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HIGHLIGHTS OF RESEARCH ON OVERLAND FLOW FOR ADVANCED TREATMENT OF WASTEWATER

by

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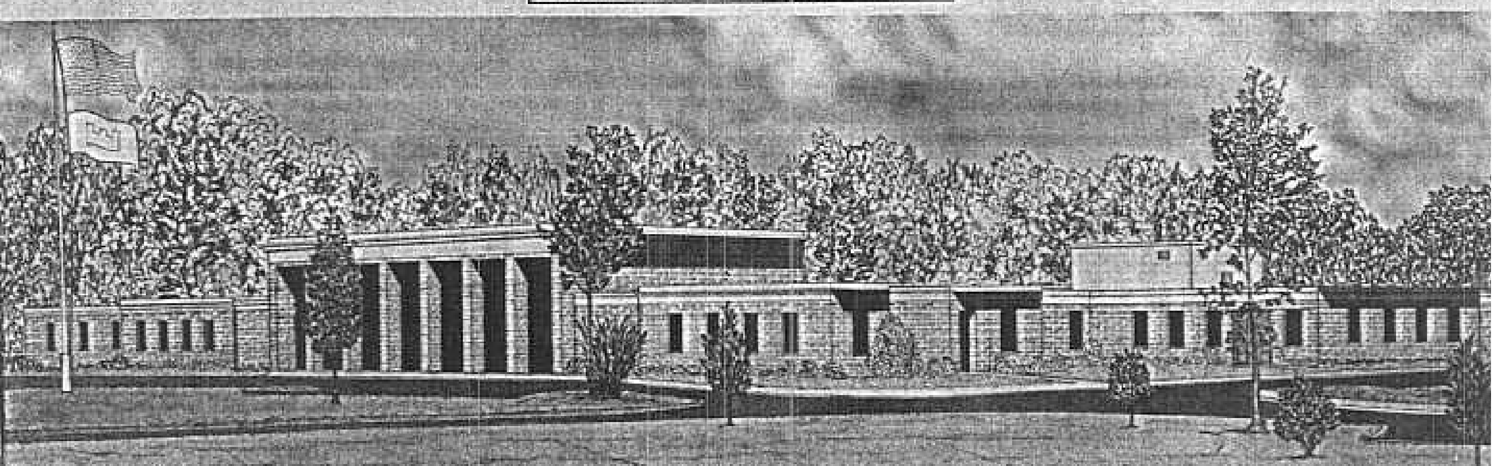

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Overland flow treatment of municipal wastewater was studied in greenhouse grass-soil models. The response of overland flow treatment of nitrogen, phosphorus, and heavy metals to various operating conditions was determined. Nitrogen removal from applied wastewater was exceptionally efficient, with best removal being obtained whenever the applied wastewater was allowed sufficient time to interact with the components of the overland flow system. Sufficient time for adequate treatment of wastewater could be obtained by increasing the application

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period from 6 to 18 hr, by decreasing the amount of applied wastewater from 1 to 1/2 in./acre, by decreasing the slope of the application surface from 8 to 2 percent, or by combinations thereof. Greater than 90 percent nitrogen and heavy metal removal could be obtained during overland flow treatment. Generally, 80 percent of the applied phosphorus was removed with overland flow treatment. Up to 98 percent phosphorus removal could be obtained by addition of stoichiometric amounts of aluminum sulfate to the wastewater prior to land treatment. Nitrogen, phosphorus, and heavy metals were found to accumulate on the soil surface in the organic mat with little movement into lower soil depths. Heavy metals accumulated on the soil surface nearest the point of wastewater application. Elevated levels of heavy metals were correspondingly found in the grass harvested nearest the point of wastewater application.

The results of this modeling study indicate that overland flow is a feasible method for treating municipal wastewater to achieve a tertiary level of water quality.

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Preface

This research was funded by the Department of the Army, Office, Chief of Engineers, through the U. S. Army Cold Regions Research and Engineering Laboratory; Mr. Sherwood Reed and Dr. Harlen McKim were Program Managers during the conduct of the research. Funding was provided by Civil Works Appropriation 96X3121, General Investigation-Research and Development.

This paper contains highlights of the results of a greenhouse modeling study that was conducted during the period July 1972-June 1975 at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., by Drs. Charles R. Lee, Patrick G. Hunt, Ronald E. Hoeppel, Charles A. Carlson, Thomas B. Delaney, Jr., and Robert N. Gordon, Sr., of the Environmental Effects Laboratory (EEL). The study was under the general supervision of Dr. Rex L. Eley, Chief, Ecosystem Research and Simulation Division, and Dr. John Harrison, Chief, EEL.

Directors of WES during the conduct of this study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

Contents

Conversion Factors, U. S. Customary To Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
inches per acre per day	6.2765	metres per square metre per day
million gallons per day	3785.4086	cubic metres per day
acres	4046.856	square metres

HIGHLIGHTS OF RESEARCH ON OVERLAND FLOW FOR ADVANCED TREATMENT OF WASTEWATER

Introduction

1. Advanced treatment of wastewater by land application can be accomplished by one of three methods--each depending to a large extent on the permeability of a soil. Treatment can be obtained during either slow infiltration through a permeable soil (0.05 to 2.5 in./hr*), rapid movement through a large sand or gravel zone (2.5 to over 10.0 in./hr), or slow sheet flow over the surface of a relatively impermeable soil (less than 0.05 in./hr).[1] Numerous systems have been operated successfully for many years and can be cited for both slow infiltration (crop irrigation) and rapid infiltration treatment methods.[2-7] Through years of experimentation and study, a good understanding of the mechanisms involved in these treatments has developed. In contrast to slow and rapid infiltration, the treatment of wastewater by overland flow on soils of low permeability has not been well understood. However, in recent years, more information on how overland flow systems function has become available.

2. A pictorial representation of an overland flow system is shown in Figure 1. Wastewater is applied at the top of gently sloping hills and is allowed to flow as a film of water over the surface of impermeable soil. Renovation of the wastewater occurs as the film of water moves over the soil surface and through an organic mat (biomass) that is predominantly composed of plant residue, grass roots, and microflora. This organic mat is believed to be extremely important to the physical, biological, and chemical functioning of an overland flow system.

