PROCEEDINGS OF THE SYMPOSIUM ON LAND TREATMENT OF SECONDARY EFFLUENT

edited by

J. Ernest Flack

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PROCEEDINGS OF THE

SYMPOSIUM ON LAND TREATMENT OF SECONDARY EFFLUENT

November 8-9, 1973

University of Colorado

Edited by J. Ernest Flack

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PREFACE

The Center for Urban Engineering Studies of the College of Engineering and Applied Science, University of Colorado and the Environmental Resources Center of Colorado State University joined together to sponsor a symposium on land treatment of effluent from secondary wastewater treatment plants. Land treatment and land disposal of effluent and sludges is receiving increased attention from cities, planners and consultants as water quality requirements are made more stringent.

Developing upon a concern first expressed by Mr. Kenneth R. Wright, a consulting engineer from Denver, Colorado, the idea for a symposium developed through the late summer and fall of 1973. The symposium was to be directed at the practical level - to explore with thoroughness the advantages and disadvantages of land treatment in a western context and emphasizing the site specific nature of the process. Experts from many disciplines - law, health, engineering, soil science, hydrology - and regulatory agencies, and from across the United States, were invited to present papers.

This proceedings contains the edited version of most of these papers. While there have been other excellent publications recently on land treatment (these are cited in the papers herein) we believe that this proceedings offers unique and worthwhile insights into the regional nature of land treatment. Bill Sopper's updated account of the Penn State experience, Stuart Dunlop's paper on health aspects, and F. E. Broadbent's challanging paper on nitrification-denitrification are examples of timely and significant contributions to the state-of-the-art and the promises of this new-old treatment concept.

Nearly 200 persons registered for the symposium, held in Boulder on November 8 and 9, 1973, and we are grateful for their interest and support. Their names and addresses are included, along with the program of the symposium, at the end of the proceedings.

Special thanks are extended to the panelists, who, at the end of the symposium, shared their viewpoints on regulation, implementation and constraints of land treatment of secondary effluent. They and the agency viewpoint they were asked to represent were:

Robert Hagan, chairman - Region VIII, EPA, Denver
Earl Balkum - Colorado Water Quality Control Commission
Andy Kurtz - Legislative council, Colorado Farm Bureau
Kenneth Wright - Consulting engineer, Denver
Donald Barnes - U.S. Corps of Engineers, Omaha District
Robert Westdyke - City of Boulder, Colorado

Appreciation is extended to the following; Region VIII, Environmental Protection Agency which through Mr. Russell Fitch assisted with travel expenses; Rocky Mountain Section, American Water Works Association for their mailing list; Colorado Section, American Society of Civil Engineers, for making available their mailing list; Region VIII, EPA for their mailing list.

Special thanks to the Bureau of Conferences and Institutes, University of Colorado and its director, Mr. George Goulette, for conference arrangements and the Department of Civil and Environmental Engineering, University of Colorado for its logistics support.

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March, 1974

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TERTIARY WASTEWATER TREATMENT BY LAND APPLICATION - CONSIDERATION OF SECONDARY EFFLUENT CHARACTERISTICS

By

Edwin R. Bennett*

Introduction:

Virtually all of the municipal wastewater in Colorado receives secondary sewage treatment before being released to the environment. With the newly enacted State Effluent Standards and proposed Federal "Best Practical Waste Treatment" rules, many communities are now in the preliminary decision making process regarding tertiary wastewater treatment. The three major alternatives in this decision are (1) mechanical plants involving advanced technology of physical, chemical and biological removal of pollutants from sewage treatment plant effluent streams; (2) land treatment involving spray irrigation and some form of agricultural production; and (3) renovation and reuse of wastewater for industrial and recreational purposes.

Application to the land is one of the oldest sewage disposal techniques. At the beginning of the twentieth century, it was quite common for small cities to provide primary treatment with

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septic or Imhoff tanks and to release the wastewater to a stream. In arid regions wastewater disposal was accomplished by allowing it to percolate into the ground through land application. In areas such as the Central Valley of California, inland Texas and other parts of the Southwest, it was recognized that surface streams often did not have sufficient assimilation capacity for sewage effluent, and for this reason, land application was practiced. It was also done to augment the amount of water available for agriculture through groundwater recharge. With the advent of major irrigation projects such as the Central Valley Project, the need for this source of irrigation water was eliminated and many of the land disposal systems were discontinued.

Another major user of the land treatment process is industry. This technique is often utilized where high strength wastes are involved. Even with primary and secondary treatment, some industrial wastes cannot be purified to a level to be acceptable for discharge to surface streams. Hundreds of industries throughout the country use the land disposal technique for their wastewater.

In recent years the assimilative capacity of streams has been redefined and new standards have been set. In order to meet the new standards, municipalities and industries will be required to provide some form of tertiary treatment. This has prompted a new interest in land application, and in a new context as a tertiary treatment process.

These new applications are designed for nutrient balance through proper application rates. They must be carefully controlled and monitored to ensure that environmental quality standards are met.

The choice between land application and advanced treatment plant processes for tertiary treatment is primarily one of cost. There is a very different economy of scale for the two methods. Advanced sewage treatment plant processes which may involve chemical coagulation and filtration or carbon adsorption or biological treatment are characterized by mechanical systems and tankage. The capital investment requirements result in pronounced economies-of-scale as measured by the unit price for large scale operations. In land application,on the other hand, major costs are the land and, in the Western States, water rights. These commodities have a nearly constant unit price and may even increase with large scale projects. As a result, land application techniques may be particularly attractive for small scale projects. Most of the present land application systems have a capacity of no more than a few million gallon per day. Land application efficacy is site specific due to land costs, climate and soil characteristics. The evaluation and process choice must be made on an individual site basis.

Secondary Wastewater Effluent Characteristics:

The pollution characteristics of wastewater effluent that has received secondary treatment and is the feed water for the tertiary process are of importance in the planning of these systems (1,2,3). Secondary effluent characteristics vary somewhat from one treatment plant to another. The variations are caused by the type and efficiency of secondary treatment involved, the amount and types of industries on the system and the chemical characteristics of the water supply. As an example of secondary treatment effluent characteristics, data from the Denver Metropolitan Sewage treatment plant effluent is given in Table I.

In order to evaluate land treatment potentials with water pollution standards, it is necessary to define several different methods for using land application treatment. The different methods of application produce quite different pollutant removals, have significantly different costs and must meet different standards. It is important to match the correct costs with the removals and standards to be met in order to obtain a proper perspective of the potential of this treatment method.

Four different land treatment systems can be described based on the possible combinations of two design variables, the liquid loading rate and the ultimate point of disposal of the water.

TABLE I. Waste Effluent Data (4)

Constituent	Wastewater Effluent
Physical:	
SS (mg/l)	98
Turbidity (JTU)	45
Color (color units)	75
Odor (TON)	27.2
Microbiological (no./100 ml):	
Coliforms	160,000
Fecal coliforms	26,000
Fecal strep	2,000
Organic constituents (mg/l):	
CCE	2.478
CAE	1.185
MBAS	0.116
COD	62.0
BOD	24.0
Phenols	0.01
Nutrients (mg/l):	
Phosphate	8.7
Nitrate-N	Trace
Ammonia-N	17.5
Kjeldahl-N	28.2
Toxic chemicals (mg/l):	
Arsenic	0.003
Barium	0.192
Cadmium	<0.001
Chromium (total)	0.050
Cyanide	<0.01
Fluoride	1.09
Lead	0.082
Selenium	<0.001
Silver	0.008
Inorganic ions (major):	
Alkalinity ($CaCO_3$) (mg/l)	246
Calcium (mg/l)	62
Chloride (mg/l)	120
Hardness ($CaCO_3$) (mg/l)	199
Magnesium (mg/l)	10.6
Sulfate (mg/l)	168
TDS (mg/l)	480
Specific Conductance (µmho	1,030
Sodium (mg/l)	155
Silica (mg/l)	10.1
Potassium (mg/l)	
pH	7.7

(Continued)

TABLE I. Waste Effluent Data (Continued)

Constituent	Wastewater Effluent
Trace elements (mg/l):	
Aluminum	0.16
Bromine	0.197
Cobalt	<0.001
Columbium	0.001
Copper	0.070
Germanium	<0.001
Gold	<0.001
Iron (filtered)	3.00
Lanthanum	<0.001
Manganese	0.075
Molybdenum	0.100
Nickel	0.120
Rubidium	0.061
Silver	0.008
Strontium	0.400
Tin	0.003
Titanium	0.124
Tantalum	<0.001
Tungsten	0.147
Uranium	0.041
Yitrium	0.001
Vanadium	<0.001
Zinc	0.185
Zirconium	0.013

It is possible to design a balanced land treatment system so that most of the nitrogen is removed from the wastewater and is taken up by the crops, for instance, corn or reed canary grass, grown on the irrigation plot. This necessitates a relatively low hydraulic loading rate and a large amount of land. A portion of the land and system distribution costs can be offset from the sale of the crops. An alternative design could incorporate a near maximum hydraulic percolation rate for the soil. Such a system would utilize much less land, usually be much less costly, produce less crops, and importantly, would not remove nitrogen to any appreciable extent from the wastewater. Other pollutants may also have a lower removal efficiency with this latter system.

The location of the ultimate disposal of the liquid is important because this determines the water quality standards to be met. The water can be permitted to percolate to the groundwater table and become a part of the groundwater resource. Since groundwater is often used as a drinking water source without treatment or dilution, a very high degree of pollution removal would be required of this type of land treatment system. As an alternate, it is possible to use sub-drains and collect the treated wastewater and return it to a surface stream. This is expensive but it allows the effluent to meet more lenient stream standards. The stream standards are less restrictive because of dilution, natural purification and the fact that stream water is not used for drinking water unless it receives extensive treatment.

The four land treatment and disposal methods resulting from these two design parameters can be summarized as follows:

A. A balanced nitrogen removal system with discharge to the groundwater resource.

B. A balanced nitrogen removal system with underdrains and discharge to a surface water body.

C. A maximum infiltration rate system (without nitrogen removal) with discharge to the groundwater resource.

D. A maximum infiltration rate system (without nitrogen removal) with underdrains and discharge to a surface water body.

If tertiary sewage effluent produced from land treatment systems is allowed to percolate into the groundwater resource as in systems (A) and (C), it does not readily intermix with the existing groundwater. As a result, it is possible for well-waters to have nearly the same mineral content as the percolate water. Recognizing this fact, the Environmental Protection

Agency has proposed new standards to define "Best Practicable Waste Treatment" as it applies to protection of groundwaters (5).

These standards are nearly identical to the USPHS drinking water standards except that levels for sodium (270 mg/ℓ), mercury (0.005 mg/ℓ) and pesticides have been added and some of the non-toxic parameters such as total dissolved solids have been omitted. When a typical secondary effluent, such as that in Table I, is compared with these standards it can be noted that several elements must be removed by land treatment in order to assure compliance with the groundwater standards. These are shown in Table 2.

TABLE 2. Removal Requirements

	Secondary Effluent mg/ℓ	Standard mg/ℓ
Iron	3.0	0.3
Manganese	0.075	0.05
Lead	0.082	0.05
CCE	2.5	0.3
CAE	1.8	1.5

Only limited data is available on the removal efficiency of pollutional constituents for the different types of land treatment systems, but it appears that all of these constituents would be satisfactorily removed with the possible exception of the

Carbon-Chloroform Extract (CCE). CCE is a measure of gross refractory organics in the water. More carefully monitored evaluation of land treatment sites will be necessary to confirm this point.

The wastewater characteristics in Table I are for Denver, Colorado, and they reflect the low mineral content of the source water which is derived primarily from snowmelt. For other communities with more highly mineralized source waters, the wastewater content of the elements sodium, chloride and sulfate may be over the standard. Each of these elements has a use increment in the range of 125 mg/ℓ and it is expected that these elements would not be effectively removed by any of the types of land treatment.

Probably the most critical element for evaluation of land treatment systems discharging to the groundwater is nitrogen. A large portion of the Kjeldahl nitrogen will be converted to nitrate by the soil bacteria nitrosomonas and nitrobacter in the land treatment process. If land treatment system (C) is used or if system (A) is poorly controlled, it is quite possible that groundwater concentration of nitrate will be well above standard. Due to the health hazard associated with nitrate, this could not be permitted.

The effluent from land treatment systems (B) and (D) utilizing underdrains and discharge to surface waters must meet applicable sewage treatment plant effluent standards and have pollutional levels low enough so that the stream standards are not violated. In Colorado, this means that the biochemical oxygen demand (BOD), suspended solids (SS), turbidity and color of the effluent must all be below 20 mg/ℓ or 20 units to meet the standards for the near future. In order to meet stream standards for a receiving water course classified as a potential drinking water source, the effluent after chlorination and dilution in the stream, at the ten percentile low flow, must have a coliform density of less than 5000 per 100 milliliters and total dissolved solids of less than 500 mg/ℓ as well as a BOD low enough so that the dissolved oxygen level of the stream does not go below 6.0 mg/ℓ. In general, these standards can be met with land treatment as well as with most other forms of tertiary treatment.

<u>Summary</u>:

Many city planners and engineers are formulating information to be used in deciding on the tertiary treatment process to be used as a part of their wastewater treatment facilities. The following is a brief comparison of the advantages and disadvantages of the four different forms of land treatment as compared with advanced wastewater treatment employing physical, chemical and mechanical systems.

Some advantages of land treatment compared to advanced wastewater treatment:

1. Simplicity and reliability - The water is simply applied to the land and receives treatment as it percolates through the soil. This is a particularly important asset for small towns where operational errors with mechanical systems are not infrequent.
2. Nutrient removal and improved stream quality - High phosphorous removal is accomplished at most land disposal sites as long as surface soil erosion and runoff is prevented. A high degree of nitrogen removal can be accomplished with systems (A) and (B). Significant nitrogen removal is not accomplished with systems (C) and (D). It should be noted that nitrogen and phosphorous removal are not a universal requirement for all discharges. The EPA has estimated that about 15% of the waterways in the U.S. require nutrient

reduction and in many of these, the problem may be caused by over application of agricultural fertilizer nutrients.

3. Less sludge to dispose - sludge disposal has both high costs involved and technological difficulties. These problems are virtually eliminated for the tertiary treatment process when land treatment is used because the site can also be utilized for sludge disposal.

4. Less potential for waterborne disease transmission - The filtering action of the soil is probably more effective than chemical disinfection for pathogen removal.

5. Eliminates effluent point source - In general, some of the water from the land treatment site will eventually become a part of a surface stream as return flow. In system (A) and (C) the return flow is a line source instead of a point source. This has some benefit in dilution and mixing in the stream but may complicate the monitoring problem.

6. Land use control - All types of land treatment utilize large areas of farmland, greenspace, and openspace which preclude housing or industrial development in or near the disposal field. This may be highly desirable in many communities.

7. Crop by-product - Land treatment systems produce crops that can be used for animal feed and the value of the nutrients in the wastewater can help to offset the disposal cost. The

method for accounting for the value of the crops must be considered somewhat differently for the West, where water is a valuable and finite resource and its use is controlled by law. In this part of the country, a city must buy the land and the water in order to utilize the land treatment concept. Under these conditions, the monetary gain from the farming operation is equivalent to the value of the "free" fertilizer or nutrients in the wastewater. Based on typical household sewage discharge, the value of the nutrients applied to the soil has been estimated to be in the range of $10/family/year. Since this involves an overdose of potassium and phosphorous, the useable nutrient value to the crop may be in the range of $5/family/year. This savings could be realized with system (A) and (B). Since nitrogen is not utilized to any large extent in systems (C) and (D), the nutrient value of the effluent wastewater in these systems is minimal. The value of water rights varies for different locations in the West. Assuming a water resource value of $35 per acre foot, the value of the water lost by evaporation in a land treatment process could exceed the value of the nutrients severalfold.

Some disadvantages of land treatment compared to advanced wastewater treatment:

1. Unknown aspect- many of the economic and technologic factors relating to land disposal are not well known. Major among these are the effect of land treatment on the groundwater. Since groundwater moves very slowly, it is possible that buildup of nitrogen, salinity, heavy metals and other elements may make the groundwater and possibly the land resource unsuitable for use in the future. The groundwater in many presently irrigated areas is unfit for drinking water use because of the build-up of nitrogen from the overdose of fertilizers. There are also problems related to airborne disease organism transport from the sprays and heavy metal transport in the food chain that need further consideration. The procedure is site-specific and highly dependent on the soil and soil-moisture relationships.
2. Water rights - in the Western U.S. nearly all waters are appropriated, including sewage effluents. If sewage effluents are withheld from the stream by land treatment irrigation systems, it would be necessary to purchase other irrigation rights to meet downstream rights. It is possible to use systems (B) and (D) with drainage pipes at some depth to recover the water and put it back in the stream. In this case, only the water lost by evaporation would have to be made up. Evaporation losses during irrigation can be as great

as fifty percent in systems (A) and (B). If these losses are not made up, the adverse effects of reduced stream flow may be encountered. The evaporation also concentrates the salts in the percolate water and would result in an increase in salinity in the return flow and in the receiving stream.

3. Power consumption - the amount of power required to drive the pumps and the spray irrigation rigs may be greater than required for alternative methods of treatment.
4. Odor problems - odor problems may exist in land disposal systems. It may be necessary to purchase large amounts of land for a buffer zone.
5. Erosion danger - surface runoff from the land treatment site caused by application rates exceeding the infiltration capacity as a result of excessive irrigation or rain storms could wash top soil into streams producing sudden high concentrations of phosphorous and heavy metals in the stream.
6. Institutional problems - the purchase and control of large land areas by municipalities may meet with resistance from the public sector.

<u>Other considerations</u>:

A major consideration in selection of a tertiary treatment system is the net cost per unit of wastewater treated. The differences in economy of scale for land treatment and advanced wastewater treatment tends to favor land treatment for small systems and advanced wastewater treatment for larger systems. If nitrogen removal is a requirement of the tertiary treatment system, the cost of the advanced wastewater treatment option increases markedly, regardless of the system adopted.

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A DECADE OF EXPERIENCE IN LAND DISPOSAL OF MUNICIPAL WASTEWATER

by

William E. Sopper*

Many water pollution problems have been created by the disposal of treated municipal wastewaters into streams, lakes, and oceans. There are currently about 16,000 sewage treatment plants in the United States discharging over 26 billion gallons of effluent daily. As environmental quality pressures mount more plants will have to be built to meet new stringent water quality standards. This move from dispersed simple wastewater treatment by many individual septic tanks to collection and concentration of wastewater for treatment at a single plant will provide only a partial solution to water pollution problems. Advanced secondary treatment eliminates the health hazard associated with untreated wastes and most of the organic matter is decomposed into its inorganic components. However, it is the concentrated discharge of these mineral-enriched effluents into a balanced aquatic environment which causes ecological chaos and disrupts the natural recycling process.

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An obvious alternate method to disposal of sewage effluent in surface waters is to dispose of such effluents on the land so as to utilize the entire biosystem--soil and vegetation--as a "living filter" to renovate the effluent for groundwater recharge. Under controlled application rates to maintain aerobic conditions within the soil, the mineral nutrients and detergent residual might be removed and degraded by microorganisms in the surface soil horizons, chemical precipitation, ion exchange, biological transformation, and biological absorption through the root systems of the vegetative cover. The utilization of the higher plants as an integral part of the system to complement the microbiological and physio-chemical systems in the soil is an essential component of the living filter concept and provides maximum renovation capacity and durability to the system.

Treated municipal sewage effluent has been spray irrigated on cropland and in forested areas for a 10-year (1963-1972) period at the Penn State Project. The results of this research will be used to illustrate the relative merits of a land disposal system. Forested areas irrigated consisted of a mixed hardwood forest, a red pine plantation (Pinus resinosa), and a sparse white spruce (Picea glauca) plantation established on an abandoned old field. Types of crops irrigated were wheat, oats, corn, alfalfa, red clover and reed canarygrass. Detailed descriptions of these areas have been previously reported by Parizek et. al. (1) and Sopper (2,3).

The two soil types present on the sites are the Hublersburg with a surface texture ranging from silt loam to silty clay loam on slopes ranging from 3 to 12 percent and the Morrison sandy loam with slopes ranging from 3 to 20 percent.

Sewage effluent was applied in various amounts ranging from 1 inch per week to 6 inches per week and over various lengths of time ranging from 16 weeks during the growing season to the entire 52 weeks. Rates of application have varied from 0.25 to 0.64 inch per week.

Chemical Composition of Municipal Sewage Effluent:

The chemical composition of municipal effluent is illustrated in Table 1 based upon samples collected from the University treatment plant. This plant services both the University and the borough of State College. Treatment consists of both primary and secondary treatment. Secondary treatment includes standard and high-rate trickling filters and a modified activated sludge process followed by final settling. The total amount of each constituent applied per acre per year at the 2 inch per week rate is also given in

Table 1.

The fertilizer value of these wastewaters is readily evident in that the 2 inch per week application provided commercial fertilizer constituents equivalent to approximately 217 pounds of nitrogen, 98 pounds of phosphate (P_2O_5), and 144 pounds of potash (K_2O). This would be equal to applying about 2000 pounds of a 9-5-7 fertilizer annually to each acre.

Table 1. Typical chemical composition of municipal sewage effluent.

Constituent	Range Minimum	Range Maximum	Average	Total Amount Applied 2/
	mg/l	mg/l	mg/l	lb/acre
pH	7.1	8.1	7.7	-
MBAS 1/	0.030	0.880	0.367	5
Nitrate-N	2.2	10.0	5.6	72
Organic-N	0.0	51.5	4.4	57
NH_4-N	2.5	25.0	6.8	88
Phosphorus	0.500	7.250	3.333	43
Potassium	1.9	16.5	9.3	120
Calcium	10.5	31.2	19.8	256
Magnesium	5.2	15.6	9.9	128
Sodium	11.5	31.3	22.5	291
Chloride	11.0	80.4	37.3	483
Boron	0.08	0.32	0.20	3
Manganese	0.02	0.04	0.02	0.2

1/ Methylene blue active substance (detergent residue).

2/ Amount applied on plots which received 2 inches of effluent per week.

Wastewater Renovation:

Nitrogen and phosphorus are the two key eutrophic elements in municipal sewage effluent and therefore discussions on renovation will be limited to these two elements.

The forested areas were highly efficient in removing phosphorus. During the past 10 years, the average concentration of phosphorus in the effluent sprayed on the land, ranged from 0.5 to 10 milligrams per liter (mg/l). The forest biosystem was able to decrease the phosphorus concentration by more than 90 percent at the 2-foot soil depth under all application rates. During the tenth year (1972), the average concentration of phosphorus in the effluent was 4.900 mg/l. This concentration was diminished to values ranging from 0.037 to 0.200 mg/l at the 4-foot soil depth indicating renovation percentages from 96 to 99 percent in the various forested areas. In control areas the percolating water at the same soil depth had phosphorus concentrations ranging from 0.035 to 0.113 mg/l. These values are not very different from the effluent-irrigated plots considering that more than 50 feet of sewage effluent had been applied over the 10-year period.

The efficiency of the forest areas to reduce nitrogen concentrations has been variable. Average annual concentration of nitrate-nitrogen in soil water percolate samples collected at the 4-foot depth are given in Table 2.

It is clear that the forested areas can handle a 1 inch per week application without having the mean annual concentration of nitrate-nitrogen at the 4-foot depth exceed the Public Health Service limit.

However, when 2 inches were applied per week either in the April-November period with red pine on the Hublersburg clay loam soil or year-around with hardwoods on the Morrison sandy loam soil, the NO_3-N concentration at the 4-foot depth rapidly exceeded the Public Health Service limit. On the other hand, 2 inches of wastewater applied weekly on the old field area on the Hublersburg clay loam soil in the April-November period did not result in excessive NO_3-N values at the 4-foot depth.

The difference between the 2-inch red pine and 2-inch old field areas on the same soil type probably resides in the difference in the recycling of the nitrogen through the two vegetative covers. In the red pine, relatively less nitrogen is assimilated in the annual growth than in the herbaceous annuals and perennials in the old field and larger amounts of readily decomposable organic residues are deposited annually in the old field. The larger quantities of carbonaceous material in the old field area may also promote a higher degree of denitrification in this fine textured soil. The sandiness of the Morrison soil on the 2-inch hardwood area would not be conducive to denitrification of the larger nitrogen load applied in a year-around irrigation period and the hardwood leaf litter although more decomposable than the red pine needle litter would not be as decomposable as the old field residue.

The explanation above was corroborated when the 2-inch red pine area was clearcut after many of the trees were felled by a heavy wet snow and windstorm in November, 1968. After the clearcutting, the area grew up to a dense cover of herbaceous vegetation similar to that on the irrigated old field area. A large mass of carbonaceous material was deposited on the surface in the fall of 1969 and in 1970 and 1971 another dense cover of herbaceous vegetation was produced and the mean annual concentration of NO_3-N dropped from a value of 24.2 mg NO_3-N/l in 1969 to a value of 8.3 mg NO_3-N/l in 1970 and to 2.9 mg NO_3-N/l in 1971.

Further support for the importance of denitrification in decreasing the inputs of nitrate to the groundwater was obtained in the data from the hardwood forest on the Hublersburg soil which received 4 inches of wastewater, weekly in the April-November period (Table 2). In spite of doubling the nitrogen load, the NO_3-N concentration at 4 feet remained below 10 mg/l, probably because the larger hydraulic load encouraged more denitrification.

Table 2. Mean Annual Concentration (mg/l) of Nitrate-Nitrogen in Suction Lysimeter Samples Collected at the 4-foot Soil Depth in Forest Areas Receiving Various Levels of Wastewater During the Period 1965-1971.

	Red Pine Hublersburg Soil in. per week			Hardwood Hublersburg Soil in. per week		Old Field Hublersburg Soil in. per week		Hardwood Morrison Soil in. per week		Hardwood Hublersburg Soil in. per week	
Year	0	1	2	0	1	0	2	0	2	0	4
1965	0.9	2.2	3.9	-	0.0	0.3	8.0	-	-	-	2.3
1966	0.1	2.1	9.3	0.1	0.2	0.1	5.0	0.1	10.6	0.1	9.1
1967	0.9	1.7	13.8	0.3	1.4	0.3	6.1	1.4	19.2	0.3	3.4
1968	0.9	2.7	19.9	0.1	8.0	0.2	3.7	0.1	25.9	0.1	0.9
1969	0.2	4.2	24.2	0.1	7.2	0.2	2.3	0.3	23.7	-	-
1970	<1	5.3	8.3	<1	5.0	<1	3.5	1.0	42.8	-	-
1971	0.9	8.2	2.9	0.5	5.8	0.5	3.8	2.8	20.7	-	-
Ave.	0.7	3.8	11.7	0.2	3.9	0.3	4.6	0.9	23.8	0.2	3.9

The average concentrations of other chemical elements were increased or decreased in variable amounts in the upper soil horizons. These elements are relatively mobile and continue to percolate through the soil profile and do not pose any potential threat to groundwater quality. Actual concentrations of the cations being released to the groundwater were found to be very low. Concentrations of potassium, calcium, magnesium, and sodium in two deep wells on the effluent irrigation site did not exceed 12, 31, 21, and 3.4 mg/l, respectively, and these concentrations were similar to those in a remote off-site well in a similar geologic location (4).

Cropped areas were also efficient in renovating the wastewater. For instance, mean annual concentrations of nitrate-N and orthophosphate-P in the soil percolate at the 48-inch depth were 11.7 and 0.080 mg/l, respectively, in a silage corn environment, and 2.1 and 0.043 mg/l in a reed canarygrass environment. On the silage corn control area, which received no effluent but did receive 600 to 1000 pounds of 10-10-10 fertilizer per acre annually, the equivalent values for nitrate-N and orthophosphate-P were 7.5 and 0.045 mg/l. It is obvious that a perennial grass environment would be preferred to minimize leakage of nitrate to the groundwater.

Effect on Soil:

Soil samples were taken to a depth of 5 feet in the fall after cessation of irrigation. Soil samples were analyzed for the same constituents as was the effluent to determine if significant concentrations of nutrients were accumulating in the irrigated plots.

Total nitrogen was analyzed by the standard Kjeldahl method with only a slight modification to include nitrates. The detergent constituent, MBAS, was extracted from the soil with benzene and methanol and analyzed by the methylene blue color method. Chloride was extracted with 0.05N NH_4NO_3 and titrated with an Aminco - Cotlove titrator. Phosphorus was extracted with 0.03N NH_4F in 0.25N HCl using the Bray procedure. Boron and exchangeable cations (K, Ca, Mg, Na, Mn) were extracted with a 1 N NH_4 Ac at pH 7.0. The total was evaporated to dryness at 105^o and the residue analyzed with an arc spectrometer.

Results from the forested area which received 2 inches of effluent per week indicated that there were no significant changes in either total nitrogen, organic matter, or detergent residue (MBAS). Phosphorus is readily fixed by the soil and held in an unavailable form. Results indicated a significant increase of Bray extractable phosphorus in the upper foot of soil on the irrigated area. However, phosphorus accumulation is not anticipated to be a problem. Adsorption experiments in the laboratory indicated that the upper 5 feet of the fine-textured Hublersburg soil had an adsorptive capacity equivalent to 20,000 pounds of phorphorus or more phosphorus than would be added in 100 years if 2 inches of effluent were applied weekly (5). There were no significant differences between the irrigated and control plots in the amounts of NH_4Ac extractable calcium, magnesium, potassium, manganese, or boron. There was, however, a significant three-fold increase in exchangeable sodium on the irrigated plot. Significant accumulations were evident to a depth of three feet. However, with a sodium adsorption ratio (SAR) value of 1.2 in the effluent, under the normal humid climate of Pennsylvania it is not anticipated that the accumulation of sodium will ever be great enough to cause a soil structure problem.

Crop Responses

Yields:

During the initial years of the project, a variety of crops were tested. Since 1968, the two primary crops used have been silage corn and Reed canarygrass. As will be discussed later, these two crops appear to be the most efficient in terms of the utilization of the crop to remove nutrients applied to a site in the effluent.

Average crop yields obtained from 1963 to 1970 are given in Table 3. During this 8-year period the crop areas irrigated with 2 inches of effluent weekly received a total of 392 inches of wastewater equivalent to applying 10,000 pounds of a 13-6-15 commercial fertilizer. Effluent irrigation at 2 inches per week resulted in annual yield increases ranging from -8 to 346 percent for corn grain, 5 to 130 percent for corn silage, 85 to 191 percent for red clover, and 79 to 139 percent for alfalfa.

Nutrient Composition:

Under the "living filter" concept the higher plants growing on the soil are an integral part of the system and assist the micro-biological and physio-chemical activities occurring within the soil to renovate the sewage effluent through removal and utilization of the nutrients applied. The crops harvested from the irrigated areas are usually higher in nitrogen and phosphorus than the control crops, however, the differences are not large. This is partially due to the fact that the control area receives a normal application of commercial fertilizer each year. For instance, the silage corn control area has received 600 to 1000 pounds of a 10-10-10 fertilizer per acre annually.

Table 3. Average Annual Crop Yields at Various Levels of Application of Sewage Effluent

	0 inch/week	1 inch/week	2 inches/week
1963			
Wheat (bushels/acre)	48	45	54
Corn (bushels/acre)	75	105	106
Alfalfa (tons/acre)	2.18	3.73	5.12
Red clover (tons/acre)	2.48	4.90	4.59
1964			
Red clover (tons/acre)	1.76	5.30	5.12
Corn (bushels/acre)	81	121	116
Corn stover (tons/acre)	3.83	7.29	8.48
Oats (bushels/acre)	82	124	97
1965			
Alfalfa (tons/acre)	2.27	4.67	5.42
Corn (bushels/acre)	63	114	111
Corn Silage (tons/acre)	3.11	3.93	4.32
Oats grain (bushels/acre)	45	80	73

Table 3. Continued

	0 inch/week	1 inch/week	2 inches/week
Oats straw (tons/acre)	1.62	2.90	2.63
Reed canarygrass (tons/acre)	--	--	6.13
1966			
Alfalfa (tons/acre)	1.95	3.86	4.38
Corn (bushels/acre)	33	98	115
Corn silage (tons/acre)	2.47	4.45	5.68
Reed canarygrass (tons/acre)	--	--	4.32
1967			
Corn Pa. 444			
19-inch row (bushels/acre)	98	101	122
38-inch row (bushels/acre)	92	83	84
Corn Pa. 602-A			
19 inch row (bushels/acre)	122	121	114

Table 3. Continued

	0 inch/week	1 inch/week	2 inches/week
Corn silage Pa. 602-A			
19-inch row (tons/acre)	4.43	4.47	4.67
Alfalfa (tons/acre)	2.43	3.77	4.36
Reed canarygrass (tons/acre)	--	--	7.03
1968			
Reed canarygrass (tons/acre)			5.09
1969			
Corn Silage			
Pa. 602-A (tons/acre)	5.19	5.77	5.49
Pa. 890-S (tons/acre)	6.90	6.66	7.27
Reed canarygrass (tons/acre)	--	--	5.18
1970			
Corn Silage			
Pa. 602-A (tons/acre)	4.35	6.44	6.00

Table 3. Continued

	0 inch/week	1 inch/week	2 inches/week
Pa. 890-S (tons/acre)	5.20	4.97	5.58
Reed canarygrass (tons/acre)	--	--	5.53

From Sopper and Kardos (6).

Nutrients Removed By Crop Harvest:

The contribution of the higher plants as renovators of the wastewater is readily evident from Tables 4 and 5 when the quantities of nutrients, expressed in pounds per acre, removed in the 1970 crop harvest are given. These data indicate that the vegetative cover can contribute substantially to the durability of a "living filter" system particularly where a crop is harvested and utilized. At the 2-inch-per week level of effluent irrigation the corn variety removed 160 pounds of nitrogen and 43 pounds of phosphorus. Reed canarygrass, which is a perennial grass, was even more efficient in that it removed 408 pounds of nitrogen and 56 pounds of phosphorus. The difference is primarily due to the fact that the grass is already established and actively growing in early spring even before the corn is planted.

The amounts of nutrients removed annually vary with the amount of wastewater applied, amount of rainfall, length of the growing season, and the number of cuttings of the reed canarygrass.

The efficiency of crops as renovating agents can be assessed by computing a "removal efficiency" expressed as the ratio of the weight of the nutrient removed in the harvested

Table 4. Quantities of Nutrients Removed by Corn Silage Receiving Various Levels of Effluent During 1970.

Nutrient	Variety and amount of effluent applied per week Corn Silage Pa. 602-A Inches Per Week 0	 1	 2
		pounds per acre	
Nitrogen	117.5	174.4	160.6
Phosphorus	18.6	35.6	42.8
Potassium	91.6	137.1	129.3
Calcium	39.9	41.4	27.0
Magnesium	14.1	27.6	23.2
Chloride	17.1	44.6	46.4
Sodium	0.11	2.13	2.39
Boron	0.06	0.10	0.09

From Sopper and Kardos (6)

Table 5. Quantities of Nutrients Removed by Reed Canarygrass Irrigated With 2 Inches of Effluent During 1970

Nutrient	Total Amount Removed
	pounds per acre
Nitrogen	408.2
Phosphorus	56.0
Potassium	246.9
Calcium	44.2
Magnesium	40.4
Chloride	158.4
Sodium	3.4
Boron	0.09

From Sopper and Kardos (6)

crop to the weight of the same nutrient applied in the wastewater. Renovation efficiencies for the silage corn and the reed canarygrass crops harvested in 1970 are given in Table 6. At the 1-inch-per-week level of application of wastewater, the corn silage removed nutrients equivalent to 334 percent of the total applied nitrogen, 230 percent of the applied phosphorus, and 280 percent of the applied potassium. At the 2-inch-per-week level, the corn silage removed more than 100 percent of the applied nitrogen, phosphorus, and potassium.

