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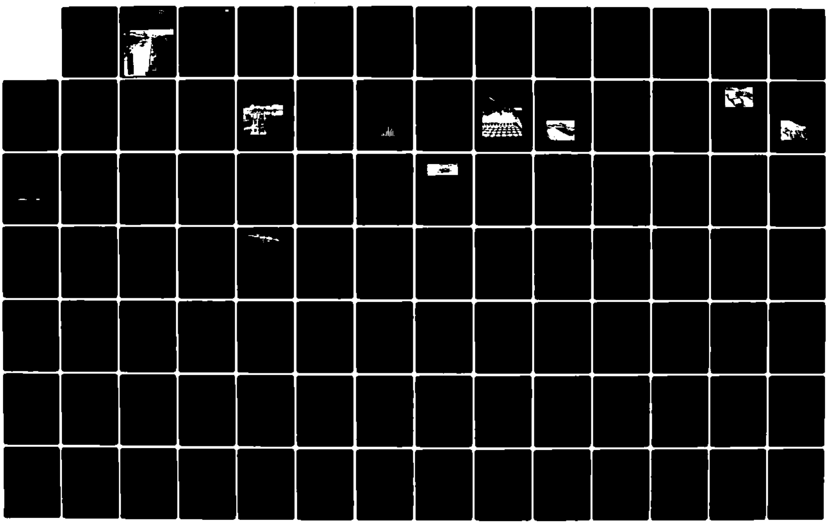

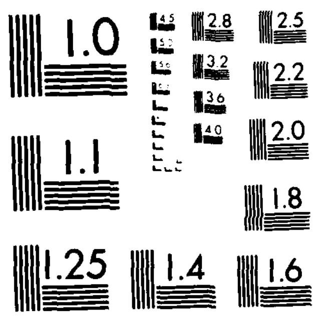
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REPORT 83-20

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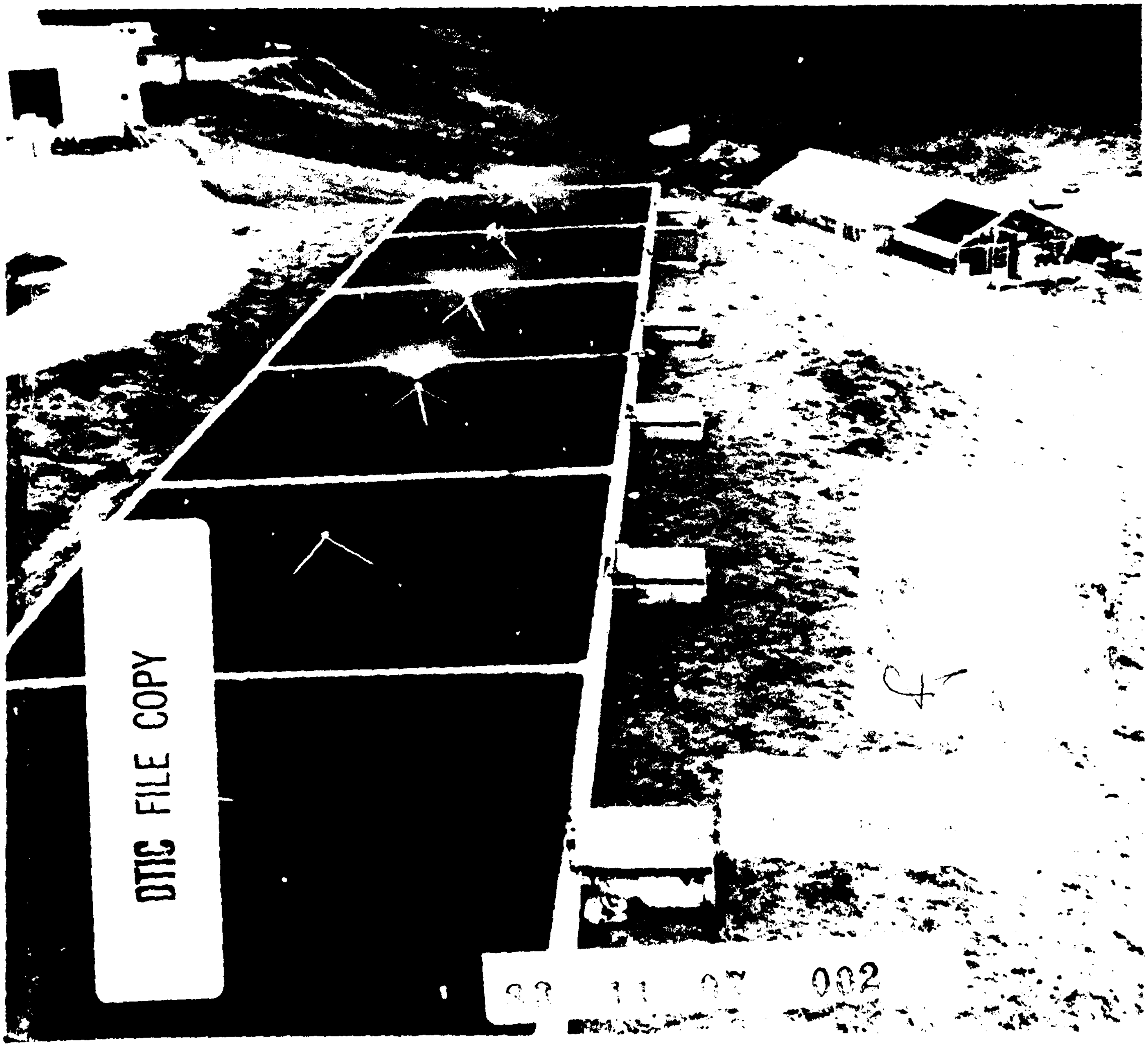
US Army Corps of Engineers

Cold Regions Research & Engineering Laboratory

Land treatment research and development program

Synthesis of research results



CRREL Report 83-20

August 1983

Land treatment research and development program

Synthesis of research results

I.K. Iskandar and E.A. Wright

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

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The major objective of the Corps of Engineers Land Treatment Research and Development Program was to provide, through research, definitive criteria and procedures to enable the cost-effective and environmentally safe use of land treatment of municipal wastewater. This research included long-term field experiments at different locations within the United States to establish design criteria, laboratory research to understand and solve fundamental problems, and evaluation of existing land treatment systems to document long-term performance. The information gathered from the land treatment research program has been published in more than 240 technical publications on regional planning, site selection, design procedures, mechanisms of wastewater renovation, site management, site monitoring and environmental effects. During the land treatment program an active technology transfer effort was maintained to transmit research

20. Abstract (cont'd).

results directly to users. The LTRP clearly demonstrated that land treatment is an attractive alternative to other waste treatment practices. It was also shown that the direct benefits of the program, in terms of increased cost-effectiveness from improved design, were much greater than the program's cost.

PREFACE

This report was prepared by Dr. I.K. Iskandar, Research Chemist, of the Earth Sciences Branch, Research Division, and E.A. Wright, Technical Publications Writer-Editor, Technical Information Branch, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Additional input was provided by personnel from the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, the Agriculture Research Service, St. Paul, Minnesota, and many universities.

This report contains three sections *(Executive Overview, Administrative Aspects and Detailed Summary)* describing the Corps of Engineers Land Treatment Research and Development Program. The *Executive Summary* is intended to give managers, supervisors and administrators a general overview on why the Corps of Engineers conducted this research program, how the research was conducted, what was learned and how the results were implemented and transferred to the users. The *Administrative Aspects* section gives more detail on how the research program was coordinated and the products from the program. The *Detailed Summary* is intended to serve as a guide to the more than 240 technical publications produced under the Land Treatment Research and Development Program.

This is the final report of the Land Treatment Research and Development Program. The report was technically reviewed by T. Jenkins, J. Martel, A. Palazzo and S. Reed of CRREL and Dr. D. Keeney of the University of Wisconsin.

The authors thank Noel Urban, Chief of the Urban Studies Program and Technical Monitor for the Land Treatment Research and Development Program, for his sincere interest and technical guidance. Appreciation is also expressed to the Land Treatment Program Managers and to all the technical researchers involved in the many aspects of the program.

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ILLUSTRATIONS

TABLES

CRREL CONTRIBUTORS TO THE LAND TREATMENT RESEARCH AND DEVELOPMENT PROGRAM*

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Peter A. Berggren	Physical Science Technician
Michael A. Bilello	Meteorologist
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Patricia L. Butler	Physical Science Technician
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Stephen T. Quarry	Physical Science Technician
Sherwood C. Reed	Environmental Engineer
Robert S. Sletten	Research Civil Engineer
Kay Sterrett	Research Leader
Ants Uiga	Environmental Engineer

*See Appendix A for publications of these individuals.

LAND TREATMENT RESEARCH AND DEVELOPMENT PROGRAM
Synthesis of Research Results

I.K. Iskandar and E.A. Wright

PART 1. EXECUTIVE OVERVIEW

1-1. PROGRAM RATIONALE

The treatment of municipal wastewater is one of the Nation's major environmental concerns. Each day over 95 billion gallons of wastewater is produced in the United States, and the discharge of partially treated or untreated wastewater has frequently resulted in pollution of our water resources. In addition, the failure of conventional wastewater treatment plants to remove harmful materials has, in some instances, resulted in the accumulation of these substances in the food chain.

In 1971 the U.S. Army Corps of Engineers conducted five comprehensive regional studies on wastewater management. These studies evaluated wastewater treatment options for San Francisco, California, Chicago, Illinois, Detroit, Michigan, Cleveland, Ohio, and the Merrimack River Basin in New England. Each study considered the overall feasibility of regional wastewater management and suggested alternative methods for achieving the treatment goals. In each case land treatment of wastewater was identified as a potential method for wastewater treatment and disposal.

Land treatment is the practice of using the soil and cover crops as a unit process in the overall wastewater treatment scheme, with great concern for the impact on the receiving environment. Because of the lack of information on the proper design of land treatment facilities and the need to evaluate and use such techniques, the Corps of Engineers Land Treatment Research and Development Program was initiated in 1972. At that time, the technology for optimizing the design and operation of cost-effective and environmentally safe land treatment systems was not available. For systems designed prior to the mid 1970's in both the United States and abroad, land application was often a disposal practice in which the land served as a receiving medium for untreated or partially treated wastes with little understanding of the impact on the environment, particularly in regard to groundwater quality.

The Water Pollution Control Amendments (PL 92-500) of 1972 reinforced the need for studies of land treatment. Public Law 92-500 established more stringent wastewater treatment quality standards in order to safeguard the public health, protect fish, shellfish, and wildlife, and provide for recreation in and on the water. A study made by the Environmental Protection Agency (EPA) showed that wastewater treatment by conventional sewage treatment plants was often not adequate to achieve these more stringent objectives (Council on Environmental Quality 1979).

In the EPA study, alternatives were proposed for better treatment of wastewater. The first involves the use of an advanced wastewater treatment step to remove pollutants such as phosphorus, nitrogen, heavy metals and pathogens. This method has been shown, however, to be costly and in many cases unreliable. The second approach was the use of innovative methods such as land treatment for treatment and disposal of wastewater.

Based partially on research results from the Corps of Engineers land treatment program, the Clean Water Act (PL 95-217) of 1977 encouraged the second approach, the use of innovative methods for renovation and reuse of wastewater as well as recycling of organic materials and nutrients to the maximum extent possible. In late 1977, the EPA issued its policy on land treatment of municipal wastewater. The 1977 Act and the EPA policy pressed vigorously for publicly owned treatment works to consider land treatment processes to treat and recycle municipal wastewater.

1-2. PROGRAM OBJECTIVES

The main objective of the Corps of Engineers Land Treatment Research and Development Program was to provide, through research, definitive criteria and procedures to enable the cost-effective and environmentally safe use of land application to treat municipal wastewater. The specific goals of the program were to:

1. Develop a research strategy for the Land Treatment Program.
2. Develop methods for land preliminary treatment, planning, site selection, and site evaluation.
3. Define the site characteristics that must be considered in the planning, design, and management of land treatment systems.
4. Understand the physical, chemical and biological processes that take place during wastewater renovation by land treatment.
5. Develop mathematical and optimization models for planning, design and management of land treatment.
6. Develop engineering design criteria.
7. Establish preapplication treatment requirements.
8. Predict the long-term effects of land treatment.
9. Establish good management practices for land treatment systems.
10. Establish monitoring requirements for land treatment systems.
11. Assess potential health and environmental effects.
12. Prepare an analysis of the costs of land treatment systems in comparison with conventional systems.

1-3. APPROACH

The approach taken in conducting the research program included long-term field experiments at different locations within the United States to establish design criteria, laboratory research to understand and solve fundamental problems, and evaluation of existing facilities of land treatment and land disposal systems to document long term performance.

Much of the Corps of Engineers research on slow rate and overland flow systems, evaluation of existing facilities, and establishment of criteria for design and operation of land treatment systems was conducted by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, the lead laboratory for this program. At Utica, Mississippi, the U.S. Army Engineer Waterways Experiment Station (WES) conducted extensive research on overland flow treatment. At Apple Valley, Minnesota, the Corps of Engineers through CRREL provided funds to the U.S. Department of Agriculture for joint field studies on crop management for slow rate land treatment. At Pack Forest near Seattle, Washington, the Corps of Engineers funded a research program with the University of Washington on the use of forest systems to renovate wastewater. The Corps of Engineers also encouraged and established cooperative investigations of the public health aspects of land treatment with the U.S. Army Medical and Bioengineering Research and Development Laboratory (USAMBRDL). Field studies on potential contamination by bacteria and viruses were conducted at Deer Creek, Ohio, Ft. Devens, Massachusetts, Utica, Mississippi, and Hanover, New Hampshire. In addition, the Corps of Engineers through CRREL provided funding to many universities, individual researchers and consulting firms in the form of grants or contracts to conduct specific research on land treatment. The CRREL technical staff visited and evaluated many existing facilities for land disposal and treatment. Some of these systems, such as the one in Calumet, Michigan, have been in operation for more than 80 years.

Every effort was made to coordinate the Corps of Engineers (COE) research program with other federal and state agencies that have responsibility in this area. This cooperation included the formation of joint committees that sponsored land treatment workshops and symposia, participation in joint publications such as the COE/EPA/USDA *Process Design Manual for Land Treatment of Municipal Wastewater,* information exchanges, and visits between the technical personnel.

In the early stages of the program, three different modes of land treatment were identified: slow rate, rapid infiltration and overland flow. The slow rate mode is somewhat similar to agricultural irrigation. Wastewater is applied to a vegetated area at an application rate that allows it to enter the soil without producing runoff. The amount of water applied is usually much higher than in conventional agriculture. The organic and suspended material is filtered out by the vegetation and soil, and the organic portion is further reduced by soil organisms. Nitrogen is absorbed by plant roots and soils, while phosphorus is bound to the soil and partially removed by plants. Bacteria, viruses and heavy metals are filtered out by the soil and vegetation or adsorbed to soil particles. This mode of land treatment requires 2 to 3 ft of soil above groundwater.

In a rapid infiltration system, wastewater is applied to very permeable soil at a much higher rate than in slow rate systems. The cover crop is not essential. In this system, organic materials, bacteria and viruses are filtered by the soil and broken down by soil organisms. Phosphorus and heavy metals are bound by the soil and nitrogen is converted by soil bacteria to gaseous forms and released to the atmosphere. A greater depth to groundwater (several feet) is required for this system.

Overland flow is the most recently developed method of land treatment. In this technique, wastewater is applied at the top of a slope and allowed to flow down in a thin layer over a relatively impermeable soil. Runoff is collected in ditches at the base of the slope for discharge. Organic matter, bacteria, and viruses are filtered out by the soil-plant system and decomposed by soil bacteria. Nitrogen is removed by soils and plant roots, or converted to gaseous forms and released to the atmosphere. Phosphorus removal is usually not as efficient as in slow rate and rapid infiltration systems.

1-4. ACCOMPLISHMENTS

The data gathered from the land treatment research program have been published in more than 240 technical publications on regional planning, site selection, design procedures, mechanisms of wastewater renovation, site management, site monitoring and environmental effects. During the land treatment program an active technology transfer effort was maintained to transmit research results directly to the users.

The following is a brief summary of some of the major accomplishments of the research program.

A. Regional planning and site selection

The research on the regional site selection showed that satellite imagery can be used in preliminary screening processes for evaluating the feasibilty of land treatment as an alternative to conventional treatment. This technology was applied in a study of the Nashville, Tennessee, area, and products derived from Landsat and Skylab imagery were found to be useful in preparing maps for regional land treatment sites. The advantage of this technique was that the information could be obtained in a very short time at a relatively low cost.

The Corps of Engineers developed a computer program as a planning tool to aid in the preliminary design and cost estimation of land treatment systems. This program was incorporated into a larger program called CAPDET (Computer Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems), which is being used to screen out several alternatives during the early planning stages. The program has been adopted by the EPA for national application, and has reduced the costs of planning several recently constructed systems.

Prior to actual design of land treatment, information on site characteristics must be acquired from the field and laboratory investigations. This information must be obtained in order to determine the land area, storage capacity, and pretreatment requirements, application rate and schedule, and the type of crop to be grown. Methods for obtaining such data were not readily available to design engineers prior to establishment of the Land Treatment Program. As a result of this program, field methods for determining the physical and chemical properties of soils were developed as adaptations of existing technology in related areas of science. These methods have been published jointly with other federal agencies in the EPA/COE/USDA *Process Design Manual for Land Treatment of Municipal Wastewater*, technical reports, a monograph, and in the proceedings of an international symposium on land treatment of wastewater.

B. Pretreatment, storage and land requirements

The research has shown that the degree of pretreatment of wastewater prior to application on land depends on the type of land treatment and the characteristics of the site and of the wastewater. Where public access is restricted, only the equivalent of primary treatment of wastewater to remove the larger solids is necessary prior to application on land. Contrary to prior belief, the research program has shown that certain methods of additional pretreatment, such as aeration during secondary treatment, may cause poor renovation because nitrogen is converted into a form that is not easily removed by soils as the wastewater is applied to land. By decreasing the degree of pretreatment, ultimate water qualilty may actually be improved while decreasing the cost of the operation. These findings present a savings, not only in capital costs, but also in the amount of chemicals and energy needed for secondary and tertiary treatment.

Because cover crops play such an important role in the renovation of wastewater, the early thinking was that wastewater must be applied to the land only when the cover crop is growing. In northern areas this meant that wastewater needed to be stored during the winter for as long as six months. The Corps of Engineers studies have shown that in many cases the effective application season is much longer than originally estimated and that wastewater can often be applied on a year-round basis. This represents a savings in capital costs due to the reduction on both the size of the storage lagoon and in the area of land required for application of the wastewater.

C. Design procedures

The *Process Design Manual for Land Treatment of Municipal Wastewater*, first published in 1977 jointly by the Corps of Engineers and the Environmental Protection Agency, with input from the Department of Agriculture's Science and Education Administration, contains detailed procedures on how to design land treatment systems. After 1977 the Corps of Engineers research efforts were focused on solving identified research needs, and the information obtained was incorporated in a revised version of the *Manual*. The revised *Manual*, which was completed in 1981, is a cooperative effort of several federal agencies including the Corps of Engineers, the Environmental Protection Agency, Department of Agriculture and Department of the Interior.

In the revised *Process Design Manual*, a rational procedure developed at CRREL for design of overland flow systems is described. This procedure allows design engineers to be more confident of system performance and to reduce construction costs.

D. Optimization of design procedures and mechanisms of renovation

Considerable insight has been gained about what happens to the wastewater as it moves through the soil-plant matrix. From the land treatment program studies, researchers were able not only to identify the mechanisms involved in the renovation of wastewater, but also to optimize these processes and to develop rational design procedures for land treatment based on actual data rather than "black box" input-output.

The Corps of Engineers researchers recognized that in slow rate systems the rate of water movement through the soil and the extent of nitrogen removal are often the critical factors for estimating the application rate of wastewater to the land. Computer models have been developed to predict the water flow in soils and the fate of nitrogen in land treatment systems. Most of these models were developed and evaluated using laboratory and field data. With the aid of these models, designers are now able to optimize plant uptake of nutrients, thus increasing the crop yield while minimizing the impact on ground-water quality and saving fertilizer and energy. Designers can also use such programs in selecting proper application rates and schedules and in recommending methods for system management and monitoring.

Transformation and movement of nitrogen to ground water and eventually to surface water were studied carefully to minimize excessive algal growth and to protect water quality. These studies show that, under proper management and operation of land treatment systems, nitrate-nitrogen concentrations in groundwater can be maintained at acceptable levels. A monograph on mathematical and optimization models for land treatment, planning, design, and management, *Modeling*

Wastewater Renovation: Land Treatment, was prepared by the Corps of Engineers with input from researchers of the Environmental Protection Agency, Department of Agriculture, Water and Power Resources Service and several universities. The monograph includes the scientific basis for such models and examples on how to use them.

