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Project Summary

Long-Term Effects of Slow-Rate Land Application of Municipal Wastewater

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Long-term effects of applying partially treated municipal wastewater to croplands were examined at six locations in the western United States. All locations had received wastewater for at least 10 years. The effects on soil, groundwater, and crop tissues were measured and compared with measurements made at nearby control sites where crops were irrigated with water from wells or other conventional sources.

Data on some 50 pollutants and other parameters measured at the six locations are summarized in the full report. The data revealed that the soil and vegetation effectively reduce the concentrations of most pollutants in the wastewater, although certain pollutants accumulate in the soil. Some pollutants pass through the soil to the groundwater, but usually in concentrations that do not exceed Federal standards for drinking water supply. An important exception is nitrate-nitrogen, which exceeded the drinking water standard at three project locations. At no site was there any reported evidence of adverse health effects on farm workers or nearby residents.

Values of two parameters—hydraulic loading and nitrogen concentration in the leachate—measured at the sites were compared with calculated values obtained using estimation procedures from the *Process Design Manual for Land Treatment of Municipal Wastewater*, published in 1976 jointly by the Environmental Protection Agency, the Army Corps of Engineers, and the Department of Agriculture. This publication presents the two above-named parameters as limiting criteria for the design of slow-rate land application systems, and gives procedures for estimating their values from climate data, soil conditions, evapotranspiration data, and other site parameters. These procedures were retrospectively applied to site data at the six locations, and the results were compared with actual measurements. Measured values of hydraulic loading at the project locations fell within the allowable limits estimated by the *Design Manual* procedure, but measured values of leachate nitrogen concentration did not correspond closely to estimated allowable limits. Recommendations are made in the report concerning possible modifications to the *Design Manual* estimating procedures.

This Project Summary was developed by EPA's Office of Environmental Engineering and Technology, Washington, DC, to announce key findings of the research work that is fully documented in a separate report of the same title. (See Project Report ordering information at back.)

Background

Disposal of domestic or municipal wastewater by application to the land was widely practiced in Europe and the United States during the 1800s for irrigation, for utilizing the plant nutrient content of the wastewater, and for reducing the amount of pollutants discharged to rivers and other surface waters. During the first half of the 20th century, many land application systems in the United States were replaced by waste treatment plants using mechanical, chemical, and biological processes. The treated effluent from such plants has generally been discharged to rivers or other surface waters. In some instances, particularly in western states, the effluent has been used for irrigation and groundwater recharge.

As late as the mid-1970s, treatment plant effluent was applied to the land primarily for irrigating crops. The effectiveness of land application in removing pollutants has been widely recognized, however, and its use as a step in total wastewater treatment systems became the subject of substantial research efforts by the U.S. Environmental Protection Agency (EPA) and other agencies. This work led to the consideration of land application as a wastewater treatment process, to be evaluated as a supplement, or possibly an alternative, to the more conventional processes.

The number of wastewater treatment systems that use land application of effluent has increased over the past 40 years from about 300 facilities, serving an aggregate population of 0.9 million in 1940, to 940 systems, serving an estimated 9 million in 1978. This is still only a small part of the total municipal wastewater treatment facilities, estimated at approximately 22,700 plants serving about 164 million people in 1979.

The growth of land treatment has been encouraged by Federal environmental legislation and policies during the 1970s. Regulations developed pursuant to the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) require that land treatment be considered, together with other alternatives, for federally funded municipal wastewater treatment projects. Continued emphasis was placed on the land treatment alternative by the Water Pollution Control Act Amendments of 1977. There was widespread interest in the land treatment provision of the regulations related to these two Acts, raising questions as to what criteria would be used to evaluate land treatment systems and to compare them with conventional systems. In response to these questions, the Environmental Protection Agency, in cooperation with the Department of Agriculture and the Army Corps of Engineers, issued the *Process Design Manual for Land Treatment of Municipal Wastewaters* in 1977.

There has been a continuing concern about the environmental and public health impacts of land treatment of municipal wastewater, especially where the practice extends over several decades. Potential problems relate to the accumulation of heavy metals and other toxic substances in the soil, the transport of these pollutants to the groundwater, and the dispersal of pathogens (bacteria, viruses, protozoa, and nematodes) during spray irrigation.

