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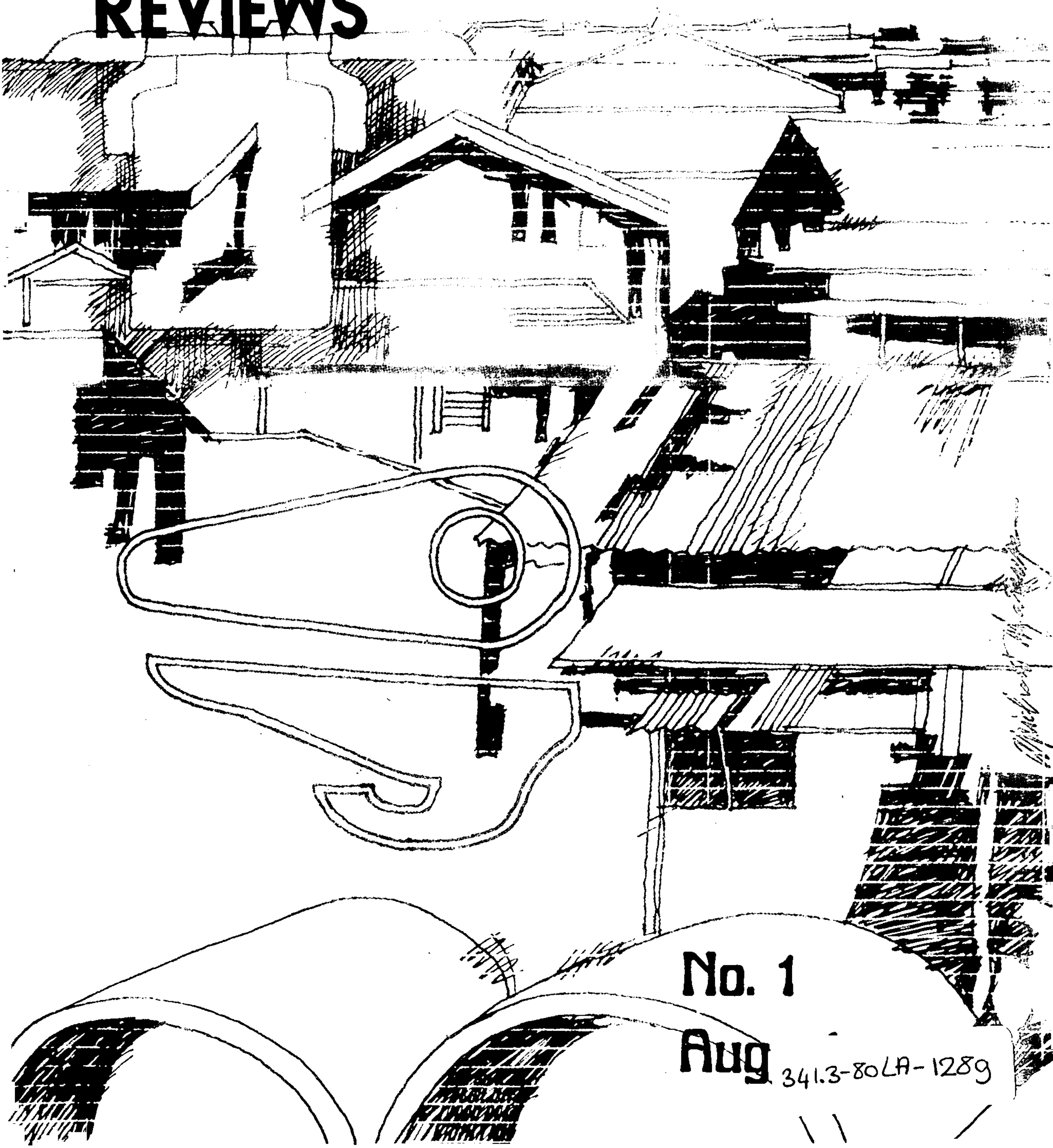

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Number 1, August 1980

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INTRODUCTION

ENSIC had announced earlier its intention to publish an "Annual Technology Review" in the form of one single book. To achieve this, ENSIC had contacted well-known specialists who did agree to write review papers on various ENSIC topics within a given time limit. Unfortunately, it soon became obvious that those renowned specialists were far too busy to write their papers on time to enable producing a single annual publication.

ENSIC then decided to publish the review paper separately in a new serial publication called "Environmental Sanitation Reviews", which will be published three times a year. Each issue will review a given topic covered by ENSIC.

When all ENSIC topics will have been reviewed once, by rather bulky papers, they will be regularly updated.

The state-of-the-art papers may either be prepared by ENSIC and reviewed by a specialist, or they may be written by well-known scientists.

In short, ENSIC will fulfill its earlier commitments to its members, i.e.. to provide them with relevant articles, but in a different and more flexible form than initially planned: instead of an Annual Review book, they will receive this journal: the "Environmental Sanitation Reviews".

The Editors sincerely hope it will be useful to its members and shall welcome any comments or suggestions aiming at improving this new publication.

The Editors

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LAND TREATMENT OF MUNICIPAL WASTEWATER : A STATE-OF-THE-ART REVIEW

by

ENSIC Review Committee on Land Treatment

K. Rajagopal
B. N. Lohani
Raymond C. Loehr

August, 1980

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LAND TREATMENT OF MUNICIPAL WASTEWATER : A STATE-OF-THE-ART REVIEW.

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by

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K. Rajagopal
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Raymond C. Loehr

1. INTRODUCTION

We are now moving towards a "recycle society" - a society in which virtually all materials are reused indefinitely. Secondary materials will become our major resources, and our natural untapped resources will become our backup supplies. Land treatment is one of the important tools for resource reuse.

Although land treatment of sewage is not a new technique, it has not received the acceptance or recognition it deserves. We have not taken full advantage of the tremendous and underexploited capacity of our soils to absorb pollutants. Data presented by Carlson and Menzies (24) and Webber and King (208) indicate the tremendous capacity of the soil to absorb organic wastes and biologically break them into compounds that can re-enter the natural cycle of plant and animal life.

The present concept of land treatment of sewage emphasizes the need for resource management rather than mere dumping for disposal (26), taking into consideration the key benefits and risks involved. Land treatment is the controlled, designed, and managed application of wastewater to land. Many people equate land treatment with landfills, dumps, odorous overloaded sites and the like. Land Treatment is not dumping or simply disposal. It is a managed, competently designed approach that utilises the most current engineering and scientific information. The result is a system that uses and conserves the resources in wastes (water, nutrients, organic matter) to enhance the soil and crop production rather than simply treat and dispose of the wastes. Although land application is the cheapest form of sewage disposal, research programs are a must to emphasize field trials and demonstrations; test design, operation and maintenance; evaluate economics; address public and institutional acceptance, and review legal problems (33, 139). Hence voluminous research has been done, and Reynolds (147, 148) has attempted to cover briefly, literature available on the subject.

Today there are so many publications on the various aspects of land treatment of sewage that to put all the information together in a vivid and concise manner is indeed, a Herculian task. This paper merely gives an overview of some of the research findings in the field upto 1979, and is done on similar lines to the work by the Canadian International Development Research Centre (IDRC) (157). In accordance with the scope of the ENSIC, this rewiew confines itself to municipal wastewater alone, although industrial wastes can also be used for land treatment. It is hoped that this review will serve as introductory material to those members of ENSIC who are beginners, or as a source of information to those who may, in one way or the other, be involved in the field. ENSIC hopes to update the review once in two years to enable its members to keep track of recent research activities in the field.

2. HISTORICAL REVIEW OF LAND TREATMENT

The practice of adding waste matter to the soil, including human and animal faeces, is a very old practice, almost as old as agriculture itself. The most outstanding example is to be found in China, where night-soil has been used for this purpose from time immemorial (116) and is still being used for agricultural development, thereby providing a positive monetary incentive for pollution control (111). According to Shende (168), application of sewage on land in the West was started as a measure to avoid stream pollution by untreated domestic wastewater in England in 1860. However, references to sewage farming as far back as the 1550's have been encountered, as indicated in Table 1 (140). Some of these systems in the past have covered very large acreages, out of which a few are still in existence. References for sewage farming in the United States date back to 1872 (140).

Table 1. Historical Data on Sewage Farming (140).

Location	Date	Type(a)	Flow, mgd	Average loading, in./wk
Non-United States				
Bunzlau, Germany	1559	SF	-	-
Croydon-Beddington, Germany	1861	SF	4.5	2.8
Berlin, Germany	1869	SF	150 (b)	1.4
Birmingham, England	1880	SF	22	4.7
Melbourne, Australia	1893	I	50 (c)	1.2
Melbourne, Australia		OF	70 (c)	5.2
Mexico City, Mexico	1902	I	570 (c)	1.3
Paris, France	1923	I	120	2.5
United States				
Augusta, Maine (d)	1872	I	0.007	0.6
Pullman, Illinois (d)	1880	I	1.85	12.0
Cheyenne, Wyoming	1881	I	7.0 (e)	1.3
San Antonio, Texas	1895	I	20 (b)	1.3
Salt Lake City, Utah	1896	I	4	5.7
Bakersfield, California	1912	I	13.0(e)	1.4

a. SF = sewage farm; I = irrigation; OF = overland flow
b. Data for 1926
c. Data for 1971
d. Abandoned around 1900
e. Data for 1973

Thus it can be seen that from prebiblical times, sewage and nightsoil have been considered as a valuable source of nutrients for crops and have been widely applied for cultivation of crops.

3. FERTILIZER POTENTIAL OF SEWAGE AND THE LIMITING PARAMETER PRINCIPLE

The present-day world, through scientific study, has recognised the importance of sewage and sludge utilization for agricultural purposes. Hershkovitz and Feinmesser (67) have listed the benefits of sewage farming and they are: the re-utilization of an additional source of water, utilization of the fertilizers present in sewage, inexpensive and efficient solution of the problems of sanitary disposal, and prevention of possible sanitary nuisances that might otherwise be caused by sewage.

Table 2. Typical Chemical Composition of Raw Municipal Sewage.