E. Site management and monitoring

The level of crop and soil management at the site is a major factor in the degree of treatment. For example, under proper management practices, such as balancing plant nutrients in the soil, correcting soil pH, and scheduling proper wastewater application, forage grasses will remove greater amounts of wastewater nutrients and persist longer at a site. Research efforts to enhance nutrient removal by agronomic crops showed that using dual cropping, e.g. the growing of corn in combination with forage grass or a cereal crop, increased crop yield and nitrogen uptake by plants and produced cash crops of high market value. The Corps of Engineers, in cooperation with the Department of Agriculture, developed guidelines for crop selection, plant adaptability to conditions imposed by land treatment operation, and application of soil conditioners. Application of potassium, a major nutrient for plant growth, was recommended to increase plant uptake of other wastewater nutrients and plant yield. Soil liming was also recommended to neutralize excess soil acidity which may result from wastewater application to some soils in the northern states. Since alkalinity problems may occur when wastewaters contain high amounts of sodium and the soil contains clay, methods of avoiding this situation were recommended.

Research on wastewater application to forests at Pack Forest, Washington, showed both a high treatment level and a substantial increase in the growth rate of the trees in the experimental areas. Winter application of wastewater was tested in a forested area at West Dover, Vermont, and found to be feasible on a year-round basis. Design guidance for wastewater application to forest systems was developed from this research.

F. Environmental and public health concerns

The fate of wastewater pollutants such as heavy metals was extensively investigated. Data collected from greenhouse studies, field experimental sites and existing facilities showed that concentrations of these compounds in municipal wastewater were not high enough to cause problems with plant toxicity, soil contamination, or accumulation in the food chain. At neutral to slightly alkaline conditions (pH 6.5-8.5) these compounds are removed by and precipitated in the soil mostly in forms not readily available to plants. Most soils were found to have a very high capacity to retain heavy metals.

Concentration of nitrate in groundwater in excess of 10 mg/L is another concern. Intensive research studies were conducted on the fate of nitrogen in land treatment systems, identifying the mechanisms involved and using mathematical models for prediction of nitrogen transport and transformation. The overall objective of these studies was to predict the concentration of nitrate in leachate from land treatment and to manage the system properly to maintain such concentrations at a minimum level.

Most of the nitrogen found in wastewater is in the form of ammonium, which is sorbed on soil particles and subsequently converted to nitrates and then to nitrate by soil bacteria (nitrification). The nitrates are then taken up by plants, converted to gaseous nitrogen by nitrate-reducing bacteria (denitrification), or leached through the soil system into ground water and eventually to water supplies and surface waters. In addition, ammonium and nitrate may be transformed to organic nitrogen (immobilization), or organic nitrogen in the soil may be transformed to ammonium nitrogen (mineralization). Due to the various physical and biological reactions that take place simultaneously, researchers found it necessary to develop computer models to predict the fate of nitrogen in land treatment. Laboratory and field experiments were also conducted to provide data for model parameters and to evaluate the validity of the assumptions used.

The effects of environmental factors (soil temperature, soil acidity, aeration status, etc.) on soil nitrogen transformations and transport were investigated and included in the models. Temperature was found to be the most important factor in determining the rate and extent of plant uptake of nitrogen, nitrification, ammonium exchange and nitrogen transport processes.

The scientific basis for these nitrogen transport and transformation models and examples of how to use them are described in *Modeling Wastewater Renovation: Land Treatment*. This monograph also includes models for phosphorus transport and transformation, virus transport, and optimization and cost evaluation of land treatment systems. Such models have not only advanced our scientific knowledge but they are helpful in public acceptance of land treatment as a method of wastewater treatment and predicting the environmental fate of wastewater constituents.

In some areas in the United States, such as in the Great Lakes region and in most recreation areas near open water, phosphorus input to surface water has resulted in high algal growth and poor water quality. The Corps of Engineers research program included studies on the fate of phosphorus in land treatment, an important factor because crops require only a small fraction of wastewater phosphorus. Most soils were found to have a high capacity to sorb phosphorus, but this capacity was not infinite. Methods were developed and tested to evaluate the ability of specific soils to remove phosphorus and to estimate site longevity. Proper estimation of the effectiveness of soil to remove phosphorus from wastewater will assist design engineers in predicting the phosphorus input to surface water and in selecting sites with soils having a high phosphorus sorption capacity.

Wastewaters also contain a wide variety of toxic organics, pathogens and pesticides. The Corps of Engineers initiated an effort to determine the fate of toxic organics when wastewater is applied to the land. These efforts are continuing in cooperation with the EPA.

The fate of pathogens in land treatment has been investigated by the Army Surgeon General using laboratory studies and field sites at Ft. Devens, Massachusetts, Hanover, New Hampshire, Deer Creek Lake, Ohio, and Utica, Mississippi. Results showed that viruses can move through very coarse soils in some rapid infiltration systems with very high wastewater loadings. However, removal of viruses and pathogens is almost complete in slow rate systems. Removal efficiency by overland flow is comparable to that of conventional wastewater treatment plants.

Understanding of the critical factors for virus removal by soils in rapid infiltration systems was required. These factors include the concentration of viruses in applied water, which depends on the degree of pretreatment, soil type, site management and climatic conditions. Information on how to change these factors to control virus transport in soils was obtained from laboratory and field studies. Microbial transmission by aerosols was investigated at the slow rate land treatment system in Deer Creek Lake, Ohio.

G. Technology transfer

To ensure that research results are available to the users—such as personnel in the Corps of Engineers Districts and Divisions, other federal and state agencies, and municipalities—the Land Treatment Research and Development Program implemented an extensive technology transfer effort. Since the beginning of the program more than 240 technical publications have been widely distributed nationally and internationally. Engineering manuals and technical books including in-depth analyses of design procedures and predictive methods of the environmental fate of wastewater constituents were published in cooperative efforts with the EPA, Department of Agriculture and universities. Fifteen Engineer Technical Letters were prepared and distributed to Corps personnel updating design and management information on land treatment. Two international symposia were held in 1978 and 1979 which acted as forums for information exchange between researchers on land treatment technology. The proceedings of these symposia were published and widely distributed. Many presentations at national and international meetings were made on different aspects of land treatment design and operation.

Two training courses were developed on the planning and design of land treatment systems. The first course was on soils and geology in relation to wastewater renovation. This course was presented to 10 different groups of Corps District and Division engineers during a four-year period. Approximately 250 individuals attended this course. The second course was prepared by Cornell University with funds from the Corps and EPA. The course was taught once a year for four years. An average of 25 individuals attended the course each time. Instructors from the Corps assisted the EPA in presenting five other seminars at different locations within the United States during 1979-1980. The total number of attendees of these seminars was about 1,000 individuals.

In addition, the Corps of Engineers technical staff has been made available to answer questions and provide assistance to individuals, consulting firms and state and federal agencies upon request.

The COE/EPA/USDA *Process Design Manual for Land Treatment of Municipal Wastewater*, published in 1977 and revised in 1981, has been widely distributed throughout the nation and is being used by design engineers in planning and designing new systems.

The CAPDET model developed by the Corps of Engineers, adopted and published by the EPA, is being used by both agencies as well as by many other state agencies and private design engineering firms. The CAPDET model has been made available through the direct-dial system.

As a result of the Land Treatment Research Program, more than 50 land treatment systems and adjoining recreation areas have been or are being constructed at Corps of Engineers facilities. In the next few years, recreation areas will need upgrading and many more areas will be constructed. The Corps will continue to encourage the use of land treatment at these facilities.

The cost of the program over eight years was $8.4 million. The direct and indirect benefits from the program are far greater than the cost. Research efforts have led to economies in the pretreatment and storage requirements, increasing the cost-effective utilization of land treatment for testing wastewater. Use of land treatment in treating wastewater has also resulted in saving energy that otherwise would have been needed to produce fertilizers and in conserving water supplies. The quantitative understanding of the mechanisms of wastewater renovation by land treatment will assure the savings of millions of tax dollars through more efficient planning, design and operation of land treatment systems.

1-5. SUMMARY AND CONCLUSIONS

The Corps of Engineers Land Treatment Research and Development Program has shown this treatment method to be an attractive alternative to other conventional waste treatment practices. Land treatment can often be more economical and more effective in removing pollutants than conventional techniques. When suitable land is available, land treatment can be readily adopted, and potential problems can be eliminated by proper design and management.

In addition, land wastewater treatment systems have shown the capability of increasing the yields of forage crops and helping to restore the groundwater table, especially in arid and semi-arid regions.

Now that land treatment has been placed on a firmer engineering basis, more systems of this type will undoubtedly be built in the future. By improving the design and operation processes of land treatment systems, the Corps of Engineers Land Treatment Research and Development Program has made a substantial contribution to developing this waste treatment alternative.

PART 2: ADMINISTRATIVE ASPECTS

2-1. BACKGROUND

In 1972, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) published a comprehensive state-of-the-art review report on land treatment of wastewater, which coincided with the passage of the Water Pollution Control Act Amendments of 1972 (PL92-500). Shortly thereafter, the Land Treatment Research and Development Program (LTRP) objectives and research needs were developed and identified. Most of the research efforts were conducted to gain better understanding of the mechanisms involved in such processes. This allowed development of cost-effective engineering criteria for planning, design and operation of land treatment.

The LTRP was multidisciplinary, including considerations of public health and acceptability, environmental fate of pollutants, engineering design procedures and in-depth research on the factors controlling the rate and extent of the renovation processes.

2-2. AUTHORIZATION

Authorization for the Land Treatment Research and Development Program was provided by the following:

- The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500).
- The Clean Water Act of 1977 (PL 95-217).
- A policy statement on Land Treatment of Municipal Wastewater. On 3 October 1977, the Administration of EPA issued a policy statement on Land Treatment of Municipal Wastewater. The policy of the EPA was to press vigorously for the utilization of land treatment for wastewater renovation and reuse by publicly owned treatment works. This policy had impact on several Corps responsibilities including the Urban Studies Program, and the design of wastewater treatment facilities at recreation areas and military bases.
- Assignment of CRREL to prepare a feasibility study and a literature search document on land treatment of wastewater in 1972.
- Designation of CRREL as the Corps of Engineers lead laboratory for the Land Treatment Research Program 1973.
- Authorization of funding for the LTRP by the Office of Management and Budget (OMB) in 1974.
- Continuation of budgets for the LTRP between fiscal years 1974 and 1980 through incremental approval by Congress and OMB on the basis of obtained and anticipated results.
- Completion of the LTRP in September 1980.

2-3. COORDINATION AND TECHNOLOGY TRANSFER

Coordination with other govenment agencies performing research and technology transfer on land treatment of wastewater was maintained throughout the program. This was accomplished in different ways to avoid duplication of efforts, to promote the application of research results and to concentrate joint efforts on accomplishing certain tasks when appropriate. Examples of such efforts can be briefly summarized as follows:

- Two memoranda of understanding between the U.S. EPA and the U.S. Army Cold Regions Research and Engineering Laboratory were signed by the Deputy Assistant Administrator for Water Program Operations of the EPA and the Commander and Director of CRREL in 1978 and 1980. The purpose was to establish arrangements whereby the EPA and CRREL would develop information on wastewater treatment and sludge management for use by the EPA in the construction grants program for publicly owned treatment works under PL92-500 and for use by CRREL and the Corps of Engineers in the military and civil works program of the Department of the Army.
- The *Process Design Manual for Land Treat-*

ment of Municipal Wastewater was published jointly by the EPA, Corps of Engineers and USDA in 1977 and was updated in 1981, with additional sponsorship by the Department of the Interior.

- Interactions between the technical staff of the Corps of Engineers and other agencies, especially the EPA and USDA, were extensive. Many joint publications and visits were accomplished during the LTRP.
- Several program review and technical meetings took place during the LTRP that included representatives from all government agencies involved in land treatment research and technology transfer.
- A training course on land treatment was jointly funded, reviewed and implemented by the EPA and the Corps of Engineers.
- Several technical committees on different aspects of land treatment research and technology were formulated during the LTRP and included members from the Corps of Engineers, EPA, USDA and several universities.
- A U.S.A.-U.S.S.R. joint agreement resulted in several exchange visits and the transfer of land treatment technology information between the two countries.

2-4. PUBLICATIONS

Numerous publications were produced under the LTRP (see Fig. 1). These include (at the time of preparing this report) the following:

- 117 open literature papers, books and chapters in books
- 51 Government technical reports
- 21 translation reports (mostly from Russian literature)
- 14 Engineering Technical Letters
- 7 dissertations (M.S. and Ph.D.)
- 21 Internal Reports
- 4 manuals and proceedings of national and international symposium
- 1 reference book
- 8 public information brochures and fact sheets
- 1 executive summary.

The open literature publications have transferred the technology of LTRP directly to the public, including the Corps District and Division personnel. These publications show the public that the Corps is interested in technology transfer and advancement of knowledge.

The reports prepared by federal agencies have been distributed free of charge to individuals from federal, state and local governments and to consultants, university researchers and private individuals. In many cases requests have exceeded the copies originally printed. However, copies of all the reports are available from the National Technical Information Center (NTIS), Springfield, Virginia, 22151.

The revised *Process Design Manual for Land Treatment of Municipal Wastewater,* is being distributed by the EPA and thousands of copies have been printed. The *Proceedings of the International Symposium of the State of Knowledge on Land Treatment* was distributed to more than 3,000 persons in the U.S. and other countries. The book, *Modeling Wastewater Renovation Land Treatment* was authored by 26 scientists and engineers

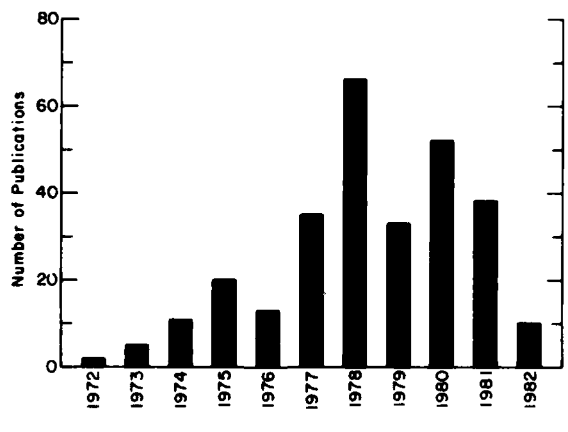

Figure 1. Publications resulting from land treatment research program.

of multidisciplinary background from the U.S. and other countries. This book, published by John Wiley and Sons, Inc. (New York), describes the state of the art of optimization and simulation methods for planning, design, operation and management of land treatment systems.

In addition, several books have been published that are based at least in part of Corps of Engineers land treatment research. For example, *Water Reuse* (edited by E. J. Middlebrooks) contains a section by S. Reed of CRREL, and *Land Application of Wastes: An Educational Program*, was published by Cornell University in 1978 as a result of the Corps-sponsored course presented there.

Appendix A contains a list of publications of the LTRP.

2-5. PROGRAM MANAGEMENT

The LTRP was directed by project managers at CRREL. The project manager and technical support staffs were responsible for technical planning, fiscal management, internal and external coordination, technical monitoring of research accomplishments, documentation and reporting, result evaluation and synthesis, information dissemination and technology transfer. In addition to implementation of certain research efforts and contract and grant management, the technical staff contributed heavily to the coordination of research activities at the three major field sites in Utica, Mississippi; Apple Valley, Minnesota; and Pack Forest, near Seattle, Washington. The field site at Utica, Mississippi, was established to investigate land treatment of wastewater by the overland flow technique in a mild climate and was operated and monitored by WES. The Apple Valley site was established by the U.S. Department of Agriculture to study the crop management of a slow rate system, and the Pack Forest site, designed to evaluate the use of wastewater in a forest ecosystem, was established and monitored by technical staff from the University of Washington Forestry Department.

The LTRP managers were S. Reed during the period from February 1972 to 1975, H. McKim during the period from 1975 to 1979, and K.F. Sterrett from 1979 to October 1980. Principal investigators were in charge of individual research tasks relevant to their expertise.

Noel Urban, Chief, Urban Studies Program, was OCE technical monitor for the LTRP. He also was the coordinator and chairman of a committee formed of representatives of several federal agencies conducting land treatment research and development.

PART 3: DETAILED SUMMARY

3-1. RESEARCH PLAN AND RESEARCH FACILITIES

The research plan for the Corps of Engineers Land Treatment Research Program was prepared in 1973. The plan included the establishment of field sites at Hanover, New Hampshire, Utica, Mississippi, Apple Valley, Minnesota, and Pack Forest, Washington, to conduct long-term field studies on wastewater renovation processes. The plan also included laboratory and greenhouse studies for short-term experiments and a task for evaluation of long-term effects of wastewater on land treatment by evaluating existing systems of disposal.

A. Research facilities at CRREL

The research facilities at CRREL in Hanover, New Hampshire, were constructed to establish criteria for design and operation of slow rate and overland flow land treatment in cold climates. Description of these facilities and results of long-term operations are presented in many publications (see App. A). The design and construction of these facilities are described in Iskandar et al. (1976) and Martel et al. (1980).

Briefly, CRREL's prototype slow rate system consists of six outdoor test cells (Fig. 2) constructed in 1973 to investigate wastewater renovation. The cells were constructed from reinforced concrete and are 8.5 m^2 in area and 1.5 m deep. Cells 1-3 were filled with Windsor sandy loam soil and cells 4-6 with Charlton loam. Table 1 summarizes selected soil characteristics. Sewage was obtained from a nearby housing community and subsequently given conventional primary or secondary treatment, disinfected with ozone in certain tests, and applied by sprinklers to the test cells (Fig. 3). Table 2 summarizes effluent characteristics, which are typical of municipal wastewater, applied to CRREL test facilities during the period from June 1973 to May 1978. The volumes of applied effluent and leachate were metered. A climatological station was established to monitor temperature (in

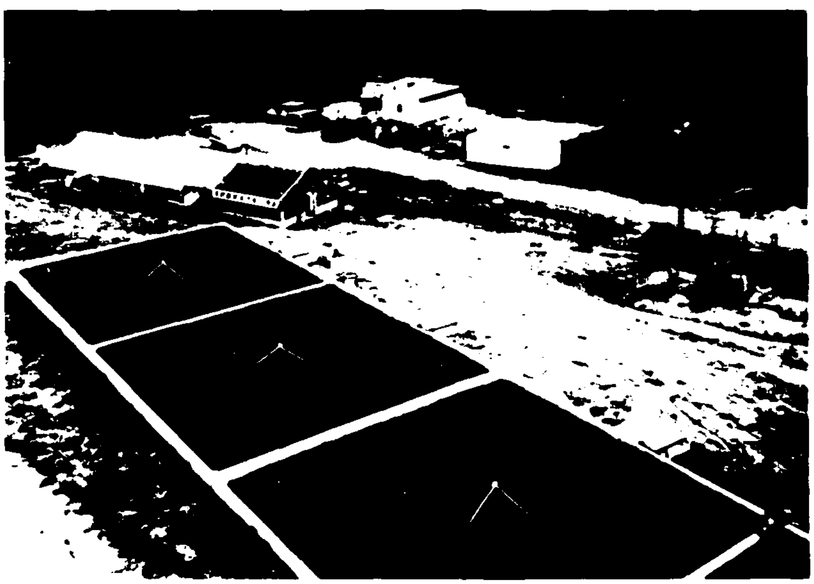

Figure 2. Prototype slow rate system at CRREL.

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Table 1. Selected soil characteristics of CRREL prototype experimental cells.*

Soil type	Depth (cm)	Particle size analysis (%) Sand	Silt	Clay	Bulk density (g/cm^3)	Permeability (10^{-4} cm/s)	CEC (meq/100 g)	pH
Windsor	0–15	87	11	2	1.335	3.82	6.8	5.0
	15–45	82	16	2	1.508	21.28	2.1	6.2
	45–150	67	31	2	1.657	8.22	1.7	6.9
Charlton	0–15	52	34	14	1.048	3.00	12.2	5.7
	15–45	53	34	13	1.420	1.18	7.8	5.5
	45–150	57	33	11	1.695	0.160	3.6	7.0

* For other soil characteristics see Iskandar et al. (1979).

Table 2. Composition of applied wastewater during the period when both primary- and secondary-treated wastewater were used (June 1973 through May 1978).

