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Wastewater Treatment And Reuse By Land Application - Volume I - Summary

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WASTEWATER TREATMENT AND REUSE

BY LAND APPLICATION

VOLUME I - SUMMARY

By

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ABSTRACT

A nationwide study was conducted of the current knowledge and techniques of land application of municipal treatment plant effluents and industrial wastewaters. Selected sites were visited and extensive literature reviews were made (annotated bibliography will be published separately).

Information and data were gathered on the many factors involved in system design and operation for the three major land application approaches: irrigation, overland flow, and infiltration-percolation. In addition, evaluations were made of environmental effects, public health consideration, and costs--areas in which limited data are available.

Irrigation is the most reliable land application technique with respect to long term use and removal of pollutants from the wastewater. It is sufficiently developed so that general design and operational guidelines can be prepared from current technology.

Overland flow was found to be an effective technique for industrial wastewater treatment. Further development is required to utilize its considerable potential for municipal wastewater treatment.

Infiltration-percolation is also a feasible method of land application. Criteria for site selection, groundwater control, and management techniques for high rate systems need further development.

This report is submitted in fulfillment of Contract 68-01-0741 by Metcalf & Eddy, Inc., Western Regional Office, under the sponsorship of the Environmental Protection Agency. Work was completed as of April 1973.

PERSPECTIVE

Municipal and industrial wastewaters have been applied to the land by many modes and for many purposes throughout the country. Crop irrigation with municipal effluent is practiced nationwide but most frequently in the western states. Land application of industrial wastewater was pioneered in states such as Iowa, Minnesota, Wisconsin, and Ohio. Many infiltration-percolation systems exist from California to New York and Massachusetts. Land application has been and continues to be a feasible alternative to surface water discharge in many cases.

Land application of wastewaters was given a substantial role in the Federal Water Pollution Control Amendments of 1972 to implement the "national goal that discharge of pollutants into navigable waters be eliminated by 1985." At several points in the law the encouragement of land application is emphasized. Thus, land application techniques must be considered as alternatives to conventional and advanced wastewater treatment in the prevention of surface water pollution.

Many times land application is interpreted in a narrow sense to mean "spray irrigation" or "percolation ponds." Land application actually covers any technique involving interaction between soil and wastewater in which use is made of the assimilative capacity of the soil system. In this report, land application techniques have been grouped into the categories of irrigation, overland flow, and infiltration-percolation.

IRRIGATION

Irrigation is the application of water to the land to meet the growth needs of plants either by surface or spray application, and is the predominant land application technique. The use of wastewater for irrigation is attractive for several reasons, including the following: (1) it is a positive alternative to advanced wastewater treatment and surface water discharge; (2) it can result in economic return on the sale of crops; (3) it can be part of a water conservation and reuse program; (4) it can provide fire protection by forested hillside spraying; and (5) it can foster the preservation and enlargement of greenbelts and open space. This last factor is emphasized in the 1972 Federal Amendments by the statement that "waste treatment management which combines open space and recreational considerations with such management" shall be encouraged.

The principal limitations to the practice of irrigation are the considerable land area required, its relatively high cost, and its relatively long distance away from large urban sources of wastewater. In some cases certain wastewater characteristics, such as high salt or boron concentrations, may preclude irrigation of many crops, especially in the arid Southwest.

Limitations to irrigation for health reasons are less severe. Adequately disinfected wastewater should not pose a danger to health when it is used for irrigation. Adequate disinfection requires complete and rapid mixing and a specified contact time of the disinfectant in the effluent. Any aerosolizing of inadequately disinfected municipal wastewater--be it in an activated sludge plant, a river outfall, or in a spray field--produces some risk to human health, and all of these risks should be minimized. Spraying downward or horizontally (especially with low nozzle pressure), adequate disinfection of the sprayed wastewater, and buffer zones all function to increase the safeguards.

OVERLAND FLOW

Overland flow or spray-runoff is a treatment method in which wastewater is sprayed onto grassed slopes and allowed to run off through the vegetated litter. Overland flow is subject to the same types of limitations as irrigation, but it can be done on relatively impermeable soil and a gently sloping terrain. The technique has considerable potential for treatment of municipal wastewater. At Ada, Oklahoma, comminuted municipal wastewater has been sprayed at low pressures in an experimental overland flow system. The effluent is of a quality approaching that from tertiary treatment. In addition to a relatively low construction cost, the system produces no sludge, which is an aspect with great appeal.

Operating costs are considerably lower than for conventional plus advanced waste treatment because of the relative simplicity of operation. Further research and development of this highly promising approach is required in the area of phosphorus removal, loading rates, and applicability to cold climates.

Overland flow has the advantages of avoiding groundwater degradation, providing economic return through the growth and sale of hay, and providing a high quality effluent suitable for industrial or agricultural reuse applications. Although it cannot be used as a complete direct recycle of wastewater to the land, the runoff will be of high quality and can be directly recycled by any other land application approach.

INFILTRATION-PERCOLATION

Infiltration-percolation is an approach to land application in which large volumes of wastewater are applied to the land, infiltrate the soil surface, and percolate through the soil pores. Benefits from infiltration-percolation of municipal wastewater include the following: (1) it is an economic alternative to surface water discharge; (2) it is a treatment system with nearly complete recovery of renovated water; and (3) it is a method of repelling salt water intrusion into aquifers. The high rate systems pioneered in the Southwest have the further benefit of requiring very little land area.

The major limitations of the process are in connection with groundwater effects. The primary concern is that influent nitrogen is converted to the nitrate form, which is leached to the groundwater. If the groundwater zone becomes anaerobic or anoxic, conversion of sulfates to hydrogen sulfide may also be a problem.

Less critical limitations are that: (1) phosphorus retention in the soil matrix may be neither complete nor of long duration; (2) suitable soils must be highly permeable yet must contain enough fine particles to ensure adequate renovation; and (3) to prevent groundwater degradation, the aquifer receiving the water must be monitored and controlled for high rate systems.

INDUSTRIAL WASTEWATER

The potential use of land application for industrial wastewaters is nearly as great as that for municipal wastewater. In addition to the food processing, pulp and paper, and dairy industries which have used land application extensively, such diverse industries as tanneries and chemical plants have also used land application successfully. In general, for plants located in rural or semirural areas that produce wastewaters containing mainly organic components, land application offers great potential. For industries producing toxic or high inorganic content wastewaters, land application probably offers small promise. There are so many modifications and combinations of land application methods for any given industrial wastewater that no sweeping limitations can be stated solely on the basis of a type of industry.

In general, industries are more amenable than municipalities to including new technology in their plans for wastewater management, which partially explains their use of the overland flow approach. Industries have allowed the soil matrix to provide a greater amount of treatment than have municipalities and have tended to search out the limits of loading for soil systems. It is therefore likely that new improvements or modifications to the common methods will continue to come from industries as well as from soil scientists and researchers.

Because land application of wastewaters has attracted considerable attention and controversy within professional, academic, and governmental circles, the purpose of this report is to focus on the principles involved in its use and to place both the positive aspects or benefits and the limitations in perspective.

CONTENTS

FIGURES

TABLES

TABLES (Continued)

ACKNOWLEDGMENTS

A great deal of cooperation has been received during the conduct of this study. Metcalf & Eddy, Inc., gratefully acknowledges the cooperation of the personnel of all of the cities and companies interviewed.

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This project was conducted under the supervision and direction of Franklin L. Burton, Chief Engineer, and Charles E. Pound, Project Manager. The report, comprising Volumes I and II, was written by Ronald W. Crites, Project Engineer, Robert G. Smith, and David C. Tedrow. Ferdinand K. Chen assisted in the literature search.

SECTION I

CONCLUSIONS

Conclusions derived from this study of the present state-of-the-art of land application of wastewater are presented in four categories: (1) general, (2) irrigation, (3) overland flow, and (4) infiltration-percolation.

GENERAL

- Irrigation, overland flow, and infiltration-percolation are the three general approaches used for the land application of municipal and industrial wastewater.

- In actual practice, numerous modifications and combinations of land application techniques have proven successful.

- Factors to be considered in site selection for a land application system include both those involving economic and land use planning and such technical factors as soil type and drainability, topography, groundwater levels and quality, underlying geologic formations, wastewater characteristics, and pretreatment.

- Primary, secondary, and intermediate quality municipal effluents have all been applied successfully to the land. Industrial wastewaters from food processing, pulp and paper, dairy, tannery, and chemical plants, often with only screening as pretreatment, also have been applied successfully.

- Effective management and monitoring are fundamental requirements for the successful operation of land application systems.

- Land application systems, in many cases, have been started as an expedient, and available technology was not incorporated in the planned operation and management of the systems.

- There is a paucity of quantitative information in the literature on the removal efficiencies of soil systems with respect to wastewater constituents.

IRRIGATION

- Irrigation of croplands, forest, and landscaping with wastewater, either by spraying, ridge and furrow, or flooding techniques, is developed sufficiently so that general design and operational guidelines can be outlined from currently available technology.

- Provided that municipal wastewaters are adequately disinfected, there are no indications of serious health hazards caused by spray irrigation.

- Irrigation is the most reliable land application approach evaluated on the basis of direct wastewater recycling, renovation, long term use, and minimization of adverse environmental effects.

OVERLAND FLOW

- Overland flow, or treatment by spray-runoff (also known as "grass filtration"), has been demonstrated to be an effective technique for industrial wastewater treatment. Further development is required to utilize its considerable potential for treatment of municipal wastewater.

- Overland flow has distinct advantages over irrigation for heavy, slightly permeable soils or rolling terrain.

- Nitrogen, suspended solids, and BOD removals are excellent, and adverse environmental effects appear to be minimal. Systems have not been in operation long enough to determine long term effects or expectant period of use.

INFILTRATION-PERCOLATION

- Infiltration-percolation is another feasible approach to land application of municipal or industrial wastewater, and several high rate systems have shown success.

- Criteria for site selection, groundwater control, and management techniques for high rate systems need further development.

- Infiltration-percolation, when practiced as a land disposal approach, is less reliable than irrigation from the standpoint of wastewater renovation and long term use.

SECTION II

RECOMMENDATIONS

The following recommendations, which have been developed as a result of this study, are grouped into three categories: (1) implementation of land application projects, (2) development of standard practices, and (3) research needs.

IMPLEMENTATION OF LAND APPLICATION PROJECTS

- Land application approaches, where feasible, should be considered as alternatives in developing wastewater management plans.
- When evaluating land application approaches for treatment as compared to conventional or advanced waste treatment processes, factors such as economics, simplicity of operation, and degree of renovation should be considered as well as the potential water reuse and the best use to be made of the land.
- To gain public acceptance and support for land application projects, realistic implementation programs, including public relations, should be developed to accompany any planning activities for wastewater management.

DEVELOPMENT OF STANDARD PRACTICES

- General evaluation procedures for design and management of land application systems should be developed by the EPA to ensure successful system operations.
- The operation of many existing systems can be enhanced through analysis of successful practices at other locations, evaluation of the key factors important to management, and initiation of monitoring of water quality changes throughout the system.

- Design and operation practices in land application are so dependent on local conditions that a detailed design or operations manual would likely stifle, rather than advance, the state-of-the-art.

RESEARCH NEEDS

Although a great deal is known, many technical questions must be answered before wastewater renovation by land application can become a scientific undertaking. Research must be initiated to define the environmental interactions of soil, groundwater, air, and wastewater. The priorities for research by subject area, as established in this study, are presented on the following list.

General Application

- Climatic investigations should be undertaken to define simultaneously surface soil and ambient air temperatures for the United States. Such information would be useful in determining the annual period in which vegetation and active bacterial metabolism might be maintained by wastewater application.

- Virological investigations should be undertaken where municipal wastewater is applied by spraying. Aerosol drift and infectivity and survival of viruses in aerosols, on vegetation, and in soil need investigation.

Irrigation

- The long term effects on soils, groundwater, and crops of (1) salt accumulation and (2) buildups of trace elements and heavy metals should be defined.

- There are several large municipal wastewater irrigation systems that have been operating for 50 to 60 years, and these could be investigated for long term effects.

- Studies on the effects of irrigation on the environment, such as those underway at Pennsylvania State University and those planned for Muskegon, Michigan, should be continued.

- Additional studies should be conducted to determine if crops grown under wastewater irrigation differ substantially in quality from crops grown using fresh water irrigation and other sources of plant nutrients.

Overland Flow

- Research on the application of the overland flow technique to municipal wastewater such as that at Ada, Oklahoma, should be continued.

- Field studies should be conducted to evaluate cold weather effects when using overland flow for industrial and municipal wastewater.

- A correlation between BOD loading and treatment efficiency should be investigated for various climates, lengths of runoff travel, types of grasses, and field slopes.

- The mechanisms of nitrogen removal for overland flow should be studied. Removals resulting from crop uptake, denitrification, and ammonia volatilization should be quantified, with the objective of optimizing nitrogen removal.

- The applicability of using grasses, such as Italian rye and common bermuda grass, as cover crops under various climatic conditions should be investigated. Such grasses have proven successful for irrigation.

- The effects of harvesting and removing hay for various grasses on BOD removal efficiency should be investigated.

- The removal of phosphorus as affected by loading cycles, length of runoff travel, and type of grass should be investigated.

Infiltration-Percolation

- Operating procedures and conditions that are necessary for optimum nitrogen removal should be identified and documented.

- The effect of nitrification in the soil on BOD removal, TDS leaching, and the degree of subsequent denitrification should be documented by field investigations.

- Studies on the effect of vegetation on nitrification and denitrification in the soil should be continued.

- The removal efficiency for refractory organics should be determined for high rate loadings, and the health hazard of any such material reaching the groundwater should be investigated.

- Environmental effects, such as increased leaching of inorganic compounds and increased groundwater hardness, should be investigated for high rate systems underlain by limestone formations. High organic loadings will result in considerable carbon dioxide production which may dissolve significant quantities of calcium and magnesium as well as lower the pH.

SECTION III

INTRODUCTION

Land application of wastewater is an old practice--it was used by the Greeks in Athens and was begun in the United States over 100 years ago. Hundreds of communities throughout the nation currently use one form or another of land application with varying degrees of success. The application of wastewater to the land brings into play elements of climate, air, land, vegetation, and water so that understanding and analysis of its many aspects requires a multidisciplinary approach.

To gain a clearer and more comprehensive understanding of the phenomena and problems associated with land application of wastewater, the United States Environmental Protection Agency in June 1972 awarded a contract to Metcalf & Eddy, Inc., for an evaluation of the state-of-the-art. For this purpose a nationwide study was conducted of systems in actual operation together with an extensive literature review. The information derived from the study was used to categorize current types of systems and to provide data necessary for system design and operation.

PURPOSE AND SCOPE OF REPORT

Current knowledge on land application of municipal and industrial wastewater has been gathered and is reported in two volumes.

The purpose of this volume (Volume I) is to summarize the state-of-the-art for engineers, planners, managers, and decision makers. Detailed engineering information and supporting operational experiences are presented in an expanded Project Report, printed separately as Volume II. The information presented in these two volumes is intended as a report of current knowledge--not as a statement of design guidelines.

The scope of this report is limited to a presentation and discussion of those methods of land application of wastewater that use the soil system to provide renovation to the wastewater. Thus, deep well injection and surface evaporation ponds are not considered in depth. Land application of municipal or industrial waste sludge was specifically omitted from the study. The report contains sufficient information on land application to provide a basis for effective management decisions.

Separate sections are included in this volume on land application approaches, wastewater and site characteristics, system design and operation, environmental effects, public health considerations, and cost evaluations.

INFORMATION SOURCES AND DEFINITION OF TERMS

Information Sources

Information was gathered from (1) the literature, (2) site visits and interviews, and (3) previous experience. The literature has been reviewed extensively, and abstracts of articles reviewed will be published separately by the EPA. Cited reports, studies, and other pertinent literature have been arranged alphabetically, numbered sequentially, and listed in Section X. Where reference is made to this material in the text, the appropriate number is enclosed in brackets.

Actual on-site visits were made to nine installations in the United States and one in Canada. The information obtained was given to the American Public Works Association (APWA) which, in turn, cooperated in making available data from their fact-finding survey. That survey was conducted during the same time period of this study and covered several hundred United States sites and several foreign ones with the object of establishing an inventory of practices at selected existing facilities. In addition, information on several sites was available prior to the conduct of this study. A listing of all sites visited and used in this study plus those contacted by APWA are given in Section XIII.