Constituent	Concentration,ppm	References
pH	6.5-8.0	6
Nitrogen		
Total nitrogen	15-60	6
" "	30	58
" "	74-30 (sic)	13
Organic nitrogen	5-19	6
Ammonia nitrogen	10-40	6
Nitrate nitrogen	0.0-1.0	6
Phosphorus		
Total phosphorus	6-20	6
" "	10	58
" "	12-14	13
Organic phosphorus	2-5	114
Inorganic phosphorus	4-15	114
BOD5 (20 C degrees)	100-300	114
" " "	200	58
COD	250-1000	114
"	450	58
TOC	100-300	114
Sulfate	20	58
Chlorides	30-100	114
"	50-116	13
"	100	58
Calcium	0-148	13
"	10	58
Magnesium	0-105	13
"	5	58
Potassium	23-40	13
"	10	58
Sodium	30-78	13
"	50	58
Toxic elements		
Cadmium	0.007-0.019	38
Chromium	0.008-0.09	38
Copper	0.12-0.21	38
Lead	0.075-0.12	38
Nickel	0.014-0.09	38
Zinc	0.200-0.25	38
Boron	0.2	58

Numerous workers have discussed the physio-chemical and biological characteristics of raw sewage. The chemical composition of municipal sewage is illustrated in Table 2 from which the fertilizer value of sewage is evident. A detailed evaluation of the waste characteristics is a necessary preliminary step when planning for any land application system (101). It is obvious that the amount of nutrients supplied to crops with sewage can vary and the amount of sewage supplied to different crops needs careful attention to be worked out.

The land area required for a wastewater irrigation system depends on many factors related to the characteristics of the soil, climate, wastewater, and crop and should be evaluated using site specific information. The application rate of water, organics, nutrients, potentially toxic elements, and salts significantly affect the required land area. When evaluating the required land area, the land area for each potentially limiting parameter should be determined. That parameter which requires the largest land area to avoid environmental problems becomes the limiting parameter. This "limiting parameter principle" states that the design land area shall be no less than that allowed by the limiting environmental parameter. In most land treatment systems treating municipal wastewaters, nitrogen is the controlling design parameter (100, 101).

A number of examples can be quoted to demonstrate the use of municipal sewage for land disposal and crop production (47,80,112,182).

4. DESIGN OF TREATMENT SYSTEMS AND EFFICIENCY

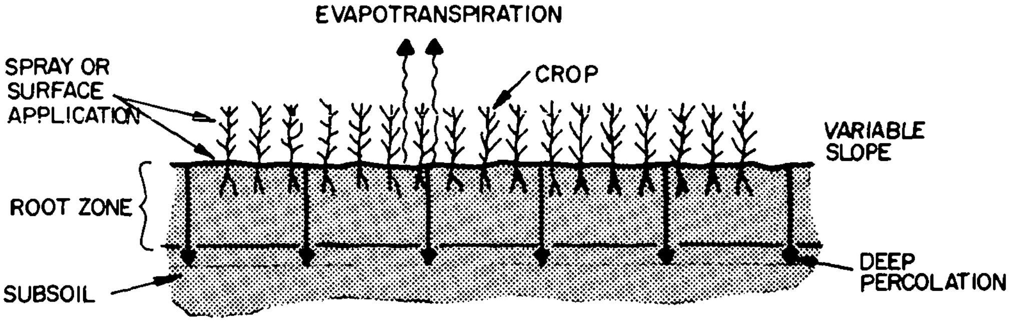
Literature available on design aspects of land treatment systems is so extensive (51,52,101,102,197,206) that designing an effective and efficient system no longer poses any problem. Land treatment of municipal wastewater encompasses three principle processes and they are slow rate, rapid infiltration, and overland flow. The other processes which are less adaptable to large scale use are wetlands and subsurface (197).

A comparison of the design features for the principle land treatment processes are given in Table 3. Figure 1 (140) illustrates the different methods of land application systems. The expected quality of treated water from the principal land treatment processes and their typical design removal efficiencies are shown in Table 4.

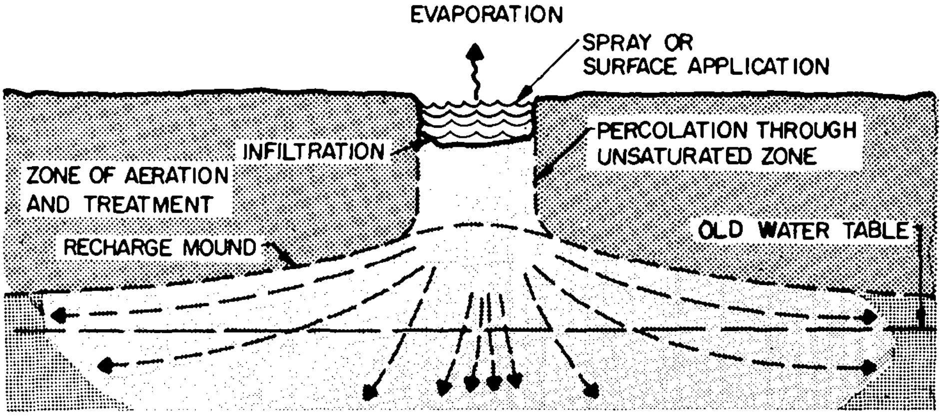
4.1 Slow Rate Process (or) Irrigation.

The slow rate process of application of effluent for land treatment is for meeting the growth needs of the plants. Treatment is essentially by physical, chemical and biological means as the wastewater seeps into the soil (51). Viraraghavan (202) also reported the same mechanisms with reference to septic tank effluent treatment. According to Fogg (58), soils treat the wastewater by filtration, oxidation or reduction, cation exchange and adsorption. Plants also aid in sewage renovation by nutrient uptake. Most quality improvement of wastewater in the percolation process occurs in the first few feet (5-10 ft.) of the soil (14). Effluent can be applied to crops or vegetation (including forest land) by sprinkling, or surface techniques consisting of ridge-and-furrow and border strip flooding (51,197) to prevent surface discharge of nutrients, get economic return from use of water and nutrients by producing marketable crops, conserve water by exchange when lawns, parks, or golf-courses are irrigated, and to preserve and enlarge greenbelts and open spaces. Sewage is applied to land by surface, subsurface and overhead methods (178).

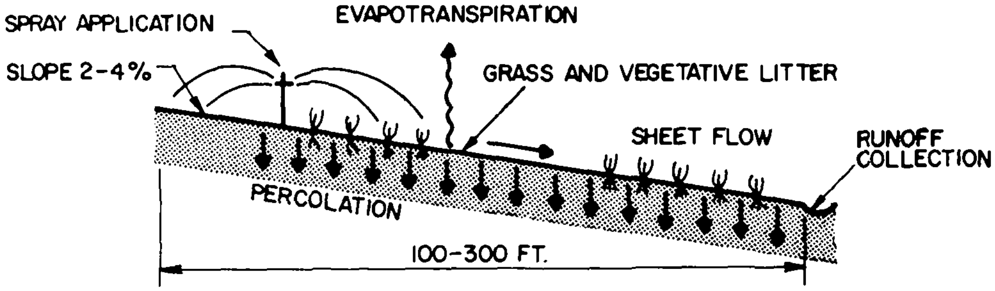
Crops can be irrigated at consumptive use rates (1 to 3 in./wk, depending on the crop) when water is scarce, and hydraulic loadings can be maximised (provided that renovated water quality criteria are met) when water is in abundance. Hydraulic loading also varies depending on the soil type (88). Sepp (166) reported that the total water balance during irrigation includes precipitation, effluent applied, water lost through evapotranspiration and deep percolation, and water retained in soil pores. According to Walcott and Cook (203), the total application



(A) IRRIGATION



(B) INFILTRATION PERCOLATION



(C) OVERLAND FLOW

Figure 1. Methods of Land Application (151)

Table 3. Comparison of Design Features for Land Treatment Processes.

Feature	Principal processes						Other processes			
	Slow rate	Ref.	Rapid infiltration	Ref.	Overland flow	Ref.	Wetlands	Ref.	Subsurface	Ref.
Application techniques	Sprinkler or Surface[a]	36 197 183	Usually surface	36 197 183	Sprinkler or surface	36 197 183	Sprinkler or surface	183 197	Subsurface piping	183 197
Annual application rate	2 – 20 ft. 2 – 20 " 0.6 – 6 m. 2 – 8 ft.	197 36 183 83	20 – 560 ft. 20 – 500 ft. 6 – 170 m. 18 – 500 ft.	197 36 183 83	10 – 70 ft. 10 – 50 ft. 3 – 21 m. 8 – 24 ft.	197 36 183 83	4 – 100 ft. – 1.2 – 30 m. –	197 183	8 – 8 7 ft. – 2.4 – 26 m. –	197 183
Typical weekly application rate	0.5 – 4 in. 1 – 5 in. 1.3 – 10 cm	197 36 183	4 – 120 in. 5 – 120 in. 10 – 305 cm	197 36 183	2.5 – 6[b] 6 – 16[c] 2 – 10 in. 6.3 – 7.5[d] cm 7.5 – 40.6[e] cm.	197 36 183	1 – 25 – 2.5 – 63 cm	197 183	2 – 20 – 5 – 50 cm	197 183
Field area required[f]	56 – 560 acres 56 – 560 acres 23 – 224 ha 140 – 560 acres	197 36 183 83	2 – 56 acres 2 – 56 acres 0.8 – 22 ha 2 – 62 acres	197 36 183 83	16 – 110 acres 22 – 110 acres 6.4 – 44 ha 46 – 140 acres	197 36 183 83	11 – 250 acres – 4.4 – 112 ha –	197 183	13 – 140 acres – 5.2 – 56 ha –	197 183
Minimum preapplication treatment provided in U.S.	Primary sedimentation[g]	197 183	Primary sedimentation	197 183	Screening and grit removal	197 183	Primary Sedimentation	197 183	Primary sedimentation	197 183
Disposition of applied waste water.	Evapotranspiration and percolation *Evapotranspiration* and deep percolation for groundwater recharge, discharge into surface waters, or recovery and reuse. Run-off controlled.	197 36 183 83	Mainly percolation *Deep percolation* maximised for groundwater recharge, recovery and reuse. Run-off not allowed. Negligible evapotranspiration.	197 36 183 83	Surface run-off and evapotranspiration with same percolation. Run-off maximised for recovery and reuse. Relatively little evapotranspiration or deep percolation.	197 36 183 83	Evapotranspiration percolation and run-off –	197 183	Percolation with same evapotranspiration. –	197 183
Need for Vegetation	Required Yes	183 197 36	Optional No	183 197 36	Required Yes	183 197 36	Required –	183 197	Optional –	183 197

Table 3. Comparison of Design Features for Land Treatment Processes. (Contd.)

