEDIES FOR BREACH OF WASTEWATER QUALITY WARRANTY

1. LIMITED REMEDY

Buyer may bring NO CLAIM against the Supplier, its agents, employees or assigns for failure to meet the wastewater quality standards imposed by regulatory agencies and warranted by this agreement excpet as provided by this section. This limited remedy will apply to negligent as well as non-negligent breach of warranty.

a. Buyer will be notified by Supplier by (specify means) of any deviation from the above specified wastewater quality standard.

b. Supplier will be liable to Buyer for damages to crops or land resulting from contact with below-standard wastewater which occurs before notification to Buyer, or before Buyer can reasonably prevent such contact after notification. Damages that may be claimed by Buyer will be limited as follows:

(Here the parties must agree upon a maximum valuation. This may be the actual loss in market value of the contaminated crop, as established by arbitration; the contract price of the water, limited to the agreed annual entitlement; or any valuation that will divide fairly the risk of the enterprise and give the buyer the substantial value of his bargain, considering the uncertainties both parties face at the outset.)

c. Buyer may bring NO CLAIM against Supplier for any damages resulting from contact with wastewater which occurs after notification has been received by him and he has had reasonable opportunity to prevent such contact.

d. TIME LIMIT FOR LEGAL ACTION ON BREACH OF WARRANTY: Any action alleging breach of warranty must be COMMENCED WITHIN ONE YEAR from the date the claim accrues, or be barred forever.

(Buyer should initial this section.) ________

2. EXCLUSION OF ALL OTHER REMEDIES

a. SOLE REMEDY: The parties agree that the remedy set forth above at Section____. B. will be the Buyer's SOLE AND EXCLUSIVE REMEDY against the Supplier for breach of the water quality warranty. The Buyer agrees that NO OTHER REMEDY WILL BE AVAILABLE TO HIM and that the wastewater Supplier will not be liable to him for incidental or consequential damages including lost income, lost use of land, lost sales, lost time, or liability incurred by Buyer due to default under contracts with other parties.

b. SUBSTANTIAL VALUE: The Buyer agrees that the bargained for price of the wastewater supplied under this contract is the result of a fair sharing of the risk between the Supplier and Buyer, and that this price justifies assuming the risk of loss due to failure to meet the water quality standards, as provided above. The Buyer therefore agrees that the exclusive remedy set forth at Section___.B. is fair and a reasonable remedy which gives the Buyer the substantial value of his bargain.

(Buyer should initial this section.) ________

C. INDEMNIFICATION AGREEMENT

(Alternative 1: third party liability is concentrated on the buyer.)

1. Buyer agrees to indemnify and defend the Supplier, its agents, employees, and assigns against all claims of any nature for loss, damage, or injury to all persons and property, arising out of any alleged defect in the wastewater or arising out of any operations and activities

under this wastewater supply contract. Buyer agrees to indemnify and defend Supplier even though the alleged wastewater defect, the loss, damage, or injury resulted from the active negligence, violation of law, breach of warranty, or strict tort liability of the Supplier.

2. Buyer agrees to name the Supplier as co-insured on a public liability insurance policy which will be obtained by the Buyer expressly to provide against liabilities arising from wastewater irrigation activities. Under this policy, the insurer must agree to indemnify and defend the Buyer and Supplier against all liabilities and expenses from claims for personal injury, death, property damage, and economic loss, resulting from any alleged product defect, act or omission by the Buyer or Seller, including the Supplier's active negligence and violation of law.

(Alternative 2: third party liability is allocated to Buyer or Supplier according to control over the source of risk. This alternative requires very explicit specification of facilities and activities in the exclusive or primary control of each party.)

1. Buyer agrees to indemnify and defend the Supplier, its agents, employees, and assigns against all claims of any nature for loss, damage, or injury to all persons and property, arising out of the acts or omissions of the Buyer, his agents or employees in using those facilities and conducting those activities identified in Section____ and____ as being under the sole or primary control of the Buyer. Buyer agrees to indemnify and defend the Supplier against such claims even though it may be alleged that the Supplier was actively negligent in entrusting such facilities or activities to the Buyer, or in monitoring, inspecting, or supervising such facilities or activities.

Buyer further agrees to indemnify and defend Supplier against all claims resulting from contact with wastewater which does not meet the water quality warranted at

Section___.A.1., when such contact occurs after notification to the Buyer and after the Buyer could reasonably act to prevent such contact following notification.

2. Buyer agrees to name the Supplier as co-insured on a public liability insurance policy which will be obtained by the Buyer expressly to provide against liabilities arising from wastewater irrigation activities. Under this policy, the insurer must agree to indemnify and defend the Buyer and Supplier against those liabilities described above at Section____C.1.

3. Supplier agrees to indemnify and defend the Buyer, his agents and employees against all claims of any nature for loss, damage, or injury to all persons and property, arising out of the acts or omissions of the Supplier, his agents, employees or assigns in using those facilities and conducting those activities identified in Section__ and___ as being under the sole or primary control of the Supplier.

   Supplier will indemnify and defend Buyer against all claims resulting from contact with wastewater which does not meet the water quality standards warranted at Section___. A.1., when such contact occurs before notification to Buyer or before Buyer could reasonably act to prevent such contact after notification.

4. Supplier agrees to name the Buyer as co-insured on a public liability insurance policy which will be obtained by the Supplier expressly to provide against liabilities arising from wastewater irrigation activities. Under this policy, the insurer must agree to indemnify and defend the Supplier and Buyer against those liabilities described above at Section___.C.3.

SECTION ___: OTHER PROVISIONS

A. SEVERABILITY

If any provision of this contract is held invalid or unconscionable in its application to any person or circumstances, such invalidity will not affect other provisions of this contract that can be given effect without the invalid or unconscionable provision. The provisions of this contract are severable.