In the early 1970s, EPA initiated a program of research, development, and demonstration to address the technical aspects of land treatment and offered the prospect of producing the sound information base needed for a better understanding of land treatment. The program included a series of site studies that examined 10 land application systems that had been in operation for at least 10 years. While the studies cover only a short interval (12 to 18 months) in the total period of wastewater application at each site, the resulting data permit inferences to be drawn about the long-term effects of this practice. In addition, the data are expected to be useful in evaluating design criteria in the *Design Manual*. Six of the 10 studies examined slow-rate systems, where vegetation plays a critical role in the absorption of water and nutrients. The other four dealt with rapid infiltration systems, which rely principally on physical and chemical action of the soil to purify the applied wastewater.

The results of the six slow-rate systems studies, performed during 1976-1978 are summarized in this report. A parallel summary, issued in 1980 by the EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, covers the four rapid infiltration land treatment systems (Report No. EPA-600/2-80-165).

The slow-rate land treatment project sites cover a broad range of climatic conditions, soils, and topographic and hydrogeological configurations. All six systems investigated had received municipal wastewater for at least 10 years and one for more than 30 years. The projects were located in the vicinity of:

Camarillo,
California

Dickinson,
North Dakota

Mesa,
Arizona

Roswell,
New Mexico

San Angelo,
Texas

Tooele,
Utah

System Design and Operation

The general design of the projects using slow-rate land treatment systems is shown in Figure 1. While this design does not correspond specifically to any one of the six projects, it represents all major components typically found in a slow-rate treatment system. All of the components shown in Figure 1 are not required for slow-rate land treatment, and are not included in every treatment system studied.

Effluent from the primary or secondary treatment plant is transferred to one or more facultative lagoons where it undergoes additional oxidation and settling. Effluent from the lagoon(s) is transported to a holding pond, then to the test site where it is applied to the land by any of several methods. A nearby control site with characteristics similar to the test site is irrigated by water from a conventional source such as a well or a river. One or more principal crops are grown on the major portion of the area at both the test and control sites. Some of the projects also have experimental garden plots where a variety of crops is grown.

Samples of applied water, leachate, groundwater, soil, and crops were collected at the test and control sites and analyzed. Crop yields were reported for three of the projects.

Site Characteristics, Operations, and Selection Criteria

All six projects were in western states, and all but one were in arid or semiarid climates. Test sites and control sites at five of the six projects were on privately-owned farms. The test site for the sixth project was on a municipally-operated farm.