Slope	Less than 20% on cultivated land, less than 40% on non-cultivated land.	197 183	Not critical; excessive slopes require much earth work.	197 183	Finish slopes 2 – 8%	197 183	Usually less than 5%	197 183	Not critical	197 183
	Cultivated crops : 0 – 6%. Forages and forest species : 0 – 15%	83	Less than 2%	83	2 – 6%	83	–		–	
Soil permeability	Moderately slow to moderately rapid	183 197	Rapid (sands, loamy sands)	183 197	Slow (clays, silts, and soils with impermeable barriers).	183 197	Slow to moderate	183	Slow to rapid	183
	Moderately slow to moderately rapid.	36	Rapid (sands, and sandy loams)	36	Slow (clays and clay loams)	36	–		–	
	Moderately permeable loamy sands to clay loams.	83	Rapidly permeable sandy loams to sands.	83	Slowly permeable silt loams to clay.	83	–		–	
Depth to groundwater	2 – 3 ft. (minimum)	197	10 ft. (lesser depths are acceptable where underdrainage is provided).	197	Not critical	197 183	Not critical	197 183	Not critical	197 183
	60 – 90 cm. (minimum)	183	3 m (10 ft.) (lesser depths are acceptable where underdrainage is provided).	183	–		–		–	
Climatic restrictions	Storage often needed for cold weather and precipitation.	197 183	None (possibly modify operation in cold weather).	197 183	Storage often needed for cold weather.	197 183	Storage may be needed for cold weather.	197 183	None	197 183

a. Includes ridge-and-furrow and border strip.
b. Range for application of screened wastewater.
c. Range for application of lagoon and secondary effluent.
d. Range for application of screened wastewater.
e. Range for application of lagoon and secondary effluent.
f. Field area not including buffer area, roads, or ditches for 1 Mgal/d (43.8 L/s) flow.
g. Depends on the use of the effluent and the type of crop.

1 ft. = 0.305 m.
1 in. = 2.54 cm.
1 acre = 0.405 ha.

Table 4 Typical Design Efficiencies and Effluent Qualities of Land Treatment Systems.

Constituent	Slow rate (or) Irrigation				Rapid infiltration				Overland flow			
	Design Removal Efficiency (%)	Ref.	Effluent Quality[a] (mg/l)	Ref.	Design Removal Efficiency (%)	Ref.	Effluent Quality[b] (mg/l)	Ref.	Design Removal Efficiency (%)	Ref.	Effluent Quality[c] (mg/l)	Ref.
BOD	90 – 99	83	< 2	197	90 – 99	83	2	197	90 – 99	83	10	197
	98 +	183	4	101	85 – 99	183	30	101	92	183	18	101
	98 +	101	1 – 2	51	85 – 99	101	2 – 5	51	92	101	5 – 10	51
				36				36				36
Suspended solids	90 – 99	83	< 1	197	90 – 99	83	2	197	90 – 99	83	10	197
	98 +	183	5	101	85 – 99	183	5	101	92	183	18	101
	98 +	101	1 – 2	51	98 +	101	1 – 2	51	92 +	101	8 – 10	51
				36				36				36
Ammonia nitrogen as N	–		0.5	197	–		0.5	197	–		0.8	197
			0.5 – 1	51			0.5 – 1	51			0.5 – 1	51
				36				36				36
Total nitrogen as N	80 – 100	83	3	197	0 – 80	83	10	197	70 – 90	83	3	197
	(may exceed 100)		6	101	0 – 50	183	15 – 30	101	70 – 90	183	3 – 9	101
	85 +	183	2 – 4	51	0 – 50	101	10 – 15	51	70 – 90	101	2 – 5	51
	85 +	101		36				36				36
Total phosphorus as P	95 – 100	83	< 0.1	197	70 – 95	83	1	197	50 – 60	83	4	197
	(may exceed 100)		2	101	60 – 95	183	4	101	40 – 80	183	2 – 7	101
	80 – 99	183	0.1 – 0.5	51	60 – 95	101	1 – 3	51	40 – 80	101	3 – 5	51
	80 – 99 +	101		36				36				36

a. Percolation of primary or secondary effluent through 5ft (1.5 m) of soil.

b. Percolation of primary or secondary effluent through 15ft (4.5 m) of soil.

c. Runoff of comminuted municipal wastewater over about 150 ft (45 m) of slope.

should not exceed 1.5 to 2 inches in a 24-hour period to avoid excessively rapid transit through the soil.

The quality of water required for irrigation has been well outlined by many authors (5,51,134,178). The important criteria in judging the suitability of irrigation water are (178) the sodium adsorption ratio (SAR), total concentrations of dissolved constituents, and concentrations of bicarbonate, boron and other toxic substances. In the United States, most state agencies require secondary treatment of wastewater, although primary treated sewage as well as raw sewage is applied to the land in many other countries (146). Among the land application systems, the irrigation process has the highest potential for removal of most pollutants, involves the largest area and widest dispersal of pollutants, and thereby has the minimum impact on the soil and vegetation (52).

4.2 Overland Flow.

Overland flow is essentially a biological treatment process in which wastewater is applied over the upper reaches of sloped terraces and allowed to flow across the vegetated surface to run off collection ditches (51). This grass filtration system has the following advantages (22): (i) it requires less extensive wastewater piping systems and less land area than spray irrigation systems, (ii) savings in terms of wastewater application equipment and land, (iii) land with low infiltration capacities can be used, and (iv) the treated water remains on the soil surface, facilitating sampling and monitoring of treatment effectiveness, and the treated effluent is readily available for recycling or reuse.

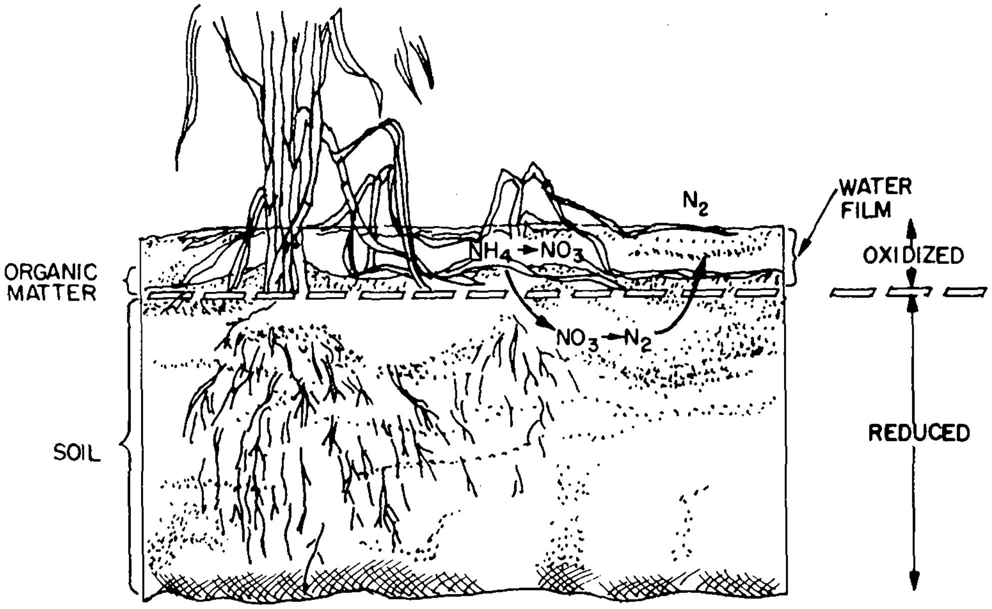


Fig.2 A Schematic Diagram of Conditions that would allow both Aerobic and Anaerobic Processes to occur in an Overland Flow System. (70)

Table 5. Literature Data Summary for Overland Flow System Efficiency (125)

Input to OLF System	Reference	Length of OLF System m	Application Rate cm/wk	Effluent															Total Coliform	Fecal Coliform
				H_2O	BOD_5	COD	TSS	TN	NH_3–N	O–N	NO_3–N	TP	TS	TVS	Na	A1	Ca	C1		
				Percent reduction, with effluent concentration from OLF system, mg/l, in parenthesis																
Raw or minimally treated domestic waste	84	365	13 (cool period)	–	96 (25)	–	95 (25)	45	–	–	–	35	–	–	–	–	–	–	–	–
	194	36	7.4 – 9.8 (warm per.)	50	93 (11)	77 (73)	95 (8)	89 (2.6)	94 (1)	86 (0.8)	– (0.4)	60 (4)	20 (826)	53 (140)	–	–	–	–	–	–
		36	7.4 – 9.8 (cool per.)	50	92 (12)	83 (53)	92 (12)	77 (5.4)	97 (0.5)	67 (1.9)	– (2.8)	56 (4.4)	31 (720)	42 (170)	–	–	–	–	–	–
	192	36	9.8 (alum addition)	50	96 (7)	86 (41)	93 (16)	88 (2.6)	94 (0.8)	86 (1.2)	– (0.6)	84 (1.6)	27 (810)	61 (120)	–	60 (0.28)	–	–	97.3 (0.2 X 10)	97.5 (0.025 X 10)
		36	9.8 (no alum addition)	50	94 (9)	84 (54)	93 (16)	86 (2.9)	95 (0.8)	82 (1.6)	– (0.5)	62 (3.7)	31 (770)	62 (120)	–	80 (0.15)	–	–	95.9 (0.3 X 10)	91 (0.09 x 10)
Secondary treated domestic waste	98	62	330 (warm period)	–	62 (12)	–	75 (8)	–	0 (16)	–	– (0.2)	–	–	–	–	–	–	–	–	–
	205	39	400	–	59 (9.7)	–	73 (15)	–	20 (8.4)	–	10 (21.9)	–	–	–	–	–	–	–	–	–
	115 a	46	6 – 25 (based on area of first terrace)	45–55	(0.5-7)	–	–	15 (15)	0 (12)	–	10 (5 – 6)	15 (5)	–	–	0 (21)	–	0 (38)	0	–	–
	23	6	5	–	0 (15)	–	–	–	100 (0)	45 (2.2)	99 (0.1)	40 (8)	–	–	–	–	–	–	–	–