Table 6. Renovation Efficiency of the Silage Corn and Reed Canarygrass Crops Harvested in 1970.

Nutrient	Variety and amount of effluent applied		
	Corn Silage Pa. 602-A		Reed canarygrass
	Inches Per Week		
	1	2	2
	%	%	%
Nitrogen	334	145	75
Phosphorus	230	143	63
Potassium	280	130	117
Calcium	38	15	9
Magnesium	53	27	19
Chloride	26	14	20
Sodium	2	1	1
Boron	10	4	2

From Sopper and Kardos (6)

During 1970, the reed canarygrass removed only 75 percent of the applied nitrogen, and 63 percent of the applied phosphorus. These are not typical annual values for the 1965-70 period. During the period 1965 to 1969, only sewage effluent was applied. In 1970, irrigation applications included a combination of sewage effluent and injected liquid digested sludge. During the period 1965-69, 1581 pounds of nitrogen were applied and the harvested reed canarygrass removed 1663 pounds, equivalent to a 105 percent renovation efficiency. In 1970, an additional 546 pounds of nitrogen were applied making the total 2127 pounds applied in 536 inches of wastewater. Since only 408 pounds were removed by crop harvesting, the overall 6-year period renovation efficiency was lowered to 97.5%.

During the same period, 797 pounds of phosphorus were applied in the wastewater and 279 pounds removed in crop harvesting resulting in an overall renovation efficiency of 35 percent. Annual renovation efficiencies have varied from 24 to 63 percent for reed canarygrass irrigated at the 2-inch-per-week level. For corn silage it has varied from 39 to 230 percent for the 1-inch-per-week level and from 21 to 143 percent for the 2-inch-per-week level. Hence, it is obvious that some process other than utilization by the vegetative cover must be used to assure the removal of this key eutrophic nutrient. This additional renovation and removal of phosphorus is usually accomplished by way of the large withholding capacity of most agricultural soils for phosphorus. At the Penn State sites, the Hublersburg soils, which range in texture from a silt loam to a silty clay loam, have persistently and effectively removed the phosphorus.

The fate of phosphorus and nitrogen on the reed canarygrass area irrigated with municipal wastewater at 2-inches-per-week since 1965 are shown in Table 7. After 6 years of applying chlorinated effluent, 797 pounds of phosphorus and 2127 pounds of nitrogen had been applied to each acre in 536 inches of effluent. Harvested crops removed 270 pounds of phosphorus, the equivalent of 35 percent of the amount added. Since the concentration of phosphorus in the percolate at the four foot soil depth was only 0.05 mg/l and was no greater than that in an unirrigated adjacent forest area, the net percolation losses of phosphorus from the wastewater treated areas were assumed to be proportional only to the excess percolation induced by the added wastewater. Further, since precipitation always exceeds potential evapotranspiration on an annual basis, the wastewater was assumed to be toally recharged. On the basis of these assumptions, the net percolation loss of phosphorus from the wastewater irrigated areas was calculated to be 6.4 pounds per acre during the 6-year period, or only 0.8 percent of the amount applied. Thus the soil with its strong absorptive capacity for phosphorus, together with the crop harvests, has persistently removed 99.2 percent of the added phosphorus.

Nitrogen removals by the soil and crop system have also been equally efficient. Over the 6 year period 2127 pounds of nitrogen were added to each acre. Protein removed in the harvested reed canarygrass was equivalent to 2073 pounds of nitrogen per acre. Kjeldahl nitrogen content of the upper foot of soil was approximately 5000 pounds per acre. Average concentration of nitrate-N in the percolate at the four foot soil depth during the 6-year period was 3.5 mg/l in the effluent irrigated areas and 0.2 mg/l in the control areas. On the basis of the same assumptions used above, the excess percolate from the 536 inches of wastewater applied per acre would have carried a total of 452 pounds of nitrogen into the groundwater. This quantity is 398 pounds in excess of the 54 pounds per acre difference between the amount of nitrogen added in the wastewater and the amount removed in the harvested crops and could easily have been derived from the large amounts of native soil nitrogen. Thus, the reed canarygrass was effective in removing 97.5 percent of the added nitrogen.

Table 7. Phosphorus and Nitrogen Balances for Reed Canarygrass Irrigated with Effluent at Two Inches Per Week During the Period 1965 to 1970

	Amount Applied		Removed		Retained
Period	Wastewater	Nutrient	By crop	By Leaching	By soil
	inches	lbs/acre	lbs/acre	lbs/acre	lbs/acre
1965-70	536	797 (P) 2127 (N)	279 (P) 2073 (N)	6.4 (P) 452 (N)	512 (P) -398 (N)

From Sopper and Kardos (6)

Forest Responses

Red Pine:

Experimental plots were established in a red pine plantation in 1963. These plots have been irrigated with sewage effluent during the past 10 years at rates of 1 inch and 2 inches per week during the growing season (April-November). The plantation was established in 1939 with the trees planted at a spacing of 8 by 8 feet. In 1963, the average tree diameter at breast height was 6.8 inches and average height was 35 feet.

Diameter and height growth measurements were made annually on sample trees selected at random on each irrigated plot and on adjacent control areas. Average annual height growth for the period 1963 to 1971 is given in Table 8. Irrigation with sewage effluent at both rates produced slight increased in height growth during the first 2 years. This slight increase in height growth has been maintained on the plot receiving 1 inch per week. However, on the plot receiving 2 inches per week, height growth continually decreased up to 1969 when high winds following a wet snowfall completely felled every tree on the plot.

Diameter growth was measured annually with dendrometer bands. In addition increment cores were taken in 1972 from sample trees in all areas. The actual measurements of average radius growth taken from the increment cores indicate that the previous diameter growth data reported which was based upon dendrometer band measurements of tree circumferences was incorrect (3). Average annual diameter growth based on

Table 8. Average Annual Terminal Height Growth of Red Pine Irrigated with Sewage Effluent

Treatment	Average annual height growth
	feet
Irrigated - 1 inch per week	1.8
Control	1.4
Irrigated - 2 inches per week 1/	1.6
Control	1.7

1/ For period 1963 to 1968 only.

increment core measurements is given in Table 9. Irrigation at the 1-inch-per-week level increased the average annual diameter growth by 183 percent. On the other hand, the 2-inch-per-week level actually caused a reduction in diameter growth. In addition, during the sixth year of irrigation the needles of the pines being irrigated at the higher rate began to turn yellow.

This result was not totally unexpected since other investigators have reported red pine growth to be adversely affected on wet soils and to be sensitive to boron toxicity. Approximately 4 pounds of boron per acre are applied annually in the sewage effluent. Other investigators have previously reported that applications of 1.1 pounds of boron per acre were sufficient to induce toxicity symptoms.

Table 9. Average Annual Diameter Growth of Red Pine Irrigated With Sewage Effluent

Treatment	Average annual diameter growth
	Inches
Irrigated - 1 inch per week	0.17
Control	0.06
Irrigated - 2 inches per week 1/	0.06
Control	0.07

1/ For period 1963 to 1968 only.

White Spruce:

Two experimental plots were established in a sparse white spruce plantation on an abandoned old-field area. The trees in 1963 ranged from 3 to 8 feet in height. One plot has been irrigated with sewage effluent during the past 10 years at the rate of 2 inches per week, while the second plot has been maintained as a control. Height growth measurements have been made annually. In 1972, all tree diameters were measured and increment cores taken to determine the average annual diameter growth.

Total height of the trees were measured in August 1972. Average height of the trees on the irrigated plot was 20 feet and ranged from 12 to 25 feet. The average height of the trees on the control plot was 9 feet and ranged from 8 to 15 feet. Over the 10-year period average annual height growth was 18 inches on the irrigated areas and 5 inches on the control areas, representing a 260 percent increase as a result of sewage effluent irrigation.

Average diameter of trees on the irrigated plot was 3.7 inches in comparison to 1.1 inches on the control plot. Measurements taken from increment cores indicated that the average annual diameter growth on the irrigated trees was 0.40 inch and on the control trees 0.18 inch, representing a 122 percent increase.

Hardwood Species Growth Responses:

Mixed hardwood forests, consisting primarily of oak species, have been irrigated with sewage effluent at rates ranging from 1 inch to 4 inches per week and for periods ranging from the growing season (28 weeks) to the entire year (52 weeks). Principal species are white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), black oak (*Q. velutina* L.), red oak (*Q. rubra* L.), scarlet oak (*Q. coccinea* Muench.), red maple (*Acer rubrum*), and hickory (*Carya spp*.).

Average annual diameter growth during the 1963 to 1972 period is given in Table 10. One inch per week applications produced only slight increases in diameter growth; however, the 2- and 4-inch-per-week levels resulted in 69 and 40 percent increases, respectively. These values pertain primarily to the oak species. Some of the other hardwood species present on the plots have responded to a greater extent. For instance, increment core measurements made on red maple and sugar maple (*A. saccharum*), indicate that the average annual diameter growth during the past 10 years has been 0.43 inch on the trees irrigated with 1 inch of effluent per week in comparison to 0.10 inch on control trees, a 330 percent increase in average annual diameter growth. Similarly, increment core measurements made on aspen (Populus tremuloides) irrigated with 2 inches of effluent weekly during the growing season indicated that the irrigated trees had an average annual diameter growth of 0.47 inch in comparison to 0.24 inch for unirrigated trees, a 96 percent increase in growth. Saplings which averaged 0.65 inch in diameter in 1963 increased in diameter to an average of 5.3 inches on the irrigated areas in comparison to 3.1 inches on the control areas.

Table 10. Average Annual Diameter Growth in Hardwood Forests Irrigated with Sewage Effluent

Weekly irrigation amount	Average diameter growth	
	Control	Irrigated
inches	inch	inch
1 1/	0.16	0.18
2 2/	0.13	0.22
4 3/	0.15	0.21

1/ Irrigated with 1 inch of sewage effluent weekly during growing season from 1963 to 1972.

2/ Irrigated with 2 inches of sewage effluent weekly during the entire year from 1965 to 1972.

3/ Irrigated with 4 inches of sewage effluent weekly during the growing season only from 1964 to 1967; during the dormant season only from 1968 to 1971; and with 2 inches of effluent during the growing season in 1972.

Renovation Efficiency of Forests:

Foliar samples were collected annually from the hardwoods, red pine, white spruce, and herbaceous vegetation to determine the extent of utilization of the nutrient elements applied in the sewage effluent. The nutrient element content of the foliage of the vegetation on the irrigated plots was consistently higher than that of the vegetation on the control plots. It is therefore obvious that the forest vegetation is contributing to the renovation of the percolating effluent; however, its order of magnitude is difficult to estimate because the annual storage of nutrients in the woody tissue and the extent of recycling of nutrients in the forest litter are extremely difficult to measure. Although considerable amounts of nutrients may be taken up by trees during the growing season, many of these nutrients are redeposited annually in leaf and needle litter rather than being hauled away as in the case of harvested agronomic crops.

A comparison between the annual uptake of nutrients by an agronomic crop (silage corn) and a hardwood forest is given in Table 11. It is obvious that trees are not as efficient renovating agents as agronomic crops. Whereas harvesting a corn silage crop removed 145 percent of the nitrogen applied in the sewage effluent, the trees only remove 39 percent most of which is returned to the soil by leaf fall. Similarly only 19 percent of the phosphorus applied in the sewage effluent is taken up by trees in comparison to 143 percent by the corn silage crop.

Table 11. Annual Uptake of Nutrients by a Silage Corn Crop and a Hardwood Forest Irrigated with 2 Inches of Effluent Weekly During 1970

Nutrient	Corn Silage Pa. 602-A	Renovation efficiency 1/	Hardwood forest	Renovation efficiency
	lbs/acre	%	lbs/acre	%
N	161	145	84	39
P	42	143	8	19
K	129	130	26	22
Ca	27	15	22	9
Mg	23	27	5	4

1/ Percentage of the element applied in the sewage effluent that is utilized and removed by the vegetation.

Disposal systems, however, must operate throughout the year, and in northern climates where the temperatures drop below freezing, the system must rely more on the adsorptive capacity of the soil and less on the microbes and roots. During this winter period, forested areas provide better infiltration conditions and larger phosphorus adsorptive capacity due to the acid conditions associated with forest soils. Thus, a combination of cropland and forestland will provide the greatest flexibility in operating a system using the living filter concept.

Groundwater Recharge:

The amount of renovated effluent recharged to the groundwater reservoir was estimated from data available on the total amount to effluent and rainfall received by the plots, and potential evapotranspiration. Annual recharge ranged from 1.1 to 1.8 million gallons per acre irrigated with an average of 1.6 million gallons. Recharge amounted to approximately 90 percent of the effluent applied at the 2 inches per week rate. Hence, it is evident that with properly programmed application, sewage effluent can be satisfactorily renovated and considerable amounts of high quality water recharged to the groundwater reservoir. In time, contributions to the groundwater of this magnitude will certainly have a beneficial effect on the local water table level.

Site Amelioration

Strip Mine Spoil Bank Reclamation:

In contrast to the utilization of an existing forest for spray irrigation, there is also the option of using municipal wastewater for reforestation and reclamation of drastically disturbed areas such as those resulting from strip mining operations.

In 1968, a feasibility project was initiated to determine if municipal sewage effluent and sludge could be used to ameliorate the harsh site conditions existing on many bituminous coal strip mining spoil banks. Revegetation of many of these banks has been unsuccessful because of high acidity, toxic levels of iron, aluminum, and manganese, low fertility, low moisture content, and extremely high summer surface temperatures.

Treatment with sewage effluent and liquid digested sludge might ameliorate these conditions. The slightly alkaline, nutrient-enriched wastewater might leach acids and toxicants below plant rooting depth and at the same time provide organic colloids to detoxify the soluble iron, aluminum, and manganese. The addition of the wastewater would also provide the necessary moisture for vegetation survival and growth and evaporational cooling should moderate the lethal surface temperatures.

To test this hypothesis spoil material was obtained from a bank over the Lower Kittanning bituminous coal seam in Clearfield County, Pennsylvania. This bank was selected because it has remained barren for 23 years despite several attempts at revegetation and is extremely acid (pH 2.0 to 3.0).

Approximately 25 tons of spoil material were placed in each of ten large boxes 32 feet long, 4 feet wide, and 4 feet deep--with an open bottom having 6 inches of sand resting on natural soil. The boxes were filled with 3.5 feet of spoil material in the fall of 1968, allowed to consolidate over the winter and refilled to capacity in the spring of 1969.

In April, 1969, each box was planted with seven species of tree seedlings--Japanese larch, white spruce, Norway spruce, white pine, European alder, hybrid poplar, and black locust. In addition, two species of grass (orchard grass and tall fescue) and two species of legumes (crownvetch and birdsfoot trefoil) were broadcast seeded in each box.

Two of the boxes were untreated and maintained as controls. The remaining eight boxes were divided into four groups of two boxes for treatment. The four treatments applied were: (1) 2 inches of sewage effluent a week, (2) 1 inch each of sewage effluent and sludge per week, (3) 2 inches each of sewage effluent and sludge per week. Irrigation treatments were applied for 24 weeks from May 6 to October 14, 1969.

The fertilizer value of the sewage effluent and sludge applied is readily apparent when average concentrations of N, P, and K are converted to commercial fertilizer equivalents. During the 24 week irrigation period the minimum amount was applied in the weekly applications of 2 inches of effluent (2000 lbs/acre of a 19-6-8 fertilizer) and the maximum amount applied in the weekly applications of 2 inches of effluent and 2 inches of sludge (12,469 lbs/acre of a 64-18-8 fertilizer).

On the unirrigated control boxes there was a complete mortality of all planted seedlings, and none of the grass or legume seed germinated.

Vegetation in the treated boxes responded dramatically. Some of the tree seedlings survived on all treated boxes. Best overall tree seedling survival percentages were obtained on the boxes which received 2 inches of effluent per week. Under this treatment, survival percentages were 65 percent for black locust, 63 percent for white pine, 40 percent for white spruce, 38 percent for European alder, 35 percent for Norway spruce, 10 percent for hybrid poplar, and 3 percent for Japanese larch. Black locust had the highest survival percentages over all treatments ranging from 65 to 85 percent.

Black locust with the best height growth of surviving species ranged from 4 to 14 inches although some individual trees attained a height of 4 feet. Hybrid poplar ranked second in average height growth.

Treatments were very effective in establishing a ground cover of grasses and legumes. Growth response of each species was measured in terms of pounds of dry matter produced per acre and percentage of ground cover. Best germination and growth was obtained with the combination, 2 inches of effluent and 2 inches of sludge per week, treatment. Orchard grass and tall fescue had the highest dry matter yields of 3237 and 2646 pounds per acre, respectively. It was quite apparent from the results that sludge is a necessary prerequisite to the establishment of grasses and legumes from seed. The organic residue in the sludge provides the necessary seed bed for germination.

The percentage cover of the spoil material by the grasses and legumes on the irrigation treatments ranged from 28 to 100 percent for orchard grass, 5 to 91 percent for tall fescue, 3 to 56 percent for birdsfoot trefoil, and 2 to 58 percent for crownvetch. The maximum cover was obtained for all species with the combination, 2 inches of effluent and 2 inches of sludge per week, treatment. Establishment of a complete ground cover of vegetation is highly desirable since it can result in earlier stabilization and reduction of erosion, in earlier mitigation of acid drainage by diminishing net recharge through increased evapotranspiration losses, and in the acceleration of inputs of organic residues for detoxifying the soluble iron, aluminum, and manganese.

The chemical properties of the spoil material and the soil water are primary factors influencing the success of failure of revegetation of strip mine spoil. The effects of the irrigation treatments on certain chemical attributes of the soil solution in the spoil were examined by sampling the percolate which passed through the 3.5 feet depth of spoil, using porous ceramic tension lysimeters installed in the sand layer below the spoil.

The potential toxicity of a spoil is best characterized by the pH. Average pH of the percolate obtained from natural rain during the months prior to the irrigation treatment ranged between 2.2 and 2.8, indicating severely toxic acidic conditions. Over the 24-week irrigation period, the average pH was relatively unchanged except for the 2-inch combination treatment of effluent and sludge (2E + 2S) where the pH increased significantly to 4.06. This is also the treatment which had the greatest dry matter production of grasses and legumes and the best height growth of tree seedlings.

The control, which had complete mortality of trees, grasses, and legumes also had the lowest average values for phosphorus and nitrate-nitrogen and the highest values for manganese, iron, and aluminum. This is not surprising since the solubility and activity of manganese, iron, and aluminum are all highly pH-dependent. On the other hand, the best treatment, 2E + 2S, ranked highest in phosphorus and nitrate-nitrogen and lowest in manganese, iron, and aluminum. Since benign spoil materials are also very low in soluble phosphorus and nitrate-nitrogen, one must conclude that the manganese, iron, and aluminum constituents are more directly related to revegetation failures. The other chemical constituents, K, Ca, Mg, Na, Zn, Cu, and B, examined were found to be relatively higher in the control than in the irrigation treatments with the exception of Na. The higher concentrations appear to be the results of solubilization of the native rock by the high acidity. Irrigation with effluent and sludge leached and diluted the native salts. In addition, solubilities of the Mn, Fe, Al, Cu and Zn were suppressed by the dual action of alkalinity of the effluent and sludge and humic precipitation by the organic colloids of the sludge.

Very little research has been done to determine the feasibility of using treated municipal wastewater for these purposes. One can find a few references in the literature on the utilization of sewage effluent for the irrigation of orchards, parks, and golf courses but for the most part, these are descriptions of small operating systems at a specific location and not reports of a pre-planned research project designed to provide a complete evaluation of the system.

Conclusions:

Ten years of research have indicated that the living filter system for renovation and conservation of municipal wastewater is feasible and that the combinations of agronomic and forested areas provide the greatest flexibility in operation. Such a system is more adaptable to small cities and suburbs than to large metropolitan areas because of the availability of open land close to the wastewater treatment plant, although the land area requirement is not a major prohibitive factor. At the recommended level of irrigation, 2 inches per week, only 129 acres of land would be required to dispose of 1 million gallons of wastewater per day. Although large contiguous blocks of agricultural and natural forest land would be the most desirable for efficiency and economy, major metropolitan areas could utilize golf courses, playing fields, forest preserves and parks, greenbelts, scenic parkways, and perhaps even divided highway and beltway medial strips. Results also indicate that municipal wastewaters might be used to reclaim and revegetate many of the barren bituminous strip mined spoil banks existing throughout the Appalachian region and restore them to a more esthetic and productive state.

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HEALTH ASPECTS OF EFFLUENT IRRIGATION

by

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It has now been well established that municipal wastes, even when subjected to partial treatment or inadequate secondary treatment, with or without chemical disinfection, may contain significant numbers of disease-producing organisms pathogenic for both man and other animals. If such effluents are used for the irrigation of crops, particularly those which may be eaten without thorough cooking, the questions must be answered as to how long such organisms may survive on the irrigated crops and in the soil, and what is the potential disease hazard involved. The list of microorganisms which may be present in partially treated effluents comprises a large variety of bacteria, spirochetes, protozoa, helminths and viruses which originate from municipal and industrial wastes, including food processing plants, slaughter houses, poultry processing operations and feed lots. Diseases associated with these organisms include Salmonella gastroenteritis, typhoid and paratyphoid fevers, bacillary and amebic dysentery, vibriosis, leptospirosis and infectious hepatitis. Less commonly seen, at least in the United States, are tuberculosis, brucellosis, cholera,

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listeriosis, coccidiosis, swine erysipelas, ascariasis, cysticercosis and tape worm disease, fascioliasis, and schistosomiasis.

Rudolfs, Falk, and Ragotzkie (1) and Sepp (2) have reviewed the literature on the occurrence and survival of pathogenic and nonpathogenic enteric bacteria and other microorganisms in soil, water, sewage and sludges, and on vegetation irrigated or fertilized with these materials. It would appear from these reviews that many crops growing in infected soil and irrigated with contaminated water can harbor pathogenic microorganisms; and that these microorganisms may survive for periods of a few days to several weeks or even months in the soil and on the crops.

Falk (3) and Rudolfs, Falk and Ragotzkie (4) studied the relative incidence of coliform organisms on tomatoes grown on three plots of ground: one plot irrigated with settled sewage concurrently with growth, one irrigated previous to planting but not further, and one with no previous or concurrent irrigation. Except for the tomatoes with abnormal stem ends, there was no material difference in coliform counts per gram of tomatoes from the three plots. These same authors further found that *Salmonella cerro* and *Shigella alkalescens* organisms sprayed on growing tomatoes disappeared within two to seven days, whereas organisms of the coliform group remained for considerably longer periods. Norman and

Kabler (5) made coliform and other bacterial counts on samples of sewage-contaminated river and ditch waters, and of soil and vegetable samples in the fields to which these waters were applied. They found that although the bacterial contents of both river and ditch waters were very high, both soil and vegetable washings had much lower counts. For example, where irrigation water had coliform counts of 230,000/100 ml, leafy vegetables had counts of 39,000/100 grams and smooth vegetables such as tomatoes and peppers, only 1,000/100 grams. High enterococcus counts accompanied high coliform counts in water samples, but enterococcus counts did not appear to be correlated in any way with coliform counts in soil and vegetable washings.

Dunlop and Wang (6) have also endeavored to study the problem under actual field conditions in Colorado. Salmonella, Ascaris ova and Endamoeba coli cysts were recovered from more than 50 percent of irrigation water samples contaminated with either raw sewage or primary-treated, chlorinated effluents. Only one of 97 samples of vegetables irrigated with this water yielded Salmonella, but Ascaris ova were recovered from two of 34 vegetable samples. Although cysts of the human pathogen, Endamoeba histolytica, were not recovered in this work, possibly due to a low carrier rate in Colorado, the similar resistance to the environment of these cysts compared with the cysts of Endamoeba coli would suggest that these organisms would also survive in irrigation water for a considerable period of time. It should be pointed out, however, that this work was done entirely with furrow irrigation on a sandy soil in a semi-arid region, and the low recoveries from vegetables cannot necessarily be applied to other regions or to sprinkler irrigation of similar crops.

Of the types of irrigation commonly practiced, sprinkling undoubtedly presents the greatest problem from a microbiological point of view, as the water and organisms are applied directly to that portion of the plant above the ground as well as the soil. This becomes of special importance for fruits and leafy crops such as strawberries, lettuce, cabbage, alfalfa, clover, etc., which may be consumed raw. Flooding the field may pose the same microbiological problems if the crop is eaten without thorough cooking. Subirrigation and furrow irrigation present fewer problems as the water rarely reaches the upper portions of the plant; furthermore, root crops, as well as normal leafy crops and fruits, ordinarily do not permit penetration of the animal and human pathogens into the inside of the plant.

As examples of hazards that may be encountered from sprinkler irrigation, Müller (7) has reported that at two places near Hamburg, Germany, where sprinkler irrigation was used with domestic drainage subjected only to mechanical purification, Salmonella organisms were isolated 40 days after sprinkling on soil and on potatoes, ten days on carrots, and five days on cabbage and gooseberries. Müller (8) has also reported that 69 of 204 grass samples receiving raw sewage by sprinkling were positive for organisms of the typhoid-paratyphoid group (Salmonella). The bacteria began to die off three weeks after sewage application; but six weeks after application, five percent of the samples were still infected.

Many other examples may be cited on the variable survival rate of microorganisms in soil, irrigation water, sewage and on crops. Table I lists a portion of the data available from the literature. These data confirm the earlier statement that pathogenic microorganisms may survive for periods of a few days to several weeks or even months on contaminated crops.

Tubercle bacilli have apparently not been looked for on irrigated crops in the United States. However, Sepp (2) states that several investigations on tuberculosis infection of cattle pasturing on sewage-irrigated land have been carried out in Germany. The investigators are in general agreement that if sewage application is stopped fourteen days before pasturing, there is no danger that the cattle will contract bovine tuberculosis through grazing. In contrast, Dedie (9) has reported that these organisms can remain infective for three months in waste waters, and up to six months in soil. The recent findings of atypical mycobacteria in intestinal

Table 1. Survival times of pathogenic microorganisms in various media.

ORGANISM	MEDIUM	TYPE OF APPLICATION	SURVIVAL TIME	REFERENCE
Ascaris ova	soil	not stated	2.5 years	34
	soil	sewage	up to 7 years	35
	plants & fruits	AC*	1 month	17
Cholera vibrios	spinach, lettuce	AC	22-29 days	36
	cucumbers	AC	7 days	36
	non-acid vegetables	AC	2 days	36
	onions, garlic, oranges, lemons, lentils, grapes rice & dates	infected feces	hours to 3 days	44
Endamoeba histolytica cysts	river water	AC	8-40 days	37
	soil	AC	8 days	38
	tomatoes	AC	18-42 hours	39
	lettuce	AC	18 hours	39
Enteroviruses	roots of bean plants	AC	at least 4 days	40
	soil	AC	12 days	19
	tomato & pea roots	AC	4-6 days	19
Hookworm larvae	soil	infected feces	6 weeks	41
Leptospira	river water	AC	5-6 days	42
	soil	AC	15-43 days	43
Salmonella typhi	dates	AC	68 days	45
	harvested fruits	AC	3 days	46
	apples, pears, grapes	AC	24-48 hours	47
	strawberries	AC	6 hours	48
	soil	AC	74 days	49
	soil	AC	70 days	50

*AC = Artificial Contamination

Table 1. Survival times of pathogenic microorganisms in various media (Cont'd).

ORGANISM	MEDIUM	TYPE OF APPLICATION	SURVIVAL TIME	REFERENCE
Salmonella typhi	soil	AC*	at least 5 days	51
	pea plant stems	AC	14 days	51
	radish plant stems	AC	4 days	51
	soil	AC	up to 20 days	52
	lettuce & endive	AC	1-3 days	52
	soil	AC	2-110 days	53
	soil	AC	several months	54
	lettuce	infected feces	18 days	55
	radishes	infected feces	53 days	55
	soil	infected feces	74 days	55
	soil	AC	5-19 days	56
	soil	AC	70-80 days	57
	cress, lettuce & radishes	AC	3 weeks	58
	lake water	AC	3-5 days	59
Salmonella, other than typhi	soil	AC	15-70 days	60
	vegetables	AC	2-7 weeks	61
	tomatoes	AC	less than 7 days	3
	soil	sprinkled with domestic sewage	40 days	7
	potatoes	"	40 days	7
	carrots	"	10 days	7
	cabbage & gooseberries	"	5 days	7
Shigella	streams	not stated	30 min - 4 days	62
	harvested fruits	AC	minutes - 5 days	46
	market tomatoes	AC	at least 2 days	63
	market apples	AC	at least 6 days	63
	tomatoes	AC	2-7 days	4
Tubercle bacilli	soil	AC	6 months	64
	grass	AC	14-49 days	64
	sewage	?	3 months	9
	soil	?	6 months	9

*AC = Artificial Contamination

lesions of cattle with concurrent tuberculin sensitivity in the United States may possibly be due to ingestion of these organisms either from soil or irrigated pastures.

Both animals and human beings are subject to helminth infections -- ascariasis, fascialiasis, cysticercosis and tapeworm infection, and schistosomiasis -- all of which may be transmitted through surface irrigation water and plants infected with the ova or intermediate forms of the organisms. The ova and parasitic worms are quite resistant to sewage treatment processes (10) as well as to chlorination (11), and have been studied quite extensively in the application of sewage and irrigation water to various crops (10, 12, 13).

The common liver fluke, Fasciola hepatica, the ova of which are spread from the feces of many animals, affects cattle and sheep (14, 15), commonly, in the United States, and man to a lesser extent. The intermediate hosts, certain species of snails, live in springs, slow-moving swampy waters, and on the banks of ponds, streams, and irrigation ditches. After development in the snail, the cercarial forms emerge and encyst on grasses, plants, bark, or soil. Cattle and sheep become infected by ingestion of the grasses and plants, or the water, in damp or irrigated pastures where vegetation is infested with metacercariae. Man contracts the disease by ingesting plants such as watercress or lettuce containing the encysted metacercariae.

Ascaris ova are also spread from the feces of infected animals and man and are found in irrigation water (10). Cattle and hogs are commonly infected, where the adult worms mature in the intestinal tract, sometimes blocking the bile ducts. Ascaris ova have been reported to survive for two years in irrigated soil and have been found on irrigated vegetables even when chlorinated effluent was used for irrigation (16, 17).

Schistosomiasis, although not prevalent in the United States except in immigrants from endemic areas, should be considered for the future as these individuals move about the country into irrigated areas. The life cycle of these schistosomes is similar to that of the liver fluke in that eggs from the feces or urine of infected individuals are spread from domestic wastes and may reach surface irrigation waters where the miracidial forms enter certain snails and multiply, releasing fork-tailed cercariae. Although these cercariae may produce disease in man if ingested, the more common method of infection is through the skin of individuals working in the infested streams and irrigation ditches. Such infections are most common in Egypt (18) and other irrigated areas where workers wade in the water without boots. It is unlikely that the cercariae would survive long on plants after harvest.

Little is known of the possibility that enteric viruses such as polio-viruses, Coxsackie, ECHO, and infectious hepatitis viruses may be spread through irrigation practices. There is ample evidence, however, that these agents are present in municipal wastes, and that significant amounts will often survive sewage treatment and even usual chlorine doses (21, 22, 23, 24). Murphy, et al (19) and Murphy and Syverton (20) studied the recovery and distribution of a variety of viruses in tomato and pea plants grown in modified hydroponic culture. FA mouse encephalomyelitis virus regularly entered the plant roots and attained significant concentration; acropetal translocation occurred infrequently. Type 1 poliovirus was also absorbed by tomato plant roots but not translocated to aerial parts. The authors conclude that it is unlikely that plants or plant fruits serve as a reservoir and/or carrier of poliovirus. However, their findings of significant absorption of two mammalian viruses in the roots of the plants suggest that more research is needed in this area.

Many other microorganisms than those specifically mentioned in this section may be transmitted to plants, animals, and human beings through irrigation practices. For example Cholera vibrios, although listed in Table 1, have not been discussed as they are no longer important in the United States. Their significance in other parts of the world, however, is well established.

Direct search for the presence of pathogenic microorganisms in streams, reservoirs, irrigation water, or on irrigated plants is too slow and cumbersome for routine control or assessment of quality. Instead, accepted index organisms such as the coliform group and fecal coli (25), which are usually far more numerous from these sources, and other biological or chemical tests, are used to assess the quality of the water. Two extensive investigations of stream basins (26, 27) have demonstrated the value of these criteria in assessing the quality of raw water. In the study of the Red River of the North (26), Salmonella were not recovered from a reference point upstream from two municipal treatment plants and a sugar company plant. Total and fecal coliforms at this upstream reference point were 500/100 ml and 100/100 ml, respectively. Salmonella were recovered in the three sources of waste and in the river below the discharges, the river samples showing 75,000 coliforms/100 ml and 15,500 fecal coli/100 ml. It is suggested in that report that the stream should be maintained at not more than 5,000 coliforms/ 100 ml even at critical periods of river flow. Such a standard could be maintained by secondary treatment plus disinfection of the waste sources.

Based on a similar, but more extensive, study of the South Platte River Basin in Colorado (27), maximum total coliforms of

5,000/100 ml and maximum fecal coli of 1,000/100 ml were recommended. In this study attention was also given to dissolved oxygen (DO) and 5-day, 20^{o}C BOD levels. Minimum levels of 4 mg/l DO and a maximum of 20 mg/l, 5-day 20^{o}C BOD levels were recommended for water used primarily for irrigation. These criteria likewise are consistent with quality that can be maintained by secondary treatment plus disinfection of all waste sources. Maintenance of quality within these recommendations should insure sufficiently low concentrations of pathogenic microorganisms that no hazard to animals or man would result from the use of the water on even those crops which are consumed raw.

In the report of the National Technical Advisory Committee on Water Quality Criteria, Federal Water Pollution Control Administration, U. S. Department of the Interior (28), the Subcommittee for Agricultural Uses recommended the following guide lines for coliform limitations in irrigation water: "The monthly arithmetic average density of the coliform group of bacteria shall not exceed 5,000 per 100 milliliters and the monthly arithmetic average density of fecal coliforms shall not exceed 1,000 per 100 milliliters. Both of these limits shall be an average of at least two consecutive samples examined per month during the irrigation season and any one sample examined in any one month shall not exceed a coliform group density of more than

20,000 per 100 milliliters or a fecal coliform density of more than 4,000 per 100 milliliters." The report further states that these limitations are particularly applicable where the tops or roots of the irrigated crop are to be consumed directly by man or livestock.