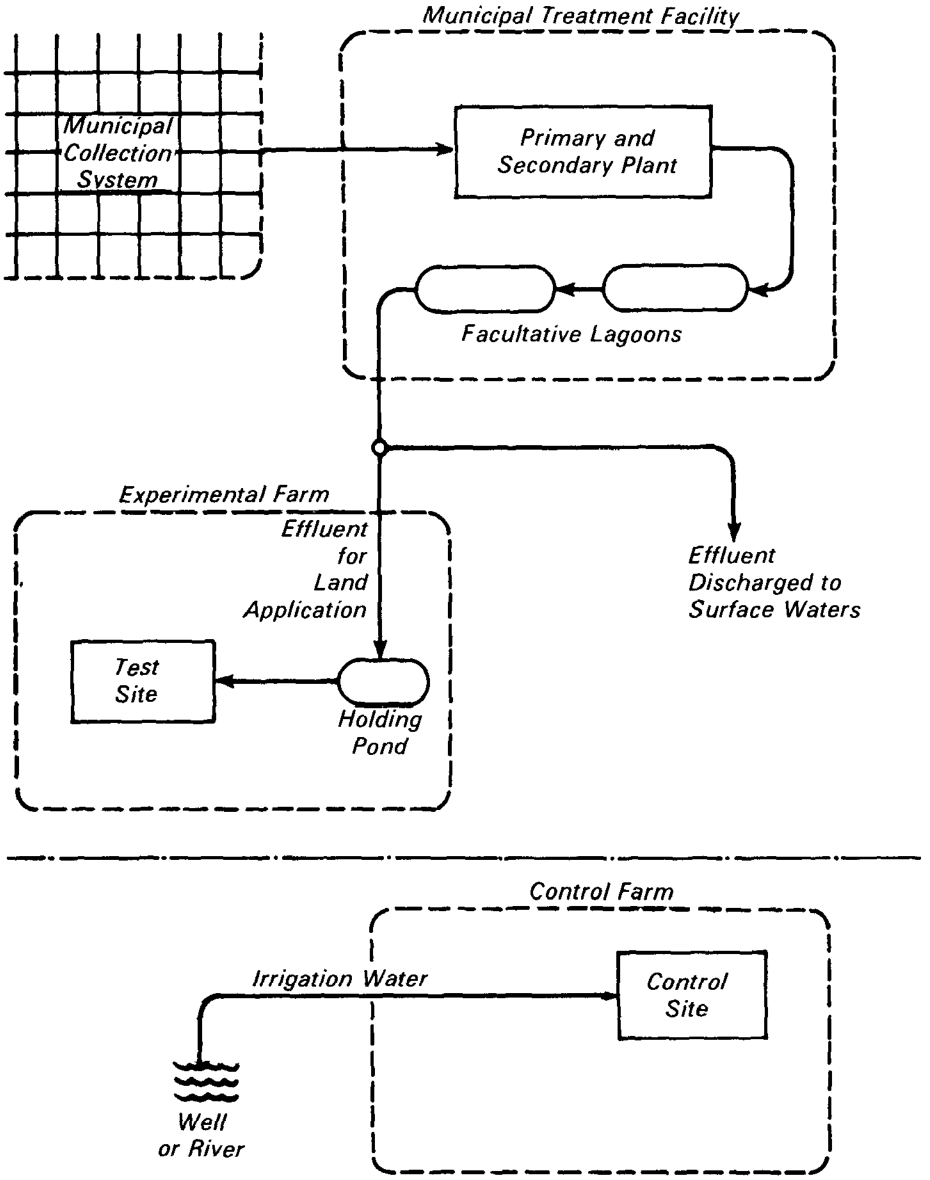


Figure 1. *Schematic of general project design.*

Specific test sites for each project were selected after examination and evaluation of several alternatives in each of six geographic regions specified by EPA. Criteria for selection of the test sites included the following:

- The site had been irrigated with effluent for at least 10 years, and historical records were available for that period.
- The applied wastewater should be an effluent from either primary or secondary treatment facilities.
- Flow rates should be at least 4.38 liters/second (l/s) [0.1 million gallons/day (mgd)].
- Crops should be representative of common usage.
- A "good control site" should be available within a reasonable distance and have the same general type of soil and hydrogeological conditions.

Results at the Six Locations

The results of measurements of approximately 50 pollutants and other water quality parameters in the three media (soil, vegetation, and groundwater, including leachate) at the six locations are presented in a series of 20 tables in the full report. One of these (Table 1) is included in this summary to indicate the arrangement of data. The tabular data are grouped first by media and then by pollutant category within each medium. The pollutant categories are: nitrogen and phosphorus, organics, suspended and dissolved soilds, alkali and alkaline earth metals, heavy metals, nonmetallic elements, and bacteriological indicators of pathogenic organisms.

Each table reports the concentrations of several pollutants in the applied water and in selected locations within a given medium for each of the six projects (for example, at different depths in the groundwater or different parts of a crop plant). The media-based approach is used on the assumptions that most readers will prefer to access the data by medium rather than by pollutant or location.

The entries in the columns for each pollutant show four values: the concentrations at the test and control sites, the percent difference with respect to the control site value, and the significance level of the difference. In cases where the values are not large enough to be detected by the analytical techniques used, the detection limits are reported but difference and significance levels are not, as they have no meaning. In some instances, control site data were not available and comparisons were omitted or were drawn between concentration measured upgradient and downgradient of the test site or at different times in the effluent application period.

Transport and Fate of Pollutants

Nitrogen

Total nitrogen and ammonium nitrogen concentrations were much higher in the sewage effluent than in the irrigation water at the four reporting projects (Camarillo and Mesa for total N, Dickinson and Roswell for NH_4^+). Nitrate levels did not differ as markedly. Considerable equalization of concentrations occurred with depth as the nitrogen compounds were taken up by plants. However, nitrate levels rose with depth, in part through nitrification and in part because of low affinity for soil particles. In fact, nitrate levels in groundwater in both the test and control sites consistently exceeded drinking water criteria in at least one location (Camarillo).

Table 1. *Concentration of Nitrogen and Phosphorus in Leachate and Groundwater (mg/l)*