3. The common length of slope for an overland flow system is

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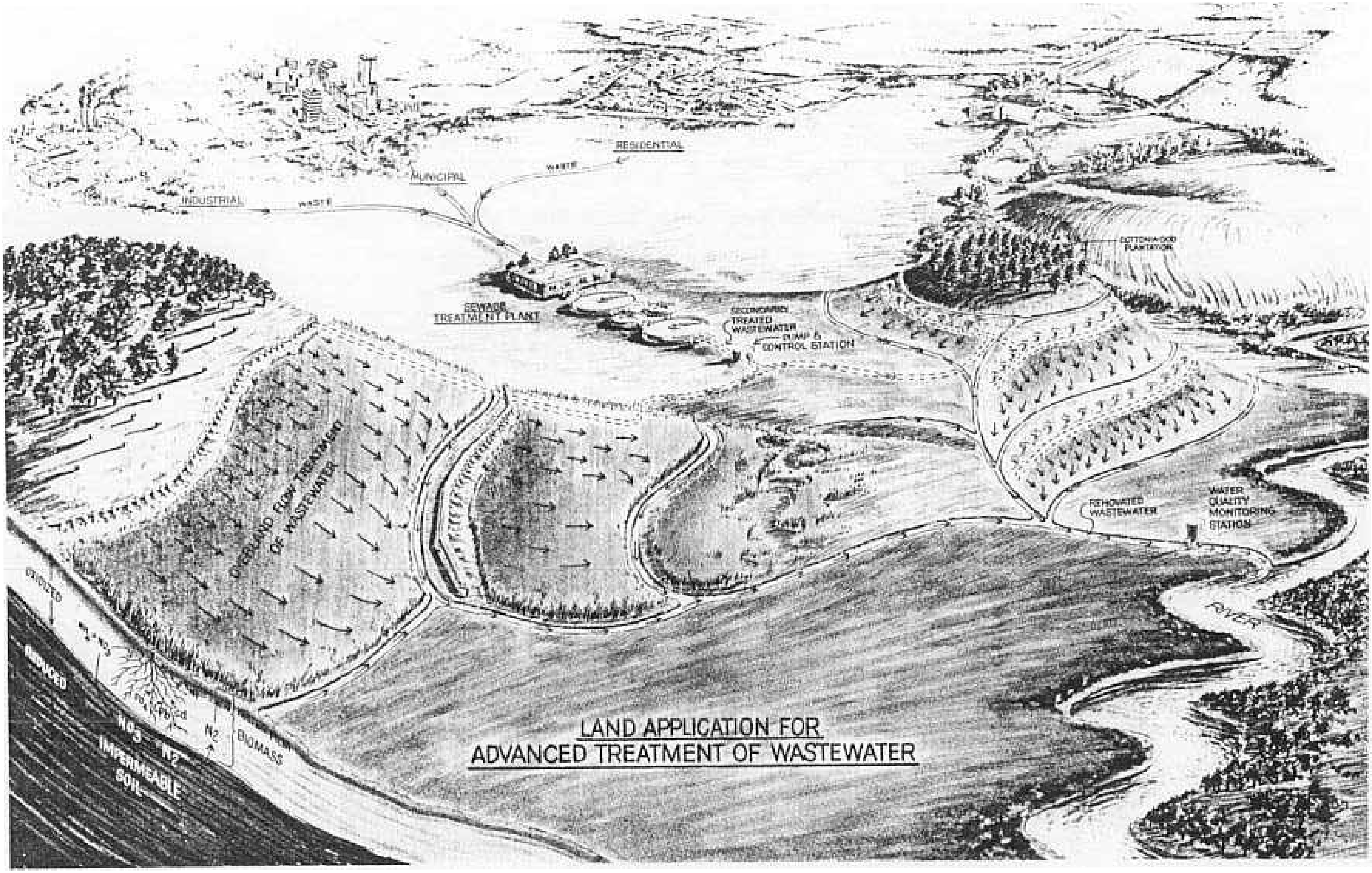
* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.



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100 to 300 ft. Normally the system is employed on slopes ranging from 2 to 8 percent.[8] Application rates are low, generally less than 0.5 in./acre/day, with wastewater being applied 5 days per week. Weekly application rates are approximately 2.5 in./acre, which are comparable to those used on slow infiltration-crop irrigation systems. Runoff water is channeled into a central collection stream. The ability to monitor wastewater as it leaves the treatment site is a valuable characteristic of overland flow systems. The renovated wastewater can be point discharged without underdrainage, and the quality of the treated wastewater can easily be determined and monitored.

4. The most publicized overland flow system is located at the Campbell Soup Company's plant in Paris, Texas. The system, which has operated for over 10 years in a satisfactory manner,[8] has been shown to have high nitrogen and phosphorus removal as well as very good biochemical oxygen demand (BOD) removal.[9] However, the reasons for the efficient wastewater treatment on the overland flow system at Paris, Texas, were somewhat nebulous. It was not known whether a properly designed overland flow system could satisfactorily renovate secondarily treated municipal wastewater.

Research Initiated

5. In 1972, an applied research program was established at the U. S. Army Engineer Waterways Experiment Station (WES), in Vicksburg, Mississippi, to evaluate the feasibility of using slightly permeable and wetland soil for advanced treatment of municipal wastewater. The program is part of the Soil as a Purification Medium for Wastewater Research Program managed by the U. S. Army Cold Regions Research and Engineering Laboratory and supported through the Directorate of Civil Works, Office of the Chief of Engineers.