B. WAIVER

If the Supplier agrees to waive any of the terms and conditions of this contract, such waiver will not be construed as a waiver of any succeeding breach of the same term or condition, or as a waiver of any other term or condition. A waiver by the Supplier as to any term or condition will not be construed as a course of performance.

C. MODIFICATION

No term or condition of this agreement may be waived or modified except by written agreement signed by the Supplier and Buyer.

D. TIME LIMIT FOR BRINGING LEGAL ACTION

Any action for breach of this contract and any action arising out of this contract must be brought within one year from the date the claim accrues, or be barred forever.

APPENDIX F

WASTEWATER RECLAMATION CRITERIA

An Excerpt from the

CALIFORNIA ADMINISTRATIVE CODE
TITLE 22, DIVISION 4

ENVIRONMENTAL HEALTH

1978

STATE OF CALIFORNIA
DEPARTMENT OF HEALTH SERVICES
SANITARY ENGINEERING SECTION
2151 Berkeley Way, Berkeley 94704

INTENT OF REGULATIONS

The intent of these regulations is to establish acceptable levels of constituents of reclaimed water and to prescribe means for assurance of reliability in the production of reclaimed water in order to ensure that the use of reclaimed water for the specified purposes does not impose undue risks to health. The levels of constituents in combination with the means for assurance of reliability constitute reclamation criteria as defined in Section 13520 of the California Water Code.

As affirmed in Sections 13510 to 13512 of the California Water Code, water reclamation is in the best public interest and the policy of the State is to encourage reclamation. The reclamation criteria are intended to promote development of facilities which will assist in meeting water requirements of the State while assuring positive health protection. Appropriate surveillance and control of treatment facilities, distribution systems, and use areas must be provided in order to avoid health hazards. Precautions must be taken to avoid direct public contact with reclaimed waters which do not meet the standards specified in Article 5 for nonrestricted recreational impoundments.

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Article 10. Alternative Reliability Requirements for Uses Requiring Oxidized, Disinfected Wastewater or Oxidized, Coagulated, Clarified, Filtered, Disinfected Wastewater

CHAPTER 3. RECLAMATION CRITERIA

Article 1. Definitions

60301. Definitions. (a) **Reclaimed Water.** Reclaimed water means water which, as a result of treatment of domestic wastewater, is suitable for a direct beneficial use or a controlled use that would not otherwise occur.

(b) **Reclamation Plant.** Reclamation plant means an arrangement of devices, structures, equipment, processes and controls which produce a reclaimed water suitable for the intended reuse.

(c) **Regulatory Agency.** Regulatory agency means the California Regional Water Quality Control Board in whose jurisdiction the reclamation plant is located.

(d) **Direct Beneficial Use.** Direct beneficial use means the use of reclaimed water which has been transported from the point of production to the point of use without an intervening discharge to waters of the State.

(e) **Food Crops.** Food crops mean any crops intended for human consumption.

(f) **Spray Irrigation.** Spray irrigation means application of reclaimed water to crops by spraying it from orifices in piping.

(g) **Surface Irrigation.** Surface irrigation means application of reclaimed water by means other than spraying such that contact between the edible portion of any food crop and reclaimed water is prevented.

(h) **Restricted Recreational Impoundment.** A restricted recreational impoundment is a body of reclaimed water in which recreation is limited to fishing, boating, and other non-body-contact water recreation activities.

(i) **Nonrestricted Recreational Impoundment.** A nonrestricted recreational impoundment is an impoundment of reclaimed water in which no limitations are imposed on body-contact water sport activities.

(j) **Landscape Impoundment.** A landscape impoundment is a body of reclaimed water which is used for aesthetic enjoyment or which otherwise serves a function not intended to include public contact.

(k) **Approved Laboratory Methods.** Approved laboratory methods are those specified in the latest edition of "Standard Methods for the Examination of Water and Wastewater", prepared and published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation and which are conducted in laboratories approved by the State Department of Health.

(l) **Unit Process.** Unit process means an individual stage in the wastewater treatment sequence which performs a major single treatment operation.

(m) **Primary Effluent.** Primary effluent is the effluent from a wastewater treatment process which provides removal of sewage solids so that it contains not more than 0.5 milliliter per liter per hour of settleable solids as determined by an approved laboratory method.

(n) **Oxidized Wastewater.** Oxidized wastewater means wastewater in which the organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen.

(o) **Biological Treatment.** Biological treatment means methods of wastewater treatment in which bacterial or biochemical action is intensified as a means of producing an oxidized wastewater.

(p) **Secondary Sedimentation.** Secondary sedimentation means the removal by gravity of settleable solids remaining in the effluent after the biological treatment process.

(q) **Coagulated Wastewater.** Coagulated wastewater means oxidized wastewater in which colloidal and finely divided suspended matter have been destabilized and agglomerated by the addition of suitable floc-forming chemicals or by an equally effective method.

(r) **Filtered Wastewater.** Filtered wastewater means an oxidized, coagulated, clarified wastewater which has been passed through natural undisturbed soils or filter media, such as sand or diatomaceous earth, so that the turbidity as determined by an approved laboratory method does not exceed an average operating turbidity of 2 turbidity units and does not exceed 5 turbidity units more than 5 percent of the time during any 24-hour period.

(s) **Disinfected Wastewater.** Disinfected wastewater means wastewater in which the pathogenic organisms have been destroyed by chemical, physical or biological means.

(t) **Multiple Units.** Multiple units means two or more units of a treatment process which operate in parallel and serve the same function.

(u) **Standby Unit Process.** A standby unit process is an alternate unit process or an equivalent alternative process which is maintained in operable condition and which is capable of providing comparable treatment for the entire design flow of the unit for which it is a substitute.

(v) **Power Source.** Power source means a source of supplying energy to operate unit processes.