	N-Kjeldahl				$N\text{-}NO_3^-$				$N\text{-}NH_4^+$				P-Total				$P\text{-}PO_4^=$			
	Test***	Cont	%Δ	(SL)	Test	Cont***	%Δ	(SL)	Test	Cont	%Δ***	(SL)	Test	Cont	%Δ	(SL)***	Test	Cont	%Δ	(SL)
Camarillo																				
● *Applied water*	15 0	3.5	+330	(0.01-0.04)	4 6	2.1	+120	(0.05-0 1)									11.8	0.5	+2,260	(0 01-0 04)
● *Leachate - 50cm*	36.6	27.5	+ 33	(>0.1)	34 6	28 2	+ 23	(>0.1)									4 8	3 8	+26	(>0 1)
● *Leachate - 100 cm*	47.5	34 1	+ 39	(>0 1)	53 0	32 5	+ 63	(0 05-0.1)									2 9	3.0	-3	(>0 1)
● *Groundwater-top**	53 9	41.3	+ 31	(0.01-0.04)	52.8	39.9	+ 32	(0 01-0.04)									0 5	0.4	+25	(>0.1)
● *Groundwater-bottom**	45.6	38 6	+ 18	(0 05-0.1)	44.3	38.2	+ 11	(0 05-0.1)									0 60	0 28	+114	(>0.1)
Dickinson																		(soluble)		
● *Applied water*					1 5	4.0	- 63		6 9	0 1	+6800		6 9	0.05	+13,700		3.8	<.01	+37,900	
● *Groundwater*					1 8	0.4	+350	(≤0 05)	0.4	0 3	+ 33	(>0 05)	0.06	0.07	-14	(>0 05)	0 03	0 05	-40	(>0 05)
Mesa																				
● *Applied water*	24 9	3 5	+611	(0 01-0.04)	1 8	2.7	- 38	(>0.1)									9 0	0.5	+1740	(0.01-0.04)
● *Leachate - 50 cm*																	5 0	1 0	+400	(>0 1)
● *Leachate - 100 cm*																	4 2	3 6	+17	(>0 1)
● *Groundwater - top**	15 2	9.1	+ 67	(0 05-0 1)	12 0	6 9	+ 74	(0 05-0.1)									1.7	1 0	+70	(>0 1)
● *Groundwater-bottom**	11.9	7 1	+ 67	(0 01-0.04)	9 9	5 8	+ 71	(0 05-0.1)									2 1	1 2	+75	(>0.1)
Roswell		(Organic N)																(soluble)		
● *Applied water*	41.3	(total)****			1 6	1 2	+ 33	(>0.05)	23 3	0 1	+23,200	(≤ 05)	7 95	0 01	+79,400	(≤ 05)	6 47	0.05	+12,840	(≤ 05)
● *Groundwater<6m*	0 7	soluble			13 0				0.2								0 08			
● *Groundwater>6m*	0.8				6 5	1 0	+550	(≤ 05)	0 2	0.4	-50	(> 05)					0.21	0.11	+91	(> 05)
San Angelo		(N-Kjeldahl)																(dissolved) *		
● *Lagoon effluent*	35 2				0 25				22 1				21 6				9 5			
● *Groundwater<10m*	<0 3				5.8				<0.3				0 06				0 04			
● *Groundwater<10m*	<0.3	<0 3			15.7	22.0	- 29		<0.3	<0.3			0.03	0 02	+50		0.02	0 01		
● *River water***	0 7	0 7	0	(>0.05)	5 7	1 6	+256	(≤0 05)	<0 3	<0.3			0.08	006	+33	(>0 05)	0 024	0 017	+41	(>0 05)

*Concentrations at the test site

**Upgradient/downgradient concentrations at test site

***Test = concentration at test site

Cont = concentration at test site

$$\%\Delta = \frac{\text{(concentration at test site) - (concentration at control site)}}{\text{concentration at control site}}$$

(SL) = significance level

****The value for total organic nitrogen in applied water appears, on review of analytical procedures in this reference, to represent total Kjeldahl-N It is used as TKN in the sample calculation

Concentrations in the soil as a function of depth were reported for total nitrogen and nitrate (Camarillo, Mesa, and Tooele), for organic and inorganic nitrogen (Dickinson and Roswell), and for ammonium (Tooele). The values at both the control and test sites generally decreased with depth, but the differences between the control and test sites did not exhibit any obvious trends.

Phosphorus

Phosphorus concentrations in leachate and groundwater decreased with depth. In the soil, phosphorus concentration decreased rather consistently with depth for both the control and test sites, although the decrease at the test sites appeared to be more rapid. Phosphorus levels in vegetation were reported in the form of total phosphorus (Dickinson, Roswell, San Angelo, Tooele) and phosphate (Camarillo and Mesa). In those investigations that afforded a comparison between the same plant species at the control and test sites, the test site plants exhibited considerably higher phosphorus levels.

Organics

The quantity of organic matter found at some of the facilities was affected by changes in the algal growth in the effluent storage and treatment lagoons (Dickinson and San Angelo), by droppings from grazing animals, and by plowing under crops grown on the sites (Camarillo). Interpretation of the data to determine the effect of land treatment in removing organic matter in applied wastewater was greatly complicated by the other sources of these materials. In most cases, the levels appeared to decrease with depth, but the number and uniformity of results were insufficient to establish definite patterns.