Parameter	Primary Mean ± std. dev.	Primary N*	Primary Max.	Primary Min.	Secondary Mean ± std. dev.	Secondary N*	Secondary Max.	Secondary Min.
Total N	28.0†				26.9†			
Kjeldahl N	27.4 ± 8.4	232	71.5	2.5	21.0 ± 11.1	138	50.5	1.5
Nitrate N	0.6 ± 1.5	245	9.6	**	6.7 ± 7.0	153	39.5	**
Ammonium N	24.0 ± 8.7	233	77.0	**	18.3 ± 9.5	139	40.0	**
Total P	7.6 ± 6.7	230	95.0	1.0	7.3 ± 4.7	136	48.0	0.8
BOD_5	100 ± 4.6	34	246	30	44 ± 31	27	134	14
Organic C	55 ± 177	159	136	2	39 ± 25	99	109	4
Total suspended solids	85 ± 177	69	1500	12	61 ± 87	54	525	4
Volatile suspended solids	67 ± 173	69	1460	0	39 ± 73	54	521	2
Fecal coliform bacteria (no./100 mL)	$2.2 \times 10^5 \pm 2.7 \times 10^5$	37	9.2×10^5	3.9×10^2	$1.4 \times 10^4 \pm 4.8 \times 10^4$	25	2.4×10^5	2
pH (pH units)	7.3 ± 0.3	178	9.0	6.6	7.2 ± 0.5	117	8.3	6.0
Specific conductance (μs/cm)	419 ± 102	205	660	120	425 ± 107	122	720	100
Chloride	35.9 ± 13.1	186	122	7.5	35.9 ± 13.3	118	116	8.5
Calcium	9.3 ± 9.1	12	28.7	2.7	11.8 ± 11.1	17	47.6	5.0
Magnesium	3.0 ± 1.3	12	5.6	1.3	2.9 ± 1.3	17	6.3	2.0
Sodium	40.4 ± 7.6	11	50.7	22.0	44.0 ± 7.3	16	53.2	29.3
Potassium	8.2 ± 5.0	76	21.8	**	10.0 ± 5.8	46	26.2	0.3

* The number of analyses.
† Obtained by adding Kjeldahl and nitrate values.
** Below detection limit of test.

air and soil at depth), precipitation, evaporation and humidity. These data are presented in Iskandar et al. (1979).

Water from soil and from applied wastewater and leachate were collected frequently for chemical and biological tests. Analyses of up to 18 water quality parameters were performed on the water samples and many soil physical and chemical analyses were also conducted. The results obtained from the slow rate test cells are presented in several reports and papers (see *Literature Cited*). In addition, the reader is referred to summaries presented by Jenkins and Palazzo (1981), Iskandar et al. (1979) and Martel et al. (1980).

In 1975, a prototype overland flow system was constructed at CRREL (Fig. 4) to establish design criteria of overland flow in cold climates. During construction the topsoil was removed from the site and subsoil graded to a 5% slope. An impermeable rubber membrane was placed on the ground surface, and 15 cm of Hartland silt loam soil was placed on the membrane and compacted to a bulky density of 1.4 g/cm^3. The membrane was used to ensure that downward percolation of

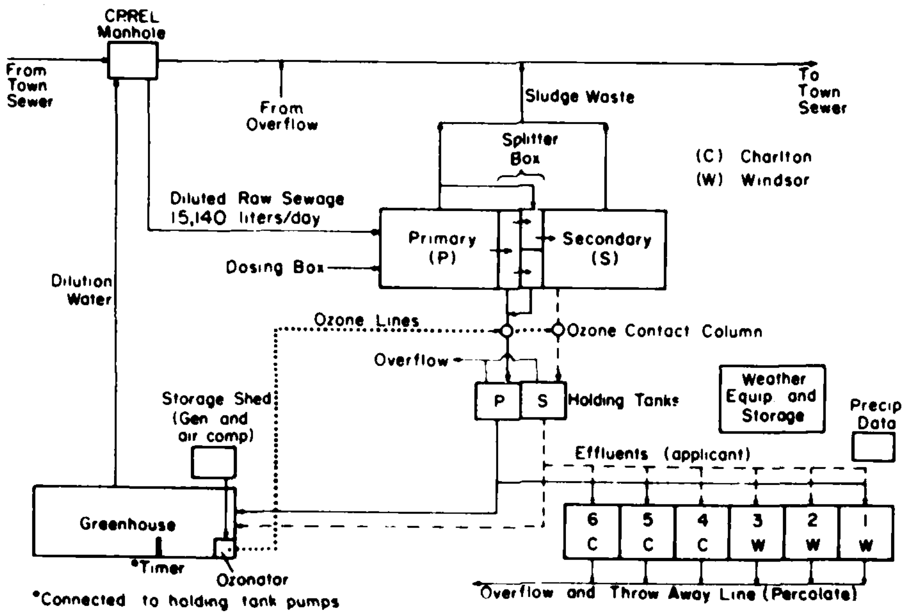


Figure 3. Design of prototype slow rate system at CRREL.

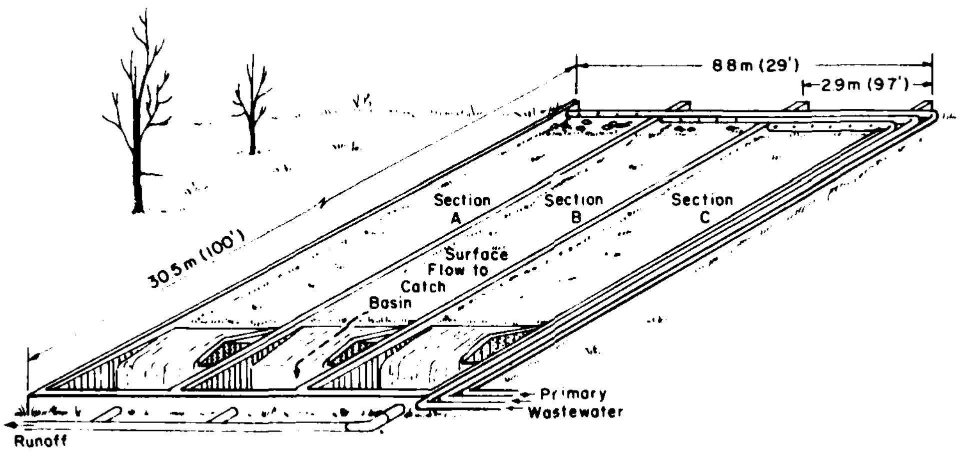


Figure 4. Design of overland treatment system at CRREL.

water would not occur. The soil was seeded with a mixture of Kentucky 31 tall fescue, orchardgrass, reed canarygrass and perennial ryegrass.

The prototype overland flow system consists of three cells, each 30.5 m in length and 8.8 m wide, separated by a raised portion of the rubber membrane. Primary or secondary wastewater or tapwater is applied at the top of the slope through perforated pipe, and applied runoff and percolate are metered and sampled frequently for analysis. Several different application rates and schedules are used depending on the objectives of the experiments. The main purpose of the CRREL overland flow system has been to obtain engineering design criteria for overland flow in cold climates and to document site performance in relation to wastewater loading rates. For more information on site construction, site characteristics and performance, the reader should consult Martel et al. (1980).

B. Overland flow research facilities at Utica, Mississippi

Hunt et al. (1973) conducted greenhouse studies of the removal of N, P and heavy metals (Zn, Cu, Mn, Pb, Ni, and Co) in secondary wastewater by

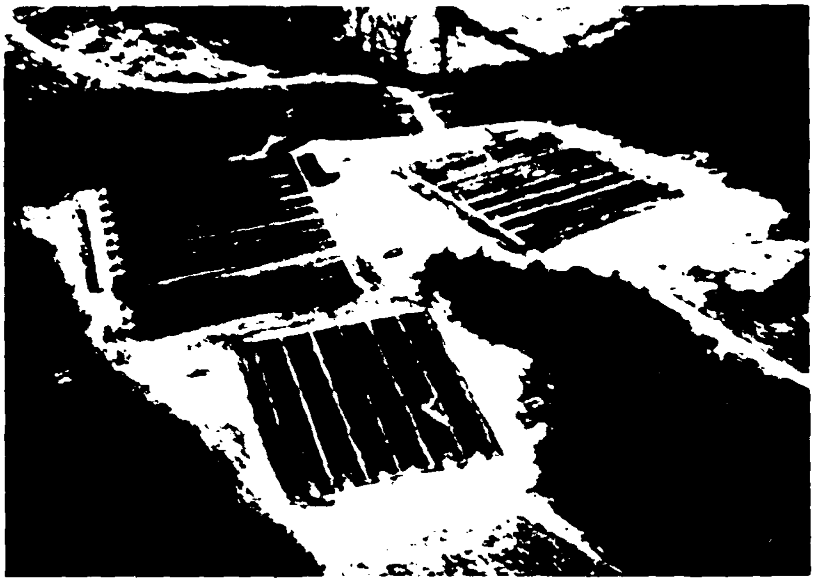


Figure 5. Overland flow treatment system at Utica, Mississippi.

Table 3. Soil characteristics at Utica, Mississippi, overland flow research facility.

Parameter	*Value*
Type	Grenada silt loam*
Particle-size distribution	Sand 15%, 67%, and clay 17%
pH	7.0
Bulk density	1.2 g/cm³
Permeability	0.042 cm/hr
Moisture content	
1/3 bar	23.0%
15 bars	9.9%
Cation exchange capacity	10.0 meq/100 g
Soil chemical analysis†	
Total phosphorus	503 ppm
Total Kjeldahl nitrogen (TKN)	1378 ppm
Potassium	735 ppm
Calcium	476 ppm
Magnesium	1999 ppm
Sodium	172 ppm
Manganese	620 ppm
Cadmium	0.8 ppm
Copper	14.2 ppm
Nickel	15.3 ppm
Zinc	52.4 ppm

* From 1917 Soil Survey. Classed as Memphis silt loam in the 1979 Soil Survey, Hinds County, Mississippi.

† Total acid digest in a 15-cm soil profile.

overland flow over a three-year period. These studies were followed by a large-scale demonstration at a site in Utica, Mississippi. This experimental overland flow treatment system (Fig. 5) consisted of 24 plots (45 × 4.6 m) having slopes of 2, 4 or 8% (8 plots for each slope). Table 3 summarizes the soil characteristics of this site. The entire plot area was seeded with a 5:2:2:1 mixture of four grass species: reed canarygrass (*Phalaris arundinacea* L.), Kentucky 31 tall fescue (*Festuca arundinacea*), perennial ryegrass (*Lolium dactylon* L.) and common Bermuda grass (*Cynodon dactylon* L.).

Wastewater was applied to the plots by surface application. Effluent was pumped from a lagoon to a holding tank, and heavy metals or other chemicals were applied to the different plots after injection of desired elevated levels of nitrogen. For a detailed description the reader should consult Peters et al. (1981).

Runoff was metered and samples were collected from a sump at the lower end of each plot. Storm water, soil and vegetation samples were also collected and analyzed. Table 4 summarizes the operational conditions for wastewater application at the Utica site. Crop management included a number of alternative methods for 1) maintaining water treatment during winter seasons, 2) reducing maintenance (cost operation), and 3) increasing forage production. For additional information on the Utica site construction and performance, the

Table 4. Summary of operational conditions at the Utica Overland Flow Research Facility.

	Application Variables			
Slope (%)	*Amount (cm/day)*	*Period (hr)*	*Frequency (days/wk)*	*Alum addition*
2, 4, 8	1.27	6	5	
2, 4, 8	1.27	18	5	
2, 8	1.27	18	7	
2, 4, 8	2.54	6	5	
2, 4, 8	2.54	18	5	x
2, 8	2.54	24	7	x
4	3.81	18	5	
4	5.08	18	5	
2, 4, 8	5.08	24	7	
2, 4, 8	10.16	24	7	
2, 8	20.32	24	7	

reader should consult Peters and Lee (1978), Lee and Peters (1979), and Peters et al. (1981).

C. Research facilities at Apple Valley, Minnesota

The objective of establishing the research facility at Apple Valley was to obtain information and design criteria on agronomic aspects of slow rate land treatment of municipal wastewater.

The site is located 8 km southwest of Rosemount, Minnesota, adjacent to the Apple Valley sewage treatment plant. The field is open and nearly level with 60 cm of a silt loam topsoil underlain by sand and gravel. The area was divided into twelve 18 × 45 m blocks (Fig. 6), each of which was irrigated and drained separately (Nylund et al. 1980). Corn and grasses were planted. The spray irrigation system was designed to deliver either fresh water or secondary effluent to all or any of the 12 blocks. Perforated plastic tile drains were installed down the center of each block and between the blocks. The drains were connected to a solid drain line which ran to a common sump and lift pump where the water was returned to a nearby stream. Porous ceramic samplers (suction lysimeters) were used to collect soil solution at depth for analysis (Linden 1977), and wells were installed to collect samples from the groundwater beneath each block.

Temperature, precipitation and evaporation were monitored. For detailed information on the engineering aspects of the Apple Valley site, the reader should consult Nylund et al. (1980).

D. Research facilities at the Pack Forest, Washington

The objective of establishing this site was to investigate the renovation of wastewater by application to forest soils. Four types of plots were established in adjacent level areas of forest. The first plot contained 50-year-old Douglas fir, the second

Figure 6. Crop management research facility at Apple Valley, Minnesota.

Table 5. Soil characteristics of Everett gravelly loamy sand prior to wastewater application.

	Soil horizon		
	A	*B*	*C*
Depth (cm)	0-10	10-60	>60
Gravel (%)	83	83	96
Sand (%)	11	13	4
Silt (%)	6	4	< 1
Clay (%)	1	1	< 1
< 2 mm fraction (%)	18	18	< 5
	(< 2 mm fraction)		
pH (1:1, soil:water)	5.0	4.8	4.8
C.E.C. (meq/100 g)	22.0	14.0	9.0
NH_4 (meq/100 g)	0.11	0.04	0.03
$NO_3 + NO_2$ (meq/100 g)	0.07	0.01	0.02

plot contained two-year-old Douglas Fir, the third plot was seeded with a mix of three grasses, and the fourth plot was kept free of vegetation.

Secondary treated wastewater was supplied by the Renton, Washington, sewage treatment plant and applied in increments of 5 cm/wk by spray irrigation. Table 5 shows the soil characteristics of the Everett gravelly loamy sand prior to wastewater application.

Soil solution samples were collected by suction plates located in the soil at depth and weighing lysimeters were used to determine water mass balance (Fig. 7). Applied effluent and leachate were collected frequently and analyzed. Soil cores were also taken for physical and chemical analysis. In addition, biomass production was monitored by measuring the tree height and diameter.

For detailed information on site description, monitoring data and findings, the reader should consult Cole and Schiess (1978) and Cole et al. (1979).

E. Greenhouse and laboratory facilities

Each of the research facilities just described has greenhouse and laboratory facilities associated with the land treatment research program. Many short- and long-term experiments were conducted in these facilities to investigate the effect of certain treatments on the renovation efficiency of soils and plants under controlled conditions. The major advantage of using these facilities was to enable researchers to include several treatments with sufficient replicates so that conclusions would be statisticly valid. Under field conditions, such trials would cost enormous amounts of money. Laboratory experiments were also conducted to obtain data for model validation for comparison with field studies. Since the laboratory studies were numerous and specific in nature, the reader should consult Appendix A for a list of such studies.

F. Observation of existing land application facilities

The objective of this task was to evaluate the

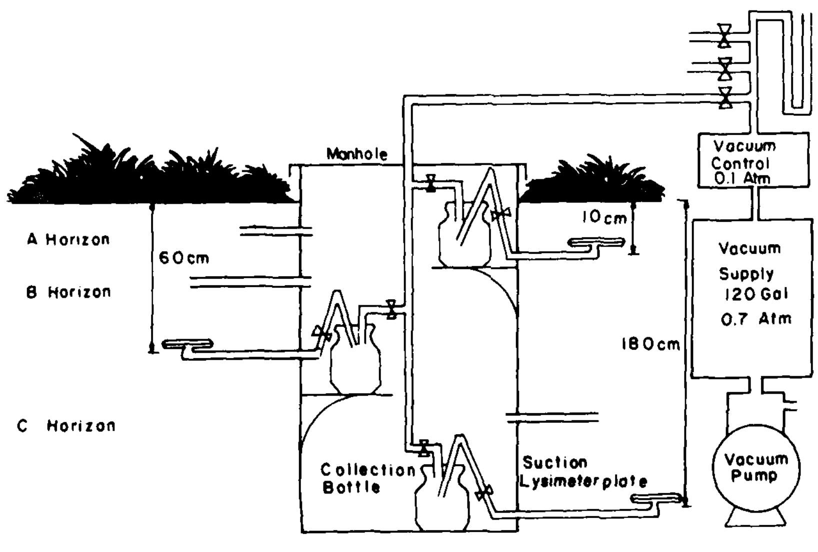


Figure 7. Soil solution sampling system at Pack Forest, Washington.

Table 6. Characteristics of sites evaluated.

Site	*Application mode*	*Application rate*	*Sewage type*	*Years of operation*	*Soil type*	*Crop*	*Comments*
Manteca, Calif. (disposal site)	Flood irrigation, slow rate	1.8 in./wk	Domestic non-disinfected secondary	11	Loamy coarse sand	Ryegrass, never harvested	High NO_3-N in soil solution in early summer. Input to ground water 10µ l – 1 ppm
Quincy, Wash. (disposal site)	Flood irrigation	6 in./wk	Domestic non-disinfected	20	Very fine sandy loam 2% slope	Corn and wheat	High NO_3-N in soil solution in early summer
Livermore, Ca.							
1) Golf course	Slow rate	0.37 in./day	Secondary, domestic. Pre and post chlorination	8	Sunnyvale clay loam	Turfgrass	Salinity problems
2) Farm field	Slow rate	24-36 in./season		8		Row crops, safflower, sugar beets, beans, cucumbers, squash, barley	Supplemented irrigation
3) Airport area	Slow rate	[illegible] in./day Apr-Oct		8		Sudan grass	Applied Apr-Oct., daily for
4) Stream discharge					Glacial till		Increased total dissolved solids. High chlorine discharge
Calumet, Mich.	Rapid infiltration	25.7 in./wk	Raw sewage non-disinfected	88	Copper Harbor conglomerate	Grassy vegetation	Soluble phosphorus increase through depth, approaching control at 20 in. TOC and COD affect ground water
Melbourne, Aus.	Overland flow	variable	Municipal, non-disinfected	85		Grassy vegetation	
Ft. Devens, Mass.	Rapid infiltration	2-day flooding	Primary treatment	30+	Stratified sands and gravels	Grassy vegetation	Total phosphate in ground water is 20% of primary effluent, 25-43% nitrogen of effluent
Dover, Vt.	Slow rate	> 2.5 in./wk	Municipal secondary effluent	2+	Stony sandy loam	forest	System operated through the winter season due to much higher flows from nearby ski resorts
Arkabutla, Miss.	Slow rate	1 in./wk	Domestic pre-chlorination	3	Pleistocene loess layer clay enriched by leaching underlain by sand and gravel terrace sequence	Bermuda grass w/ mixture of other types of grass	Recreation area. Application rate matched summer ET
Rochester, Minn.	Slow rate	0.555 in./wk	Industrial—pea, corn and carrot processing	20	Unnamed loam - 2-6% slopes 20-42 in. Thick over shale residum and shale	Reed canary and bluegrass 3-4 cuts/yr	High BOD and suspended solids.
Lodi, Wis.	Slow rate	2.75 in./wk	Industrial—pea and corn processing	24	Brown clay loam soil; after 24 in., 100-120 in. sand with gravel	Broom and quack grass	High BOD and suspended solids.
Deer Creek, Ohio	Slow rate	1 in./wk	Municipal	8	Miamian silt loam, poor drainage	Reed canarygrass	

long-term effects of wastewater application to land and to correlate site performance with design criteria and site management. The procedure established for site evaluation included selecting a suitable site, collecting all available information, visiting the site, monitoring performance, collecting and analyzing soil, plant, and water samples, and analyzing and documenting the findings. Sites were selected to represent a wide range of conditions in regard to the mode of wastewater application, climatic constraints, soil type, length of operation and preapplication treatment. Because many existing facilities did not keep accurate records concerning the amounts and lengths of wastewater application, a procedure was developed to overcome this problem. A control field was selected that had never received wastewater and had the same soil type as the disposal field. Soil pits were dug and soil cores from both the control and treated soils were collected and analyzed. Soil solution samples were collected using suction porous cups. From the analysis of the soils, plants, and water samples, an assessment of long-term effects of land application was drawn. Table 6 summarizes the systems evaluated and documented. For detailed information on those sites, the reader should consult Satterwhite et al. (1976a, 1976b), Baillod et al. (1977), Murrmann and Iskandar (1977), Uiga et al. (1977) and Iskandar et al. (1978).

3-2. REGIONAL PLANNING, SITE SELECTION, AND EVALUATION

A. Objective

The objective of this task was to develop methods for land treatment planning, site selection, and site evaluation.

B. Approach

In the research effort, the feasibility of using satellite data products in preliminary planning of land treatment on a regional basis was investigated, the use of published soil survey data in reports for site selection was assessed, and site investigation for evaluation of site characteristics and actual design parameters was documented. The developed methods were tested in the field with actual design systems.

C. Summary of research accomplishments and conclusions

1) Preliminary regional planning

Research efforts showed that preliminary planning and selection of land treatment can be accomplished by the use of imagery from Landsat and other satellites. Satellite data products can provide the necessary resolution for mapping land use categories of a study area (level I), identification of various factors influencing the regional hydrology and geology, and classification of land according to existing use (level II). The smallest features that can be recognized on the Landsat imagery are linear features such as roads, bridges, etc., about 70 m (230 ft) in length that contrast sharply with the surrounding terrain.