(w) **Standby Power Source.** Standby power source means an automatically actuated self-starting alternate energy source maintained in immediately operable condition and of sufficient capacity to provide necessary service during failure of the normal power supply.

(x) **Standby Replacement Equipment.** Standby replacement equipment means reserve parts and equipment to replace broken-down or worn-out units which can be placed in operation within a 24-hour period.

(y) **Standby Chlorinator.** A standby chlorinator means a duplicate chlorinator for reclamation plants having one chlorinator and a duplicate of the largest unit for plants having multiple chlorinator units.

(z) **Multiple Point Chlorination.** Multiple point chlorination means that chlorine will be applied simultaneously at the reclamation plant and at subsequent chlorination stations located at the use area and/or some intermediate point. It does not include chlorine application for odor control purposes.

(aa) **Alarm.** Alarm means an instrument or device which continuously monitors a specific function of a treatment process and automatically gives warning of an unsafe or undesirable condition by means of visual and audible signals.

(bb) **Person.** Person also includes any private entity, city, county, district, the State or any department or agency thereof.

NOTE: Authority cited: Section 208, Health and Safety Code and Section 13521, Water Code. Reference: Section 13521, Water Code.

History: 1. New Chapter 4 (§§ 60301–60357, not consecutive) filed 4-2-75; effective thirtieth day thereafter (Register 75, No. 14).
2. Renumbering of Chapter 4 (Sections 60301–60357, not consecutive) to Chapter 3 (Sections 60301–60357, not consecutive), filed 10-14-77; effective thirtieth day thereafter (Register 77, No. 42).

Article 2. Irrigation of Food Crops

60303. Spray Irrigation. Reclaimed water used for the spray irrigation of food crops shall be at all times an adequately disinfected, oxidized, coagulated, clarified, filtered wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 2.2 per 100 milliliters and the number of coliform organisms does not exceed 23 per 100 milliliters in more than one sample within any 30-day period. The median value shall be determined from the bacteriological results of the last 7 days for which analyses have been completed.

60305. Surface Irrigation. (a) Reclaimed water used for surface irrigation of food crops shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 2.2 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

(b) Orchards and vineyards may be surface irrigated with reclaimed water that has the quality at least equivalent to that of primary effluent provided that no fruit is harvested that has come in contact with the irrigating water or the ground.

60307. Exceptions. Exceptions to the quality requirements for reclaimed water used for irrigation of food crops may be considered by the State Department of Health on an individual case basis where the reclaimed water is to be used to irrigate a food crop which must undergo extensive commercial, physical or chemical processing sufficient to destroy pathogenic agents before it is suitable for human consumption.

Article 3. Irrigation of Fodder, Fiber, and Seed Crops

60309. Fodder, Fiber, and Seed Crops. Reclaimed water used for the surface or spray irrigation of fodder, fiber, and seed crops shall have a level of quality no less than that of primary effluent.

60311. Pasture for Milking Animals. Reclaimed water used for the irrigation of pasture to which milking cows or goats have access shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 23 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

Article 4. Landscape Irrigation

60313. Landscape Irrigation. (a) Reclaimed water used for the irrigation of golf courses, cemeteries, freeway landscapes, and landscapes in other areas where the public has similar access or exposure shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if the median number of coliform organisms in the effluent does not exceed 23 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed, and the number of coliform organisms does not exceed 240 per 100 milliliters in any two consecutive samples.

(b) Reclaimed water used for the irrigation of parks, playgrounds, schoolyards, and other areas where the public has similar access or exposure shall be at all times an adequately disinfected, oxidized, coagulated, clarified, filtered wastewater or a wastewater treated by a sequence of unit processes that will assure an equivalent degree of treatment and reliability. The wastewater shall be considered adequately disinfected if the median number of coliform organisms in the effluent does not exceed 2.2 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed, and the number of coliform organisms does not exceed 23 per 100 milliliters in any sample.

NOTE: Authority cited: Section 208, Health and Safety Code and Section 13521, Water Code. Reference: Section 13520, Water Code.

History: 1. Amendment filed 9-22-78; effective thirtieth day thereafter (Register 78, No. 38).

Article 5. Recreational Impoundments

60315. Nonrestricted Recreational Impoundment. Reclaimed water used as a source of supply in a nonrestricted recreational impoundment shall be at all times an adequately disinfected, oxidized, coagulated, clarified, filtered wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 2.2 per 100 milliliters and the number of coliform organisms does not exceed 23 per 100 milliliters in more than one sample within any 30-day period. The median value shall be determined from the bacteriological results of the last 7 days for which analyses have been completed.

60317. Restricted Recreational Impoundment. Reclaimed water used as a source of supply in a restricted recreational impoundment shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 2.2 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

60319. Landscape Impoundment. Reclaimed water used as a source of supply in a landscape impoundment shall be at all times an adequately disinfected, oxidized wastewater. The wastewater shall be considered adequately disinfected if at some location in the treatment process the median number of coliform organisms does not exceed 23 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

Article 5.1. Groundwater Recharge

60320. Groundwater Recharge. (a) Reclaimed water used for groundwater recharge of domestic water supply aquifers by surface spreading shall be at all times of a quality that fully protects public health. The State Department of Health Services' recommendations to the Regional Water Quality Control Boards for proposed groundwater recharge projects and for expansion of existing projects will be made on an individual case basis where the use of reclaimed water involves a potential risk to public health.

(b) The State Department of Health Services' recommendations will be based on all relevant aspects of each project, including the following factors: treatment provided; effluent quality and quantity; spreading area operations; soil characteristics; hydrogeology; residence time; and distance to withdrawal.

(c) The State Department of Health Services will hold a public hearing prior to making the final determination regarding the public health aspects of each groundwater recharge project. Final recommendations will be submitted to the Regional Water Quality Control Board in an expeditious manner.