Solids

The term "total solids" encompasses suspended solids and dissolved solids. The first two terms are of small consequence in land treatment because suspended matter is usually filtered out by the first few centimeters of the soil. Concentrations of both total and individual dissolved solids were generally higher in the sewage effluent than in the irrigation water. The notable exception was at the Roswell facility, which used groundwater for irrigation. Other exceptions were the concentrations of magnesium and sulfate at most of the four reporting facilities.

The inequality in dissolved solids concentrations at test and control sites persisted in water sampled at increasing depths, with the exception of deep groundwater samples. Furthermore, concentrations of total and individual dissolved solids in leachate and groundwater generally increased with depth at both the test and control sites. The key exception was potassium which was taken up by plants as an important nutrient in relatively large amounts.

Heavy Metals

Heavy metals are of special concern in land treatment because of their toxicity, their persistence in the environment, and the ability of living organisms to bioaccumulate them. These substances may be taken up by crops grown on land treatment sites and ingested by humans or animals, or they may percolate to groundwater or surface water supplies. Concentrations of cadmium, chromium, copper, lead, molybdenum, nickel, and zinc were reported as a function of depth for leachate and groundwater at the Camarillo and Mesa projects. More limited results were provided for most of these metals as well as for aluminum, cobalt, iron, manganese, and mercury at Dickinson, Roswell, and San Angelo. In general, metal levels were low at both the control and test sites and did not change appreciably with depth. In several cases the concentrations were higher at the *control* sites.

Heavy metals levels in the soil showed no appreciable change at different depths. In a number of cases, higher concentrations were noted at the control sites. Heavy metals levels in various portions of crops grown on the control and test sites were reported for all six projects. At those projects that afforded a comparison between the same crops, all metals exhibited higher or equivalent concentrations in plants grown on the control site. None of the concentrations approached hazardous limits.

Biological Indicators of Pathogenic Organisms

Although indicator organisms levels were substantially higher in the sewage effluent than in the irrigation water, all but total coliforms were reduced to below detectable limits by passage through 300 cm of soil. Some elevated levels on crops were attributed to droppings from grazing animals.

Comparison of Leachate Parameters with Drinking Water Standards

Although the *Design Manual* does not recommend that drinking water standards other than nitrate-nitrogen concentration be considered as limiting criteria in the design of slow-rate land treatment systems, it is nevertheless interesting to compare the allowable levels of criteria parameters specified in EPA standards for drinking water supply with the measured concentration of the same substances in the groundwater at test sites. An overall summary comparison is shown in Table 2.

Data in Table 2 indicate that the concentrations of most drinking water criteria parameters are well within the acceptable maximum levels at most of the treated sites. However, the measured levels at nitrate-N, selenium, and total coliform equal or exceed the criteria levels at all sites reported. This observation does not, in itself, indicate that the higher-than-acceptable levels of these constituents are a result of land treatment, since the levels of selenium and total coliform in groundwater at some of the control sites also exceed criteria levels for drinking water supply.

Comparison of System Design Factors with Criteria in Process Design Manual

The report examines possible design and predicted performance changes that might have resulted if the six slow-rate systems had been designed according to criteria in the *Design Manual*. Such comparisons between the features of existing systems and the design criteria in the *Design Manual* are entirely hypothetical, since all of the systems were designed and in operation long before the *Design Manual* was published.

The *Design Manual* considers two principal limiting criteria for the design of slow-rate systems: hydraulic loading, and concentration of nitrogen in the leachate.

Given minimal information on soil characteristics at any location in the

Table 2. *Comparison of Drinking Water Criteria and Groundwater Parameters at Treatment Sites*