6. The first 3 years of laboratory studies were conducted under controlled greenhouse conditions with grass-soil models similar to that shown in Figure 2. Models were either 5 by 10 ft or 5 by 20 ft and contained 6 in. of a soil with a very low permeability. The soil

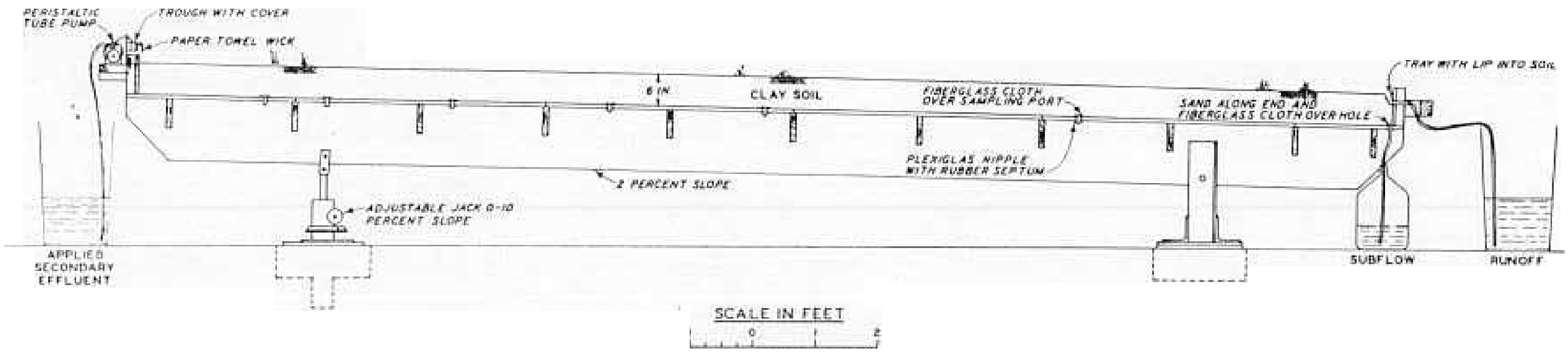

Figure 2. Longitudinal section of the overland flow wastewater treatment model

was Susquehanna clay loam (USDA textural class). The grass cover consisted of a mixture of reed canary grass, tall fescue, bermuda grass, and ryegrass. Further details on the description of the models have been published by Carlson et al.[10] and Hoeppel et al.[11] Treatment of wastewater was evaluated for slopes that ranged from 2 to 8 percent.

7. The wastewater used in these studies was secondarily treated, chlorinated, and normally had total nitrogen contents of 14 to 18 ppm and phosphorus contents of 12 to 14 ppm. Initially, the source of wastewater was a package treatment plant at a local motel. During 1974, wastewater was subsequently obtained from the Vicksburg municipal treatment plant. Concentrations of total nitrogen and phosphorus from the Vicksburg municipal trickling filter system have generally been 15 to 20 ppm and 8 to 12 ppm, respectively. Wastewater was amended at the laboratory with heavy metals (cadmium, copper, lead, manganese, nickel, and zinc), each at a concentration of 0.2 ppm to simulate an industrialized municipal wastewater.

8. Wastewater was applied at the upper slope of each model at rates ranging from 0.5 to 1.0 in./acre/day during either a 6- or 18-hr application period for 5 days per week (wastewater was not applied during weekends). Runoff, subflow (underflow), and surface samples of effluent were collected and analyzed eight times during an 8-week treatment period. Grass and soil samples were collected and analyzed periodically.

Results of Greenhouse Model Research

9. The following discussion summarizes the findings of the greenhouse model studies concerning the response of overland flow treatment of nitrogen, phosphorus, and heavy metals to various operating conditions.

10. The volume of subflow or underflow water generally accounted for less than 25 percent of the applied volume of wastewater during the study. The concentration and amount of nitrogen, phosphorus, and heavy metals in subflow waters were very small and represented less than 5 percent of the amount applied. Because of this insignificant amount of

nutrients and heavy metals found in the subflow component of the overland flow system, the following discussion will emphasize runoff waters.

Nitrogen

11. Generally, overland flow was exceptionally efficient for the removal of nitrogen from wastewater. Total nitrogen removal from wastewater applied at a volume of 0.5 in./acre varied with slope and application period (Figure 3). Up to 99-percent nitrogen removal was obtained at a 2-percent slope with an application period of either 6 or 18 hr.

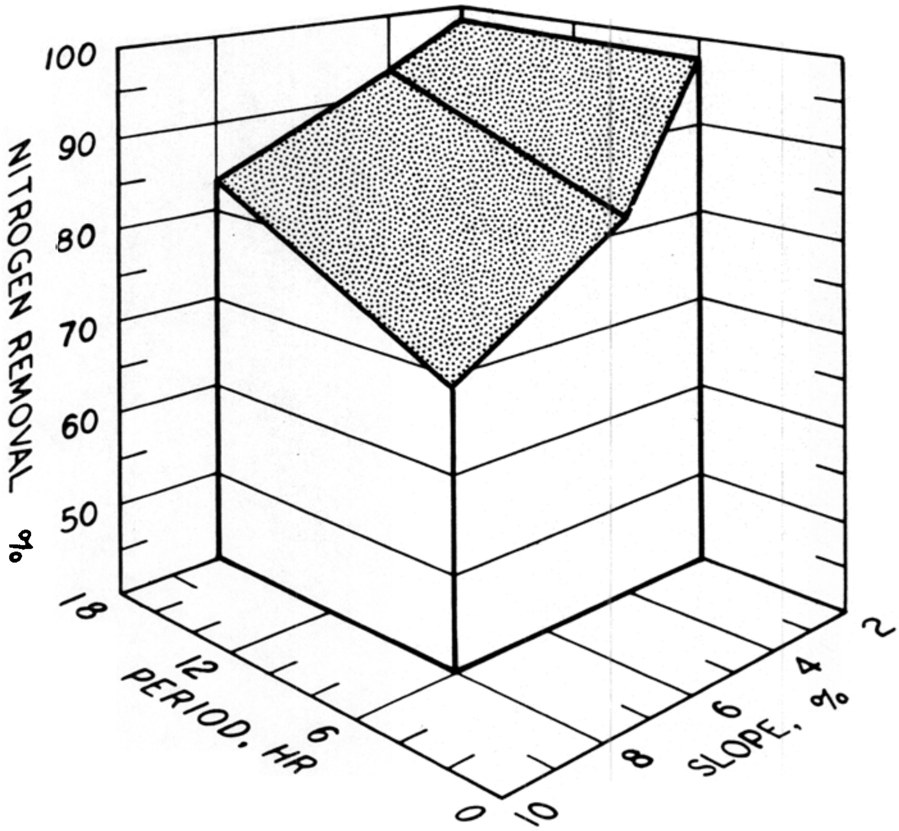

Figure 3. Effect of length of application period and slope on the efficiency of nitrogen removal from wastewater applied at a volume of 0.5 in./acre

Increasing the slope to 8 percent decreased nitrogen removal to 69 percent during a 6-hr application period; lengthening the application period to 18 hr improved nitrogen removal to 80 percent.