NOTE: Authority cited: Section 208, Health and Safety Code and Section 13521, Water Code. Reference: Section 13520, Water Code.

History: 1. New Article 5.1 (Section 60320) filed 9-22-78; effective thirtieth day thereafter (Register 78, No. 38).

Article 5.5. Other Methods of Treatment

60320.5. Other Methods of Treatment. Methods of treatment other than those included in this chapter and their reliability features may be accepted if the applicant demonstrates to the satisfaction of the State Department of Health that the methods of treatment and reliability features will assure an equal degree of treatment and reliability.

NOTE: Authority cited: Section 208, Health and Safety Code and Section 13521, Water Code. Reference: Section 13520, Water Code.

History: 1. Renumbering of Article 11 (Section 60357) to Article 5.5 (Section 60320.5) filed 9-22-78; effective thirtieth day thereafter (Register 78, No. 38).

Article 6. Sampling and Analysis

60321. Sampling and Analysis. (a) Samples for settleable solids and coliform bacteria, where required, shall be collected at least daily and at a time when wastewater characteristics are most demanding on the treatment facilities and disinfection procedures. Turbidity analysis, where required, shall be performed by a continuous recording turbidimeter.

(b) For uses requiring a level of quality no greater than that of primary effluent, samples shall be analyzed by an approved laboratory method of settleable solids.

(c) For uses requiring an adequately disinfected, oxidized wastewater, samples shall be analyzed by an approved laboratory method for coliform bacteria content.

(d) For uses requiring an adequately disinfected, oxidized, coagulated, clarified, filtered wastewater, samples shall be analyzed by approved laboratory methods for turbidity and coliform bacteria content.

Article 7. Engineering Report and Operational Requirements

60323. Engineering Report. (a) No person shall produce or supply reclaimed water for direct reuse from a proposed water reclamation plant unless he files an engineering report.

(b) The report shall be prepared by a properly qualified engineer registered in California and experienced in the field of wastewater treatment, and shall contain a description of the design of the proposed reclamation system. The report shall clearly indicate the means for compliance with these regulations and any other features specified by the regulatory agency.

(c) The report shall contain a contingency plan which will assure that no untreated or inadequately-treated wastewater will be delivered to the use area.

60325. Personnel. (a) Each reclamation plant shall be provided with a sufficient number of qualified personnel to operate the facility effectively so as to achieve the required level of treatment at all times.

(b) Qualified personnel shall be those meeting requirements established pursuant to Chapter 9 (commencing with Section 13625) of the Water Code.

60327. Maintenance. A preventive maintenance program shall be provided at each reclamation plant to ensure that all equipment is kept in a reliable operating condition.

60329. Operating Records and Reports. (a) Operating records shall be maintained at the reclamation plant or a central depository within the operating agency. These shall include: all analyses specified in the reclamation criteria; records of operational problems, plant and equipment breakdowns, and diversions to emergency storage or disposal; all corrective or preventive action taken.

(b) Process or equipment failures triggering an alarm shall be recorded and maintained as a separate record file. The recorded information shall include the time and cause of failure and corrective action taken.

(c) A monthly summary of operating records as specified under (a) of this section shall be filed monthly with the regulatory agency.

(d) Any discharge of untreated or partially treated wastewater to the use area, and the cessation of same, shall be reported immediately by telephone to the regulatory agency, the State Department of Health, and the local health officer.

60331. Bypass. There shall be no bypassing of untreated or partially treated wastewater from the reclamation plant or any intermediate unit processes to the point of use.

Article 8. General Requirements of Design

60333. Flexibility of Design. The design of process piping, equipment arrangement, and unit structures in the reclamation plant must allow for efficiency and convenience in operation and maintenance and provide flexibility of operation to permit the highest possible degree of treatment to be obtained under varying circumstances.

60335. Alarms. (a) Alarm devices required for various unit processes as specified in other sections of these regulations shall be installed to provide warning of:

(1) Loss of power from the normal power supply.
(2) Failure of a biological treatment process.
(3) Failure of a disinfection process.
(4) Failure of a coagulation process.
(5) Failure of a filtration process.
(6) Any other specific process failure for which warning is required by the regulatory agency.

(b) All required alarm devices shall be independent of the normal power supply of the reclamation plant.

(c) The person to be warned shall be the plant operator, superintendent, or any other responsible person designated by the management of the reclamation plant and capable of taking prompt corrective action.

(d) Individual alarm devices may be connected to a master alarm to sound at a location where it can be conveniently observed by the attendant. In case the reclamation plant is not attended full time, the alarm(s) shall be connected to sound at a police station, fire station or other full-time service unit with which arrangements have been made to alert the person in charge at times that the reclamation plant is unattended.

60337. Power Supply. The power supply shall be provided with one of the following reliability features:

(a) Alarm and standby power source.

(b) Alarm and automatically actuated short-term retention or disposal provisions as specified in Section 60341.

(c) Automatically actuated long-term storage or disposal provisions as specified in Section 60341.

Article 9. Alternative Reliability Requirements for Uses Permitting Primary Effluent

60339. Primary Treatment. Reclamation plants producing reclaimed water exclusively for uses for which primary effluent is permitted shall be provided with one of the following reliability features:

(a) Multiple primary treatment units capable of producing primary effluent with one unit not in operation.

(b) Long-term storage or disposal provisions as specified in Section 60341.

Article 10. Alternative Reliability Requirements for Uses Requiring Oxidized, Disinfected Wastewater or Oxidized, Coagulated, Clarified, Filtered, Disinfected Wastewater

60341. Emergency Storage or Disposal. (a) Where short-term retention or disposal provisions are used as a reliability feature, these shall consist of facilities reserved for the purpose of storing or disposing of untreated or partially treated wastewater for at least a 24-hour period. The facilities shall include all the necessary diversion devices, provisions for odor control, conduits, and pumping and pump back equipment. All of the equipment other than the pump back equipment shall be either independent of the normal power supply or provided with a standby power source.

