DEVELOPMENTS IN LAND METHODS OF WASTE WATER TREATMENT AND UTILISATION

EXECUTIVE EDITOR
S. H. JENKINS

DEVELOPMENTS IN LAND METHODS OF WASTEWATER TREATMENT AND UTILISATION

Proceedings of a Conference held at
THE UNIVERSITY OF MELBOURNE
MELBOURNE, VICTORIA, AUSTRALIA
23-27 October 1978

EXECUTIVE EDITOR — S. H. JENKINS

SPONSORS

THE INTERNATIONAL ASSOCIATION ON WATER POLLUTION RESEARCH
THE AUSTRALIAN NATIONAL COMMITTEE OF IAWPR
THE AUSTRALIAN WATER AND WASTEWATER ASSOCIATION
THE ASIAN REGIONAL DIVISION OF
THE INTERNATIONAL ASSOCIATION OF HYDRAULIC RESEARCH
THE MELBOURNE AND METROPOLITAN BOARD OF WORKS
THE UNIVERSITY OF MELBOURNE
and
THE COMMONWEALTH SCIENTIFIC AND INDUSTRIAL
RESEARCH ORGANISATION, DIVISION OF CHEMICAL TECHNOLOGY

PERGAMON PRESS

OXFORD · NEW YORK · TORONTO · SYDNEY · PARIS · FRANKFURT

Conference President

Mr. A. H. Croxford, LLB, Chairman
Melbourne and Metropolitan Board of Works

Conference Organizing Committee

Chairman

Mr. W. J. Robertson

Vice-Chairmen

Dr. M. J. Flynn
Mr. D. J. Lane
Mr. J. S. F. Rogerson

Secretary

Mr. J. H. Greer

Members

Mr. F. B. Barnes
Professor J. D. Lawson
Dr. N. E. Norman
Mr. C. D. Parker
Mr. N. J. Sutherland
Dr. D. E. Weiss

Volume 11
Numbers 4/5
1979

PROGRESS IN
WATER TECHNOLOGY

A Journal of the International Association on Water Pollution Research for the Rapid Publication of Conference Proceedings that Record Important New Advances and their Applications in all Fields of Water Pollution Control

DEVELOPMENTS IN LAND METHODS OF WASTEWATER TREATMENT AND UTILISATION

Proceedings of a Conference held in Melbourne, October 1978

CONTENTS

Continued from outside front cover

Prog. Wat. Tech. Vol.11, Nos 4/5, pp.1-14. 0306-6746/79/0801-0001 $02.00/0
Pergamon Press Ltd. 1979. Printed in Great Britain.

LAND TREATMENT METHODS IN PERSPECTIVE

Curtis C. Harlin, Jr.

Chief, Wastewater Management Branch, Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma, U.S.A.

ABSTRACT

Land treatment systems have been used for many years in countries around the world for disposal of wastewater and sludges. In recent years, there has been a renewed interest in the use of these systems with the emphasis on treatment rather than disposal. This interest has resulted from several factors including economics, benefits of recycle and reuse of valuable resources, and energy conservation. Research programs are being conducted in areas of major concern which impede the use of land treatment. Major research efforts relate to health effects, nutrient management, and agricultural aspects. Other areas which are being researched include economics, legal and institutional questions, insect and other vector problems, environmental impacts, and design criteria development. An indication of the magnitude of this research effort and the identification of some of the researchers involved in various areas is presented.

INTRODUCTION

The use of the land as a receptor of wastewater has been practiced for hundreds of years throughout the world. History records that irrigation with wastewater was practiced in Athens before the birth of Christ (Metcalf and Eddy, 1972). Sewage farming was used in Germany as early as the sixteenth century (DeTurk, 1935) and was common in England until the late 1800's (Wolman, 1977). Sewage farming was first introduced in the United States in the 1870's (Rafter, 1899). Other countries in Europe and Asia have long histories of applying their wastewaters to the land.

With these early practices, some agricultural benefits were undoubtedly realized, however, the primary consideration was disposal of the wastewater. The concept of treatment and management of the wastewater for beneficial reuse was probably given very little thought. Because of the availability of land and sparse populations, this manner of handling wastes produced by communities was generally acceptable.

As populations increased and land became more difficult to reserve for this purpose, the use of sewage farms declined. A major factor in this decline was also concern for public health. As populations became more concentrated, the threat of waterborne diseases increased resulting in the development of new wastewater treatment processes. The old type sewage farms were not designed with wastewater treatment in mind and were, therefore, unable to meet the sanitary requirements of the day.