12. The nitrogen removal response to application rate and time

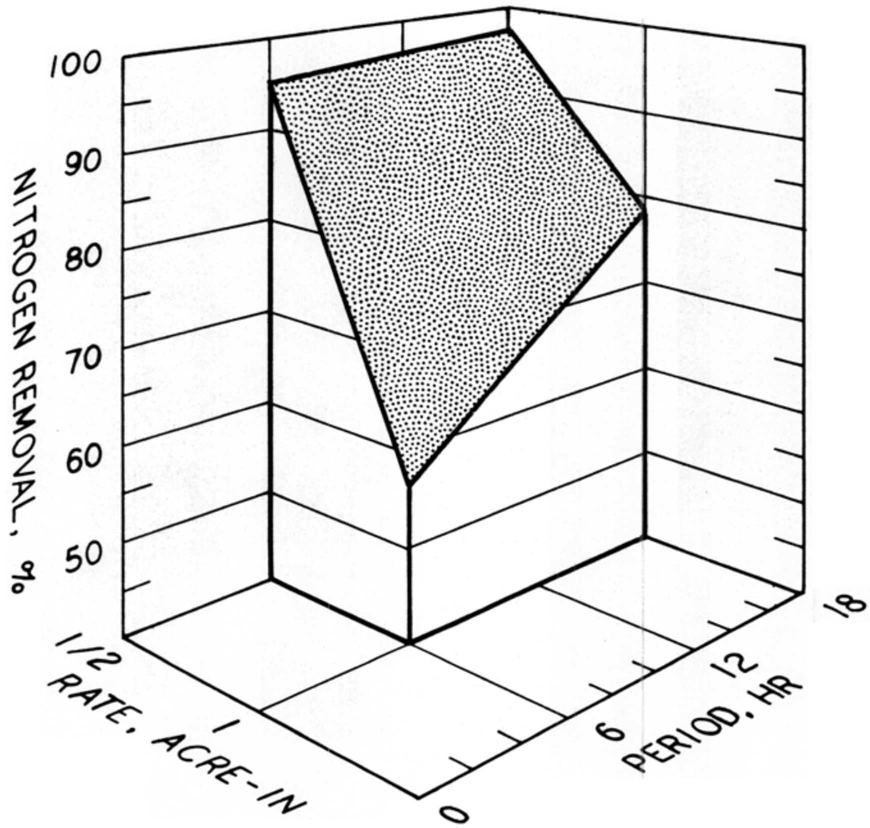

Figure 4. Effect of application volume and length of application period on nitrogen removal from wastewater applied to a 2-percent slope

period is shown in Figure 4. Total nitrogen removal was always 90 percent or better when 0.5 in./acre of wastewater was applied in either 6 or 18 hr on a 2-percent slope. However, when the application volume was increased to 1 in./acre, nitrogen removal decreased to 75 percent and 55 percent for the 18- and 6-hr application periods, respectively. From this, it was quite obvious that overland flow treatment would fail when too large a volume of wastewater was applied during a short time period.

13. The organic layer on the soil surface as well as the shallow root system of the flooded cover crop usually removed from 50 to 75 percent of the applied nitrogen. Significant denitrification appeared to be responsible for the remaining nitrogen removal.

14. Nitrogen treatment by overland flow is envisioned to occur

similar to nitrogen loss from flooded rice fields or marshes.[12-14] The conditions that would permit the processes to occur are presented conceptually in Figure 5. An aerobic or oxidized zone exists in the

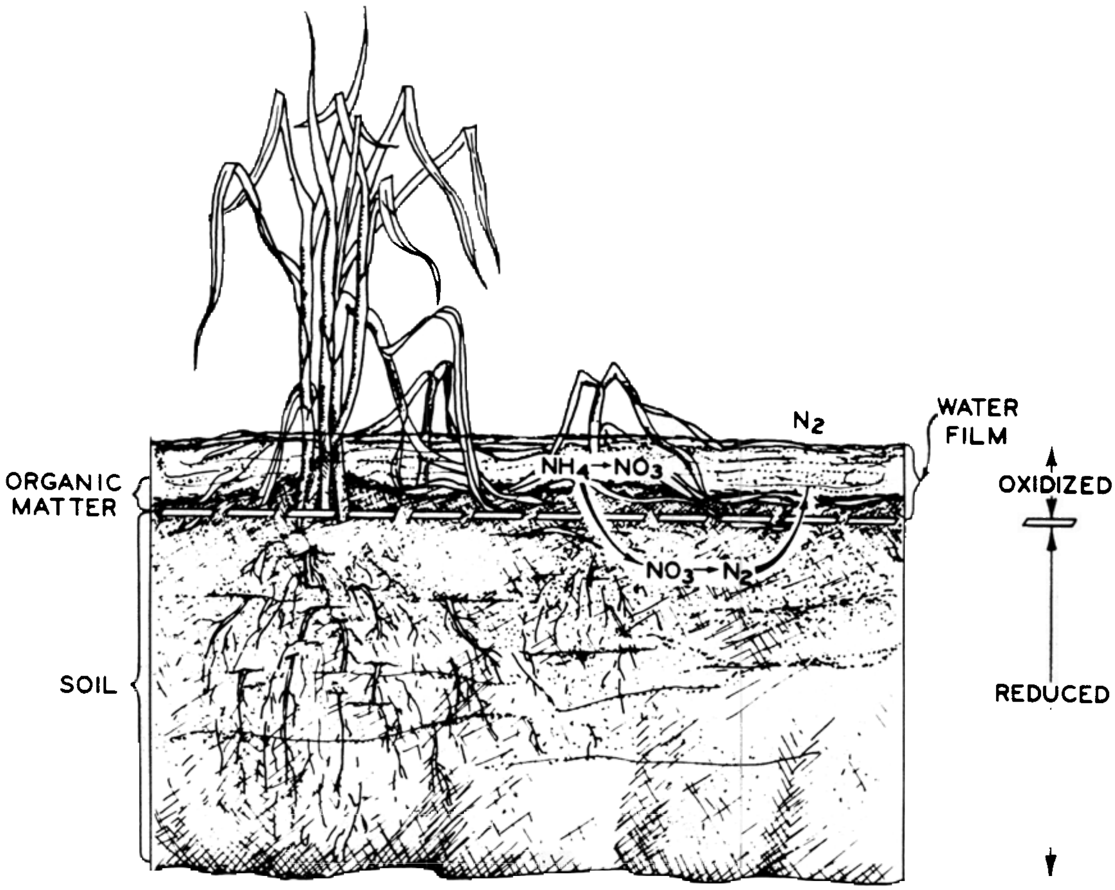

Figure 5. A schematic of conditions that would allow both aerobic and anaerobic processes to occur in an overland flow system

organic matter and film of water on the soil surface. In this zone, ammonium nitrogen is nitrified to nitrate. Nitrate nitrogen is very mobile and moves down into the anaerobic or reduced zone just beneath the soil surface. In this zone, nitrate nitrogen is denitrified to gaseous nitrogen and evolved through the water film to be lost to the atmosphere. The presence of an aerobic-anaerobic double layer at the soil surface was determined by periodically measuring redox potentials during a wastewater application-drying cycle (Figure 6).[10] The redox potential did not reach an oxidized level during wastewater application