Definition of Key Terms

Because several key terms will be used extensively in this report, they will be defined here. A complete glossary and list of abbreviations is in Section XII.

Irrigation--Application of water to the land to sustain the growth of plants.

Overland flow--Wastewater treatment by spray-runoff (also known as "grass filtration") in which wastewater is sprayed onto gently sloping, relatively impervious soil planted to vegetation. Biological treatment occurs as the wastewater flow contacts biota in the ground cover vegetation.

Infiltration-percolation--An approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores.

Loading rates--The average amount of liquid or solids applied to the land over a fixed time period taking into account periodic resting.

Application rates--The rates at which the liquid is dosed to the land, usually in in./hr.

Conventional wastewater treatment--Reduction of pollutant concentrations in wastewater by physical, chemical, or biological means.

Sewage farming--Originally involved the transporting of sewage into rural areas for land disposal. Later practice included reusing the water for irrigation and fertilization of crops.

HISTORICAL BACKGROUND

Wastewater application to the land was practiced in Athens in the B.C. period [34] and the recorded history of irrigation has been traced to Germany in the sixteenth century, A.D. [11]. The practice of sewage farming spread to England in the 1700s and to the United States in the 1870s [46]. Rafter [45] and Mitchell [38] present data on European practice in England, at Paris, France, at Berlin, Germany, and at Moscow, Russia, in the 1890s to 1920s. In surveys conducted in the United States in 1895 [46] and 1935 [20], over 100 systems were found across the country. Historical data on a few of the more notable operations in the world are listed in Table 1. Unless otherwise noted the data are for the dates given in the first column of the table. Many of these facilities, including the ones at Mexico City and Melbourne, Australia, are still in operation.

Table 1. Historical Data on Sewage Farming

Date	Location	Description	Wetted area, acres	Flow, mgd	Average loading, in./wk	Reference
	Non-United States					
1559	Bunzlau, Germany	Sewage farm	--	--	--	11
1861	Croydon-Beddington, England	Sewage farm	420	4.5	2.8	35
1864	South Norwood, England	Sewage farm	152	0.7	1.2	35
1869	Berlin, Germany	Sewage farm	27,250[a]	150[a]	1.4	35
1875	Leamington Springs, England	Sewage farm	400	0.8	0.5	45
1880	Birmingham, England	Sewage farm	1,200	22	4.7	45
1893	Melbourne, Australia	Irrigation	10,376[b]	50[b]	1.2	30
	Melbourne, Australia	Overland flow	3,472[b]	70[b]	5.2	30
1902	Mexico City, Mexico	Irrigation	112,000[b]	570[b]	1.3	--
1923	Paris, France	Irrigation	12,600	120	2.5	35
1928	Cape Town, South Africa	Irrigation	--	--	--	8
	United States					
1872	Augusta, Maine[c]	Irrigation	3	0.007	0.6	46
1880	Pullman, Illinois[c]	Irrigation	40	1.85	12.0	46
1881	Cheyenne, Wyoming	Irrigation	1,330[d]	7.0[d]	1.3	--
1887	Pasadena, California	Irrigation	300	--	--	35
1895	San Antonio, Texas	Irrigation	4,000[a]	20[a]	1.3	35
1896	Salt Lake City, Utah	Irrigation	180	4	5.7	46
1912	Bakersfield, California	Irrigation	2,400[d]	11.3[d]	1.2	--
1928	Vineland, New Jersey	Irrigation	14	0.8	14.7	37

a. Data for 1926.
b. Data for 1971.
c. Abandoned around 1900.
d. Data for 1972.

SECTION IV

LAND APPLICATION APPROACHES

Irrigation, overland flow, and infiltration-percolation are the three basic approaches to land application. These three approaches are shown schematically on Figure 1. The wastewater may be applied to the land by spraying or surface techniques in any of the three approaches. Municipal wastewater, usually treated to secondary quality, has been applied mainly by irrigation. Some municipalities have practiced infiltration-percolation; however, the only municipal installation identified in this study using overland flow is at Melbourne, Australia [22]. Industrial wastewater, generally screened or settled, has been applied using all three approaches with the choice usually depending upon the soil type of the nearby land. Food processing, pulp and paper, dairy, and tannery wastewaters have been used for irrigation and infiltration-percolation. The few overland flow systems in the United States are for food processing wastewaters.

The major characteristics of irrigation, overland flow, and infiltration-percolation are listed in Table 2. A discussion of each characteristic is included for each approach. Factors involved in selecting among these approaches are presented following the discussion of each approach.

IRRIGATION

Irrigation is the most widely used type of land application with over 300 U.S. communities practicing this approach, according to the 1972 Municipal Wastewater Facilities Inventory conducted by the EPA. Aspects of irrigation covered in the following discussion include the controlling factors in site selection and design, the methods of irrigation, loading rates, management and cropping practices, and the expected wastewater renovation or removals of wastewater constituents.

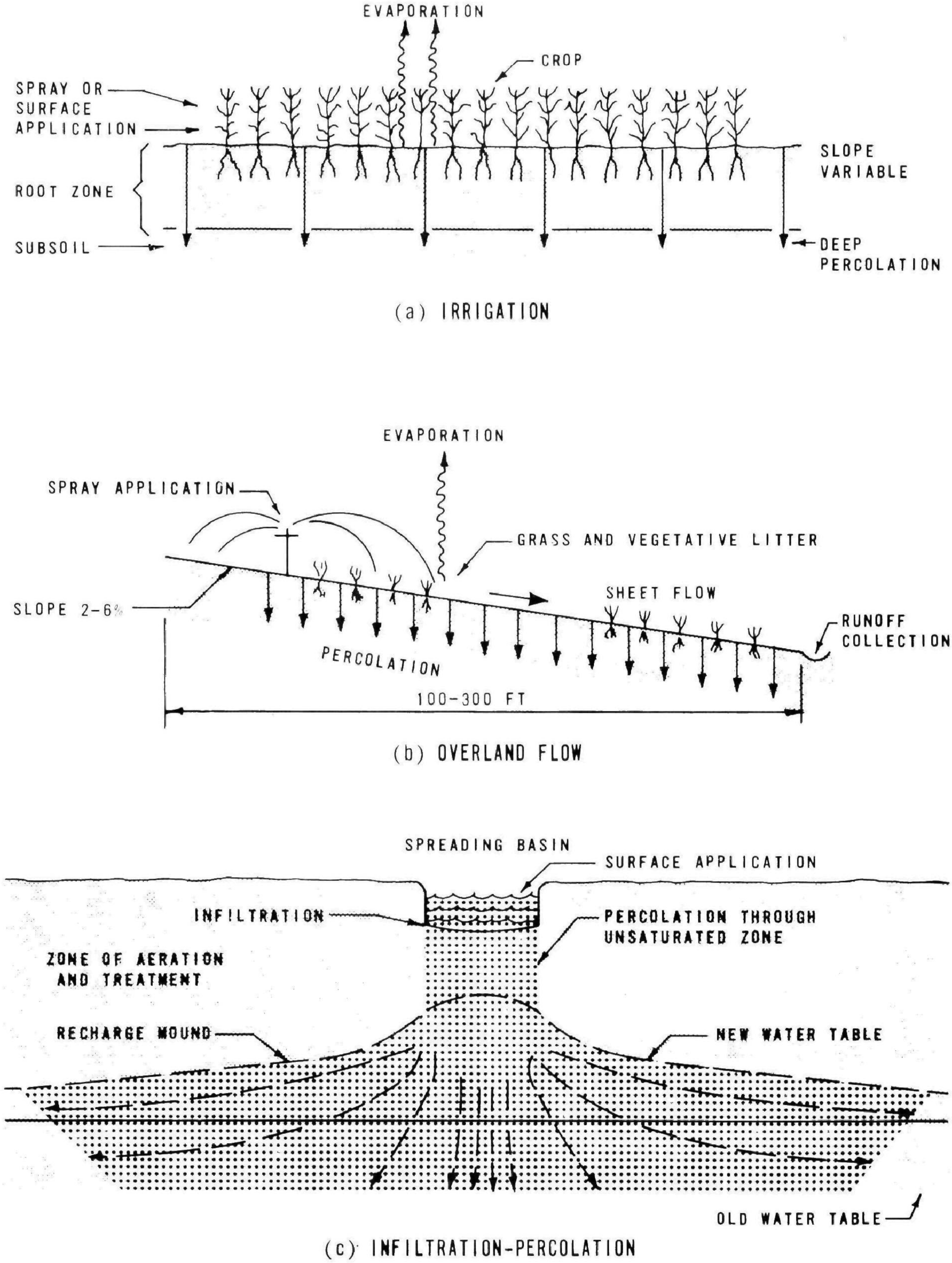


FIGURE 1
LAND APPLICATION APPROACHES

Table 2. Comparative Characteristics of Irrigation, Overland Flow, and Infiltration-Percolation Systems[a]

	Type of Approach		
Factor	Irrigation	Overland flow	Infiltration-percolation
Liquid loading rate[b]	0.5 to 4 in./wk	2 to 5.5 in./wk	4 to 120 in./wk
Annual application	2 to 8 ft/yr	8 to 24 ft/yr	18 to 500 ft/yr
Land required for 1-mgd flow	140 to 560 acres plus buffer zones	46 to 140 acres plus buffer zones	2 to 62 acres plus buffer zones
Application techniques	Spray or surface	Usually spray	Usually surface
Soils	Moderately permeable soils with good productivity when irrigated	Slowly permeable soils such as clay loams and clay	Rapidly permeable soils, such as sands, loamy sands, and sandy loams
Probability of influencing groundwater quality	Moderate	Slight	Certain
Needed depth to groundwater	About 5 ft	Undetermined	About 15 ft
Wastewater lost to:	Predominantly evaporation or deep percolation	Surface discharge dominates over evaporation and percolation	Percolation to groundwater

a. Adapted from [62].

b. Irrigation rates of 4 in./wk are usually seasonal; yearly maximum loads of 8 ft/yr would average about 2 in./wk.

Factors in Site Selection

The major factors involved in site selection are: the type, drainability, and depth of soil; the nature, variation of depth, and quality of groundwater; the location, depth, and type of underground formations; the topography; and considerations of public access to the land. Climate is as important as the land in the design and operation of irrigation systems. In site selection, however, it is not a variable since most economically feasible sites will be located within a limited transmission distance from the source.

The major factors and generalized criteria for site selection are listed in Table 3. Soil drainability is perhaps the primary factor because, coupled with the type of crop or vegetation selected, it directly affects the liquid loading rate. A moderately permeable soil capable of

Table 3. Site Selection Factors
and Criteria for Effluent Irrigation

Factor	Criterion
Soil type	Loamy soils preferable but most soils from sands to clays are acceptable.
Soil drainability	Well drained soil is preferable; consult experienced agricultural advisors.
Soil depth	Uniformly 5 to 6 ft or more throughout sites is preferred.
Depth to groundwater	Minimum of 5 ft is preferred. Drainage to obtain this minimum may be required.
Groundwater control	May be necessary to ensure renovation if water table is less than 10 ft from surface.
Groundwater movement	Velocity and direction must be determined.
Slopes	Up to 15 percent are acceptable with or without terracing.
Underground formations	Should be mapped and analyzed with respect to interference with groundwater or percolating water movement.
Isolation	Moderate isolation from public preferable, degree dependent on wastewater characteristics, method of application, and crop.
Distance from source of wastewater	A matter of economics.

infiltrating approximately 2 in./day or more on an intermittent basis is preferable. In general, soils ranging from clay loams to sandy loams are suitable for irrigation. Soil depth should be at least 2 feet of homogenous material and preferably 5 to 6 feet throughout the site. This depth is needed for extensive root development of some plants and for wastewater renovation. For cropland, agricultural extension service advisers or adjacent farmers should be consulted. For forest or landscape irrigation, university specialists should be consulted.

The minimum depth to groundwater should be 5 feet to ensure aerobic conditions [50]. If the native groundwater is within 10 to 20 feet of the surface and site drainage is poor, control procedures, such as underdrains or wells, may be required. If the groundwater quality is significantly different from the renovated water quality, control procedures may again be necessary to prevent intermingling of the two waters.

For crop irrigation, slopes should be limited to about 10 percent or less depending upon the type of farm equipment to be used. Forested hillsides up to 30 percent in slope have been spray irrigated successfully [53].

A suitable site for wastewater irrigation would preferably be located in an area where contact between the public and the irrigation water and land is controlled. Landscape irrigation, however, often makes this condition difficult.

Methods of Irrigation

There are three basic methods of effluent irrigation: spray, ridge and furrow, and flood. Spray irrigation may be accomplished using a variety of systems from portable to solid-set sprinklers [40]. Ridge and furrow irrigation consists of applying water by gravity flow into furrows. The relatively flat land is groomed into alternating ridges and furrows with crops grown on the ridges. Flood irrigation is accomplished by inundation of land with several inches of water. The type of irrigation system to use depends upon the soil drainability, the crop, the topography, and the relative economics.

Loading Rates

Important rates are liquid loading in terms of inches per week, and nitrogen loading in terms of pounds per acre per year. Organic loading rates are less important provided that an intermittent application schedule is followed.

Liquid loadings may range from 0.5 in./wk to 4.0 in./wk depending on the soil, crop, climate, and wastewater characteristics. Crop requirements generally range from 0.2 to 2.0 in./wk, although a specific crop's water needs will vary throughout the growing season. Typical liquid loadings are from 1.5 to 4.0 in./wk. Although wastewater irrigation rates have ranged in some cases up to 7 or 8 in./wk, the upper limit for irrigation, on the basis of this study, should be 4 in./wk. Therefore, the division between irrigation and infiltration-percolation systems as defined in this study is 4 in./wk.

Nitrogen loading rates have been calculated because of nitrate buildup in soils, underdrain waters, and groundwaters. To minimize such buildup, the pounds of total nitrogen applied in a year should not greatly exceed the pounds of nitrogen removed by crop harvest. For example, an effluent containing 20 mg/L of nitrogen applied at 5 ft/yr would equal a nitrogen loading rate of 270 lb/acre/yr. If the irrigated crop takes up only 150 lb/acre/yr, most of the excess nitrogen will leach to the subsoil and ultimately to the groundwater. In most cases, with loamy soils, the permissible liquid loading rate will be the controlling factor; however, for more porous, sandy soils the nitrogen loading rate may be the controlling factor.

Management and Cropping Practices

Crop selection can be based on several factors: high water and nutrient uptake, salt or boron tolerance, market value, or management requirements. Grasses with high year-round uptakes of water and nitrogen and low maintenance requirements are popular choices. To ensure the die-off of anaerobic bacteria, an aerobic zone in the soil is necessary. A drying period ranging from several hours each day to several weeks is required to maintain aerobic soil conditions. The length of time depends upon the crop, the wastewater characteristics, and the length of the application period. A ratio of drying to wetting of about 3 or 4 to 1 should be considered a minimum.

Wastewater Renovation

Renovation of the wastewater occurs generally after passage through the first 2 to 4 feet of soil. Monitoring to determine the extent of renovation is generally not practiced; when it is practiced, however, removals are found to be on the order of 99 percent for BOD, suspended solids, and fecal coliforms. As irrigation soils are loamy with considerable organic matter, the heavy metals, phosphorus, and viruses are retained in the soil by adsorption and other mechanisms. Nitrogen is taken up by plant growth, and if the crop is harvested, the removals can be on the order of 90 percent.

OVERLAND FLOW

Overland flow or spray-runoff (see Figure 1) has been used for some time at Melbourne, Australia, where it is known as grass filtration. Although it is being tried experimentally on municipal wastewater at Ada, Oklahoma, it has been more completely developed for use in the United States on food processing wastewater. Site selection factors, design loadings, management practices, and renovation to be expected will be discussed here.

Factors in Site Selection

Soils with limited drainability, such as clays and clay loams, are suited to overland flow. The land should have a slope between 2 and 6 percent [10] and a very smooth surface so that the wastewater will flow in a sheet over the ground surface. Slopes greater than 6 percent can be used successfully but may introduce problems, such as erosion, and difficulties in using farm machinery. Grass is planted to provide a habitat for the bacteria which provide the renovation. As runoff is expected, a suitable means of final disposal should be provided.

Because groundwater will not likely be affected by overland flow, it is of minor concern in site selection. The groundwater table should be deeper than about 2 feet, however, so that the root zone is not waterlogged.