The selection of satellite imagery should be based on the cloud cover and the date of acquisition. The percentage of cloud cover should be at a minimum so that mapping can be easily accomplished. The optimum season for photographic coverage is dependent on the type of map information required. During spring the conifers can be differentiated from the hardwoods since the canopy cover of the hardwoods is minimal. Wetlands are also easily identifiable on the spring photography. Winter coverage is usually not acceptable in northern climates as the snow cover masks the land cover. However, winter scenes can sometimes enhance topographic detail and geologic structure. Generally, the best photography for land use is from the summer and fall months. The acquisition date of the photography should be fairly recent as current information is necessary for the regional site evaluation.

The land use classification scheme used during the mapping is modified from the U.S. Geological Survey Land Use Classification System (Anderson et al. 1976). This scheme uses the best criteria of existing land use classification systems to the extent that they are amenable for use with remote sensing data products. This open-ended approach can be used by regional systems for compatibility with the national USGS system.

In the land classification system of Anderson et al. (1976), *urban and built-up land* includes areas of intensive urban use with most of the land covered by buildings. Included in this category are cities, towns, villages, strip developments along highways, transportation, power and communications facilities, and areas such as those occupied by shopping centers, industrial and commercial complexes, and institutions that may be isolated from urban areas. *Agricultural land* includes land primarily used for the production of cash crops. These areas are characterized by fewer buildings and roads than the urban areas, a lower concentration of population, and by farming activities Examples include crop land, pasture, and orchards. *Forest land* is defined as land that is at least 10% covered with trees. Hardwoods and conifers are included in this level I unit. The *water* category comprises areas predominantly covered by water and includes streams, waterways, lakes, reservoirs, bays, and estuaries. The *non-forested wetlands* comprise seasonally flooded basins such as meadows, marshes, and bogs. The last unit, *barren land*, consists of land with limited ability to support life, for example, sand and rocks.

The land use map can be prepared from the satellite photography to map the level I land use categories at scales of 1:1,000,000, 1:500,000, or 1:250,000. These land maps can be quantified by planimetric techniques on a state or county basis, whichever is required. The Landsat map can be used to identify where land treatment potential would be low, moderate, or high. Agricultural land has the highest potential for all three modes of land treatment. Areas where forests compose at least half the land cover can be considered of high potential for slow infiltration systems using woodlands. The urban and built-up land has the lowest potential for land treatment, except in the case of golf courses, parks, and possibly greenbelt areas. Partially forested areas (forests composing less than half the land cover) can be given moderate ratings for the three modes of land treatment, as a mixed land cover may necessitate a combination of land treatment processes or the alteration (total clearing or reforestation) of existing land cover to suit a given process. Water and barren land use categories have a low potential for the three modes of land treatment. Nonforested wetlands have a moderate to low land treatment potential. Land treatment systems on wetlands have shown good potential for renovation of wastewater but they are still in the experimental stage.

The Landsat imagery can be used for preparing a preliminary land use map of an area. The time involved in mapping an area such as Nashville, Tennessee, was approximately two hours (Merry 1978). This preliminary land use map can then be used to pinpoint areas where more detailed land use maps are required. The satellite land use map can be compared with existing information on topography and soil associations on a regional basis and potential sites for land treatment can be selected.

A request for a computer search of available satellite imagery can be accomplished through the EROS Data Center, Sioux Falls, South Dakota. Black and white or color photographic prints can be ordered from this organization.

2) Site selection and site evaluation

Once regional planning studies have been completed, detailed site selection and evaluation for potential land treatment proceeds. This involves identification of soil types and soil series of the selected areas and then assignment of numerical rating values to each soil. Many types of soil survey information can be used for site selection. This information can be divided into two categories: 1) data that have direct relevance to system design, such as slope of land, depth to groundwater or bedrock and measured soil chemical and physical parameters, and 2) data that can be used indirectly to estimate relevant soil properties such as soil texture and organic matter content. These data may also be useful for indirectly predicting soil structure and preferential flow patterns during the detailed design.

Table 7. Rating values for soil series.

Soil characteristics	Land Treatment Process: Slow rate	Overland flow	Rapid infiltration
Soil depth (m)			
< 0.1	E*	E	E
0.1-0.6	E	0	E
0.6-1.5	3	5	E
1.5-3	8	7	4
> 3			
Limiting permeability (cm/hr)			
< 0.15	0	8	E
0.15-0.5	2	10	E
0.5-1.5	5	7	0
1.5-5	8	2	6
5-50	6	E	9
Predominant slope (%)			
0-3	7	7	8
3-8	7	8	5
8-15	4	2	1
15-30	0	E	E
30-45	E	E	E
45	E	E	E
Overall suitability rating			
Suitable	20-25	20-25	20-25
Moderately suitable	14-19	15-19	15-19
Unsuitable	< 14	< 15	< 15
Excludes use of process	E	E	E

* E means excluded from process consideration.

Moser (1979) and Ryan and Loehr (1981) discussed a numerical method of rating soil as to their suitability for land treatment. The three soil characteristics used in this rating scale include soil depth (depth to bedrock or groundwater), limiting permeability and the predominant slope. Permeability is defined as the rate at which water or air moves through the soil. The classification of soils as to their permeability includes: very slow (<0.15 to 1.5 cm/hr), moderate (1.5 to 5.1 cm/hr), moderately rapid (5.1 to 15.2 cm/hr), rapid (15.2 to 50.8 cm/hr), and very rapid (>50.8 cm/hr).

The rating values were selected to allow clear distinctions between suitable, moderately suitable, and unsuitable soils, and soils with properties automatically excluding their use. Table 7 shows the rating values for soils at potential land treatment sites, as developed for the 1981 *Process Design Manual for Land Treatment of Municipal Wastewater.*

3-3. SITE CHARACTERIZATION

A. Objective

The objective of this task was to define the site characteristics that must be considered in the planning, designing and managing of land treatment systems.

B. Approach

Following preliminary planning and site evaluation, a thorough examination was conducted of the different aspects of the site that affect the renovation capacity and the wastewater application rate and schedule, including climatic considerations, soil properties and crop selection.

C. Research accomplishments and conclusions

1) Climatic considerations

The climate has a large influence on wastewater application because it is a major factor affecting plant growth and microbial transformations of nitrogen and biochemical oxygen demand. In northern areas, winter storage facilities for wastewater are often required because frozen soils limit wastewater infiltration and movement into soils. The mean frost-free period in days (growing season) between the last 0°C temperature in spring and the first 0°C temperature in autumn in areas east of the Rocky Mountains varies from about 100 days along the Canadian border to 300 or more days along the Gulf Coast. The frost-free period varies from 150 to 180 days in most of the Corn Belt. In mountainous regions the frost-free period varies with both altitude and latitude.

Because wastewater must infiltrate the soil, the length of the period when soils are frozen is important. The number of days when the minimum temperature is 0°C and below defines the practical length of time when cold weather limits infiltration of water into the soil, although the number of days of frozen soil would be somewhat lower. The period of below-freezing temperatures may also define the length of time when large-scale sprinkler infiltration and irrigation could be operated if care is taken to protect equipment from damage by freezing. The mean time when the minimum temperature is below 0°C varies from approximately one-half year along the Canadian border to only a few days in the southern United States. In the Corn Belt the values vary from about 90 to 160 days.

Temperature is a major factor in the transformation of organic materials. Each organism has its own growth range and optimum temperature. The optimum growth temperature for any organism is commonly within 3° to 8°C of its upper limit of growth. In general, organic transformation increases two- to three-fold for each rise of 10°C between minimum and optimum temperature. One would expect microbial activity during July to be about twice as rapid in central Texas (average air temperature 29.4°C) as in central Minnesota (average air temperature 21.1°C) if other factors are not limiting.

2) Soil physical considerations

The hydraulic properties of soil are important for land application of wastewater because they influence the amount of water runoff and the amount of water leached through the soil profile. Transport of water over the soil surface or through the soil mantle may carry contaminants. The water retention characteristics of the soil will also influence its aeration status and thus may influence microbial reactions within it.

Moderately high, but not excessive, soil hydraulic conductivity is desired for most conditions where wastewater is applied on land. It is desirable for the water placed on the surface to move rapidly into the soil to reduce the probability of runoff. However, excessively rapid transport through the profile may not allow sufficient time for organic materials to biodegrade, nutrients to be absorbed by plants, or other chemical reactions to take place between the waste components and soil.

A common problem during wastewater application is that the surface of the soil "seals" and has a much lower hydraulic conductivity than underlying layers. The seals may develop because of organic materials clogging the soil pores or soil particles sorting into a thin, dense layer by the action of falling water drops. The infiltration rate, in either case, may be reduced so that either tillage or a thorough drying may be required to break up the seal. A sufficient depth of unsaturated soil profile is needed for both biological and chemical reactions to take place.

3) Soil chemical and biological considerations

The chemical properties of soils are extremely important in removing dissolved chemicals as wastewater percolates through the soil. The ability of a soil to absorb constituents from solution increases with clay and organic matter content. Of the three main groups of clay minerals in soils, the montmorillonite group has the greatest cation exchange capacity (80 to 100 meq/100 g), the illite group an intermediate exchange capacity (20 to 40 meq/100 g), and the kaolin group the smallest exchange capacity (5 to 15 meq/100 g).

The negative charge that gives clay minerals the property of cation exchange arises from isomorphous substitution within the crystal structure of the mineral and broken bonds on crystal edges. Anion exchange is a soil property highly dependent upon pH. The ratio of cation- to anion-exchange capacity at intermediate soil pH's is about 6.7 for montmorillonite, 2.3 for illite, and 0.5 for kaolinite.

Some wastes may contain large enough quantities of sodium and potassium that, when absorbed on the exchange complex, they may damage soil structure and reduce its hydraulic conductivity. Exchangeable sodium percentages of 15% are usually considered the dividing point above which hydraulic conductivity is reduced.

The fate of phosphorus applied in wastewater is important because most effluents contain considerably more phosphorus than is removed in a crop. Phosphorus in concentrations greater than about 0.015 mg/L can cause nuisance aquatic plant growth in lakes. Adsorption on the surface of solid materials is the major mechanism of removal of orthophosphate from solution. Phosphorus may also precipitate as calcium phosphates at soil pH's above 7.0. Iron and aluminum phosphates may form at low pH's. Adsorption will increase as concentrations of clay in the soil increase.

Applications of wastewaters at high rates supply considerable nitrogen and could result in leaching of nitrates to groundwaters. Thus, the amount of wastewater applied should not produce significantly more nitrate than crops can utilize or that can be removed by denitrification. The drinking water standards allow 10 mg/L of nitrate at the project boundary.

Most of the nitrogen in wastewater is in the form of ammonium, nitrate, or organics. No good estimates of the denitrification rate in a soil management system using wastewater are available, but the rate may be higher than in most soils without wastes because of an abundant energy source and possibly a lower level of soil oxygen. An observed average N loss from lysimeter experiments of about 15% could have been from denitrification. It has been speculated that, under high loadings of sewage sludge or effluents, denitrification losses could run as high as 40 to 50% of the mineralized nitrogen.

4) Crop considerations

Considerations in crop selection and management on land receiving wastewater include 1) the adaptability and management of the crop to the conditions imposed by the wastewater, 2) the amount of nutrients and elements taken up by the crop and 3) the yield potential of the crop.

Grass crops for haylage, hay, or grazing are often used under high water application conditions because 1) some grasses will grow well in wet soil, 2) grasses remove large amounts of nutrients, 3) tillage after planting is not required, and 4) sealing of the soil surface is minimized. Other crops often used are the cereal grains and corn.

There are obvious differences in the adaptation of different forage species to applications of large amounts of wastewaters. However, field testing has not yet been sufficient to delineate crop adaptation.

The production potential of crops is important because yields are closely associated with amounts of plant nutrients removed in the crop. The mean maximum yields of corn fodder are about 18 metric tons/ha (200 bushels grain/acre) which may contain as much as 250 kg N/ha, 35 kg P/ha, and 250 kg K/ha. The near-maximum yield of forage crops at St. Paul, Minnesota, is 14 mt/ha, which may contain as much as 400 kg N/ha, 50 kg P/ha, and 450 kg K/ha. The potential nutrient removals for forages in southern regions of the country are probably at least twice those given for St. Paul.

3-4. WASTEWATER RENOVATION PROCESSES

Wastewater renovation by land treatment means the removal of undesirable compounds by the soil-plant systems to an acceptable level. The processes involve physical, chemical and biological mechanisms. The rate and extent of the processes vary greatly in slow rate, rapid infiltration and overland flow land treatment.

A. Objectives

The objectives of this research were:

1. To develop methods, data and quantitative information on the physical processes involved in wastewater renovation. This includes removal of suspended solids and BOD.
2. To develop quantitative information on the fate of nitrogen in land treatment.
3. To develop methods for predicting the fate of phosphorus in land treatment.

B. Approach

Data obtained from operating land treatment research facilities at CRREL, Utica, Apple Valley and Pack Forest and from laboratory studies were used to determine the rate and extent of the renovation processes.

C. Research accomplishments and conclusions

1) Physical processes

The physical processes involved in wastewater renovation include water and solute transport in soils, physical entrapment of suspended solids and BOD, and mixing of wastewater with soil solution and groundwater.

Proper estimation of wastewater application rate and schedule is an important step in the design of land treatment systems. Conservative estimation of application rate will result in a larger area of land and larger area of storage wastewater than necessary, while an overestimation of the application rate will cause insufficient wastewater renovation.

The rate of water movement through soils can be estimated by using neutron probes and tensiometers (Nakano and Iskandar 1978, Iskandar and Selim 1981). The water content at different soil depths is determined by consecutive readings made by a neutron probe at these depths at different periods of time following water redistribution in soil. This method is valid for slow rate and rapid infiltration systems.

The amount of wastewater that can be applied to a soil can be calculated from the mass balance equation:

$$Q_a = ET - P + L + RO \qquad (1)$$

where Q_a = quantity of wastewater to be applied (cm/yr)
ET = evapotranspiration (cm/yr)
P = precipitation (cm/yr)
L = leaching (cm/yr)
RO = runoff (cm/yr).

In slow rate and rapid infiltration systems, runoff is not allowed. An estimate of evapotranspiration and precipitation for a particular region may be found in the climatological records. Therefore, the amount of wastewater applied to land is highly dependent on the rate of water percolation through the soil.

Several methods for the determination of the rate of water percolation were studied. These include actual field measurement and predictive methods based on empirical relationships of some soil physical properties.

2) Field measurement of soil infiltration

Abele et al. (1980) described a method for field measurement of the infiltration rate for slow rate systems (summarized in an Engineering Technical Letter). Briefly, the soil infiltration was measured by applying a certain volume of water to a saturated known volume of soil and observing the rate of change in water percolation with time. Soil tensiometers were installed at different depths in the soil to indicate the degree of soil saturation. To avoid runoff, a berm made from 35-cm-wide aluminum flashing was inserted into the soil to a depth of 15 cm. The berm was installed to form a circle of 3 to 10 m diameter. The infiltration rate could then be determined from

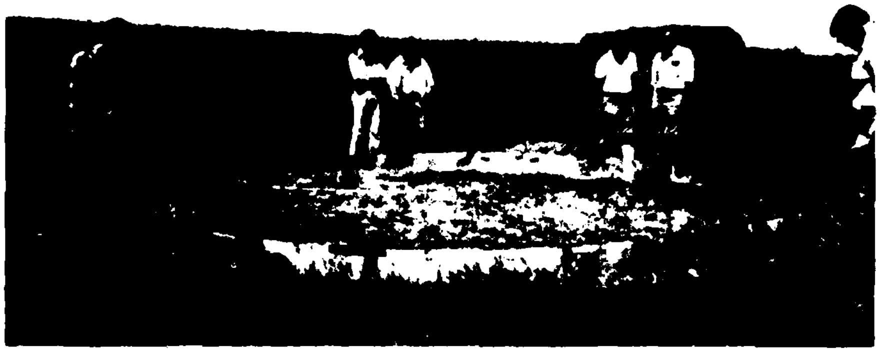
$$I = (\Delta y / \Delta t) \qquad (2)$$

where I is infiltration rate, Δy the change in water head (water percolation), and Δt the time increment in hours.

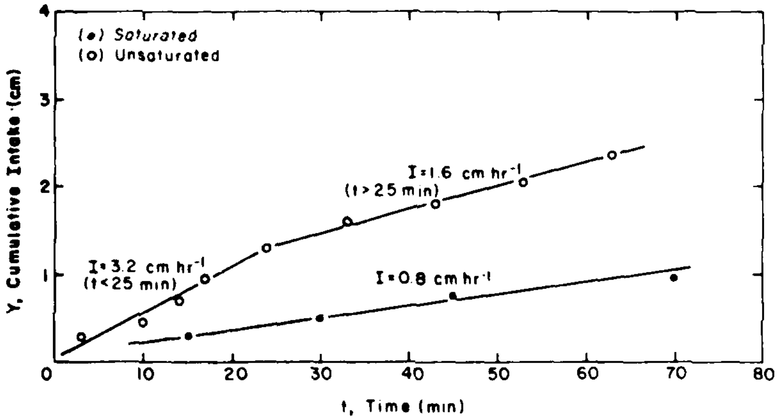
The method was tested at three land treatment sites at Apple Valley, Minnesota, Clarence Cannon Dam, Missouri, and Deer Creek Lake, Ohio. Figure 8 shows the infiltration test and the relationship between cumulative water intake and time for the Deer Creek Lake site.

3) Fate of nitrogen in land treatment

Nitrogen is often the most troublesome constituent to remove in the treatment of municipal wastewater. With the exception of N-fixing legumes, cropping systems are generally N-limited, permitting at least a partial offsetting of the costs of land treatment by replacement of fertilizer N with wastewater N. However, in most cases, N discharges to ground or surface waters must be limited to protect these resources. This requires careful management of the land treatment systems with due consideration to the many factors affecting the fate of N in the soil-plant-water environment. Figure 9 shows the reactions that may occur to varying degrees in wastewater-treated soils. The important biological transformations of N in land treatment are 1) immobilization of organic forms of N by plants and microorganisms to form organic N compounds, 2) ammonification (or mineralization), the decomposition of organic N to ammonium, 3) nitrification, the oxidation by ammonium to nitrate, and 4) denitrification, the reduction of nitrate to nitrogen gas and nitrogen oxides. The important chemical reactions in soil in-



a. Infiltration test.



b. Cumulative water uptake and time.

Figure 8. Infiltration test and the relationship between cumulative water uptake and time.

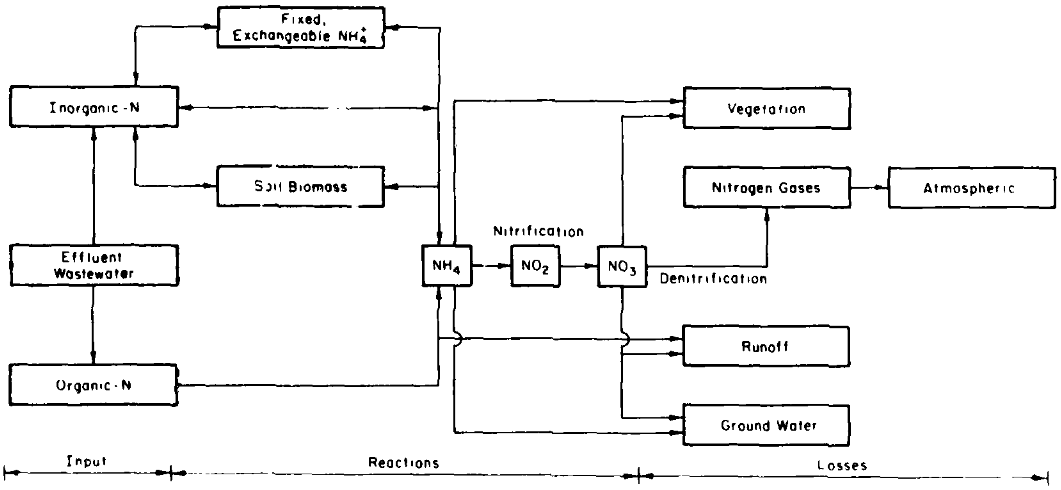


Figure 9. Nitrogen cycle in soils.

clude ammonia volatilization, ammonium exchange reactions, ammonium fixation and the entrapment of ammonium in clay minerals.