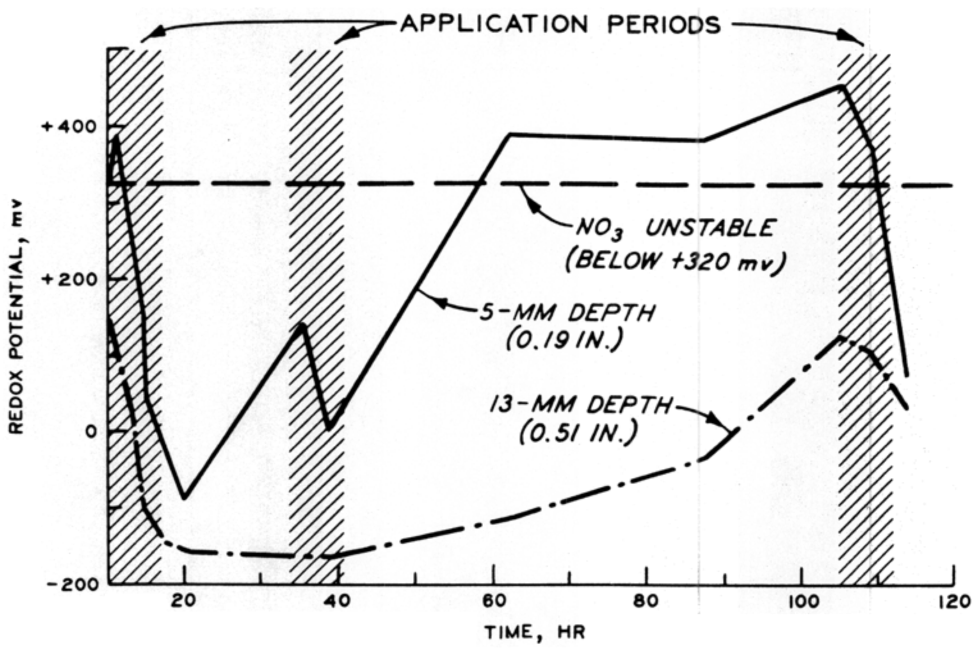

Figure 6. Redox potential of the Susquehanna clay during a wastewater application-drying cycle[10]

at the 0.19-in. depth, but oxygen was present in the surface water and rapid nitrification (an aerobic process) occurred. To date, available evidence suggests that denitrification conditions and substantial losses of nitrogen are associated with both field and model overland flow systems.

15. Nitrogen removal by grass during overland flow was also an interesting phenomenon in that a grass-growth gradient was established down the slope. This gradient has been observed on slopes ranging in length from 180 ft in the field to 18 in. in the greenhouse.[10] This is quite reasonable since grass is very responsive to nitrogen and a growth gradient associated with the decreased nitrogen content would be expected (Figure 7).

Phosphorus

16. Since phosphorus removal via land treatment is best when the wastewater is in close contact with the surface area of clay particles as it moves through the soil, overland flow would intuitively seem to be the poorest method of phosphorus removal. To some extent, this is in fact true; wastewater flowing over the soil surface does not have

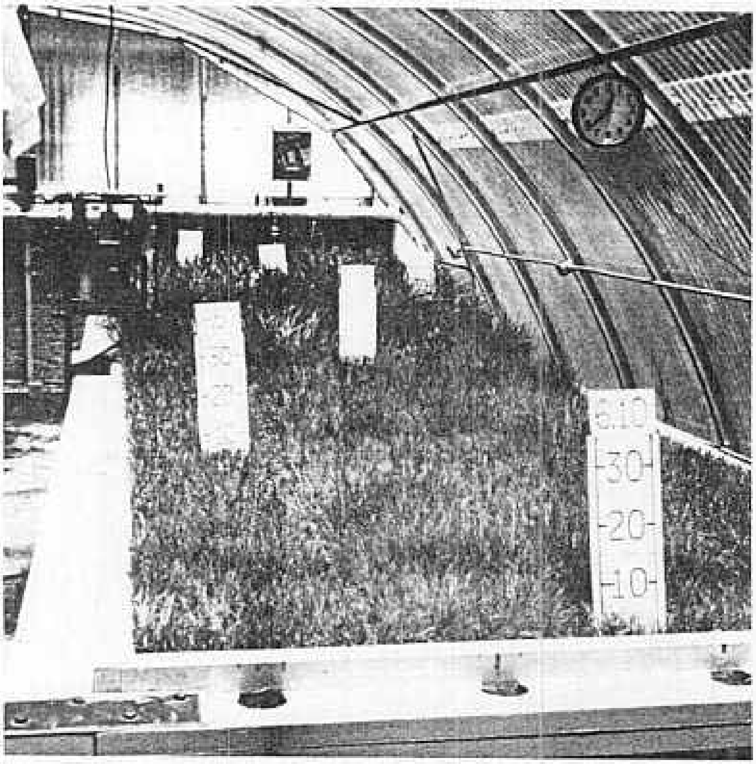

Figure 7. Wastewater model 43 days after start of treatment. Grass height reached 20 to 40 cm (7.87 to 15.74 in.) in upper 10 ft (3.05 m); practically no increase in height and zero nitrogen content in surface water beyond 15 ft (4.57 m)[10]

extensive contact with the iron and aluminum compounds of the soil that normally fix massive amounts of phosphorus.