More recent studies have emphasized the value of the fecal coliform density as an index of the probable occurrence of the most common bacterial pathogen in irrigation water, the Salmonella. Geldreich and Bordner (29) in their review of field studies involving irrigation water, field crops and soils, stated that when the fecal coliform density per 100 ml was above 1000 organisms in various stream waters, Salmonella occurrence reached a frequency of 96.4%. Below 1000 fecal coliforms per 100 ml (range 1-1000) the occurrence of Salmonella was 53.5%.

Further support for the limit of 1000 fecal coliforms per 100 ml of water is shown in the recent studies of Cheng, Boyle and Goepfert (30), who reported that as the fecal coliforms decreased in number downstream from a sewage treatment plant, Salmonella were not recovered after the fecal coliforms reached less than 810 per 100 ml.

Direct evidence that man or animals have in fact become infected through the ingestion of contaminated irrigation water or of crops irrigated with contaminated water is more difficult to find. Gaub (31) described an outbreak of bacillary dysentery presumably incriminating irrigated vegetables. However, the samples examined had been handled for marketing, thus the exact source of the contamination cannot be stated. A high incidence of cysticercosis among beef cattle ingesting contaminated irrigation water in Arizona was reported by Hutchins (32).

Although direct evidence of infection is not well documented there is considerable epidemiological evidence indicating that fresh foods irrigated or fertilized with sewage or sewage-polluted water have caused many communicable diseases in the United States, Europe and other parts of the world. Sepp (2) in his excellent literature review on the use of sewage for irrigation, lists many reports of infection both of human beings and of other animals believed to be caused by the ingestion of sewage-contaminated vegetables or fruits. These will not be repeated here because in all instances either night-soil, raw sewage or raw sludge was the irrigation or fertilization source and the distinct hazards of such practices should be apparent. To the knowledge of this author no such epidemics or outbreaks have been traced to irrigation with properly treated and disinfected municipal effluents.

Marketing practices must also be considered in the contamination of vegetables and fruits following harvesting. Obviously such crops should not be rinsed or "freshened" in water other than that of drinking water quality. Furthermore, it is stated in a 1968 publication on Salmonella Surveillance from the National

Communicable Disease Center in Atlanta, Georgia, (33) that wooden crates in which dressed poultry has been iced and packed are potential sources of Salmonella or other enteropathogenic microorganisms that may contaminate fresh vegetables which are frequently consumed without heat treatment; and that the Food and Drug Administration, therefore, will regard as adulterated shipments of vegetables or other eatable foods in such used crates or containers.

In view of the widespread distribution of Salmonella and other enteric pathogens in excreta of both man and other animals, it would seem inevitable that fresh vegetables and fruits would at least occasionally be contaminated with these organisms. However, it is generally the case that foods which cause epidemic outbreaks of enteric disease have been mishandled in some manner to permit extensive multiplication of the responsible organism prior to ingestion. As the pathogens would not multiply on raw vegetables or fruits, it may be that small numbers of these organisms can be tolerated by most individuals, or result only in sporadic cases of infection, the source of which is difficult to trace. Paradoxically, waterborne outbreaks have occurred when the dilution factor must have resulted in the ingestion of only a few of these same organisms. Because of this paradox, and considering the epidemiologic evidence incriminating fresh foods irrigated or fertilized with untreated excreta as sources of disease in man and other animals, it would appear that only thoroughly treated and disinfected municipal effluents should be used for irrigation, particularly of those crops consumed without thorough cooking.

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LEGAL ASPECTS OF LAND TREATMENT OF SECONDARY EFFLUENT

by

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Environmentally, there is little doubt that land treatment of secondary effluent is a desirable method of sewage disposal. Nor is it a new concept, as witness any golfer who has played at the old Las Vegas golf courses, at Patty Jewett in Colorado Springs, or at the course at Page, Arizona.

Several years ago, I had occasion to visit a feed lot on the outskirts of Omaha. The cattle were fed in a building with slotted wooden floors and the manure was flushed into a concrete pit below, from which point it was pumped through pipes that sprayed an adjacent corn field.

Attorneys who do a substantial amount of water law work for cities and developers have noted the tendency of these clients to examine the alternative of land treatment of secondary effluent. It has many attractions, particularly as effluent discharge standards become more rigorous, and as golf courses, greenbelt areas and parks become more important parts of a planned development.

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We are all very conscious of the goal of zero pollutant discharge. Although municipal sewage discharges are excluded from the zero discharge rule, the high cost of supplying the best available treatment techniques to sewage effluent forces operators of municipal sewage facilities to examine alternatives. Land treatment of secondary effluent discharges is a most attractive alternative.

Despite all the good things going for land treatment of secondary sewage effluent, there are disadvantages.

Let us consider two major problems.

(1) One problem arises from the fact that the fertilization of crops is effective only during the growing season. Except for a few areas, such as the Imperial, Yuma or Salt River Valleys, crops are grown only during a portion of the year. It is, therefore, necessary to provide lagoons where the effluent may be stored during the non-growing season. In areas of high development, land costs are high enough to make the considerable land required for such off-season storage a very expensive part of the overall cost. This, however, is an economic problem, and not a legal one, and is, therefore, not really germane.

The second is that of legal problems associated with land treatment of secondary effluent. In order to bring the legal problems into proper perspective, we should review briefly the basic principles of Western water law.

The appropriation doctrine, prevalent in the West, gives priority of right among users to the earliest beneficial use, or, as it is commonly stated, "first in time, first in right." This is a vast departure from the riparian doctrine which controls in more humid areas where there is no scarcity of water.

Under the riparian doctrine ownership of land adjacent to the stream is required; not so under the appropriation doctrine. Under the riparian doctrine the senior appropriator can (and frequently does) dry up the stream - there is no sharing of shortages. Under the riparian doctrine, an upstream owner should pass the water on to a downstream owner unaffected in quantity and quality. Such a restriction is essentially a "non-use" doctrine, and is wholly incompatible with Western water needs.

Coupled with the "first in time, first in right" concept of the appropriation doctrine is the rule that a junior appropriator is entitled to have conditions on a stream remain as they were at the time the junior appropriator made his appropriation. In other words, a person desiring to appropriate water from a stream observes the available supply, taking into consideration all then existing appropriations, and then makes his economic decision as to whether enough water will be available, <u>under existing conditions</u>, to satisfy his requirements.

If the potential appropriator makes an affirmative determination, and perfects his appropriation, then nothing may be done by a senior appropriator which would alter conditions on the stream to the detriment of the junior appropriator.

When a city, which has historically returned its sewage effluent to a stream, determines instead, to irrigate land with that water, three things happen. There is a change of type of use, there is an enlarged consumptive use, and there is a reduction in return flow.

Let us see what the courts say about this:

> There is absolutely no question that a decreed water right is valuable property; that it may be used, its use changed, its point of diversion relocated . . .
>
> Equally well established, as we have repeatedly held, is the principle that junior appropriators have vested rights in the continuation of stream conditions as they existed at the time of their respective appropriations, and that subsequent to such appropriations they may successfully resist all proposed changes in points of diversion and use of water from that source which in any way materially injures or adversely affects their rights. (1)

This quotation comes from the leading Colorado case of Farmers Canal and Reservoir Company v. Golden, decided in 1954. After the language quoted above, the Colorado Supreme Court cited seven other similar cases, five of which involved cities attempting to enlarge the use of a water right, all unsuccessfully. There are other similar Colorado cases not specifically cited in the Golden case. (2)

Cities have to have dependable water rights, and therefore they are usually among the most senior on the stream. It is good to be senior, but being very senior means that there are a great many juniors who will object, and promptly, if the regimen of the stream is changed.

At one time cities (and others) thought that they had a right to "use up" water once it was diverted. The courts disabused them of that concept, saying:

> Once an appropriation has been diverted, used and returned, it becomes again a part of the stream in which junior appropriators below acquire a vested rights. (3)

One thing should be made perfectly clear, however. For those who are able to go out and appropriate a reliable new source of water, there is absolutely no legal inhibition against appropriating that water for both municipal use <u>and</u> land treatment of secondary effluent. At the moment the appropriation is made that use is the most junior right on the stream and any subsequent appropriators will be junior and take the stream as they find it, with the right in existence to utilize the secondary effluent for land treatment. Therefore the subsequent juniors have no right to complain.

There are three other Colorado cases one should be aware of that deal directly with the right to re-use sewage effluent.

The earliest case is <u>Pulaski Irrigating Ditch Company v. the City of Trinidad</u> (4) in which the court said:

In 1892, a sewer system was completed by the City of Trinidad, and the sewage carried therein was emptied directly into the Las Animas river. Very soon thereafter this disposal of the sewage was enjoined by the district court. Thereupon the city extended its sewers and discharged the sewage into settling pits on land adjoining the river. From the record it appears that a considerable part of the water content of the sewage seeped or ran back into the river, and soon became a part of the supply for the appropriations below the point of discharge.

In 1917 the city began the construction of two purification plants, and upon their completion proposed to sell the purified water to said Model Land & Irrigation Company, hence this suit.

There seems to be no substantial controversy over the facts, and the sole question presented for our consideration is as to the right of the city to sell the water.

Plaintiffs in error (the junior appropriators) contend that, inasmuch, as the water which escaped from the pits and ran into the river contributed to supply appropriations down the river, the city cannot now divert that water for use below the points where it has been in use for some years past. They contend also that the water, having performed the purpose for which it was diverted, must, under the law, be returned to the river from which it was taken.

(1) Defendents in error contend that "the application of water to domestic use is a use which consumes." They also contend, in effect, if not in words, that sewage is a thing which may be considered regardless of its constituents; and that the water resulting from its purification is salvage or developed water; that is, water produced from something which was not water.

The first proposition is true only as to a part of the water applied to city uses. It is not true of water used in the sewers for the purpose of diluting and conveying away solid matter. This water in the sewers exists as fully as before it was used, but in connection with solid matter, which makes it unfit for further use, as it is. It has been used as a means of conveying matter, a merely mechanical use. That it may be used for irrigation before purification is not denied, but such use is highly objectionable for reasons well known. When it is purified, it is again the same element which was originally diverted. The separation will take place, to a large degree, if the sewage be allowed to stand, and that, too, without any external aid. That fact is conclusive that the sewage is not fundamentally different from water. A title by use is not acquired any more than it is in the case of water used for power purposes; in either case when the use has been completed the right of the user terminates.

. . . .

To turn this water back into the river will not increase the river's flow above what it would have been had the water not been diverted, and it is not therefore developed water. Applying the principle heretofore laid down, it seems clear that the water here in question does not belong to the city, and that it has no right to sell it.

Two very recent cases are Metropolitan Denver Sewage Disposal District v. Farmers Reservoir and Irrigation Company (5) and Denver v. Fulton Irrigating Ditch Company. (6) Each is a rather special fact situation and does not alter the case law I referred to, but each should be mentioned.

Metropolitan is a case which held that someone returning sewage effluent to a stream has a right to change the place of return, and is not governed by the rules involved in a change of point of diversion. It based its decision on early cases involving irrigation return flows, citing with approval Green Valley Ditch Company v. Schneider, (7) where the Court said:

> Plaintiff's rights were limited and only attached to the water discharged from the Tegeler lateral, whatever that happened to be, after the defendents and and cross-complainants had supplied their own wants and necessities. This does not vest her with any control over the ditches or laterals of appellants, or the water flowing therein, nor does it obligate appellants to continue or maintain conditions so as to supply plaintiff's appropriation of waste water at any time or in any quantity, when acting in good faith.

citing other cases. (8)

Fulton confirmed the right under Colorado law of an appropriator of transmountain water to reuse that water for other than municipal purposes. Denver had brought water over from the Western Slope and wanted to trade sewage effluent to Coors for rights Coors owned on Clear Creek. The Court said Denver would have had a right to make the exchange except for an earlier contract with Fulton and others agreeing not to do so.

As you will note from the decision in the Fulton case, water imported from another basin holds a different and higher status. An importation made after junior appropriators perfect their claims adds water to the stream and the juniors, while permitted to utilize this windfall, have no right to demand its continued delivery. For the purposes of this paper, it is assumed that we are not dealing with imported water.

What, therefore, is the legal status of land treatment of secondary effluent?

To answer this question, I must be allowed to play engineer for a moment.

Normal municipal treatment of sewage permits the return of about 90 to 95% of water used for sanitary purposes; 40 to 60% of water used for lawn irrigation is returned to the stream either through storm sewers or percolation through the soil. Sanitary sewer effluent is normally transmitted directly to the stream after treatment.

Land use of secondary effluent affects the 95% return flow portion of municipal use. By land use, the 95% figure will be reduced substantially, depending on the location of the land upon which the effluent is applied with references to the stream, the porosity of the soil, and the method of application. If the effluent is sprayed on the land, the portion returned to the stream is diminished as the efficiency of irrigation increases.

The net result is a very substantial increase in consumptive use, from a previous 5 to 10% to as much, perhaps, as 70%. This change has a direct and adverse effect on junior appropriators and impairs their vested legal rights. We must assume that junior appropriators would protest promptly, vigorously, and - under the law cited - successfully.

How, then, can municipalities move toward land use of secondary effluent?

From a legal point of view, the answer is simple. The municipality must acquire and leave in the stream an amount of water, of a priority at least as senior as the priority it is diverting, sufficient to keep the stream whole, so that there will be no difference in the water supply available for junior appropriators.

While the legal solution to the problem is simple, severe economic problems arise. Water rights of a seniority adequate for municipal supply are difficult to obtain and command a higher price. Although a city can condemn such a right, condemnation is the most expensive method of obtaining the right and should be avoided if possible.

Land use of secondary effluent has appeal not only because of its environmental advantages, but because it allows the municipality to avoid the high cost of additional treatment to meet required discharge quality standards. It is essential, therefore, to weigh the comparative costs of installing advanced treatment facilities and foregoing land use, on the one hand, and the costs of acquiring the make-up water needed to permit land use, on the other hand.

Costs of acquisition of water rights vary from place to place, depending on supply. It is impossible and, therefore, unwise to make any blanket recommendations as each city's situation must be analyzed to determine whether land use is economically practical.

Although the citations here are Colorado cases for advising on the legal principles involved, I am of the opinion that the law is similar in all of the appropriation states, although the procedures may vary considerably.

In conclusion, we find that land use of secondary effluent is legal provided the municipality replaces any diminution in return flow so that junior appropriators are not adversely affected by the new utilization of secondary effluent. The decision to inaugurate land use of secondary treatment requires some hard economic decisions.

References

1. Farmers Highline Canal & Reservoir Company v. City of Golden, (1954) 129 C.575, 272 P. 2d 629, citing Baer Brothers Land & Cattle Co. v. Wilson, 38 Colo. 101, 88 P. 265; Vogel v. Minnesota Canal & Reservoir Co., 47 Colo. 534, 107 P. 1108; City and County of Denver v. Colorado Lane & Livestock Co., 86 Colo. 191, 279 P. 46; Baker v. Pueblo, 87 Colo. 489, 491, 289 P. 603; Farmers Reservoir & Irrigation Co. v. Town of Lafayette, 93 Colo. 173, 24 P. 2d 756; Faden v. Hubbell, 93 Colo. 358, 369, 28 P. 2d 247; Del Norte Irrigation District v. Santa Maria Reservoir Co., 108 Colo. 1, 7, 113 P. 2d 676.

2. Farmers High Line & Reservoir Co. v. Wolf, 23 Colo. App. 570, 131 P. 291 (1913), and Mendenhall v. Lake Meredith Reservoir Company, (1953) 127 C. 444, 257 P. 2d 414. See also a case decided after the Golden case: Hallenbeck v. Granby Ditch & Reservoir Company, (1966) 420 P. 2d 419.

3. Vogel v. Minnesota Canal & Reservoir Co., <u>supra</u>, n.1.; Farmers High Line & Reservoir Co. v. Wolf, <u>supra</u>, n. 2.

4. 70 Colo. 565, 203 P. 681 (1922)

5. 499 P. 2d 1190 (1972)

6. 506 P. 2d 144 (1972)

7. 50 Colo. 606, 115 P. 705 (1911)

8. Mabee v. Platte Land Co. 17 Colo. App. 476, 68 P. 1058 (1902), the Fairplay Hydraulic Mining Co. v. Weston, 29 Colo. 158, 67 P. 160 (1901).

SOIL ORGANISMS: THEIR ROLE IN SOILS USED FOR WASTE RECYCLING

by

Burns R. Sabey*

Introduction:

Too often the general public and even some soil scientists look upon the soil as dead, static mineral and organic material. However, the soil is full of life. With modern techniques of soil management and well adapted plant varieties, an acre of pasture can produce sufficient feed for three or four cows during the summer. Thus, an acre of land can feed three to four thousand pounds of animal life above the surface. In addition, that acre of soil may feed other living organisms equal in weight to five or ten cows.

The soil has a tremendous capacity to maintain living organisms. On a summer day the soil is literally teeming, not only with macroscopic plant life (alfalfa, corn, soybeans, etc.) and microscopic plant life (bacteria, fungi, actinomycetes, algae, etc.), but also with microscopic and macroscopic animal life, including such things as ants, springtails, earthworms, protozoa, and prairie dogs. Table 1 shows typical numbers and weights of some animals and plants found in an acre of soil.

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Suppose that the nutrients which this life ordinarily uses were used instead to produce extra feed in order to produce more milk or meat. At first, production would be greatly enhanced, except that it is this microscopic life that allows the soil to produce food and fiber. What would eventually happen without this life? Not only would the agricultural production fall off, but all living things would have soon ceased to exist.

Table 1. Organism Numbers and Weights in Soils*

		No. per Acre	Lb. per Acre (live weight)
Soil Animals:	Earthworms	5×10^{5}	500-1500
	Myriapods	8×10^{5}	100-300
	Nematodes	3×10^{10}	25-100
	Protozoa	10^{13}	200-400
	Others	-	800-2000
Soil Plants:	Fungi	4×10^{14}	1000-2000
	Actinomycetes	7×10^{14}	500-1000
	Bacteria	1.5×10^{16}	2000-6000

* Calculations and estimates from Russell (25), Burges (6), Burges and Raw (5).

This life in the soil is the actual survival mechanism of other life on earth. Without it, the carbon, nitrogen, phosphorus, and sulfur cycles would soon become static because the elements would be tied up in unavailable forms. We might reason that nitrogen, phosphorus, and sulfur could be chemically synthesized and added to the soil to take care of the need. This may be partially true, but another problem would arise -- that of an ever-rising accumulation of undecomposed organic debris on the soil surface. This debris would soon cause numerous problems.

An Analogy:

The soil is a habitat in which individuals are fighting for existence in an environment that is sometimes friendly and at other times not so friendly, but always keenly competitive.

Imagine that the earth is a Petri dish of agar and that we are super human beings so large that we can hold it in the palm of the hand. Being that large, our vision cannot distinguish small objects like people. We can see large cities, however, which to us look like little dots on the plate of agar (our earth satellite photos give a similar perspective). We can determine that in one of the large cities, such as Chicago, changes are taking place. We cannot see any of these changes, but we can measure them in various ways. For instance, if we put a large cap over the city we may be able to gather the smoke that accumulates and measure the amount. We may be able to measure another by-product if we happen to find the sewage disposal plant. As we measure these products, we wonder what causes these changes. Are they chemical, biological, or physical?

We spray the city with chloroform, ether, or some other anesthetic and within a short time we find that some of the products are no longer being formed, so we assume that living entities are causing these changes. What are these living entities like? After the effects of the anesthetic wear off, we get out our giant microscope, search the area and see an individual come out of a hole, which happens to be his house, get into a black thing that is a method of locomotion, and move toward the most active part of the dot, which is actually the "loop" of Chicago. It is not long until we lose it. It happens that the individual parked his car in an underground parking lot and we no longer can follow him, but there are thousands of other individuals we can study and their patterns of activities are not exactly alike. It becomes difficult to make generalizations.

We decide to take out our giant inoculating needle, and try to pick up some of the individuals and place them on another planet whose environment we can control. As we swish across this speck, we knock over a number of buildings and pick up a dwelling that contains some of the individuals we want to study. As we drop these slightly damaged dwellings on the experimental planet, the frightened inhabitants, after getting their breath, make their way out of the house to find that they are in a considerably different environment -- an environment where there is ample, immediately available food, plenty of sunshine causing optimum temperatures, plenty of clear, fresh, running mountain water, a virtual "utopia". In other words, optimum environmental conditions prevail.

Since we are super human beings, a few hundred years is only a short period to us, and within that time we study the group that happened to be in this dwelling. The individuals grow and develop, multiply and divide, and form a colony. We study them, we measure their activities under varying conditions which we can control and from these measurements we make generalizations.

Now, when we come back to the original speck that was the city of Chicago and try to use the same generalizations in this area where there are many millions of individuals, our generalizations simply do not fit. Why? In a large city there are television and radio sets, automobiles, crowded conditions, and pollution; there is competition and antagonism; and there are symbiotic-like (mutually beneficial) relationships. Conditions are quite different from the "utopian" conditions on the planet on which we placed our experimental individuals. We conclude that people react differently under different conditions. The job, then, is to map out all the conditions that influence the activity of the individual and the composite activity of the whole community. This is a monumental task.

Soil - A Complex System:

Notwithstanding the imperfections in the foregoing analogy, the soil biologist finds himself in somewhat the same situation as the super human being when he attempts to study the biology of the soil. Many soil biologists have attempted to isolate various organisms from the soil, grow them on nutrient media and study them, and then from this information generalize about what goes on in the soil. This approach, though sometimes necessary, has not been very effective in answering our biological problems because there are so many complicating factors in the soil mass that it is unrealistic to generalize about the soil from pure culture work. Some have felt that a more productive approach is to measure the biological activities of the soil mass as a whole, almost thinking of the soil as a living entity or a biological unit (14).

Antagonistic, symbiotic, or mutually beneficial and competitive relationships have made it difficult to elucidate the many problems associated with soil microbiology and biochemistry. All the steps in the organic matter synthesis and decomposition cycle are greatly influenced by competitive as well as symbiotic associations.

We have hardly scratched the surface in explaining the complex interrelationships among the chemical, physical, and biological properties of the soil. Although work has been done on isolated chemical, physical, and biological properties, we usually do not know just how they fit together. These problems will not be answered by individual chemists, physicists, or biologists, but through concerted, cooperative and coordinated efforts of workers in all three areas. Soil research is inadequate unless we recognize the plant and animal life in the soil and the influence this life has on various soil properties.

Waste Recycling

Sewage Sludge Decomposition in Soils:

Soil organisms (at least the heterotrophs -- those requiring an organic carbon source for energy) attack most organic residues that are incorporated into the soil. The organic compounds provide energy and nutrients. The compounds derived from green plants such as celluloses and hemicelluloses are degraded first, leaving the more stable and more difficult to decompose compounds such as the lignins. As decomposition proceeds, therefore, the rate usually decreases.

Figure 1 shows a generalized concept of aerobic organic matter decomposition. The complex organic compounds in sludge or other organic materials are oxidized stepwise to more simple organic compounds until CO_2 and H_2O are formed, along with numerous inorganic ions and compounds. Few organic molecules are immune to biological attack and degradation, however, there are compounds that are extremely stable and decompose very slowly. A mixture of these compounds, along with others synthesized by the organisms, form various possible combinations of stable complexes that gradually accumulate in the soil (29). This mixture of compounds and complexes make up the "humus". Humus has not been well characterized chemically because it is so intimately associated and attracted to the mineral sands, silts, and particularly the clays, and is extremely difficult to isolate and study unaltered. Possible combinations of compounds that have been theorized to account for a large part of the humus include: (a) sugars with amines, (b) phenols and quinones with amines (12), (c) lignins with ammonia (16), (d) lignins with proteins (29), along with several others. This intimate mixture of humic substances results from the

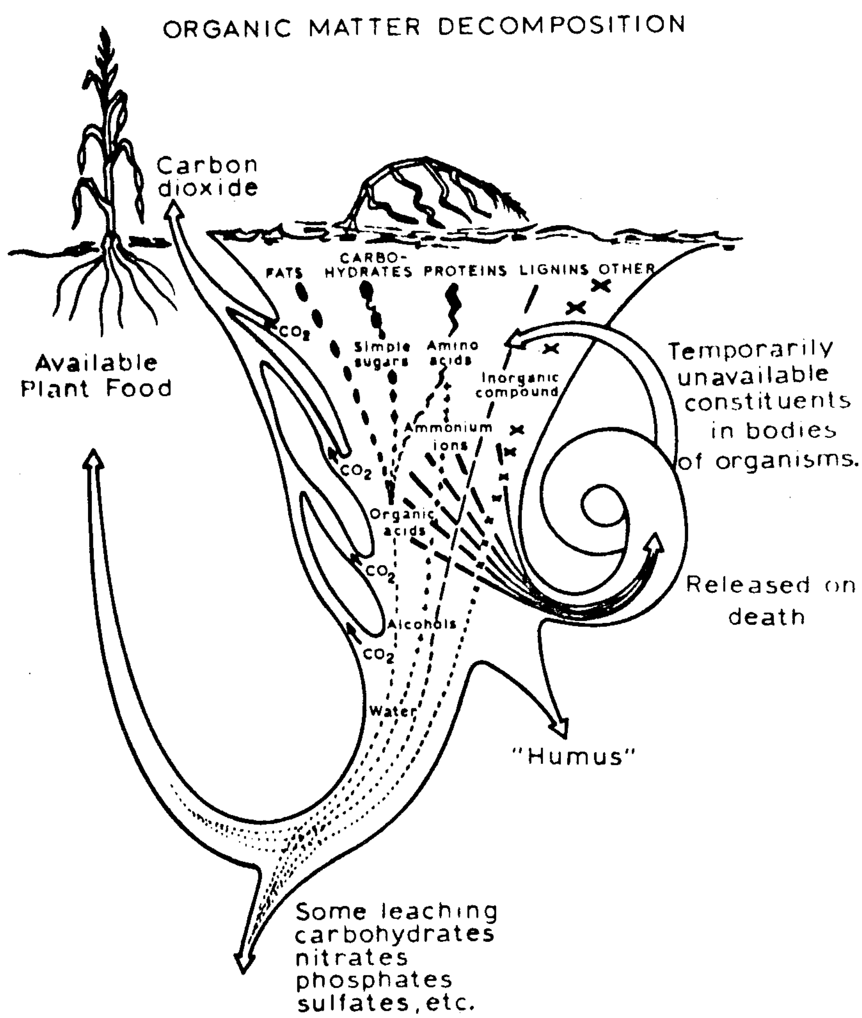

Figure 1. Generalized Scheme for Organic Matter Decomposition

continued recycling and mixing of nutrients and compounds by the soil population. Resistance to decomposition is also due to the attractive mechanisms or forces that exist between the positive and negative charges on the soil mineral and organic colloids.

Unlike fresh plant and animal residues that are incorporated into the soil, most sewage sludges have been through a biological treatment, wherein partial decomposition and stabilization has occurred. This results in a decrease in total amount of organic material, due to loss of carbon, either as carbon dioxide (CO_2) in an aerobic environment, or as methane (CH_4) and carbon dioxide (CO_2) in an anaerobic digestion. When the sludge is added to soil, the rate of decomposition will be somewhat slower than that of most fresh organic residues since the available energy material (soluble organic carbon compounds) and nutrients for microbial growth are less. The result is an increase in the level of soil organic matter, sustained over a longer period of time. In a given environment this may have its advantages or disadvantages. The advantages stem from the increased source of plant nutrients and improved air and water relationships, resulting in greater plant growth. However, the possible increased mobility of some of the heavy metals due to the addition of naturally occurring chelating compounds in the sludge (21) may cause leaching of the chelated metals into the groundwater.

The specific decomposition rates of many plant and animal residues in soils have been determined, but little data are available on the rate of decomposition of sewage sludges added to soils. Miller at Ohio State (20) has shown that as little as 20% of a sewage sludge added to soils is decomposed within one year. This illustrates the relative stability of sewage sludge compared to the 30-50% (or more) per year decomposition of many plant and animal residues in soil.

Nutrient Cycles

Most nutrient cycles are greatly influenced by the soil organisms.

Nitrogen - Many consider nitrogen to be the most limiting element controlling ecologically sound application rates of sewage sludges or effluents to soils. The nitrogen cycle will illustrate why this can be the case. Figure 2 shows a generalized nitrogen cycle.

Most parent materials of soils (minerals) have little or no nitrogen. Before plants will grow abundantly in the soil, nitrogen must be added. This is done naturally by nitrogen fixing organisms that have the facility to take N_2 gas from the atmosphere and combine it with hydrogen, from which amino acids and eventually proteins and other organic nitrogen coumpounds are synthesized. These organic nitrogen compounds are released to the soil and are decomposed to form ammonia. Several things can happen with this ammonia. It can be volatilized, especially if dried at the high pH. It combines with water to form ammonium, and the ammonium ion can be fixed in and/or adsorbed on the clay colloids; it can be used by plants and other organisms, or it can be attacked by a group of autotrophic organisms called nitrifiers and oxidized, first to nitrite and subsequently to nitrate. The nitrate ion is very mobile and very elusive in the soil. It can be used by plants, it can be leached into the ground water, or it can be denitrified and go back into the atmosphere as N_2, whereupon the cycle is complete.

Most of these reactions have been studied extensively under controlled and specified conditions of temperature, moisture, pH, etc., but because the organisms that promote these biochemical reactions are so sensitive to environmental changes, it is difficult to model and successfully quantify the entire nitrogen cycle, though some attempts have been made (2, 9, 10, 26).

Several aspects of the nitrogen cycle are of significance to environmentally sound and successfuly management of a land effluent or sludge recycling system. If we do not want to pollute the ground water by sludge or effluent applications to soil, we must either add only enough to supply the nitrogen for plant growth and haul the plants away (using the plant as a nutrient pump) or we must learn to manipulate the cycle to decrease nitrogen in the soil-sludge mixture. This latter alternative is possible at two places in the cycle. We can enhance ammonia volatilization or enhance denitrification. Ammonia volatilization can be promoted by raising the pH, spraying or aerating or drying the material before incorporating into the soil. Denitrification can be increased in soils by adding readily available sources of energy material, such as sugars, alcohols, or other easily oxidizable carbon compounds, and by depleting the oxygen by saturating the soil after nitrite or nitrate have been produced.

Phosphorus - Phosphorus may be the limiting factor governing the rate of application of wastes to land once we learn to manage the nitrogen. Even though most wastes contain less than half as much phosphorus as nitrogen, there are not as many ways to promote phosphorus losses from the soil as with nitrogen. Short of incineration, little or no phosphorus volatilization occurs in soils, except possibly phosphine (PH_3) in paddy soils (27), but even this possibility is questioned by Burford and Bremner (7). However, because of the large amounts of

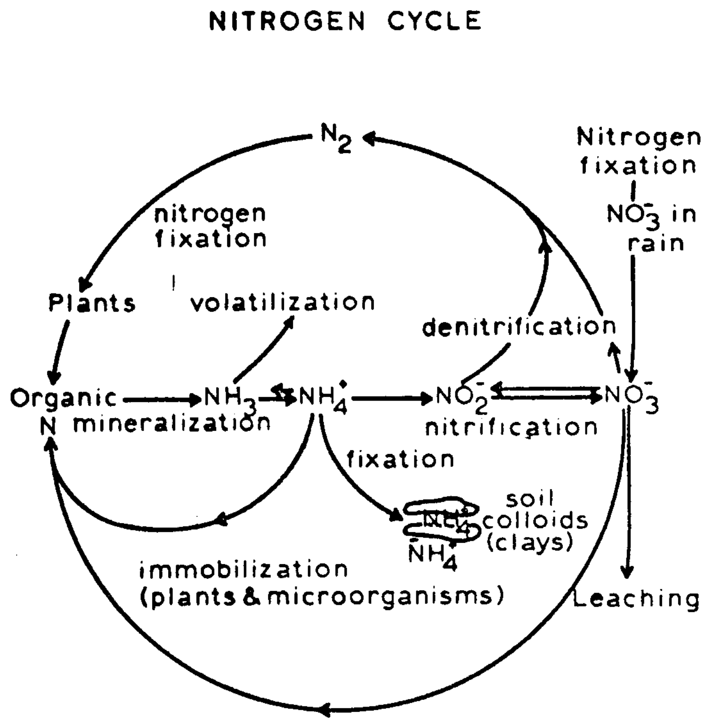

Figure 2. Generalized Scheme for the Nitrogen Cycle

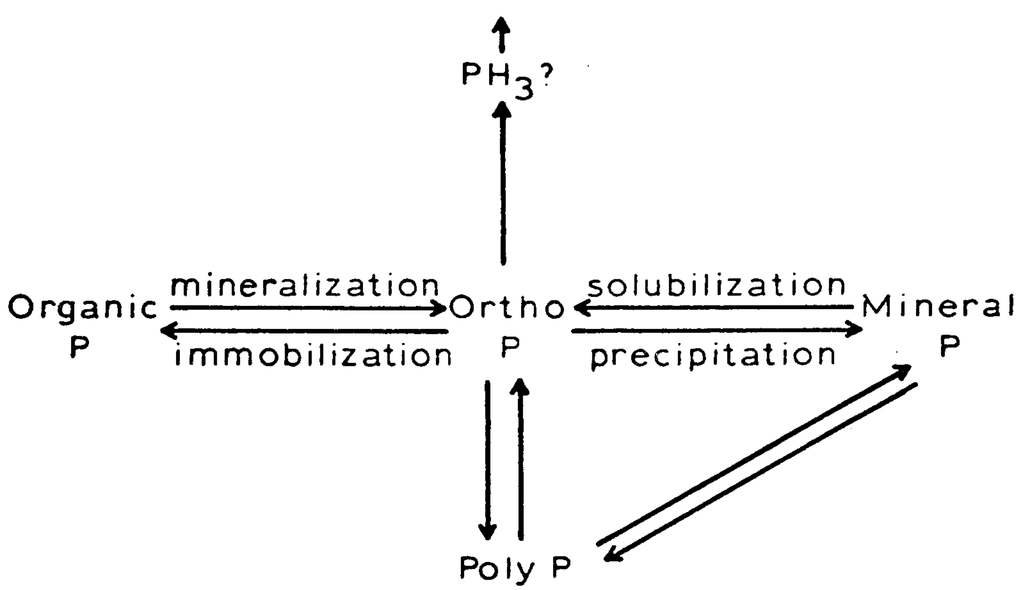

Figure 3. Generalized Scheme of Some Major Phosphorus Transformations in Soils. Adapted from Miller (19)

aluminum, iron, and calcium they contain, most medium to fine textured soils have an almost unlimited capacity to convert phosphorus into nearly insoluble compounds with these elements. It is doubtful that on these soils phosphorus will limit sewage sludge applications.

Figure 3 illustrates the general phosphorus situation in soils. Prior to man's influence, most of the soil phosphorus originated from weathering of apatite minerals contained in soil parent materials, however, as organic matter accumulated in the soils, some of the inorganic soil phosphorus became immobilized, fixed, or chelated as organic phosphorus compounds. The supply of soluble phosphorus available to plants was dependent not only on apatite decomposition, but also on the decomposition of organic phosphorus compounds by organisms much the same as organic nitrogen compounds, with similar environmental conditions affecting the mineralization and immobilization processes.