The rate and extent of each of these reactions vary tremendously both among the different land treatment types and from site to site depending on several environmental factors. These factors are temperature, pH, water regime, aeration, plant cover, soil characteristics and site management.

a) *Mineralization-immobilization.* A dynamic biological equilibrium exists between the inorganic and organic forms of N in unfertilized soils. The amount of inorganic N in these soils is a function of the relative magnitude of the two opposing processes, immobilization and mineralization. As long as conditions are favorable for biological activity, these processes are constantly occurring although the rate of N turnover may be low. Net mineralization (the amount of inorganic N released in excess of that immobilized) often is about 2 to 4% of the total soil N per year in temperate zone soils. However, since agriculture soils (slow rate and overland flow systems) may contain 1000 to 5000 kg N/ha, the N mineralized can provide a significant portion of total crop needs. In land treatment most of N applied is in the ammonium form (Iskandar et al. 1976). Therefore, net immobilization will be limited and may serve only as a temporary N sink.

b) Nitrification. Nitrification is a key reaction in the N cycle of wastewater-treated soil. It transforms the relatively immobile ammonium ions into nitrate, which can be readily leached, taken up by plants, or denitrified. This process occurs in two steps, both of which are almost exclusively mediated by obligate aerobic bacteria. *Nitrosomonas* is usually mentioned as the most common bacterium for the first step, the transformation of ammonium to nitrate. The second step is the oxidation of nitrate to nitrite which is carried out by *Nitrobacter* species. Nitrifiers of both types are widely distributed in soils. Although they have a relatively slow growth rate, the nitrification rates are on the order of 7 to 70 kg N/ha day under optimum conditions. Therefore, complete nitrification of applied ammonium may occur in the top few centimeters of soils during the warm months. Temperature, oxygen supply and pH are the major factors influencing the rate of nitrification (Parker et al. 1981). When wastewaters are applied to soils during colder months, or when sufficient wastewater is added to soils to inhibit oxygen diffusion such as in rapid infiltration, exchangeable ammonium can accumulate. When conditions are again favorable for nitrification, the exchangeable NH_4 is rapidly converted to nitrate, resulting in a high nitrate concentration in leachate (Iskandar et al. 1976, Iskandar 1978).

Iskandar et al. (1980) studied the dynamics of ammonium and nitrate in a slow rate system during the summer and fall months. They found that, under a certain application rate and schedule of wastewater application (5 to 7.5 cm/wk, 3 days weekly), soil ammonium and nitrate concentrations reached a daily quasi-steady state. Total ammonium concentrations, however, were much higher than those of nitrate at all soil depths (Fig. 10). The concentrations of both ammonium and nitrate were much higher at the surface and decreased with depth, consistent with the higher soil cation exchange capacity, the slow movement of ammonium in soils, and the higher soil organic matter in the surface. Both ammonium and nitrate concentrations were higher in the fine-textured

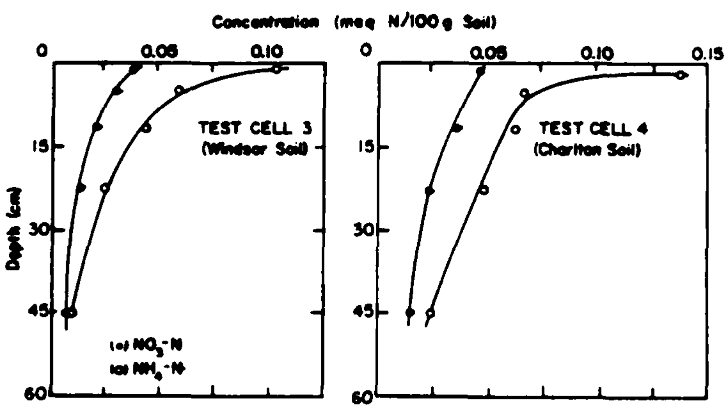


Figure 10. Depth distribution of NH_4 and NO_3 in soils.

soil than in the coarse soils and both ions were higher during the warmer months than during the colder months.

c) Nitrogen gaseous losses. Nitrogen losses other than plant uptake and leaching in land treatment include denitrification and ammonia volatilization. Denitrification can present a major N sink in many wastewater application systems. In most systems, the rate of denitrification is governed by the amount of available organic carbon, which is required by bacteria involved as an energy source.

In laboratory experiments, Jacobson and Alexander (1979) evaluated the effect of pH, temperature and the amounts and nature of carbon sources on the rate of denitrification. They found that denitrification was very slow in soil of pH <4.2 and was much faster at pH 5.5–6.8. No denitrification occurred at temperature below 1 °C. Denitrification was highest at 30 °C and decreased with the decreasing temperature to low values at 7 °C. Denitrification was higher in primary effluent or in a mixture of secondary and primary effluent than in secondary effluent alone due to the presence of higher concentrations of organic carbon in the primary effluent. By adding sources of organic carbon such as glucose, methanol or succinate, the rate of denitrification was increased substantially.

In prototype field experiments simulating slow rate systems (conducted at CRREL), denitrification was estmated from a nitrogen balance sheet (Iskandar et al. 1976, Jenkins and Palazzo 1981). Depending on the amount of wastewater applied, scheduling, and pretreatment of wastewater prior to application to land, from 9 to 15% of the applied nitrogen was not accounted for. This included nitrogen losses due to nitrification and to ammonia volatilization. Similar conclusions were obtained from greenhouse experiments using soil lysimeters with ^{15}N as a tracer under controlled conditions (Iskandar and Selim 1981).

In a field study conducted at Santa Maria, California, the rate and extent of nitrogen losses by denitrification were determined from direct measurement of N_2O and NH_3 fluxes following wastewater irrigation in a slow rate system (Fig. 11). Estimated annual N losses ranged from 78 to 107 kg N/ha or 7.3 to 9.4% of applied N; 61 to 72% of which was attributable to denitrification. Ammonia volatilization increased when wastewater was applied by spray irrigation and when soils contained high amounts of calcium carbonate (Ryden et al. 1981).

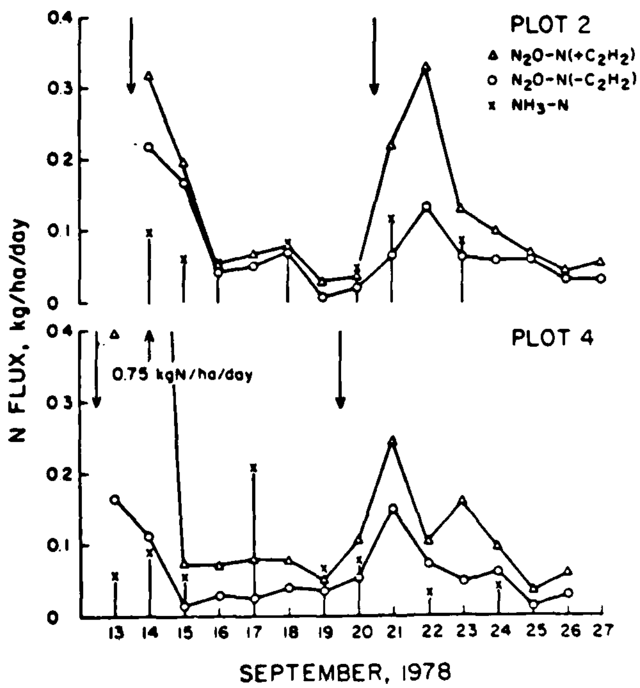


Figure 11. Fluxes of N_2O and NH_3 in a slow rate system.

Denitrification is the main mechanism of nitrogen removal in rapid infiltration systems (Bouwer et al. 1974). These investigators showed that it is possible to manage a system for enhanced denitrification and to remove over 60% of applied N using 9-day flooding and 12-day drying cycles. Apparently, nitrification of ammonium was complete by the end of the drying period so that denitrification occurred when more wastewater was added. The denitrification process could be enhanced even more by decreasing the infiltration rate and adding additional organic carbon to the reduced zone.

Experience with rapid infiltration in cold locations such as Calumet, Michigan (Baillod et al. 1976), or Ft. Devens, Massachusetts (Satterwhite et al. 1976b), showed that partial treatment of wastewater for nitrogen removal by this method is also feasible.

Less is known of the fate of N in overland flow systems. The only operating systems studied in any detail were the ones at Paris, Texas, where cannery wastes were being treated (Law et al. 1969), and at Werribee Farms, Australia (McPherson 1978). While the Texas system provided a high degree of removal of N (60 to 70%), the high BOD of the waste probably contributed to the removal. The overall reduction in N concentration in the Werribee system is about 30 to 45% (Scott and Fulton 1978). Experimental field systems in Vicksburg, Mississippi (Peters and Lee 1978), and in Hanover, New Hampshire (Jenkins et al. 1978), have achieved N reductions of 80% or better. Plant uptake of N, incorporation of N in the litter, and denitrification are the main mechanisms. Although incorporation of N in the litter could account for a high percentage of short-term N removal, this N is stored temporarily and eventually will be mineralized so that the removal efficiency will decline markedly.

Climate has a major influence on the performance of overland flow sytems. Thus, while overland flow gave high apparent reductions of N year-round in Mississippi (Peters and Lee 1978), removal efficiency was found to decrease with a soil temperature below 17 °C in New Hampshire (Jenkins et al. 1978). This is due to decrease in plant uptake, N immobilization, nitrification-denitrification and ammonia volatilization with lower temperature.

4) Plant uptake of nitrogen

Plants play an important role in removing nitrogen from applied wastewater. In fact, plant uptake is the major process of N removal in slow rate and some overland flow systems as well. In addition to removing nitrogen from wastewater, agronomic crops and trees have other beneficial effects in land treatment. These include cash return, reduction in energy use for fertilization, reduction in soil erosion problems and maintenance of soil permeability. Plant uptake of N was studied in growth chambers to evaluate environmental effects on plant growth and uptake of nutrients, in greenhouse pot studies to enable researchers to study many application treatments, and at field sites to evaluate the laboratory results and assess the effect of climate on plant uptake of nutrients.

Barber (1979) studied the effect of temperature on the uptake rates of NH_4 and NO_3 by tall fescue and reed canarygrass. In a range from 5° to 35 °C, uptake of N was greatest at 25 °C (Fig. 12), and uptake increased linearly with temperatures between 5° and 20 °C. Above 25 °C, uptake rate decreased rapidly. Tall fescue absorbed N faster than reed canarygrass at temperatures below 20 °C. At 25 °C and below, both grasses absorbed NH_4 faster than NO_3. At 30° and 35 °C reed canarygrass absorbed NO_3 and the plants became unhealthy. The relative effect of temperature on

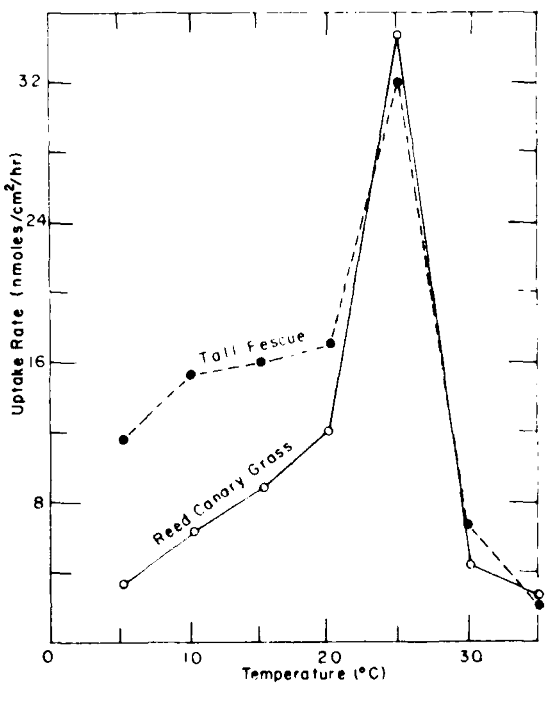


Figure 12. Plant uptake of N as a function of temperature.

the mean rate of N uptake can be calculated as follows by using the rate at 20°C as 1.0:

Temperature (°C)	Relative uptake rate
5	0.4
10	0.6
15	0.8
20	1.0
25	1.4
30	0.4
35	0.1

Plant uptake of nitrogen at various nitrogen application rates has also been studied at CRREL and in Minnesota for slow rate systems (Palazzo 1976, 1977, Clapp et al. 1977, Linden et al. 1978, Palazzo and McKim 1978, Jenkins and Palazzo 1981). Figure 13 shows the information developed from experiments on the test cells at CRREL. Plant uptake of nitrogen in the CRREL overland flow system also increased for increasing loading rates of nitrogen, with removal being as high as 332 kg N/ha (Palazzo et al. 1981). In a WES study, uptake of nitrogen ranged from 179 to 222 kg/ha (Peters et al. 1981).

The conclusion drawn from these studies is that the removal of applied nitrogen increases as its application rate increases, although the increase is not linear. Increases in the application rate will decrease the percentage of the applied nitrogen removed by the crop and increase the amount of nitrogen that leaches to the groundwater through the soil profile. Jenkins and Palazzo (1981) showed that, as nitrogen loading rates increased beyond 800 kg/ha, the removal efficiency of the plants was greatly reduced and nitrate concentrations in the percolate increased dramatically. Crop nitrogen removal curves for different application rates of nitrogen from various locations in the United States and Canada have also been developed specifically for different forages (Clapp et al. 1978).

Corn has been shown to be less efficient in nitrogen removal than grasses but is a more economically desirable crop since it has a higher market value. Dual cropping, growing a second crop in combination with corn, has been shown to result in greater nitrogen uptake than corn production alone (Linden et al. 1977, Marten et al. 1980).

Figure 14 shows a comparison between nitrogen uptake by corn only and by corn seeded with rye or reed canarygrass at the Apple Valley site. The corn alone removed about 150 kg N/ha-yr. The corn/reed canarygrass system removed more nitrogen than either corn alone or corn/rye (as much as 260 kg N/ha-yr). This increased crop uptake of nitrogen would help to maintain low

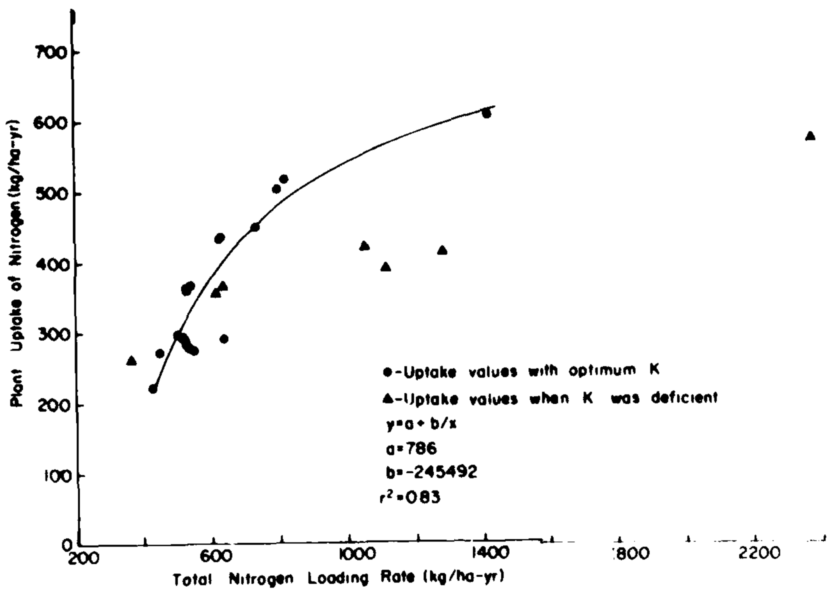


Figure 13. Plant uptake of N in slow rate system as a function of applied N.

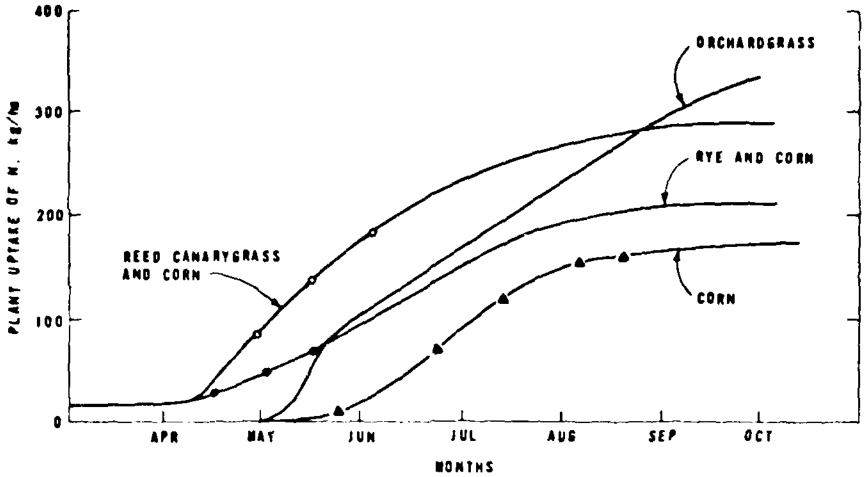


Figure 14. Plant uptake of N by dual cropping.

Table 8. Relationship between applied N, N uptake and leachate concentration of NO_3 at various forest systems.

Species	*Age (yr)*	*Period (A,GS*)*	*Application Rate (cm wk⁻¹)*	*Duration (years)*	*Nitrogen (kg ha⁻¹ yr⁻¹) Loading*	*Uptake Tree*	*Uptake Grass*	*Concentration in leachate (mg L⁻¹) NO_3-N*	*Total N*
Western Forests									
Poplar seedlings	4	A	5	4	400	166	173	0.1	0.7
Douglas-fir seedlings	4	A	5	4	350	111	121	5.3	5.6
Douglas-fir forest	50	A	5	3	370			0.6	0.9
Southern Forests									
Mixed hardwood	45	A	7.6	5	684	--		8.0 (3.7)†	9.6 (4.6)†
Eastern Forests									
Mixed hardwood	70	GS	2.5	16	150	95		4.6	
Red pine	25	GS	2.5	16	150			3.8	
White spruce (old field)	8	GS	5	16	310		120	5.3	
Mixed hardwood	50	A	5	13	650			23.3	
Red pine	25	GS	5	7	310			14.2	
Pioneer succession	1-9	GS	5	9	310			5.2	
Lake States Forests									
Poplar	5	GS	3	5	44	22		1.9	2.5
Poplar	5	GS	7	5	103	68		2.8	3.6
Red pine	20-25	GS	2.5	6	36			1.5	2.9
Red pine	20-25	GS	5	6	73			1.8	2.8
Red pine	20-25	GS	8.[illegible]	6	131			5.4	6.5

*A = Annual (year-around), GS = Growing season

† At base of slope

nitrate concentrations in the leachate at a land treatment site and would permit increasing the application rate of wastewater.

The crop grown in conjunction with corn can be either a cereal, such as rye or wheat, or a forage grass, such as reed canarygrass. The degree of nutrient uptake expected from the cereal or grass crop during the winter season is minimal. However, during the spring and fall, this crop will grow and assimilate wastewater nutrients as long as climatic conditions are suitable. The practice of growing a grass or cereal crop before and after corn effectively lengthens the growing season, thereby increasing plant uptake of nutrients and decreasing the wastewater storage period.

Plant uptake of nitrogen was most intensive (3.4 kg/ha-day in 1979) during the period before the first harvest (Palazzo 1981). Therefore this would be the most appropriate time for higher nitrogen loading. Tree uptake of N is much lower than forage uptake, particularly with the very young trees. For this reason, it is recommended that grass should be grown with the trees during the first few years of establishing a forest land treatment system. Table 8 summarizes the relationship between N loading, plant uptake and leachate quality in various forest ecosystems.

Trees can remove up to 40% of applied P in municipal wastewater. Leachate from the forest ecosystems usually contains < 1 mg P/L (Sopper and Kerr 1978a). The procedure developed for estimation of soil sorption capacity and prediction of P in leachate for non-forested areas can also be applied to forest soils.

Trees usually are not as sensitive to trace metal toxicity as agricultural crops, and food chain accumulation of trace metals is not considered a problem in forest systems. Forest soils show a high capacity to remove trace metals, BOD and suspended solids. Wastewater percolated from forest soils contains acceptable levels of trace metals, BOD, and suspended solids (Cole et al. 1979).

5) Nitrogen leaching losses

Nitrogen in leachate from land treatment is mainly present in the NO_3 form. It is generally desirable to decrease the concentration of NO_3-N in leachate to less than the 10 mg/L as recommended by the EPA for drinking water.

Conclusions drawn from the extensive studies conducted at Hanover, New Hampshire, Apple Valley, Minnesota, and at Santa Maria, California, may be summarized in the following:

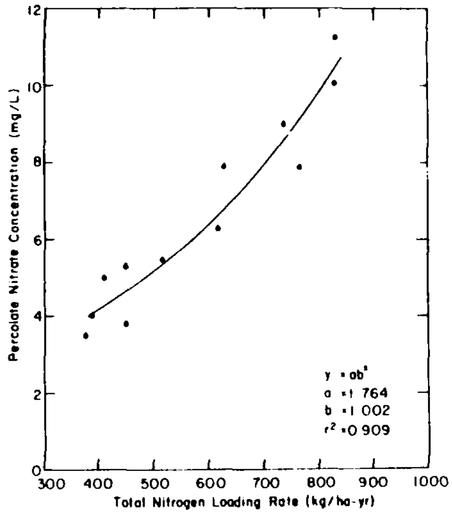


Figure 15. Relationship between NO_3 concentration in leachate and applied N.

a) Slow rate systems.

1. In slow rate systems with forage grass in cold-dominated areas such as New Hampshire and Minnesota, the concentration of nitrate in percolating water was found to correlate with the nitrogen loading rate (Fig. 15). To average less than 10 mg/L of NO_3-N in the leachate, a loading rate of about 800 kg N/ha was acceptable. This amounted to about 7.5 cm/wk of wastewater containing 20-30 mg N/L (Iskandar et al. 1976, Jenkins and Palazzo 1981).

2. High concentrations of NO_3 in percolate water are expected during the first year or two of operation due to disturbance of the soil surface, which increases the mineralization of native organic nitrogen. Lower rates of wastewater should be applied during those years (Iskandar et al. 1976).