In a meeting such as this, having in attendance representatives from many different countries, there is probably a need for some consideration of definitions. There is apparently a lack of standardization in terminology in the area of land treatment technology. There is even different terminology used when referring to the general area itself.

The practice of applying wastewaters to the land may be called land treatment, land application, or soil treatment. At times, one hears this practice referred to as "land disposal"; however, this is totally inappropriate in view of the modern day concept of using the soil as a treatment medium.

In the United States, there is gradually developing a standard designation for three recognized types of land treatment systems: slow rate, rapid infiltration, and overland flow. Slow rate refers to irrigation systems where the application rate will range between 0.6 m (2 ft) and 6 m (20 ft) per year with typical weekly application rates of 1.27 cm (0.5 in.) to 10.16 cm (4 in.) (USEPA, 1977). These systems are more often than not called wastewater irrigation systems; and, in some areas, they are referred to as land filtration systems.

Rapid infiltration refers to systems receiving application rates as great as 152 m (500 ft) per year. These systems are suitable only for highly permeable soils such as sands, sandy loams, and loamy sands. The objective of these systems is the treatment of the wastewater as it percolates through the soil. Agricultural practices are normally not a part of these systems. In fact, a vegetative cover is usually not necessary. These systems are also referred to as infiltration-percolation systems.

Overland flow systems receive annual loading rates in the range of 3 m (10 ft) to 21 m (70 ft), depending to a large extent on the type of pretreatment (USEPA, 1977). These systems are suitable for use on impermeable soils which have very limited infiltration capacity. The applied wastewater is treated as it moves down carefully graded slopes in sheet flow. A vegetative cover is necessary to prevent erosion of the slopes and may produce a valuable crop. These systems are also referred to as grass filtration or spray-runoff systems.

CURRENT STATUS

In the United States, land treatment of municipal wastewaters has been used for the past 100 years. During this time, many systems have been abandoned for various reasons; but, there are numerous systems currently in operation which have long histories of operation. The exact number of systems in operation at the present time is not known but, considering all sizes and types, there are probably many hundreds.

In many countries, there appears to have been a more consistent attitude, through time, toward land treatment than has prevailed in the United States. Thus, we find systems which have been in continuous operation for very long periods of time in Germany, Poland, France, Australia, and other countries.

Within the past decade, there has been a renewed interest in many parts of the world in the use of land treatment for wastewaters. This has resulted from several factors. Whether coincidental or not, the start of this new interest appears to be closely related to the widespread concern for environmental issues which arose in the mid to late 1960's. As a result of the renewed interest in land treatment in the United States, several things have occurred which have given added impetus and encouragement to its use.

The Federal Water Pollution Control Act Amendments of 1972 declared: "it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985." The act also provided that the Administrator of the Environmental Protection Agency (EPA) "shall encourage waste treatment management which results in the construction of revenue producing facilities providing for the recycling of potential sewage pollutants through the production of agriculture, silviculture, or aquaculture products, or any combination-thereof." Following the passage of this legislation, the EPA adopted the policy

that land treatment must be evaluated as an alternative for all wastewater treatment systems funded under its Construction Grants Program. The Construction Grants Program of the EPA is the major source of funds for construction of all municipal treatment systems within the United States.

In October of 1977, the EPA Administrator issued a much stronger policy statement which stated that ". . . the Agency will press vigorously for publicly owned treatment works to utilize land treatment processes to reclaim and recycle municipal wastewaters."

The most recent impetus to utilizing land treatment came with the passage of the 1977 Amendments to the Federal Water Pollution Control Act. These amendments include the provision that the EPA ". . . Administrator shall not make grants . . . to any state, municipality, or intermunicipal or interstate agency for . . . treatment works unless the grant applicant has satisfactorily demonstrated . . . that innovative and alternative wastewater treatment processes and techniques which provide for the reclaiming and reuse of water, otherwise eliminate the discharge of pollutants, and utilize recycling techniques, land treatment, new or improved methods of waste treatment management for municipal and industrial waste . . . have been fully studied and evaluated . . . ." The act further provides for certain monetary incentive for the construction of land treatment systems. The government of the United States is thus strongly committed to the implementation of land treatment systems where they are an acceptable alternative. It is not known if similar legislative actions have been taken in other countries; nevertheless, from what is reported in the literature, there are other countries that appear to be equally interested in the adoption of land treatment practices.

ATTITUDES TOWARD LAND TREATMENT

In recent years, the concept of land treatment of wastewaters has changed drastically. Prior to this time, these systems were generally considered to be disposal systems with little or no thought given to their treatment capability or their potential for wastewater recycle for beneficial reuse. Land treatment systems are now considered to be systems which are to be designed to achieve a predetermined result just as any of the more "conventional" mechanical processes. This change in concept has not resulted in universal adoption of these systems as alternatives to other types of systems. As would be expected, there is a wide range of attitudes toward land treatment utilization, both positive and negative.