Man introduced fertilizer phosphorus both in the organic and inorganic forms as the natural supply became limiting to plant growth. This contributed greatly to the supply of plant available phosphorus. More recently, detergents and other materials found in wastes added to soils have provided additional phosphorus in the form of polyphosphates which undergo various biological cycling and chemical reactions as illustrated in Figure 3.

The greatest amount of soluble and leachable phosphorus occurs in soils having pH values near 6.5, but the mobility of phosphorus compounds in soils is considerably less than nitrate (3, 15). Phosphorus is much more likely to accumulate in the topsoil especially in high or low pH soils.

Less research on biological transformations of phosphorus, either from plant residue or wastes, has been done than with nitrogen, but if land treatment of wastes becomes a widespread and ecologically sound practice, phosphorus concentrations (polyphosphates) may have to be lowered to acceptable levels in the effluents and sludges before applications to some soils is permitted.

Sulfur - Figure 4 indicates the sulfur reactions influenced by soil organisms. The biological mineralization and immobilization reactions of sulfur are influenced by variations in environmental conditions much the same as nitrogen and phosphorus. The mercaptan compounds are decomposed to form either hydrogen sulfide (H_2S) under anaerobic and sulfate ($SO_4^=$) under aerobic conditions. Sulfates are quite soluble and can be leached or they can be utilized by plants. Under reducing conditions H_2S is produced either from organic sulfur decomposition or from sulfate. Although reducing conditions do not persist for extended period in most agricultural soils, small amounts of H_2S can be volatilized, can be oxidized to elemental sulfur or sulfate by microorganisms, or can be united with metal ions to form insoluble sulfides.

There are fewer pollutional concerns for sulfur in soil and water than for nitrogen or for phosphorus at the present time.

Influence of Soil Organisms on Solubility of Inorganic Ions:

The numerous metals that are contained in sewage sludges and effluents vary greatly in concentration, depending on origin of the wastes. During sewage processing and subsequent separation of the effluent and the sludge, most of the metals remain in the sludge. Some sludges, therefore, contain high concentrations of some metals, depending on quality of influent. The solubility and mobility of the metals added to soil with effluent or sludge vary with soil conditions and organism activity. This is illustrated by Figure 5. The organisms cause mineralization and immobilization and/or chelation of the metals either under oxidized or reduced conditions. Immobilization of the oxidized or reduced metal froms insoluble organic complexes. Biological mineralization reverses this

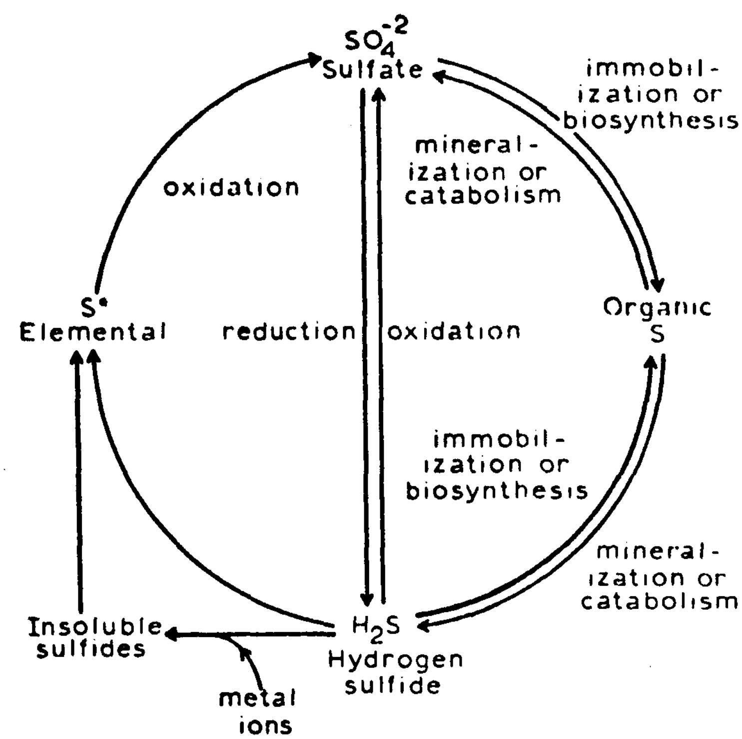

Figure 4. Generalized Scheme for Some Major Sulfur Reactions in Soils. Adapted from Miller (19)

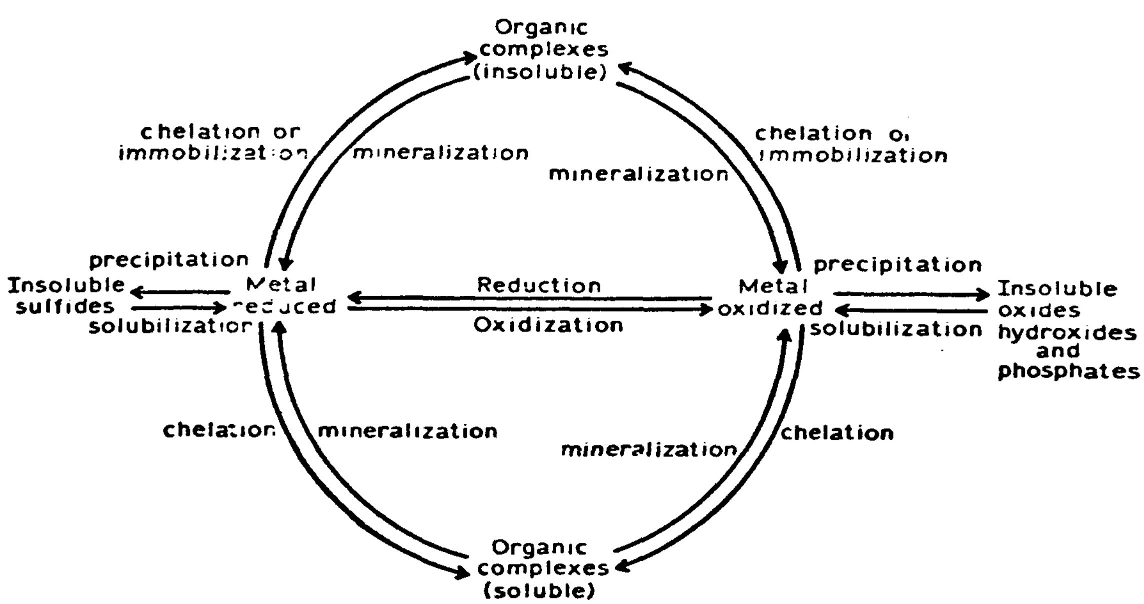

Figure 5. Generalized Scheme of Some Metal Reactions in Soils. Adapted from Miller (19)

process. The reduced form of the metal is generally soluble. Soil organisms not only affect oxidation-reduction potential that influences solubility of the metals, but also produce organic chelates that combine with metals to form a soluble organic complex (21). In this form, leaching of the metals into the ground water could occur if the concentration gets high enough, especially in acid soils.

Pathogen Survival and Movement:

One of the greatest concerns of scientists and of the general populace associated with sludge and effluent application to soils is the potential pathogenic contamination of the water and food chains. As a result, one of the cardinal principles prohibits the application of raw sewage to soils. We are aware that in the Far East, raw sewage has been applied to soils, keeping them fertile and productive, for hundreds of years. In that area, those who survive childhood have an apparent immunity to the illnesses caused by eating fresh, raw vegetables grown in those soils. A foreigner traveling in the area needs only experience a severe case of dysentery, however, to realize the pathogen problem caused by frequent application of raw human wastes to soils.

Well-digested sewage sludges have far fewer pathogens than raw sewage although they are not pathogen-free. Some pathogens can and do survive the digestion process in the sewage treatment plant. What is the fate of the pathogens when the sludge is applied to the soils? Generally, with time after sludge addition to soil, the pathogenic population decreases quite rapidly. Disappearance of these organisms is caused by antagonistic effects of saprophytic soil organisms, predation, by nutritional factors, or by other adverse environmental conditions. If the soil has a healthy active native organisms population, the rate of pathogen "die-away" is rapid. Figure 6 shows some data from Van Donsal and associates on survival of fecal coliform and fecal streptococcus in soil (28). These data indicate a rapid decrease in the fecal coliform and fecal streptococcus. Other investigators have not shown population decreases as dramatic as this figure shows (8, 24).

Our data (see Table 2) show that the numbers of some groups of organisms found in plots to which Denver sewage sludge was added were greater after five months of crop growth and summer weather than the check plots, where no sludge was added. This was true of total aerobic bacteria and generally of total coliform and fecal streptococcus, but was not true of fecal coliform.

Klein and Casida (11) reported a reduction of 90% of E. coli numbers within five days in unamended soils, but if glucose were

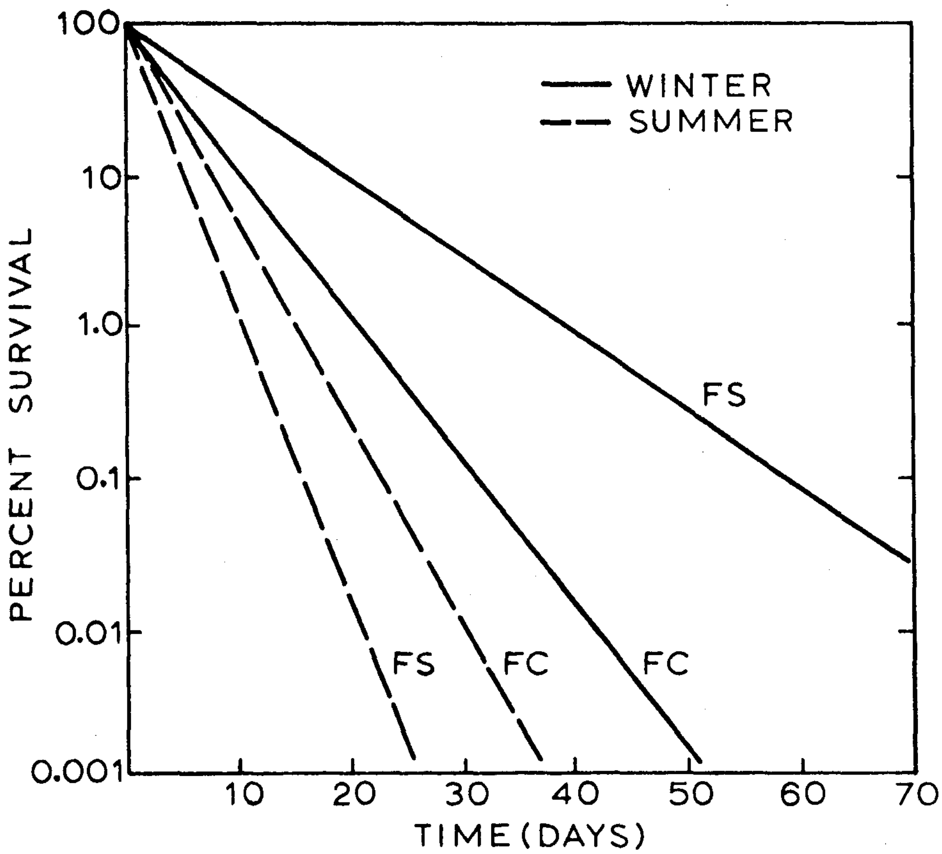

Figure 6. Survival of Fecal Streptococcus (FS) and Fecal Coliform (FC) Bacteria in Soils (28).

added, the life of these organisms was prolonged in the soil.

Evans and Owens, as reported by Robinson (23), found that it took 57 days to reach 90% reduction in numbers of *E. coli* (applied to soils) in pig manure. Their studies showed that *E. coli* appeared in subsurface drainage tile within 1.5 hours after application to an English soil and that the number of these organisms carried through the soil was related to flow rate of water to the tile system. If one assumes that *Salmonella* and related organisms act similarly, there is a possibility that pathogenic organisms found in sewage effluent and sludge, and animal manures may escape from soil in drainage water before being inactivated by soil.

Work done near Chicago at a Northwestern University research site reported by Peterson (22) showed that there was a rapid decrease in fecal coliform bacteria with lateral movement in ground water even in sandy soils. However, in test wells on the sludge application sites, fecal coliform bacteria were detected, especially after a heavy rain. Organism movement into the well was due to gravitational water movement. In a test well, off the sludge application site, no test organisms were detected, indicating the filtering effect of soils as ground water moves laterally.

Table 2. Effect of Metropolitan Denver Sewage Sludge Application Rate on Survival of Four Bacterial Groupings* (five months after sludge application).

Sludge Applied (T/A)+	Soil Depth	Total Aerobic Bacteria	Total Coliform	Total Coliform	Fecal Strept
dry basis	inches				
			Fallow Plot		
0	0 - 2-1/2	3.3×10^6	2.2×10^3	1000	100
55	0 - 2-1/2	24×10^6	6.9×10^3	1000	320
			Sorghum Plot		
0	0 - 1-1/4	4×10^6	1.4×10^3	100	100
11	0 - 1-1/4	13×10^6	0.3×10^3	100	1300
55	0 - 1-1/4	14×10^6	30×10^3	100	100

* Appreciation is expressed to Dr. Kenneth G. Doxtader and Nnaemeka N. Agbim for making the microbial counts on these soils. (no./gm. of dry soil)

+ Tons/Acre.

Work done at Colorado State University by Martin Allen, under the direction of Waltz and Morrison, showed that a high percentage of mountain well waters are contaminated by fecal organisms from septic tank leach fields, especially where there is insufficient fine textured soil to provide adequate filtering between the well and the leach field (1).

Bouwer (4) reports that percolation through 5 to 10 feet of soil effectively removes fecal bacteria. Coliforms below 5 to 10 feet depth can sometimes be detected but they are usually of soil origin rather than human origin (17). Bouwer suggests that lateral ground water travel through 500 to 1000 feet of soil with transit time of several months is sufficient to provide hygenically safe well water. Work at Pennsylvania State University indicated no bacterial contamination in well waters when sewage effluent was recycled in forested lands with the leachate being filtered through the soil to the well.

Although there is a rapid decrease with time in pathogens added to soil via effluents and sludge, some organisms have the capacity to survive in the soil by spore formation or other protective mechanisms. However, many persons work around sewage sludge and effluents daily with few documented cases of illness due to the pathogens contained in the wastes. Nevertheless, the potential for disease is there. With reasonably low rates and infrequent applications of wastes, the possibility of problems caused by pathogens will be small.

Viruses present a more difficult problem to handle, since culturing and isolating them is more complicated than with many other organisms. Most work on pathogens in the soil due to sewage effluents or manure application has been with bacteria. Merrell and Ward in California (18) reported an absence of viruses after 1500 feet of soil percolation, but presence of viruses when the distance was only 400 feet

Other work on pathogenic organisms survival and movement through soils has been reported by Krone and Dunlop (13, 8).

Much more research is needed on bacteria viruses and other pathogens added with effluents, sludge, and other organic waste materials.

Conclusions:

The soil provides food for numerous microscopic and macroscopic plants and animals. Many complicated biochemical reactions occur in the soil, many of which have yet to be elucidated because of the complexity of this growth medium. General plant and animal tissue decomposition pathways have been worked out, but many of the specific and detailed biochemical reactions, along with the environmental factors influencing them, need further study. The soil organic matter, particularly the somewhat stable "humus" has never been satisfactorily characterized because of its chemical complexity and the problems associated with separating it unaltered from the mineral portion of the soil.

Sewage sludge decomposition in the soil is generally slower than that of fresh plant and animal residues, therefore sludge should tend to increase in the content of soil organic matter with continued and frequent applications. As little as 20% of the organic fraction of the sewage sludge added to soil is decomposed per year. This rate is dependent on the environmental conditions, however.

Nutrient cycling is caused and greatly affected by biological activity. This is particularly significant in carbon, nitrogen, phosphorus, and sulfur, as well as those elements that are organically bound to a lesser extent. Nitrogen is most often cited as the limiting factor controlling maximum sewage sludge application rates. Some consider that phosphorus will become the limiting factor if and when we learn to control the nitrogen cycle with proper and economical management practices. Chelation due to organic compounds produced during organic matter decomposition may render some of the metals soluble and increase the possibility of leaching them into the ground water.

Pathogenic organisms added to the soil by sewage sludge or effluent application tend to decrease rapidly in number due to competition, antagonism, lack of proper food or lack of proper environmental conditions. Some pathogens have the capacity to withstand adverse conditions, enabling them to survive in the soil. This leaves an ever-present threat of disease possibilities, yet few, if any, documented cases of epidemics have resulted from applying thoroughly digested anaerobic sewage sludge to soils.

Pathogens do move through soils to a limited extent, yet soils, particularly medium textured soils, provide an excellent filter for many pathogens if there is 10 to 20 feet of such material and transit time is extended.

Viruses present a special, largely unexplored, problem to the practice of sludge and effluent application to soils. One study showed that over 400 feet of lateral ground water movement through coarse textured soils was necessary to remove viruses.

Much more work with the pathogens related to sludge application to soils is needed before systems can be designed most efficiently and economically.

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SOIL TRANSFORMATION OF NITROGEN IN EFFLUENTS

by

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Most of the soluble nitrogen in wastewater applied to land is in the form of ammonium or nitrate. Some soluble organic nitrogen may be present, but this is readily convertible to ammonium, since it is readily attacked and mineralized by a large number of soil organisms. When ammonium nitrogen comes in contact with the soil, it normally is adsorbed on exchange sites near the surface of the soil. In soils which have clay minerals of the expanding lattice type; that is, soils which tend to swell when wet and to shrink upon drying, ammonium may be trapped within the crystal lattice in a relatively inaccessible condition. Exchangeable ammonium, however, may be converted to nitrate through activities of nitrifying bacteria.

Nitrification:

Nitrifiers are present in almost all soils, and they have the capability of remaining active over a wide range of moisture and temperature conditions. Although these bacteria are

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obligate aerobes, they are able to function at oxygen concentrations substantially lower than that of the atmosphere. Their activities may be curtailed in acid soils and may cease altogether in locations where the pH is on the order of 4.0-4.5 or lower. Nitrifying bacteria are classed as autotrophic and require no organic material as a source of energy, since they derive their energy from oxidation of ammonium or nitrite to nitrate. In addition to the autotrophic nitrifiers, a number of heterotrophic microorganisms which do require organic material as a source of energy have been found capable of oxidizing ammonium to nitrate and a few to nitrate, but present evidence indicates that their activity is small in relation to that of the autotrophic nitrifiers. For all practical purposes, it can be said that nitrification does not require organic material in order to proceed.

Although a number of intermediates occur in the oxidation of ammonium to nitrate, normally in soils these do not accumulate, and the reaction proceeds to completion with nitrate being formed as the end product. The reactions may be written as shown below:

$$NH_4^+ + 1\tfrac{1}{2}\,O_2 \dashrightarrow NO_2^- + H_2O + 2\,H^+$$

$$NO_2^- + \tfrac{1}{2}\,O_2 \dashrightarrow NO_3^-$$

The first of these reactions is carried out by bacteria of the genera *Nitrosomonas* and *Nitrosococcus*, and the second by *Nitrobacter* species.

Denitrification:

Another reaction which can proceed when wastewater is applied to soil is that of denitrification. If nitrate is initially present in the wastewater, denitrification can occur immediately, provided environmental conditions are favorable for this process. If, however, nitrogen in the wastewater is in the ammonium or organic form, then nitrification must take place before denitrification can occur. Denitrifying bacteria, like the nitrifiers, are abundant in most soils but they differ from nitrifying bacteria in a number of ways. First of all, denitrifiers are heterotrophic and require organic matter as a source of energy to drive their cellular processes. Whereas nitrifiers are obligate aerobes, denitrifiers are facultative anaerobes. Denitrification cannot take place in the presence of any significant concentration of oxygen. Considering their contrasting environmental requirements, it would seem that nitrification and denitrification would not occur at the same place or at the same time in a soil. If fact, however, nitrification and denitrification can under certain circumstances occur simultaneously a short distance apart in a particular soil or even in the same location at different times.

This situation is more easily understood if we consider the micro-environment in which many soil organisms live. This is the thin moisture film surrounding soil particles, some of which are very small in size. Their habitat may be in what can be termed a micropore in which the immediate environment is much different from that of the larger pores where water and soil gases can move more freely. If in the micro-environment of the bacteria oxygen is being consumed more rapidly than it is diffusing to the microsite, then a deficiency of oxygen will develop and the environment becomes an anaerobic one. It follows that as long as oxygen is present nitrification can go on and nitrate will be produced. However, once the oxygen supply is depleted, as it would be if any significant quantity of organic matter is present either in the soil itself or in the wastewater, then the situation becomes anaerobic and denitrification will take place.

Nitrification produces a substance which is a potential contaminant in groundwater, namely, nitrate. Denitrification, on the other hand, has the capacity to convert nitrate to an innocuous gas which is a normal atmospheric constituent and which is readily lost from the soil. In this sense denitrification is an ideal decontamination process. The relative magnitude of nitrification and denitrification in soils to which wastewater is being applied will have an important bearing on whether nitrate is produced in excess and moves down through the soil to an aquifer or is largely eliminated from the soil through conversion to nitrogen gas. The relative balance between these two processes can be modified by proper management of wastewater application. For example, if wastewater is applied intermittently rather than continuously then cycles which are alternately aerobic and anaerobic can develop in the soil. During the aerobic cycle between periods of wastewater application, soil pores tend to fill with air and nitrification can take place. Once the nitrate is produced, if the soil is then flooded to eliminate oxygen and to provide conditions favorable for denitrification, a considerable part of the nitrate may be lost. This is illustrated in the work of Lance and Whisler (3) who found that short cycles of flooding soil columns with secondary sewage effluent caused no net removal of nitrogen, but transformed almost all the nitrogen to nitrate. With longer cycles, during which the soil was flooded from 9 to 23 days and allowed to dry for 5 days, nitrogen removal was 30% of that applied in the wastewater. They found that alternate flooding and drying periods were necessary for consistent nitrogen removal. Similar findings have been reported with application of dairy wastewater (1).

Soil conditions favoring denitrification:

The denitrification reaction may be written:

$$C_6H_{12}O_6 + 4\ NO_3^- \dashrightarrow 6\ CO_2 + 6\ H_2O + 2\ N_2$$

where glucose is used as an example of any readily decomposable organic substance which can be used as a source of energy by soil microorganisms. The needed organic matter may be already present in the soil, may be carried in the wastewater, or may be produced by the roots of plants growing on the soil. Organic matter indigenous to the soil tends to be higher in soil horizons near the surface, and typically decreases with increasing depth. Since deep soil layers contain little organic matter, denitrification may occur only at insignificant rates even though the soil is saturated. This is illustrated in the data of Table 1, which indicated essentially constant nitrate concentration at the 10 ft. depth in a soil over a two-month period, although decreases occurred at 6 and 8 ft.

Table 1. Nitrate concentrations in Yolo fine sandy loam soil as functions of depth and time. Values in ppm N.

Date	Depth, ft. 4	6	8	10
July 14	6.1	55.1	61.6	49.2
July 23	3.4	48.8	56.0	46.4
August 3	-	49.6	57.2	48.6
August 13	-	33.4	54.8	48.1
August 27	-	25.9	49.3	50.1
September 7	-	15.2	45.7	51.5

The decreases at 6 and 8 ft. are not clearly attributable to denitrification, but the constant values found at 10 ft. are strong evidence that denitrification did not occur. The water applied at the surface during this period was just equal to evapotranspiration losses, so that net flux of water was minimal at the lower levels.

Nitrogen transformations in relation to soil acidity:

In the conversion of ammonium to nitrate, two hydrogen ions are produced for each ammonium ion oxidized. Similarly, one hydrogen ion is produced for each organic nitrogen converted to nitrate. This formation of acid by nitrifying bacteria will result in a decrease in pH in soils receiving a constant input of wastewater containing either organic nitrogen, ammonium salts, or both. Some concern has been expressed that wastewater application on land may increase the hardness of the underlying groundwater as a result of increased leaching of calcium and magnesium due to soil acidification. While most attention has been centered on the nitrification process, it is well to keep in mind that denitrification may have the opposite effect, that of diminishing soil acidity. The denitrification reaction may be written in the following way:

$$H^{+} + NO_3^{-} \dashrightarrow \tfrac{1}{2} N_2 + \tfrac{1}{2} H_2O + 5/4\ O_2$$

It may be seen that one hydrogen ion is neutralized for each nitrate ion reduced. Consequently, the relative magnitudes of the nitrification and denitrification processes will have an important bearing on whether soil acidification occurs as a result of wastewater application.

Some data relative to the effect of wastewater application on leaching of bases are presented in Tables 2 and 3. In one case, columns of a calcareous soil were leached with the equivalent of 7.2 feet of sewage effluent in which all the nitrogen was present in the ammonium form. In the second case, all the nitrogen was present as nitrate, but the composition of the applied water was comparable with regard to other ions. A comparison of Tables 2 and 3 indicates that there was in fact more leaching of calcium, magnesium, and total bases in the sewage containing ammonium nitrogen than where nitrification was precluded by addition of N already in the nitrate form. However, since net loss of calcium occurred even in the columns receiving nitrate, it is not certain that the observed differences can be attributed solely to acid formation during nitrification.

Applications:

Enough is known about the influence of environmental conditions on soil nitrogen transformations to permit some control or manipulation through judicious management in the application of wastewater. Obviously, all biological processes are retarded by low temperatures, and winter storage may be preferable to spreading on land in cold climates where infiltration is impeded by freezing. However, at any temperature above freezing, some nitrification may occur, though at a slow rate. The same is true of mineralization and denitrification. Movement of nitrate downward in moderate climates appears to be greater in winter than during the growing season when plant roots are present to intercept some of the nitrate (2). Intermittent rather than

Table 2. Cation and nitrate balance after 19 weeks. Calcareous soil, NH_4^+ sewage.

	Ca^{++}, m.e.	Mg^{++}, m.e.	K^+, m.e.	Na^+, m.e.	NH_4^+, m.e.	Total bases m.e.	No_3^-, m.e.	N-balance, m.e.
Input, m.e.	7.00	5.26	1.07	14.21	10.98	38.24	0.00	
Output, m.e.	27.50	8.70	0.28	7.10	0.06	43.64	7.68	
Net, m.e.	-20.50	-3.44	0.79	7.11	10.92	-5.40	-7.68	3.24

Table 3. Cation and nitrate balance after 19 weeks. Calcareous soil, NO_3^- sewage.

	Ca^{++}, m.e.	Mg^{++}, m.e.	K^+, m.e.	Na^+, m.e.	NH_4^+, m.e.	Total bases m.e.	No_3^- m.e.	N-balance, m.e.
Input, m.e.	7.75	5.26	11.49	14.26	0.00	39.01	10.23	
Output, m.e.	22.42	6.80	0.29	5.87	0.10	35.48	9.09	
Net, m.e.	-14.67	-1.54	11.20	8.39	-0.10	3.53	1.14	1.04

continuous application has distinct advantages in terms of favoring denitrification during wet cycles and consequent reduction in the quantity of nitrate which might eventually leach to an aquifer. Where there is a continuous flow of wastewater more than one disposal site is required to take advantage of the nitrification-denitrification processes.

Further investigation is needed to determine whether nitrification plays a significant role in relation to hardness of groundwater. If conclusive evidence is obtained to indicate that it does, this will provide another reason to maximize denitrification.

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LAND TREATMENT OF SECONDARY EFFLUENT:
EFFECTS ON THE BIOLOGICAL FOOD CHAIN.

by

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The classic concept of the biological food chain involves a series of organisms, each small one being devoured by the next larger. The top of the food chain is usually some carnivorous animal, bird of prey, or man. During the course of this progression of predator-prey relationships, certain substances are neither metabolized nor excreted. They tend to accumulate to higher concentrations through the chain. Some persistent hydrocarbon pesticides and a few potentially toxic heavy metals are well known examples.

When asked to discuss biological food chain aspects of land treatment with sewage effluent, my first thought was that the food chain concentration of hazardous factors was so unimportant as to be uninteresting. But the real question is "what are the hazards in this effluent practice to plants, animal, or man? There seems to be some merit in discussing this question in the context of the food chain concept.

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The food chain for this purpose goes from water to soil to plant to animal to man. This is obviously not the conventional predator-prey chain. There are probably true predator-prey chains as well. These go from microorganisms to microarthropods, to higher soil fauna, to soil animals, to predatory land animals or birds. Effluent spraying on land is not much of a threat to this food chain. Perhaps some harmful organic compounds or toxic metals can accumulate in this food chain to a point where they could be harmful to foxes or hawks at the top of the chain. However, this would probably occur only if these predators got all of their food from the effluent treated area. There is much less likelihood of this than in the case of pervasion pollution of a whole region by something like persistent pesticide. We should also remember that the starting concentration of these toxic compounds is much lower than would be the case where a substance is deliberately applied for pest control, for example. In any case, these natural animal food chains do not lead to man.

The natural aquatic food chains are not going to be affected by effluent treatment on land except in-so-far as the water bodies receive drainage from treated land. Any toxic organic compounds or heavy metals will be effectively filtered out as the water moves through the soil. That is really what the whole system is being used for. There is no point in arguing that surface run-off would be more of a hazard. Of course it is, but if this occurs it is a misuse of the system. In view of the requirements of pretreatment of effluents and the safeguards that will be needed in design of effluent treatment sites, drainage water will be less of a hazard to aquatic food chains than alternative disposal of waste water directly to streams.

To come back to the original important food chain of water-soil-plant-animal-man, what are the possibilities and dangers of harmful substances being passed up the chain to man? With the analytical resources available today, it is no doubt possible to show that some harmful organic compounds or pathogenic agents can survive up the food chain to reach man. This is obviously true with potentially toxic metals. It is even possible that these substances can move as aerosols or somehow reach drinking water sources. Demonstrating such a possibility, however, is easier than evaluating the level of risk involved compared with background risks or risks inherent in alternative disposal methods.

It is disturbing to realize how often we say that "more research is needed" before we can decide whether a proposed procedure is environmentally safe or not. But more data will not eliminate the final subjective judgement. This being so, there will always be argument on the safety of any waste disposal system. These remarks on the food chain will not settle these arguments; they may even start some more.

This food chain is different from the classic ones. It is short. It has a non-biological link--the soil. It has a higher plant link with some unusual implications. It has, at the most, only one animal link before man. And, finally, both the plant and animal link are directly under our control. Perhaps the most important pecularity of this chain, however, is that it has strong tendencies to diminish toxic factors rather than concentrate them. In addition, for each link in the chain there are techniques available to increase this dilution or exclusion tendency.

The soil is the concentrating link. This is why we use the soil for water renovation. It is clear that the main toxic factors--pathogens, exotic organics, and heavy metals--accumulate in the feeding zone of the next link--the plant cover. There are important reactions in the soil, however, which inhibit the transfer of this soil concentration up the chain. Pathogens tend to die out in the soil because of adverse factors-either biological or non-biological. There is no general mechanism for pathogen uptake into plants through their root system. Organics may or may not be degradable in the soil, but usually are.

Their uptake by plants is inhibited by their molecular size.

Heavy metals are taken up by plants but it is well known that only a very small fraction of the heavy metal content of soil is removed by plants. Chemical reactions in the soil involving complexing with organic compounds, chemical or microbial oxidation to insoluble oxides, adsorption on the exchange complex, and eventual combinations into crystalline "reversion" states, may all be involved. A small available fraction remains and this is the fraction that, by repeated effluent treatment, may eventually reach concentrations that can cause trouble. But, basically, the soil is working towards exclusion rather than to concentration up the food chain.

There are several ways to manipulate the soil link of the chain to reduce transfer of heavy metals to plants. Control of pH is the most obvious. Solubilities of such elements as zinc, nickel, copper, and cadmium are much reduced above pH 6.5. This pH can easily be achieved by liming. The practical concern is how to assure, over the years, that this is done. Other possibilities are occasional deep plowing or actual removal of the contaminated surface layer.

Turning to the plant link, an obvious difference from conventional food chains is that the plant does not ingest the soil. It absorbs soluble components selectively. It excludes pathogenic organisms and most organic compounds. Some plant species are accumulators of heavy metals but most crop plants are not. Cereals, in general, take up less of the heavy metals than do some of the vegetable crops. Data obtained by Chaney in the USDA laboratory show that species of the beet family are probably the highest accumulators of heavy metals among our food crops. For example, in one experiment swiss chard accumulated almost 2000 parts per million zinc from sludge treated soil, whereas fescue took up only 86 ppm. The uptake of copper was 82 and 7 ppm, respectively. A second point is that most crops tend to confine toxic metals to their roots. This is especially notable in the case of mercury and lead. Third, plants generally translocate only a small part of their heavy metal uptake from vegetative tissues into the seed. Corn and small grains are especially selective against heavy metals because of low uptake and the fact that we generally harvest only the grain.

A final point about the potential toxic metal hazard in the plant link of the food chain is that for zinc, cobalt, copper, and nickel the crop itself will be obviously damaged before the toxic metal content is high enough to be harmful to man or animals. Such crops can be discarded and corrective action taken on the site.

Food chain hazards can be minimized by manipulation of the crop. We can avoid growing vegetables or other metal accumulating crops on soil being used for waste water renovation. It may be possible to selectively breed varieties that do not accumulate these metals, but we probably do not need to go this far. A special concern is the future possibility that renovation sites, after they are abandoned, can become low in pH and may be planted to vegetables.

Domestic animals fed on effluent treated crops can accumulate toxic metals into the milk or into certain organs such as liver and kidney. This possibility needs to be monitored against the established permissible levels of such metals in animal products. An interesting point that should receive some attention is that grazing animals, especially sheep, short circuit the food chain to some extent by direct ingestion of soil. If the heavy metals are accumulating at the soil surface, this might be a significant source of metals in the animal.

The final step of the food chain--human consumption of the plant or animal products--is where we have ultimate control. Production of crops to be eaten raw can be prohibited under effluent irrigation. There is no good argument for not doing this. The crop on effluent treated land is directly contaminated by the water, thus short circuiting the soil link in the chain. With cereals and other seed crops, such contamination is much less of a hazard. Whether it is significant or not will have to be decided by health authorities.

My thesis has been that, fortunately, the chain of most importance to us tends to exclude hazardous substances rather than accumulate them up to our food supply. There are possible hazards, but they are correctable. Compared to other alternative methods of wastewater treatment, these are probably minor. The heavy metal elements seem to pose the biggest problem. Even though the input of toxic metals is very low, eventually any system will become overloaded. Our main concern should be to monitor these systems and stop them before the danger level is reached.

ENGINEERING DESIGN CONSIDERATIONS- FOR LAND TREATMENT AND DISPOSAL OF SECONDARY EFFLUENT

by

Norman A. Evans*

Hundreds of land treatment and disposal (LTD) installations are operating across the United States and around the world. Yet, for many, LTD is a "far-out" alternative to municipal waste disposal. Perhaps this is because design guidelines for such systems have not been fully developed nor widely understood. Consulting engineers are reluctant to recommend LTD to clients. Public officials are understandably cautious about adopting a relatively unknown technology.

In Colorado, a recent survey shows at least ten LTD installations in operation. The cities of Colorado Springs and Aurora are both using LTD for limited amounts of secondary effluent. Several new subdivisions near Denver have made plans for LTD and the Aspen community is seriously studying the possibility.