Climatic constraints have not been thoroughly tested, but industrial systems are being operated in California, Texas, Ohio, Pennsylvania, Indiana, and Maryland. In an industrial system designed in 1972 at Glenn, Michigan, an attempt will be made to use overland flow when the ground is frozen. At Melbourne, Australia, overland flow is used during the mild winters when evaporation and rainfall are low [30].

Design Loadings

Systems are generally designed on the basis of liquid loading rates, although an organic loading or detention time criterion might be developed in the future. The process is essentially biological with a minimum contact time between bacteria and wastewater required for adequate treatment. Liquid loading rates used in design have ranged from 2.5 to 5.5 in./wk, with a typical loading being 4 in./wk for food processing wastewater. At Ada, Oklahoma, the optimum loading for comminuted municipal wastewater has been around 4 in./wk, while at Melbourne, Australia, the loading rate is 5.2 in./wk for untreated municipal wastewater.

Management Practices — Important management practices are: maintaining the proper hydraulic loading cycle, maintaining an active biota and a growing grass, and monitoring the performance of the system. Hydraulic loading cycles, or periods of application followed by resting, have been found to range from 6 to 8 hours of spraying followed by 6 to 18 hours of drying for successful operations. Periodic cutting of the grass with or without removal is important, but the effects on organic oxidation have not been fully demonstrated. Monitoring is needed to maintain loading cycles at optimum values for maximum removal efficiencies.

Wastewater Renovation — Overland flow systems at Melbourne, Australia, and Ada, Oklahoma, using municipal wastewater, and at Paris, Texas, using industrial wastewater, have been monitored to determine removal efficiencies. The expected ranges based on results at these sites are BOD and suspended solids removals of 95 to 99 percent, nitrogen removals of 70 to 90 percent, and phosphorus removals of 50 to 60 percent. Removal of solids and organics is by biological oxidation of the solids as they pass through the vegetative litter. Nutrient removal mechanisms include crop uptake, biological uptake, denitrification, and fixation in the soil.

INFILTRATION-PERCOLATION

The infiltration-percolation approach, illustrated in Figure 1, has been used with moderate loading rates (4 to 60 in./wk) as an alternative method to effluent discharge into surface waters. High rate systems (5 to 10 ft/wk) have been designed for groundwater recharge. These latter systems have been carefully designed and monitored, and most of this discussion, concerning site selection, design loadings, management practices, and wastewater renovation, will deal with them.

Factors in Site Selection

Soils with infiltration rates of 4 in./day to 2 ft/day, or more, are necessary for successful use of the infiltration-percolation approach. Acceptable soil types include sand, sandy loams, loamy sands, and gravels. Very coarse sand and gravel is not ideal because it allows wastewater to pass too rapidly through the first few feet where the major biological and chemical action takes place.

Other factors of importance include percolation rates, depth, movement and quality of groundwater, topography, and underlying geologic formations. To control the wastewater after it infiltrates the surface and percolates through the soil matrix, the subsoil and aquifer characteristics must be known. Recharge should not be attempted without specific knowledge of the movement of the water in the soil system and the groundwater aquifer.

Design Loadings

As indicated, there are two ranges of liquid loading rates, moderate and high, depending upon the loading objective. For direct recycling of wastewater to the land by infiltration-percolation, liquid loading rates range from 4 to 60 in./wk [26]. Organic loading rates are generally of secondary importance for moderate rate systems.

For high rate systems, liquid loadings range from 5 to 10 ft/wk. Organic loading rates range from 3 to 15 tons of BOD/acre/yr. Municipal high rate infiltration-percolation systems generally pretreat the wastewater to secondary quality to maintain high liquid loading rates. Industries have tended to rely more on the assimilative capacity of the soil, and thus have generally used pretreatment only to avoid operational problems.

Management Practices

Important management practices include maintenance of hydraulic loading cycles, basin surface management, and system monitoring. Intermittent application of wastewater is required to maintain high infiltration rates, and the optimum cycle between inundation periods and resting periods must be determined for each individual case. Basin surfaces may be bare, covered with gravel, or vegetated. Each type requires some maintenance and inspection for a satisfactory operation. Monitoring, especially of groundwater levels and quality, is essential to system management.

Wastewater Renovation

Removals of constituents by the filtering and straining action of the soil are excellent. Suspended solids, fecal coliforms, and BOD are almost completely removed in most cases. Nitrogen removals are generally poor unless specific operating procedures are established to maximize denitrification. Phosphorus removals range from 70 to 90 percent depending on the physical and chemical characteristics of the soil that influence retention of phosphorus.

OTHER LAND APPLICATION APPROACHES

There are several other approaches to land application, including subsurface leach fields, deep well injection, and evaporation ponds. Such techniques are generally limited in their applicability. Leach fields are prevalent in rural areas for small systems and are likely to remain so. Deep well injection provides no substantial renovation to the wastewater. Pretreatment must be to a high quality, and geologic conditions must be such that the water will not spread to other aquifers. Evaporation ponds also have limited applicability because of the large land requirements and climatic constraints.

RELIABILITY OF APPLICATION APPROACHES

Reliability of land application involves considerations of long term use, wastewater renovation, and minimization of adverse environmental impacts. Unlike mechanical treatment facilities, land application facilities do not have a fixed expected useful life. The useful life depends upon factors such as the management, the soil, the climate, and the wastewater characteristics. Also, changing land use needs and wastewater management objectives affect the expected life of a system. These factors, as they affect the reliability of irrigation, overland flow, and infiltration-percolation, will be discussed here.

Irrigation

Wastewater irrigation has proven to be reliable in terms of long useful life. Examples are the systems at Cheyenne, Wyoming, operating since 1881; at Fresno, California, operating since 1891; and at Bakersfield, California, operating since 1912.

As indicated previously, wastewater renovation as a result of irrigation is quite high. With proper management, degradation of groundwater and health risks can be avoided. Irrigation has had many positive effects on the environment, such as improving soil conditions and providing wildlife habitats. It can therefore be concluded that irrigation is the most reliable approach to land application of wastewater of the methods investigated.

Overland Flow

Less is known about the useful life of an overland flow system than of an irrigation system. The system at Melbourne, Australia, has been operating successfully for many years as a wintertime alternative to irrigation. The oldest operating system in this country, however, has been treating industrial wastewater for less than 20 years. From the evidence in the literature, an indefinite useful life may be possible if effective management is provided.

Removal efficiencies are also quite good for overland flow. As it is a biological process, a period of intermediate treatment will occur before the biota are fully established. Renovation of wastewater by overland flow is only slightly less complete than that for irrigation, the major exception being a rather low removal of phosphorus.

Adverse environmental effects from overland flow systems should be minimal. As a runoff flow is created, it must be either stored and reused or discharged to a surface watercourse. Because infiltration into the soil is slight, the chances of affecting groundwater quality are minimal. Buildups of salts may occur over time, depending on the operation, but these would have little effect on other aspects of the environment.

Infiltration-Percolation

The useful life of an infiltration-percolation system will be shorter, in most cases, than that for irrigation or overland flow. This is caused by higher loadings of inorganic constituents, such as phosphorus and heavy metals, and the fact that these constituents are fixed in the soil matrix and not positively removed. Therefore, exhaustion of the fixation capacity for phosphorus and heavy metals will be a function of the loading rate and the fixation sites available. At Lake George, New York, phosphorus retention on the basis of recent monitoring in some percolation beds appears to have been exhausted through 10 feet of soil. The system had been operating about 35 years at moderate rates of 7 to 15 in./wk [3].

The degree of wastewater renovation achieved by infiltration-percolation varies considerably with the soil characteristics and management practices. Nitrogen removals up to 80 percent have been obtained by careful management of the hydraulic loading cycle at Flushing Meadows, Arizona (2 to 3 weeks' wetting, 2 weeks' drying). Overall nitrogen removal, taking into account the high nitrate concentration flushed to the groundwater at the beginning of inundation, averages 30 percent [6]. Removals of phosphorus and heavy metals are also generally less than for irrigation.

From the standpoint of environmental effects, infiltration-percolation has demonstrated the least amount of reliability of the three approaches. Most systems that have been monitored and managed properly, however, are quite reliable in this regard. Infiltration-percolation also has the advantage of providing a tertiary level of treatment at a relatively low cost.

APPROACH SELECTION

Irrigation, overland flow, and infiltration-percolation have many common aspects, but many different factors must be considered in selecting among them. Approach selection will be discussed from the standpoint of (1) the 1972 Federal Amendments to the Water Pollution Control Act of 1970, (2) wastewater management objectives, and (3) technical factors.

1972 Federal Amendments

Land application was given a substantial role in the Federal Water Pollution Control Amendments of 1972. Elimination of the discharge of pollutants to navigable waters by 1985 is the stated goal of those amendments. Land treatment and the recycling of potential wastewater pollutants through irrigation must be given due consideration in wastewater management plans.

Wastewater Management Objectives

Objectives for wastewater management have been listed in Table 4 along with the capabilities of each approach in meeting them. There are other possible objectives and those that might be specific to industrial wastewaters have not been included. As indicated, irrigation provides considerable renovation; however, the major portion of the wastewater applied is lost to evapotranspiration. Unless excess irrigation water is applied and underdrains or recovery wells are used, the approach is impractical as a means of reclaiming wastewater.

Technical Factors

Physical aspects of the available land, such as soil type, underground formations, and ground slope, will influence the approach selection. Other technical factors include wastewater characteristics and flow rates, climate, and whether the flow remains constant throughout the year. For seasonal flows, such as those from canneries, the selection of the overland flow system, like any biological system,

Table 4. Comparison of Irrigation, Overland Flow, and Infiltration-Percolation for Municipal Wastewater

Objective	Type of approach: Irrigation	Overland flow	Infiltration-percolation
Use as a treatment process with a recovery of renovated water	Impractical	50 to 60% recovery	Up to 90% recovery
Use for treatment beyond secondary:			
1. For BOD and suspended solids removal	90-99%	90-99%	90-99%
2. For nitrogen removal	Up to 90%[a]	70-90%	0-80%
3. For phosphorus removal	80-99%	50-60%	70-95%
Use to grow crops for sale	Excellent	Fair	Poor
Use as direct recycle to the land	Complete	Partial	Complete
Use to recharge groundwater	0-30%	0-10%	Up to 90%
Use in cold climates	Fair[b]	--[c]	Excellent

a. Dependent upon crop uptake.

b. Conflicting data--woods irrigation acceptable, cropland irrigation marginal.

c. Insufficient data.

must take into account an annual startup period. Soil classification, an important independent variable, has been graphed against liquid loading rates as the dependent variable. The resultant combinations have been blocked out, as shown on Figure 2, for the typical ranges for each land application approach. These are not intended to be a design guideline but rather a general aid in the process of approach selection.

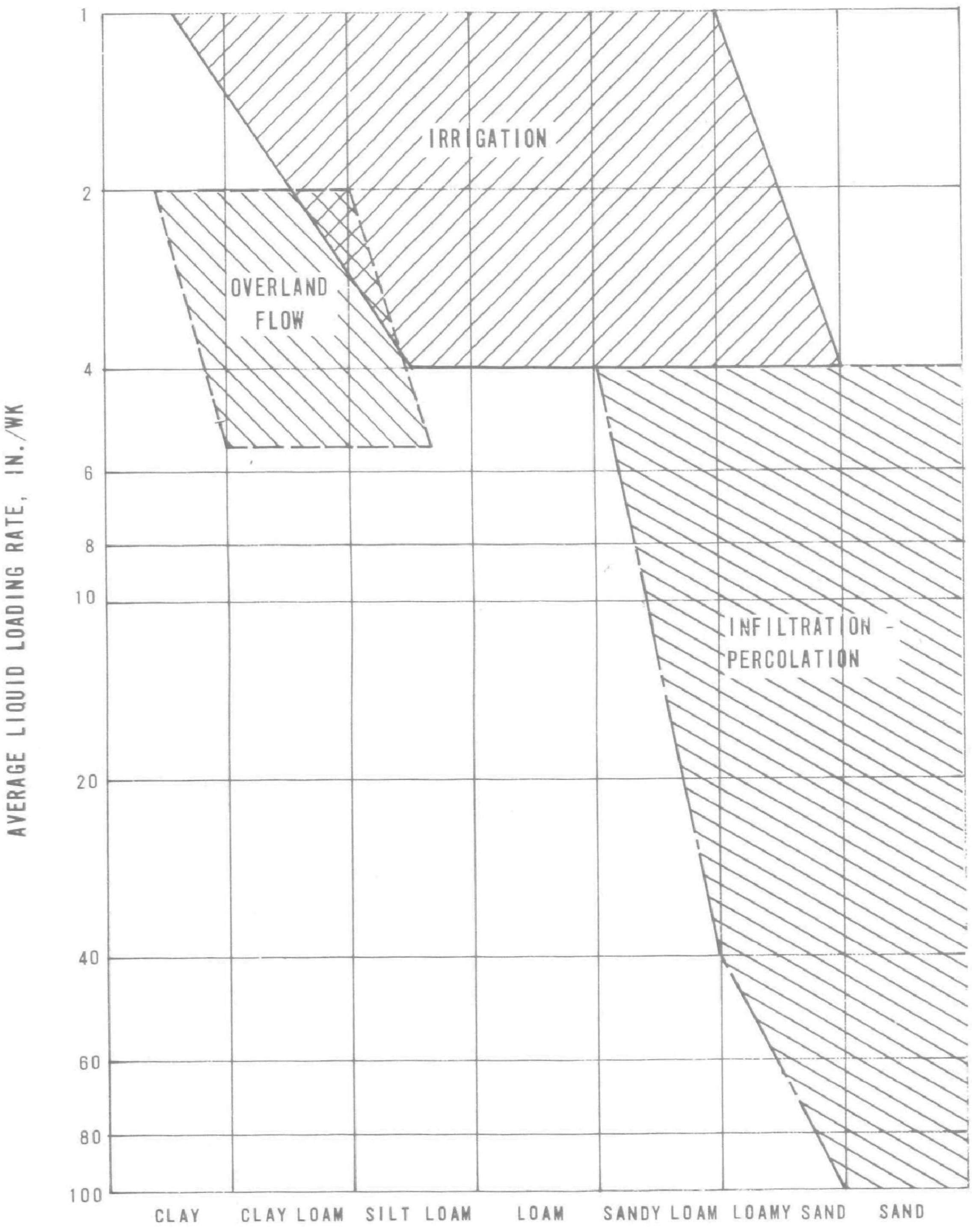


FIGURE 2
SOIL TYPE VERSUS LIQUID LOADING RATES
FOR DIFFERENT LAND APPLICATION APPROACHES

SECTION V

WASTEWATER AND SITE CHARACTERISTICS

Knowledge of the characteristics of both the wastewater to be applied and the site where the application will take place is critical to successful design and operation of land application systems. In this section, municipal and industrial wastewater characteristics that affect land application methods will be discussed. The factors involved in site selection for individual land application approaches have been discussed in Section IV. The discussion here will present overall characteristics of sites successfully used for land application.

WASTEWATER CHARACTERISTICS

The characteristics of municipal and industrial wastewater may be classified as physical, chemical, and biological. Municipal wastewater characteristics are listed in Table 5 for (1) untreated wastewater, (2) a typical secondary effluent, and (3) effluents that have been applied to the land. The degree of pretreatment normally given by secondary treatment processes can be seen by comparing columns 1 and 2. A discussion of the effects of conventional wastewater treatment on characteristics is presented at the end of this subsection.

Industrial wastewaters contain many of the constituents found in municipal wastewaters, but their characteristics vary widely by industry, by product, and even by processing technique. A typical industrial wastewater does not exist; however, ranges or maximum values of characteristics of industrial wastewaters that have been successfully applied to the land are listed in Table 6. Important characteristics will be discussed here by classification.

Physical Characteristics

The most important physical characteristic of wastewater is its total solids content. The solids include floating, suspended, colloidal, and dissolved matter.