Positive Factors

Some of the major positive attitudes relate to the following factors: (1) economics, (2) recycle and reuse of water and wastewater constituents, (3) energy conservation, and (4) use of natural processes.

At many locations, the total annualized cost of a land treatment system including construction, operation, and maintenance can be less than other alternative processes. Construction costs will be influenced significantly by the cost of land and the distance the wastewater must be transported. Pretreatment requirements may also have a significant impact on original costs if it is a part of the original construction (Pound, 1975). Operating and maintenance costs may be quite low depending on the type of system and pumping requirements. The net result of low cost wastewater treatment should be reflected in the charges paid by the users of the system. In Muskegon County, Michigan, sewer user charges in 1976 were lower than any of several systems surveyed with the exception of one large system which provided primary treatment only (USEPA, 1976). Muskegon County wastewater is treated by a modern design, slow rate, land application system.

The recycle and reuse aspects of land treatment are positive factors which are cited in favor of these systems. The value of wastewater for crop irrigation has been recognized for years in arid and semiarid regions of the world, such as some parts of Mexico (Aquirre, 1977). The use of land treatment is also increasing in importance in the more water plentiful areas as a beneficial conservation measure. The nitrogen and phosphorus contained in municipal and some industrial wastewaters are valuable plant nutrients which can be of significant economic value in wastewater irrigation. The scientific literature of the past few years reports results of many studies on the beneficial effects of wastewater nutrients on plant growth. In addition to the principal nutrients, wastewaters also contain other elements which may be beneficial.

In the past five years, the world has become extremely conscious of energy requirements and the need to reduce these requirements where possible. Land treatment of wastewater is considered by many to be a less energy-intensive alternative than mechanical systems. Very few comprehensive studies have been made on the subject to date. Those who cite this advantage point not only to the operating requirements for energy but to energy savings resulting from such factors as less material required for construction and the absence of the need for chemicals. It is claimed that when all energy inputs are totaled, the results are favorable for land treatment.

The final positive factor to be discussed is one which cannot be quantified with any degree of accuracy. Some proponents of land treatment feel strongly that there is an advantage for these systems in the fact that they use natural processes and, therefore, are more environmentally acceptable. A part of this positive factor is the benefit derived in enhancing the environment by creation of greenbelts, open spaces, and various types of recreational areas. Indeed, wastewater is being used at numerous locations for park and landscape watering, maintenance of golf courses and athletic fields, and recreational lakes and ponds. This factor, while worthy of consideration, is probably the least compelling positive factor because of the difficulty in accurately assessing the economic benefits accruing from it.

Negative Factors

Most negative attitudes to land treatment relate to the following factors: (1) public health, (2) long-term effects, (3) land requirements, and (4) public acceptance.

Possible adverse health effects raise the most serious questions regarding the use of land treatment for municipal wastewaters. It is quite appropriate that these effects be seriously considered in view of the consequences of the spread of waterborne diseases. The most commonly expressed concerns relate to pathogens, heavy metals, and toxic organic compounds. The concern regarding pathogens includes the fate and effects of bacteria, viruses, and parasites in the air, soils, crops, and groundwaters. The transmission of disease through direct contact with the applied wastewater, by aerosol transport, through the human food chain, and from contaminated groundwater are major considerations (Barth, 1978).

Heavy metals in applied wastewater are of concern because of their potential uptake by crops and, thereby, their entrance into the human food chain. Also, there is concern for heavy metals buildup in the soil to phytotoxic levels and their migration to groundwater. A large fraction of metals in wastewaters is accumulated in the sludge during conventional treatment; therefore, land application of sludges is of more concern relative to the heavy metals problem than is wastewater application (Garrigan, 1977). There is, nevertheless, some concern with land treatment of wastewater.

The implication of the presence of toxic organic compounds in wastewaters and sludges has become a concern only relatively recently. Some of these compounds are either suspected or proven mutagens and carcinogens. There is, therefore, much interest in learning of their fate and transport in land treatment systems, their effects on the food chain, and potential for groundwater contamination (Dacre, 1978).

Even though there are land treatment systems in existence which have had many years of operation, there is concern for the long-term effects of these systems on the environment. This concern includes the possibility of permanent damage to the soil profile by accumulation of metals, organics, and inorganic salts. The fear is expressed that permanent irreversible damage can be done to a land treatment site even if wastewater application is suspended. The problem of groundwater contamination is also cited as a possible long-term effect because of the inability to restore its quality other than by very slow natural processes.