Melbourne, Australia has used LTD since 1892. Its 15,000 acres of grass support 19,000 head of cattle and other livestock. About 1.0 inch of primary effluent per week is applied to the

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land in an area having 19 inches of rainfall annually. The land requirement ranges from 180 to 250 acres for each million gallons per day (MGD). The annual per capita disposal cost is slightly over $1.00.

At the heart of the LTD system is soil--often described as a "living filter". Admitedly, there is much to be learned about the soil as a facility for treatment and disposal of secondary municipal waste. For example, the fate of heavy metals introduced into the soil over a wide range of conditions is one uncertainty. Much is known about the equilibrium chemistry of heavy metals in simple solutions but very little about their chemistry in complex soil solutions. Their uptake by lower plants and animals and migration through food chains is also poorly understood. Likewise, tranformations of many inorganics within the soil matrix are little known.

Nevertheless, the soil system is far from being an unknown. There is a tremendous amount of scientific knowledge about soil chemical, physical, mineralogical and microbiological characteristics. Many of the chemical and physical interactions which occur within the soil affecting plant growth are well known and understood. This is so because more than 100 years ago the Congress, concerned for the future of American agriculture and its capacity to feed the citizenry, established agricultural experiment stations as part of the Land Grant college system.

Although much basic scientific data concerning soil characteristics and responses to various chemical and physical changes is available, it must be retrieved and reanalyzed so that a reasonable synthesis or interpretation can be developed for behavior under LTD circumstances. The information is deposited in the archives of agricultural experiments stations across the nation as well as in research bulletins. Scientific journals also contain some of the information and data. In many cases, research results pertaining to local problems were not widely disseminated but were made available to those directly concerned through progress reports and extension service leaflets. It would be profitable to the waste disposal technical fraternity to have the massive amount of data screened and summarized by soil scientists and plant scientists. Although such an undertaking would be expensive in manpower, it would probably be more cost effective than a heavy research expenditure for basic data today which may duplicate what has been done before.

One important result of the agricultural experiment station work has been documentation of field behavior of an almost infinite number of combinations of the soil-plant-water systems. These cases represent a priceless data bank useful to the design of LTD systems.

Land treatment and disposal offer several possibilities for meeting goals and objectives for environmental quality. Effluent can be renovated to a level of quality acceptable for discharge into surface or groundwater supplies. The process recycles certain pollutants which become a resource for productive use. Finally, LTD may provide environmental benefits such as greenbelts and open spaces within urbanizing areas. Recreational opportunities and improvements in visual quality can be gained with these facilities.

The purpose of this paper is to draw attention to certain engineering design steps in land treatment and disposal. Two are particularly different from the engineering encountered in normal municipal water and sewage projects: planning the irrigation system and designing the drainage facilities. Concepts will be described and basic design parameters will be emphasized but this paper is not intended more than to point out that the design tools are available to the engineer for these most crucial design steps in land treatment and disposal.

The author's background in this subject arises from a career in research, teaching and design of irrigation and drainage systems. Recent research on improving efficiency in border irrigation has provided new methods of design and operation fortuitously now available for this application. The author acknowledges with pleasure information used in this paper taken from a feasibility-level study covering the Cleveland-Akron

Basin in Ohio, prepared for the U.S. Corps of Engineers by Wright-McLaughlin Inc. of Denver. Several of the illustrations are taken directly from that report with permission. The author and several of his associates (1) at Colorado State University had the opportunity of contributing to the innovative planning which was done for that project.

Designing the Irrigation System:

A distribution system for secondary treated effluent is no different, physically, from familiar irrigation systems. It does offer an innovative challenge because more precise control over distribution is demanded. No surface waste can be allowed because of the nature of the effluent and its potential public health hazard. Surface irrigation systems have not been customarily designed or operated with this constraint. (Although the pressures have been growing for greater efficiency in agricultural irrigation systems due to competitive water demands. This led to study improvements in border irrigation design a few years ago.)

The fundamental objective in the distribution system is to maximize the amount of effluent passing through the soil. (In contrast to the opposite objective for irrigation water.)

Automation and precise control are necessary characteristics of sewage effluent irrigation systems if LTD is to be an acceptable alternative to conventional plants. The system will have to operate with a minimum of operator attention and with a relatively small manpower requirement. Experience to date with LTD systems has shown that they are highly demanding of consistent and uniform operational control and equally demanding of constant maintenance. Systems which depend entirely upon the sustained attention of operators without the aid of automated sequencing and timing, monitoring instrumentation, and well-prepared sites have given less than satisfactory performance.

In general, the requirements of automation and precise control have been met through adaptation of spray irrigation equipment. Solid-set systems with valves controlled remotely by a timer-sequencer device have been very satisfactory. More recently, center-pivot systems have been used satisfactorily at less cost.

Surface distribution systems can also be fully automated thanks to research and development efforts of the Agricultural Research Service (2). An inflatable rubber "pillow" is placed within a conventional irrigation riser valve used with border irrigation systems. The pillow is inflated to close the valve opening. A small compressor operated by a timing-sequencing device and small plastic tubing supplies compressed air to the pillows. Buried pipe supplies the effluent to these borders.

Unfortunately, many site conditions are not inherently suitable for conventional spray or surface systems. Although spray systems are flexible in terms of rate of application, the kinetic energy of spray droplets striking the soil surface tends to destroy surface structure and thereby reduces infiltration capacity. This is particularly serious on soils with high silt content at the surface. Many public health officials dislike the idea of spray irrigation because of the hazard of aerosol drift which might carry pathogens outside the treatment area. There is evidence to show that pathogens can be carried in this manner although the human health effects have not been adequately documented. (3)

A variation in the center-pivot equipment replaces the rotating sprinkler heads with spray jet nozzles pointed downward from the rotating boom. Lower pressures are required with these nozzles and thus a lower energy demand makes this variation very attractive. However, the problem of soil aggregate dispersal due to drop impact is still present. A land management innovation consisting of alternate strips of grass and corn, for example, can be used to overcome that problem. Figure 1. illustrates such a system. The corn strips are irrigated by lateral soil moisture movement from the irrigated grass strips.

Another variation permitting use of automated center-pivot equipment without the problems of spray application consists of

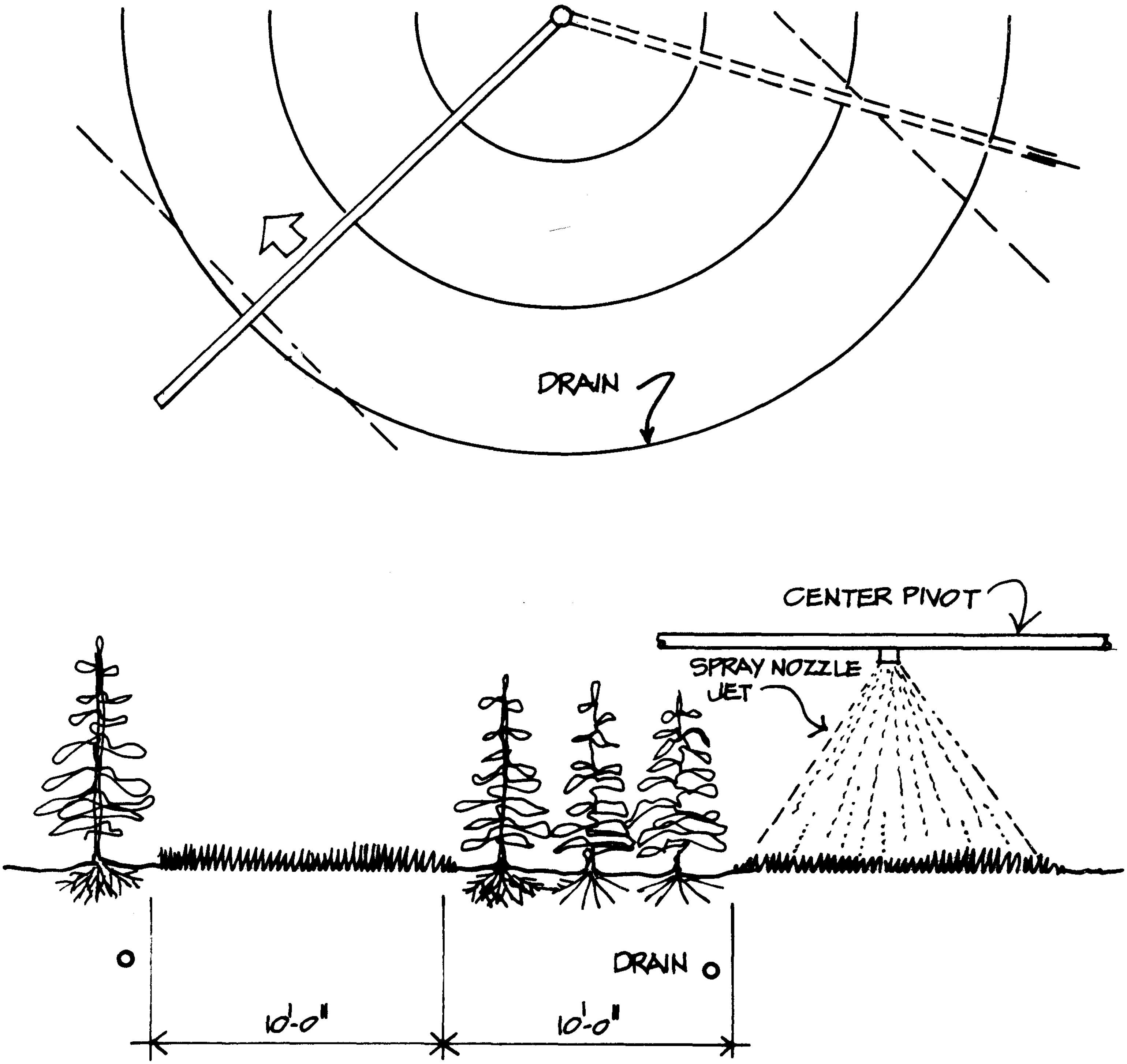


Figure 1. Modified Center Pivot System to Minimize Spray Drift, Reduce Energy Demand, and Avoid Soil Sealing.

substituting drip tubes for spray heads or nozzles. Figure 2. illustrates such a system with drip tubes discharging into shallow furrows filled with crop residue from the previous season. The residue helps maintain a maximum infiltration capacity in the furrow. Lateral soil moisture movement accomplishes irrigation between furrows. A similar variation can be used where clay layers may impede percolation through the soil profile. In this case, slit trenches about 18 inches deep which cut through the clay lenses can be formed with conventional farm equipment. These trenches also fill with crop residue. The trench functions as a conduit for water into the profile and lateral movement carries soil moisture between trenches. (Figure 3).

Surface irrigation systems have been less popular than spray systems because land preparation is necessary. Many installations have relied upon level basins to assure uniform distribution of effluent over the surface and these perform very well if properly operated. Intermittent flooding with drying time between applications has proved to be necessary.

Border systems on sloping land have seldom been used because design criteria have not been developed.

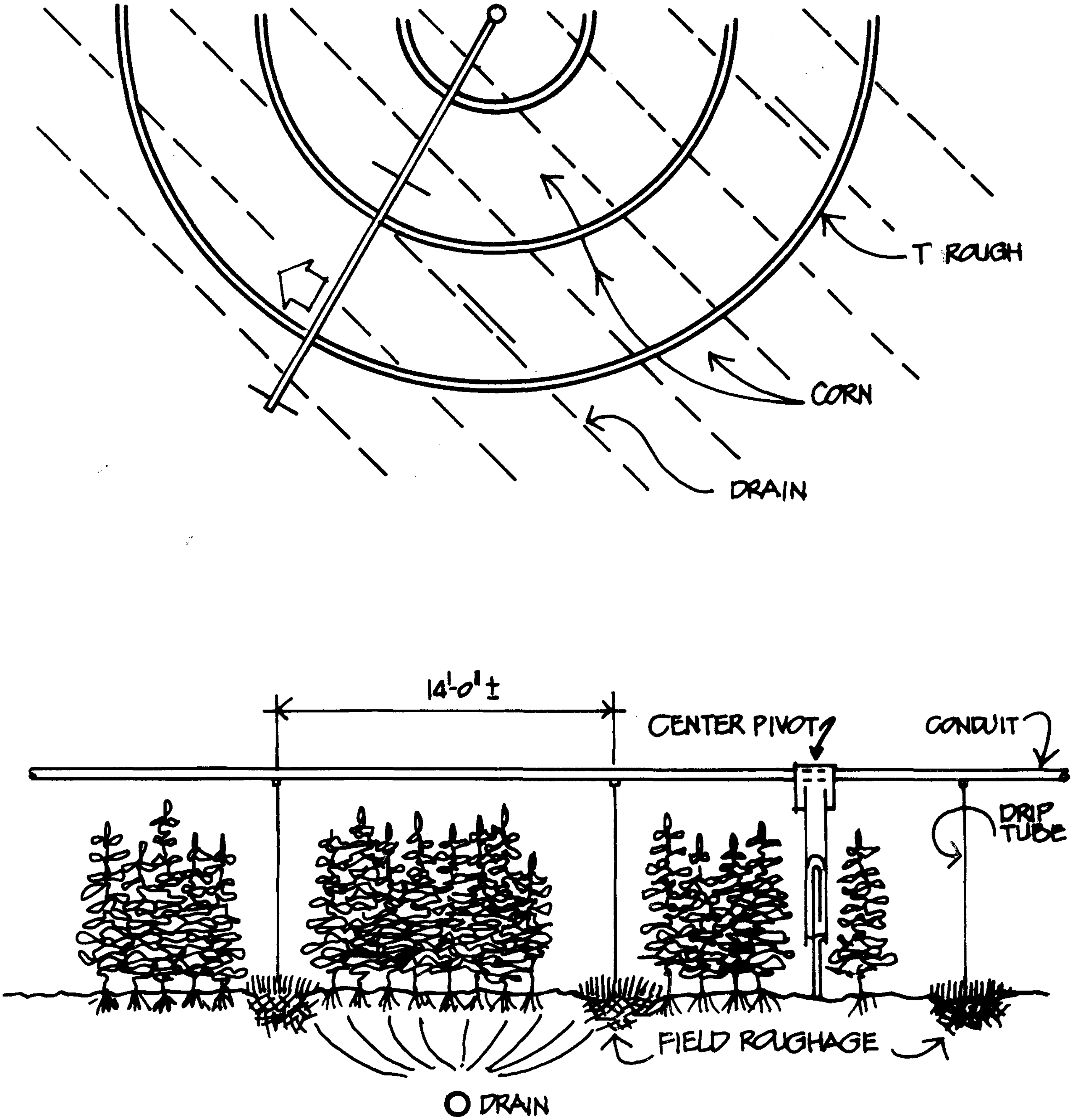


Figure 2. Modified Center Pivot System With Drip Tubes to Eliminate Spray.

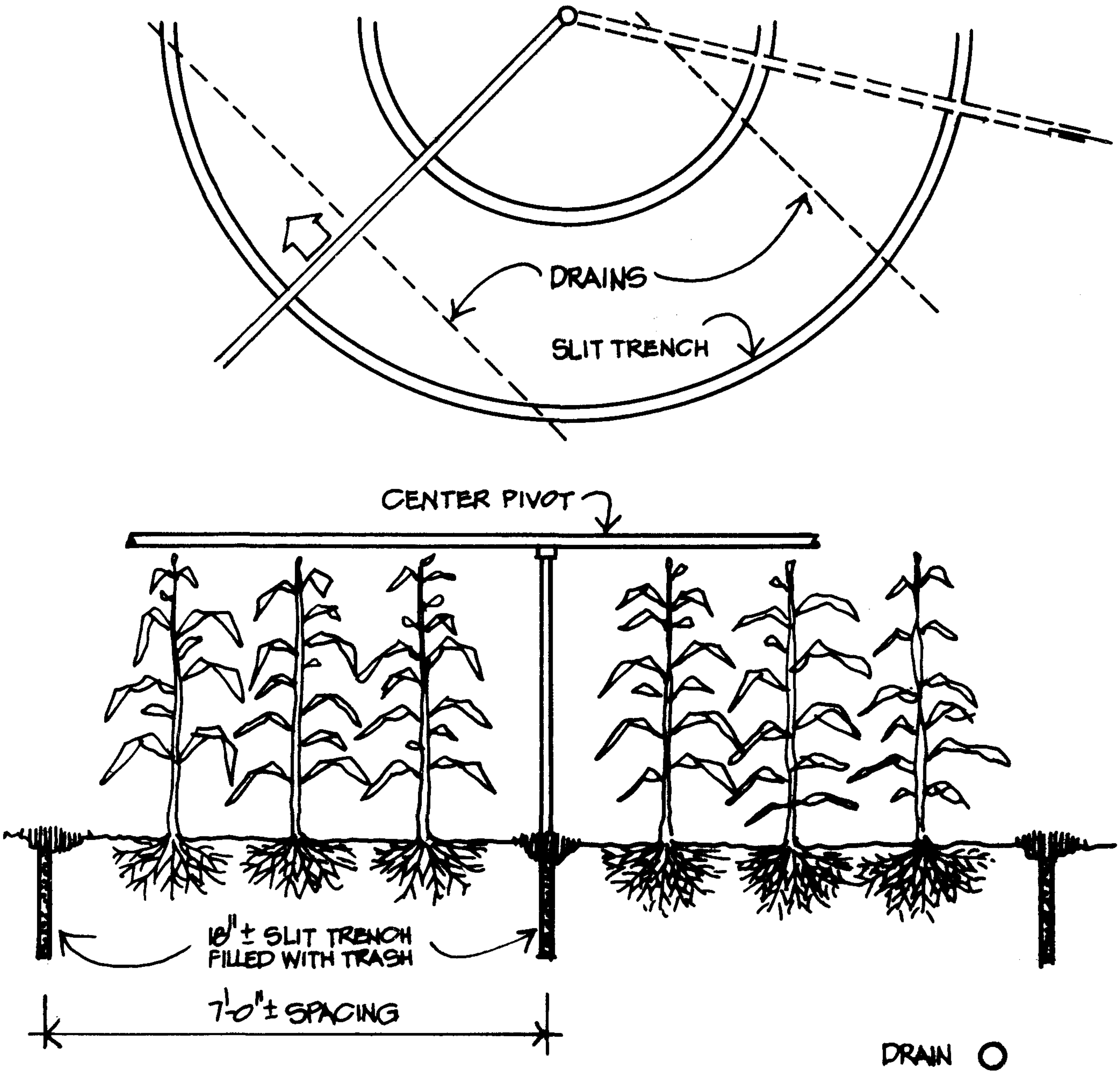


Figure 3. Modified Center Pivot System With Drip Tubes Discharging Into Slit Trenches.

However, new advances in design of border systems on sloping lands will permit precise control of distribution over the surface yet prevent runoff. (1) Figure 4 illustrates a border system.

A design principal is to adjust the discharge rate and application time so that every square foot of border surface is exposed to the same intake opportunity time. That is, water is in contact with each part of the border strip for an equal amount of time and therefore the intake of water into the soil will be uniform over the entire surface. (Subject to variability of intake rates due to changes in soil texture within the border strip.)

For example, Figure 5 shows how the advancing front of water moves down a border strip reaching 700 feet after two hours. This particular site had a clay loam soil on which alfalfa was growing. The water discharge into the border was 0.06 cfs per foot width of border, a discharge calculated to produce the parallel characteristic of advance and recession. When the advancing front reached 700 feet (after two hours) the inflow was stopped. The advancing front was dissipated at 800 feet and the recession front reached 800 feet approximately two hours after the water was turned off. In this brief four hour period, 2.5 inches of water infiltrated into the soil.

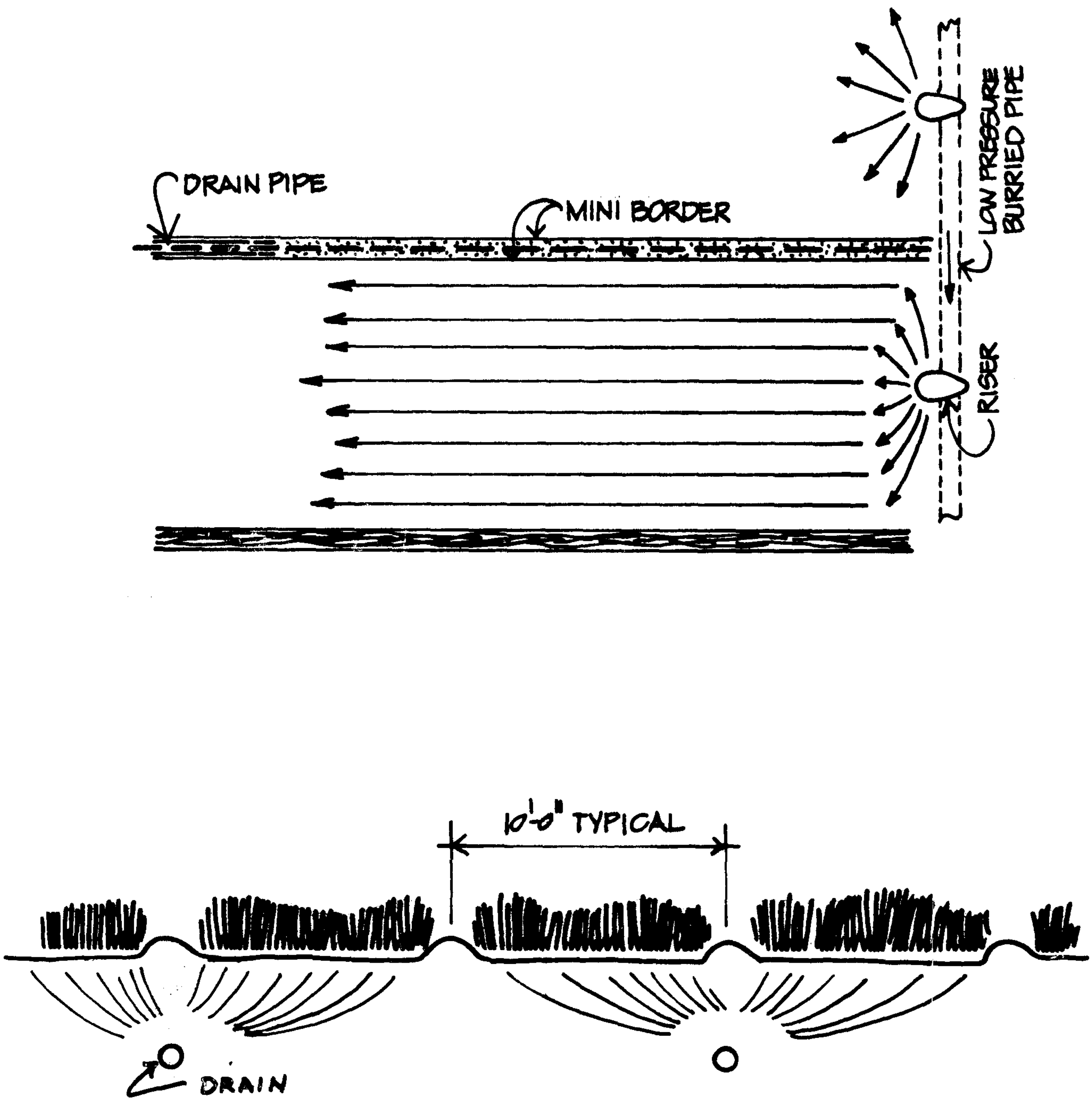


Figure 4. Border Irrigation System.

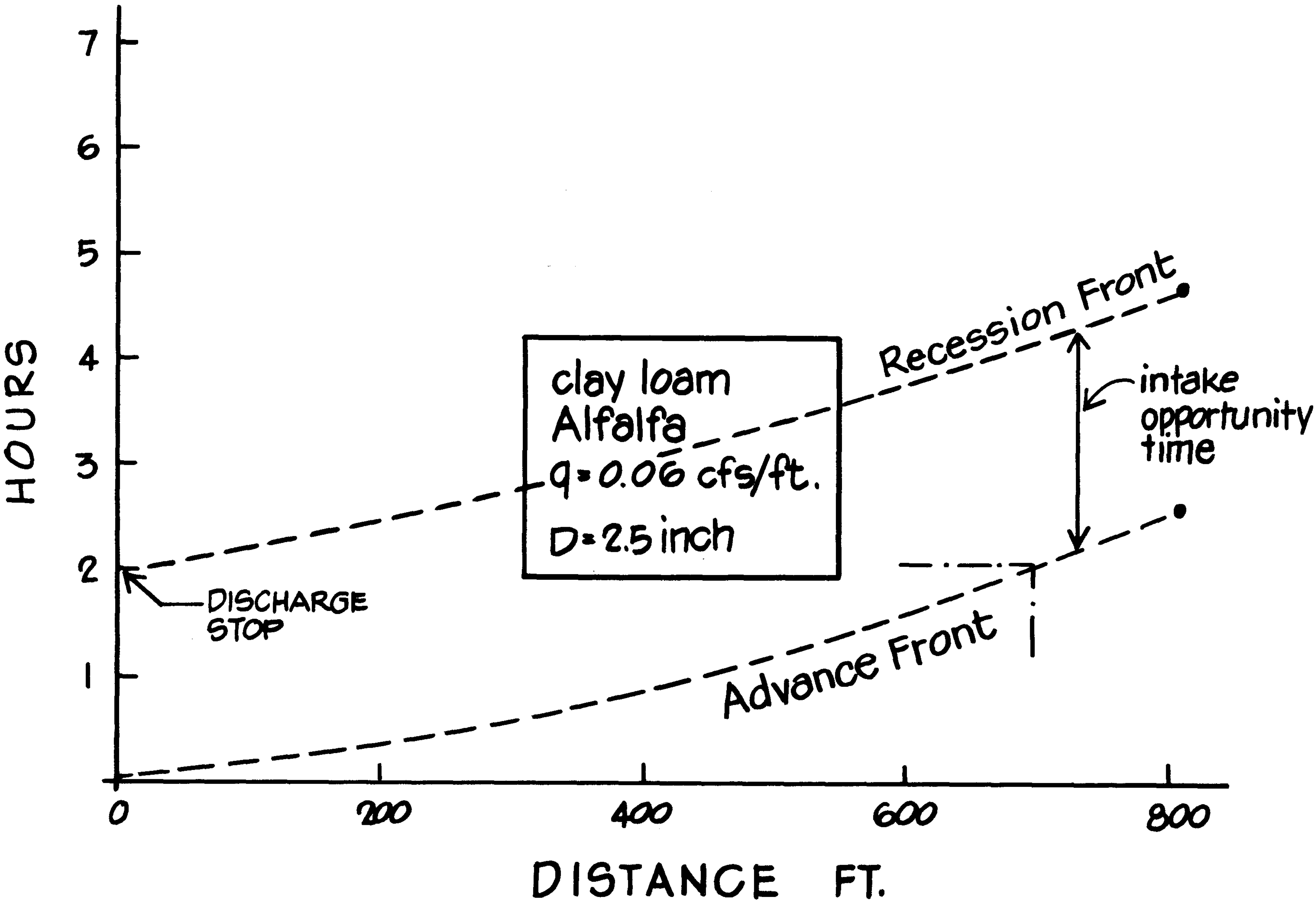


Figure 5. Proper Combination of Discharge, and Time for Efficient Border Irrigation.

The resulting irrigation was 100 percent efficient in that no water was wasted from the end of the border at 800 feet. Furthermore, the uniformity of distribution over the surface of the border was very good (measured by the coefficient of uniformity of soil moisture intake.) The proper combination of discharge, length of border and duration resulted in values consistently greater than 90 percent.

The infiltration characteristic of the soil is a key parameter determining suitability of a treatment site. However, it is not as crucial as most of us have been inclined to believe. It is true that for ordinary irrigation where a large depth of water is desired to be applied at each irrigation with irrigation duration on the order of 8 to 12 hours, the infiltration characteristic is a determining factor.

Soils normally have a high infiltration rate in the early part of an irrigation with the rate decreasing quite rapidly to a nearly constant rate. For heavy textured soils, this constant rate determines the amount of water which can be passed into the soil over an extended period of time. Figure 6 shows the results of infiltration studies extending over a wide geographic area in the Rocky Mountain region covering a range of soil types.

The curves represent two extremes--a sandy loam soil having a high rate and a clay loam soil having a very low rate. For

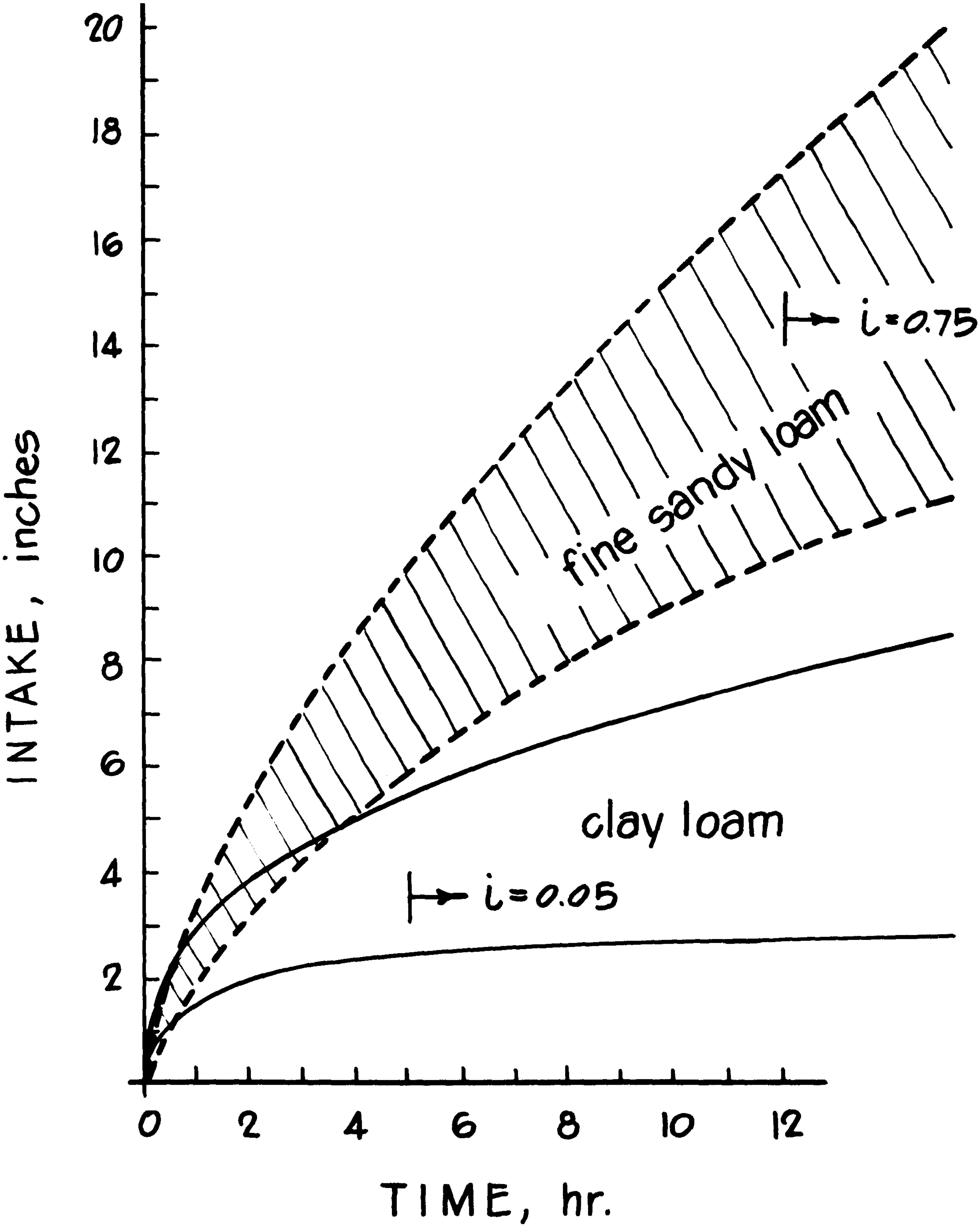


Figure 6. Infiltration Characteristics of Typical Soils of Rocky Mountain Region.

example, the near-constant infiltration rate on the clay loam (which is reached after approximately five hours of irrigation) is 0.05 inch/hour. In contrast, the near-constant rate on the sandy loam soil is 0.75 inch/hour which is 15 times greater. However, if one looks only at the first four hours of irrigation on these two soils, the clay loam would take in four inches and the sandy loam would take in nine inches. This is because the early infiltration rates are high and even though the rate drops very rapidly in the first few hours, the total volume of water taken in is substantial.

The border irrigation method is very well adapted to secondary treated effluent disposal where a relatively small depth of liquid is to be put into the soil at relatively frequent intervals such as one week. The normal practice which has developed through field experience is to apply two inches over the area of the disposal site at once per week intervals.

The annual disposal capacity at the rate of 2 inches/week and assuming a forty-week operating season would be 80 inches. For each one million gallon per day of effluent to be treated, the land surface area required would be 120 acres. Remembering that an economic return would be expected from the crop produced on the land, and that other benefits can be counted also (open space, greenbelt), the land investment is not at all prohibitive, even in highly urbanizing areas where land values are high.

With adequate drainage at the clay loam site, it would be possible to introduce four inches per week and the land area required to dispose of one million gallons per day would be only 60 acres. Later in this paper I will show that adequate drainage can be provided if the soil profile is of a reasonable depth for the installation of drain tubes.

The key to uniform applications without runoff on the border strips is an equal rate of recession and advance fronts. This is accomplished by shutting off the inflow when the recession front has reached the proper distance along the border strip. Our research has provided guidelines for determining the proper distance. As a first approximation, that distance is 75 percent of the border length. This factor varies slightly with the infiltration characteristics of the soil and the size of inflow stream. However, the stream size is not critical (5).

For best precision and water control, the width of borders should be relatively narrow. For conventional irrigation, borders normally range from 30 feet wide on sandy soils to as much as 100 feet wide on clay soils. For waste effluent on sloping land, we suggest borders on the order of ten feet wide. Borders with little or no slope can, of course, be the normal width. The real limitation on border width is discharge and height of dike. For wide borders, the discharge must be large in order to force total coverage over the width of the strip. This requires a six inch depth of flow within the border strips. Dikes must be somewhat higher than 6 inches. The narrower strips can operate well with less precise land leveling and smoothing and therefore less costly site preparation.

Designing the Drainage System:

The necessary conditions in the LTD site, if one is to expect an economic return from crop production, is an aerated zone within the root depth of the crop. However, this zone need not be continuously aerated; most crops can tolerate three days without air diffusion in the root system and many crops can tolerate up to five days. However, for most crops, the latter period would result in some yield reduction. The depth to which the aerated zone must extend is less than the full "normal" root zone generally associated with optimum crop production. For grasses, the aerated zone need not be more than six to eight inches deep. For corn, 12 to 18 inches is sufficient.

Air diffusion into the soil is a function of the degree of saturation. Figure 7 A is an illustration of a typical saturation-capillary pressure characteristic for a normal soil. Shown on that plot is a characteristic called bubbling pressure, p_b.

Bubbling pressure, p_b, can be expressed as inches of water. When the capillary pressure is at or above p_b, air can diffuse through the soil matrix at a rate adequate to supply oxygen needs of the roots. As a rule of thumb, p_b is reached when saturation is approximately 0.8, i.e., 80 percent of the pore volume is occupied by water.