In overland flow, renovation is accomplished by physical, chemical and biological means as the sewage flows in a thin sheet down the relatively impervious slope (51) of up to 8% (70). This is particularly suited to high nitrogen removal. The conditions that would allow both aerobic and anaerobic processes to occur in an overland flow system is illustrated in Fig. 2 (70). Overland flow is also used as a secondary treatment process where discharge of a nitrified effluent low in BOD is acceptable or as an advanced wastewater treatment process for the effective removal of BOD and nitrogen. The latter objective allows higher rates of application (5 in./wk or more), depending on the degree of treatment required (51). Thomas (192) reported loading rates of upto 9.8 cm/wk and Hunt, Lee and Peters (71) reported application rates of upto 0.5 in. (1.27 cm)/day with application periods of 6-8 hours. The efficiency of treatment in overland flow systems has been well documented by Overcash (125) and is set out in Table 5. Since it provides only limited removal of phosphorus and heavy metals, overland flow can achieve an ultra-high level of treatment only with chemical aids such as lime or alum (52).

Erosion must be kept to a minimum if the overland flow system is to work effectively. To prevent erosive flows, spaces between terraces should be according to the Universal Soil Loss Equation. Spaces of 100-300 feet between terraces are effective for renovating wastewater in overland flows (102). Secondary pretreatment is generally best, although other levels can also be used.

4.3 Rapid Infiltration (or) Infiltration Percolation.

Rapid infiltration is a system in which most of the applied wastewater percolates through the soil and the treated effluent eventually reaches the groundwater. Rapidly permeable soils, such as sands and loamy sands are used. The method of application is by spreading in basins or by sprinkling, and the sewage is treated as it travels through the soil matrix. Vegetation may or may not be used (197). The advantages of this system are (51): (i) groundwater recharge, (ii) natural treatment followed by pumped withdrawal or underdrains for recovery, (iii) natural treatment with renovated water moving vertically and laterally in the soil and recharging a surface water course, and (iv) minimum land area required.

The infiltration-percolation process has the lowest potential for removal of soluble pollutants (52). However, favorable results have been reported by Bouwer, Lance and Riggs (17) in the Flushing Meadows Project at Phoenix, Arizona (USA). Essentially complete removal of suspended solids and BOD was achieved when secondary sewage was treated in sandy and gravelly beds. Most fecal bacteria were removed in the first 2 ft. (0.69m) of the soil and none were encountered after 300 ft. of horizontal travel of the renovated water (17). In the same place, one acre (0.4047 ha) of basin area was found to be capable of receiving 1350 cu.m./day of effluent and a mature stand of grass could receive higher infiltration rates than bare soil (18). Application rates in high rate systems are of the order of 1.6 to 33 ft. (0.5 to 10 m) per week, depending on the soil, climate, and the wastewater characteristics (16). According to Crites (160), hydraulic loading rates can range from 18 to 500 ft. (6.21 to 172.5 m)/yr or 4 to 120 in. (10.16 to 304.8 cm)/wk.

Numerous laboratory experiments have been carried out simulating high-rate effluent renovation (76,94) to trace the mechanisms of removal of important nutrients. The influence of differing soil properties and the effect of continuous utilization of phosphorus removal has been described vividly by John (76). Lance (94) reported that phosphate removal from secondary sewage effluent by calcareous sand columns was proportional to the infiltration rate. He also reported that Bermudagrass (*Cynodon dactylon*) greatly increased PO4-P concentrations in column effluent samples. Primary or secondary pretreatment has been used for rapid-infiltration systems (146). Secondary treatment allows higher rates and longer inundation periods.

4.4 Combined Waste Treatment and Land Application.

There are many instances where waste treatment has been combined with recycling and utilization of sewage for agricultural irrigation. This is, in other words, a kind of pretreatment and utilization in beneficial irrigation (107). In the Dan Region Project in Israel, chemical treatment in the form of high lime magnesium process is applied to municipal wastewater, and polishing ponds are used for detention. The process removes phosphorus, ammonia and total nitrogen, organics, trace elements including boron and fluorides, bacteria and viruses from oxidation pond effluent. The resulting groundwater is good for unrestricted crop irrigation (72). Applegate and Gray (2) have described a system for treatment of combined sewage and industrial wastewaters. It comprises of an extended aeration activated sludge treatment of sewage and pH adjustment of the industrial wastes; the combined effluents are directed to an aerated lake. They are then sprayed over a 10-acre field containing a network of subsurface drainage pipes.

4.5 Literature : A Panacea for Design.

Literature available on design aspects of land treatment systems is so vast that it merely requires a few moments spent in perusing them to solve any kind of problem. Enfield (48) has described a preliminary graphical procedure illustrating P-reactions with soil and has adapted it to develop a design approach for evaluating phosphorus removal by a land application system. Sopper and Kerr (186) have used sewage for groundwater recharge by irrigating several forest ecosystems. They have used application rates of 2.0 to 7.5 cm/wk. Loehr (99) and Loehr et al. (102) have presented design criteria for land application of sewage. Irrigation is the most popular land treatment system and hence it has received the widest attention in design aspects (66,97,138,149). Kutera (92) has designed a year-round system for spreading and/or irrigation of household wastewaters from small rural communities. He has also discussed ice formation, winter irrigation and types and kinds of soils. Heukelekian (68) has given the irrigation application rates and types of primary and secondary treatments for Israel. Similarly, design aspects for Hawaii have been outlined by Dugan et al. (45). Sewage farming has been practiced from time immemorial in India and numerous literature is available on the design features adopted in India (13,27,34).

4.6 Wastewater Storage.

Whatever may be the process of land treatment, the possible need for storage of the wastewater during inclement weather cannot be overlooked in designing such systems. Disposal of wastewater on land in cold climates may not be practised continuously because of cold weather operating problems and/or because crop uptake for nitrogen is minimal in the winter and hence storage of the wastewater during such periods is desirable. In addition, storage will be necessary when natural precipitation prevents application of the wastewater. In such cases where wastewater is stored in lagoons or ponds, there is the added advantage of intermediate treatment of the wastewater through biological action, solids deposition and pathogen reduction (100,101,102).

As previously quoted, vegetation plays a significant role in the treatment process of slow rate systems and, to a lesser extent, in the case of the other systems. It is interesting to delve a little more into this aspect.

5. VEGETATION ASPECTS

5.1 Role of Vegetative Cover.

The roles of vegetation in wastewater treatment are the following (197) :

(a) As a nutrient extractor, vegetation concentrates nitrogen and phosphorus above the ground and thus makes these nutrients available for removal through harvest.

(b) Plants effectively reduce erosion by reducing surface run-off velocity. The extension of root growth maintains and increases soil permeability and the leaf shelter protects the soil against the compacting effect of falling water.

(c) For overland flow and wetlands, the vegetation, in addition to taking up nutrients, provides a matrix for the growth of microorganisms that decompose the organic matter in the wastewater.

5.2 Crop Selection.

Selection of crops should be based on rate of water uptake, rate of nitrogen and phosphorus uptake, tolerance to potentially harmfull wastewater constituents, ease of cultivation, production of a marketable crop and minimum net cost of production after deducting the current market value of the crop (197).

5.3 Crop Response.

The typical nutrient uptake rates for different crops are set out in Table 6. The prominent nutrients in wastewater as seen earlier are nitrogen, phosphorus and potassium. Since the major nutrients essential to plant growth are nitrogen, phosphorus, potassium, calcium, magnesium and sulfur, they effectively remove these elements from sewage when it is applied for irrigation (165).

Research conducted in different parts of the world has revealed the uptake pattern of nutrients and physiological characteristics of crops grown on sewage. In Tucson, Arizona (USA), significant changes were observed in the growth, fibre, acid-soluble nucleotides, protein and amino-acid content in grain from wheat by using treated municipal wastewater (41). Sopper (182) has reported annual yield increases of 0-350% for corn grain, 5-130% for corn silage, 85-190% for red clover and 79-140% for alfalfa at weekly loadings of 5 cm. High nutrient uptake has also been reported. Experiments conducted at the National Environmental Engineering Research Institute (NEERI), India, have shown that balanced growth and maximum crop yield of wheat is obtained by dilution of sewage with water at 1:0.5 and 1:1 ratios (167). Southern Arizona experiments conducted by Day et al. (40) indicated that barley irrigated with 50:50 mixture of pump water and municipal wastewater was superior in growth, grain yield and grain quality.

Similarly, trees have also shown increased diameter and biomass production when sewage is applied to forest lands (182,184,185). In Southern Michigan, irrigated red pine showed increases in length and dry weight of needles by as much as 36 and 56% (191). The array of crops suiting different conditions in sewage farms have been well established (12,34,161).

The contribution of Overman (126,127) and Overman in combination with Nguy (131), Ku (130) and Evans (129), in assessing the response of forage and other grain crops to irrigation with secondary domestic effluent in the Southwest Wastewater Treatment Plant in Tallahassee, Florida (USA), is monumental. The soil used in these experiments was lakeland fine sand and application rates ranged from 1-8 in. (2.54-20.32 cm)/wk. In general, it was found that the yields and forage quality were comparable to those obtained in standard fertility trials. While the yields, nutrient uptake (N,P,K) of pearl millet, sorghum x sudangrass and kenaf, coastal bermuda grass, rye and ryegrass, all increased with irrigation, the recovery efficiency and, in some cases, the dry matter content decreased with irrigation rate. Potassium deficiency was noticed in some cases. In an experiment with split application of sewage at different frequencies with sorghum x sudangrass, corn silage and corn grain (128), it was found that both yields and

Table 6. Nutrient Uptake Rates for Selected Crops.