A large land requirement is seen by some as a disadvantage of land treatment systems. Land requirements can vary over a wide range depending not only on the size of systems but the type of system. Slow rate systems (irrigation) have the largest land requirements which can be as great as 227 ha (560 acres) for a daily flow of 3785 m^3 (1 M gal) while rapid infiltration can require as little as 0.8 ha (2 acres) for the same flow (USEPA, 1977). Overland flow systems are intermediate between slow rate and rapid infiltration. For an irrigation system with low rates of application, land availability could be a problem in some locations although land requirements for rapid infiltration may be no more than for some of the mechanical plants.

Public acceptance of land treatment, in general, tends to be negative. These attitudes are influenced by many factors including lack of understanding, selfish interests, resistance to new or different concepts, and institutional conventions. An informed public is essential to rational decisions. It is equally essential that public information regarding land treatment be accurate and complete. The scientific community must assume the primary responsibility for a well informed public regarding land treatment of wastewaters.

CURRENT RESEARCH

During the past decade, there has been a great increase in research in various aspects of land treatment of wastewaters and sludges. Much of this research is directed to providing data relative to the problem areas just discussed. Sufficient data must be obtained to either verify the existence of a suspected problem or to positively prove that a suspected problem does not exist. Where problems are found to be real, research must provide the means whereby these problems can be minimized or eliminated. For problems that cannot be entirely eliminated, research must provide data for rational decisions regarding risk assessments.

Research in land treatment technology is being conducted in many different subject areas. The following discussion is not intended to be a comprehensive review of current research in land treatment. Neither is any attempt made to evaluate or compare research results. It is intended to present the general areas being researched, an indication of the magnitude of the efforts, and the identification of some of the researchers involved in the various areas.

Health Effects

Research concerning the health aspects of land treatment is being given high priority. This research is concerned with the possible risks of disease transmission and toxic reactions from aerosol drift from sprinkler systems, through food chain components, by ingestion of wastewater or water sources contaminated by wastewater, and by direct human contact.

Research interests include infectious disease organisms, heavy metals, and organic and toxic compounds.

Infectious Disease Organism. Research related to infectious disease organisms in land treatment includes viruses, bacteria, and parasites. Much of the research in the United States has been concerned with viruses. Wellings has studied virus survival and movement through the soil (Wellings, 1978), Sorber has conducted research on transport of viruses in aerosolized wastewaters (Sorber, 1976), and Schaub has evaluated virus removal in overland flow treatment of municipal wastewaters (Schaub, 1978). A symposium was held at the University of Florida during June 1976 on virus aspects of applying municipal wastes to land. The published proceedings of this meeting includes 15 papers dealing with various research topics in this area (University of Florida, 1976).

Many research investigations include data on bacterial transport and survival in land treatment systems. In the United States, recent studies have reported on the movement through the soil, die-off rates, contamination of crops and groundwater, and effects on livestock (Weaver, 1978; Pound, 1978; Benham Blair & Affiliates, Inc., 1978; Larkin, 1978; Guentzel, 1978). Many studies have also been done in other countries including Canada (Ehlert, 1973), Denmark (Kristensen, 1977), Mexico (Aquirre, 1977), East Germany (Hirte, 1970), Poland (Szyfelbejn, 1965; Wachnik, 1963; Bocko, 1975), and the USSR (Wierzbicki, 1966).

Research has been conducted on transmission of parasitic diseases to animals and man by means of land application of municipal wastewaters. A significant study was recently completed at the San Angelo, Texas, wastewater irrigation site (Weaver, 1978). This study indicated that parasites did not increase in cattle grazed on wastewater irrigated pastures during the period of the study. These results are similar to those reported earlier in Poland (Patyk, 1958; Jankiervicz, 1972). Extensive studies have also been performed by the Melbourne and Metropolitan Board of Works in Australia to determine parasite problems in cattle and sheep grazed on wastewater irrigated pastures.

Heavy Metals. Heavy metals are important in land treatment because of their uptake by plants, their possible migration to groundwaters, and their toxicity to plants at high levels in the soil.

The metals found in wastewaters which are of primary concern are nickel, manganese, lead, chromium, cadmium, tin, zinc, copper, iron, mercury, molybdenum, and aluminum. All of these metals can have adverse effects above certain concentrations; however, cadmium causes the most concern from a human health standpoint (Lucas, 1978). The concentration of any of the metals depends to a great extent on the amount of industrial contribution to the wastewater system. In wastewaters from domestic sources only, the concentration of most of the metals is usually very low.