17. Phosphorus removal was approximately 80 to 84 percent when 0.5 in./acre of wastewater was applied to a 2-percent slope in either 6 or 18 hr (Figure 8). Increasing the slope to 8 percent reduced phosphorus removal to 64 and 50 percent with 18- and 6-hr application periods, respectively. Both increasing slope and shortening application period effectively decreased the residence time in which the wastewater was in contact with the soil surface and organic mat for treatment.

18. The effect of application volume and time period on the efficiency of phosphorus removal (Figure 9) also illustrated the importance of residence time or contact time for proper treatment of wastewater. An application volume of 0.5 in./acre applied in 18 hr

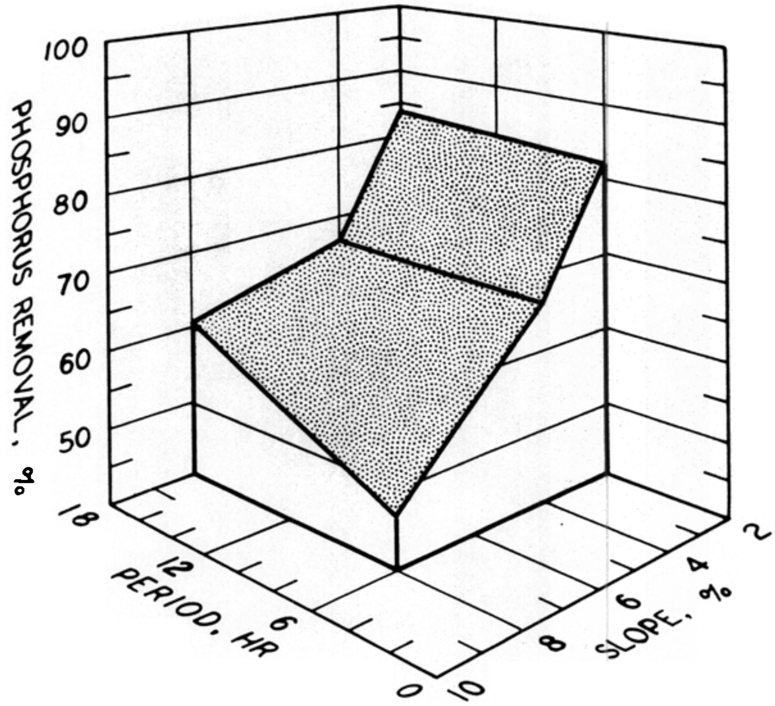

Figure 8. Effect of length of application period and slope on phosphorus removal from wastewater applied at a volume of 0.5 in./acre

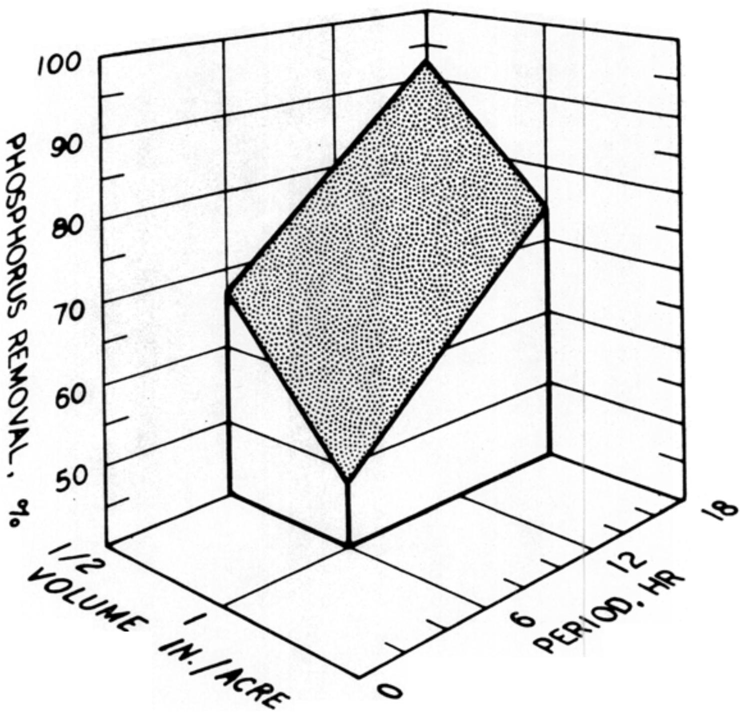

Figure 9. Effect of application volume and length of application period on phosphorus removal from wastewater applied to a 2-percent slope

resulted in more than 80-percent removal. However, an application volume of 1 in./acre applied in 6 hr resulted in less than 50-percent removal.

19. The distribution of phosphorus at various intervals along the slope in the greenhouse model is shown in Table 1. While the concentration of phosphorus in the wastewater decreased down the length of the slope, phosphorus never became limiting as in the case of nitrogen. Since there was always adequate phosphorus in the wastewater down the slope, the grass and the organic mat contained similar concentrations of phosphorus from the upper to the lower ends of the slope. Phosphorus accumulated on the soil surface in the organic mat and did not penetrate deep into the soil profile.

20. A further step to improve phosphorus removal has been tested. Thomas (personal communication, R. E. Thomas, EPA, Ada, Oklahoma) has shown that greater than 80 percent of the phosphorus in raw wastewater can be removed by overland flow if stoichiometric amounts of aluminum sulfate are added before wastewater is applied to the slopes. Similar results have been found with secondarily treated wastewater (unpublished data, C. R. Lee, WES, Vicksburg, Mississippi). As much as 98-percent phosphorus removal could be obtained when aluminum sulfate was added to the wastewater before application to a 2-percent slope. If this pretreatment is used, the aluminum phosphate that accumulates on the soil surface could in time be plowed under and fixed by the reduced clay subsoil.

Heavy metals

21. Heavy metal removal by overland flow was very good; greater than 90 percent of all and greater than 98 percent of some heavy metals[10] were removed when 0.5 in./acre of wastewater was applied in 6 hr on a 2-percent slope. Table 2 shows the effect of slope on the removal of zinc, cadmium, nickel, copper, and manganese when 0.5 in./acre of wastewater was applied in 6 hr. Increasing the slope to 8 percent reduced the percent removal of these heavy metals from wastewater. The effect of application volume and time period on the removal of heavy metals by overland flow is shown in Table 3. The application of 0.5 in./acre

of wastewater in either 6 or 18 hr to a 2-percent slope resulted in removal of 90 percent or more of each heavy metal. When 1 in./acre of wastewater was applied in 18 hr, heavy metal removal was still approximately 90 percent or better. The concentration of heavy metals found in runoff waters generally ranged from a low of 0 to 20 ppb at a 2-percent slope and a 0.5-in./acre application rate to a high of 70 ppb at the 1-in./acre application rate. Since the soil used in these experiments naturally contained a relatively high concentration of zinc, zinc concentrations in runoff waters were larger than normally would be expected.