Constituent	*Drinking Water Standard*	*Concentrations in Groundwater or Leachate at Treated Sites*					
Chemical (mg/l)	*(Value)*	*Camarillo*	*Dickinson*	*Mesa*	*Roswell*	*San Angelo*	*Tooele*
Arsenic	*0.05*	*0.01*	*0.014*	*0.02*	*<0.02*	*—*	*No Measurements*
Barium	*1.0*	*0.16*	*—*	*0.19*	*—*	*—*	
Cadmium	*0.01*	*0.02*	*<0.01*	*0.01*	*<0.02*	*<0.004*	
Chromium	*0.05*	*0.03*	*<0.02*	*0.03*	*<0.02*	*<0.005*	
Fluoride	*1.4 to 2.4**	*1.1*	*—*	*0.79*	*—*	*—*	
Lead	*0.05*	*0.12*	*<0.1*	*0.19*	*<0.10*	*<0.05*	
Mercury	*0.002*	*—*	*<0.0001*	*—*	*<0.0005*	*—*	
Nitrates (as N)	*10.*	*52.8*	*1.8*	*9.9*	*6.5*	*15.7*	
Selenium	*0.01*	*0.01*	*0.02*	*0.01*	*0.03*	*—*	
Silver	*0.05*	*—*	*—*	*—*	*—*	*—*	
Bacteriological (No./100 ml)							
Total coliform	*1*	*410*	*59*	*9*	*TNTC***	*1000 to 100,000*	
Pesticides (mg/l)							
Endrin	*0.0002*	*—*	***	*—*	***	*—*	
Lindane	*0.004*	*—*	*~0.00001*	*—*	*0.00007*	*—*	
Methoxychlor	*0.01*	*—*	***	*—*	***	*—*	
Toxaphene	*0.005*	*—*	***	*—*	***	*—*	
2, 4-D	*0.01*	*—*	*~0.000008*	*—*	*0.00001*	*—*	
2, 4, 5-TP	*0.01*	*—*	*~0.00003*	*—*	*0.00003*	*—*	

— = Not reported.

**= Dependent on temperature; higher limits for lower temperatures.*

***= TNTC - Too numerous to count.*

**** = Not observed at detectable limit.*

Table 3. *Acceptable Wastewater Hydraulic Loading (L_w) as Calculated by Design Manual Procedure*

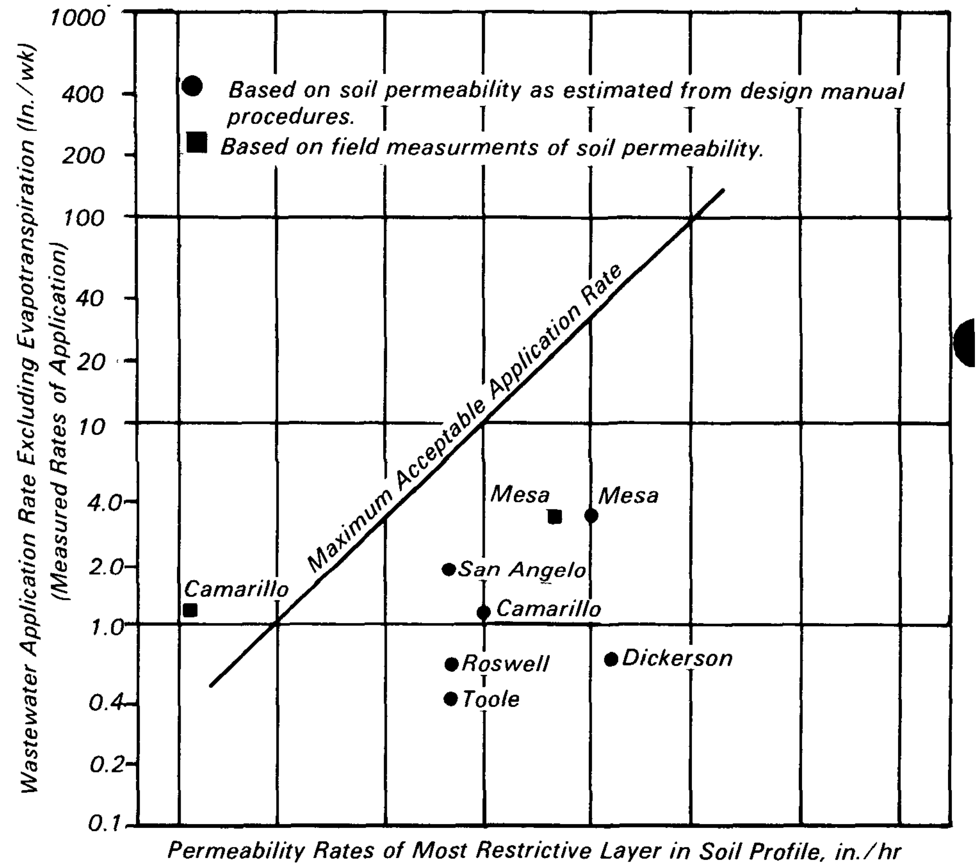
Location	Textural Classification of Soil	Permeability Range Value Used For Computation In /hr	Upper Limit of Application Rate Excluding Evapotranspiration In /week	Growing Season Weeks	Percolation Rate (W_p) In /yr	Percolation Rate (W_p) Ft/yr	Evapotranspiration Less Precipitation (ET-Pr) Ft/yr	Wastewater Loading (L_w) Max. Allowable per Design Manual Ft/yr	Wastewater Loading (L_w) Actual Measurements Ft/yr	Wastewater Loading (L_w) Actual Measurements In /wk
Camarillo	Loam (mocho loam with 25% clay)	Moderate to Moderately Slow (0 6) (0.03)	10 0.5	52	520 26	43 3 2.2	1 7	45.0 3 9	5 0	(1 2)
Dickinson	Fine sandy loam	Moderately Rapid (3 0)	45	30	1350	112 5	1 7	114 2	2 6	(0.6)
Mesa	●Vinity loam fine sand ●Gilman Loam	Moderate (2.0) (1 04)	38 20	52	1976 1040	165 87	4 6	170 92	16 5	(3.8)
Roswell	Silty clay, loam	Moderately Slow (0 4)	7 0	22	154	12 8	4 6	17 4	2 6	(0 6)
San Angelo	Silty clay Sand Gravel	Moderately Slow (0 4)	7 0	52	364	30.3	4.2	34 5	8 7	(2 0)
Tooele	Loam Sandy loam Clay loam	Slow to Moderately Slow (0 4)	7 0	30	210	17 5	2.5	20.0	2 0	(0.5)