During treatment of wastewater by conventional processes, a large amount of heavy metals are accumulated in the sludge fraction. The effluent normally has low heavy metal concentrations and may pose no problem if applied to the land. When sludge is applied to the land, greater care must be exercised to avoid problems from heavy metals.

Because the problems of heavy metals are more pronounced with land application of sludge than with wastewater application, more research has dealt with sludge. Garrigan has reviewed various guidelines for sludge application to the land and found wide variation (Garrigan, 1977). Chaney reviewed factors controlling metal toxicity to plants, dangers to the food chain from metals, factors affecting plant accumulation, and presented interim recommendations for permissible levels for addition to agricultural soils (Chaney, 1973).

Sidle compared the effects of soil receiving effluent and sludge with soil receiving effluent only (Sidle, 1977).

An interesting study of two farms in the Netherlands is presented by de Haan; one had received treated wastewater for 50 years while the other received sewage sludge for 15 years (de Haan, 1977). Heavy metal concentrations reported were considerably higher on the farm receiving the sludge as compared to the one receiving wastewater only.

Organic and Toxic Compounds. The widespread application of various pesticides and other toxic substances and the increasing number of organic compounds in daily use has resulted in increasing concentrations of some of these materials in wastewaters and sludges. The presence of these materials in wastewaters applied to land has caused concern in recent years. There has been very little research done relative to this concern. Dacre looked at toxic organic chemicals in municipal wastewaters and sludges and found the dominant compounds to be organochlorine insecticides and chlorinated phenolics (Dacre, 1978). He presents the concept of Soil Pollutant Limit Values to control the hazard levels of toxic compounds in soils.

In a survey of the Muskegon County, Michigan, wastewater irrigation system, 56 organic compounds were identified in the raw wastewater entering the system. Approximately 60% of the contribution to the system is of industrial origin. Twenty compounds were identified in the water which was applied to the land following aerated lagoon treatment and storage. Only seven organic compounds, at low levels, were identified in the samples collected from the tile underdrains. Five of these were found in the influent wastewater, one (atrazine) was from herbicide applied to the irrigated fields, and the other compound was of unknown origin (Ground Water Research Branch, 1977). The conclusion was that the system appeared to be relatively quite effective in removing organic pollutants.

Nutrient Management

Much research has been conducted to determine the best utilization of wastewater nutrients, primarily nitrogen and phosphorus, to maximize their beneficial use without creating adverse conditions. Most municipal wastewaters contain significant concentrations of nitrogen and phosphorus in various form. Both nitrogen and phosphorus can be serious pollutants if discharged to surface waters. Nitrogen can cause potential health problems if it reaches the groundwaters. When applied to the land, these materials can be a valuable plant nutrient and have considerable economic value in agriculture. Most of the research dealing with nitrogen and phosphorus in wastewaters applied to the land has been concerned with loading rates for different soil types; optimum application rates for plant uptake; mechanisms involved in transformations, retention, and movement in the soil; and management practices for controlling phosphorus and nitrogen behavior in land treatment systems.

Broadbent has investigated the transformation of nitrogen forms through nitrification and denitrification reactions. He concluded that minimization of pollution from nitrate in land treatment requires management of the denitrification process (Broadbent, 1977). Enfield presents a system for optimizing denitrification in soil columns using a servo controller (Enfield, 1977). Several studies have been conducted to determine changes on soil, groundwater, and crops, with respect to nitrogen levels on land treatment sites versus sites not receiving wastewater (Pound, 1978; Benham Blair & Affiliates, Inc., 1978; Reynolds, 1977).

Research investigations of phosphorus in land treatment systems have been concerned primarily with sorption kinetics and retention capacity of various soil types. Black, in Canada, investigated phosphorus removal in a spray irrigation system receiving stabilization pond effluent (Black, 1972). Thomas reported on increasing phosphorus removal in an overland

flow system by alum additions (Thomas, 1976). Enfield reported on the kinetics of phosphorus in several different types of soil (Enfield, 1975). Subbarao has presented models for predicting phosphorus movement in soils having widely varying physical and chemical properties (Subbarao, 1977). Studies have also been reported to determine changes in phosphorus level with time in soils receiving wastewater over extended periods (Pound, 1978; Benham Blair & Affiliates, Inc., 1978; Reynolds, 1977).

Agricultural Aspects

One of the advantages of land treatment is the recycle and reuse of wastewater and wastewater constituents for beneficial purposes. Many studies have been conducted to determine the effects on crop and livestock production. The objective of agricultural-based land treatment is to maximize production while optimizing the treatment aspects of the system. The primary objective of any land treatment system must be the treatment of the applied water to meet water quality requirements. At times, the treatment aspects of land application may be in conflict with agricultural production goals. With well designed and operated systems, however, the operator should be able to realize a significant revenue from these systems.