(b) Where long-term storage or disposal provisions are used as a reliability feature, these shall consist of ponds, reservoirs, percolation areas, downstream sewers leading to other treatment or disposal facilities or any other facilities reserved for the purpose of emergency storage or disposal of untreated or partially treated wastewater. These facilities shall be of sufficient capacity to provide disposal or storage of wastewater for at least 20 days, and shall include all the necessary diversion works, provisions for odor and nuisance control, conduits, and pumping and pump back equipment. All of the equipment other than the pump back equipment shall be either independent of the normal power supply or provided with a standby power source.

(c) Diversion to a less demanding reuse is an acceptable alternative to emergency disposal of partially treated wastewater provided that the quality of the partially treated wastewater is suitable for the less demanding reuse.

(d) Subject to prior approval by the regulatory agency, diversion to a discharge point which requires lesser quality of wastewater is an acceptable alternative to emergency disposal of partially treated wastewater.

(e) Automatically actuated short-term retention or disposal provisions and automatically actuated long-term storage or disposal provisions shall include, in addition to provisions of (a), (b), (c), or (d) of this section, all the necessary sensors, instruments, valves and other devices to enable fully automatic diversion of untreated or partially treated wastewater to approved emergency storage or disposal in the event of failure of a treatment process, and a manual reset to prevent automatic restart until the failure is corrected.

60343. Primary Treatment. All primary treatment unit processes shall be provided with one of the following reliability features:

(a) Multiple primary treatment units capable of producing primary effluent with one unit not in operation.

(b) Standby primary treatment unit process.

(c) Long-term storage or disposal provisions.

60345. Biological Treatment. All biological treatment unit processes shall be provided with one of the following reliability features:

(a) Alarm and multiple biological treatment units capable of producing oxidized wastewater with one unit not in operation.

(b) Alarm, short-term retention or disposal provisions, and standby replacement equipment.

(c) Alarm and long-term storage or disposal provisions.

(d) Automatically actuated long-term storage or disposal provisions.

60347. Secondary Sedimentation. All secondary sedimentation unit processes shall be provided with one of the following reliability features:

(a) Multiple sedimentation units capable of treating the entire flow with one unit not in operation.

(b) Standby sedimentation unit process.

(c) Long-term storage or disposal provisions.

60349. Coagulation.

(a) All coagulation unit processes shall be provided with the following mandatory features for uninterrupted coagulant feed:

(1) Standby feeders,

(2) Adequate chemical stowage and conveyance facilities,

(3) Adequate reserve chemical supply, and

(4) Automatic dosage control.

(b) All coagulation unit processes shall be provided with one of the following reliability features:

(1) Alarm and multiple coagulation units capable of treating the entire flow with one unit not in operation;

(2) Alarm, short-term retention or disposal provisions, and standby replacement equipment;

(3) Alarm and long-term storage or disposal provisions;

(4) Automatically actuated long-term storage or disposal provisions, or

(5) Alarm and standby coagulation process.

60351. Filtration. All filtration unit processes shall be provided with one of the following reliability features:

(a) Alarm and multiple filter units capable of treating the entire flow with one unit not in operation.

(b) Alarm, short-term retention or disposal provisions and standby replacement equipment.

(c) Alarm and long-term storage or disposal provisions.
(d) Automatically actuated long-term storage or disposal provisions.
(e) Alarm and standby filtration unit process.

60353. Disinfection.

(a) All disinfection unit processes where chlorine is used as the disinfectant shall be provided with the following features for uninterrupted chlorine feed:

(1) Standby chlorine supply,
(2) Manifold systems to connect chlorine cylinders,
(3) Chlorine scales, and
(4) Automatic devices for switching to full chlorine cylinders.

Automatic residual control of chlorine dosage, automatic measuring and recording of chlorine residual, and hydraulic performance studies may also be required.

(b) All disinfection unit processes where chlorine is used as the disinfectant shall be provided with one of the following reliability features:

(1) Alarm and standby chlorinator;
(2) Alarm, short-term retention or disposal provisions, and standby replacement equipment;
(3) Alarm and long-term storage or disposal provisions;
(4) Automatically actuated long-term storage or disposal provisions; or
(5) Alarm and multiple point chlorination, each with independent power source, separate chlorinator, and separate chlorine supply.

60355. Other Alternatives to Reliability Requirements. Other alternatives to reliability requirements set forth in Articles 8 to 10 may be accepted if the applicant demonstrates to the satisfaction of the State Department of Health that the proposed alternative will assure an equal degree of reliability.

APPENDIX G

CONVERSION TABLE

A	B[a]	To convert A to B, multiply A by:
Length		
foot	meter	0.3048
inch	centimeter	2.54
Area		
acre	hectare (ha)	0.4046
acre	square foot	43,560
square foot	square meter	0.0929
Volume		
gallon	liter (L)	3.785
gallon	cubic meter	0.003785
acre-ft	gallon (gal)	325,850
acre-ft	cubic meter	1233.5
liter	cubic meter	1000
Flow rate		
million gallons/day (mgd)	cubic meter/sec	0.0438
million gallons/day	acre-ft/year	1120.0
million gallons/day	acre-inch/day	36.828
gallons/minute	liter/second	0.06308
gallons/minute	acre-inch/day	0.5303
gallons/minute·square foot	liter/square meter·sec	0.67902
cubic feet/second	liter/second	28.450
cubic feet/second	acre-inch/day	23.8
inch/week	centimeter/week	2.54
Concentration		
parts per million (ppm)	milligram/kilogram	1.00
milligram/liter	gram/cubic meter	1.00
parts per billion (ppb)	milligram/liter	0.001
millequivalents/liter	milligram/liter	gram equivalent weight
Mass or weight		
pound	kilogram (kg)	0.4536
ton (U.S.)	ton (metric)	0.9072
Yield		
pounds/acre	kilogram/hectare	1.12
ton (U.S.)/acre	ton (metric)/hectare	2.24
Pressure		
pound/square inch	Pascal (Pa)	6895