Referring to Figure 7 B an aerated zone can be achieved to a given depth only if the water table is below that depth by a distance equal to p_b (inches). Therefore, the engineering design challenge is to provide for the water table to drop from the ground surface immediately after irrigation to a depth of aerated zone plus p_b ($yc + p_b$) within three to five days after irrigation. Many field sites would have such good internal drainage conditions that the water table would never rise to the ground surface and the problem of adequate rate of water table drop is very easily solved or does not even exist.

The determination of p_b is easily done by laboratory methods. The magnitude of p_b depends upon the particle size and aggregate characteristics of the soil. Table I gives typical values of p_b for a wide range of soils found throughout the western region.

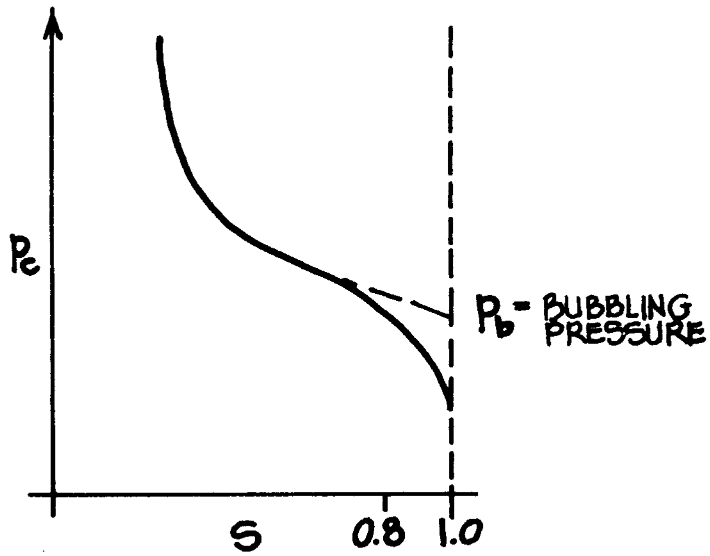


Figure 7 (A). Typical Capillary Pressure-Saturation Relationship.

Figure 7 (B). Zone of Adequate Aeration

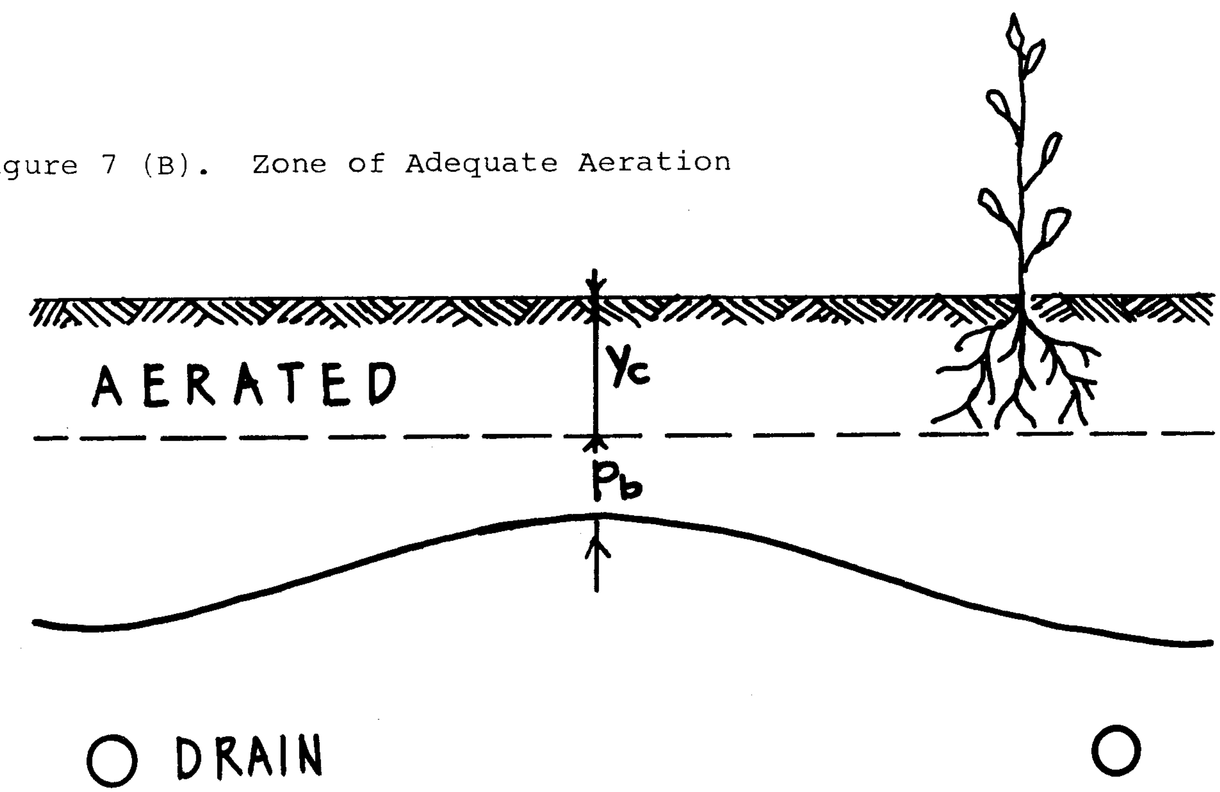


TABLE I.

TYPICAL BUBBLING PRESSURES

SOIL	INCHES OF WATER
Oakley Fine Sand	14.2
Pachappa Sandy Loam	22.4
Yolo Fine Sandy Loam	18.1
Indio Loam	28.0
Ida Silt Loam	23.6
Diablo Loam	23.2
Yolo Clay	8.6
Yolo Clay	19.7
Chino Clay	12.6
Weld Loam	6.2
Cass Sandy Loam	3.7
Monona Silt Loam	7.1

The bubbling pressure characteristics for each proposed LTD site should be obtained before designing the drainage system.

The engineering problem in designing the drainage system is to establish the depth and spacing for drain tubes that will provide the rate of water table drop required. At some sites, the depth of drain tubes is limited by geologic conditions such as impermeable strata of clay, shale, or rock. A naturally high water table would constitute no constraint if permeable soil material occurs to sufficient depth. Drain tubes should not be placed into impermeable material.

There is reason to believe that effluent renovation depends in part upon the length of travel (time of contact) through the soil but limiting criteria for length of travel have not been established. Laboratory research has generally indicated a smaller distance requirement than is customarily used in design at the present time. The Corps of Engineers currently suggest a drain tube depth of at least five feet.

With a drain tube depth established, either by preference or site limitations, the rate of water table drop is determined by the spacing between drain tubes (a function of soil hydraulic conductivity). There are available several theories for this purpose which have been widely field tested and which are considered reliable design theories.

A theory based upon steady-state analysis of the drainage system generally credited to Hooghoudt and modified by Bauwer and Schilfgaarde (6) is illustrated in Figure 8 which is really a locus of solutions for a given site. The average water table drop at the mid-point between drain tubes is plotted against drain tube spacing. For example, if the water table must drop from ground surface to 1.5 feet in three days to produce the required aerated zone, the average drop at mid-point must be 0.5 feet per day. From the curve, drain tube spacing must be approximately 35 feet. If the water table drop within three days should be 3.0 feet, an average of 1.0 feet per day, the drain tube spacing must be 20 feet.

Figure 9 is based upon a non-steady analysis of the drainage system generally credited to Glover (7). One-half the space between drain tubes is represented on the chart and the curves represent successive positions of the water table with time after drainage begins. At the mid-point between drain tubes ($\frac{x}{L}$ = 0.5) the water table drop after three days would be shown by the appropriate curve. The design engineer would find this procedure very simple and convenient.

A framework for classifying lands to their suitability for LTD can be created by setting limits on the parameters discussed above. Other parameters can be added either with or without

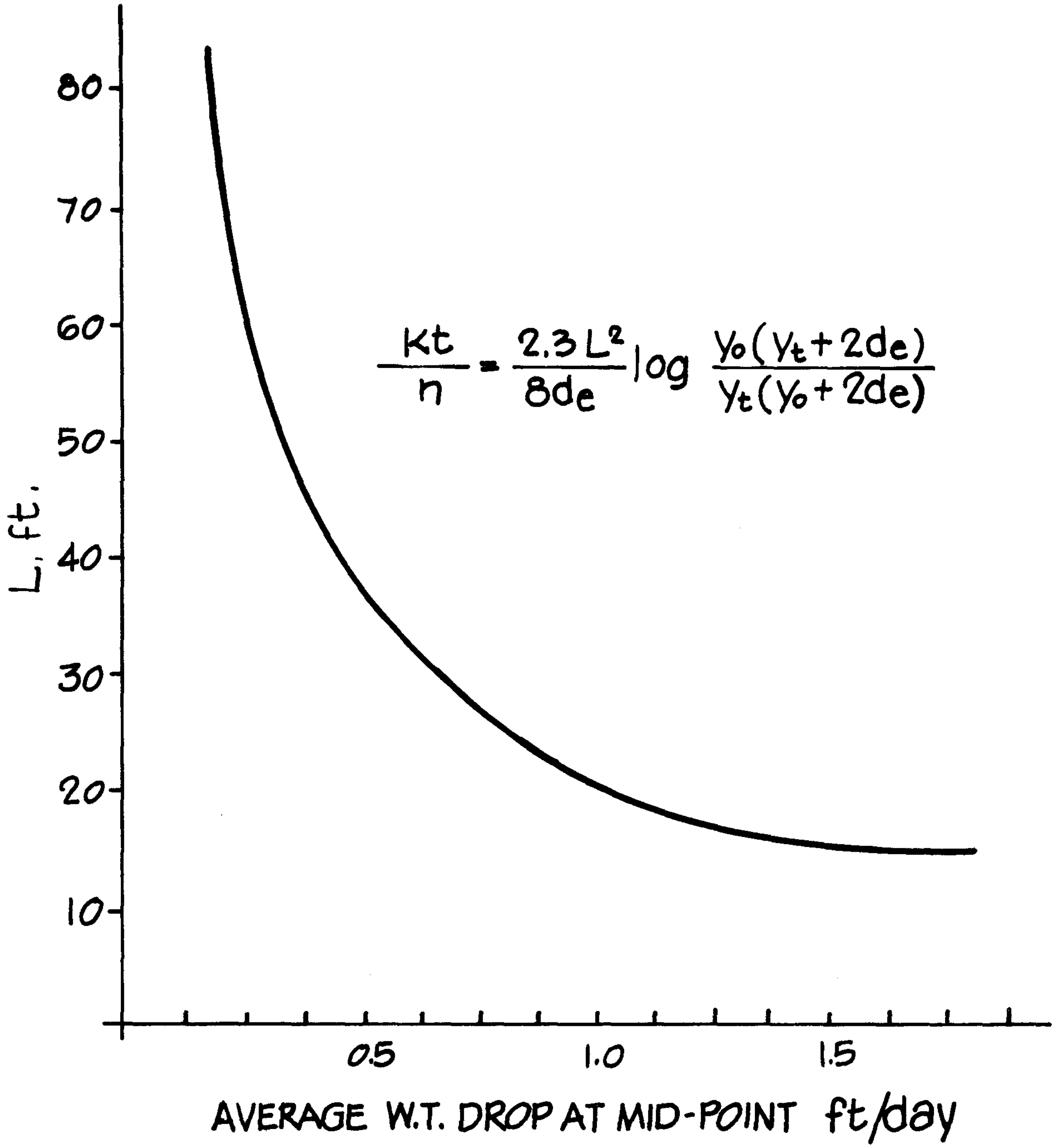
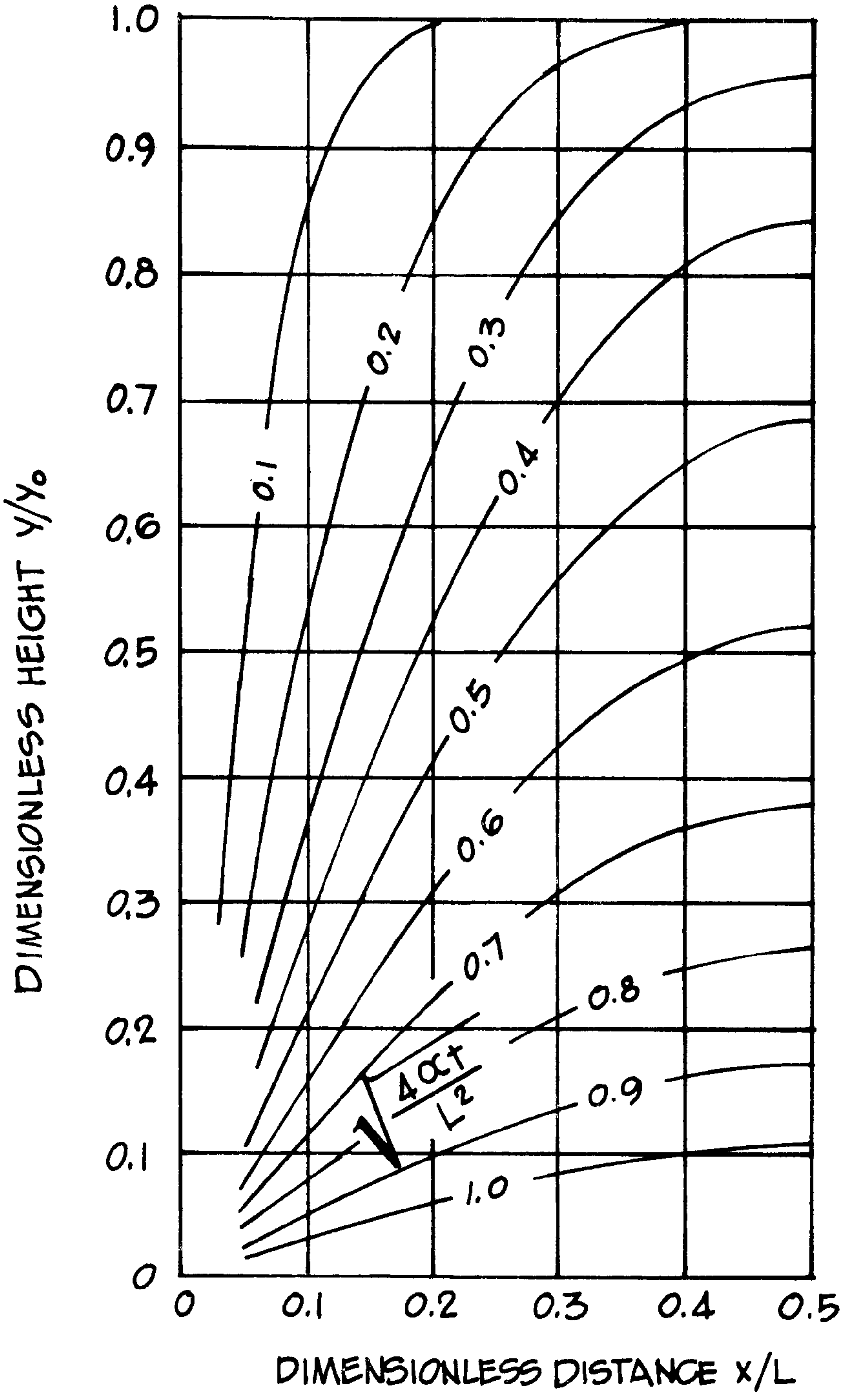


Figure 8. Watertable Drop After Irrigation, After Bauwer and van Schilfgaarde (2)



$$y(x,t) = \frac{4y_0}{\pi} \sum_{n=1}^{\infty} \frac{1}{(2n-1)} e^{-\left(\frac{\alpha(2n-1)^2\pi^2 t}{L^2}\right)} \sin \frac{(2n-1)\pi x}{L}$$

Figure 9. Watertable Drop After Irrigation, After Glover (3).

quantitative limits. As more experience is gained from new installations, the limitations will be adjusted and new parameters can be added. Economic considerations can be more fully incorporated.

Table 2 illustrates a land classified scheme showing tentative specifications for three classes: ideal, acceptable, and limited. This is an adaptation for illustration purposes from the Wright-McLaughlin study in the Cleveland-Akron basin for the Corps of Engineers (1973) referred to in the introductory remarks.

Summary:

In summary, adequate tools are available for the engineering design of works for distribution of secondary treated effluent to the land and for the facilities needed to provide necessary internal drainage. The design engineer need not depend upon "rule of thumb" criteria but can use the available tools to develop designs based upon specific site characteristics. Although there are many unknowns and uncertainties in the process of land treatment and disposal of secondary created effluent, these are mainly knowledge gaps within reasonably well understood phenomena, e.g., complex equilibrium chemistry of soil solutions, ultimate limits on adsorptive capacity of various soils, a fuller assessment of plant uptake of potentially toxic elements and their fate in biological food chains. Nevertheless, and in spite of the knowledge gaps which do exist, a great deal is, in fact, known about most of these questions. This paper points out that the technology for designing the land application and flow-through system is now available at a sufficiently advanced stage that reliable designs can be made.

TABLE 2. Land Treatment Land Class Specifications*

Characteristics A. SOIL	Suitability Classes** Class I Ideal	Class II Acceptable	Class III Limited
Texture			
Plow Layer	Loam to sandy loam	Sandy clay loam to silt loam	Clay to silty clay
Subsurface	Clay <40% Silt <50 Sand >20	Clay <60% Silt <40 Sand >20	Clay >60% Silt <40 Sand <10
Depth			
to barrier	>60"	> 48"	<48"
to gravel	>30"	$18 \le d \le 36$"	<18"
Chemical properties in drainable profile in equilibrium with effluent			
Electrical conductivity, E.C.x 10^{-3}	<2.0	2 to 8	>8
pH	5 to 7.5	3-5 or 7.5-9	<3 or >9
Exchangeable Sodium Percentage, %	<15	<15	<15
Cation Exchange Capacity, meq/100g	>15	7-15	< 7
Hydraulic Conductivity of Subsurface, inch/day	$3 \le K \le 20$	$2-3 \le K \le 20$	$2-3 \le K \le 20$
Infiltration Rate, inch/hr.	$i > 0.4$	$0.10 \le i \le 0.40$	$0.05 \le i \le 0.10$
Bubbling Pressure, inches of water	$p_b > 18$	$18 \le p_b \le 24$	$p_b > 24$

*Typical for a Great Lake lacustrine basin.

**Class I --Represents land with minimal hydraulic constraints, and routine irrigation and drainage management.

Class II --Land requiring more intensive land preparation and drainage.

Class III --Requires special land management techniques, intensive drainage, and application must be carefully controlled.

- continued -

Characteristics B. TOPOGRAPHY	Suitability Classes Class I Ideal	 Class II Acceptable	 Class III Limited
Slope, %	< 2	$2 \leq S \leq 15$	> 15
Surface	Smooth, planar	Slightly hummocky, moderate grading necessary	Hummocky, heavy grading necessary
Cover Woods	No limitations on density or type.		
Brush	No limitations on density or type. Sprinklers must extend above canopy.		
C. SURFACE DRAINAGE			
Outlet	No restriction for surface water disposal	Surface water disposal may require minor ditching	Surface water disposal requires extensive ditching
Flooding	Not susceptible to surface backwater	Surface backwater recurrence interval > 10 years	Surface backwater recurrence < 10 yr.
D. INTERNAL DRAINAGE			
Artificial water table control	Tile drains spaced ≥ 100 ft. will lower w.t. to (yc + p_b) in three days	Tile drains spaced $40 \leq L_s \leq 100'$ will lower w.t. to (yc + p_b) in five days	Tile drains spaced $< 40'$ will lower w.t. to (yc + p_b) in five days
Outlet	Gravity outlet immediately available	Gravity outlet requires limited conveyance	Gravity outlet requires extensive conveyance

References and Footnotes

1. Particularly Mr. Donald L. Miles, Extension Irrigation Engineer and Dr. Burns Sabey, Professor of Agronomy.

2. Information on equipment and its availability can be obtained from Dr. Howard R. Haise, Agricultural Research Service, Federal Building, Fort Collins, Colorado, 80521.

3. Statistical studies on sewer plant operating personnel exposed daily to similar aerosols are reported to show no significant incidence of disease in sewer plant operators compared to other occupations.

4. Coefficient of Uniformity, $CU = 100\ (1 - \frac{y}{d})$, in which y = average absolute deviation from mean and d = mean soil moisture intake.

5. Horne, O. W. and D. F. Heermann, "Efficient Border Irrigation Design", Trans. A.S.A.E., Vol. 13, No. 1, 1970, pp. 126-130.

6. Bouwer, H. and J. Van Schilfgaarde, "Simplified Method of Predicting Fall of Water Table in Drained Land", Trans. A.S.A.E., Vol. 6, No. 4, 1963, pp. 288-291.

7. Dumm, L. D., "New Formula for Determining Depth and Spacing of Subsurface Drains in Irrigated Lands", Agric. Engineering, Vol. 35, 1954, pp. 726-730.

Project Status and Research at Muskegon, Michigan

by

Robert K. Bastian*

Considerable interest has been directed toward the cropland spray irrigation wastewater management system designed by Bauer Engineering, Inc. and adopted by Muskegon County, Michigan. Data (including O&M costs) to evaluate the overall effectiveness of this large scale land treatment system in renovating wastewater will not be available until the system has reached full operational status. With over 90 per cent of the construction now completed, full-scale irrigation of wastewater should commence during the 1974 growing season. This article is intended to serve as a status report for EPA's demonstration project at Muskegon and its associated R&D activities, as of 1 October, 1973.

Design Criteria:

The basic design of this 43.4mgd system has been described in detail by earlier articles (1,2,3,4). Essentially the system's design calls for the low-pressure spray irrigation of an aerated, settled, and chlorinated municipal/industrial effluent via center

*Resident Research Representative, EPA Project Support Office, Muskegon, Michigan.

pivot irrigation rigs onto lake deposited sands (mainly of the Rubicon, Roscommon, Au Gres-Saugatuck, and Grandby series). The irrigated land is underdrained for the most part on 500 foot centers (5 to 12 foot deep) to recollect the renovated water and route it through collection ditches to surface waters. Two treatment sites are involved. The No. 1 Site is a 10,800+ acre site with 5,405 acres actually planned to be under irrigation rigs, while the smaller Whitehall/Montague Site is a 600+ acre tract with 145 acres planned to be under center pivot rigs.

While full-scale irrigation of wastewater as called for in the design will not occur before the 1974 growing season, the Muskegon system has been accepting, aerating, and storing effluent (currently at the rate of 28 to 33mgd) since May, 1973, at the No. 1 Site and since mid-July, 1973, at the Whitehall/Montague Site. With approval by the State of Michigan a portion of the flow to the No. 1 Site has been released to outlet ditches after being filtered through the sands under the storage lagoon.

A current breakdown of point source discharges that contribute effluents to this system is shown in Table 1. Note the present proportion of industrial effluent is approximately 65 percent by volume.

Construction Status:

Bidding on the construction contracts for this $43 million (estimate) project was broken into 18 major construction contracts. The current status of these contracts is summarized in Table 2. Construction activities remaining involve mainly installation of the field drainage pipe and irrigation systems. Even with these last few contracts barely started, construction of the overall project is more than 90 percent completed.

Total project cost estimates are subject to change orders, but the most current estimates by EPA are as follows:

Estimated eligible line item costs:			
	Construction............	$	27,596,408.13+
	Technical services......		2,280,018.97
	Legal and fiscal........		163,302.18
	Administration..........		338,943.15
	Contingency.............		4,017,827.57+
*Total estimated EPA eligible costs.......		$	34,396,500.00
**Local Costs (estimated non-eligible costs)			8,202,341.26
Estimated Total Project Cost....		$	42,598,841.26

* Estimates from EPA Region V Construction Grants Branch, 13 September, 1973.

** Estimate from Muskegon County Dept. of Public Works, 31 July, 1973. Does not include 20% of $34,396,500 which is also a local cost. Does include land acquisition and interest during construction.

+ Includes all approved change orders as of 13 September, 1973, but not all submitted change orders. Work items transferred from R&D project and others awarded under recent contracts are included.

Note that grants of EPA and the State of Michigan construction funds are based on eligible construction costs only, at 55 percent and 25 percent respectively. Land aquisition costs (approximately $5,000,000) are not included since this grant was awarded prior to the Act Ammendments of 1972, which provide federal funds for land used in land treatment systems. However, EPA will reimburse Muskegon County for expenses incurred (approximately $856,700 to date) in relocating 154 homeowners, 30 tenants, 2 farm owners, 4 businesses, and 2 non-profit organizations previously located on the project site area.

Table 1

Point Source Discharges to the
Muskegon County Wastewater Management System

No. 1 Site	Current mgd*
City of MUSKEGON	8.7
S.D. Warren Paper Mill**	16.0
Continental Motors**	0.7
City of MUSKEGON HEIGHTS	1.4
City of NORTON SHORES	0.6
City of NORTH MUSKEGON	0.4
City of ROOSEVELT PARK	0.6
LAKETON TOWNSHIP	NIS
FRUITPORT TOWNSHIP	NIS
EGLESTON TOWNSHIP	NIS
DALTON TOWNSHIP	NIS
MUSKEGON TOWNSHIP	NIS
Current Total Flow	28.4mgd
1992 DESIGN FLOW	42mgd (average) 88mgd (peak) a

Whitehall/Montague Site	
City of WHITEHALL	0.5
Whitehall Leather Co.**	NIS
City of MONTAGUE	NIS
WHITEHALL TOWNSHIP	NIS
Current Total Flow	0.5mgd
1992 DESIGN FLOW	1.36mgd (average) 3mgd (peak) a

Start-up dates:

5/7/73 - lift station "C"; the bulk of the City of MUSKEGON, ROOSEVELT PARK, and part of NORTON SHORES.
5/30/73 - MUSKEGON HEIGHTS and the remainder of NORTON SHORES.
6/4/73 - S.D. Warren Paper Mill
6/16/73 - NORTH MUSKEGON
7/19/73 - WHITEHALL

* three month avg. flow; data from Mr. George Hall, Teledyne Triple R.

** To date 19 industrial plants are connected to the county system, with six more soon to be connected. These plants include a craft sulfide paper mill, chromium tannery, chemical plants, engine parts manuf., business equip. manuf., sporting goods manuf., metal works, a foundry, a gas and a food distributor.

NIS = Not in system to date; in general, industries contract with city or township governments directly rather than with the county.

a = domestic flow projections were developed using a unit average flow rate of 100gpcd and a peak rate of 250 gpcd.

Table 2

Status of Construction Contracts*

Contract No.	Description	Accepted Bid	Percentage Completion
1	Clearing, paving, fencing	$ 1,916,572.00	98%
2	6", 8", 10" Drainage pipes	782,184.25	33%
3	Main drainage pipe	1,878,149.80#	100%
4	Two culverts & runaround	108,174.00#	100%
5	Ditches, channels, pump stations	1,177,715.98#	100%
6	Irrigation pipe	1,453,761.20	56%
7	Service building	339,674.03	100%
8	Power distribution	544,689.94	88.5%
9	Observation & drainage wells	383,600.50	94%
10	66" Force main	4,683,614.20	100%
11	Force mains, gravity sewer	1,230,930.00	100%
12	36" Force main G to C	841,309.20	100%
13	30-36-42" Force main	1,135,400.00	100%
15	Lift station "C"	1,701,191.00	99%
16	Seven lift stations	1,312,439.71	99%
17	Two irrigation pump stations	437,140.00#	100%
18	Treatment & storage lagoons	8,884,758.00	100%
22	Irrigation rigs	1,373,159.00	10%
	Total Construction Costs	$30,184,462.81	91.6% (Wted Avg)

* Data from Bauer Engineering, Inc. resident engineer's report for September, 1973.

\# final cost; all other values still subject to change orders which are presently estimated to bring the Total Construction Costs to $31.6 million.

Research Activities:

The Muskegon County Wastewater Management System will eliminate many of the existing significant point sources of domestic and industrial wastewater previously discharged directly into the surface waters of Muskegon County, Michigan. It also provides an outstanding opportunity to evaluate the water quality, soil dynamics, and other impacts resulting from a large scale use of the "living filter" concept of effluent treatment.

The Muskegon Project is a "demonstration" project with many objectives including the detailed evaluation of an entire wastewater management system, not just laboratory or pilot research work. Studies will be undertaken to improve the system's operation as well as to help improve our understanding of the value of land disposal especially in the north central United States.

This large-scale land spray system will be the subject of simultaneous investigations by a number of disciplines. It provides an opportunity for these diverse interests to come together and take advantage of the complementary data that will be generated about this system.

Currently funded are two EPA Research and Development grants involving research projects ongoing at the Muskegon Project's No. 1 Site. These are a Section 104 EPA Demonstration Grant

11010 GFS (FY71) to Muskegon County, titled "Muskegon County, Michigan Wastewater Management System," and a Section 108 EPA Grant G005104, titled "Muskegon Land Disposal Monitoring Program," to the Water Resources Commission, a division of the Michigan Department of Natural Resources. Both research grants are being administered by the Environmental Protection Agency's Region V-Office of Research and Development in Chicago.

Grant 11010 GFS (FY71):

Teledyne Triple R (TTR) is the company hired by Muskegon County to carry out day-to-day operations and maintenance, including farming activities, on the project site. TTR and Bauer Engineering, Inc. are undertaking activities to fulfill Muskegon County's research commitments on the project.

Table 3 presents a breakdown of the research and development grant as agreed to by Muskegon County and FWQA, the Federal Water Quality Administration, in October, 1970. The initial grant, with total eligible costs of $1,445,000, includes: a surface and groundwater quality monitoring program, pre-construction studies involving but not limited to irrigation equipment optimization studies, and farm management studies by TTR; a socio-economic and environmental impact study by Bauer Engineering, Inc.; and the

Table 3

Muskegon County R&D Grant 11010 GFS (FY71)

	Eligible Costs	FWQA Grant
Initial Grant (FY71):		
1. Water Quality Monitoring (TTR)		
5 yrs @ $75,000/yr............$	375,000	75%
2. Socio-economic & environmental impact study (Bauer Engineering, Inc.)		
5 yrs @ $30,000/yr............	150,000	75%
3. Pre-construction studies (TTR)		
2 yrs @ $100,000/yr...........	200,000	75%
4. Farm management (TTR)		
7 yrs @ $40,000/yr............	280,000	75%
5. Drainage wells..................	440,000	75%
Sub total	$ 1,445,000	($1,083,750)
First follow-on grant:*		
1. Irrigation rigs................	1,457,000	60% ($874,200)
Second follow-on grant:**		
1. Treatment performance (TTR)		
3 yrs @ $80,000/yr............	240,000	75%
2. Agricultural productivity (TTR)		
5 yrs @ $50,000/yr............	250,000	75%
Sub total	$ 490,000	
GRANT OFFER FUNDINGS SCHEDULE (OCTOBER, 1970)		
TOTAL...........................	$ 3,392,000	$2,325,450
TOTAL GRANT OFFER LESS IRRIGATION RIGS	$ 1,935,000	$1,451,250

(TTR) = Teledyne Triple R research activity

* funded under Sect. 201 construction grant as of June, 1973.

** monies available for project, but not finally approved.

installation of special groundwater control wells on the project site.

The grant agreement between Muskegon County and FWQA included several additional commitments. First FWQA set aside further monies for the county, to be applied for at a later date, for use in treatment performance and agricultural productivity studies. The agreement included 25 special conditions which committed Muskegon County to undertake additional research activities, including cost analyses of the entire system and monitoring of public health related aspects such as virology, bacteriology, insect and odor control.

Although the entire R&D grant work program is currently being revised and updated, a brief description of each research component as funded under the initial grant and proposed for follow-on monies will now be presented.

1. Water Quality Monitoring; surface and groundwaters.

This research component was designed to establish background data as baseline information on physical and chemical surface and groundwater quality before the Muskegon Project began operations, and to allow follow-up tracing of any changes in water quality which might occur during the system's operations. To carry out the analytical work needed to support this and other research activities on the project, Muskegon County has established a highly sophisticated analytical laboratory on the project site. Methodology and quality control procedures utilized by this lab are currently under review by EPA's Analytical Quality Control Laboratory in Cincinnati, Ohio.

Sampling points (Table 4) were selected to monitor surface and groundwater quality throughout the project site's watershed area and receiving surface waters, including Lake Michigan. Table 5 summarizes the analyses made on both surface and groundwater samples for this project. Figure 1 depicts the surface waters and 34 sampling stations at which samples are collected on a monthly basis.