3. Year-round applications of wastewater did not result in a substantial increase in the concentration of N in percolating water (Fig. 16). A peak of NO_3 concentration in the percolate was observed during the spring after wastewater had been applied during the winter. This was explained by the presence of a large amount of NH_4 in the soil during the spring, which apparently was nitrified and then leached (Jenkins and Palazzo 1981).

4. Nitrogen treatment was not improved by spreading wastewater applications over several days as opposed to applying the same volume in one day. In fact, slightly better treatment per-

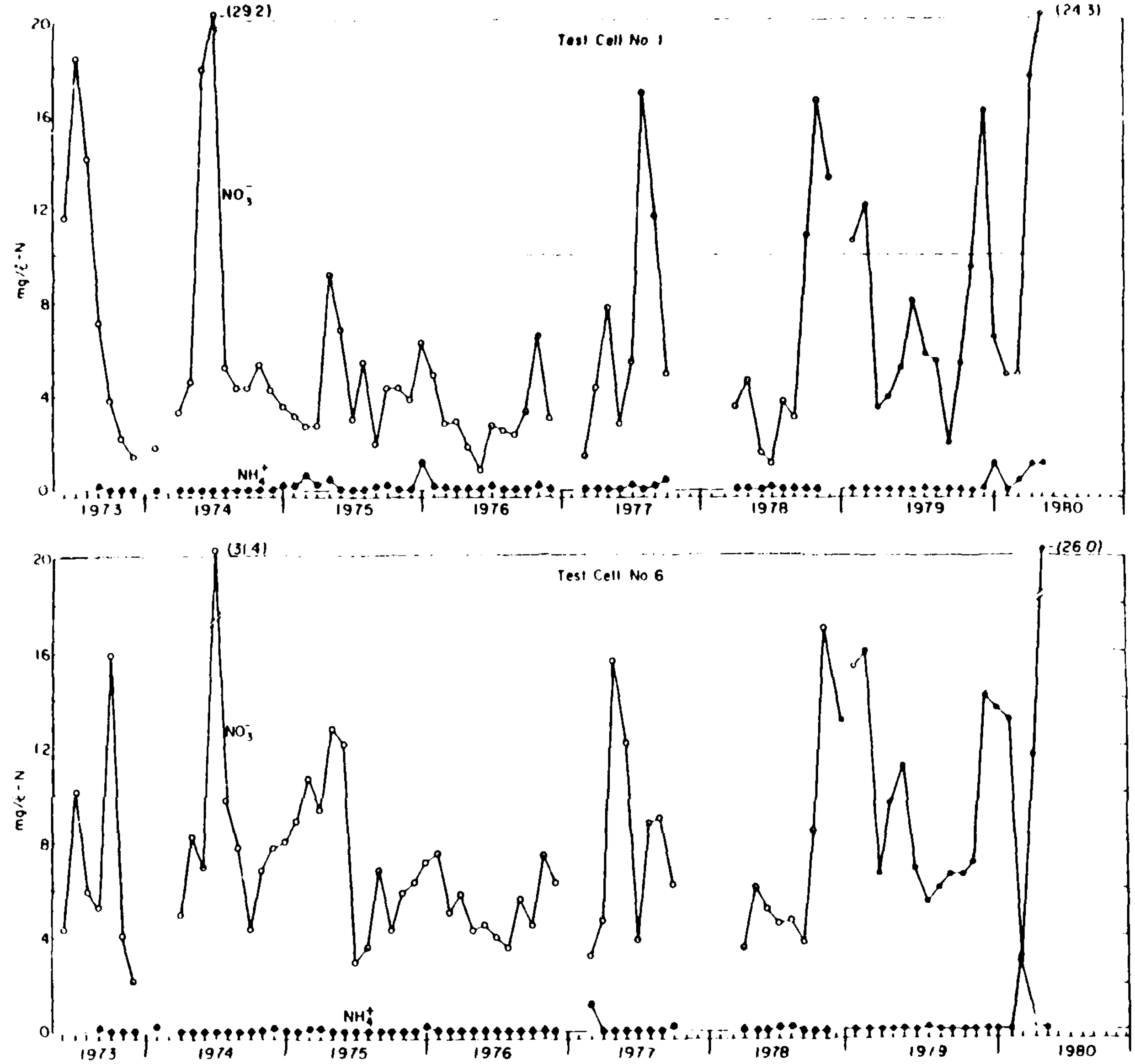


Figure 16. Seasonal concentration of NO_3-N in leachate from slow rate systems in cold-dominated areas.

formance was achieved with one application period (Jenkins et al. 1981).

5. No significant difference in the effectiveness of treatment was observed when a sandy loam and silt loam soil were compared (Jenkins et al. 1981).

6. In moderate climates, such as in California, mean NO_3-N concentrations in leachate ranged from 15 to 32 mg N L depending upon location. This was probably due to fertilization, low plant uptake and high concentrations of NO_3 in both applied effluent and native groundwater. Crop uptake in this system accounted for only 32% of applied N (Lund and Page 1979).

7. Proper crop and soil management will prolong the persistence and extend the life of forage grasses at land treatment sites. Appropriate harvesting procedures, K fertilization, and addition of lime to acid soils and gypsum to alkali soils are required to increase plant uptake and hence decrease NO_3 in leachate from land treatment (Palazzo 1981).

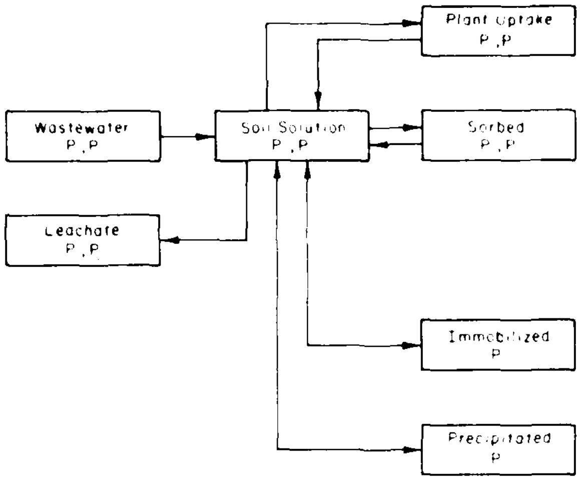


Figure 17. General interactions and processes relevant to the chemistry of phosphorus in land treatment.

b) Overland flow systems.

1. Inorganic N in the runoff from overland flow could be present often in the form of NO_3 or NH_4. Low concentrations of organic-N may often be incorporated in algal cells. The concentration of NO_3 in the effluent was found to be dependent on the forms and amounts of N applied, detention time, plant uptake of N and temperature. In general, less than 10 mg N/L in the runoff water was obtained when wastewater containing 20–30 mg N/L was applied in the rate of 2.5 cm per 18-to 24-hr day for 5 to 7 days a week (Martel et al. 1980, Peters et al. 1981). However, during the summer months, higher application rates (10 cm/day) may be used for one or two days and about 10–15 mg N/L in runoff can be expected. If the concentration of N in wastewater is high (50–100 mg/L), low N in the runoff may be achieved if the wastewater is applied only 1 day/wk.

2. Experiments in Hanover, New Hampshire, showed that NO_3-N concentration in the runoff is dependent on the NO_3-N concentration in applied wastewater, being high when applied NO_3 was high (Martel et al. 1980). It is therefore recommended that in overland flow (as well as other types of land treatment) applied N should be in the ammonium form. This means that less pretreatment (aeration) is required prior to land application to keep N in the NH_4 form in order to achieve high N removal efficiency.

c) Fate of phosphorus in land treatment. Domestic wastewaters contain from 1 to more than 40 mg/L phosphorus (P) as total P and most of this is present in the inorganic form. The concentration of P in the effluent from a sewage treatment plant is highly dependent on its concentration in the raw wastewater and the method and efficiency of treatment. In contrast to nitrogen, phosphorus is usually applied at rates far in excess of crop removal. Movement of P in soils, therefore, is largely dependent on the rate and extent of removal by the soil. Some of the general interactions and processes relevant to the chemistry of phosphorus in the land treatment of wastewater are shown in Figure 17.

The potentially important mechanisms of P removal in soils receiving effluent include precipitation-dissolution reactions, sorption-desorption reactions and immobilization reactions. Syers and Iskandar (1981) evaluated these processes in relation to vertical P movement in land treatment systems and concluded that sorption-desorption reactions are the most important chemical reactions influencing P removal by soils. The factors affecting the amount of P sorbed in soils are the amount and nature of P-retaining components, soil pH, cations, inorganic and organic anions, kinetics, and the degree of saturation of the sorption complex.

In New Hampshire, at a P loading rate below 75 kg P/ha, plant uptake was found to account for about 50% of the P applied (Jenkins and Palazzo 1981). Most of the remaining P was retained in the topsoil. Ryden et al. (1981) estimated the soil capacity (to a 150-cm depth) to retain P to be 50 years for a Windsor sandy loam soil and 150 years for a Charlton silt loam soil. Very small amounts of P (<0.1 mg/L) were found in the leachate during 7 years of monitoring this system.

In the overland flow, treatment of P is not as efficient as in slow rate or rapid infiltration systems. At Vicksburg, Mississippi, the best results for P removal were obtained by applying 1.25 cm of wastewater in 19 hours, 5 days per week (Peters et al. 1981). In this treatment about 70% of the applied P was removed and the runoff water contained >5 mg P/L. Reduction efficiency increased to 90% by adding aluminum sulfate to wastewater prior to application. In this case, runoff contained as little as 1-2 mg P/L. Similar results were obtained in cold climate overland flow (Jenkins et al. 1978, Martel et al. 1980, Palazzo et al. 1980).

In rapid infiltration systems, removal of P occurs by sorption and precipitation. Evaluation of existing systems at Fort Devens, Massachusetts, indicated that, after 34 years of operation, the soils are saturated with P to a depth greater than 150 cm (Ryden et al. 1981). Iskandar and Syers (1980) evaluated the effectiveness of a slow rate system at Manteca, California, in removing P from a wastewater containing about 10 mg P/L. They found that the system had failed in removing P from wastewater after only 4 years of operation due to the nature of the soil at this site. The soil was saturated with soluble P to a depth of 150 cm.

3-5. DEVELOPMENT OF MATHEMATICAL AND OPTIMIZATION MODELS FOR PLANNING AND MANAGEMENT OF LAND TREATMENT

A. Objectives

The objective of this task was to optimize automated procedures for planning, design and management of the land treatment systems. Specific objectives were develop the following:

1. A water flow model that simulates water movement in land treatment.
2. Mathematical models for nitrogen transport and transformation processes in land treatment.
3. A phosphorus model for prediction of P concentration in leachate.
4. A method for calculation of storage capacity.
5. A design model for overland flow.
6. A model for estimating construction and operation costs of land treatment.
7. An optimization model for design and operation of slow rate systems.

B. Approach

To accomplish the objectives of this task, several mathematical and optimization models were developed, most of which were evaluated. Many experiments were conducted to collect the required model parameters and the data for model validation, and in some cases data from the literature were used to evaluate the models. Most of the modeling efforts were accomplished at CRREL with input from WES, the Agricultural Research Service, and the University of Washington at Seattle. Modeling efforts were conducted from April 1976 to October 1980.

C. Research accomplishments and conclusions

Many technical reports, publications in open literature, presentations and a technical book have been produced as a result of this effort. Model documentation, and computer programs with a user's guide are available (Berggren and Iskandar 1982). Computer program listings and/or magnetic tapes may be obtained from CRREL.

1) Water flow modeling

Prediction of the rate of water movement in soils is very important in land treatment systems, not only for estimation of the maximum amount of water that can be applied to a system, but also for prediction of the fate of dissolved wastewater constituents in the soil-plant system. Four water flow models were developed and evaluated with field and laboratory data. Furthermore, the four models have been used to describe the fate of nitrogen in land treatment. One of the models is of a compartmental or mass balance type while the other three are mechanistic models. The following is a brief summary of each model.

a) Compartmental water flow model. This mass balance model includes the processes contributing to losses and gains of water in the water-plant system. These processes are irrigation, precipitation, evapotranspiration, surface return flow (or runoff), and deep percolation. All water fluxes are in units of centimeters per year. Three coefficients must be determined or estimated for irrigation application efficiency, precipitation runoff, and deep percolation. In order to estimate leaching losses, the evapotranspiration must be provided. Figure 18 is a schematic diagram of the compartmental water model. Input parameters include 1) irrigation (wastewater, cm/yr), 2) preirrigation (soil water, cm), 3) precipitation (rainfall and snowfall, cm/yr), 4) pan evaporation during the growing season and for fallow soils, and 5) coefficients for irrigation application efficiency, precipitation runoff, potential evapotranspiration for the crops grown, and deep percolation (if known).

Output from the computer program is the

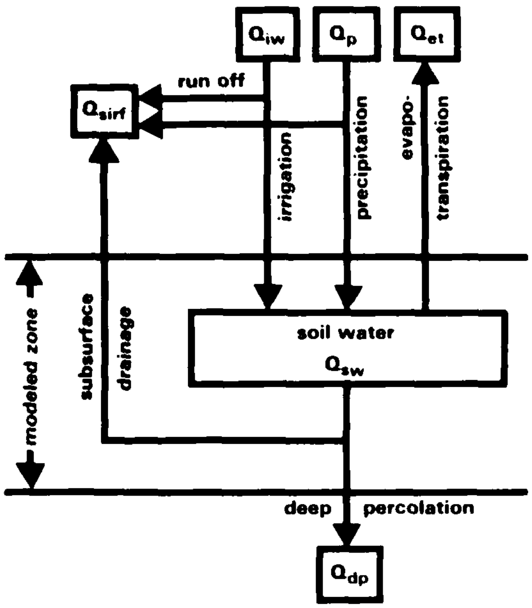
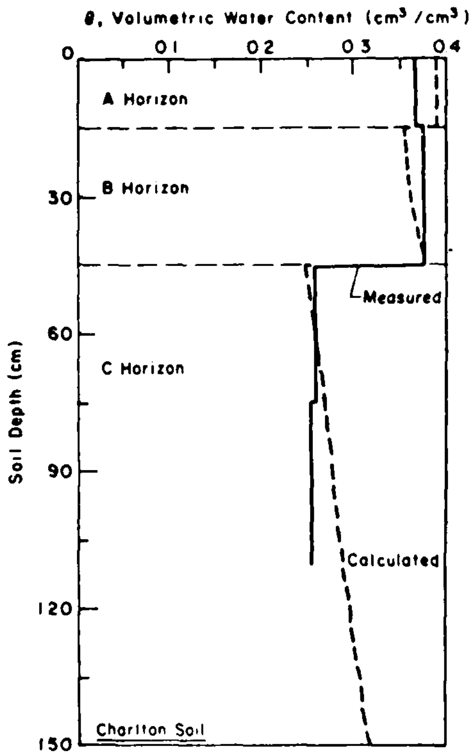


Figure 18. Schematic diagram of the compartmental water flow model.

amount of water percolated from the soil (cm/yr). This model has been evaluated with the data from field systems located at Davis, California, and Hanover, New Hampshire. Reasonably good agreement was obtained. The model has been incorporated with a nitrogen mass balance model which will be described later. For detailed information on this model, the reader should consult Mehran et al. (1981).

b) Water flow model for slow rate and rapid infiltration systems. This one-dimensional model is valid for uniform as well as multilayered soils and for unsaturated or saturated conditions. The computer program is flexible and is designed to incorporate the following input conditions as desired: 1) rate of wastewater application, 2) duration of wastewater application, 3) depth of individual soil layers, 4) wastewater application cycle, 5) soil water properties (hydraulic conductivity and diffusivity), 6) initial soil water distribution, and 7) rate of evapotranspiration.The output from the water flow model is water distribution in the soil profile at any specified time. The model can also be used to estimate maximum water application rate.

The model has been validated with experimental data from greenhouse lysimeters. Good agreement between model predictions and measured data was obtained (Iskandar and Selim (1981). Figure 19 shows a comparison between model prediction and experimental data for two different soils.



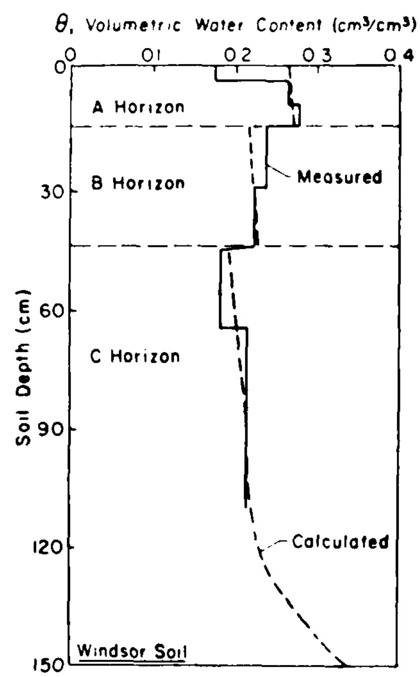


Figure 19. Comparison between predicted and measured water content in slow rate soils.

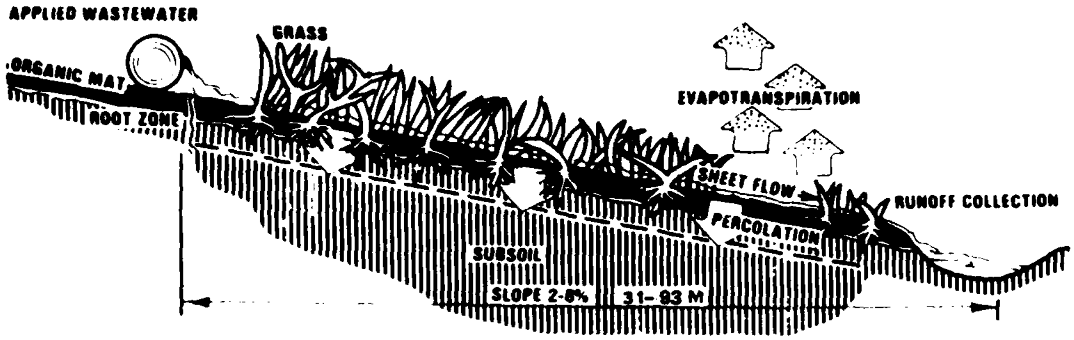


Figure 20. Schematic representation of water flow in overland flow (from U.S. EPA et al. 1981).

c) The Bureau of Reclamation model (hydrosalinity model). This model was developed by the Bureau of Reclamation and has been adapted for land treatment (Schaffer and Gupta 1981). The model is also valid for both steady and unsteady states and for uniform and multilayered soils. It has the capability of describing irrigation return flow and subsurface drainage. This water model has been incorporated with a chemistry model for predicting the fate of salts and ion species (including nitrogen compounds) in soils. The input-output data are similar to those of the water model. The model has been evaluated with the field data from South Montezuma Valley, Colorado, Apple Valley, Minnesota, and Siusun Marsh, California. Comparison between model prediction and expermental data for salt transport is presented in Schaffer and Gupta (1981).

d) Water flow model for overland flow. This model simulates water in overland flow in two dimensions: 1) as a shallow water flow over the surface combined with soil-water flow and 2) as evapotranspiration. A schematic representation of an overland flow system and the processes included in this model is presented in (Fig. 20). Theoretical development and comparison between predicted and measured data are presented in Nakano et al. (1981). The model was developed as an integral part of a nitrogen transport and transformation model. At the present time the water flow model cannot be used separately.

2) Nitrogen transport and transformation modeling

The amounts of N applied to land treatment systems are in many cases limited by the amounts removed from the system by plant uptake (and harvesting), losses to the atmosphere, storage in the soil and leaching. For economic reasons, it is desirable to apply the maximum amount of N (or wastewater) to the minimum area of land. Therefore, the nitrogen modeling objective was to maximize N removal mechanisms and to minimize N concentration in leachate.

Several models were developed and evaluated to describe single processes such as nitrification or plant uptake, or to describe combined processes of nitrogen transport and transformations in land treatment. The models vary greatly in their complexity and purpose. However, the developed models could be grouped into two major types: 1) management-oriented models and 2) research-oriented models. For development of the management models, simple mass balances of statistical relationships were used. The research-oriented

Table 9. Uptake of nitrogen by different plant species.