Crops	Uptake, kg/ha. yr**									
	Nitrogen	Ref.	Phosphorus	Ref.	Potassium	Ref.	Calcium	Ref.	Magnesium	Ref.
Barley	70.6	197	17	197	22	197				
	168	181	27	181	140	181				
Corn	174 - 193	197	19 - 28	197	108	197				
	207 - 269	181	39 - 49	181	199 - 223	181				
	140*	203	25*	203	31*	203	3*	203	11*	203
Cotton	74 - 112	197	13	197	38	197				
Potatoes	230	197	22	197	246 - 323	197				
Soybeans[a]	105 - 143	197	12 - 20	197	33 - 54	197				
	288	181	24	181	112	181				
	134	203	13	203	40	203	6	203	7	203
Wheat	56 - 91	197	17	197	20 - 47	197				
	140	181	25	181	102	181				
	81*	203	15*	203	16*	203	2*	203	5	203
Grain Sorghum	280	181	45	181	186	181				
Oats	168	181	27	181	140	181				
Alfalfa[a]	224 - 538	197	22 - 34	197	174 - 224	197				
	504	181	39	181	446	181				
Bromegrass	130 - 224	197	39 - 56	197	246	197				
	186	181	33	181	236	181				
Coastal Bermuda Grass	392 - 672	197	34 - 45	197	224	197				
Kentucky Blue Grass	202 - 269	197	45	197	202	197				
	224	181	27	181	167	181				
Quackgrass	235 - 280	197	30 - 46	197	274	197				
Reed Canary Grass	336 - 448	197	40 - 45	197	314	197				
	457	203	63	203	277	203	49	203	45	203
Ryegrass	202 - 280	197	62 - 84	197	269 - 332	197				
Sweet Clover[a]	177	197	18	197	101	197				
Tall Fescue	151 - 325	197	29	197	299	197				
	151	181	33	181	173	181				
Orchardgrass	336	181	49	181	348	181				
Hardwood Forest	94	203	9	203	29	203	25	203	6	203

* Grain

[a] Also takes N from atmosphere.

** Converted from original in lb/ac. yr. (1 lb/ac. yr = 1.12 kg/ha yr) nutrient uptake were comparable for single and split applications below 4 in. (10.16 cm)/wk.

Quin (142) reported that harvested plots of reed canarygrass surface-irrigated at 3 weekly intervals over 12 months with treated sewage effluent produced similar dry matter yields, and removed similar quantities of nutrients, as plots of ryegrass-white clover. The reed canarygrass maintained low NH3-N levels (3 mg/l) in the drainage water due to a continuing uptake of N by the plants rhizome system. The persistence and yields of dry matter and feed nutrients of seven cool season perennial grasses and alfalfa irrigated with municipal effluent, when they were harvested at each of three cutting schedules has been reported by Marten et al. (108).

Some plants are sensitive to salinity, excess acidity, or excess concentrations of any of a large number of micronutrients and they have specific tolerance limits. These have been well documented (102,197) and the choice of crop, hydraulic loading and management should be based on this.

6. SOIL ASPECTS

6.1 Importance of Soil for Land Treatment.

Soil properties are an important factor in identifying and selecting sites for an economical land application system and in the choice of such a system (52). The important physical and hydraulic properties of the soil that decide the choice of the land treatment system are given in Table 7.

Table 7. Interpretation of Soil Physical and Hydraulic Properties (197).

Depth of soil profile, ft	
<1-2	Suitable for OF (a)
>2-5	Suitable for SR and OF
5-10	Suitable for all processes
Texture and structure	
Fine texture, poor structure	Suitable for OF
Fine texture, well-structured	Suitable for SR and possibly OF
Coarse texture, well-structured	Suitable for SR and RI
Infiltration rate, in./h	
0.2-6	Suitable for SR
>0.2	Suitable for RI
<0.2	Suitable for OF
Subsurface permeability	
Exceeds or equals infiltration rate	Infiltration rate limiting
Less than infiltration rate	May limit application rate

a. Suitable soil depth must be available for shaping of overland flow slopes. Slow rate process using a grass crop may also be suitable.
1 ft = 0.305 m
1 in. = 2.54 cm

The chemical properties of the soil are important for assessing (i) potential treatment efficiency for infiltration systems, (ii) need for soil ammendments, and (iii) baseline levels of any constituents expected to accumulate in the profile and cause long-term problems (197). Thus soil monitoring programs are necessary to detect the changes in the soil properties with special reference to salinity, levels of various elements, pH and cation exchange capacity. Soil pH affects both chemical and biological treatment mechanisms. The optimum soil pH for retention of many sewage constituents is the neutral range (51). The chemical properties of the soil that affect the crop are shown in Table 8.

Land application systems are generally related to the vertical water transmission of the soil; rapid infiltration for high transmission irrigation or slow rate for moderate transmission, and overland flow for low transmission of the applied water (101). In wastewater application on land, soil clogging is an important phenomenon which acts as a constraint on the quality and quantity of wastewater that can be treated in a particular facility. The factors that cause clogging can be physical, chemical or biological or combinations of these (201). High rate systems are generally saturated flow systems in which water flow is described by the Darcy equation. In low rate irrigation systems water flow is as unsaturated flow. Serious pollution problems may arise if water application rates exceed the soil infiltration rate except on level areas where runoff will not occur (160).

6.2 Effect of Land Treatment on Soil Physical and Hydraulic Properties.

Many experiments have been conducted to determine the effect of municipal wastewater on soil physical properties. Sopper and Richendeferder (187) used two soil types and six vegetative cover types to determine the effect of sewage spray irrigation on the infiltration and percolation capacities of the soil. It was found that spray irrigation did produce significant changes in the infiltration capacity, percolation, capillary and non-capillary porosity, soil aggregate water stability and root masses depending on the vegetation and soil type. There were no changes in the bulk density.

Klausner and Kardos (85) found that application of 5.1 cm of sewage effluent at weekly intervals did not degrade the aeration status of the soil. The average gaseous oxygen concentrations to a depth of 46 cm ranged from 19.6-19.8 to 8.4% as weekly application of effluent changed from 0 to 2.5 to 5.1 cm. Gaseous oxygen concentrations was not affected by crop cover (corn or hay), but oxygen diffusion rate was less under hay than under corn. In the case of rapid infiltration basins in Phoenix, Arizona, it was found that one acre of basin area could receive upto 1350 cu.m./day of sewage effluent without degrading the soil, and that a stand of grass could take higher infiltration rates than bare soil (18).

6.3 Effect of Land Treatment on Soil Chemical Properties.

Sopper (182) has reported significant changes in the soil concentrations of calcium, magnesium, sodium, manganese, boron and phosphorus by using municipal wastewater for groundwater recharge. A column study to determine the passage of sodium, calcium, magnesium, chloride and sulfate ions through the A,B and C horizons of a loamy sand and the A horizon of a clay has revealed that neither temperature (7, 12 or 18 C degrees) nor method of application (flood or trickle irrigation) affects the passage (43). There are reports to show that the soil pH is not affected by treatment with municipal wastewater (40). The process of mineralization and decomposition of organic matter in soil has also been extensively studied (150,198).

There are reports to prove that waste can be utilized for soil improvement. A sand dune in San Francisco, California was successfully developed into the Golden Gate State Park by a long-term irrigation with raw sewage (135).

7. PATHOGENIC IMPLICATIONS

From strictly a technological view point, we can design land disposal systems of many types but the overiding question is, what quality of wastewater should be applied to the land ? (77) The concern about the use of primary and secondary

Table 8. Interpretation of Soil Chemical Tests (197).

Test Result	Interpretation
pH of saturated soil paste	
<4.2	Too acid for most crops to do well
4.2 - 5.5	Suitable for acid-tolerant crops
5.5 - 8.4	Suitable for most crops
>8.4	Too alkaline for most crops, indicates a possible sodium problem
CEC, meq/100 g	
1 - 10	Sandy soils (limited adsorption)
12 - 20	Silt loam (moderate adsorption)
> 20	Clay and organic soils (high adsorption)
Exchangeable cations, % of CEC (desirable range)	
Sodium	= or<5
Calcium	60 - 70
Potassium	5 - 10
ESP, % of CEC	
<5	Satisfactory
>10	Reduced permeability in fine-textured soils
>20	Reduced permeability in coarse-textured soils
ECe,mmhos/cm at 25 degrees of saturation extract	
<2	No salinity problems
2 - 4	Restricts growth of very salt-sensitive crops
4 - 8	Restricts growth of many crops
8 - 16	Restricts growth of all but salt-tolerant crops
>16	Only a few very salt-tolerant crops make satisfactory yields

sewage for land disposal has become widespread and a number of scientists all over the world have attempted to prove or disprove the so-called hazards of land treatment of sewage (160,175,214).

The use of human excreta or night soil for crop fertilization has been widely practiced for years in many regions of the world. From pre-biblical times, the Chinese farmer has practiced the conservation of all human wastes for use as fertilizer. Since their methods were non-hygienic, it must have cost a lot in terms of ill health and loss of human life. Recently, educational campaigns have reduced the spread of intestinal diseases due to this practice. Although the improvement in soil productivity is of vital importance, the health risks caused by disease transmission to farm workers or to consumers of vegetable crops eaten raw must be carefully considered before any land treatment venture can be initiated (111,164,174).

7.1 Hazards Associated with Pathogens in Sewage and Sludge.

The risks involved in the reuse of municipal effluents for agricultural purpose has been well recorded (217). Hazards associated with different methods of land application, viz, irrigation, high rate systems and overland flow systems have been put forward by Lance (93). According to him, irrigation systems may lead to contamination of the crop grown, hazards due to aerosols, groundwater contamination in coarse sandy soils, health risk to farm workers and livestock; high rate systems present danger of groundwater contamination; and overland flow systems may not remove pathogens from the sewage.