Groundwaters (Figure 2) are monitored by sampling four different types of wells. (1) LAGOON SEEPAGE WELLS, 33 groups with seven wells of various depths, in each group, are located on the south and west sides of the storage lagoons to evaluate the performance of the interceptor ditches surrounding the storage lagoons and monitor the quality of groundwater leaving the lagoon area. (2) PERIMETER or OBSERVATION WELLS, 42 wells, generally in clusters of three varying depth wells, are located to monitor groundwater quality near the site boundaries. (3) Sixteen GROUNDWATER CONTROL WELLS are sampled to monitor the quality of groundwater that might leave the northern edge of the site into

Table 4

Water Quality Monitoring Stations

A. Surface Waters

Location	No. of Samples	Sampling Frequency	Parameters Monitored
Mosquito Creek	3	Monthly	48
Muskegon River	7	Monthly	48
Muskegon Lake*	11	Monthly	48
Big Black Creek	2	Monthly	48
Mona Lake	5	Monthly	48
Lake Michigan	4	Monthly	48
Wolf Lake	1	Monthly	48
Whitehall/Montague Site	9	Monthly	48
	42		

B. Groundwater

Perimeter or Observation Wells**	60	Monthly	10
Lagoon Seepage Wells	240	Semi-Annual	5
Private Wells+	180	Semi-Annual	4

* includes sampling stations on Bear Lake and Greens Creek
** includes groundwater control wells
\+ Private Well sampling not funded under EPA Grant funds

Table 5

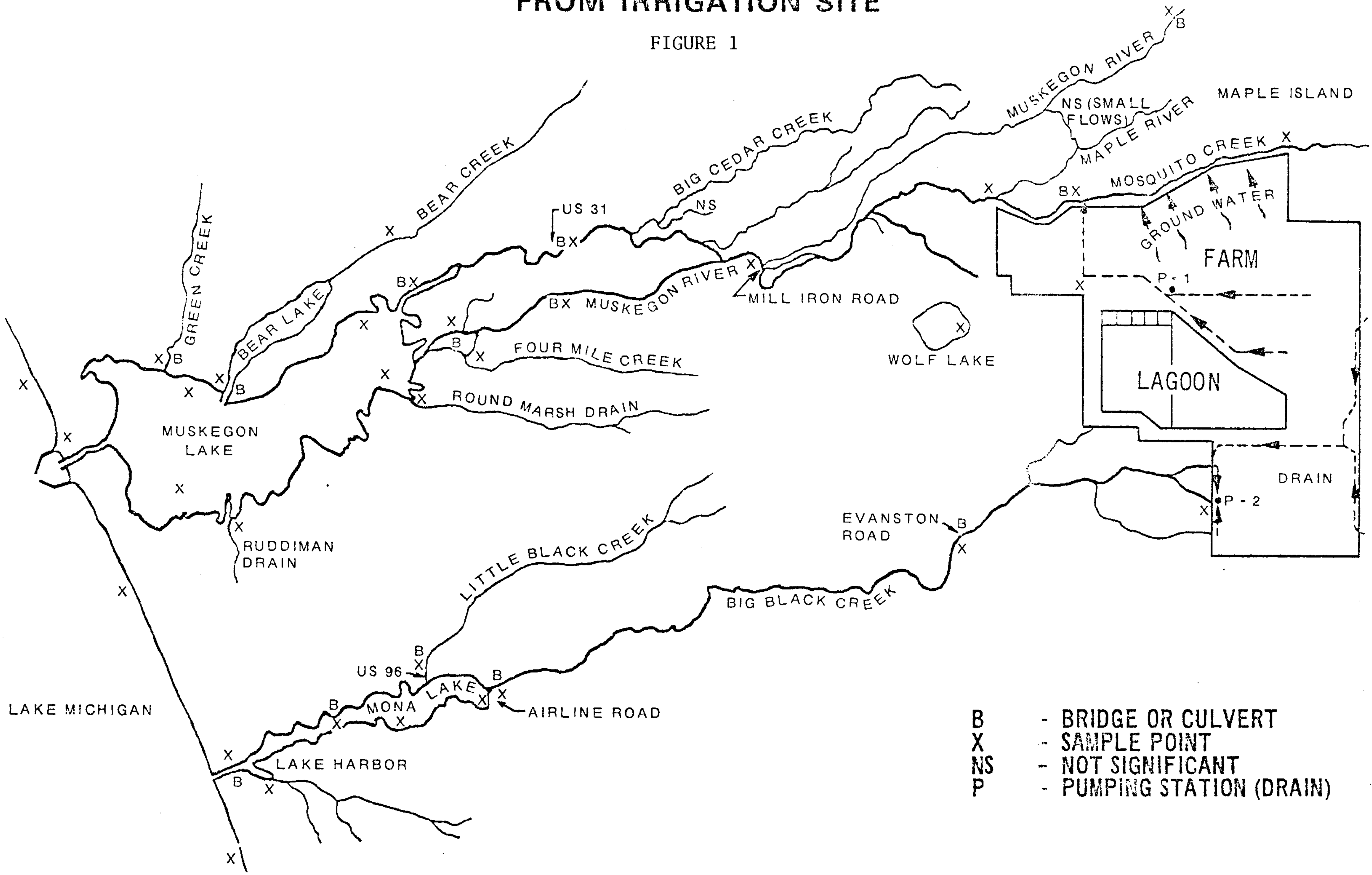
Parameters Measured in Water Quality Monitoring Studies

Solids (total dissolved, suspended, total volitile)		
Temperature	Turbidity	pH
Conductivity	Color	
Trace heavy metals - total & free		
Hg, Ni, Zn, Cd, Cr, Pb, Cu		
Iron and Magnesium - total & free		
Alkali earth metals and hardness		
Na, Ca, Mg, K		
Sulfate & Sulfite		
Chloride		
Halides		
Alkalinity		
Ortho-phosphate		
Total P		
Nitrogen (NO_3/NO_2, N, NH_4^+)		
Total Kjeldal N		
BOD, COD, TOC, DO		
Phenols		
Pesticides, hervicides, etc.		
Residual Chlorine		
Bacteria - Total & Fecal Coliforms		
Fecal Streptoccoci		
Salmonella		
Virus		
Plankton		

Perimeter or Observation Wells	Seepage Wells	Private Wells
Conductivity	Conductivity	Detergent
Color	Chloride	Nitrate
BOD, COD, TOC	Phosphate	Total & Fecal Coliforms
Chloride	Nitrate	
Phosphate	Total Coliform	
Nitrate		
Total & Fecal Coliforms		

SURFACE WATER DRAINAGE FROM IRRIGATION SITE

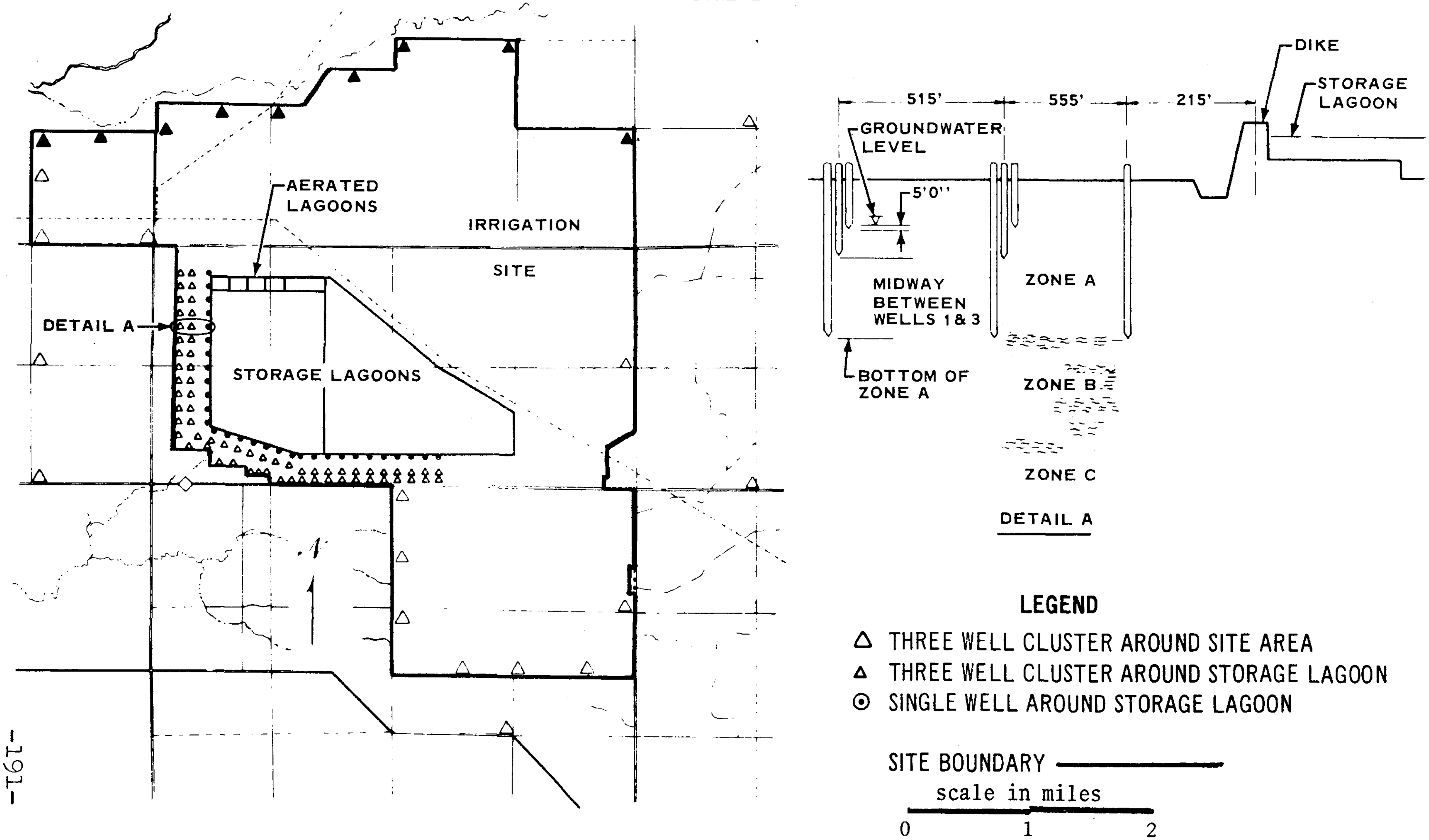
FIGURE 1



B - BRIDGE OR CULVERT
X - SAMPLE POINT
NS - NOT SIGNIFICANT
P - PUMPING STATION (DRAIN)

GROUNDWATER OBSERVATION POINTS

FIGURE 2



Mosquito Creek without passing through the field tile drainage system. (4) In addition, 180 PRIVATE WATER SUPPLY WELLS in the area surrounding the project site are to be sampled semi-annually at the county's expense as a further check on groundwater quality near the project area.

2. Socio-Economic Environmental Impact Study.

Monies were included in the R&D grant to Muskegon County to carry out sociological studies into the impact of the new wastewater management system in such areas as county residents' attitudes and values, the county's economic situation, and the general environmental esthetics of the county. The major objectives of this five year study are as follows:

1. Develop a mechanism for disaggregating measured change into direct, indirect, and non-correlative effects of the wastewater system.

2. Identify a framework for comparing total change and impact with desired change; the desired change will be an expression of the Community Goals Framework.

3. Formulate a forecast model to predict the short-term (five year) development of Muskegon County based on past trends and superimpose on it the predicted development caused by the wastewater system.

4. Gather information from several perspectives; among these are: desired change (goals), measured change (quantitative data) and perceived changes (perceptual data).

5. Identify a set of social indicators to describe the impact of the wastewater system, which is commensurate with reliable and reasonably accessible data.

At present baseline attitude data are being collected, community goals determined, and adequate indicators of social change sought. This Bauer Engineering, Inc. undertaking is currently in its second year of work effort.

3. Pre-construction Studies; including irrigation equipment optimization studies.

The design of the Muskegon County Wastewater Management System necessitates the spray irrigation of large volumes of water, which differs from the concept of conventional irrigation systems that call for spraying no more water than is required for actual irrigation of crops plus that required for adequate leaching to prevent salt build-up. The large amount of water to be applied will require that the machines at Muskegon be operated during a seven month irrigation season to supply up to 4 inches of water per week (average 3 inches per week) at the No. 1 Site and up to 4.3 inches per week at the Whitehall/Montague Site.

Certain design criteria regarding structural loads, mechanical operation and water distribution, needed on center pivot irrigation rigs for this project were not available with existing machine designs. Therefore, the basic objectives of the rig testing program included:

1. Testing, evaluating and recommending a type of spray nozzle which provided an adequate spray pattern with minimum aerosal drift and would operate at low pressure (15psi or less).

2. Evaluating drive mechanics, uniformity of water application, power requirements, rate of wear and reliability of structure with increased load of the larger-than-standard diameter water delivery pipe required on some of the machines.

3. Developing procedures for machinery operation including optimum operation speed, weather condition restrictions, starting and shutdown procedures, and optimum maintenance practices.

The irrigation equipment optimization studies undertaken by Teledyne Triple R contributed data for the final design specifications by Bauer Engineering, Inc. under which the Lockwood Corporation is providing the center pivot rigs for the project. The design calls for downward-spraying, low-pressure (15psi or less) nozzles on a spray bar suspended 7 to 9 feet above the ground surface from a bow string struss.

Each support tower has electrically driven heavy-duty Lockwood gear drives which transmit torque to two 44 inch diameter rubber-tired wheels. An anti-collision mechanism has been incorporated to prevent any interference in the operation of one machine by another where irrigation circles overlap. Additional details regarding the rig design and operation are available from Teledyne Triple R and Bauer Engineering, Inc.

Other originally designated pre-construction studies, including remote monitoring and public health related aspects, in general have been incorporated into other components of the county's R&D grant. Results from these studies again will not be available until the system is in full operation.

4. Management of Project Farming Operations

The farm management program was designed to aid in the development of detailed plans for initial agricultural activities and the development of a "Master Farm Plan" for the most effective management of the entire acreage throughout the project period. The following list of goals for the project suggests the importance of a well managed farming program:

1. The removal, via cropping, of the maximum quantity of nutrients from the irrigated effluent.
2. The production and sale of the highest cash yield products.
3. The practice of a soil husbandry which will provide maximum improvement of the soil year by year.
4. Determining the best use of agriculture production, and incorporation of these results into future management practices.

In developing a Master Farm Plan with the ultimate goal of producing a final product (both water and crops) of the highest quality, the farm manager must deal with many factors, including soil, weather, water demand, labor, capital, and market, which influence the design of such management tools as crop selection, planting and harvesting schedules, irrigation schedules, herbicide and pesticide applications, tillage practices, maintenance schedules and other elements.

The research aspects of the farm plan deal mainly with soils analyses and crop nutrient uptake/production/marketing considerations. Soils studies involve both baseline data (Table 6) and changes in soil characteristics over the project period (Table 7) to support crop nutrient needs. Initial soil sampling will be undertaken twice, before the first crop is planted, and after the crop has been harvested. Later sampling will be only once per year. Crop production and marketing studies will concentrate on crop selection and sales, nutrient uptake, irrigation schedules, tillage practices, herbicide and pesticide selection.

While wastewater will not be utilized in growing crops until the 1974 growing season, over 1500 acres were dry cropped during 1973. Also two irrigation circles utilized in the rig optimization studies received supplemental fertilizer and were irrigated using well water on an irregular schedule. The irrigation of corn on these two test circles has resulted in a substantial yield increase as compared to fertilized, dry cropped areas.

5. <u>Treatment Performance Studies</u> (Proposed for follow-on funds)

To manage the system in an efficient, meaningful and precise manner, comprehensive monitoring of water quality is required as the wastewater moves through the system. Such a study could reveal information which would allow more flexibility in the over-

Table 6

Characteristics of four major soil types on the Muskegon Wastewater Management System Project Sites.

Soil Name	Depth to Water Table*	USDA Texture	% Plow Layer Passing Sieve No. 4	% Plow Layer Passing Sieve No. 10	% Plow Layer Passing Sieve No. 200	Plow layer pH
Rubicon Sand	10-20 ft or more	sand	95-100	90-100	0-15	4.5-6.0
Roscommon	1-4 ft	sand	100	95-100	0-10	5.0-6.0
Au Gres-Saugatuck	1-6 ft	sand	100	95-100	0-15	4.5-6.0
Granby	seasonably at or near the surface	loamy sand	100	90-100	15-25	6.0-7.5

* Before operation of the underdrainage system which was designed to provide a minimum of five feet of aerobic soil at maximum irrigation rates.

Table 7

Soil Analyses for Baseline Soil
and Crop Production Studies

Soil pH	Res. "NO_3"N
Buffer pH	Avail. P, S, Zn, B, Cu
Excess Lime	Exch. K, Mg, Ca, Na, Mn
% Soluble Salts	*Sol. Al, Cd, Pb, Ni, Hg, Cr, Cn, Fe, Cl
% Organic Matter	
% Sand (sieve analysis)	Meq. per 100gm soil of: H, K, Mg, Ca, Na
% Silt (hydrometer)	
% Clay (hydrometer)	% Saturation of: H, K, Mg, Ca, Na
% Held in Sieve Meshes 18, 35, 60, 150, 200 & 325	Cation Exchange Capacity

* for Baseline Soil Analyses only

all operation of the system. By systematically modifying operations within the system, possible savings in time, energy, manpower and money may be realized.

Sampling sites are to be located from intake at the downtown collection stations to the final discharge from the field drainage system collection ditches into surface waters (Table 8). Parameters measured (same as in the Water Quality Monitoring Studies - Table 5) were selected on their significance for the monitoring of the wastewater treatment performance, their potential effects on agricultural productivity, as well as their impact on the receiving surface waters.

The Treatment Performance and Surface and Groundwater Monitoring Programs are designed to monitor water quality both on and off the project site. Treatment Performance Studies would follow the actual renovation of the wastewater as it moves through the treatment system, while the Surface and Groundwater Monitoring Studies will concentrate on the potential impacts of the renovated waters discharged into receiving waters.

Table 8

Sampling Sites and Procedures for Treatment Performance Studies

Location	No. of Samples	Sampling Frequency	Parameters Monitored
"C" Station	1	Continuous	5
Inlet to Treatment Wells	1	Continuous	5
#1 Aerated Lagoon*	4	Daily	5-48
#2 Aerated Lagoon*	4	Daily	5-48
#3 Aerated Lagoon*	4	Daily	5-48
Settling Lagoon	2-3	Daily	10-48
Outlet Lagoon	2	Daily	48
#1 Storage Lagoon	10	Weekly	10-48
#2 Storage Lagoon	10	Weekly	10-48
Sprayed Water**	2	Daily	10-48
North Observation Wells	27	Monthly	48
North Drainage Ditch	2	Daily/Weekly	5-48
South Drainage Ditch	2	Daily/Weekly	5-48
Sludge from Settling Lagoon	2	Weekly	48
Sludge from #1 Storage Lagoon	10	Weekly	48
Sludge from #2 Storage Lagoon	10	Weekly	48
Outlet to Mosquito Creek	2	Daily/Weekly	5-48
Groundwater in Seepage Interception Ditch	2	Daily/Weekly	10-12

* The BOD, COD, pH, TOC, Conductance and Bacteriology will be analyzed several times daily to establish the kinetics patterns.

** Water sprayed during the farming operations will be analyzed for residual chlorine and fecal coliform at several locations to establish a pattern. Later samples will be taken as needed.

6. Agricultural Productivity Studies (Proposed for follow-on funds)

In an effort to more fully understand the role of crops and soils in the land disposal system and to answer certain questions concerning the effect of wastewater irrigation on the soils and crops to be utilized by the Muskegon Wastewater Management System, three separate types of experimentation have been proposed by Muskegon County as follows:

1. SOIL COLUMN LYSIMETER STUDIES...Twenty 4-inch diameter 54-inch deep Roscommon soil column lysimeters would be established to study ionic adsorption capacities of the soil for nutrients and heavy metals under various loading rates of effluents of varying ion concentrations. The adsorption capacity of the soil for each parameter tested (Table 9), adsorption profile, and potential would be emphasized.

2. GROWTH BOX LYSIMETER STUDIES...A 17' X 96' greenhouse including 38 growth box lysimeters (4' X 4' X 4') filled with Roscommon soil profile, would be established to study both the beneficial and harmful effects of wastewater irrigation on various agricultural crops. Greenhouse growth boxes are suggested to allow year around research activities.
From analyses of plant tissues, soils and effluent percolate (Table 9), conclusions could be drawn concerning the following:
   a. An inventory of all plant nutrients and heavy metals put into the system from the effluent.
   b. Nutrient removal of corn grain vs corn plant vs alfalfa.
   c. Concentration of elements and compounds in various plant tissues and soil horizons.
   d. Materials most easily leached from soil.
   e. Nutrient composition of crops under the different conditions.
   f. Quantity (weight) of nutrients and heavy metals removed by different crops under the various regimes.
   g. Beneficial effects of wastewater irrigation vs conventional agriculture.
   h. Effect of effluent application and crop removal on soil chemistry.

Table 9

Parameters Measured for Agricultural Productivity Studies

A. Soil from the column lysimeters will be removed and divided into six inch increments by depth using nine soil samples from each column.

B. Soil analysis and determinations will include the following: pH, % soluble salts, "NO_3"N, total N; available P, S, Zn; exchange K, Mg, Ca, Na, Mn; Pb, Cr, Cl; cation exchange capacity; % sand, silt and clay (hydrometer); sieve analyses; Meq/100gm for H, K, Mg, Ca, Na; % sat. H, K, Mg, Ca, Na.

C. Analyses of effluent will be done on samples taken from weekly batches used to irrigate lysimeter crops. Analyses will include the following; pH, conductivity, Ca, Mg, K, Na, Zn, total N, Pb, Cr, Cl, SO_4, PO_4, "NO_3"N, "NH_3"N.

D. Plant tissue analysis would be done on alfalfa plants in 10-20% bloom. The sample would consist of the top six inches of ten plants within each growth lysimeter. In the case of corn, tissue samples prior to tasseling (first fully developed leaf would be used) and at roasting ear stage would be taken. Tissue analysis would be done by neutron activiation analysis. Soil samples will be taken at the same time as tissue samples.

3. DEMONSTRATION PLOTS...It is proposed to establish field demonstration plots (one acre and less) to determine the most responsive and best suited crop and crop varieties, the best performing herbicides and insecticides (combinations and rates), and the optimum weekly rate of applied irrigation wastewater that will provide maximum yields while achieving maximum nutrient removal. Crops to be grown would include corn, alfalfa, alfalfa-grass mixtures, and various "special" crops (possibly turf grasses, nursery stock, and vegetables such as carrots, parsnips, celery, sweet & popcorn, potatoes, sugar beets, turnips and onions). Soil and tissue analyses would provide uptake data that can be compared with that in the more comprehensive greenhouse studies.

Both soil column and growth box studies should be predictive of the total system's responses to stresses, such as high wastewater application rates and crop toxicities, but will need to be verified by observations of the larger scale demonstration plots as well as system-wide farm performance.

Grant G005104:

The second currently funded and operating R&D project at Muskegon involves the Water Resources Commission (WRC) staff of the Michigan Department of Natural Resources, and researchers of both the University of Michigan and Michigan State University. This grant, administered by WRC, takes a closer look at the entire watershed involving the Muskegon Wastewater Management System and should provide recommendations regarding the extension of the land disposal concept to other cities in Michigan.

While sampling duplication does occur, this research effort is designed to complement the Muskegon County research efforts, not replicate it, and make the entire project more meaningful. Table 10 gives a brief outline of this grant, while summaries of each research component of the project follow.

Table 10

Water Resources Commission R&D Grant G005104*
Budget Breakdown

University of Michigan..............................	$ 223,293
Michigan State University..........................	243,650
Water Resources Commission Staff..................	155,646
TOTAL PROJECT	$ 622,589

* current funding schedule 1 July, 1972 thru 31 September, 1975

University of Michigan: EFFECTS OF THE LAND DISPOSAL OF SEWAGE ON THE WATER RESOURCES OF MUSKEGON COUNTY

Purpose: Monitor any changes in chemical (and some biological) parameters in the receiving streams, above and below the points of discharge, and in White, Mona and Muskegon Lakes. To create a predictive model for long-term projections.

Sampling at points above and below the land disposal site in the drainage of Black Creek, the Muskegon River, and the White River, including White, Mona and Muskegon Lakes and their outlets into Lake Michigan, is carried out twice monthly from April to November and once monthly from December through March. Parameters measured include:

*Ammonia	*Temperature	*Chloride	DO
*Total N	*Chlorophyll	*Nitrate-Nitrite	Conductivity
*Total P	+Zooplankton	Silicon	*Phytoplankton
*Total Organic C	+Transparency	*Dissolved P	+Primary Productivity
*pH	+Benthos	*Alkalinity	+Relative Irradiance

*sampled at each station
+sampled at lake stations only

Note: Zooplankton, phytoplankton, and benthos samples are analyzed for both composition and abundance.

The above generated data and all other available data will be incorporated into phytoplankton and biological production models developed by the Sea Grant Program for Grand Traverse Bay to predict the impact of changes in nutrient and waste loads into the three river-lake-Lake Michigan systems. In conjunction with WRC personnel, these data will be utilized in a study to evaluate the extension of the land disposal concept to other cities in Michigan.

Michigan State University: INFLUENCE OF SOIL PHASE ON THE ADSORPTION OF NUTRIENTS AND CHANGE IN PHYSICAL PROPERTIES DURING SPRAY IRRIGATION OF EFFLUENT

Purpose: Study soil chemistry and soil physics to obtain information on soil parameters such as infiltration, hydaulic conductivity, soil structure, and related aeration and/or oxidation properties of the soil; attempt to determine the quantity of nutrients, metals, etc. adsorbed by the soils.

Eight replicate soil profiles are sampled by six inch increments to a ten foot depth from each major soil phase on the project site, including Rubicon Sand, Roscommon Sand, Au Gres Sand, Saugatuck Sand, and Grandby Sand. The samples are air-dried, screened, and stored in sealed glass containers until analyzed. To adequately follow changes, samples are obtained and analysed twice yearly, before and after the growing season. Each sample is collected from a distance no more than 50 feet from the original site.

The following chemical analyses are performed on samples from the project area:

Total C, N, P
K, Ca, Mg, Zn, Cu, Mn, Fe, Pb, Hg, Na
Water soluble NO_3
Adsorbed P
Ammonium acetate extractable Ca, Mg, K, Na
Chelate extractable Zn, Cu, Mn, Fe, Pb, Hg - also Cr

Physical measurements including infiltration rates, redox profiles, pore size distribution, hydraulic conductivity, texture of the soil profiles and structure of surface soils and depth to water table will be determined on the major soil phases yearly. Pesticides and PCB's are identified and quantified in input waste waters and soils by gas chromatography, column extraction, and thin layer chromatography.

WATER RESOURCES COMMISSION (Michigan Department of Natural Resources)

<u>Water Quality Appraisal Section</u>: BENTHOS AND SEDIMENT SAMPLING OF MONA, WHITE AND MUSKEGON LAKES

<u>Comprehensive Studies Section, Hydrology Survey Division</u>: WATER QUALITY SAMPLING STUDY

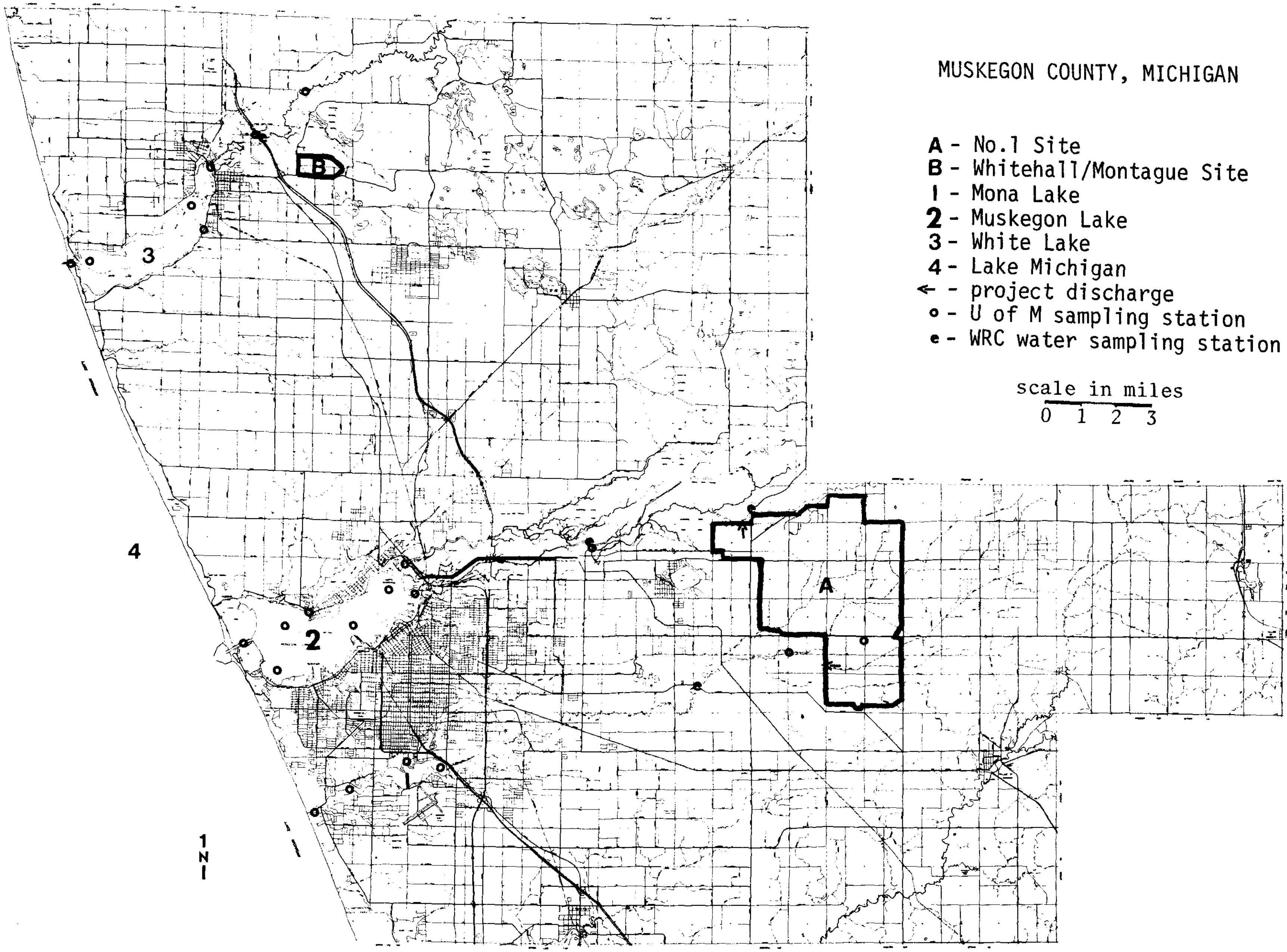
Purpose: Benthos sampling of the three lakes as well as monthly sampling at four locations for a variety of chemical and bacteriological parameters.

Benthos organisms are an important part of the aquatic ecosystem and can serve as a sensitive indicator of water quality. Not only do these organisms indicate something about the present water quality, but they reflect the water quality of the past which in part is responsible for the nature of the sediments where the organisms live.

The major objective of this study is to establish baseline information for the benthos of Mona, White and Muskegon Lakes in order to assess the changes that may occur due to the new Muskegon County Wastewater Management System. Baseline bottom sample concentrations for the following parameters are also being determined:

Total P	As	Cr
Total Kjeldal N	Pb	Cu
Sediment oils	Hg	Ni
	Zn	

As part of a state-wide net of water quality monitoring, WRC has


MUSKEGON COUNTY, MICHIGAN
A - No.1 Site
B - Whitehall/Montague Site
1 - Mona Lake
2 - Muskegon Lake
3 - White Lake
4 - Lake Michigan
← - project discharge
o - U of M sampling station
e - WRC water sampling station
scale in miles
0 1 2 3
A
B
1
2
3
4
N

established four water quality monitoring stations on the receiving waters of the Muskegon County Wastewater Management System. Suspended solids concentrations, dissolved oxygen, BOD, pH and where possible continuous or instantaneous flow records will be obtained and included in the overall program for monitoring of downstream waters.

ADDITIONAL ON-GOING AND PROPOSED RESEARCH

While the research activities so far described are currently funded or earmarked for funding by EPA, there are other research projects either on-going or proposed for the Muskegon County Wastewater Management System.

Modeling of Groundwaters: The U.S. Geological Survey, in cooperation with the Michigan Geological Survey and other Department of Natural Resources agencies, will soon be obtaining information on various aspects of the aquifer hydraulics of the treatment operation. At present very little is known regarding either groundwater flow patterns at the project site, or potential effects of the operation on regional flow patterns.

A series of digital models will be developed to simulate various aspects of the groundwater system. Some models will be designed for detailed simulation of flow in the interior of the project site, and others for simulation of the effect of operations on regional groundwater bodies. It will be necessary, of course, to take into account surface flows moving into, through, and out of the system. Data already being collected at the site will be utilized, and new data, particularly on static groundwater levels and geologic characteristics, will be collected both within the site and in the surrounding areas. These activities will be funded jointly by the U.S. Geological Survey and the Michigan Geological Survey.

P Adsorption Survey: Dr. Carl Enfield, EPA Robt. S. Kerr Environmental Research Laboratory at Ada, Oklahoma, is currently carrying out a nation wide survey on P adsorption capacities of various soil types. Included in his survey are two of the major soil types found on the Muskegon Project sites, Rubicon and Roscommon-Au Gres Sands.

Virological Monitoring: A proposal submitted by Dr. K. W. Cochran, School of Public Health, University of Michigan, is being reviewed and considered for funding under existing county R&D grant funds. This proposal outlines a six month virus monitoring program for the entire system, including aerosols from the spray rigs and aerated lagoons.

Remote Sensing Monitoring Program: The Water Resources Commission has proposed an overflight remote sensor monitoring program utilizing a 12 channel mutispectral ERIM sensor to document the rate of water quality improvement of the three downstream lakes, observe crop health and possible water ponding within the irrigation areas, and monitor for possible leakage from the storage lagoons. Ground surveys would help substantiate and increase confidence of the aerial findings.

Limnology of Storage Lagoons: A pre-proposal (for doctoral student research support funds) has been submitted to EPA's Pacific NW Environmental Research Laboratory, Corvallis, Oregon, to follow the limnological dynamics of the two 850 acre storage lagoons for three years by Dr. Peter Meier, Department of Environmental and Industrial Health, University of Michigan. Analyses over the three year period proposed would include primary productivity, chlorophyll measurements, zooplankton and phytoplankton quantification and identification.

Background Heavy Metal Levels in Native Flora: Dr. Lloyd Hess, a botanist from Grand Valley State Colleges, Allendale, Michigan, is generating limited background heavy metal data for several native plant species on the No. 1 Site by neutron activation analyses at no cost to the county or EPA.

Summary:

While cropland irrigation with municipal effluents may be a well-established practice in the water-short areas of the southwestern United States (5, 6), little useful data have been available to predict the long-term effects of spray-irrigation of effluents at Muskegon or other areas.

Presently over $2.5 million in research funds are committed to or earmarked for support of programs designed to evaluate the performance of the Muskegon County Wastewater Management System. Data resulting from these efforts may be useful in designing other spray irrigation projects. However, the problems created by various climatic conditions, soil types, effluent characteristics, etc. facing land disposal of effluents as it is being envisioned today will not be overcome without further research in the various geographical areas of the country.

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A SURVEY OF LAND APPLICATION OF WASTEWATER EFFLUENTS IN THE ROCKY MOUNTAIN-PRAIRIE REGION

by

Roger Dean*

A survey of the use of application of wastewater effluents was conducted encompassing the Rocky Mountain-Prairie Region of the EPA, Region VIII, which includes the States of Colorado, Wyoming, Utah, Montana, North Dakota and South Dakota. Of prime interest were those sites utilizing spray irrigation, or overland flow, or ridge and furrow irrigation which had pre-planned or intentional direct uses of effluents. Not included are sites such as lagoons with emergency outfalls to land or to streams or return flow irrigation ditches where dilution or ultimate destination of the effluent is unknown.

The list of sites to be surveyed was developed through review of known listings such as the 1968 Inventory of Municipal Waste Facilities by the EPA, EPA files on federal installations, and inquiries to engineers of the U.S. Forest Service, various engineering firms and the state water pollution control engineers of the states within the region. All sites of possible land application of secondary effluents were first investigated by

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means of telephone inquiries to complete survey questionnaires. This assured obtaining at least some data for all sites without extensive travel. It also avoided the poor response of mail surveys, and allowed direct immediate inquiry into the unique aspects of each site as they were discussed with the person being interviewed. Six industrial and 37 municipal sites were surveyed.

The survey questionnaire centered around three main topics; (1) general, (2) legal aspects, and (3) engineering systems. These included; flow rate and storage quantity, pretreatment, significant effluent water characteristics, soil, geological, and topographical characteristics of the site, irrigation methods used, crop or land use, environmental monitoring of the site, and capital and operating and maintenance costs. Some of the highlights of the survey are presented below.

General Site Data:

The state location of known sites categorized as operating, under construction, planned or seriously being considered for the near future are indicated in Table 1. The year each site was placed, or planned to be, in service is given in Table 2 and a breakdown of land use of the sites in Table 3.