Plant species	*N uptake (kg/ha/yr)*
Forage crops	
Alfalfa	225-540
Bromegrass	130-225
Coastal bermuda grass	400-675
Kentucky bluegrass	200-270
Quackgrass	235-280
Reed canary grass	335-450
Ryegrass	200-280
Sweet clover	175
Tall fescue	150-325
Orchardgrass	250-350
Field crops	
Barley	125
Corn	175-200
Cotton	75-110
Grain sorghum	135
Potatoes	230
Soybeans	250
Wheat	160

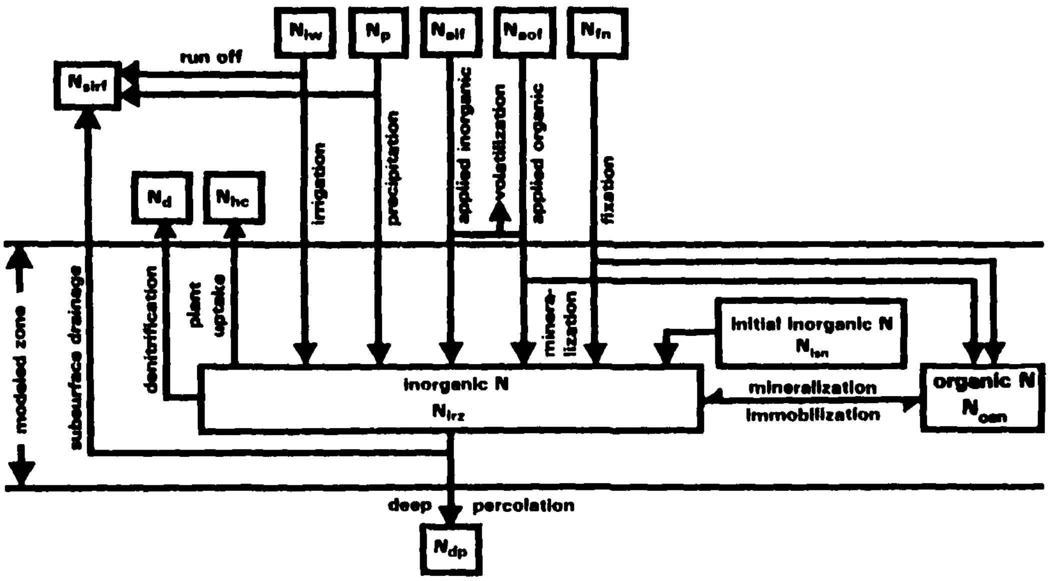


Figure 21. Major pools and fluxes of N in slow rate system.

models were developed for better understanding of the kinetics of nitrogen transport and transformation in soils under transient and steady-state conditions. These models are easily convertible to simpler versions and information from sensitivity analysis is particularly useful in understanding the limiting factors for each process.

a) Management-oriented models. A general rule of thumb in determining the amount of N to be applied to slow rate systems on an annual basis is to apply 150% of optimum plant uptake of N. Table 9 summarizes information pertinent to uptake of N by the different plant species.

For calculation of NO_3-N level (say 10 mg N/L), a compartmental model was developed and evaluated with field data from Davis, California, and Hanover, New Hampshire. In this model, the major pools and fluxes believed to contribute to N leaching or accumulation in the soil-plant system are represented as shown in Figure 21. Applied N is composed of inorganic (N_{aif}) and organic (N_{aof}) fertilizers. N fixation is N_{cn}, and addition of N as a result of irrigation, rain and snowfall is N_p. Wastewater nitrogen is N_{iw}. Soil N consists of two pools (inorganic N and organic N) that may serve as sources, sinks or both. The outputs of N include deep percolation (N_{dp}), plant uptake (N_{hc}), denitrification (N_d), and N in runoff (N_{sirf}). All fluxes are in units of kg N/ha-yr. For a complete description of the model and model documentations, the reader should consult Mehran et al. (1981).

Input parameters include amounts of N applied to the soil from precipitation, wastewater application, water flow, crop uptake characteristics, and initial soil nitrogen. Data for the amounts of N in precipitation are usually available and the amounts are always small compared to applied N. Applied N in wastewater is normally in the range of 20 to 40 mg N/L. Crop uptake varies with the geographic location and crop type. Initial soil nitrogen must be determined by analyzing soil samples at depth from the site. Model output includes mass and concentration of N leaching from the system.

Figure 22 shows an example of a comparison between predicted and measured values of plant uptake and N in leachate from a prototype slow rate system in Hanover, New Hampshire. The model predicted the plant uptake and the mass of N in the leachate much better than the concentration of N leachate. However, the model was successful in predicting the trends over 5 years and is probably adequate for design purposes. For better prediction of N concentrations in the leachate, the mechanistic (research-oriented) models must be utilized. Those models will be discussed later.

b) Modeling the nitrification process. Most of the N applied to land treatment is in the ammonia form (more than 80%). Applied NH_4 is transferred to NO_3, taken up by plants or stored in the soil. In order to predict the fate of NH_4, the rate of nitrification must be estimated. Since this is a microbial process, several enzyme kinetic models

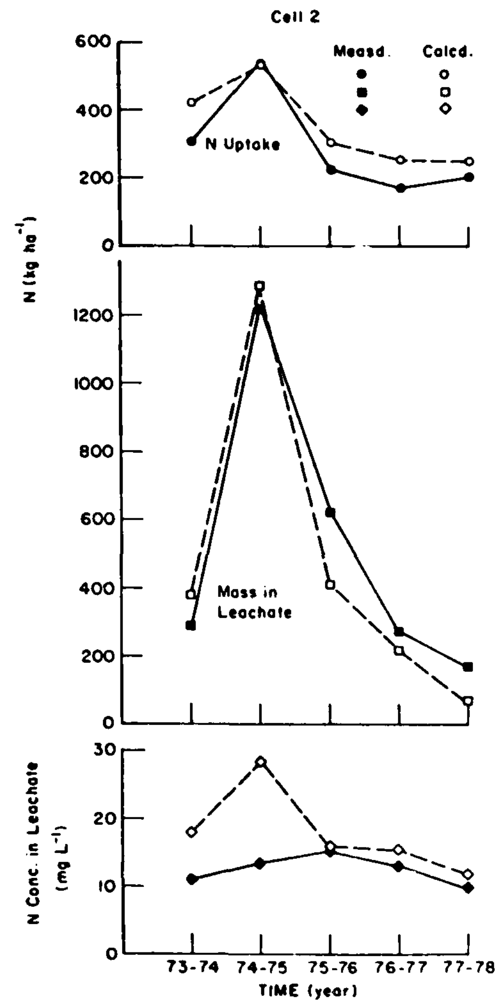


Figure 22. Comparison between predicted and measured N uptake and leachate NO_3 concentration in slow rate system.

were developed (see Leggett and Iskandar 1980). For simplicity, a study of the factors affecting the rate of nitrification in soil spiked with low levels of NH_4 (similar to wastewater) was conducted (Parker et al. 1981). Temperature and pH were found to be the most important factors affecting the rate and extrent of NH_4 oxidation to NO_3. At 5 °C, the maximum amount of NH_4 nitrified to NO_3 was 1.6 kg N/ha-day, while at 23 °C, the maximum amount was 2.8 kg N/ha-day.

c) Modeling the denitrification process. Several studies conducted at CRREL and elsewhere concluded that potential denitrification in slow rate systems could not have exceeded 10% of unaccounted-for N (Jenkins and Palazzo 1981). For design purposes, the 5 to 10% value could be used for such systems. In rapid infiltration systems, denitrification is the main mechanism for nitrogen removal. For promotion of denitrification, the presence of organic (biodegradable) carbon and anoxic conditions must prevail. An empirical relationship was developed in which the amount of N denitrified was assumed to be equivalent to 50% of the biodegradable carbon applied to soils (U.S. EPA et al. 1981). In overland flow systems, the denitrification of N is higher than that in the slow rate system but lower than that in rapid infiltration. About 15 to 40% of applied N may be lost by denitrification and NH_3 volatilization (Chen and Patrick 1980, Nakano et al. 1981).

d) Modeling immobilization and mineralization. Over a short period of time (a few years) the net change in soil N due to immobilization was found to be equal to mineralization. However, in the first two years of a new land treatment system, the immobilization of inorganic N will exceed the mineralization, and buildup of organic N will become evident. For further discussion on this subject the reader is referred to Keeney (1981).

3) Research-oriented nitrogen models

Two nitrogen models were developed and evaluated using data from lysimeters. One of the models was developed for slow rate and rapid infiltration systems (Selim and Iskandar 1978, 1980, 1981, Leggett and Iskandar 1980, 1981) and other model for overland flow (Nakano et al. 1981). Both models contain water flow and nitrogen submodels. The models are flexible and valid for uniform and multilayer soil profiles. The processes included in the nitrogen submodels are nitrification, denitrification, immobilization, mineralization, ammonium exchange, plant uptake and nitrogen transport.

a) Nitrogen model for slow rate and rapid infiltration. This is a one-dimensional model that can be used for 1) estimating the application rate and schedule of wastewater to land, 2) determining the fate of N species in soils, 3) predicting plant uptake of N, 4) predicting groundwater depth in land treatment, 5) estimating land area required to renovate wastewater, 6) estimating storage capacity, and 7) assisting managers and decision makers in further simplifications. Sensitivity analysis showed that the rate of nitrification, NH_4 exchange rate and plant uptake are the most significant parameters affecting model predictions. For a short period of time (several months to 3 years), it was found that the net changes in soil nitrogen due to immobilization/mineralization are very

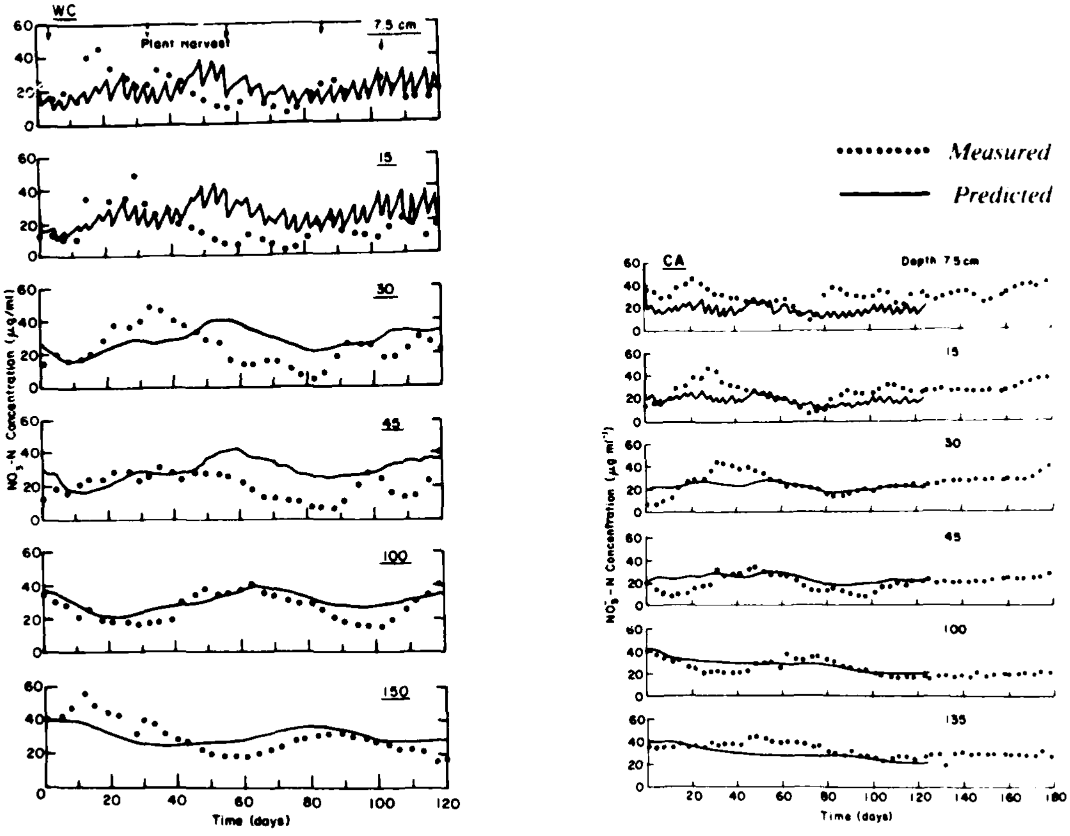


Figure 23. Comparison between predicted and measured NO_3 in soil solution at depth.

small and that, therefore, these processes may be ignored in the model to save computer time and data input.

To validate this model, greenhouse soil lysimeters were constructed (Iskandar and Nakano 1978) and instrumented to measure the water flow and the forms and amounts of nitrogen species in soils and soil solution at different depths with time (Iskandar et al. 1981). To follow the fate of N in soils, tracer experiments were conducted using tagged N (in the form of ^{15}N) applied in wastewater as NH_4 (Jenkins et al. 1978, Iskandar et al. 1981). Data obtained were used to validate the nitrogen model. Figure 23 shows a comparison between model prediction of NO_3 in soil solution at different depths and measured data for two different soils. Figure 24 shows a comparison between model prediction of plant uptake of N and measured data. In both cases, good agreement was obtained for up to 120 days. Also, the water flow submodel was evaluated as a prerequisite to using the nitrogen submodel.

It was concluded from these studies that both the water flow and the nitrogen submodels are valid for slow rate and rapid infiltration systems (Iskandar and Selim 1981).

b) Nitrogen model for overland flow. This two-dimensional flow model has been used for better understanding of the rate and extent of the N transport and transformation processes in overland flow. Based on the model, N removal in overland flow consists of four major processes in series: 1) adsorption of applied NH_4 by the soil surface, 2) nitrification of NH_4, 3) transport of NO_3 to the subsurface soil and 4) removal of NO_3 and NH_4 by plant roots. The model was evaluated with data from a prototype overland flow where ^{15}N was used as a tracer. Based on this N model, Nakano et al. (1981) suggested new management alternatives to enhance N losses by overland flow. This allows the use of higher rates of wastewater application. If N is the limiting factor for higher application rates, this means that the cost of treating wastewater as well as the cost of con-

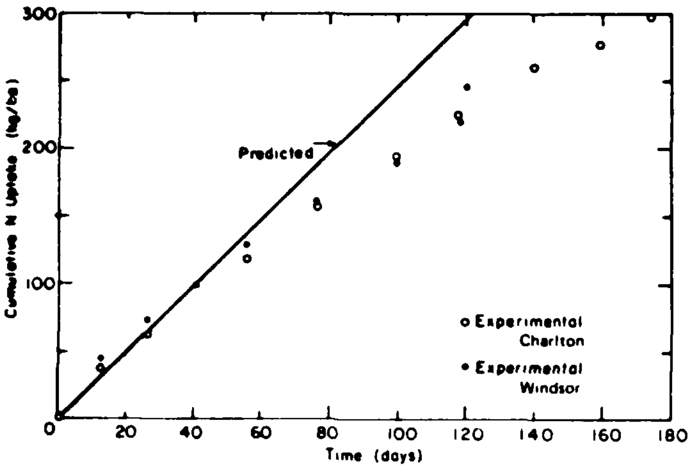


Figure 24. Comparison between predicted and measured plant uptake of N.

structing overland flow systems will be decreased (Chen and Patrick 1980).

4) Model for prediction of phosphorus transport and transformations in land treatment

This model is discussed in Section 3-8 under *Long-Term Effects of Trace Elements and Phosphorus.*

5) Calculation of storage capacity

In the design of a land treatment system, consideration must be given to the sizing of a storage lagoon for storing wastewater during unfavorable conditions for application. The proper design of such storage has a direct relationship with the cost of wastewater renovation.

The method developed for calculating the size of the storage lagoon consists of determining the monthly water balance, which can be calculated from the following equation:

$$S = (P - E) + Q - W - I \quad (3)$$

where S = storage volume need for the month
P = volume of precipitation falling into the pond during the month
E = volume of water lost by evaporation during the month
Q = volume of wastewater entering the pond during the month
W = volume of wastewater leaving the pond during the month
I = volume of water lost by seepage from the bottom of the pond during the month.

Precipitation (P) and evaporation (E) volumes can be estimated from climatological data supplied by the National Oceanic and Atmospheric Administration (NOAA). All available monthly and annual data for the closest station to the proposed land treatment site should be compiled and the 10% chance of exceeding annual values for both precipitation and evaporation should be calculated. These annual values are apportioned according to the average percentage of rainfall and evaporation for each month. To convert these data from depth of water to volume, the surface area of the pond must be known. One method of calculating surface areas is to

1. Estimate the number of storage days required. EPA-1, 2, or 3 programs could be used (Whiting 1976).
2. Multiply the number of storage days by the average daily design flow to obtain a volume of storage.
3. Assume a depth of water in the pond and calculate surface area by dividing volume of storage by depth. A depth of 3 m is usually reasonable for a first estimate.

It may be necessary to adjust the surface area once the actual storage volume known. However, adjusting surface area requires a recalculation of precipitation and evaporation volumes. The other alternative is to change the depth. The latter method is preferred because P and E volumes remain unchanged.

The volume of wastewater entering the pond per month (Q) can be calculated by multiplying the average daily design flow by the number of days in the month.

The volume of wastewater leaving the pond (W) can be calculated by multiplying the depth of wastewater applied by the spray area. Depth of wastewater applied can be determined from the planned irrigation schedule. Spray area (in acres) can be determined from a simple relationship:

$$F = \frac{Q_a + P_a - E_a}{L_w} \qquad (4)$$

where F = field area (acres)
Q_a = volume of wastewater entering the pond (acre-ft/yr)
P_a = volume of precipitation falling into the pond (acre-ft/yr)
E_a = volume of evaporation from the pond (acre-ft/yr)
L_w = wastewater loading (ft/yr).

The volume of water lost by seepage (I) is difficult to estimate over the design life of the system. State standards for allowable seepage rates from ponds vary from 0.062 to 0.25 in./day. These standards are becoming more stringent, and essentially impervious linings may be required in the future. Therefore, for a conservative design, assume seepage losses to be negligible.

6) Cost analysis of wastewater renovation

The computer model CAPDET (Computer-Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems) was developed in 1972 to compile a Corps of Engineers design manual on wastewater management. In 1974, a revised portion of this model was developed and was updated in 1979 to include design information on land treatment processes (Merry, in prep.). Currently over 65 unit processes are available in CAPDET that have been programmed using standard sanitary engineering design formulations. When using CAPDET, one person may input design parameters of a particular system or allow the use of "default" parameters for any unknown characteristics. The user may also set effluent quality limits on any of the 20 wastewater characteristics, thereby screening out treatment alternatives that do not satisfy water quality standards or effluent limitations. CAPDET can be used as a screening tool to quickly compare a wide range of alternative treatment designs with a common design base, each capable of meeting specified effluent water quality criteria. CAPDET can simultaneously rank wastewater treatment alternatives on the basis of cost effectiveness. In addition, schemes for alternative conventional wastewater treatment can be used as input and may be ranked against land treatment to compare costs and treatment efficiency.

An important input to CAPDET is the proper application rate of wastewater. This is site-specific information which depends on many factors, and the designer has to use the best available data to estimate it. Input data for each of the three land treatment systems and examples of design parameters and cost analysis may be found in Merry (in prep.). The CAPDET model has been recently adopted by the U.S. Environmental Protection Agency and is being used as a planning tool in evaluating the cost of wastewater treatment alternatives.

7) Optimization model for land treatment planning, design and operation

Baron et al. (1983a) reviewed the literature on available optimization models applicable to land treatment. A model was developed using nonlinear programming to generate optimal site plans, designs, and operation procedures in cold-dominated areas (Baron 1983b).

The model was applied to a hypothetical slow rate land treatment system in a cool-humid area with a forage crop, where the operation and design were constrained by the potential for renovation of nitrogen in the storage lagoon and in the soil-plant system.

A range of optimal design alternatives was examined to reduce some general cost characteristics of slow-rate systems ranging from 0.5 to 10 MGD. The model also included options for by-passing the storage lagoon and possible winter application. From the simulation, it was concluded that tightening the environmental constraints has a large influence on the feasible slow-rate system design and cost. The costs associated with lowering the N concentration in the percolate on an annual and monthly basis are significant.

3-6. DEVELOPMENT OF ENGINEERING DESIGN CRITERIA

The Corps of Engineers Land Treatment Research and Development Program has focused on concept-scale experiments and full-scale demonstration studies that could be used to define the exact fate of pollutants while providing practical engineering data on operation, maintenance, and long-term effects. Aspects that have been defined include all pollutant interactions ranging through pretreatment requirements, plant accumulations of nutrients and toxic chemicals, soil assimilation and transformations of most pollutants, fate of trace organics, and detailed characterization of the effluent quality. The results of this program enable the engineer to model, predict, design, and estimate system requirements and costs of land treatment of domestic wastewater in all climates.

The following are some of the areas for which the Corps of Engineers Land Treatment Research Program provided improvement in the criteria for planning, design and management of land treatment:

1. Development of techniques to improve phosphorus treatment in overland flow systems (Peters et al. 1981).
2. Evaluation of N treatability in overland flow systems (Martel et al. 1980).
3. Development of an improved design procedure for overland flow systems (Martel et al. 1980, Martel et al. 1982).
4. Evaluation of long-term performance of slow infiltration systems (Jenkins and Palazzo 1981, Iskandar et al. 1977).
5. Establishment of the importance of flow distribution on overland flow systems (Martel 1980).
6. Development of improved procedures to select land treatment sites on a regional and site-specific basis (Merry, in prep., 1978).
7. Development of an improved procedure for measuring hydraulic characteristics of potential land treatment sites (McKim et al. 1982, Abele et al. 1980, 1981).
8. Determination of the performance of land treatment systems during systems operation (Martel et al. 1980, Jenkins and Palazzo 1981).
9. Determination of the treatability of trace organic substances by overland flow and slow infiltration systems (Jenkins et al. 1981).
10. Land treatment cost analysis (Merry in prep.).
11. Algae reduction from lagoon effluent by overland flow (Peters et al. 1981).
12. Agronomic design guidance for land treatment (Palazzo 1982).