Numerous hazards have been associated with sprinkler irrigation. According to Katzenelson et al. (81), the incidence of shigellosis, salmonellosis, typhoid fever and infections hepatitis was 2-4 times higher in Israeli communities practicing spray irrigation of partially treated nondisinfected oxidation pond effluent. In USSR, it has been found that sprinkling of sewage produces bacterial contamination of the air, its degree depending upon the wind velocity, and a sanitary zone of at least 1000 m has been recommended around sewage farms (170). Coliform bacteria has been found in the air at 350 m downwind from the irrigation line in Israel (82).

Virus hazard has also been associated with sprinkler irrigation. It has been demonstrated that poliovirus 1 persists on vegetable surfaces for as long as 36 days, indicating potential contamination of vegetables when spray irrigation systems are used (95). Aerosols also pose problems of viral contamination (117). Land disposal of sewage may cause hazardous buildup of pathogenic viruses in soil and in groundwater. It has been reported that spray irrigation of secondary wastewater on sandy soils produced a burst of virus in groundwater at 10 and 20 ft. (3.48 and 6.96 m) depths (210) and can survive in the soil for at least 28 days. Secondary wastewater treatment processes, including chlorination, do not provide a virus-free effluent (209). Groundwater contamination of virus in organic soils has been attributed to the interfering effect of water-soluble "humic substances" (163). Virus, added to secondary effluents before land application, has been recovered from crops grown and from the soil. In the soil, virus was found upto 100 days after application in winter, although reduced by a factor of about 10,000. Summer survival was for about 10 days (216).

There are many reports showing evidence of plant and human diseases that have resulted from sewage disposal on land. In India, the incidence and multiplication of infection has been found to be high in sewage farm workers (27,91,161). Typhoid fever, infectious hepatitis, fascioliasis and cholera have been transmitted by foods contaminated by sewage (21). Although no disease outbreak has been traced to irrigation with properly treated and disinfected sewage, many epidemics have been caused by irrigation with improperly treated wastes. The survival times of various pathogenic organisms in soils, plants and waters are given in Table 9.

7.2 Treatment and Corrective Measures.

Research has been done to find effective solutions to the problem of pathogenic contamination and water quality standards have been drawn up (28). Pathogen removal by soil under various land treatment systems has been studied. Grunnet and Olesen (63) reported that indicator bacteria and phages are completely removed after infiltration and percolation through 20m of sand. Bouwer et al. (17) reported that fecal bacteria were removed in the first 2 ft. (0.6 m) of the soil and none were encountered after 300 ft (91 m) of horizontal travel of secondary sewage effluent using high rate system. It has been shown that drip irrigation under plastic sheet cover with the drip lines placed either on the soil surface or buried at a depth of 10 cm significantly reduces bacterial and viral crop contamination (158).

Chlorine has been found to be a good disinfectant for sewage at a safe application dose of 15 mg/l for a 2-h contact time (90), or a dose of 10-20 mg/l for a contact time of 1 h to achieve coliform counts of about 100 per 100 ml (172). As much as 10 times the amount of chlorine dose is required to accomplish an equivalent degree of inactivation of poliovirus.

Table 9. Survival Times of Pathogenic Microorganisms in Various Media (46)

Organism	Medium	Type of Application	Survival Time	Reference
Ascaris ova	soil	*not stated*	*2.5 years*	64
	soil	sewage	up to 7 years	120
	plants & fruits	AC*	1 month	155
Cholera vibrios	spinach, lettuce	AC	22 – 29 days	137
	cucumbers	AC	7 days	137
	non-acid vegetables	AC	2 days	137
	onions, garlic, oranges, lemons, lentils, grapes rice & dates	infected feces	hours to 3 days	169
Endamoeba histolytica cysts	river water	AC	8 – 40 days	29
	soil	AC	8 days	9
	tomatoes	AC	18 – 42 hours	154
	lettuce	AC	18 hours	154
Enteroviruses	roots of bean plants	AC	at least 4 days	119
	soil	AC	12 days	122
	tomato & pea roots	AC	4 – 6 days	122
Hookworm larvae	soil	infected feces	6 weeks	5
Leptospira	river water	AC	5 – 6 days	30
	soil	AC	15 – 43 days	180
Salmonella typhi	dates	AC	68 days	179
	harvested fruits	AC	3 days	199
	apples, pears, grapes	AC	24 – 28 hours	124
	strawberries	AC	6 hours	110
	soil	AC	74 hours	57
	soil	AC	70 days	86
	soil	AC	at least 5 days	32
	pea plant stems	AC	14 days	32

*AC = Artificial Contamination

Table 9. Survival Times of Pathogenic Microorganisms in Various Media (Cont'd)

Organism	Medium	Type of Application	Survival Time	Reference
Salmonella typhi	radish plant stems	AC*	4 days	32
	soil	AC	up to 20 days	62
	lettuce & endive	AC	1 – 3 days	62
	soil	AC	2 – 110 days	136
	soil	AC	several months	8
	lettuce	infected feces	18 days	113
	radishes	infected feces	53 days	113
	soil	infected feces	74 days	113
	soil	AC	5 – 19 days	105
	soil	AC	70 – 80 days	104
	cress, lettuce & radishes	AC	3 weeks	218
	lake water	AC	3 – 5 days	156
Salmonella, other than typhi	soil	AC	15 – 70 days	11
	vegetables	AC	2 – 7 weeks	56
	tomatoes	AC	less than 7 days	53
	soil	sprinkled with domestic sewage	40 days	121
	potatoes	"	40 days	121
	carrots	"	10 days	121
	cabbage & gooseberries	"	5 days	121
Shigella	streams	not stated	30 min – 4 days	44
	harvested fruits	AC	minutes – 5 days	199
	market tomatoes	AC	at least 2 days	79
	market apples	AC	at least 6 days	79
	tomatoes	AC	2 – 7 days	153
Tubercle bacilli	soil	AC	6 months	103
	grass	AC	14 – 49 days	103
	sewage	?	3 months	42
	soil	?	6 months	42

*AC = Artificial Contamination

According to Gerba et al. (59), the removal of bacteria from sewage during percolation through soil is accomplished largely at the soil surface by straining, sedimentation, and absorption. Fecal coliforms on alfalfa plants irrigated with sewage lagoon effluent are completely destroyed by exposure to 10 h of bright sunlight (10). According to Baubinas (7), E. Coli and other pathogenic organisms contaminating perennial grasses by overhead irrigation generally die off within 1 week when exposed to direct solar rays. Self purification of diseases has been well explained by Babov et al. (4).According to Pahren et al. (132), bacteria are the most fragile of the pathogens and are greatly reduced in wastewater storage systems and by sunlight, drying, or competition in the soil. Contamination of plant surfaces can occur by direct contact and by rain splashing, but survival is only on the order of a week or two.

It has been found that human viral pathogens do not move through the soil into groundwater but are apparently absorbed and degraded by the soil (60). The survival of enteroviruses on vegetables irrigated with chlorinated oxidation pond effluents has also been studied. A factor has been found in oxidation pond effluents that, affected by solar radiation (over a minimum of 0.35 cal/cm per minute) accelerates the rate of inactivation of viruses on the vegetable surface.

Solar radiation has also been used for dehelminthization of sewage sediments at 60 C degrees for 20 min. with a sediment layer thickness of 25 cm (152). Subsurface irrigation through clay pipes laid at 60-cm depths has been found to be very effective even when unclarified effluent is used since root crops are free of helminth eggs (151). Amirov and Salamov (1) reported that vegetable furrows irrigated with domestic sewage showed no contamination of viable helminth eggs. In India, pretreatment of sewage in waste-stabilization ponds is encouraged for safer irrigation (200) and immersing vegetables (grown in sewage farms) in warm water at 60 C for 10-30 min has been found to be an effective method of decontamination in farms using raw and undiluted sewage.

Extensive research is being done in different parts of the world for safe recycling of municipal sewage (219). There are also opinions that direct reuse of sewage should be limited to industrial and agricultural purposes (173) and that a project to re-use wastewater must meet the strictest criteria in the interests of public welfare (171). But since there is no evidence for disease transmission from the application of treated wastewater to land, and because it is unrealistic to insist upon pathogen free waste, land application of treated sewage can be considered an acceptable risk unless future epidemiological evidence indicates the contrary (188,207,215). According to Wolman (216), application of wastewater to land is a practicable method of wastewater disposal provided, among other things, it is carefully, efficiently and continuously managed, crop production is restricted to those not eaten raw, monitoring is exercised to prevent undue hazard to groundwater or drainage effluent, and pontential hygienic risks are detected and controlled.

8. POTENTIALLY TOXIC ELEMENTS

The sources of potentially toxic elements to sewages are residential, urban and industrial areas. These elements are transferred to sludges during primary and secondary wastewater treatment. When sludges are applied to soil, these elements may be taken up by plants and may be available to animals consuming them. Boron, cadmium, copper, molybdenum and nickel are five elements that may exert potentially toxic effects. Secondary sewage effluents may contain less or more potentially toxic element concentrations than maximum permissible levels set by the U.S Environmental Protection Agency (EPA) for drinking or irrigation water (102), depending on the quantity in the untreated wastewater and the process used as part of a treatment plant. Table 10 lists 18 elements and their maximum contaminant levels in drinking water (196) and irrigation water (49) set by the

EPA. Standards for elements have also been established in the United Kingdom, Israel and other countries (67,109).

8.1 Effect of Sewage Application to Land.

Sidle and Sopper (177) applied treated municipal wastewater with Cd concentrations of 0.47 and 0.61 kg/ha in an old field area and a mixed hardwood area. The foliage sampled showed no increase in Cd as a result of wastewater irrigation. Soil cadmium levels were also not affected except in the 0-5 cm of some areas. Similar results have been reported by Reynolds et al. (149) and Novoderzhkina et al. (123), who have proved that application of treated and raw sewage containing high concentrations of toxic elements to crops do not cause hazard to crop and man.