continental United States, a rough estimate of the allowable hydraulic load (L_w) can be made from information in the *Design Manual*. Estimates of L_w have been made for each project location in this study and are compared with the actual wastewater loading applied.

Actual wastewater application rates and estimated acceptable rates obtained by means of the *Design Manual* procedure for all six slow-rate projects (together with data used in determining the estimated rates) are presented in Table 3. Actual application rates for each project are plotted against permeability rates for the six projects in Figure 2. The format of this figure shows the line indicating maximum acceptable wastewater application. It is clear from both Figure 2 and Table 3 that actual application rates at the sites fall below the acceptable maximum as estimated from the *Design Manual* in all cases, except the Camarillo estimate, based on field measurements of soil permeability. For this one exception, actual rate exceeds the estimated acceptable rate by about a factor of two.

The concentration of total nitrogen in the percolate from the treatment site is one of the limiting criteria in the *Design Manual*. The allowable concentration depends on the use classification of the groundwater. In this example, the most stringent use classification—drinking water source—will be assumed. The allowable concentration for this use is 10 mg/l.

Input data for all projects are presented in Table 4, and computed values of C_{Np} are compared with measured values at each project. There is relatively low



Permeability*, Soil Conservation Service Descriptive Terms						
Very Slow	Slow	Moderately Slow	Moderate	Moderately Rapid	Rapid	Very Rapid
< 0.08	0.06-0.20	0.20-0.60	0.60-2.0	2.0-8.0	6.0-20.0	> 20.0

*Measured with clear water. 1 in./wk = 2.54 cm/wk

Figure 2. *Measured values of application rate versus soil permeability at six slow-rate project sites.*

Table 4. *Nitrogen Concentration in Percolate*

	Con of Total N in Wastewater (C_{Nw})	Hydraulic Loading of Wastewater Actual (L_w)	Crop Uptake of Nitrogen (U_N)	Percolation Rate (from Site Data) (W_p)	Nitrogen Loading from Wastewater ($2.7\,C_{Nw}L_w$) $=(L_{Nw})$	Net Nitrogen Loading $0.8L_{Nw}-U_N$	Conc. of in Percolate $C_{Np}=\frac{0\,81_{Nw}U_N}{2.7\,W_p}$	Nitrogen Applied as Fertilizer (L_{Nt})	Total Nitrogen Loading $L_{NT}=0.8\,(L_{Nt}+L_{Nw})-U_N$	Nitrogen Concentrations in Percolate, C_{Np}	
										Calculated Values $L_{Nt}/2.7\,W_p$	Measured Values at Sites
	mg/l	ft/yr	lb/a-yr	ft/yr	lb/a-yr	lb/a-yr	mg/l	lb/a-yr	lb/a-yr	mg/l	mg/l
CAMARILLO	15	5.1	194	2.9	207	(-28)	Calculated Negative	242	165	21.1	64
Tomatoes Broccoli			Combined Uptake								
DICKINSON	11.8 (Total organic-N +NH_3-N +NO_3-N)	4.6	160	0 8	147	(-13)	Calculated Negative	14	(-18)	Calculated Negative	2.4
MESA	24.9 (Total N)	16.5	262	11.6	1109	625	20	None	--	20	46 4
Barley Sorghum Corn			Combined Uptake								
ROSWELL	42.9	2 6	160	1.1	~300	80	26.9	None	--	26 9	13.7 (<6m) 6 4 (>6m)
Corn											
SAN ANGELO	34 5 avg	8.7	550	7.5	832	115	5 7	62.5 (Does not include manure from livestock grazing)	165	8.1	5.8 (Groundwater) 6.4 (River)
TOOELE Grasses (50%) Alfalfa (50%)	13.2	2.0	310 avg.	-0 3	71 3	(-253)	Calculated Negative	51	-202	--	--