TABLE 1

REGION VIII SITES

STATE	OPERATING	UNDER CONSTRUCTION	PLANS & SPECS	SERIOUS CONSIDERATION
Colorado	10	6	4	3
Utah	4	2	-	-
Montana	2	2	1	2
Wyoming	1	2	-	1
North Dakota	1	-	-	1
South Dakota	1	-	-	-
TOTAL	19	12	5	7

TABLE 2

YEAR SITES PLACED IN SERVICE

DATE	NUMBER OF SITES	DATE	NUMBER OF SITES
1951	1	1970	2
1958	1	1971	1
1959	1	1972	2
1960	1	1973	6
1964	2	1974	11
1967	1	Future	12
1969	2		

TABLE 3

DISTRIBUTION OF SITES BY LAND USE

Golf	14	Natural Vegetation	6
Crops		Landscaping	3
Hay & Grass	5	Pasture	3
Alfalfa	2	Forest	1
		Undecided	1

The predominant reasons given for choosing land application of secondary effluents at existing and proposed sites were:

REASON CHOSEN	NUMBER OF SITES
Water already owned by user and suitable for secondary use such as golf course irrigation	18
To avoid direct discharge to strem	15
Lower cost of treatment on seasonal waste	4
No stream available for discharge	2
Offensive odors if lagooned	2
To maintain water rights	1
Overloaded lagoon	1

Some complaints from the public had been received for five sites due to odors. These were usually associated with algae blooms in the lakes on golf courses which are used both for wastewater storage and as water hazards, or were associated with industrial food processing wastes that were not kept fresh. In general, public attitude toward the sites was quite good although the practice of most golf courses of watering at night helps maintain a low awareness among golfers of the practice as well as avoiding direct water spray contact with golfers. The only significant complaint on the part of the effluent users themselves was the occasional algae problem and associated odor problem in golf course lakes. Significant water rights problems were not encountered at any of the sites surveyed since in almost all cases the effluent had originally been water which was newly purchased or for which the water rights had not been maintained, or the water originated as groundwater.

Systems Descriptions:

The types of pretreatment received by the effluents before application to the land at the existing sites are given in Table 4.

The significant industrial effluent constituents reported were whey by-products, in the three cheese factory effluents, and high BOD and suspended solids in three food processing plants. The average daily flow of sites presently in operation was 0.75 MGD per site with a range from 8000 GPD to 3.0 MGD. The average design flow for all plants surveyed was 0.75 MGD with a range

TABLE 4

EFFLUENT PRETREATMENT

NUMBER OF SITES	PRETREATMENT
6	Activated sludge with chlorination and polishing pond
1	Activated sludge with no chlorination
1	Activated sludge with tertiary treatment and chlorination
4	Extended aeration with chlorination and polishing pond
1	2-cell aerated lagoon with no chlorination
5	2-cell aerated lagoon with chlorination
3	2-cell aerated lagoon with chlorination and polishing pond
1	Anaerobic lagoon with polishing pond
3	Trickling filter with chlorination and polishing pond
1	Trickling filter with chlorination
4	Screening only (industrial)
1	Septic tank with chlorination

from 40,000 GPD to 3.6 MGD. Only 6 of the 31 existing sites had design flows greater than 1.0 MGD. These values are comparable to statistics for California (1) where 110 waste treatment facilities whose effluents are used for crop or landscape irrigation have an average flow rate of 0.79 MGD per facility with a range from 40,000 GPD to 14 MGD (2).

The average area of existing sites by use in Region VIII where effluent is used for irrigation is:

NUMBER OF SITES	USE	AREA
14	Golf	112 acres
11	Crop/Pasture	60 acres
3	Landscape/Recreation	82 acres
6	Natural vegetation	6 acres
1	Forest	8 acres

Soil types (for existing sites) ranged from sandy to clayey to unknown types with the following distribution:

SOIL TYPE	NUMBER OF SITES
Sandy loam	11
Sandy	6
Loam	1
Clay loam	1
Silty Clay	1
Silty loam	1
Unknown	10

Irrigation equipment utilized was almost exclusively of the below ground, solid set, impact sprinkler type as noted below:

IRRIGATION EQUIPMENT	NUMBER OF SITES
Solid set (below ground)	21
Solid set (above ground)	4
Portable	3
Movable boom	2
Overland flow	2

Irrigation rates were quite variable. Eight sites, predominately golf courses, irrigate on an "as required" basis. For those sites where a known quantity of water was being applied each week the range of effluent application was from 0.6 inches per week to 3.5 inches per week with an average of 1.7 inches per week.

Eight sites employed only seasonal irrigation with effluent discharging to streams during the winter months. These sites require discharge permits. Some sites appear to have adequate winter storage; however, many of these sites were golf courses near new housing developments with the adequacy of the storage dependent upon ultimate housing development size. The availability of capital cost and operating and maintenance cost data varied from minimal to non-existent, thereby preventing a meaningful determination of typical costs.

Monitoring:

Observed during the survey was a widespread lack of awareness of the pollution potential from the use of effluents for irrigation coupled with a comparable lack of state guidelines or requirements on design discharges or monitoring. The sites are designed so that percolation to groundwater occurs, yet, none of the states in Region VIII have promulgated standards for groundwater quality nor established specific requirements or a permit system for discharges to groundwater. Federal agencies such as the Forest Service and National Park Service have been including monitoring capabilities for parameters such as groundwater quality in the design for land application sites within the Region. Some site monitoring is performed at industrial sites primarily because of the nature of their effluents. Most golf courses do not monitor.

The need for the states within Region VIII to take the lead in promulgating standards and requirements for land disposal of wastewater effluents is evident. Including sites for land disposal of effluents in an effluent discharge permit system will provide a mechanism for review of site design and operation by state water pollution control engineers. Monitoring and sampling requirements will help ensure that the sites are properly operated and maintained.

The do-nothing alternative may result in lawsuits similar to that which involved the City of Hobbs, New Mexico recently. Because of lack of management of their site (which was essentially a sewage farm) hydraulic overloading polluted over twenty wells within a two mile radius of the site with nitrate concentrations as high as 140 ppm NO_3. The City has been directed by the District Court to pump the groundwater mound to remove the nitrate water and to provide a separate source of potable water to the polluted well owners. Hobbs is not unique. Lubbock, Texas, and Fresno, California, have nitrate pollution problems beneath their land disposal sites. Because groundwater pollution through land disposal of effluents is much less transitory than stream pollution, the need is to ensure, as far as possible, that groundwater pollution does not occur.

The proper design of a facility for the land application of effluents is site specific. Therefore, state standards and requirements need flexibility to allow the designer the latitude required for proper design. Some points for consideration along these lines, based on the survey, are:

1. Proper effluent application rates are site specific as to soil type, topography and annual precipitation. Numerical guidelines can either be too conservative or

too liberal for a specific site and also run the risk of becoming an unquestioned design parameter whose use can lead to inadequate design.

2. Many industrial effluents such as food processing wastes are best handled while they are fresh. Therefore, inflexible mandatory pretreatment standards such as a minimum of secondary treatment with chlorination may be self defeating.

3. The goal of zero discharge to surface waters should not give freedom to pollute groundwaters. Therefore, up-gradient and down-gradient wells to monitor groundwater quality should be mandatory. Groundwater monitoring is not necessarily more complex than the effluent monitoring already in use.

4. Annual soil sample analysis can be useful in heading off soil toxicity problems such as a buildup of salts. These tests can be performed by agencies such as the state Agriculture Extension Services.

5. Design review and approval by a team consisting of a qualified soils engineer, a hydrologist, a geologist and an agronomist would be a desirable requirement to ensure proper design.

6. Design feasibility review and approval by the state water engineer could avoid many potential water rights conflicts.

7. Total analysis of the wastewater effluent being considered for land disposal is mandatory to identify potential toxic and trace element problems before design is initiated.

8. Insect abatement requirements (such as mosquitos) need to be addressed as to both nuisance effects and disease vector potential. Aerosol drift must be considered.

9. Land disposal requirements need to be continuously updated to include new developments in the areas of virus and toxic element control and monitoring.

10. Use of water hazards on golf courses as storage for secondary effluents with high fecal coliform counts should be reviewed.

11. Chlorination requirements for effluent uses on golf courses or other recreational sites should be reviewed in comparison to the California requirements and the present knowledge of virus pathogen survivability.

12. It is the demonstrated intent of the EPA to bring groundwater pollution under control by 1983. Design engineers therefore need definition of the state requirements now.

In conclusion, it should be noted that all requests for Federal aid for construction after June 30, 1974 will have to consider land treatment as an alternative method of wastewater treatment in the cost effective analysis per Public Law 92-500. What is to be considered at the state level in such an analysis is presently undefined due to the lack of state control or state requirements. The preliminary EPA definition of "best practical treatment" for municipal effluents clearly indicates the intent to bring groundwater pollution under control by 1983. Waste treatment facilities to meet these requirements are now being designed. Therefore, the need for state requirements is now, and initiation of requirements cannot wait until after the current effort on stream standards is complete.

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REGULATORY AGENCY EXPERIENCE

by

Richard C. Rhindress

The following article is essentially the same as a paper by Mr. Rhindress titled, "Spray Irrigation - The Regulatory Agency View," in Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland, pp. 440-453, edited by William E. Sopper and Louis T. Kardos, copyright 1973 by the Pennsylvania State University Press, 215 Wagner Building, University Park, Pennsylvania 16802, and printed by permission.

SPRAY IRRIGATION - STATE REGULATORY AGENCY EXPERIENCE

by

Richard C. Rhindress*

Introduction:

The Bureau of Water Quality Management of the Pennsylvania Department of Environmental Resources is the regulatory agency concerned with pollution of waters within the state. Interest in land disposal for liquid wastes has been growing for quite some time. The increasingly stringent waste quality requirements for the discharge of waste water to streams, coupled with the upgrading of requirements for waste water treatment, plus the need for disposal in areas where streams are not readily accessible, have increased the importance of land disposal as one of the alternatives for the treatment and ultimate disposal of waste water.

A regulatory agency becomes aware of spray irrigation from two separate sources: 1) as a new technique, and 2) as an existing problem. As an environmental protection agency, we have an obligation to consider all techniques of waste disposal and to assess their applicability to various wastes and their impact upon the environment. The problems which we recognize with operating spray irrigation systems indicates that regulation is needed. The imposition of regulation, however, carries with it a responsibility to provide guidance in the construction and location of such facilities so that the potential user can develop a plan satisfactory to the regulatory agency. This paper will discuss the experiences of our Department with spray irrigation, our philosophy concerning the use of land disposal techniques, and some important concepts which we have included in our Spray Irrigation Manual.

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Definitions:

Spray irrigation must be defined. Under the general classification "land disposal of liquid wastes" there have been a number of confused interpretations. I believe the definition should be, "the application of waste water to the land surface for treatment and/or ultimate disposal, using aerial dispersion (sprinklers) to distribute the effluent evenly over the land surface".

However, there are a number of other land application methods which have been described as spray irrigation. These methods are mentioned here because we in a regulatory agency have found that we must deal with all of them. For the most part they are significantly different; they usually require different technologies, and different site selection. One is the technique of spreading; i.e., driving a tank truck across a field, letting the effluent spew from the open valve, sometimes with the benefit of a spreading device. Another variation is simply pipe discharge to a land area, often down a hillside. Third is the dumping of sewage treatment plant sludges and septic tank sludges onto the land surface, with or without the benefit of spreading or burial. Several persons have chosen to call the application of even these non-sprayable wastes to the land surface a form of spray irrigation. Somewhat more akin to classic spray irrigation is ridge and furrow irrigation, where the effluent is spread through a series of shallow trenches. One other technique is the use of surface flow, much on the idea of a standard sand filter where the effluent is allowed to flood an area and slowly sink in. None of these techniques are equivalent to spray irrigation; however, to some extent they are each valid techniques of land disposal for liquid wastes when properly executed.

This paper will deal only with spray irrigation - the disposal of waste water using a system of sprinklers, piping, and sprinkler nozzles.

Status and Regulation:

Pennsylvania presently has 75 spray irrigation installations in operation, and another 10 to 15 in planning and design stages.

The vast majority of these installations are relatively small, serving a single industry or small sewage treatment plant. Most are industrial waste applications. The largest number of these are in southeastern Pennsylvania, primarily in the Great Valley of Piedmont. Most of those which are presently under permit from the state have their permits because they have had pollution problems in the past. Although regulation has always been possible under the Pennsylvania Clean Streams Law, discharge to land surface was not clearly recognized as a discharge to the waters of the Commonwealth. It was considered similar to septic tank installations where the interpretation was that there was no direct discharge, therefore, no need for a permit. Spray irrigated water, of course, does discharge to ground water by percolating down through the soils, overburden, and rocks to the water table. Thus, it is definitely a discharge to the waters of the Commonwealth as defined by the Cleam Streams Law. A new program in which all spray irrigation installations are under permit was implemented with the publication of our spray irrigation manual and new regulations.

Groundwater Discharges:

At the same time that spray irrigation was becoming more prominent in Pennsylvania, we, like many other states, were becoming increasingly aware of the need to protect the quality of groundwater. Many septic systems are not, in fact, doing their job of renovating waste completely before it reached groundwater. Even the best sanitary landfills are recognized as sources of groundwater pollution. The spray irrigation project at Pennsylvania State University recognized the potential danger of spray irrigation to groundwater. Spray irrigation presents itself as a new technique for the treatment and ultimate disposal of waste water. It keeps waste water out of the streams but in doing so poses a very real threat to the quality of groundwater.

Unlike streams which can rebound from polluted conditions in a few years, groundwater does not experience the flushing action of streamflow. It does not experience the purifying effects of air, light, and biological organisms. Instead, it flows very slowly, receives little dilution, has essentially no oxygen to degrade pollutants, and flows through a medium where surface tension tends to hold pollutants in contact with it.

The general public seems to think that groundwater is clean, fresh and pure, and available wherever they may choose to drill a well. Fortunately, in Pennsylvania, groundwater has these properties.

Although both the law and the public attitude demand that groundwater remain drinkable, the conditions under which groundwater exists deny significant renovation. Therefore, our goal for groundwater quality is that it be usable for domestic purposes without treatment. It is imperative to preserve groundwater in its purest possible state.

Experience with the presently operating systems is generally poor. Two basic problem areas have been defined: (1) improper system design and (2) management errors.

Design Problems:

Design problems can be traced to several sources. Waste treatment plant designers have had little or no education or experience with this new technology. Attempts have been made to design systems without the understanding of the following basic tenets of spray irrigation design: First, spray irrigation is only an alternative method for disposal and treatment; Second, spray irrigation must be integrated into the environment rather than imposed upon it; and Third, as a dispersed operation, it is difficult to control and manage.

Spray irrigation, and land disposal, have been advocated as the panacea for wastewater disposal problems. The literature has been attractive and promising. Unfortunately, very little of the literature speaks to potential problems and the limitations on such a technique. Thus, the consulting engineer has often been given a false sense of security. Any proposal to disperse wastes into the environment must consider the multiple constraints that the environment will place upon it. It is only after a thorough consideration of these constraints that the decision can be made that spray irrigation should be used alternatively to some other method of disposal, such as direct discharge to a stream or groundwater. For example, one agricultural waste was applied to a field for a number of years until eventually the soils were so altered that infiltration and percolation ceased resulting in only sheet runoff. The fields were entirely ruined and will be a long time in recovery. The loss of these agricultural lands and the degradation of groundwater in the area has forced the industry into acquiring both new lands and a more expensive water source. In this case, it would have been far better to construct a direct pipeline to discharge to a creek over a mile away, or to treat the waste that the soil could accept it indefinitely.

When using the "living filter" for waste renovation, it is extremely important that the wastewater treatment and disposal system be matched to the environmental capabilities rather than impressed upon them. The addition of the extra hydraulic load will be a major stress on the soil system. Further, the requirement that the soil system act as a treatment facility in decaying and renovating the waste is an added stress. Most natural areas are in a state of dynamic equilibrium. This dynamic equilibrium has the ability to respond to passing stresses. However, when a stress is applied uniformly over long periods of time, equilibrium of the ecosystem is severely altered and may, in fact, be destroyed. For example, a soil with a fragipan layer will have a low permeability, and be capable only of accepting infiltrating water at normal precipitation rates. Dosages much above this result in waterlogged soils and runoff or swampiness. A second example: vegetative communities are adapted to a soil and its available moisture capacity. However, when spray irrigation applies a hydraulic stress the vegetative system must adapt with the disappearance of some species and introduction of others. In addition, streams below the site will have to adapt to a different flow regimen with a different chemical quality. All this is not necessarily bad, although in all but one of our experiences it has been. There are a few cases where environmental improvement may be realized through the stressing of the natural system. The assessment of the natural system, and the strains which it may show as the result of the new stresses are the prime subject matter of the Department's Spray Irrigation Manual.

For several reasons, lack of control has been a major problem in the design of spray irrigation systems. Consultants have usually ignored the valuable assistance available from the agricultural irrigation industry and have pieced together a system of pipes and valves from a catalog. But even here, differences are significant. Agricultural irrigation systems are designed simply to get water to a field. There is little concern about loss and leakage until it becomes a major problem. Agricultural systems are designed for ease of mobility and minimum maintenance. They are also used primarily for a short season. Conversely, wastewater irrigation systems are generally to be used year-round, must be watertight, should rarely be moved or moved only in conjunction with a carefully designed plan, and should be considered part of a long-term investment and installation. Also, in the agricultural sense the irrigation system is part of the profit-making package. It is carried on the profit side of the ledger books, whereas a waste disposal system is usually considered as a liability - as something that must be done- but which is not important to the success of the operation. Thus, it is rarely adequately budgeted. Further, it is usually located at a considerable distance from the plant and the base of company operations. Often, it is completely out of sight. Thus, routine operations such as checking for blockages and turning valves to change irrigated sections of the field are often neglected or relegated to a minor priority in company operations. The need for mechanical, electrical, or computer control of the operations becomes very important to successful continued routine operations. Automation of the controls has been entirely neglected at the majority of sites.

With any new technique, there is the problem of education regarding its values and execution. Poor design of the spray irrigation systems presently in existence is due to the unfamiliarity of the design consultants with a new technique, and the technologies and equipment necessary to carry it out. Training courses and symposia are needed to fill this educational hiatus.

Management Problems:

As mentioned above, management and maintenance are a second major problem area for spray irrigation. Management views spray irrigation, or any waste discharge area, as a liability and consistently relegates its consideration to a very low priority. Maintenance of a spray field is normally the responsibility of the bottom man on the maintenance staff. He, of course, is usually the man called upon to fill in whenever there is another important task to be done or when other employees may be absent. Spray fields can go unattended for considerable periods of time without causing a problem. A well operated spray field may, in fact, go for many months without appreciable maintenance problems. However, a single malfunction within the system can stress the ecosystem to its irreversible limit. Thus, it is important to have someone overseeing the field on a routine basis. Unfortunately, the usual experience in Pennsylvania has been that when inspectors inspect the site, they find evidence that no one has viewed the field or cared to make necessary repairs for quite some time.

Some common problems are contained in the following list:

1. Broken pipe
2. Leaky joints
3. Vegetation blocking sprinklers
4. Valves and/or sprinklers corroded in position
5. Rutted areas from vehicular traffic in wet soils
6. Clogged sprayers
7. Unharvested vegetation
8. Swampy conditions with ponding, with even aquatic flora and fauna
9. Vector problems - flies, mosquitos and rats
10. Anaerobic soil conditions producing swamp gases and other foul odors
11. Sheet runoff directly to adjacent streams
12. Waste material build-ups which inhibit plant growth - solids and greases

In addition, we find evidence of application of wastes which are non-degradable by the living filter system. These usually are toxic and may stress the field beyond recovery.

Solutions

The solutions to the problems with spray irrigation can come from three levels: the designer, the management, and the regulatory agency.

Design Solutions:

The primary solution for the problem of securing adequate designs is one of education. Engineering schools will have to recognize spray irrigation and other techniques of land disposal as valid waste management alternatives to be included in the curricula. For the continuing education of the graduate designer, the state regulatory agencies and professional societies will need to provide data and information on the new techniques. For the consultant, it is imperative at this time to go to those who have had experience both in the experimental development phases of land disposal and in the regulatory phases, and to learn from their experience. In addition, he should rely heavily upon the expertise available from the irrigation industry.

The following fifteen steps in the implementation of a spray irrigation installation were compiled by Lewis W. Barton, a spray irrigation consultant from Cherry Hill, New Jersey, and the author. They should serve as guidelines to anyone considering land disposal of liquid waste.

1. Before deciding on land disposal or spray irrigation, examine all the alternatives regardless of any apparent restrictions. Consider recycling of wastewater and direct discharge of treated wastes to a stream or to groundwater.

2. Weigh the motives for using land disposal. Is the desired result groundwater recharge? Agricultural irrigation? Green belt irrigation for fire protection? Or just plain final treatment and ultimate disposal? Or some combination?

3. Make a preliminary tour of the area (not just the site) with reference to suitable land, a route for the force main, sites for any pumping stations, field drainage, and lagoons for storage and flow equalization.

4. Study the effluent characteristics in detail. Assess their biodegradability by the living filter. Determine if any inorganics may be present which will not be removed by the soil system or which will poison the environment.

5. Select a site. Choose the best site available. Work with the local real estate man for an option or a lease. Work with hydrogeologist and a soil scientist in making this preliminary site selection. If there is any doubt about the acceptability of the land for spray irrigation use, negotiate options or leases on double an amount of land that you expect to use.

6. Map the selected site, showing contours, topography, soils, geologic structures, bedrock geology, streams, springs, wells, woodland areas, existing buildings, and present land use patterns for the designated acreage.

7. Choose sites for background and down-gradient groundwater quality monitoring.

8. Draft a preliminary proposal to the state regulatory agency which includes the above data and a preliminary design of the irrigation system. Secure their preliminary approval before proceeding with detailed design and further financial commitments.

9. Design the piping system, force main, and drainage; specify the hardware, field preparation, seeding, fertilizing, and agricultural maintenance.

10. Design and specify the automated programmers which will provide the central operating system, including pump signals and malfunction alarms.

11. Prepare and present the appropriate applications to regulatory agencies.

12. Bid the project and supervise construction. Establish and sample groundwater monitoring points before any other construction proceeds.

13. Prepare an operating manual that is simple and easy to follow. The operating manual is one of the most important pieces of the design engineer's task. It is also probably the most often neglected.

14. The design consultant should include in his contract monthly inspections of the operation for at least the

first year. These inspections should involve the consultant, management, the operator, and the regulatory agency.

15. Conduct quarterly inspections through at least the second year and even into the fourth and fifth year. These inspections will provide for continuing surveillance of system efficiency as well as for keeping the facility out of trouble with the regulatory agency.

Management Solutions:

From the management point of view the main steps which can be taken are the following:

1. Responsibility for spray field maintenance should be a full-time position. Interviews with a number of maintenance personnel have indicated that they consider their job a full-time project. Many have even suggested that we confer with management to help convince them of the amount of work necessary to keep a spray field functioning properly.

2. Put the effluent to some good use rather than just disposing of it; i.e., use it for irrigation where it will be an integral part of company operations.

3. Maintain a schedule of routine inspections.

4. Wherever possible install a buried or permanently set system. Experience has shown that movable systems either do not get moved or suffer from severe wear and tear.

5. Do not try to overload the system as production increases. Redesign or add to the system.

Regulatory Solutions:

Under present Pennsylvania law, the operator of a spray irrigation system which is disposing of sewage is required to obtain a certificate for sewage treatment plant operation. As another step in solving problems with spray irrigation systems, the state may have to extend certification to all spray field operators. In fact, it may be desirable to make "Spray Irrigation Field Operation" one of the classes of certification. Certification of spray field operators would give the regulatory agencies a stronger lever for improved operations, as withdrawal of the certificate for improper operation of the facility could put the operator out of work and place his company in violation of the law for not having a certified operator. The present condition of many spray fields within the Commonwealth suggest that this is a very likely path to follow. Again, the state has an obligation to provide information for training for spray field operator certification.

Other regulatory solutions include normal enforcement activity, design review and permitting, and the issuance of regulations and design standards.

Pennsylvania's Spray Irrigation Manual:

The fast rising number of spray irrigation installations and applications indicated that the Department of Environmental Resources should publish a manual or set of guidelines to site selection and system design. The manual includes instructions for the preparation of plans and reports for securing a permit. The manual has been published as the "Spray Irrigation Manual", Bureau of Water Quality Management Publication No. 31, and is available from the Bureau, located in the Fulton National Building, Third and Locust Streets, P. O. Box 2063, Harrisburg, Pennsylvania 17120.

It speaks to the consulting engineer and designer, the hydrogeologist and soil scientist. It also speaks to corporate management which may desire a spray irrigation system, and it often speaks to local officials and the land owner who knows very little of the technology or responsibilities involved. In speaking to a wide audience, it is both an educational tool and a design manual of sorts.

Writing a design manual is not entirely feasible since one of the main tenets of spray irrigation is that the system must be integrated into the environment rather than imposed upon it. And since the environment is extremely variable with the respect to groundwater, soils, geology, agriculture, and climate across the state, it is impossible to write a design book for all the possible variations in the environment. The assessment of these variations in the natural environment is what the manual is about. It speaks of concepts and their importance, and how each of them relates to the spray irrigation techniques of land disposal.

Basic criteria for spray irrigation have been set as a baseline from which judgement as to the acceptability of a site can be related. First, we insist that the entire waste handling package must be considered together: the pre-treatment, the storage, flow regulation, and the irrigation system. We emphasize that spray irrigation installations may be utilized only where the wastewater contains pollutants of such type and concentration that they can be satisfactorily treated through distribution to the soil mantle. Generally, only biodegradable wastes are acceptable, and the equivalent of secondary treatment must precede spray irrigation. However, we do allow for variability in earth materials, spray field use, and effluent constituents by stating that treatment requirements and performance criteria will have to be determined on a site-by-site basis. The prime consideration for site selection is the ability of the organic and earth materials to properly treat the waste.

One item which has caused considerable difficulty in drafting the spray irrigation manual has also proven to be a cause of much misunderstanding on the part of manual users. A large number of potential users for spray irrigation are industrial waste generators. These firms want to place a wide variety of biodegradable and non-degradable waste on their fields. Because of the wide latitude in constituents and concentrations, it would be impossible to write a spray irrigation manual which tries to speak to each of these wastes. It is far more practical to write a manual which is oriented toward the spray irrigation of sewage. Considerations of industrial wastes must then be made as they compare to sewage. Flows and concentrations are calculated and adjusted as percentages of normal sewage effluent.

Manual Organization:

The remainder of this paper will review important points and concepts in the Pennsylvania Spray Irrigation Manual, with a discussion of the reasoning behind some of the more important ones.

1. Certain criteria have been stated for the pretreatment of waste, application rates, acceptability of soils, agricultural practices, etc. These criteria have been set primarily as guidelines based upon spray irrigation of sewage effluent. However, throughout the manual there are numerous statements which demonstrate our intention to be flexible and willing to consider special applications and experimental designs. Although a number of spray irrigation sites have been in existence for many years, they have not benefited from a total environmental impact study before implementation and have usually resulted in some form of pollution. The lessons we have learned from them have been mostly negative--what not to do. Thus, we feel that this technique is still in the developmental stage and we are willing to permit justifiable experiments which vary from the basic criteria.

2. For most water pollution control facilities, construction-ready plans are required with the permit application. But, because of the need for land purchasing and extensive testing and drilling programs to determine subsurface geology and hydrology of the spray field, the Department has instituted the preliminary review to determine the general acceptability of the proposed fields before capital investments or detailed designs are made. For a preliminary review the applicant submits:

a. A short statement of the nature of the project and wasteload characteristics; information on location, soils and climatology.

b. Preliminary spray field design and operation plans.

If the Department grants preliminary approval of the spray fields, the applicant is notified and the complete permit application is then submitted. The preliminary approval does not permit construction or operation, nor does it assure approval of the complete design report. Issuance of the Department of Environmental Resources permit must precede construction and operation.

3. Factors for Consideration: A large section of the manual is devoted to detailed explanations of factors that must be considered as they affect the renovation of the wastewater and its movement to groundwater. We are very concerned that the best soils and geologic and hydrologic conditions are available for these processes, because once the wastewater reaches the water table only minimal renovation of the waste can be expected. Thus, extreme care must be exercised in assessing these environmental factors.

a. Earth Materials: The earth materials at a spray irrigation site may consist of soil, unconsolidated surficial deposits, weathered rock, and bedrock. Infiltrating wastewater will pass through these materials as it percolates to the water table. The earth materials near the land surface serve as a substrate for biological activity, while the unconsolidated material, weathered rock, and bedrock may react chemically and physically with the wastewater. The texture of these materials must be such that a direct rapid movement (short circuit) of the irrigated water to the groundwater does not occur. Coarse sands and gravels, open fractures in bedrock, and shallow soils are all examples of conditions which may result in short circuits. The earth materials should be moderately permeable and of a uniform quality so that they will provide slow but continuous downward movement of the infiltrating wastewater, yielding an adequate residence time for renovative reactions to take place. Detailed information on the geology, soils, and hydrology should be gathered.

b. Soils: In addition to meeting the various textural criteria, we urge that during the preparation of the field and installation of the equipment, particular attention be paid to avoiding disruption of the established soil profile as much as possible. Recommended application rates are based on the drainage and permeability of the soil, available moisture capacity, and the depth to the water table.

c. Geology: Once the irrigated wastewater leaves the soil zone and enters the zone of weathered and fresh bedrock, it is particularly important to know the structure of this rock. Are fractures present which will short-circuit the water directly to the water table or route it preferentially in directions which modify its assumed direct route to the water table? Will the waste react with the rock? The geology also affects the direction of movement within the water table as it flows through and away from the site.

d. Hydrology: Under most conditions in Pennsylvania, spray irrigated wastewater will recharge the local groundwater. With pretreatment, adequate dispersal of the waste, and properly chosen earth materials, the wastewater should be adequately treated during its passage through the zone of aeration to the water table. Thus, pollution of the receiving groundwater will be prevented. But once the wastewater reaches the water table only minimal renovation can be expected. Thus, to insure that the applicant has considered groundwater, its movement, and the potential result of its contamination, we have required that monitoring facilities be placed beneath the site and in all directions of groundwater flow away from the site. In addition, a background water quality well must be established where the quality of water flowing into the area may be assessed for comparison. A secondary benefit to monitoring is that the data provide a valuable tool to the operator in limiting potential legal action from nearby groundwater users. These legal actions often are the result of fear and ignorance, thus the acquisition and maintenance of background and discharge data is imperative to the operator. This data also provides the regulatory agency with data for evaluating the efficiency of the operation.

The submission of routine (generally, quarterly) reports of water quality data from both background and downgradient monitoring points is required. The exact chemicals that are reported are dependent upon the waste. For sewage, routine reports would include phosphate, ammonia nitrogen, nitrate nitrogen and MBAS.

e. Agricultural Practice: Although the Department has no specific requirements as to agricultural practice, other than the maintenance of the vegetative cover on the field, we recommend that the agricultural management coordinate closely with slopes of the field and the excess hydrologic loads. Research projects such as the one at Penn State University have demonstrated that agricultural product yield can be significantly improved using spray irrigation. Yet, relatively few farmers have been willing to accept the long-term commitment to use the wastewater that is necessary to implement a system. Self-serving industry systems apparently are working. But for municipal sewage systems, this raises the questions of the applicability of funding to the purchase or rental of spray fields, the desire of the community to get into agricultural land management, and an educational problem of convincing would-be lessees of the value of a long-term commitment.

f. Research: As stated above, existing spray irrigation facilities have demonstrated that the technique has not been adequately planned or managed in the past. Certain research facilities and a few showplace operations have demonstrated the value of spray irrigation both for wastewater treatment and disposal, and as an agricultural benefit. However, these projects have been limited in their scope and in the geographic diversity. There is an immediate need to expand research and demonstration projects to soils and environments which are less ideal than these research installations. New environmental constraints must be tested, and engineering techniques of field preparation and modification should be considered. We can integrate spray irrigation into a natural system and we can learn through applied research how this integration can take place, but spray irrigation cannot be impressed upon natural systems.

Summary:

Like all rapidly developing technologies waste treatment and disposal by spray irrigation has suffered from misunderstanding, inadequate design, mismanagement, and misapplication. Conversely, it shows great promise as a valuable alternative technique for waste water management. New research and regulatory action will help, but a new attitude of environmental understanding is necessary by all potential users. The key to this understanding is the acceptance of the basic tenet that spray irrigation must be integrated into the environment rather than imposed upon it.

SYMPOSIUM ON LAND TREATMENT OF SECONDARY EFFLUENT

PROGRAM

All sessions held in the Forum Room of the University of Colorado Memorial Center (UMC).

THURSDAY, NOVEMBER 8, 1973

8:00 a.m.	Registration - Alumni Hall, UMC
8:30 a.m.	Welcome and Introduction - J. Ernest Flack, University of Colorado, and Norman A. Evans, Colorado State University, Co-Directors of the Symposium
8:45 a.m.	"Significant Characteristics of Secondary Effluents for Land Treatment" - Edwin R. Bennett, Associate Professor, Department of Civil and Environmental Engineering, University of Colorado
9:20 a.m.	"Health Aspects of Effluent Irrigation" - Stuart G. Dunlop, Professor of Microbiology, University of Colorado School of Medicine, Denver
10:00 a.m.	Refreshments
10:20 a.m.	"Engineering Design Considerations" - Norman A. Evans, Director, Environmental Resources Center, Colorado State University
11:00 a.m.	"A Decade of Experience in Land Disposal of Municipal Wastewater" - William E. Sopper, Professor of Forest Hydrology, Pennsylvania State University
12:00 noon	Luncheon - Aspen Room, UMC
12:45 p.m.	Movie: "The Living Filter," Pennsylvania State University
1:15 p.m.	"Soil Transformations of Nitrogen in Effluents" - F. E. Broadbent, Professor of Soil Microbiology, Department of Soils and Plant Nutrition, University of California, Davis

1:55 p.m. "Soil Organisms" - Burns R. Sabey, Professor of Soil Science, Department of Agronomy, Colorado State University

2:30 p.m. Refreshments

2:50 p.m. "Trace Metals" - Roger M. Jorden, Assistant Professor, Department of Civil and Environmental Engineering, University of Colorado

3:20 p.m. "Food Chain Aspects of Effluent Irrigation" - James D. Menzies, Chief, Biological Waste Management Laboratory, Agricultural Research Center, USDA/ARS, Beltsville, Maryland

4:00 p.m. "Legal Aspects of Land Treatment of Secondary Effluent"- Raphael J. Moses, Attorney, Boulder, Colorado

FRIDAY, NOVEMBER 9, 1973

8:30 a.m. "A Survey of Land Application of Wastewater Effluents in the Rocky Mountain-Prairie Region" - Roger Dean, Graduate Student, Department of Civil and Environmental Engineering, University of Colorado

9:00 a.m. "Project Status and Research at Muskegon, Michigan" - Robert K. Bastion, Resident Research Representative, EPA Project Support Office, Muskegon, Michigan

9:40 a.m. Regulatory Agency Experience - Richard Rhindress, Commonwealth of Pennsylvania, Harrisburg, Pennsylvania

10:20 a.m. Refreshments

10:40 a.m. Panel on Regulation, Implementation and Constraints of Land Treatment of Secondary Effluent:

Robert Hagan, Chairman - Region VIII, EPA
Earl Balkum - Colorado Water Quality Control Commission
Kenneth Wright - Consulting Engineer, Denver
Donald Barnes - U.S. Corps of Engineers, Omaha District
Robert Wesdyke - Director of Public Works, City of Boulder, Colorado
Andy Kurtz - Director of Research, Colorado Farm Bureau, Denver

12:00 noon   Adjournment

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