Table 5. Municipal Wastewater Characteristics

Constituent	Untreated sewage (1)	Typical secondary treatment effluent (2)	Actual quality applied to land (3)
	mg/L (except as noted)		
Physical			
Total solids	700	425	760-1,200
Total suspended solids	200	25	10-100
Chemical			
Total dissolved solids	500	400	750-1,100
pH, units	7.0±0.5	7.0±0.5	6.8-8.1
BOD	200	25	10-42
COD	500	70	30-80
Total nitrogen	40	20	10-60
Nitrate-nitrogen	0	--	0-10
Ammonia-nitrogen	25	--	1-40
Total phosphorus	10	10	7.9-25
Chlorides	50	45	40-200
Sulfate	--	--	107-383
Alkalinity ($CaCO_3$)	100	--	200-700
Boron	--	1.0	0-1.0
Sodium	--	50	190-250
Potassium	--	14	10-40
Calcium	--	24	20-120
Magnesium	--	17	10-50
Sodium adsorption ratio	--	2.7	4.5-7.9
Biological			
Coliform organisms, MPN/100 ml	10^6	--	$2.2\text{-}10^6$

Sources:

Column 1 – Medium strength [34].
Column 2 – [2].
Column 3 – Range of values obtained from site visits.

Table 6. Characteristics of Various Industrial Wastewaters Applied to the Land

Constituent	Food processing	Pulp and paper	Dairy
BOD, mg/L	200-4,000	60-30,000	4,000
COD, mg/L	300-10,000	--	--
Suspended solids, mg/L	200-3,000	200-100,000	--
Total fixed dissolved solids, mg/L	1,800	2,000	1,500
Total nitrogen, mg/L	10-50	--	90-400
pH	4.0-12	6-11	5-7
Temperature, deg F	145	195	--

The suspended solids are very important because they have a tendency to clog the soil pores and coat the land surface. Other physical characteristics are temperature, color, and odor. Temperature is not a great problem for municipal wastewater effluents because they have a fairly even temperature, 50 deg F to 70 deg F, which is not harmful to soil or vegetation. High temperature (above 150 deg F) industrial wastewaters, such as spent cooking liquors from pulping operations, can sterilize the soil, thus precluding the growth of vegetation and reducing the renovative capacity of the soil mantle.

Color is of minor importance in municipal wastewater; however, some industrial wastewaters (spent sulfite liquor) have significant color, which can be transmitted through the soil [5].

Odors in wastewater are caused by the anaerobic decomposition of organic matter. Although hydrogen sulfide is the most important gas formed from the standpoint of odors, other volatile compounds such as indol, skatol, and mercaptons also cause noxious odors. These odors are often released to the atmosphere by spraying or aerating.

Chemical Characteristics

Important chemical characteristics have been listed in Table 5. TDS (total dissolved solids) are important because, at least for the fixed or mineral TDS, the soil does not provide a positive long term removal mechanism. With irrigation, evaporation will concentrate the salts in the soil, and the subsequent high concentrations may be injurious to plants, or may be leached to the groundwater.

The pH and alkalinity are generally of concern only for industrial wastewater. For example, cannery wastewater often exhibits wide fluctuations in pH, and neutralization may be required.

Organic matter as measured by the COD and degradable organics as measured by the BOD will be effectively removed by land application. If the COD is much greater than the BOD, or if the wastewater contains organic matter that is starchy or fibrous, the organics may build up and cause clogging of the soil pores.

Nitrogen is important because, converted to the nitrate form, it can pass easily through the soil matrix. Total nitrogen is the sum of the organic, ammonium, nitrite, and nitrate form concentrations. Nitrogen can be removed by land application through plant uptake with harvest and by denitrification.

Phosphorus and heavy metals are easily fixed in most soils by precipitation and adsorption. Sandy soils provide fewer sites in the soil matrix for adsorption; hence phosphorus retention capacities are relatively short. Concentrations of heavy metals, such as copper and zinc, can build up to phytotoxic levels in time, depending on the soil type and method of operation.

High sodium concentrations relative to calcium and magnesium concentrations can cause deflocculation of clay soils and reduce the permeability. For such soils "hard water makes soft land and soft water makes hard land" [63].

Biological Characteristics

Municipal wastewater contains many bacteria and viruses. Industrial wastewaters are not free of microorganisms, but usually do not have enteric bacteria. The presence of enteric pathogens is often ascertained by testing for the coliform group. E. Coli (*Escherichia coli*) are used as indicator organisms because they are present in the digestive tract of man and are more numerous and more easily tested for than pathogenic organisms. Aerobacter, a common soil bacteria, exhibits many of the same responses as E. Coli, and the differences must be tested for using the confirmed test for coliforms. If fecal coliforms are not distinguished from soil coliforms, the efficiency of the soil system in removing fecal coliforms will be indeterminate.

Effects of Pretreatment on Wastewater Characteristics

Conventional wastewater treatment begins with preliminary operations, such as screening and sedimentation. Effluent from these operations, referred to as primary, has had the bulk of large objects, grit, and floatable and settleable material removed. Sedimentation typically removes 50 to 65 percent of the suspended solids, 25 to 40 percent of the BOD, and many pollutants such as Ascaris eggs.

Secondary treatment consists of biological oxidation by activated sludge or trickling filters, or physical-chemical treatment by precipitation, filtration, and carbon adsorption. Effluent is low in suspended and organic matter and readily disinfected. Most dissolved inorganics are not affected by secondary treatment. Secondary treatment does provide an additional removal of bacteria and viruses by flocculation and secondary sedimentation.

Disinfection, the selective destruction of disease-causing organisms, may be accomplished using heat, ozone, bromine, iodine, or, most commonly, chlorine. Adequate disinfection requires complete and rapid mixing and a minimum contact time. The presence of suspended solids hinders the process of disinfection; therefore, secondary effluent is more readily disinfected than primary effluent. The number of coliform organisms can be reduced by disinfection techniques from 10^6 organisms per 100 ml to less than 2.2 organisms per 100 ml.

SITE CHARACTERISTICS

Important site characteristics for land application systems are climate, soil, topography, geologic formations, and groundwater.

Climate

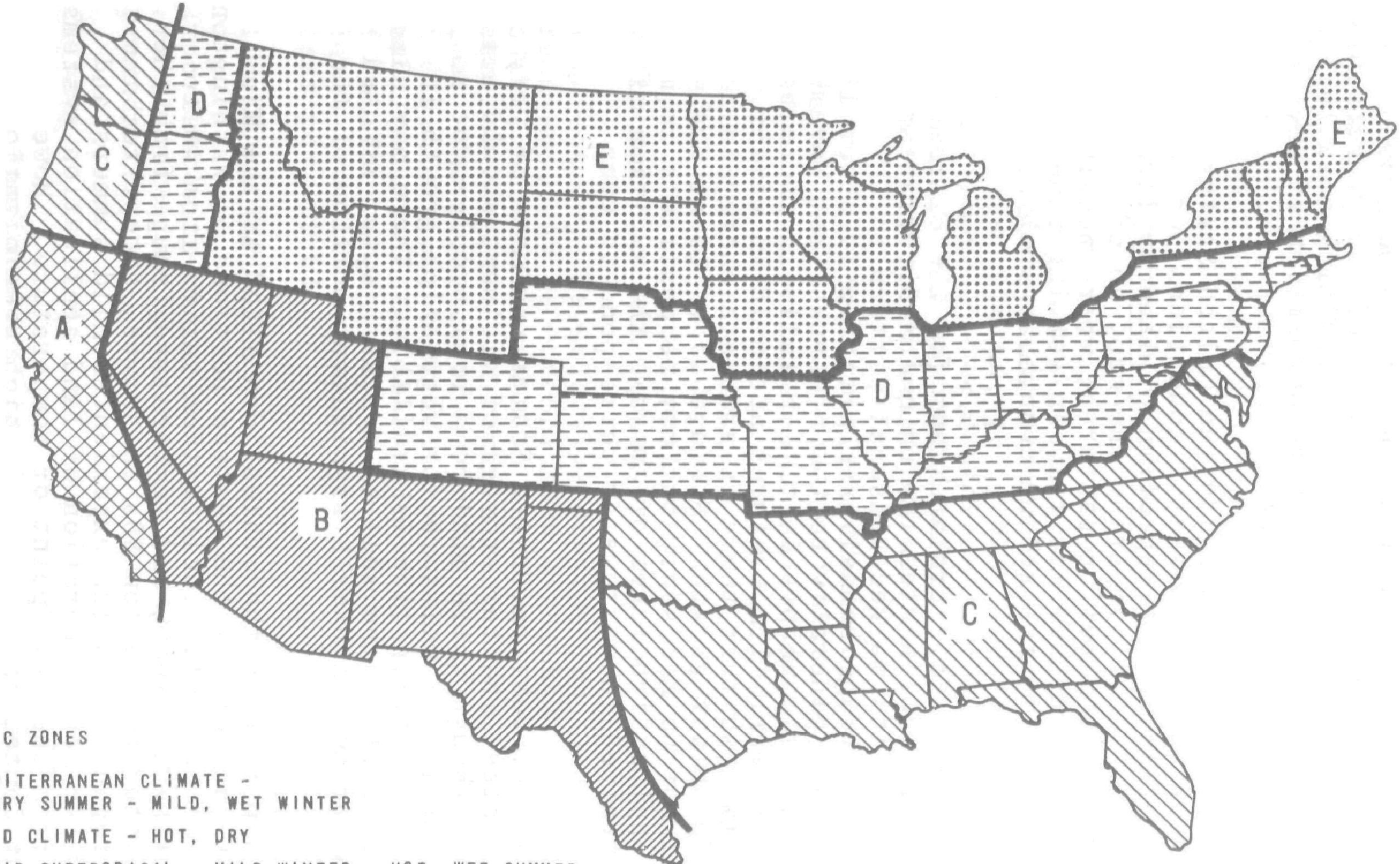
In most land application systems, the vegetation cover is a major factor in the success of the system. Both the rate of growth of vegetation and the rate of decomposition of organics in the effluent are regulated, in large part, by the energy available. Most places in the United States have sufficient energy for the development of a good ground cover of vegetation, although low levels of energy receipts in the winter in northern areas, with resulting cold temperatures, will limit the rate of decomposition of any solids removed from the effluent.

It has been possible to subdivide the United States into 5 zones or areas in which climatic conditions pose quite similar constraints to the operation of land application systems (Figure 3). In preparing the map, an effort was made to simplify distribution patterns; where possible, state boundaries were used for ease in setting zone boundaries even though climates seldom change at such political subdivisions.

Zone A, which covers California except for the extreme southeastern part, delineates the unique Mediterranean climatic region with its marked seasonal pattern in precipitation. Average annual precipitation is about 15 to 25 inches confined generally to the 6 months from November to April; practically no precipitation falls in the other 6 months of the year. Temperatures are mild in winter and hot in summer so that there is adequate energy in almost all seasons for plant growth. Storage of effluent due to freezing will not be necessary but may be desirable to maximize summer application rates or to make the addition of nutrients contained in wastewater correspond to crop requirements.

Zone B covers southwestern United States, an area of very hot, arid climates. Winter storage of effluent should not be a concern although there will be a real problem due to the lack of sufficient moisture for vegetation growth in all seasons unless irrigation is available. There may also be problems of salt in the soil if brackish water is used in irrigation or constitutes a significant portion of the effluent.

Zone C covers primarily the states identified as the Mid- and Deep South as well as the western portions of Washington and Oregon. In general, precipitation varies from 40 to 60 inches during the year, and temperatures range from the low 40s in winter to the low 80s in summer, except for the Washington-Oregon area which experiences mild summers and winters. Twelve-month operation of land application systems is possible from the standpoint of temperature. However, the well distributed and relatively high precipitation eliminates the need for extended periods of irrigation which are desirable from the standpoint of wastewater application.



CLIMATIC ZONES

A MEDITERRANEAN CLIMATE - DRY SUMMER - MILD, WET WINTER

B ARID CLIMATE - HOT, DRY

C HUMID SUBTROPICAL - MILD WINTER - HOT, WET SUMMER (WASHINGTON, OREGON AREA MILD, MOIST SUMMER)

D HUMID CONTINENTAL - SHORT WINTER, HOT SUMMER

E HUMID CONTINENTAL - LONG WINTER, WARM SUMMER

FIGURE 3
GENERALIZED CLIMATIC ZONES FOR LAND APPLICATION

Zone D covers the middle tier of states running eastward from Colorado to southern New England and the eastern portions of Washington and Oregon. The climates are marked by moderately cold winters (average temperatures in the 20s), hot summers (average temperatures in the mid-70s), and precipitation well distributed through the year. Some irrigation might be needed in the western portion for vegetation development but little would be needed in the east. Winter temperatures are cold enough so that effluent storage for several months or so may be necessary.

Zone E covers the northernmost tier of states. Very cold winters with warm summers and adequate moisture for vegetation exist. Winter operations are quite limited because the cold winter temperatures, with ice and snow, require the storage of effluent for anywhere from 3 to 6 months.

Because the water needs of plants are affected by the air temperature, humidity, inclination of the sun, and wind velocity, climate will affect irrigation and overland flow more than infiltration-percolation. The United States Weather Bureau collects and publishes a great deal of important climatic data and should be consulted for local records.

Soil

The important soil characteristics are its drainability, which is related to soil structure and texture as well as geological constraints, and soil renovative capacity, which is related to texture and chemical characteristics.

Drainability — Drainability is the ability of a soil to allow water to infiltrate the surface and percolate through the soil pores. Light, coarse textured, granular soils are usually well drained and are most suitable for infiltration-percolation. On the other hand, heavy, fine textured soils, such as clays, are usually poorly drained and are most suitable for overland flow.

Soils may be considered well drained if an application of 2 in./day will infiltrate into the ground within 24 hours. In determining drainability local farmers, agronomists, or agricultural extension service experts should be consulted. The standard percolation test results should not be relied upon for design purposes because they represent conditions of constant inundation, in a localized pit, without taking into account lateral flow within the soil.

Renovation Capacity — Nearly all soil systems are efficient in removing organic matter. This removal is a result of the filtering action of the soil followed by biological oxidation of the organics. Fine textured soils, such as clays, and soils with considerable organic matter, such as loams, will also retain wastewater constituents through mechanisms such as adsorption, precipitation, and ion exchange. The fixation (includes all three mechanisms mentioned) capacity of a soil can be determined in laboratory or pilot investigations. Excellent sources for detailed descriptions of the renovation capacity of soil are Bailey [48] and McGauhey and Krone [28]. The Soil Conservation Service of the U.S. Department of Agriculture has extensive soil maps that include data on physical characteristics such as soil type and texture to a depth of 5 feet.

Topography and Geologic Formations

Topography will influence the land application approach and the method of wastewater application. Rolling hills can be used for overland flow or spray irrigation depending on the soil. Infiltration-percolation generally requires flat land, although in Wisconsin a ridge and furrow system was carved into a 5 percent slope using a series of terraces [4].

Cropland irrigation requires relatively flat land in order to use farm machinery, but forested hillsides up to 30 percent in slope have been used for land application by spraying [53].

The drainability of a soil can be restricted or enhanced by underground formations. Underlying rock or impermeable layers may serve as a barrier to percolating water. On the other hand, a fine textured soil can be underlain by sand and gravel layers or fractured limestone layers which are more permeable than the top soil. As indicated in Section IV, infiltration-percolation site selection requires the thorough mapping of underlying formations. The U.S. Geological Survey is the major source for these data.

Groundwater

The depth, movement, and quality of groundwater are important considerations in determining site characteristics. For infiltration-percolation the location and possible control by pumping of aquifers are major factors in site selection. As indicated in Section IV, the chances of irrigation and overland flow affecting groundwater quality are moderate and slight, respectively. The major concern with irrigation is that the groundwater level be maintained below the root zone to protect the vegetation. A minimum depth to groundwater has not been determined for overland flow.

SECTION VI

SYSTEM DESIGN AND OPERATION

Land application systems, in many cases, have been started as an expedient and available technology did not contribute to the planned operation of the system. This is especially true for moderate sized and small systems. Those features that have proved successful at different locations and are worthy of note are discussed in this section.

IRRIGATION

Irrigation systems in operation in 1972 range from new spray systems at St. Petersburg, Florida, and Ephrata, Washington, to a 90-year old flood system at Cheyenne, Wyoming. The design and operation of municipal and industrial irrigation systems will be described here.

System Design

Important criteria in design are wastewater quality and pretreatment, loading rates, drying period, crop selection, distribution, and provisions for seasonal change.

Wastewater Quality and Pretreatment – For municipal wastewater irrigation, pretreatment is generally required by state regulations. Irrigation with untreated wastewater is forbidden in many states, and the quality of wastewater is often dictated for irrigation of edible crops. In most of the cities surveyed, secondary treatment is provided prior to irrigation. Minimum pretreatment for industrial wastewaters has generally consisted of screening to remove large solids. This was found to be required for efficient operation of sprinkler systems.