A	B[a]	To convert A to B, multiply A by:
Electrical conductivity		
millimhos/centimeter (mmho/cm)	deciSiemens/meter (dS/m)	1.00
Temperature		
degrees Fahrenheit, °F	degrees Celsius, °C	5/9 (°F-32)
degrees Celsius, °C	degrees Fahrenheit, °F	9/5 (°C)+32

a. Most of these are SI units or derivatives of SI units. Systeme Internationale (SI) is a universal measurement language which makes use of only 7 base units and also uses derived units which are expressed algebraically in terms of base units. The base units are: meter (m), kilogram (kg), second (s), ampere (A), candela (cd), kelvin (K) and mole (mole).

APPENDIX H
GLOSSARY

activated sludge process - A biological wastewater treatment process in which a mixture of wastewater and activated sludge is agitated and aerated.

advanced wastewater treatment - Any physical, chemical, or biological treatment process used to accomplish a degree of treatment greater than that achieved by secondary treatment. Usually implies removal of nutrients and a high percentage of suspended solids.

alkalinity - The capacity of water to neutralize acids; a property imparted by carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams of equivalent calcium carbonate per liter.

available water - The portion of water in a soil that can be readily absorbed by plant roots. Considered by most workers to be that water held in the soil against a pressure of up to approximately 15 bars. See **field capacity**, **permanent wilting point**, and **soil moisture tension**.

BOD - (1) Biochemical oxygen demand. The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. (2) A standard test used in assessing wastewater strength.

cation exchange capacity (CEC) - The sum of exchangeable cations that a soil can adsorb expressed in millequivalents per 100 grams of soil or in millimoles of positive charge per kilogram of soil. CEC is directly related to a soil's ability to retain cations against leaching. CEC is also used in calculating exchangeable sodium percentage (ESP) - a measure of excessive sodium hazard in the soil.

COD - Chemical oxygen demand. A quantitative measure of the amount of oxygen required for the chemical oxidation of carbonaceous (organic) material in wastewater using dichromate or permanganate salts as oxidants in a two-hour test.

denitrification - The biological conversion of nitrate or nitrite to gaseous N_2 or N_2O.

effluent - Partially or completely treated wastewater flowing out of a treatment plant, reservoir, or basin.

electrical conductivity (EC_w for water, EC_e for the soil saturation extract) - A measure of salinity expressed in millimhos per centimeter (mmho/cm) or deciSiemens per meter (dS/m) at 25°C. Empirically related to total dissolved solids (in mg/L) divided by 640.

evapotranspiration (ET) - The combined loss of water from a given area and during a specified period of time by evaporation from the soil surface and by transpiration from plants. ET_o is reference ET defined as the ET from an extended surface of 3 to 6-inch tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water. E_p or E_{pan} is evaporation from a standard evaporation pan.

exchangeable sodium percentage (ESP) - The ratio (as percent) of exchangeable sodium to the remaining exchangeable cations in the soil. See **SAR**.

field capacity (FC) - The percentage of water (either weight or volume) remaining in a soil 2 or 3 days after having been saturated and after free drainage has practically ceased. This term is obsolete in technical work. For many soils, FC is in the range of 1/10 to 1/3 bar water potential. See **soil moisture tension**.

gypsum requirement - The quantity of gypsum or its equivalent required to reduce the exchangeable sodium fraction of a given increment of soil to an acceptable level (see Chapter 7).

horizon - A layer of soil differing from adjacent genetically related layers in properties such as color, structure, texture, consistency, pH, etc.

hydraulic conductivity - The rate of water flow in soil per unit gradient of hydraulic head or potential.

immobilization - The conversion of an element from the inorganic to the organic form in microbial or plant tissues. Often used to describe the conversion of nitrate or ammonium into organic forms in soil microorganisms.

infiltration - (1) The downward entry of water into soil. (2) The flow or movement of water through the pores of a soil or other porous medium. (3) The quantity of groundwater that leaks into a pipe through joints, porous walls, or breaks. (4) The entrance of water from the ground into a gallery.

infiltration rate - (1) A soil characteristic describing the maximum rate at which water can enter the soil under specified conditions, including the presence of excess water. It has the dimensions of velocity, i.e., inch/hr or cm/sec. Formerly, the infiltration capacity. (2) The rate, usually expressed in cubic feet per second or million gallons per day per mile of waterway, at which groundwater enters an infiltration ditch or gallery, drain, sewer, or other underground conduit.

infiltrometer - Any of several devices for measuring the rate of entry of water into a soil.

influent - Wastewater flowing into a treatment plant, or treatment process.

land application - The recycling, treatment, or disposal of wastewater or wastewater solids to the land under controlled conditions.

land disposal - Application of raw or treated wastewater, sludges, or solid waste to soils and/or substrata without production of usable agricultural products. (See also **land treatment**).

land treatment - Irrigation with partially treated wastewater on land; additional treatment is provided by soil, microorganisms, and crops which are grown to utilize nutrients. See also **land application, land disposal**.

leaching fraction (LF)- The fraction of water applied to soil that leaches below a depth of interest such as the rooting depth.

leaching requirement (LR) - The leaching fraction required to maintain average root zone salinity below a phytotoxic threshold value.

management allowed depletion (MAD) - The amount of water which the irrigator will allow to be depleted by evapotranspiration between irrigations, expressed either as a percent of available water in the root zone or a depth of water.