22. Each heavy metal had an overland flow distribution that was similar to that of nickel (Table 4). The high removal of heavy metals from wastewater by overland flow was found to occur in the organic mat, with little movement deeper into the soil profile. The greatest accumulation of heavy metals occurred nearest the point of wastewater application. The grass nearest the point of wastewater application also contained the greatest concentrations of heavy metals.

23. The long-term effects of heavy metal accumulations on an overland flow system need to be further evaluated since the greenhouse studies indicated heavy metal accumulations in the organic mat. Periodic plowing under of the surface organic mat would tend to fix the heavy metals in the clay subsoil.

Apparent Problem Areas for Overland Flow

24. One of the first considerations in building an overland flow system is to obtain a slope that will allow sufficient residence time to provide adequate treatment. Generally, slopes less than 8 percent are required. In addition, the slope surface must be relatively smooth to produce a uniform flow of wastewater. Depressions may cause treatment problems and erosion. Considerable earthwork may be necessary to obtain the desired slopes and surface conditions. The overland flow system used by Campbell Soup Company in Paris, Texas, for instance, had both timber clearing and soil cut-and-fill operations in its construction. Insufficient preparation of an overland flow treatment site is no less

a problem than underdesign of a settling basin or clarifier in a standard treatment plant.

25. A cover crop is an integral part of overland flow treatment and also an erosion retardant; therefore, good vegetative cover is essential. A mixture of rye, fescue, bermuda, and reed canary grasses has been used most extensively on overland flow systems. Reed canary grass usually dominates in a few years. The major characteristic that any cover crop must have is the ability to live in a reduced (anaerobic) wet soil environment. Plants that require an aerobic soil environment will not be adequate cover crops for an overland flow system.

26. Cold weather is another serious concern. Microbial processes are a significant component in overland flow processes, and their metabolic rates are reduced under cold conditions. The formation of ice may adversely affect treatment performance. A storage reservoir may therefore be necessary to hold wastewater during the adverse weather periods.

27. Even with the proper soil preparation, plant cover, and weather conditions, the most common mistakes made on land treatment of wastewater systems are hydraulic and/or chemical overloading. Overland flow systems are slow rate systems; volumes greater than 0.5 in./acre/day have generally been found unsatisfactory. In addition, the rate at which a given volume of wastewater can be treated each day will vary with slope, climate, and other factors that affect treatment efficiencies.

Cost of Overland Flow Systems

28. Cost of overland flow systems will vary from location to location across the nation. To give specific cost figures may not be meaningful in this report. However, specific components of the system that should be considered include quantity and quality of wastewater to be treated; quality of renovated water required; total land area required; land acquisition; earthwork required in site preparation; distribution system; distance of site from wastewater source; wastewater storage facility; runoff recovery system; monitoring system; system

control and maintenance; manpower requirements for operation and maintenance; monitoring requirements; and emergency procedures and safeguards. Detailed information of these and other considerations can be found in References 8, 15, 16, and 17.

Pressing Needs for Acceptance and Use of Overland Flow Treatment of Wastewater

29. The major need in order to obtain public acceptance and use of overland flow treatment is the construction of several demonstration research systems in various parts of the United States. These systems would provide the data necessary to refine overland flow planning, design, and operation. One such system has been established at Utica, Mississippi, for a field evaluation of overland flow treatment of municipal wastewater. The greenhouse results reported herein will be evaluated and verified under field conditions for 3 years.

30. However, there is sufficient information available at present to clearly indicate that land treatment of wastewater should be considered on soils having low permeability.

Interim Performance Criteria for Planning and Designing Overland Flow Systems

31. The interim criteria related to planning, designing, and operating a successful overland flow treatment system are summarized below. These criteria are primarily based on results of the discussed modeling research and are subject to greenhouse conditions that do not reflect the effects of storm events or cold temperatures. However, these criteria will be updated as information from the field research site is obtained. These criteria should achieve wastewater renovation of greater than 90-percent removal of nitrogen, phosphorus, and heavy metals. They relate to soils with very low infiltration capacities and impermeable barriers such as hard pans, and therefore soils with higher infiltration rates will obviously respond differently. Further information on land treatment systems is contained in References 15, 7, and 17.

a. Overland flow should be used on soils that have restricted permeability, such as soils with infiltration rates of less than 0.05 in./hr.

b. Application sites should have slopes of 2 to 8 percent, preferably between 2 and 4 percent. Wastewater should not be applied to slopes greater than 8 percent.

c. Land surface must be as smooth as possible to minimize channeling.

d. A vegetative cover should be established on the slopes as soon after slope construction as possible to minimize soil erosion. Normally, a high rate of seeding, adequate fertilization, and irrigation with tap water or very low rates of wastewater are needed. A cover crop, such as reed canary grass or rice, that can withstand reduced (anerobic) soil conditions should be used.

e. Wastewater can be applied by spraying or flooding.

f. Application rates of wastewater should not exceed 0.5 in./acre/day unless evapotranspiration is very high.

g. Application periods can be from 6 to 18 hr. The longer application periods are needed for steeper slopes.

h. Wastewater should be applied for 4 or 5 days per week, weather conditions permitting, in order to maintain a balance between aerobic and anerobic conditions.

i. Wastewater storage will be required in periods of inclement weather such as cold or storm incidences.

j. At a rate of 0.5 in./acre/day, 100 acres of land treatment system will renovate 0.66 million gal/day (mgd), considering allowances of 8-percent inclement weather, 5 days application per week, and 75-percent treatment area.

k. Normally, grass may be harvested and processed for animal feed. However, where potential toxicants are contained in the wastewater, grass should be monitored for these constituents.

l. Greater than 90-percent phosphorus removal can be obtained by the addition of stoichiometric quantities of aluminum sulfate to the wastewater prior to land application. Otherwise, as much as 80-percent phosphorus removal can be expected.