Loading Rates – As indicated in Section IV, typical liquid loading rates are 1.5 to 4.0 in./wk. Liquid loadings should be based on the consumptive use of the crops irrigated. Irrigation practiced with wastewater having TDS concentrations above 750 mg/L (especially in the southwest) should include applying wastewater in excess of crop requirements to leach the salts out of the root zone. The determination of liquid loadings should be made from previous operational experience, experience with closely similar conditions, consultation with agricultural experts, or from pilot work.

Nitrogen loading rates should not greatly exceed the nitrogen taken up annually by the crop. For example, Reed canary grass can take up 226 lb/acre of nitrogen per year based on 3.65 tons/acre/yr (additional uptake data in Volume II). Organic loading rates for industrial wastewaters of 150 to 200 lb BOD/acre/day without adverse effects have been reported [43].

Resting Period – As a result of a 10-year study at Pennsylvania State University, a loading cycle of spraying for 12 hours followed by resting for 6 days has been established [41]. Hill [19] reported resting periods for spray systems ranging from 1 to 14 days. Ridge and furrow and flooding systems generally result in applications of 3 to 4 inches in a matter of hours. Resting periods for these systems have been as long as 6 weeks but are typically 7 to 14 days.

Crop Selection – As indicated in Section IV, crop selection can be based on several factors. Pasture grasses and alfalfa have been popular choices for municipal effluents. Industries have generally chosen hydrophytic grasses that take up large quantities of water. The National Engineering Handbook of the Soil Conservation Service contains lists of boron and salt tolerances of various crops [56].

Distribution System – Sprinkler irrigation systems generally have the most complicated distribution network. Two handbooks on sprinkler irrigation are available [40, 58]. Surface irrigation systems consist of open ditches or buried mains for distributing water to the furrows or strips. Such systems have to distribute the water across only one dimension of the field.

Provisions for Seasonal Change – After the summer crop is harvested, a winter cover crop should be planted if possible. In climatic Zones A and B it may be possible to double- or triple-crop a piece of ground.

Storage is required where freezing temperatures do not permit winter operation. When irrigation begins again in the spring, the stored volume as well as the daily occurring flow must be used.

Some industrial systems provide continuous spraying through freezing weather without adverse effects on the vegetation [15]. At other systems damages to vegetation from winter spraying are claimed [42].

Operation and Management

It is vital that management personnel have a working knowledge of farming practices. Crops have changing needs for water and nutrients throughout their growth period, and application frequency must reflect these changes.

Monitoring of changes in the weather, soil characteristics, soil water, groundwater, and crops is important to successful long term operation. Analysis of the results of such monitoring will indicate any adverse changes. Management changes can then be initiated to correct for the environmental impacts.

If the crop is to be harvested, wastewater applications must be halted to allow drying of the soil, harvesting of the crop, and, if necessary, planting of another crop. Industries have tended to shy away from grazing irrigated lands. They often mow the grass but do not harvest it. At Beardmore, in Canada, the grass is kept between 2 and 5 inches high for optimum operation.

OVERLAND FLOW

The design and operation of overland flow systems have been developed for industrial wastewaters; therefore these systems will serve as a basis for most of this discussion.

System Design

The design of an overland flow system entails selection of a suitable site and land preparation, considerations of wastewater quality and pretreatment, determination of loading rates, selection of cover crop, and layout of the distribution and collection system. Site selection factors have been discussed in Section IV.

Land Preparation — Uniform slopes between 2 and 6 percent are preferred with no depressions or gullies. The surface must be quite smooth to promote a thin sheet flow. A slope length of 175 feet has been found to provide sufficient detention time to achieve effective treatment for the degradable food processing wastewater at Paris, Texas [10].

Wastewater Quality and Pretreatment — Pretreatment requirements for overland flow are screening for large solids removal and probably grease removal. At Paris, Texas, the grease concentration in the untreated wastewater is quite high and must be reduced to minimize buildups in the distribution lines. At Ada, Oklahoma, municipal wastewater with comminution as pretreatment has been sprayed successfully in a pilot operation.

Loading Rates – Liquid loading rates that have been used successfully in the design of overland flow systems have ranged from 0.25 to 0.7 in./day. Nutrient and organic loadings have not been correlated with treatment efficiency, detention time on the field, or crop type as yet.

Crop Selection – The cover crop is essential to the design because it serves as a media or habitat for the biota that are responsible for the oxidation of organic matter. The crop also serves to prevent erosion and to take up significant quantities of nutrients from the wastewater. Effective cover crops include Reed canary, tall fescue, trefoil, and Italian rye grasses. Italian rye grass is the dominant species in the "grass filtration" system at Melbourne, Australia [22].

Distribution and Collection System – Distribution systems include the same basic components as spray irrigation systems. Buried, permanently set systems have been found to be preferable to portable or above ground aluminum systems.

A network of ditches must be constructed to intercept the runoff and to channel it to the point of discharge or storage. The collection system should be designed to accept the added flow from rainfall runoff.

Operation and Management

The major tasks involved in operating an overland flow system include (1) maintaining the proper application frequency or hydraulic loading cycle, (2) managing the cover crop, and (3) monitoring the system performance.

Hydraulic Loading Cycle – Cycling of the wastewater application must be programmed to keep the microorganisms on the soil surface active. The application period should be controlled so as not to overstress the system and bring about anaerobic conditions. The resting period should be long enough to allow the soil surface layer to reaerate, yet short enough to keep the microorganisms in an active state. Experience with existing systems indicates that practical cycles range from 6 to 8 hours on and 6 to 18 hours off, depending on the time of the year.

Cover Crop Management — Removal of the crop is necessary (1) to realize the removal of the nutrients and minerals that have been taken up by the plants and (2) to realize any cash value of the crop as hay. Cutting of the crop is beneficial from an operating standpoint, because it eliminates the possibility of tall grass interfering with wastewater distribution. On the basis of experimental work conducted at Paris, Texas, it is possible to predict the time of year and stage of growth when hay of the highest value can be harvested [10, 16].

Monitoring — Monitoring is necessary to maintain loadings on the system within design limits. A routine monitoring program should be established to determine both the applied and runoff flow rates as well as selected influent and effluent quality parameters.

INFILTRATION-PERCOLATION

This approach encompasses groundwater recharge projects, municipal effluent recycle to the land, and industrial wastewater recycle to the land. All three types have been demonstrated to be successful; however, high rate recharge systems involving municipal wastewater will be the focus of most of this discussion.

System Design

The important elements of design are site selection, wastewater quality and pretreatment, loading rates, types of basin surface, and recovery. Site selection factors have been discussed in Section IV.

Wastewater Quality and Pretreatment — The major quality factors affecting the infiltration capacity of a system are the concentrations of suspended solids and organic material. Pretreatment to secondary quality is suggested for municipal wastewaters to be applied at high rates. Again, industrial wastewaters have been screened or settled to prevent sprinkler nozzles from clogging.

Loading Rates — Liquid loading rates generally range from 4 to 60 in./wk for moderate rate systems and 5 to 10 ft/wk for high rate systems. The design rate must be determined on the basis of pilot work where infiltration and percolation rates are studied for the particular soil over a considerable period of time. It should be established for the poorest climatic conditions that can be reasonably expected. Because the liquid loading rate will undoubtedly change during the course of operation in response to variations in climate, wastewater characteristics, or groundwater levels, an excess capacity should be included in the design. A reasonable range for excess emergency capacity would be 10 to 25 percent with 20 percent as typical.

Organic loading rates of 150 to 200 lb/acre/day or 27 to 36 tons BOD/acre/yr have been used successfully for industrial applications. For municipal wastewater a loading rate of 30 tons ob BOD/acre/yr has been reported [61]. These loadings should be considered upper limits for design unless pilot studies show otherwise.

Type of Basin Surface – The surface of an infiltration-percolation basin should be designed to disperse the clogging solids [28]. This has been accomplished by growing vegetation or by adding a layer of graded sand or gravel to the surface. At Flushing Meadows, Arizona, the vegetated basins were successful [47]. At Whittier Narrows, California, adding a layer of pea gravel is reported to have increased the infiltration capacity [29]. Selection of the type of basin surface should be based on comparative pilot studies at the infiltration site.

Recovery – Recovery of renovated water can be an integral part of the system design, as at Flushing Meadows, Arizona, and Santee, California [31, 47], or it can be incidental with the normal withdrawal from the groundwater basin as at Whittier Narrows and Hemet, California [29, 59].

Designed recovery systems can prevent the spread of renovated wastewater to aquifers outside the system of recharge basins and recovery wells. By keeping the renovated wastewater separated from the natural groundwaters, contamination can be prevented, especially with regard to nitrates. In addition, renovated water recovered in this manner could receive additional treatment, such as for nitrogen removal, or could be used exclusively for purposes best suited to its quality, such as irrigation or recreational lakes.

Operation and Management

Important aspects of infiltration-percolation system management include (1) hydraulic loading cycles, (2) basin surface management, and (3) monitoring.

Hydraulic Loading Cycle – Intermittent operation is required to maintain design loading rates and the renovative capacity of the soil. Experimentation is required to determine the best loading cycles consistent with the objectives of the system.

The resting period, which may vary from 1 to 20 days, is essential to allow atmospheric oxygen to penetrate the soil and reestablish aerobic conditions. As the surface dries, aerobic bacteria become active in organic matter decomposition and nitrification. Organic matter decomposition helps break up the clogging layer, and the microbial nitrification will free ammonium adsorption sites on clay and humus materials. When inundation begins again the converted nitrate will be leached with the applied water until anaerobic conditions occur and denitrification begins.

Basin Surface Management – Where bare soil or gravel surfaces are used, they should be scarified or raked when soils accumulate. For vegetated surfaces, careful operation of the loading cycle is necessary in the spring until the vegetation is well established. The surface may be harrowed on an annual basis to break up any solids buildup.

Monitoring – Monitoring is needed to maintain successful operation and to avoid conditions, such as nitrate or phosphate buildups, leading to significant environmental degradation. Flow meters or measuring flumes are necessary to measure the wastewater application rate.

Sampling of the wastewater applied should be done on a regular basis for characteristics such as BOD, suspended solids, nitrogen, phosphorus, TDS, and coliforms. A complete analysis of minerals, including heavy metals, should be performed at less frequent intervals. Groundwater or percolate water quality should be sampled for the same types of characteristics.

Monitoring data should be analyzed to define the operational efficiency of the system. The results should be recorded to maintain an historical record of the conditions under which the system has operated and to serve as a basis for system expansion.

SECTION VII

ENVIRONMENTAL EFFECTS

The performance of a land application system can be measured in terms of its effects on the terrain ecosystem. The effects of land application of wastewater on the climate, soil, vegetation, groundwater, surface water, and air will be described in this section. Public health considerations are discussed in Section VIII.

CLIMATE

Evaluation of the effect of large land application systems on local climatic conditions is difficult because of the lack of observations. However, it is possible to draw certain conclusions on the basis of observations taken around reservoirs both before and after their establishment, from studies in the vicinity of large irrigation enterprises, from investigations around large evaporative cooling towers for industry, and on the basis of various theoretical considerations.

The cities man has built, the swamps he drains, and the reservoirs he creates have resulted in modification of the climatic conditions over rather limited areas (neglecting air pollution effects). The reason for this lies mainly in the relatively small magnitudes of the heat and moisture inputs involved in man's activities as compared with those in nature.

The climatic changes that accompany irrigation enterprises are relatively local in extent. Air moving over an irrigated tract will rapidly pick up moisture and the air temperature will cool. Within the first few hundred feet in all but the most arid region, the air will have essentially reached equilibrium. Once the air has left the moist area, turbulent mixing will, within just a few miles, reduce its moisture content to its original low value and return the temperature to its value upwind of the irrigated tract.

SOIL

Soil is affected greatly by the application of wastewater, and in many cases the effects are beneficial. Soil fertility is increased by the addition of nutrients. Soil tilth is increased by the addition of organics, and in some cases, excess sodium conditions have been corrected. For example, at Woodland, California, alkali soil that was practically impermeable to rain and unacceptable for commercial irrigation purposes, has been partially renovated by wastewater application. Although the soil is still alkaline, wastewater will infiltrate into it at moderate rates.

The effects of sodium on clay soil permeability is dramatically illustrated by the pulping mill wastewater system in Terre Haute, Indiana, which handles wastewater containing sodium concentrations in the range of 16 percent of the dry solids. The sealing effect of the sodium is so severe that the fields must be rested several years and treated extensively with gypsum before they can be used again.

Irrigation with wastewater can lead to salt and heavy metal buildups depending on the soil, constituent concentrations, and system operation. Toxic concentrations of copper and zinc have apparently accumulated in the soil at two sewage farms in France, but it has taken over a century for them to develop [63]. Toxic levels of TDS in the soil can be remedied by leaching, resulting in increased TDS levels in the groundwater.

VEGETATION

The application of wastewater to crops is very beneficial because of the natural fertilizers and nutrients in the liquid. Virtually all essential plant nutrients are found in wastewater. On the basis of measurements made at Pennsylvania State University [21, 41], it was found that the crop yield increases when wastewater rather than ordinary water is used for irrigation. Yields for hay increased as much as 300 percent, and for corn, 50 percent.

Heavy applications of wastewater can damage and kill vegetation, especially trees [26, 42, 53]. High temperature industrial wastewaters [18] and high organic loadings (2,000 lb/acre/day) have also resulted in killing vegetation [51].

GROUNDWATER

Pollution of the groundwater by wastewater applied to the land is a serious environmental effect that must be guarded against. As indicated in Table 2 (Section IV), infiltration-percolation will definitely affect groundwater quality, and irrigation may affect it. The wastewater constituents of major concern here are nitrogen, TDS, toxic elements, and pathogens.

Nitrogen Effects

Nitrogen contained in wastewater applied to the land may be in any of four forms: organic, ammonium, nitrate, and nitrite. Nitrite nitrogen is easily oxidized to nitrate in the presence of oxygen so that concentrations above 1.0 mg/L for nitrite are rare. Nitrate nitrogen may be applied to the land when effluents are nitrified. Generally, however, organic and ammonium nitrogen are the principal forms applied to land.

Organic nitrogen, being suspended instead of dissolved, is filtered out in the soil matrix and mineralized (decomposed) into ammonium nitrogen. The ammonium nitrogen, under aerobic conditions, is oxidized by bacteria in two steps (nitrification) to nitrate nitrogen. Nitrate is not retained in soil and will leach readily with applied water [52]. Nitrate may be removed by plant uptake or by bacterial reduction to nitrogen gas (denitrification).

TDS Effects

The TDS concentration in the groundwater is affected by the leaching of minerals from the soil. The U.S. Public Health Service has recommended maximum level for TDS of 500 mg/L in public water supplies. An extreme example of the increase of TDS in groundwater due to irrigation occurred at Ventura in southern California. The applied irrigation water had a TDS concentration of 1,702 mg/L and the test wells had concentrations of up to 8,128 mg/L [60].

TDS buildups as a result of infiltration-percolation are less severe because only about 10 percent or less of the applied wastewater evaporates. Because of the high liquid loading rates, the concentration in the applied wastewater and that in the percolate will soon come to equilibrium.

Industrial dischargers with high TDS wastewaters may be constrained against using land application. At Beardmore, Canada, application of tannery wastewater with a salt concentration reaching 3,000 mg/L has resulted in a chloride increase in adjacent potable water supply wells which is threatening the existence of the plant [42].

Trace Elements

Trace elements include heavy metals, such as chromium, lead, or copper, and refractory organics. Heavy metals may be fixed in the soil and rendered nontoxic by bacteria under cometabolism [36]. Chemical precipitates that are formed can be leached out of the soil if a heavy loading occurs or if a significant decrease in pH occurs.

Organics that are degradable are easily oxidized in the soil matrix and refractory organics are usually fixed in the soil by adsorption. Some organics such as humic acids are mobile in the soil.

Bacteria and Viruses

The movement of bacteria and viruses with the percolating water is not likely to cause a threat to health. On the basis of results from numerous studies at existing sites and in laboratory experiments, it can be concluded that most bacteria and viruses are removed after passage through a few feet of soil [6, 14, 17, 23, 24, 25, 29, 64]. At Santee, California, viruses injected into the percolating water were completely removed in 200 feet of travel [31].