8.2 Uptake of Toxic Elements from Sewage and Soil Accummulation.

The uptake of toxic elements by vegetation grown on sewage has been a topic of intense research. A study conducted by Sutherland et al. (191) has shown that sewage pond effluent irrigation of hardwood and conifer plantings increases the boron levels in red pine foliage that may lead to toxicity conditions. According to White (212), when sewage or sludge has a heavy metal content, the most useful guide for safe application is based on application rates of five important heavy metals on the maximum amount which can never be applied to soil as given in Table 11.

In addition to heavy metals, biocides and other carcinogens present in sewage also cause hazard to public health. The accumulation, translocation and degradation of biocides such as malathion, carbaryl, diazinon and 2,4-D butoxyethyl ester have been dealt with in great detail by Jenkins et al. (75).

9. PRETREATMENT NEEDS OR STRATEGIES

Loehr (100) has presented a vivid description of the preapplication strategies that may be adopted for wasterwater irrigation systems. Similar strategies can be adopted for other systems. Preapplication approaches that should be used with wastewater irrigation systems are those which reduce risks to the public, the environment and the equipment, and permit the pollutant removal mechanisms in the soil to renovate the wastewater.

There have been philosophical differences regarding the levels of pretreatment that are needed before wastewaters are applied to land. Many people in the developed countries feel that secondary treatment, including possibly chlorination, should be achieved before land application. Experience in developing countries has shown that this need not be so. With wastewater irrigation, the applied wastewater does not have to have a quality equivalent to that which would be permitted for stream discharge. There are numerous examples of slow rate systems treating primary treated municipal sewage and producing percolate water that is virtually free of organics, pathogens, and toxic elements and chemicals. The soil has a capacity to treat contaminants in wastewater and the capacity should be utilised.

The sound design of a well-managed wastewater irrigation system should be based on the limiting parameter principle, as stated before, which is generally cost effective for slow rate systems for the constituents in typical municipal wastewater. This approach reduces the risks of adverse effects due to contaminants in the wastewater. When a wastewater has characteristics that may be detrimental to the equipment, the public health, the soil, or the crops --- such as excessive grit or organic solids, a high SAR or pH, potentially high concentrations of toxic

Table 10. Eighteen Potentially Toxic Elements Identified in Two Sources.

Element	Max. Level in Drinking water (mg/l) (196)	Max. Level for Continous Use Irrigation Water, All Soils (mg/l) (49)
As Arsenic	0.05	0.01
Al Aluminum		5.00
B Boron		0.75
Ba Barium	1.00	
Be Beryllium		0.50
Cd Cadmium	0.01	0.01
Cr Chromium	0.05	0.01
Co Cobalt		0.05
Cu Copper		0.20
Hg Mercury	0.002	
Mn Manganese		0.020
Mo Molybdenum		0.21
Ni Nickel		0.20
Pb Lead	0.05	5.0
Se Selenium		0.02
Ag Silver	0.05	
Zn Zinc		2.0
F Fluorine	varies with mean temp.	

Table 11: Maximum Amounts of Heavy Metals That Can Be Safely Applied to Land (212)

Metal	Soil Cation Exchange Capacity (meq*/100g soil) 0-5	5-15	more than 15
	Max. metal addition, lb/acre		
Zinc	200	500	1000
Copper	125	250	500
Nickel	125	250	500
Cadmium	5	10	20
Lead	500	1000	2000

*Milli-equivalents

compounds, or high numbers of human or animal pathogens --- the adverse effect of wastewater irrigation should be evaluated carefully prior to full scale design and operation. Preapplication methods that will reduce the parameters of concern should be used. Two types of preapplication approaches exist : (i) strategies to sustain the capability of the soil as a treatment process such as pretreatment to reduce excessive amounts of nitrogen and potentially toxic elements and chemicals, and to adjust abnormal pH and SAR values in the wastewater to be applied, (ii) strategies to avoid nuisances and maintain system reliability such as wasterwater storage, odor control, and removal of large solids to avoid ditribution and clogging.

The fact that the potential health effect of wastewater irrigation has not been completely resolved is cause for using conservative management and design procedures but should not preclude the use of wastewater irrigation systems when they are cost effective. It also should not result in the use of unnecessarily stringent preapplication requirements (100).

10. MANAGEMENT AND MONITORING OF LAND TREATMENT SYSTEMS

10.1 Management of Treatment Systems.

Management of a land treatment system includes aspects such as management of crops, soil, irrigation and monitoring as well as mechanical equipment. The wastewater irrigation plan should be drawn after considerable planning with enough flexibility to allow for adequate crop management including planting, tillage and harvest. Good crops indicate good wastewater treatment. Site ownership or lease, and farm operation constitute other important management factors (52). Research on management aspects has received wide attention and many models have been put forward for effective and efficient operation of land treatment systems.

Markland et al. (106) have described the use of a mixed integer programming model for the planning of land disposal facilities, giving due consideration to relevant construction and operating costs for land sites, transmission arteries, land acquisition costs, tangible benefits from land use, controls on aquifers, and various other engineering and chemical constraints. The model can be used to determine which land disposal sites should serve which treatment plants, when initial construciton should be initiated and completed, and when capacity expansion should occur. A method to aid in the preliminary design and evaluation of alternative spray irrigation and application systems has been established by Haith et al. (65). A mathematical model based on monthly mass balance equations for water and nitrogen in a storage pond and soil provides estimates of costs of system components and the nitrogen concentration of water draining the spray irrigation site. A heuristic algorithm for regional wastewater planning problems for land application of wastewater has been given by Chiang (31). This also helps in defining which land sites should be developed to serve which treatment plants and with what capacity. By a series of straight-forward marginal cost analysis, the algorithm implicitly evaluates most of the solutions to the problems while explicitly evaluating only a few to reach a final least cost solution.

10.2 Monitoring at Land Application Sites.

A comprehensive monitoring program is required for any land treatment facility to ensure that proper renovation of wastewater is occuring and that environmental degradation is not occuring. The three aspects to be monitored regularly are (i) renovated water, (ii) vegetation, and (iii) soils.

Renovated water may be required for groundwater or recovered water or both, and nitrate nitrogen must be closely observed in both. A comparison of the changes in the groundwater quality and levels with the quality and levels of background wells gives the overall impact of the system (51). Water samples collected for background water quality should be analysed for chlorine, specific conductance, pH, total hardness, alkalinity, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total phosphorus, methylene blue active substances, chemical oxygen demand and any heavy metals or toxic substances found in the applied wastes (102). Recovered water monitoring requirements depend on the disposition of the water. Optimization of growth and yield is the objective of monitoring vegetation if it forms part of the treatment system. As already mentioned, soils should be monitored at least annually to detect changes in salinity levels of various elements, pH and cation exchange capacity (51).

11. ECONOMICS OF LAND TREATMENT FACILITIES

According to Loehr et al. (101), the cost of a total system is the sum of pretreatment and land application components. The system components used in land application useful in computing costs is shown in Fig. 3. It is apparent that costs increase as wastewater pretreatment becomes more complex. The smaller the volume of the plants, the higher is the operating costs.

A comparison of the costs of pretreatment plus land application with costs of physical chemical tertiary treatment gives the feasibility of using pretreatment-land application as a substitute for tertiary treatment. It has been established that flooding of wastewater is generally cheaper than spraying of wastewater. In the case of monitoring, the total costs of monitoring systems depend on both the type of installation used and the number of devices used in the system. Breakpoint decisions can be more easily made by a careful selection of system components given in Fig. 3. It has also been established that rapid infiltration is the cheapest regime (101).

These findings are the outcome of research conducted for effectively least-cost management of land treatment systems, a few more of which are outlined below:

Crites et al.(35) have presented curves for cost comparison between an advanced wastewater treatment (AWT) system and land treatment for use in upgrading existing conventional secondary treatment facilities. These curves aid in regional planning on issues such as generalized costs of each alternative and break-even point at which the costs of two alternatives are the same. A demand curve for land treatment of municipal wastewater assuming a profit-maximising framework has been derived by Carlson and Young (25) and has been used to estimate demand for land treatment technology by utilization of data collected from 125 U.S. cities. The price of byproducts (water), required degree of treatment, price of capital, and local construction cost share, all significantly increase adoption, and volume of river flow, rainfall, and volume of effluent flow, all have a significant negative effect on adoption. Land prices were found to be insignificant.

In a high rate land treatment system at Phoenix, Arizona, Bouwer et al. (17) have estimated the cost of renovation system at about the cost of equivalent inplant tertiary treatment to produce renovated water of similar quality. A land treatment system yielding the best original construction cost and at the lowest possible operating cost has been devised by Hennesy and Small (66).

In South Tahoe, USA, a land treatment system involving use of secondary effluent in an existing flood irrigation system was found to be substantially lower in cost than continued use of physical-chemical advanced wastewater treatment (tertiary) processes. Total costs were reduced by about 27% and local costs by about 40% (37). Economics has become an important criterion in the choice of land treatment systems and in making decisions for waste treatment alternatives as a whole (47,74).