Most of the research on irrigation with wastewater has been concerned with yield studies, plant quality, and determining response of various types of plants. Studies have also addressed the effects on livestock grazed on wastewater irrigated pastures or feed crops raised on wastewater irrigated lands. Generally, the results of these studies have shown benefits to agriculture.

Studies have been conducted in many parts of the world on a wide variety of crops. In Poland, studies have included hops (Baranowski, 1970), willow trees (Bialkiewicz, 1968), various grasses (Biernacka, 1970), poplar trees (Bialkiewicz, 1968), and fruit trees (Kutera, 1968). In the USSR, studies are reported on lucerne and corn (Chrustowa, 1974) and barley, peas, and sunflower (Mazejko, 1965). Other crops that have been studied are spruce trees in East Germany (Schwarz, 1969), and pumpkin and pepper in Bulgaria (Syjeu, 1964). In the United States, studies have been reported on pearl millet (Overman, 1975), sugar cane (Dugan, 1975), and corn (Demirjian, 1978). Reynolds irrigated a wide variety of plants with wastewater including alfalfa, beans, carrots, corn, lettuce, onions, peas, potatoes, radishes, tomatoes, and wheat (Reynolds, 1977). He reported that all plants in this study exhibited greater growth than controls not receiving wastewater and that, generally, the levels of heavy metals in the plants were lower than amounts reportedly harmful.

Other Research

Research has been conducted in other subject areas, usually to a lesser extent than those already discussed. Some of these studies deal with economics, legal and institutional questions, insect and other vector problems, environmental impacts, and design criteria development. The goal of most of the research areas which have been discussed is to develop design criteria to achieve the most efficient and cost-effective treatment and management of our municipal wastewaters. Good progress has been made already in achieving this goal. More attention will probably need to be focused on the non-technical aspects of land treatment in the future as we move closer to developing the technology of these systems.

SUMMARY

Land treatment of wastewaters has been practiced for centuries in many parts of the world. In recent years, there has been a renewed interest in these systems and in the development of sound design criteria for their use as alternative treatment processes. While there is widespread interest in utilizing land treatment where appropriate, there is

a wide range of attitudes, both positive and negative, toward these systems.

Some major positive attitudes regarding land treatment relate to economics, recycle and reuse of water and wastewater constituents, energy conservation, and use of natural processes. Some of the most commonly held negative attitudes relate to public health, long-term effects, land requirements, and public acceptance.

During the past decade, there has been a great increase in research directed to providing information regarding possible problems associated with land treatment of wastewaters and sludges and the development of design and operation criteria. High priority is being given to research regarding public health questions. Health research is generally concentrated on the fate and effects of infectious disease organisms, heavy metals, and organic and toxic compounds. Major research efforts are also being conducted in nutrient management, primarily nitrogen and phosphorus, and agricultural aspects including both crop and livestock production.

The use of land treatment appears to offer an attractive approach to wastewater management in many situations. Planners, designers, and public officials should make certain that these systems are utilized to their fullest extent where technically sound and cost effective. They should be equally certain that they are not used under circumstances that would not be in the public's best interests. It is felt that as research and experience expand our knowledge of these systems, many of the present restraints on their utilization will be lifted resulting in increased benefits to users in many parts of the world.

REFERENCES

AQUIRRE, J. and URROZ, E. (1977) "Water Reclamation and Wastewater Reuse for Irrigation of Agricultural Lands in Mexico," Wastewater Renovation and Reuse, Frank M. D'Itri, ed., Marcel Dekker, Inc., New York, NY, pp. 1-33.

BARTH, D.S. (1978) "EPA's Research and Development Program on the Health Effects of Land Application of Municipal Wastewater and Sludges," Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, The Center for Applied Research and Technology, The University of Texas at San Antonio, San Antonio, TX; Bernard P. Sagik and Charles A. Sorber, eds., pp. 1-8.

BARANOWSKI, A. and KUTERA, J. (1970) "Experiments on Hop Irrigation with Municipal Sewage," Wiad. Inst. Melior. 9, f. 13, p. 101-114, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 001, p. 1.

BENHAM BLAIR & AFFILIATES, INC. (1978) "Long-Term Effects of Applying Domestic Wastewater to the Land, Roswell, New Mexico, Slow Rate Irrigation Site," Prepared for U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, under Contract No. 68-02-2363 (In preparation).

BIALKIEWICZ, F. and NOWINSKI, S. (1968) "The Effect of Irrigation with Urban Sewage of Willow Shrubs Plantation on Crop Volume and Quality," Pr. Inst. Bad. Les., No. 342, p. 307-363, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 002, pp. 2-4.