SURFACE WATER

The effect on surface waters of land application of wastewater can be in two areas. First, the discontinuance of discharge of treated effluent into surface waters could affect navigation and the flow rates associated with downstream uses of the water; in tidal areas, it could also permit the intrusion of saline waters further upstream than usual.

Second, irrigation with underdrains and the overland flow techniques will produce an effluent that could be discharged to surface waters. In these cases stream discharge standards apply and the effects of effluent constituents must be evaluated. Generally, with overland flow runoff, the only constituents that may be of concern would be the phosphorus concentration. The bacteria and viruses should not pose a problem. Overland flow at Melbourne, Australia, resulted in a 99.5 percent reduction in *E. Coli* [22].

AIR

Concern for effects on the air from land application centers around the use of sprinklers. The effects of land application on air include generation of aerosols and odor. Aerosols will be discussed in Section VIII. Odors are not produced by spraying but can be spread that way. Odors are generally a sign of system overloading, poor management, or both, provided the wastewater applied has not become septic or anaerobic. Once a wastewater becomes anaerobic it is difficult to spray, aerate, or spread it without producing some odors.

SECTION VIII

PUBLIC HEALTH CONSIDERATIONS

The passing of the Federal Water Pollution Control Act Amendments of 1971 and 1972 has drawn attention to the use of land application of wastewater. Stricter laws and regulations by both state and federal agencies on health aspects of land application will undoubtedly be passed in the future.

Public health aspects are related to (1) the pathogenic bacteria and viruses present in municipal wastewater and their possible transmission to higher biological forms including man, (2) chemicals that can pose dangers to health, and (3) the propagation of insects that could be vectors in disease transmission.

REGULATIONS BY STATE AGENCIES

There is no uniform pattern to the regulations in the United States. In 1968, Coerver [9] indicated that 11 states had a specific policy toward sewage irrigation, while in 1972 at least 17 states had specific regulations [8]. The use of untreated sewage or primary effluent on vegetables grown for human consumption is generally prohibited. Some states allow the use of completely treated, oxidized, and disinfected sewage on fruits and vegetables which are eaten raw. Other states ban the use of any sewage effluent for irrigation of truck crops and vegetables. Milk cows may not pasture on sewage irrigated lands in some states, for fear of typhoid infection transmitted by udder contamination [54]. Many states are currently revising or producing new regulations concerning land application of wastewater.

SURVIVAL OF PATHOGENS

The survival of pathogenic bacteria and viruses in sprayed aerosol droplets, on and in the soil, and on vegetation has received considerable attention. It is important to realize that any connection between pathogens applied to land with wastewater and the contraction of disease in animals or man would require a long and complex path of epidemiological events. Nevertheless, questions have been raised, concern exists, and precautions should be taken in dealing with the possible disease transmission.

Aerosols

Aerosols are droplets of liquid that have become airborne. Aerosols generated in connection with inadequately disinfected wastewater may contain bacteria and viruses. Spraying such wastewater will produce aerosols as will aeration tanks, trickling filters, and nonsubmerged outfalls [44].

The travel time and distance of bacteria in air has been studied in the United States and in Europe. The study reported by Merz [33] concludes that the bacterial travel is limited to the distance of travel of the mist from sprinklers. Sepp [54] reported that, in a German study, the bacteria traveled from 460 feet to 530 feet with a 6.7-mph wind velocity. It was estimated that the maximum travel would range from 1,000 feet to 1,300 feet with an 11-mph wind. Most of the mist and bacteria landed within half the maximum measured distance.

Studies have been made on the favorable conditions for bacteria to live in aerosol particles. It was found that, as the relative humidity decreased and air temperature increased, the death rate of the bacteria increased [44]. Sorber [57] indicates that a 50-micron water droplet will evaporate in 0.31 seconds in air, with 50 percent relative humidity and a temperature of 22 deg C. Thus, dessication is a major factor in bacterial die-off.

Finally, although much remains to be determined in investigating aerosols and their potential infectivity, many safeguards can be established. Among these are adequate disinfection, sprinklers that spray horizontally or downward with low nozzle pressure, and adequate buffer zones. Buffer zones may range from 50 feet to 1/4 mile around a site [54]. Low trajectory nozzles and screens of trees and shrubs can be used to limit aerosol travel. The traveling rig sprinklers designed for Muskegon, Michigan, have been modified to direct the spray trajectory downward. Studies of aerosol drift are being planned for the Muskegon operation [57].

Survival in Soil and on Vegetation

The survival of pathogenic organisms in the soil can vary from days to months depending on the soil moisture, soil temperature, and type of organism. Sepp [54] and Dunlop [13] have prepared extensive tabulations of survival times of various organisms in soil, in water, and on vegetation. In relation to survival of coliform organisms, some bacteria do survive for a longer time in soil. The survival of viruses in soil is essentially unexplored [57]. In general, bacteria die more rapidly on vegetation than in soil.

GROUNDWATER POLLUTION

Chemicals such as nitrates and TDS can present health hazards if they are present in high concentrations in groundwater that is used as a water supply. Because nitrate has been demonstrated to be the causative agent of methemoglobinemia in children, its concentration in drinking water is limited by the U.S. Public Health Service Drinking Water Standards to 10 mg/L as nitrate nitrogen. TDS limits in drinking water are recommended to be 750 mg/L because high values of TDS can be harmful to people with cardiac, viral, or circulatory diseases [57].

INSECT PROPAGATION

Propagation of mosquitoes and flies poses a health hazard as well as a nuisance condition. Mosquitoes are known vectors of several diseases [57]. In the Pennsylvania State study, mosquitoes increased in population mainly because of the wetter environment and the availability of standing puddles for breeding [41].

At several California industrial land application sites the major adverse environmental effect has been the propagation of mosquitoes. At Hunt-Wesson, Davis, California, the problem was anticipated, and mosquito fish or gambusia were planted in the runoff collection sump. Where vegetation is grown ample drying should be scheduled in the operation to prevent massive mosquito propagation.

SECTION IX

COST EVALUATION

Cost evaluations for irrigation, overland flow, and infiltration-percolation will be discussed in this section. Costs of existing systems will be reported, and typical costs will be presented for a hypothetical 1-mgd system operating under each of the three approaches.

REPORTED COSTS

Costs reported in the literature are scarce and are given in various units. Capital costs will be presented, as often as possible, in dollars per mgd or dollars per acre. Where amortization of capital costs is possible, the results will be given in cents per thousand gallons of treated wastewater. Operating and maintenance costs will be given in cents per thousand gallons of treated wastewater whenever possible.

Irrigation

Capital costs for irrigation include those for land, pretreatment, transmission, and distribution. Operating and maintenance costs are for labor, maintenance, and power. There are direct economic benefits from irrigation that can offset some of the operating costs.

Land costs vary tremendously but APWA found that a typical price in 1972 was $500 per acre. Pretreatment costs for a 1-mgd system range from 2.7¢/1,000 gal. for screening to 34.6¢/1,000 gal. for activated sludge. These costs are totals determined by adding amortized capital costs (25 years at 7 percent) from Smith [55] to operating and maintenance costs. The costs were updated to a Sewage Treatment Plant Construction Cost Index of 192.8 for January 1973 (Index was 100 in 1957-1959).

Spray Irrigation – Costs for spray irrigation are highly variable, as shown in Table 7. Reported capital costs

Table 7. Reported Capital and Operating Costs for Spray Irrigation

Location	Year started	Flow, mgd	Area, acres	Capital cost,[a] $/acre	Capital cost,[a] ¢/gpd	Operating cost,[b] ¢/1,000 gal.	Reference
Belding, Michigan	1973	0.80	15.6	5,100	11.5	--	64
Ephrata, Washington	1972	0.44	55	3,700	47.0	6.8	--
Pennsylvania State University	1967	1.0	129	2,700	--	--	1, 39
Middleville, Michigan	1970	0.15	30.6	2,090	41.8	--	64
St. Charles, Maryland	1966	0.50	50	1,900	19.0	8.7	--
Wayland, Michigan	1970	0.5	53	1,890	20.0	--	64
Moulton-Niguel Water District, California	1966	1.0	--	1,500	--	--	--
Idaho Supreme Potato Co., Firth, Idaho	1968	0.63	80	800	--	--	--
Portales, New Mexico	1968	1.0	120	140	--	--	--
Calabasas, California	1965	3.0	420	--	23	2.7	--

a. Capital improvements made from initial year to 1972.

b. Based on 1972 budget.

range from $5,100 per acre for a solid set system to $140 per acre for a center pivot rig. Solid set systems are most common for municipalities, and the remaining systems that are listed in Table 7 are predominantly solid set. Capital cost components for spray irrigation include pumping, transmission lines, and distribution network. In some cases earthwork, such as leveling and cultivation, or drainage systems are required.

Operating and maintenance costs range from a low of 2.7¢/1,000 gal. as shown in Table 7 to 23.9¢/1,000 gal. for a cannery operating on a seasonal basis. Cost components are power, maintenance, and labor.

Ridge and Furrow Irrigation – Ridge and furrow systems require a uniform slope of 0.2 to 0.3 percent, and thus earthwork may be a major cost item. In rolling terrain, such as in western Wisconsin, the cost is high because of earthwork, as shown in Table 8. On the other hand, in the relatively flat land near Bakersfield, California, the costs are much less. At the Mount Vernon Sanitary District, the cost was $75 per acre which included leveling, furrow preparation, and fertilizing [32].

Operating and maintenance costs are dependent upon the amount of maintenance required. If frequent cultivation and maintenance of furrows is required, the costs will be higher than for spray systems.

Flood Irrigation – Capital costs for flood irrigation, provided the land is relatively level, are less than for spray or ridge and furrow systems, as shown in Table 9. As with ridge and furrow irrigation, the entire transmission and distribution system can be by gravity. Maintenance for flood systems is generally less than for ridge and furrow, and this is reflected in the lower operating costs in Table 9.

Economic Benefits – Cities such as Woodland, California, Abilene, Texas, Pomona, California, and San Angelo, Texas, derive direct benefits in different ways. At Woodland, the city's land is leased for $23 per acre for summer irrigation, and in addition, a duck club pays about $6 per acre for the same land for late fall duck hunting privileges. At Abilene, city land is leased for $12 per acre, and additional effluent is provided to adjacent farms in place of cash payments as a result of a lawsuit settlement. Pomona purchases treated wastewater from the Los Angeles County Sanitation Districts at $7 per acre-foot and sells it to various users at $5 to $22 per acre-foot. At San Angelo, four city employees operate the 750-acre city farm at a

Table 8. Reported Capital and Operating Costs for Ridge and Furrow Irrigation

Location	Year started	Flow, mgd	Area, acres	Capital cost,[a] $/acre	Capital cost,[a] ¢/gpd	Operating cost,[b] ¢/1,000 gal.	Reference
Wisconsin creamery	1954	--	3	2,000	--	--	49
Minnesota creamery	1950	--	2.8	300	--	--	49
Bakerfield, California	1912	12.3	2,400	--	21	4.8	--
Mount Vernon Sanitary District, California	1948	--	1,000	75	--	--	32
Minnesota cannery	1953	--	--	--	--	22.2[c]	49
Ontario tannery	1958	0.7	--	--	--	12.7[c]	49

a. Capital improvements made from initial year to 1972.

b. Based on 1972 budget.

c. Costs for the year started.

Table 9. Reported Capital and Operating Costs for Flood Irrigation

Location	Year started	Flow, mgd	Area, acres	Capital cost,[a] $/acre	Capital cost,[a] ¢/gpd	Operating cost, ¢/1,000 gal.
Abilene, Texas	1920	4.5	1,550	--	--	7.0
Woodland, California	1889	8.7	240	--	--	4.2
Ely, Nevada	1908	1.5	1,400	--	11	4.0
San Angelo, Texas	1933	5.0	640	--	4	3.0

a. Capital improvements made from initial year to 1972.

b. Based on 1972 budget.

profit of $30 per acre. The operating costs for 1972 of $54,000 were offset by an annual return of $76,700.

Overland Flow

An overland flow system is similar to a spray irrigation system in that sprinklers are used to distribute the water. The main differences are that the land is sloping, the water runs off, and the crop is not always harvested. The capital and operating costs are evaluated in the following discussion.

Capital Costs – Capital cost items include land, pretreatment, transmission, earthwork, distribution, and collection. Land costs are quite variable; even at the Paris, Texas, site they varied from $50 to $600 per acre for the 500 acres purchased [8]. Pretreatment generally consists of screening. Transmission generally is by pumping.

Earthwork will vary with the original topography of the site. At Paris, Texas, rolling land was regraded at a cost of $306 per acre for clearing, $108 per acre for grass cover, and $188 per acre for miscellaneous work. On the other hand, complete regrading of flat land to 2.5 perçent slopes at Davis, California, cost $1,500 per acre.

The original distribution system for Paris, Texas, cost $348 per acre to install [8]. The cost in 1971 for the piping at the Hunt-Wesson site at Davis, California, was about $1,250 per acre.

Collection systems for the runoff are normally included under earthwork. At Davis, California, the collection ditches amounted to 10 percent of the earthwork cost or about $150 per acre.

Operation and Maintenance – Data on overland flow facilities are scarce because of the limited number of overland flow sites in operation. At Paris, Texas, the annual operational cost is 5¢/1,000 gal. The operational cost is reduced slightly by the income of 0.4¢/1,000 gal. from crops produced on the site. At Davis, California, the annual cost is approximately 5 to 10¢/1,000 gal.

Infiltration-Percolation

Capital and operating costs for infiltration-percolation systems will generally be less than those for irrigation or overland flow because smaller land areas are used and distribution is by gravity flow. For high rate systems, however, pretreatment needs are substantially greater for infiltration-percolation than for irrigation or overland flow.

Capital Costs – These are costs for land, pretreatment, earthwork, transmission and distribution, and recovery.

At Westby, Wisconsin, basins were constructed in a 5 percent hillside. Land cost was $750 per acre and earthwork was $2,500 per acre. The earthwork cost at Flushing Meadows, Arizona, was $1,500 per basin or $4,500 per acre. This was an experimental research effort and costs for the 2 acres are expected to be high.

Buxton [7] has calculated the cost of transmission and distribution at Flushing Meadows at $98,000. The recovery wells there (600 gpm) are estimated to cost $35 per foot, or $17,500 for each well.

Operation and Maintenance – Operation and maintenance costs for infiltration-percolation systems consist of costs for labor, maintenance, and power. At Flushing Meadows, Arizona, the operating cost is 2.4¢/1,000 gal. while at Whittier Narrows, California, it is 2.7¢/1,000 gal.

Simpson Lee Paper Company operates two pulp and paper waste disposal systems by infiltration-percolation. At Kalamazoo, Michigan, 7 in./day is applied by spraying and at Vicksburg, Michigan, 1 in./day is applied by spraying. At Kalamazoo the operating cost is 2.6¢/1,000 gal., and at Vicksburg the cost is 2.9¢/1,000 gal. Pretreatment costs for primary settling are included in both costs.

COST COMPARISON FOR HYPOTHETICAL 1-MGD SYSTEMS

Hypothetical 1-mgd systems for spray irrigation, overland flow, and infiltration-percolation were assembled so that their capital and operating costs could be compared. These systems were assumed to operate continuously without storage. Typical costs were assigned for each component of the system, and the totals are shown in Table 10. Capital costs in cents per 1,000 gallons are 10.1 for spray irrigation, 9.5 for overland flow, and 5.3 for infiltration-percolation. Operating costs in cents per 1,000 gallons are estimated to be 9.6 for spray irrigation, 7.6 for overland flow, and 3.5 for infiltration-percolation.

Pretreatment

Costs for pretreatment have not been included in the cost buildup. The extent of the need for pretreatment for irrigation and overland flow has not been firmly established.