12. SOCIETAL CONSTRAINTS AND LEGAL ASPECTS

12.1 Public Acceptance.

Public acceptance is a determining factor in the success of land treatment of wastes. The public should be informed about processes that are being used to protect public health to allay their fear of disease transmission, and they can also be informed that as yet there are no cases of toxic element poisoning of humans associated with land treatment (101). A survey of 10 cities in California

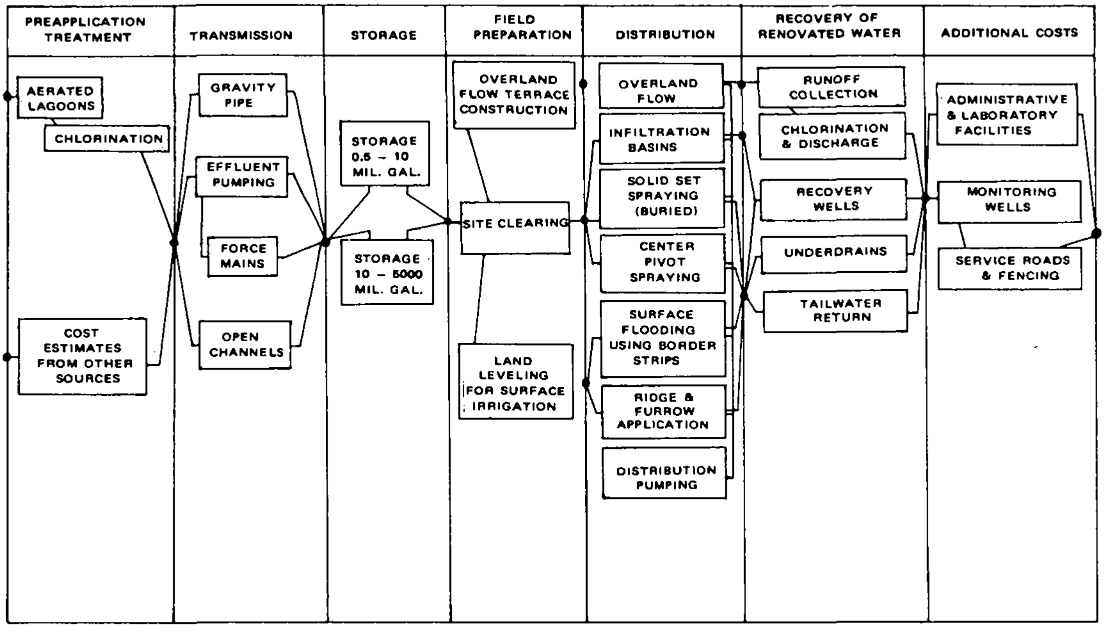


Figure 3. System Components Used in Land Application. Relationship of Various Components of Sewage Treatment by Land Application (141).

of public opinion on the use of reclaimed wastewater revealed that there is no major opposition to such reuse (20). Another study in Southern California indicates the general order of reuse preferences as non-body contact to body contact to consumptive uses (190). In site selection, public participation fosters public acceptance. At all stages of development of a land treatment project, society-participation generates useful and informed feedback and public support. Thus an extension service in the form of a public information program will go a long way in ensuring public acceptance by allaying public ignorance of the innumerable benefits of land application of sewage (101).

12.2 Legislation.

In the U.S.A., all land treatment systems must meet effluent limitation standards, cost-effectiveness guidelines and other legal restrictions. Besides meeting the requirements of the federal legistations, state regulations and guidelines should also be complied with. Five pieces of federal legislations have relevance to land treatment. They are (101) :

1) the Federation Water Pollution Control Act Amendments of 1972 (referred to as PL 92-500);
2) the National Environmental Policy Act (NEPA);
3) the Safe Drinking Water Act (SDWA);
4) the Resources Conservation and Recovery Act (RCRA); and
5) the Clean Water Act of 1977.

Table 12. Summary of Several Common Aspects of State Guidelines for Land Application of Wastewater Which Have Major Impact on the Final Design (118)*
(NI - No Information Given)

State	Storage Requirement	Buffer Zone Requirement	Cover Crop	Hardware	Loading Rate (Max. in./ acre–wk.)
California	NI	500 ft to water supply wells	NI	Maximum attainable separation	NI
Colorado	NI	NI	NI	NI	NI
Delaware	Reserve area required	200 ft	Crop planted before irrigation begins	Minimize aerosol formation	Not to exceed infiltration rate
Florida	7–day flow plus 3 ft	150 ft to houses; 200 ft to water wells	Crop planted before irrigation begins	Minimize aerosol formation	4
Georgia	30 days design flow	At least 300 ft	Woodlands or non–food crop	*Fixed distribution* system	1
Idaho	NI	NI	NI	NI	NI
Illinois	To accomo–date flows in excess of irrigation	150 ft to water supplies; 200 ft to surface water	NI	Stationary systems capable of being drained	NI
Kansas	NI	NI	NI	NI	NI
Maine	NI	300 ft for spray irrigation	No application on bare soil	NI	NI
Michigan	NI	NI	NI	NI	NI
Minnesota	210 days	To extent possible	Acceptable vegetative cover	Minimize aerosol drift; automatic shutoff during rain	2 (4 during July and August)
Missouri	Winter flow plus allowance for wet Spring	NI	Reed canary grass, tall fescue	Drains to prevent freeze–up	NI
Nebraska	180 days	50 ft	NI	No cross connections between potable and reclaimed water pipes	3
New Hampshire	2/3 yearly flow	Site dependent	NI	NI	2
New Jersey	Site dependent	200 ft	No application on bare soil	Portable systems unacceptable	2
New York	To handle maximum reasonable variation in flow	Buffer zone required	Cover crop required; harvest when necessary	Station systems preferred	NI
Ohio	NI	NI	No application on root crops, leafy vegetables	NI	NI
Oregon	*Adequate* storage	NI	*No irrigation of* crops for human or dairy cattle consumption	NI	NI
Pennsylvania	To handle maximum reasonable variation in flow	200 ft	Few restrictions	Fixed lines for winter irrigation; low spray trajectory	2
S.Carolina	3 days flow	100 ft	No application on bare soil or crops for human or grazing animal consumption	*Drains to prevent* freeze–up	2
S.Dakota	210 day flow	To extent possible	"Suitable"	Minimize wind drift and aerosol formation	2
Texas	NI	500 ft to water supplies	No irrigation of food crops for raw consumption	No cross connections between potable and reclaimed water pipes	NI
Vermont	April–May flows	100 ft to surface waters	NI	Pump system must deliver daily flow within 8 hours	2
Virginia	60 days	200 ft for forested site; 600 ft for open site	No irrigation of food crops for raw consumption	Permanent spray system	2
W.Virginia	60 days	400 ft	NI	Permanent spray system, drains to prevent freeze–up	1
Wisconsin	NI	1,000 ft from public water supplies	NI	Minimize runoff, incorporate sludge	NI

1 ft = 0.305 m

* As of 1975.

Most of the states in the U.S.A. have issued guidelines for land application of wastewater and these are presented in Table 12. Till 1975, in most of the states in the U.S.A., secondary treatment of waste prior to application to land was a must (144). Of late, the U.S. Environmental Protection Agency (EPA) has realised that imposition of stringent wastewater treatment requirements prior to land application has quite often nullified the cost-effectiveness of land treatment processes, and hence nowadays whenever states insist upon placing unnecessarily stringent preapplication requirements upon land treatment, such as requiring EPA secondary effluent quality in all cases prior to application on the land, the unnecessary wastewater treatment facilities are not funded by the EPA (101).

Although nightsoil and sewage have been used for crop cultivation in countries like China and India for many years, the developing countries have not recognised land treatment as an effective waste treatment system warranting the application of scientific and engineering principles. It has merely been adopted with the intention of waste reuse. Hence, unlike the developed countries, legislations and guidelines have not been developed to any great extent in these countries and literature on this aspect is forthcoming.

13. CASE STUDIES

A number of experimental/operational systems have been designed to renovate municipal wastewater by land application. Some properly managed systems of land application of municipal wastewater are listed below :

1) The Michigan State University Water Quality Management Project (WQMP), U.S.A. (50,101,197).
2) The City of Tallahassee Spray Irrigation Project (TSIP), U.S.A. (50, 197).
3) The Flushing Meadows Project (FMP), U.S.A. (50,101,197).
4) The Pennsylvania State University Wastewater Renovation and Conservation Project (WRCP), U.S.A. (50).
5) The City of Boulder Colorado Project (BCP), U.S.A. (50).
6) Cape Cod Wastewater Renovation and Retrieval System, Otis Air Force Base, U.S.A. (99,101).
7) Fort Devens Rapid Infiltration, Massachusetts, U.S.A. (99,100,197).
8) Lubbock, Texas, U.S.A. (99,197).
9) Monteca, California, U.S.A. (99).
10) Quincy, Washington, U.S.A. (99).
11) Calumet, Michigan, U.S.A. (99).
12) Livermore, California, U.S.A. (99).
13) Fairbanks, Alaska, U.S.A. (99).
14) Werribee Farm System, Melbourne, Australia (101,133).
15) Fresno Wastewater Treatment, Fresno County, California, U.S.A. (101).
16) Southeast Bakersfield, California, U.S.A. (101,197).
17) Deer Creak Lake, Recretional Area, Ohio, U.S.A. (101).
18) Winter Spray Irrigation, Big Bromley Ski Area, Manchester, Vermont, U.S.A. (101).
19) Campbell Soup Company, Paris, Texas, U.S.A. (101,197).
20) Campbell Soup Company, Napoleon, Ohio, U.S.A. (101).
21) Padre Dam Municipal Water District, Santee, California, U.S.A. (101).
22) HYDIG, Hertfordshire, England (101).
23) Pleasanton, California, U.S.A. (197).
24) Walla Walla, Washington, U.S.A. (197).
25) San Angelo, Texas, U.S.A. (197).
26) St. Charles, Maryland, U.S.A. (197).
27) Lake George, New York, U.S.A. (197).
28) Pauls Valley, Oklahoma, U.S.A. (197).

These and other projects in the U.S.S.R., South America, Hawaii, Israel and other countries (54,55,73,78,145,159,189,213) exemplify how land treatment can solve waste treatment problems effectively and successfully. A glance at the case studies given above indicate that most of the research in this field is being carried out in the developed countries where, as mentioned previously, land treatment is being viewed as a waste disposal method based on scientific and engineering principles. Not much research has been done on land treatment of sewage in South East Asia, although some successful studies have been undertaken at the Asian Institute of Technology, Bangkok, on land treatment of industrial and agro-industrial wastes (143,144). This method has tremendous scope for waste disposal and reuse in the developing countries and research should be undertaken to design land application systems for tropical areas. Land treatment of sewage has come to stay, and will play a significant role, forming an integral part of the waste treatment systems of the future.

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