correlation between the observed average values of percolate nitrogen concentration and the estimated values obtained from the procedures in the *Design Manual*. The differences between observed and estimated values of this parameter suggest that the estimating procedures should be carefully reviewed and their limitations explicitly identified.

Conclusions

- All six slow-rate land treatment systems generally reduced the levels of major pollutants in the applied wastewater well below the corresponding levels typically found in effluent from secondary treatment.
- None of the six investigations reported any significant threat to the public health through airborne dispersion of pathogens or contamination of drinking water supplies or vegetation.
- Large amounts of nitrogen and phosphorus were taken up by the crops, but nitrate levels in the leachate increased with depth and in some cases exceeded the EPA standard for drinking water supply.
- The organic matter content, as indicated by BOD and COD levels, was effectively attenuated by the soil, although precise measurement of the attenuation was not always possible when the amount of applied wastewater varied rapidly with time.
- Since suspended solids were filtered out within the first few centimeters of the soil bed, their concentration in the leachate was not measured.
- Concentrations of both total dissolved solids and individual dissolved solids generally increased with depth.
- None of the six facilities received much industrial wastewater with its typically high concentration of heavy metals. The low concentrations of heavy metals found in the soil did not change appreciably with depth. Heavy metal levels in vegetation were within normal ranges, and levels in groundwater were within the limits set by drinking water standards.
- Water-borne pathogen levels, as indicated by measurements of fecal coliform bacteria, protozoa, and nematodes, appear to have been reduced below limits of detection by passage through the soil; some indicators of pathogenic organisms detected on vegetation were attributed to droppings by grazing animals.
- All six test sites investigated would have met the *Design Manual's* land area criteria based on hydraulic conductivity of the soil.
- Three of the six test sites would not have met the *Design Manual's* land area criteria based on nitrogen content in the percolate.
- On the basis of experience during 10 or more years of wastewater application at each of the six sites, the effective life of land treatment systems is estimated to be several decades.
- The economic benefits of wastewater application extend beyond the lower cost of the water and include, in some cases, higher crop yields than at sites where conventional irrigation water was used. One project (Camarillo) reported a 12 percent higher yield at the test site.

Recommendations

- Slow-rate land treatment of municipal wastewater is demonstrated to be an effective means of reducing the concentration of most categories of pollutants. On the basis of the results of the six studies examined here, this method of treatment is recommended for

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consideration as a technically and economically viable supplement to conventional treatment processes and as an alternative to certain of the processing steps typically included in a treatment plant that discharges its effluent to surface waters.

- Although levels of many pathogens (fecal coliform, protozoa, and nematodes) were reduced below limits of detection by soil treatment, the degree of reduction of viruses is not clearly established. Information on viruses in the source reports suggests that further investigations be undertaken to obtain a better understanding of the prevalance and transport of viruses under various conditions of land treatment of wastewater. However, the subject of viruses was not the primary emphasis in the source documents, and was not addressed in depth. It is therefore recommended that the need for additional studies of viral prevalance and transport be reviewed in the light of more recent investigations on these subjects.

- The *Design Manual* procedure for estimating land requirements for slow-rate wastewater treatment systems should be reviewed for adequacy. In particular, the following modifications should be considered for any future edition of the *Design Manual*:

- The procedure for estimating maximum allowable application rates on the basis of the hydraulic conductivity of the most restrictive layer should be more thoroughly discussed.

- The procedure for estimating percolate nitrogen concentration could easily be modified to account for sources of nitrogen other than the applied wastewater (for example, fertilizer or animal droppings) Also, the discussion should point out that the procedure is based on the assumption of equilibrium (or steady-state) conditions, which could yield estimates that differ markedly from measurements made in the field, where conditions may be highly dynamic and may not approach equilibrium during a short-term period of measurement

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The complete report, entitled "Long-Term Effects of Slow-Rate Land Application of Municipal Wastewater," (Order No. PB 82-105 610; Cost: $9.50, subject to change) will be available only from:

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