BIERNACKA, E. (1970) "Effect of Irrigations with Sewage on Content of Trace Elements in Meadow Plants and Hay," Rocz. Nauk rol. Seria F, 77, f. 4, p. 569-582, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 003, pp. 5-7.

BLACK, S. A. and RUPKE, J. W. G. (1972) "An Interim Report on the Phosphorus Removal Activities of the Research Branch Ministry of the Environment," Research Branch Paper No. W2031, Ministry of the Environment, Toronto, Ontario, Canada, 28 pp.

BOCKO, J. (1975) "Qualitative and Quantitative Changes of Ground Waters on Fields Irrigated with Sewage," Non published. Agriculture Academy in Wroclaw, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 170, pp. 248-250.

BROADBENT, F. E., PAL, D., and AREF, K. (1977) "Nitrification and Denitrification in Soils Receiving Municipal Wastewater," Wastewater Renovation and Reuse, Frank M. D'Itri, ed., Marcel Dekker, Inc., New York, NY, pp. 321-348.

CHANEY, R. L. (1973) "Crop and Food Chain Effects of Toxic Elements in Sludges and Effluents," Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land, National Association of State Universities and Land-Grant Colleges, One Dupont Circle, N.W., Washington, DC, pp. 129-141.

CHRUSTOWA, T. N. (1974) "The Effect of Irrigation with Distillery Sewage on Crop Yields of Lucerne and Corn and Soil Salinity," Melior. i vodn. chozj., f. 30, p. 31-41, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 010, pp. 15-17.

DACRE, J. C. (1978) "The Potential Health Hazards and Risk Assessment of Toxic Organic Chemicals in Municipal Wastewaters and Sludges with Special Reference to Their Effects on the Food Chain," Proceedings of the Conference on Risk and Health Effects of Land Application of Municipal Wastewater and Sludges, The Center for Applied Research and Technology, the University of Texas at San Antonio, San Antonio, TX; Bernard P. Sagik and Charles A. Sorber, eds., pp. 141-152.

de HAAN, F. A. M. (1977) "The Effects of Long Term Accumulation of Heavy Metals and Selected Compounds in Municipal Wastewater on Soil," Wastewater Renovation and Reuse, Frank M. D'Itri, ed., Marcel Dekker, Inc., New York, NY, pp. 283-319.

DEMIRJIAN, Y. A., KENDRICK, D. R., SMITH, M. L., and WESTMAN, T. R. (1978) "Muskegon County Wastewater Management System," Prepared for U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, Grant Project No. 802457 (In preparation).

DeTURK, E. E. (1935) "Adaptability of Sewage Sludge as a Fertilizer," Sewage Works Journal, 7, No. 4, p. 597.

DUGAN, G. L., YOUNG, R. H. F., LAU, L. S., EKERN, P. C., and LOH, P. C. S. (1975) "Land Disposal of Wastewater in Hawaii," Journal WPCF, Vol. 47, No. 8, pp. 2067-2087.

EHLERT, N. (1973) "Land Disposal of Lagoon Effluent at Shelburne," Research Branch Publication No. W 42, Ministry of the Environment, Toronto, Ontario, Canada, 37 pp.

ENFIELD, C. G. and BLEDSOE, B. E. (1975) "Kinetic Model for Orthophosphate Reactions in Mineral Soils," Environmental Protection Technology Series EPA-660/2-75-022, EPA, RSKERL, Ada, OK, June 1975, 133 pp.

ENFIELD, C. G. (1977) "Servo Controlled Optimization of Nitrification-Denitrification of Waste Water in Soil," Journal of Environ. Qual., Vol. 6, No. 4, pp. 456-458.

GARRIGAN, G. A. (1977) "Land Application Guidelines for Sludges Contaminated with Toxic Elements," Journal WPCF, Vol. 49, No. 12, pp. 2380-2389.

GROUND WATER RESEARCH BRANCH (1977), "Preliminary Survey of Toxic Pollutants at the Muskegon Wastewater Management System," USEPA, RSKERL, Ada, OK, 22 pp.

GUENTZEL, M. N. (1978) "Potential Impact on Water Resources of Bacterial Pathogens in Wastewater Applied to Land," Proceedings of the Conference on Risk and Health Effects of Land Application of Municipal Wastewater and Sludges, The Center for Applied Research and Technology, the University of Texas at San Antonio, San Antonio, TX; Bernard P. Sagik and Charles A. Sorber, eds., pp. 180-195.