Table 10. Comparison of Capital and Operating Costs for 1-mgd Spray Irrigation, Overland Flow, and Infiltration-Percolation Systems[a]

Cost item	Spray irrigation	Overland flow	Infiltration-percolation
Liquid loading rate, in./wk	2.5	4.0	60.0
Land used, acres	103	64	--
Land required, acres[b]	124	77	5
Capital costs			
Land @ $500/acre	$ 62,000	$ 38,500	$ 2,500
Earthwork	10,300	64,000	10,000
Pumping station	50,000	50,000	--
Transmission	132,000	132,000	132,000
Distribution	144,000	64,000	5,000
Collection	--	6,000	30,000
Total capital costs	$398,300	$354,500	$179,500
Capital cost per purchased acre	$3,200	$4,600	$35,800
Amortized cost[c]	$37,000	$34,700	$19,500
Capital cost, ¢/1,000 gal.	10.1	9.5	5.3
Operating costs			
Labor	$10,000	$10,000	$ 7,500
Maintenance	19,400	12,000	3,500
Power	5,800	5,800	1,800
Total operating costs	$35,200	$27,800	$12,800
Operating cost, ¢/1,000 gal.	9.6	7.6	3.5
Total cost, ¢/1,000 gal.	19.7	17.1	8.8

a. Estimated for 1973 dollars, ENRCC index 1860 and STPCC index 192.

b. 20 percent additional land purchased for buffer zones and additional capacity.

c. 15-year life for capital items, excluding land; interest rate 7 percent.

Irrigation with primary effluent has been successful; however, recent regulations may require secondary quality for irrigation. Screening and comminuting may be the minimum pretreatment required for overland flow, but this requires full-scale substantiation. High rate infiltration-percolation requires secondary quality, although moderate rates can be maintained successfully with primary effluent.

Land

The land needed for each system was calculated from the 1-mgd flow rate and the liquid loading rate. Typical loading rates were chosen, and the resultant land area was increased by 20 percent for buffer zones for spray irrigation and overland flow, or excess capacity for infiltration-percolation. A land price of $500 per acre was chosen as typical.

Earthwork

For earthwork costs it was assumed that some land preparation was required for spray irrigation at $100 per acre. For overland flow, terracing required major earthwork (assuming previously level land) at $1,000 per acre. Also included were costs for preparation, planting, and fertilizing. For infiltration-percolation basins, ten 1/2-acre basins were required at $1,000 per basin.

Pumping Stations

A 1-mgd package pumping station would cost $50,000 for both the spray irrigation and overland flow cases. It was assumed that the wastewater could be transmitted to the site by gravity flow; therefore, no pumping stations for distribution were included for infiltration-percolation.

Transmission

The hypothetical site was located 1 mile from the treatment plant or wastewater source. Transmission was by gravity flow through a 24-inch pipe, installed at a cost of $25 per foot. It should be noted that the same plot of land was not being considered for each approach.

Distribution

For spray irrigation the cost per acre in 1973 dollars is $1,400. In determining this cost, use was made of a set of curves developed by Allender [1] presented in Volume II.

For overland flow, the distribution pattern was not square so a typical cost of $1,000 per acre was chosen. Similarly, a cost of $1,000 per acre was assigned for distribution among the 10 basins for infiltration-percolation.

Collection

For overland flow, a series of collection ditches were required at a cost of approximately 10 percent of the distribution costs, or $6,000. For infiltration-percolation, 3 wells for recovery were required. The wells had a capacity of 600 gpm each and, at 100-foot depths, cost $30,000, including $15,000 for recovery pumps.

Operation and Maintenance

Labor requirements were based on one man, full-time, for spray irrigation and overland flow. A single man three-fourths of the time was necessary for infiltration-percolation.

Maintenance costs were calculated as 10 percent of the capital costs of pumping stations, distribution, and collection. Power costs were variable, but were expected to be 2¢/hp-hr.

SECTION X

REFERENCES

1. Allender, G. C., "The Cost of a Spray Irrigation System for the Renovation of Treated Municipal Wastewater," Master's Thesis, The Pennsylvania State University (September 1972).

2. "Assessment of the Effectiveness and Effects of Land Disposal Methodologies of Wastewater Management," Department of the Army, Corps of Engineers, Wastewater Management Report 72-1 (January 1972).

3. Aulenbach, D. B., Glavin, T. P., and Rojas, J. A. R., "Effectiveness of a Deep Natural Sand Filter for Finishing of a Secondary Treatment Plant Effluent," Presented at the New York Water Pollution Control Association Meeting (January 29, 1970).

4. Bendixen, T. W., et al., "Ridge and Furrow Liquid Waste Disposal in a Northern Latitude," ASCE San. Engr. Div., 94, No. SA-1, pp 147-157 (1968).

5. Blosser, R. O., and Owens, E. L., "Irrigation and Land Disposal of Pulp Mill Effluents," Water and Sewage Works, III, No. 9, pp 424-432 (1964).

6. Bouwer, H., "Renovating Secondary Effluent by Groundwater Recharge With Infiltration Basins," Presented at the Symposium on Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland," The Pennsylvania State University, University Park, Pennsylvania (August 21-24, 1972).

7. Buxton, J. L., "Determination of a Cost for Reclaiming Sewage Effluent by Ground Water Recharge in Phoenix, Arizona," Master's Thesis, Arizona State University (June 1969).

8. Center for the Study of Federalism, Green Land--Clean Streams: The Beneficial Use of Waste Water Through Land Treatment, Stevens, R. M., Temple University, Philadelphia, Pennsylvania (1972).

9. Coerver, J. F., "Health Regulations Concerning Sewage Effluent for Irrigation," Proceedings of the Symposium on Municipal Sewage Effluent for Irrigation, Louisiana Polytechnic Institution (July 30, 1968).

10. C. W. Thornthwaite Associates, "An Evaluation of Cannery Waste Disposal by Overland Flow Spray Irrigation," Publications in Climatology, 22, No. 2 (September 1969).

11. DeTurk, E. E., "Adaptability of Sewage Sludge as a Fertilizer," Sewage Works Journal, 7, No. 4, pp 597-610 (1935).

12. Duffer, W., "EPA Supported Research," Presented at the Symposium on Land Disposal of Municipal Effluents and Sludges, Rutgers University, New Brunswick, New Jersey (March 12-13, 1973).

13. Dunlop, S. G., "Survival of Pathogens and Related Disease Hazards," Proceedings of the Symposium on Municipal Sewage Effluent for Irrigation, Louisiana Polytechnic Institution (July 30, 1968).

14. Eliassen, R., et al., "Studies on the Movement of Viruses With Groundwater," Water Quality Control Research Laboratory, Stanford University (1967).

15. Fisk, W. W., "Food Processing Waste Disposal," Water and Sewage Works, III, No. 9, pp 417-420 (1964).

16. Gilde, L. C., et al., "A Spray Irrigation System for Treatment of Cannery Wastes," Jour. WPCF, 43, No. 8, pp 2011-2025 (1971).

17. Gotaas, H. B., et al., "Annual Report on Investigation of Travel of Pollution," Sanitary Engineering Research Project, University of California, Berkeley (1953).

18. Guerri, E. A., "Sprayfield Application Handles Spent Pulping Liquors Efficiently," Pulp & Paper, 45, No. 2, pp 93-95 (1971).

19. Hill, R. D., Bendixen, T. W., and Robeck, G. C., "Status of Land Treatment for Liquid Waste--Functional Design," Presented at the Water Pollution Control Federation Conference, Bal Harbour, Florida (October 1964).

20. Hutchins, W. A., "Sewage Irrigation as Practiced in the Western States," Technical Bulletin No. 675, U.S. Dept. of Agriculture (March 1939).

21. Kardos, L. T., "Crop Response to Sewage Effluent," Proceedings of the Symposium on Municipal Sewage Effluent for Irrigation, Louisiana Polytechnic Institution (July 30, 1968).

22. Kirby, C. F., "Sewage Treatment Farms," Dept. of Civil Engineering, University of Melbourne (1971).

23. Krone, R. B., "The Movement of Disease Producing Organisms Through Soils," Proceedings of the Symposium on Municipal Sewage Effluent for Irrigation, Louisiana Polytechnic Institution (July 1968).

24. Krone, R. B., McGauhey, P. H., and Gotaas, H. B., "Direct Discharge of Ground Water With Sewage Effluents," ASCE San. Engr. Div., 83, No. SA-4, pp 1-25 (1957).

25. Krone, R. B., Orlob, G. T., and Hodgkinson, C., "Movement of Coliform Bacteria Through Porous Media," Sewage and Industrial Wastes, 30, No. 1, pp 1-13 (1958).

26. Larson, W. C., "Spray Irrigation for the Removal of Nutrients in Sewage Treatment Plant Effluent as Practiced at Detroit Lakes, Minnesota," Algae and Metropolitan Wastes, Transactions of the 1960 Seminar, U.S. Dept. of HEW (1960).

27. "Liquid Wastes From Canning and Freezing Fruits and Vegetables," National Canners Association, Office of Research and Monitoring, Environmental Protection Agency, Program No. 12060 EDK, pp 61-65, 73-74 (August 1971).

28. McGauhey, P. H., and Krone, R. B., "Soil Mantle as a Wastewater Treatment System," SERL Report No. 67-11, University of California, Berkeley (December 1967).

29. McMichael, F. C., and McKee, J. E., "Wastewater Reclamation at Whittier Narrows," Calif. State Water Quality Control Board, Publication No. 33 (1966).

30. Melbourne and Metropolitan Board of Works, "Waste Into Wealth," Melbourne, Australia (1971).

31. Merrell, J. C., et al., "The Santee Recreation Project, Santee, California, Final Report," FWPCA, U.S. Dept. of the Interior, Cincinnati, Ohio (1967).

32. Merz, R. C., "Continued Study of Waste Water Reclamation and Utilization," Calif. State Water Pollution Control Board, Publication No. 15, Sacramento, Calif. (1956).

33. Merz, R. C., "Third Report on the Study of Waste Water Reclamation and Utilization," Calif. State Water Pollution Control Board, Publication No. 18, Sacramento, Calif. (1957).

34. Metcalf & Eddy, Inc., Wastewater Engineering, McGraw-Hill Book Co., New York (1972).

35. Metcalf, L., and Eddy, H. P., American Sewerage Practice, Vol. III, Disposal of Sewage, 3rd Ed., pp 233-251, McGraw-Hill Book Co., New York (1935).

36. Miller, R. H., "The Soil as a Biological Filter," Presented at the Symposium on Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland, Pennsylvania State University, University Park, Pennsylvania (August 21-24, 1972).

37. Mitchell, G. A., "Municipal Sewage Irrigation," Engineering News-Record, 119, pp 63-66 (July 8, 1937).

38. Mitchell, G. A., "Observations on Sewage Farming in Europe," Engineering News-Record, 106, No. 2, pp 66-69 (1931).

39. Nesbitt, J. B., "Cost of Spray Irrigation for Wastewater Renovation," Presented at the Symposium on Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland, Pennsylvania State University, University Park, Pennsylvania (August 21-24, 1972).

40. Pair, C. H., edit., Sprinkler Irrigation, 3rd Ed., Sprinkler Irrigation Association, Washington, D. C. (1969).

41. Parizek, R. R., et al., "Waste Water Renovation and Conservation," Penn State Studies No. 23, University Park, Pennsylvania (1967).

42. Parker, R. P., "Disposal of Tannery Wastes," Proceedings of the 22nd Industrial Waste Conference, Part I, Purdue University, Lafayette, Indiana, pp 36-43 (1967).

43. Parsons, W. C., "Spray Irrigation of Wastes From the Manufacture of Hardboard," Proceedings of the 22nd Industrial Waste Conference, Purdue University, Lafayette, Indiana, pp 602-607 (1967).

44. Poon, C. P. C., "Viability of Long Storaged Airborne Bacterial Aerosols," ASCE San. Engr. Div., 94, No. SA 6, pp 1137-1146 (1968).

45. Rafter, G. W., "Sewage Irrigation," USGS Water Supply and Irrigation Paper No. 3, U.S. Dept. of the Interior, Washington, D. C. (1897).

46. Rafter, G. W., "Sewage Irrigation, Part II," USGS Water Supply and Irrigation Paper No. 22, U.S. Dept. of the Interior, Washington, D. C. (1899).

47. "Renovating Secondary Sewage by Ground Water Recharge With Infiltration Basins," Bouwer, H., Rice, R. C., and Escarcega, E. D., U.S. Water Conservation Laboratory, Office of Research and Monitoring, Environmental Protection Agency, Project No. 16060 DRV (March 1972).

48. "Role of Soils and Sediment in Water Pollution Control," Part 1, Bailey, G. W., Southeast Water Laboratory, FWPCA, U.S. Dept. of the Interior (March 1968).

49. Schraufnagel, F. H., "Ridge-and-Furrow Irrigation for Industrial Wastes Disposal," Jour. WPCF, 34, No. 11, pp 1117-1132 (1962).

50. Schwartz, W. A., and Bendixen, T. W., "Soil Systems for Liquid Waste Treatment and Disposal: Environmental Factors," Jour. WPCF, 42, No. 4, pp 624-630 (1970).

51. Scott, R. H., "Disposal of High Organic Content Wastes on Land," Jour. WPCF, 34, No. 9, pp 932-950 (1962).

52. Sepp, E., "Nitrogen Cycle in Groundwater," Bureau of Sanitary Engineering, Calif. State Dept. of Public Health, Berkeley (1970).

53. Sepp, E., "Survey of Sewage Disposal by Hillside Sprays," Bureau of Sanitary Engineering, Calif. State Dept. of Public Health, Berkeley (March 1965).

54. Sepp, E., "The Use of Sewage for Irrigation--A Literature Review," Bureau of Sanitary Engineering, Calif. State Dept. of Public Health (1971).

55. Smith, R., "Cost of Conventional and Advanced Treatment of Wastewater," Jour. WPCF, 40, No. 9, pp 1546-1574 (1968).

56. "Soil-Plant-Water Relationships," Chapter 1 in Irrigation, Section 15 of SCS National Engineering Handbook, Soil Conservation Service, U.S. Dept. of Agriculture (March 1964).

57. Sorber, C., "Protection of Public Health," Presented at the Symposium on Land Disposal of Municipal Effluents and Sludges, Rutgers University, New Brunswick, New Jersey (March 12-13, 1973).

58. "Sprinkler Irrigation," Chapter 11 in Irrigation, Section 15 of SCS National Engineering Handbook, Soil Conservation Service, U.S. Dept. of Agriculture (July 1968).

59. "Study of Reutilization of Wastewater Recycled Through Groundwater," Vol. 1, Boen, D. F., et al., Eastern Municipal Water District, Office of Research and Monitoring, Environmental Protection Agency, Project 16060 DDZ (July 1971).

60. Sullivan, D., "Wastewater for Golf Course Irrigation," Water & Sewage Works, 117, No. 5, pp 153-159 (1970).

61. Thomas, R. E., and Bendixen, T. W., "Degradation of Wastewater Organics in Soil," Jour. WPCF, 41, No. 5, Part 1, pp 808-813 (1969).

62. Thomas, R. E., and Harlin, C. C., Jr., "Experiences With Land Spreading of Municipal Effluents," Presented at the First Annual IFAS Workshop on Land Renovation of Waste Water in Florida, Tampa (June 1972).

63. Thomas, R. E., and Law, J. P., Jr., "Soil Response to Sewage Effluent Irrigation," Proceedings of the Symposium on Municipal Sewage Effluent for Irrigation, Louisiana Polytechnic Institution (July 30, 1968).

64. Williams, T. C., "Utilization of Spray Irrigation for Wastewater Disposal in Small Residential Developments," Presented at the Symposium on Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland, Pennsylvania State University, University Park, Pennsylvania (August 1972).

SECTION XI

PUBLICATIONS

1. Pound, C. E., and Crites, R. W., "Nationwide Experiences in Land Treatment," Presented at the Symposium on Land Disposal of Municipal Effluents and Sludges, Rutgers University, New Brunswick, New Jersey (March 12-13, 1973).

2. Pound, C. E., and Crites, R. W., "Characteristics of Municipal Effluents," Presented at the EPA-USDA-Universities Workshop, University of Illinois (July 9-13, 1973).

3. "Land Application of Sewage Effluents and Sludges: Selected Abstracts," To be published by EPA (fall 1973).

SECTION XII

GLOSSARY OF TERMS, ABBREVIATIONS, AND CONVERSION FACTORS

TERMS

Adsorption--A process in which soluble substances are attracted to and held at the surface of soil particles.

Advanced waste treatment--Additional treatment designed to reduce concentrations of selected constituents present in wastewater after secondary treatment.

Alkali soil--A soil with a high degree of alkalinity (pH of 8.5 or higher) or with a high exchangeable sodium content (15 percent or more of the exchange capacity), or both.

Application rates--The rates at which the liquid is dosed to the land, usually in in./hr.