References

1. U. S. Department of Agriculture, Soil Survey Manual Handbook No. 18, U. S. Government Printing Office, Washington, D. C., 1951.

2. Bower, H. "Renovating Secondary Effluent by Groundwater Recharge with Infiltration Basins," Recycling Treated Municipal Wastewater and Sludges Through Forest and Cropland, W. E. Sopper and L. T. Kardos, ed., The Pennsylvania State University Press, University Park and London, 1973, pp 164-175.

3. Pound, C. E. and Crites, R. W., "Wastewater Treatment and Reuse by Land Application--Volume I: Summary," EPA Technology Series 660/2-73-006a, 1973.

4. __________, "Wastewater Treatment and Reuse by Land Application--Volume II, EPA Technology Series 660/2-73-006b, 1973.

5. Reed, S. (Coordinator), "Wastewater Management by Disposal on the Land," Special Report 171, 1972, U. S. Army Cold Regions Research and Engineering Laboratory.

6. Sopper, W. E. and Kardos, L. T., ed., Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland, The Pennsylvania State University Press, University Park and London, 1973.

7 Sullivan, R. H., Cohn, M. M., and Baxter, S. S., "Survey of Facilities Using Land Application of Wastewater," EPA 430/9-73-006, 1973.

8. Gilde, L. C. et al., "A Spray Irrigation System for Treatment of Cannery Wastes," WPCF 43, 1971, pp 2011-2025.

9. Law, J. P., Thomas, R. E., and Myers, L. H., "Nutrient Removal from Cannery Wastes by Spray Irrigation of Grassland," FWPCA Water Pollution Control Series 16080, 1969.

10. Carlson, C. A., Hunt, P. G., and Delaney, T. B., Jr., "Overland Flow Treatment of Wastewater," Miscellaneous Paper Y-74-3, 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

11. Hoeppel, R. E., Hunt, P. G., and Delaney, T. B., Jr., "Wastewater Treatment on Soils of Low Permeability," Miscellaneous Paper Y-74-2, 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

12 Patrick, W. H., Jr., and Mikkelsen, D. S., "Plant Nutrient Behavior in Flooded Soil," Fertilizer Technology and Use, 2nd ed., Soil Science Society of America, Madison, Wis., 1971, pp 187-215.

13. Patrick, W. H., Jr., Delaune, R. D., and Engler, R. M., "Soil Oxygen Content and Root Development of Cotton in Mississippi River Alluvial Soils," Louisiana State University Agricultural Experiment Station Bulletin No. 673, 1973.

Ponnamperuma, F. M. (Moderator), The Mineral Nutrition of the Rice Plant. The Johns Hopkins Press, Baltimore, Md., 1965.

Pound, C. E., Crites, R. W., and Griffes, D. A., "Costs of Land Application Systems," EPA Office of Water Program Operations Contract No. 68-01-0966, 1974.

U. S. Environmental Protection Agency, Region III, "Land Application of Wastewater," Proceedings of a Research Symposium, University of Delaware, Newark, Del., EPA 903-9-75-017, 20-21 Nov 1974.

17. U. S. Environmental Protection Agency, Office of Water Program Operations, "Evaluation of Land Application Systems," EPA Technical Bulletin 430-9-75-001, 1975.

Table 1

Distribution of Phosphorus in Overland Flow Treatment*

Component	Phosphorus Content, ppm, at Distance Downslope, ft					
	0	2.5	5.0	10.0	15.0	20.0
Wastewater	13.0	12.6	12.4	9.4	7.4	5.0
Grass		9725	10,118	10,238	9870	9725
Organic mat		5250	3,900	4,100	3250	5950
Soil: 0-1 in.		1450	1,100	1,050	1200	650
1-6 in.		400	300	150	200	440

* After 8 months of wastewater application at 0.5 in./acre/day for 5 days/week.

Table 2

Effect of Slope on the Efficiency of Removal of Heavy Metals from Runoff Waters

Slope, %	Removal, %				
	Zinc	Cadmium	Nickel	Copper	Manganese
2	94.2 a	97.1 a	93.0 a	96.7 a	100.0 a
4	92.7 a	94.6 b	91.1 ab	85.4 b	96.4 b
8	54.7 b	91.3 c	87.8 b	87.0 b	95.8 b

Note: Values within a column followed by the same letter are not statistically different at the 5-percent level of significance according to the least significant difference test.

Table 3

Effect of Application Volume and Time Period on Efficiency of Removal of Heavy Metals from Runoff Water

Application Volume in./acre	Application Period hr	Removal, % Zinc	Cadmium	Nickel	Copper	Manganese
	6	94.2	97.1	93.0	96.7	100.0
	18	92.1 a	97.0 a	90.5 a	96.0 a	99.8 a
1	6	77.0 b	79.9 c	78.4 b	87.0 a	99.2 a
1	18	90.5 a	91.6 b	87.9 ab	95.3 a	97.6 a

Note: Values within a column followed by the same letter are not statistically different at the 5-percent level of significance according to the least significant difference statistic.

Table 4

Distribution of Nickel in Overland Flow Treatment*

Component	Nickel Content, ppm, at Distance Downslope, ft 0	2.5	5.0	10.0	15.0	20.0
Wastewater	0.190	0.138	0.085	0.052	0.042	0.025
Grass		12.0	14.3	9.3	4.0	3.0
Organic mat		234	179	114	37	21
0-1 in.		36	14	10	6	6
1-6 in.		27	9	3		

After 8 months of wastewater application at 0.5 in./acre/day for 5 days/week.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Lee, Charles R

Highlights of research on overland flow for advanced treatment of wastewater, by Charles R. Lee, Patrick G. Hunt, Ronald E. Hoeppel, Charles A. Carlson, Thomas B. Delaney, Jr. [and] Robert N. Gordon, Sr. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.

24 p. illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper Y-76-6)

Prepared for U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H.

References: p. 21-22.

1. Land treatment of wastewater. 2. Models. 3. Overland flow. 4. Wastewater treatment. I. Hunt, Patrick G., joint author. II. Hoeppel, Ronald E., joint author. III. Carlson, Charles A., joint author. IV. Delaney, Thomas B., joint author. V. Gordon, Robert N., joint author. VI. U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper Y-76-6)

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