HIRTE, W. F. (1970) "Biologico-Hygienic Aspects of Purification Efficiency in Sewage Disposal by Land Treatment," Dtsch. Akad. Landwirtschaftwiss. Berl. Tagungsber. 106, p. 93-104, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 192, pp. 274-275.

JANKIEWICZ, L. (1972) "Survival of Ascaris Eggs on Soils Irrigated with Communal Sewage," Zesz. nauk. A.R. - Wroc. Melioracje, XV, No. 90, p. 61-66, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 193, pp. 275-276.

KRISTENSEN, K. K. and BONDE, G. J. (1977) "The Current Status of Bacterial and Other Pathogenic Organisms in Municipal Wastewater and Their Potential Health Hazards with Regard to Agricultural Irrigation," Wastewater Renovation and Reuse, Frank M. D'Itri, ed., Marcel Dekker, Inc., New York, NY, pp. 387-419.

KUTERA, J. and SKWIERCZYNSKA, K. (1968) "Irrigation with Sewage of Berry Shrubs and Fruit Trees," Rocz. Nauk rol. Seria F, 77, f. 4, p. 611-623, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 046, pp. 66-67.

LARKIN, E. P., TIERNEY, J. T., LOVETT, J., DONSEL, D. V., and FRANCIS, D. W. (1978) "Land Application of Sewage Wastes: Potential for Contamination of Foodstuffs and Agricultural Soils by Viruses and Bacterial Pathogens,"

Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, The Center for Applied Research and Technology, The University of Texas at San Antonio, San Antonio, TX; Bernard P. Sagik and Charles A. Sorber, eds., pp. 102-115.

LUCAS, J. B., PAHREN, H. R., RYAN, J. A., and DOTSON, G. K. (1978) "The Impact of Metals Present in Municipal Sludges upon the Human Food Chain - A Risk Assessment," Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges, The Center for Applied Research and Technology, The University of Texas at San Antonio, San Antonio, TX; Bernard P. Sagik and Charles A. Sorber, eds., pp. 132-140.

MAZEJKO, A. (1965) "Utilization of Municipal Sewage Containing Phenol of Charkov for Agriculture Land Irrigation," Isdatielstwo "Kolos," Moskwa, p. 3-15, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 064, pp. 95-96.

METCALF & EDDY, INC. (1972) Wastewater Engineering: Collection, Treatment, Disposal, McGraw-Hill Book Company, New York, NY, 782 pp.

OVERMAN, A. R. (1975) "Effluent Irrigation of Pearl Millet," Journal Environ. Eng. Div., ASCE, Vol. 101, No. EE2, pp. 193-199.

PATYK, S. (1958) "Worms Eggs in Wroclaw Sewage and on Meadows and Pastures Irrigated with Municipal Sewage," Wiad, parazyt. 4, f. 5/6, p. 479-481, In Critical Review and Assessment of Polish Literature on Sewage Irrigation, Institute of Meteorology and Water Management (Wroclaw, Poland), Technical Interim Report No. 1 on Project JB-5-532-24, Dec. 1977, Abstract No. 205, pp. 288-289.

POUND, C. E., CRITES, R. W., and GRIFFES, D. A. (1975), Technical Report, Costs of Wastewater Treatment by Land Application, EPA-430/9-75-003, Prepared for U.S. Environmental Protection Agency, OWPO, Washington, DC, under Contract No. 68-01-0966, 156 pp.

POUND, C.E., CRITES, R. W., and OLSON, J. V. (1978), Long-Term Effects of Land Application of Domestic Wastewater, Hollister, California, Rapid Infiltration Site, EPA-600/2-78-084, Prepared for U.S. Environmental Protection Agency, RSKERL, Ada, OK, under Contract No. 68-03-2361 (In Press).

RAFTER, G. W. (1899), "Sewage Irrigation, Part II," USGS Water Supply and Irrigation Paper No. 22, USDI, Washington, DC, 41 pp.

REYNOLDS, J. H., ANDERSON, L. R., MILLER, R. W., and CAMPBELL, W. F. (1977) "Assessment of the Long-Term Effects of Applying Domestic Wastewaters to the Land at Tooele, Utah," (Interim Report: First Year Data), Prepared for U.S. Environmental Protection Agency, RSKERL, Ada, OK, under Contract No. 68-03-2360, 244 pp.

SCHAUB, S. A., KENYON, K. F., BLEDSOE, B., and THOMAS, R. E. (1978) "Evaluation of the Overland Runoff Mode of Land Wastewater Application for Virus Removal," In International Symposium on State of Knowledge in Land Treatment of Wastewater, Vol. 2, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, August 20-25, 1978, pp. 245-252.