mineralization - The conversion of an element from an organic to an inorganic form (e.g., the conversion of organic nitrogen in wastewater to ammonium nitrogen by microbial decomposition).

overland flow - A type of land treatment in which water flows over the surface of vegetated land before entering some defined channel.

oxidation pond - A relatively shallow pond or basin in which biological oxidation is effected by natural or artificially accelerated transfer of oxygen (e.g., algae pond, lagoon).

pan - A horizon or layer in soil that is strongly compacted, indurated, or very high in clay content. **Caliche** is a pan cemented by calcium or magnesium carbonates. A **fragipan** is a natural pan in non-calcareous soils seemingly cemented when dry but when moist showing a moderate to weak brittleness.

permanent wilting point (PWP) -A plant physiology term referring to the soil water content at which plants wilt and do not recover. By convention, often considered to be the soil water content at -15 bars water potential. Actual PWP can vary greatly from this value.

permeability - The ease with which gas, liquids or plant roots penetrate or pass through a soil horizon.

pH - The degree of acidity or alkalinity, defined as the negative logarithm of hydrogen ion activity of water.

primary treatment - (1) The first major treatment in a wastewater treatment facility, usually sedimentation but not biological oxidation. (2) The removal of a substantial amount of suspended matter but little or no colloidal and dissolved matter. (3) Wastewater treatment processes usually consisting of clarification with or without chemical treatment to accomplish solid-liquid separation. See also **secondary treatment, tertiary treatment.**

rapid infiltration - A type of land treatment in which water is applied to relatively porous soil at rates far in excess of normal crop irrigation.

secondary treatment - (1) Generally, a level of treatment that produces removal efficiencies for BOD and suspended solids of 85%. (2) Sometimes used interchangeably with concept of biological wastewater treatment, particularly the activated sludge process. Commonly applied to treatment that consists chiefly of a biological process followed by clarification with separate sludge collection and handling.

slow rate land treatment process - A type of land treatment of wastewater. Wastewater is applied to a vegetated land surface with the applied wastewater being treated as it flows through the plant-soil matrix.

sodium adsorption ratio (R_{Na} or SAR) - A measure of the amount of sodium relative to the amount of calcium and magnesium in water or in a soil saturation extract. It is defined as follows:

$$R_{Na} \text{ or SAR} = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

where the quantities Na, Ca, and Mg are expressed in milliequivalent/liter. The SAR can be used to predict the exchangeable sodium percentage of a soil equilibrated with a given solution. A procedure for calculating an adjusted R_{Na} for waters high in bicarbonate is presented in Chapter 3.

soil moisture tension (or pressure) - The soil water content expressed as an equivalent negative pressure. It is equal to the equivalent pressure that must be applied to soil water to bring it to equilibrium, through a permeable membrane, with a pool of water of the same composition. Usually expressed in bars or atmospheres.

soil structure - The combination or arrangement of primary soil particles into secondary particles, aggregates, or peds. These secondary units are classified by soil morphologists on the basis of size, shape, and degree of distinctness.

reclaimed wastewater - Wastewater that, as a result of treatment, is suitable for a beneficial use.

soil texture - The relative proportions in a soil of sand, silt, and clay-sized mineral particles.

soil total water potential - The amount of work which must be done to transport a unit of pure water to the soil water isothermally and at atmospheric pressure. Comprised mainly of osmotic, gravitational, and capillary components.

soil water content -The amount of water lost from the soil upon drying to constant weight at 105°C, expressed as g water per g dry soil or cm^3 water per cm^3 bulk soil. In the field, water content is often expressed on a percent dry weight basis. This can lead to ambiguity when it is not stated whether a weight or volume basis is being used.

tertiary treatment - See **advanced wastewater treatment.**

total dissolved solids (TDS) - The sum of all dissolved solids in a water or wastewater and an expression of water salinity in mg/L. Empirically related to electrical conductivity (EC) multiplied by 640.

trickling filter - A coarse filter used to provide secondary treatment of wastewater. A film of aerobic microorganisms on the filter media metabolizes the organic material in the wastewater trickling downward to underdrains; biofilm that sloughs off is subsequently removed by sedimentation.

wastewater irrigation - Land application of wastewater with the primary purpose of maximizing crop production per unit of water applied. Often used in a broader sense to mean land treatment and disposal of wastewater where maximum crop production is a secondary objective.

wastewater reclamation - The process of treating wastewater to produce water for beneficial uses, its transportation to the place of use, and its actual use.

wastewater reuse - The additional use of once-used water.

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APPENDIX I

HEAVY METAL CONTENTS OF SELECTED CALIFORNIA SOILS

Appendix I. Heavy metal contents of selected California soils[a]