Aquifer--A geologic formation or strata that contains water and transmits it from one point to another in quantities sufficient to permit economic development.

Border strip method--Application of water over the surface of the soil. Water is applied at the upper end of the long, relatively narrow strip.

Consumptive use--Synonymous with evapotranspiration.

Contour check method--Surface application by flooding. Dikes constructed at contour intervals to hold the water.

Conventional wastewater treatment--Reduction of pollutant concentrations in wastewater by physical, chemical, or biological means.

Drainability--Ability of the soil system to accept and transmit water by infiltration and percolation.

Effective precipitation--Precipitation that enters the soil and is useful for plant growth.

Evapotranspiration--The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, snow, or intercepted precipitation in any specified time.

Field area--Total area of treatment for an overland flow system including the wetted area and runoff area.

Fixation--A combination of physical and chemical mechanisms in the soil that act to retain wastewater constituents within the soil, including adsorption, chemical precipitation, and ion exchange.

Flooding--A method of surface application of water which includes border strip, contour check, and spreading methods.

Grass filtration--See overland flow.

Groundwater--The body of water that is retained in the saturated zone which tends to move by hydraulic gradient to lower levels.

Groundwater table--The free surface elevation of the groundwater; this level will rise and fall with additions or withdrawals.

Infiltration--The entrance of applied water into the soil through the soil-water interface.

Infiltration-percolation--An approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores.

Irrigation--Application of water to the land to meet the growth needs of plants.

Land application--The discharge of wastewater onto the soil for treatment or reuse.

Loading rates--The average amount of liquid or solids applied to the land over a fixed time period taking into account periodic resting.

Lysimeter--A device for measuring percolation and leaching losses from a column of soil. Also a device for collecting soil water in the field.

Micronutrient--A chemical element necessary in only small amounts (less than 1 mg/L) for microorganism and plant growth.

Mineralization--The conversion of an element from an organic form to an inorganic form as a result of microbial decomposition.

Overland flow--Wastewater treatment by spray-runoff (also known as "grass filtration") in which wastewater is sprayed onto gently sloping, relatively impermeable soil which has been planted to vegetation. Biological oxidation occurs as the wastewater flows over the ground and contacts the biota in the vegetative litter.

Pathogenic organisms--Microorganisms that can transmit diseases.

Percolation--The movement of water through the soil pores once it has passed the soil-water interface.

Phytotoxic--Toxic to plants.

Primary effluent--Wastewater that has been treated by screening and sedimentation.

Refractory organics--Organic materials not removed in secondary treatment.

Ridge and furrow method--The surface application of water to the land through formed furrows; wastewater flows down the furrows and plants may be grown on the ridges.

Saline soil--A nonalkali soil containing sufficient soluble salts to impair its productivity.

Secondary treatment--Treatment of wastewater by physical, chemical, or biological means such as trickling filters, activated sludge, or chemical precipitation and filtration.

Sewage farming--Originally involved the transporting of sewage to rural areas for land disposal. Later practice included reusing the water for irrigation and fertilization of crops.

Soil texture--The relative proportions of the various soil separates--sand, silt, and clay.

Soil water--That water present in the soil pores in an unsaturated zone above the groundwater table.

Spraying--Application of water to the land by means of stationary or moving sprinklers.

Spray-runoff--See overland flow.

Tilth--The physical condition of a soil as related to its ease of cultivation.

Transpiration--The net quantity of water absorbed through plant roots and transpired, plus that used directly in building plant tissue.

Viruses--Submicroscopic biological structures containing all the information necessary for their own reproduction.

Wetted area--Area within the spray diameter of the sprinklers.

ABBREVIATIONS

acre-ft--acre-foot

BOD --biochemical oxygen demand

BOD_5 --5-day BOD

bu --bushel

cm --centimeter

COD --chemical oxygen demand

deg C --degree Centigrade

deg F --degree Fahrenheit

diam --diameter

ENRCC --*Engineering News-Record* construction cost (index)

fps --feet per second

ft --foot

gad --gallons per acre per day

gal. --gallon

gpd --gallons per day

gpm --gallons per minute

hr --hour

hp-hr --horsepower-hour

in. --inch

kw --kilowatt

lb --pound

m --meter

max --maximum

mgd --million gallons per d y

mg/L --milligrams per liter

mi --mile

min --minute

ml --milliliter

mm --millimeter

mo --month

mph --miles per hour

MPN --most probable number

ppm --parts per million

psi --pounds per square inch

SAR --sodium adsorption ratio

sec --second

sq ft --square foot

SS --suspended solids

STPCC --sewage treatment plant construction cost (index)

TDS --total dissolved solids

wk --week

yr --year

CONVERSION FACTORS

million gallons x 3.06 = acre-feet

acre-inch x 27,154 = gallons

mg/L x ft/yr x 2.7 = lb/acre/yr

SECTION XIII

APPENDIX

Table 11. Land Application Sites Visited for This Study

1. Abilene, Texas
2. Moulton-Niguel WD, California
3. Portales, New Mexico
4. San Francisco, California
5. Woodland, California
6. Lake George, New York
7. Phoenix, Arizona
8. Westby, Wisconsin
9. Idaho Supreme Potato Co., Firth, Idaho
10. Beardmore & Co., Ltd., Acton, Ontario, Canada

Table 12. Sites Visited Prior to Study

1. Bakersfield, California
2. Mount Vernon Sanitary District, California
3. Campbell Soup Company, Chestertown, Maryland
4. Campbell Soup Company, Napoleon, Ohio
5. Campbell Soup Company, Paris, Texas
6. Hunt-Wesson Foods, Inc., Davis, California
7. California Canners & Growers, Thornton, California
8. Campbell Soup Company, Sumter, South Carolina
9. Seabrook Farms Company, Seabrook, New Jersey
10. Sebastopol, California
11. Tri/Valley Growers, Stockton, California

Table 13. Land Application Facilities, On-Site Visits by APWA

No.	Agency and State	No.	Agency and State
	A. MUNICIPAL		
	ARIZONA		
1	City of Casa Grande	17	Irvine Ranch Water Dist., Irvine
2	Lake Havasu San. District, Lake Havasu	18	City of Oceanside
3	City of Mesa	19	City of Ontario
4	City of Prescott	20	City of Pleasanton
5	City of Tucson	21	City of Santa Maria
	CALIFORNIA	22	City of San Bernardino
6	Las Virgenes Municipal Water District, Los Angeles	23	Santee County Water Dist., San Diego
		24	City of San Clemente
7	Camarillo San. District, Camarillo	25	City of San Luis Obispo
		26	City of Ventura
8	City of Colton		
9	City of Dinuba		COLORADO
10	City of Fontana	27	City of Colorado Springs
11	City of Fresno		FLORIDA
12	City of Hanford	28	Walt Disney World
13	Valley Sanitation District.	29	Oskaloosa County Water and Sewer District Eglin Air Force Base
14	Rossmoor Sanitation, Inc.,Laguna Hills	30	City of St.Petersburg
15	City of Livermore	31	City of Tallahassee
16	City of Lodi		MARYLAND
		32	St. Charles Utilities, Inc., St. Charles

Table 13. (Continued)

No.	Agency and State
	NEW JERSEY
33	Forsgate Sanitation, Inc., Cranbury
34	City of Vineland
	NEW MEXICO
35	City of Alamogordo
36	City of Clovis
37	City of Raton
38	City of Roswell
39	City of Santa Fe Silver Road Plant
40	City of Santa Fe Airport Road Plant
	NEVADA
41	Clark County
42	City of Ely
43	Incline Village
44	City of Las Vegas
	OKLAHOMA
45	City of Duncan
	OREGON
46	Unified Sewerage Agency, Forest Grove
47	City of Hillsboro
48	City of Milton-Freewater
	PENNSYLVANIA
49	Pennsylvania State U. State College-University Park
	TEXAS
50	City of Dumas
51	City of Kingsville
52	City of LaMesa
53	City of Midland
54	City of Monahans
55	City of San Angelo
56	City of Uvalde
	WASHINGTON
57	City of Ephrata
58	Town of Quincy
59	City of Walla Walla
	WYOMING
60	City of Cheyenne
61	City of Rawlins
	MEXICO
62	Mexico City, dry weather flow, treated
63	Mexico City, dry weather flow, raw

Table 13. (Concluded)

No.	Name, City, and State	No.	Name, City, and State
	B. INDUSTRIAL		
1i	Green Giant Company Buhl, Idaho	13i	Hunt-Wesson Foods, Inc. Bridgeton, New Jersey
2i	Western Farmers Assoc. Aberdeen, Idaho	14i	U. S. Gypsum Company Pilot Rock, Oregon
3i	Celotex Corporation Largo, Indiana	15i	Weyerhauser Company Springfield, Oregon
4i	Commercial Solvents Terre Haute, Indiana	16i	Pet Milk Company Biglerville, Pennsylvania
5i	Chesapeake Foods Cordova, Maryland	17i	Howes Leather Company Frank, West Virginia
6i	Celotex Corporation L'Anse, Michigan	18i	American Stores Dairy Company, Fairwater, Wisconsin
7i	Gerber Products Co. Fremont, Michigan	19i	Libby, McNeill & Libby Janesville, Wisconsin
8i	Michigan Milk Producers Assoc., Ovid, Michigan		
9i	Simpson Lee Paper Co. Vicksburg, Michigan		
10i	Green Giant Company Montgomery, Minnesota		
11i	Stokely Van Camp Fairmont, Minnesota		
12i	H.J.Heinz Company Salem, New Jersey		

Table 14. Facilities Visited by APWA, Data Not Tabulated

No.	Name	Reason
1	Barstow, California	Irrigate only sewage treatment plant grounds
2	Madera, California	Infiltration-percolation
3	Porterville, California	Infiltration-percolation
4	Visalia, California	Flow discharged to ditch All flow used by abutting property owner
5.	Whittier Narrows, California	Infiltration-percolation
6	Yuba City, California	Infiltration-percolation
7	Nantucket, Massachusetts	Infiltration-percolation
8	Scituate, Massachusetts	Infiltration-percolation
9	Gallup, New Mexico	Facility abandoned
10	Hobbs, New Mexico	Facility abandoned

Table 15. Responses to Mail Survey by APWA

No.	Agency and State	No.	Agency and State
	A. MUNICIPAL		
	ARIZONA	17	City of Hanford
1	City of Winslow, WW Plant	18	City of Healdsburg
	CALIFORNIA	19	City of Kerman
		20	City of Kingsburg
2	City of Banning	21	City of Leucadia
3	City of Brentwood	22	City of Loyalton
4	Buellton Comm. Dist.	23	City of Patterson
5	City of Corning	24	City of Pinedale
6	City of Corcoran	25	City of Pixley
7	Co. Dept. of Honor Camps	26	Pomerado Co. Water District
8	Cutler Public Utilities Dist.	27	City of Paso Robles
9	City of Dixon	28	City of Reedley
10	City of Elsinore	29	City of Ripon
11	Dept.of Parks & Rec. San Diego	30	City of Riverbank
		31	City of Riverside
12	Eastern Mun. Water Dist., San Jacinto	32	San Bernardino County Special Districts Div.
13	City of Escalon	33	San Juan Bautista
14	Fallbrook Sanitary District	34	City of Santa Paula
15	City of Greenfield	35	City of Santa Rosa
16	City of Gridley	36	City of Soledad

Table 15. (Continued)

No.	Agency and State	No.	Agency and State
	CALIFORNIA	53	Village of Middleville
37	Strathmore Pub. Util. Dist.	54	Ottawa County, Co. Road Commission
38	Terra Bella Sewer Main. Dist.		MONTANA
39	City of Tipton	55	City of Helena
40	City of Tulare	56	City of West Yellowstone
41	City of Tuolumne		NEBRASKA
42	Valley Center Munic. Water District	57	City of Grant
			NEVADA
43	Waterford Comm.Serv. District	58	City of Winnemucca
			NEW MEXICO
44	Westwood Comm. Serv. District	59	City of Lovington
45	Wheatland Dept. of Public Works		NORTH DAKOTA
46	City of Woodland	60	City of Dickinson
	KANSAS		OKLAHOMA
47	City of Scott City	61	Boise City
48	City of Sublette		OREGON
	MICHIGAN	62	City of Bend
49	Village of Cassopolis		TEXAS
50	City of East Jordan	63	City of Cotulla
51	Harbor Springs Area, Sewage Disposal Auth.	64	City of Coleman
52	City of Harrison	65	City of Comanche
		66	City of Dalhart

Table 15. (Continued)

No.	Agency and State	No.	Agency and State
	TEXAS	73	City of Ralls
67	City of Denver City	74	City of San Saba
68	City of Elsa	75	City of Seagraves
69	City of Goldthwaite	76	City of Van Horn
70	City of Idalou	77	City of Winters
71	City of Morton		WASHINGTON
72	City of Munday	78	City of Soap Lake

No.	Name, City, and State	No.	Name, City and State
	B. INDUSTRY		
1	Beardmore, Div. of Can Packers, Acton, Ontario, Canada	11	Simpson Lee Paper Co. Kalamazoo, Michigan
2	Simpson Lee Paper Co. Redding, California	12	Green Giant Company Blue Earth, Minnesota
3	Joan of Arc Company (Princeville-Peoria) Illinois	13	Green Giant Company Cokato, Minnesota
4	Joan of Arc Company (Hoopeston-Vermilion) Illinois	14	Green Giant Company Winsted, Minnesota
5	Green Giant Company Belvidere, Illinois	15	Borden Co., Comstock Foods, Waterloo, New York
6	Campbell Soup Company Saratoga, Indiana	16	H.P.Cannon & Sons,Inc. Dunn, North Carolina
7	Popejoy Poultry Logansport, Indiana	17	The Beckman & Gast Co. Mercer, Ohio
8	Weston Paper & Mfg.Co. Terre Haute, Indiana	18	Crown Zellerbach Baltimore, Ohio
9	Albany Cheese, Inc. Grayson, Kentucky	19	Deeds Bros.Dairy, Inc. Lancaster, Ohio
10	Duffy-Mott Co., Inc. Hartford, Michigan	20	Libby, McNeill & Libby Liepsic, Ohio

Table 15. (Concluded)

No.	Name, City, and State	No.	Name, City, and State
21	Sharp Canning, Inc. Rockford, Ohio	29	Green Giant Co. Ripon, Wisconsin
22	Campbell Soup Co. Paris, Texas	30	Green Giant Co. Rosendale, Wisconsin
23	Tooele City Corp. Tooele, Utah	31	Hoffman Corners Coop Creamery Kendall, Wisconsin
24	Lamb-Weston Div. of Amfac Connell, Washington	32	Kansas City Star Co. Park Falls, Wisconsin
25	Alto Coop Creamery Astico, Wisconsin	33	Kimberley Clark Niagara, Wisconsin
26	Cobb Canning Co. Cobb, Wisconsin	34	Loyal Canning Co. Loyal, Wisconsin
27	Frigo Cheese Corp. Wyocena, Wisconsin	35	Mammoth Spring Canning Oakfield, Wisconsin
28	Green Giant Co. Fox Lake, Wisconsin	36	Oconomowoc Canning Co. Sun Prairie, Wisconsin

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Pound, C. E., and Crites, R. W.

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16. Abstract

A nationwide study was conducted of the current knowledge and techniques of land application of municipal treatment plant effluents and industrial wastewaters. Selected sites were visited and extensive literature reviews were made (annotated bibliography will be published separately). Information and data were gathered on the many factors involved in system design and operation for the three major land application approaches: irrigation, overland flow, and infiltration-percolation. In addition, evaluations were made of environmental effects, public health considerations, and costs--areas in which limited data are available. Irrigation is the most reliable land application technique with respect to long term use and removal of pollutants from the wastewater. It is sufficiently developed so that general design and operational guidelines can be prepared from current technology. Overland flow was found to be an effective technique for industrial wastewater treatment. Further development is required to utilize its considerable potential for municipal wastewater treatment. Infiltration-percolation is also a feasible method of land application. Criteria for site selection, groundwater control, and management techniques for high rate systems need further development.

17a. Descriptors

*Irrigation systems, *Design criteria, *Wastewater treatment, *Costs, *Groundwater recharge, *Public health, *Environmental effects, *Sewage treatment, *Industrial wastes, Climatic zones, Reclaimed water, Wastewater disposal, Soil treatment, History, Crops, Percolation

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