Soil Series	pH	CEC (meq/100 g)	O.M. (%)	Cd (μg/g)	Cr (μg/g)	Cu (μg/g)	Ni (μg/g)	Pb (μg/g)	Zn (μg/g)	Fe (μg/g)	Mn (μg/g)	Reference[b]
Holland	6.4	8.8	1.24	0.24	-	33.3	21.0	-	142	-	-	1
Ramona	5.2	4.4	0.43	<0.1	-	16.3	13.2	-	52.9	-	-	1
Helendale	7.5	5.4	0.25	<0.1	-	17.3	12.7	-	44.2	-	-	1
Baywood	4.9	4.5	0.30	0.5	32	4	29	-	11	11,375	144	2
Calhi	8.1	2.9	0.15	0.5	4	5	8	-	21	9,750	188	2
Delhi	7.5	4.7	0.55	0.6	11	11	13	-	40	19,000	275	2
Hanford	6.1	6.8	0.48	0.8	9	11	9	-	44	20,500	400	2
Milham	7.5	16.3	0.40	1.0	27	18	36	-	58	23,000	425	2
Redding	5.8	15.6	1.68	0.6	13	12	10	-	30	21,000	313	2
Greenfield	6.5	8.7	0.8	0.4	19	15	7	9	82	-	-	3
Domino	7.8	14.0	4.3	0.3	14	22	17	22	91	-	-	3
Ramona	6.5	-	-	0.5	10	14	11	13	53	-	-	3
Redding	5.0	9.8	0.44	0.2	-	9	5.6	11.3	5	8,564	113	4
Oakley	7.0	5.2	0.09	0.3	-	10	10.0	8.1	28	9,845	210	4
Holtville	7.7	27.3	0.61	1.1	-	20	21.0	26.9	57	17,690	193	4
Redding	4.8	9.8	2.6	<0.1	-	6.5	5.5	-	26	9,500	200	5
St. Miguel	5.0	17.7	3.3	<0.1	-	9.5	8.0	-	63	23,000	660	5
Hanford	5.3	7.6	0.9	<0.1	-	12	8.0	-	47	16,000	310	5
Altamont	5.7	37.9	3.0	<0.1	-	14.5	12.5	-	84	20,500	450	5
Domino	7.4	16.2	1.4	<0.1	-	29	24.5	-	112	39,000	740	5
Arizo	7.5	6.5	0.6	<0.1	-	14.5	9.5	-	87	10,000	500	5
Holtville	7.7	27.3	0.9	<0.1	-	20.5	21.5	-	78	16,000	450	5
Simona	7.8	7.4	0.7	<0.1	-	10.5	10.0	-	44	5,400	220	5
Lindsay	4.2	11.9	-	0.2	-	-	-	-	50	-	-	6
Omni	7.6	46.1	-	0.3	-	-	-	-	110	-	-	6
Sacramento	7.8	37.0	-	-	-	-	-	-	100	-	-	6
Mean				0.34	15.4	14.6	14.1	16.6	60.4	16,477	340	
Standard deviation				0.29	9.0	7.1	7.9	8.1	33.0	8,080	179	

a. All soils were extracted with 4 M HNO_3 extraction (5 g of soil with 30 ml of 4 M HNO_3 at 70°C for 24 hr., dilute to 50 ml with additional HNO_3, shake for 30 min. and then filter).

b. References:

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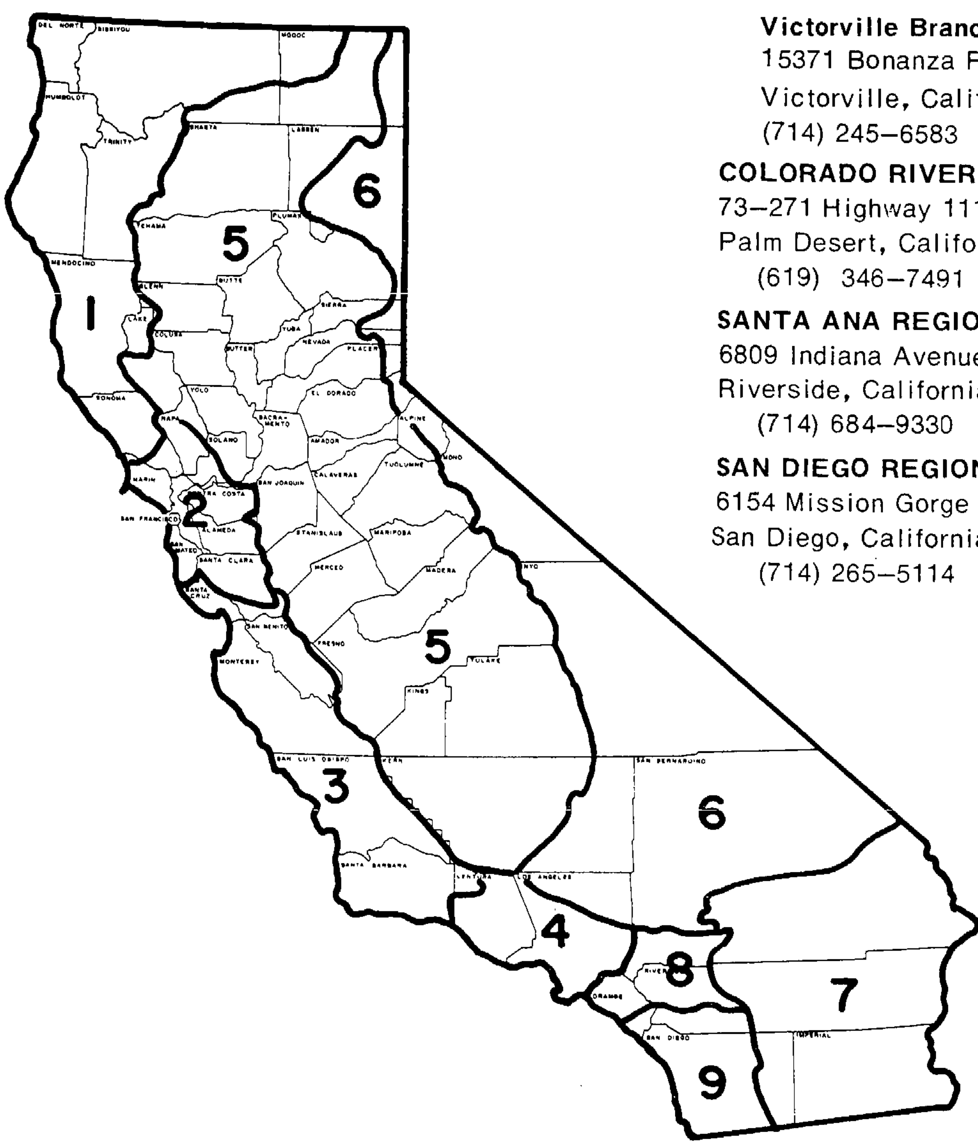

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