Examples of the engineering design criteria developed during the land treatment research program are the development of rational design criteria for overland flow systems, forest application systems, and slow rate systems based on research results. A brief summary of each follows.

A. Rational design of overland flow systems

The previous design procedure was based solely on the hydraulic loading rate, which doesn't take into account other variables such as slope gradient, length of slope and surface roughness. These variables are important and have been discussed elsewhere (Nakano et al. 1981).

Detention time studies were conducted at three overland flow test sites. The first site, located at CRREL in Hanover, N.H., has three sections, each 30 m long by 2.9 m wide (0.009 ha) and graded to a 5% slope. Primary effluent containing average biochemical oxygen demand (BOD) and total suspended solids (TSS) concentrations of 72 and 59 mg/L, respectively, was applied to this system. The second site (no longer in operation), was located in Utica, Mississippi, and operated by the U.S. Army Engineer Waterways Experiment Station (WES). Lagoon effluent was applied to a total of 24 sections, each measuring 45 × 4.6 m (0.02 ha) and graded to 2, 4 and 8% slopes. The third overland flow test facility was located indoors at the University of California at Davis. This facility consisted of the three overland flow sections, each 6 m long by 1.5 m wide. The slope was set at 4% during detention time studies.

At both CRREL and WES, detention times were measured using a slug addition of sodium chloride at the top of the slope. The tracer was applied after hydraulic steady-state conditions had been reached, and runoff concentrations of sodium chloride were plotted vs time. The time at the peak of the tracer response curve was assumed to represent detention time. A typical chloride response curve is shown in Figure 25. The detention time in this case was 40 minutes, for an application rate of 0.6 m/hr. Many similar detention time measurements were taken during the 1978 and 1979 growing seasons. The average detention time was calculated for each application rate along with the average BOD and total suspended solids removal. This procedure was repeated for several application rate ranging from 0.24 to 1.20 m^3/hr. At Davis, deionized water was used as the tracer and specific conductance was used to measure detention time.

As shown in Figure 26, the percent BOD removal E vs average detention time $\overline{T}$ relationship can be expressed as a plug flow, first-order equation in the form of

$$E = (1 - Ae^{-k\overline{T}})100. \qquad (5)$$

The coefficients A and K obtained from a least-

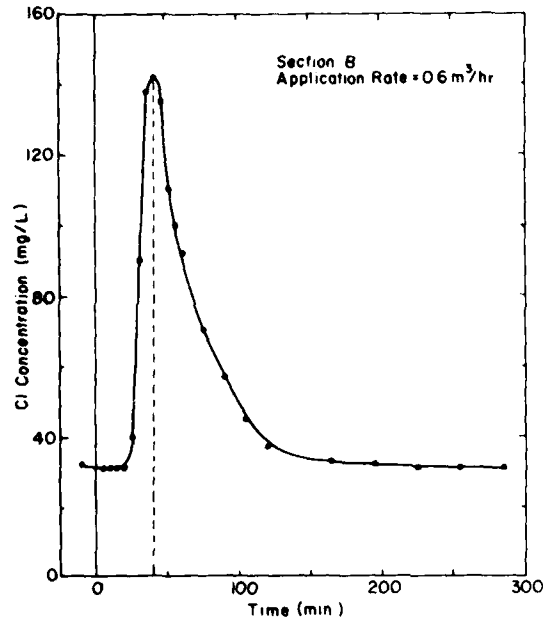


Figure 25. Detention time of wastewater flow in overland flow as measured by chloride.

squares fit of the data are 0.52 and 0.03 min, *respectively. The coefficient A can be interpreted* as the non-settleable fraction of BOD in the applied wastewater. The coefficient k is the average kinetic rate constant.

Percentage total suspended solids removal vs detention time is shown in Figure 27. Suspended solids removal was less dependent on detention time than BOD removal because most of the solids were removed by the physical process of the sedimentation, as was evident from the buildup of solids at the top of each section.

To complete the design procedure, a method is required for predicting the application rate needed to obtain the desired detention time. A mathematical relationship developed from Poiseuille's formula and calibrated with CRREL data is

$$\overline{T} = \frac{0.078\ L}{S^{1/3} q} \qquad (5)$$

where L = length of section (m)
S = slope of section (m/m)

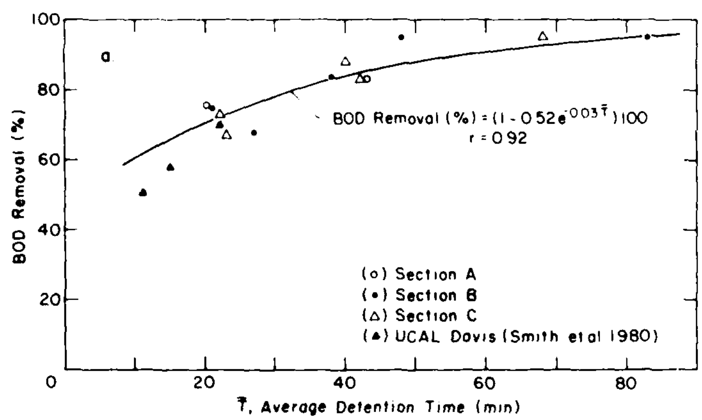


Figure 26. BOD removal in overland flow.

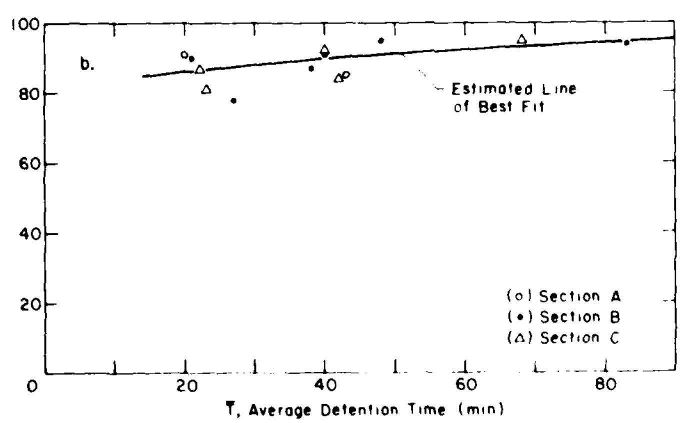


Figure 27. Total suspended solid removal in overland flow.

q = average overland flow rate
$[(q_{applied} + q_{runoff})/2]$
(m^3/hr) per meter of width.

This equation was validated with data from the overland flow systems at Utica, Mississippi, and University of California at Davis. The average difference in detention time between actual and predicted values was not found to be significant at 95% level. However, individual differences can vary considerably, depending on the degree of channeling on the slope, evapotranspiration, changes in vegetative density and harvesting operations.

B. Design criteria for forest system land application

1) Application mode

The most important mode for forest system land application is slow rate infiltration since it provides for adequate aeration in the root zone, and is compatible with the high topography relief common to forests. However, rapid infiltration and overland flow may also be used.

2) Pretreatment

In most cases, only primary treatment or less is required for forest systems. The degree of pretreatment is only that which will facilitate pumping, sprinkler irrigation or regulatory constraints. Disinfection is not required in most cases due to the remoteness of most forests.

3) Distribution system

Forest systems usually use a solid-set system design. Wastewater is distributed with rotating impact sprinklers 1 to 1.5 m high, spaced 18 to 24 m apart. Operating pressures at the sprinkler nozzle should not exceed 0.38 MPa, although pressures up to 0.5 MPa are possible in forests of some thick-barked hardwood species. In situations where spray is not desirable, a gated pipe arrangement may be preferable. The selection of either a buried or an aboveground solid-set system for forests is a site specific decision based on soil type and weather conditions. Detailed discussion has been presented by McKim et al. (1982).

4) Buffer zone requirements

A buffer zone is not necessary in forest systems, but if required it may be much smaller than that for agriculture systems due to reduction of aerosols and wind speed by standing trees.

5) Public access

Public access may have to be restricted during wastewater application. Another reason to restrict public access is potential vandalism of spray equipment.

6) Hydraulic loading

Hydraulic loading usually is not a limiting factor because of the high infiltration rate which exceeds precipitation plus applied wastewater. Poplar may tolerate rates as high as 15 cm/wk.

C. Engineering assessment of results of the slow rate and overland flow pilot studies at CRREL

Jenkins et al. (1981) summarized the data from the slow rate pilot study at CRREL and obtained empirical relationships for design purposes. They concluded that:

(1) In the Northeast the land area required for treatment of municipal wastewater is about 100 ha/10,000 people if slow rate is used and about 30 ha/10,000 people if overland flow is used.
(2) The seven years of operation of the CRREL slow-rate system showed that water quality that meets all drinking water standards can be obtained, which exceeds that produced by conventional tertiary treatment.
(3) Statistical analysis of seven years of data obtained on the slow-rate treatment was used to obtain loading rate relationships. Temperature was found to be a critical factor in the treatment of wastewater. The temperature relationship to treatment was divided into two ranges: greater than 8°C and less than 8°C.
(4) For overland flow, at warmer temperatures, a BOD loading rate of about 2.5 g/m^2-day will produce an effluent of less than 30 mg/L, but at colder temperatures, the loading rate should be slightly lower.
(5) Complete suspended solid removal was obtained in the slow rate system. With overland flow, an effluent of <30 mg/l TSS is obtained at a loading rate of about 20 g/m^2-day at the higher temperature, whereas below 8°C, this decreases to a loading rate of <10 g/m^2day of TSS in order to achieve an effluent of <30 mg/L.
(6) Examination of nitrogen mass flow showed that more than 75% of the N loading could be removed in the slow-rate systems. In overland flow, the effect of temperature was more pronounced. Relatively little N

removal occurred at loading rates above 0.4 g N/m² day at the lower temperature, whereas the removal continued at loading rates up to 1 g N/m² day above 8°C.

(7) Nearly 100% of the P was removed in the slow-rate spray irrigation at all loading rates, whereas only slightly more than 50% of P applied to the overland flow slopes was removed.

3-7. ESTABLISHMENT OF PREAPPLICATION TREATMENT REQUIREMENTS

A. Objective

The objective of this task was to establish requirements for minimum treatment of wastewater prior to application on land.

B. Approach

Several studies were conducted to establish the necessary preapplication treatment using the long-term facilities at CRREL, WES and several existing systems. System performance in relationship to the degree of pretreatment was established.

C. Research accomplishments and conclusions

Research results showed that the degree of preapplication treatment depends on the type of system and on intended use of product water. For slow rate systems, the pretreatment is performed to prevent problems during distribution of the water and to protect the public health.

Settleable solids may accumulate in the distribution system. It is recommended for sprinkler irrigation systems that the size of the particles be less than one-third of the diameter of the sprinklers. No pretreatment is necessary for the removal of N, P and heavy metals prior to application to land in slow rate systems.

For rapid infiltration systems, preapplication is used to reduce soil clogging. Primary treatment is sufficient, although secondary treatment may be used if high water quality is required.

For overland flow, primary treatment is not recommended because the runoff is usually collected and treated or applied again. It is not recommended that the effluent be nitrified because N removal in this form is very slow. Pretreatment with allum to remove P and heavy metals may be used, but addition of the alum to the runoff may be more beneficial during the pretreatment process if the runoff is to be further treated.

3-8. PREDICTION OF THE LONG-TERM EFFECTS OF WASTEWATER APPLICATION ON LAND

A. Objectives

The objectives of this task were to 1) investigate the effects of long-term operation of land treatment on the environment and on system performance, and 2) develop methods of predicting the longevity at the time of land treatment design and construction.

B. Approach

The approach taken to accomplish this task was to 1) visit and document performance characteristics of existing land application systems in operation for many years, 2) document possible reasons for failure or success of these systems, 3) summarize design parameters of existing systems, 4) identify the parameters of long-term effect and 5) develop procedures for determining site longevity.

C. Research accomplishments and conclusions

Available information on more than 350 existing systems in the United States and 150 systems in foreign countries was gathered and summarized. Due to the large number of these systems, a computer file was established at CRREL. Design information such as system name, location, system type (operational or prototype), flow rate, waste type, ground cover (if any), treatment type, application mode (spray, flood), application rate, purpose of the system, and the year of construction were entered into the computer. Published literature on these systems was also included. To assist the users, two computer programs were developed and made available with the existing system data file. The first program was SEARCH, and the second program UPDATE. SEARCH can be used to print out a list of systems from the file based on two or more design criteria (parameters mentioned above). If the information from the computer printout is not sufficient for planning and design purposes, the associated literature should be obtained and examined. The UPDATE program is to be used to place new information into the data file. A user's quide was prepared (Iskandar et al. 1978, Iskandar 1979).

Detailed examinations of the selected land treatment systems in the United States and other countries were also conducted and documented. These included systems at Manteca, California (Iskandar et al. 1977, Murrmann and Iskandar et al. 1977), Quincy, Washington (Iskandar et al. 1977, Murrmann and Iskandar 1977), Livermore, California

(Uiga et al. 1977), Calumet, Michigan (Baillod et al. 1976), Ft. Devens, Massachusetts (Satterwhite et al. 1976a, 1976b), Dover, Vermont (Bouzoun 1977, Cassell et al. 1979), and Deer Creek Lake, Ohio (Abele et al. 1981). The type of wastewater applied to the land varied in these systems from municipal to industrial. These systems have been in operation for periods from 2 to 90 years. The systems included rapid infiltration, slow rate and overland flow types. The application rate varied depending on the system and on the climate.

Based on thorough investigations of these systems, it was concluded that trace metals and phosphorous accumulation and changes in the rate of water percolation through the soil are potentially the most important factors affecting site longevity.

D. Long-term effects of trace elements and phosphorus

The term "trace elements" is used broadly in the literature to describe a number of chemical elements that are present in low concentrations in water and biological systems. With the present interest in environmental contamination, trace elements are defined here as elements with no known physiological function that are toxic to living systems when present in sufficient concentrations. In soils, uncontrolled trace element input is undesirable because of 1) possible toxicity to plants, 2) food chain accumulation and toxicity to humans and animals, and 3) transport of trace elements to groundwater and surface water, affecting drinking water quality.

Dowdy et al. (1976) summarized information on the concentration of trace elements in wastewater from municipal treatment plants (Table 10). It is evident that the concentrations of some of these elements decrease substantially when wastewater is treated. Using the typical concentrations in Table 11, Page et al. (1981) calculated the amounts of wastewater that can be applied to soils without reaching the maximum load. These data show that the amounts of trace elements that can be applied varied with the soil characteristics and the element of interest. Cadmium is the most limiting factor. However, based on cadium toxicity, and using the most limited soils (soils having a low cation exchange capacity), it is possible to apply 5 cm of typical wastewater per week for about 400 years before exceeding the maximum suggested load.

Plant tolerance to trace elements varies with species and type of trace element of concern. The amounts of trace elements taken up by plants are very low and range from < 1 to 8% of applied

Table 10. Input of typical wastewater required to reach suggested loading limits for metal applied to soil in the form of sewage sludge.

Element	*CEC of soil (meq/100 g)*	*Suggested loading limit* (kg/ha)*	*Conc. in typical wastewater (ug/mL)*	*Input to reach loading limits (m)*
Cd	< 5	5	0.005	100
	5-15	10		200
	> 15	20		400
Cu	< 5	125	0.10	125
	5-15	250		250
	> 15	500		500
Ni	< 5	125	0.02	625
	5-15	250		1250
	> 15	500		2500
Zn	< 5	250	0.15	167
	5-15	500		333
	> 15	1000		666
Pb	< 5	500	0.05	1000
	5-15	1000		2000
	> 15	2000		4000

* From U.S. Environmental Protection Agency (1978).

Table 11. Average concentration (mg/kg dry plant material) of selected elements in agronomic crops and suggested tolerance level for monitoring purposes.

Element	*Average composition range*	*Suggested tolerance level*
Arsenic	0.1-4.0	>5
Boron	30-75.0	75
Cadmium	0.05-0.5	2
Chromium	0.1 0 1.0	2
Cobalt	0.01-0.5	5
Copper	5-20	50
Lead	0.1-5	10
Manganese	15-150	500
Molybdenum	0.2-1.0	3
Nickel	0.1-1.0	50
Selenium	0.05-2.0	3
Zinc	15-200	400

trace elements (Page et al. 1981). The principal mechanisms by which dissolved elements are removed are adsorption on the soil particles and by precipitation. Factors that tend to influence trace element removal by soils include soil texture, pH, water content, organic matter content, and other soil chemical characteristics. The following is a summary of research results conducted on existing systems and greenhouse studies:

1. Research results from evaluation of existing systems (Baillod et al. 1976, Satterwhite et al. 1976a, Uiga et al.1976, Iskandar et al. 1977, Murrmann and Iskandar 1977), and from greenhouse and field studies (Iskandar 1975, Larson 1981, Page et al. 1981) have shown that certain heavy metals may accumulate in soils and plants in land treatment systems.
2. The accumulation of heavy metals in plants from municipal wastewater will not reach toxic levels (Iskandar 1975, Lund and Page 1981, Page 1981).
3. Studies conducted at four slow rate systems in California (Lund and Page 1981), namely Santa Maria, Shafter, Oildale and Delano, concluded that heavy metals in soils receiving municipal wastewater for many years did not increase substantially in the topsoils compared to untreated soils. Moreover, there was no migration of any of the studied heavy metals (Cd, Zn, Cu, Ni) to soil depths or to ground water.
4. Studies conducted at existing rapid infiltration systems at Calumet, Michigan; Ft.Devens, Massachusetts; and Flushing Meadows, Arizona showed that there is a substantial increase in trace metals in soils with depth within the top 1 to 1.5 m due to wastewater application to these systems. Leachate from these systems, however, contains trace metals in concentrations well below the maximum recommended levels for irrigation waters.

The following procedures were developed to estimate long-term effects of heavy metals and phosphorus on soils and plants.

1) Development of a soil test for evaluating heavy metal uptake and metal accumulation

The major concern of metal accumulation in the soils is the potential uptake of these metals by plants followed by possible food chain accumulation. To determine the validity of this concern, studies were conducted at 10 sites in Michigan and in greenhouse pot experiments at CRREL.

Three soil tests commonly used by soil scientists to test metal availability to agronomic crops include total metal content in the soil, and the HCl and 2-hr DTPA extractable metal tests which are used to simulate plant root uptake. The three tests were performed on 17 soils (7 controls and 10 sludge and effluent treated soils) before cultivation with corn or soybeans.

In general, soybean growth was reduced more severely by sludge-treated soils than corn growth. In comparing metal concentrations in plants grown on sludged soils to plants grown on control soils, Ni appeared to be the metal causing the greatest growth reductions. The data indicate that growth reduction could be expected when Ni concentrations in field corn and soybean tissue reach 20 to 30 ppm. Other metal concentrations in plants that appeared unusually high occurred with sludge-treated soils where Cd levels in corn were 19 to 41 ppm (compared to 0.3 to 1.2 ppm in the control) and 4.5 to 10 ppm in soybeans (compared with 0.5 to 1.0 ppm in the control). Metal interaction was thought to enhance toxicity to the plants.

Correlations between plant metal levels and HCl and DPTA extractable metal concentrations were generally high for Cd, Cu, Ni and Zn in corn and for Ni and Zn in soybeans. Correlation was similar for the HCl and DPTA data.

Since most laboratories report metal concentration in the soils as total metal content, correlations between total metal content and HCl and DPTA data were conducted. The correlation coefficient values obtained for total vs HCl extractable metal levels using the data from 20 sludged soils were 0.993, 0.0802, 0.955, 0.777, 0.998, and 0.987 for Cd, Cr, Cu, Pb, Ni and Zn, respectively. These relationships were all statistically significant at the 1% level of probability. Regression equations for prediction of HCl and DPTA extractable metals from total analysis are summarized in Jacobs (1981). It was concluded that chemical extraction tests for heavy metals are useful for prediction of potential plant uptake.

2) Long-term effect of phosphorus in land treatment

Phosphorus has been regarded as a major factor controlling eutrophication in many lakes, reservoirs, and rivers. Domestic wastewaters contain from 1 to 40 mg P/L, but decreasing P effluent discharged to groundwater or surface water to less 0.1 mg/L may be desirable. With proper management, land treatment can achieve this goal. Removal mechanisms of P in land treatment include plant uptake, leaching to groundwater, and runoff. Plant uptake of P in slow rate and overland flow systems is less than 40 kg P/ha-yr and soil removal of P is the main mechanism. Although soils have a high capacity to remove P from effluents, this capacity can decrease with time. In land treatment, P is the factor determining how many years the system can be used to renovate wastewater before its restoration.

Ryden et al. (1981) developed and evaluated a simple procedure for estimating site longevity in terms of P removal and for prediction of P concentrations in leachate from slow rate and rapid infiltration systems:

$$T_z = S_p/I_p \cdot H_p \qquad (6)$$

where T_z = time in years for the P saturated soil front to reach a soil depth z

S_p = soil storage capacity (kg P/ha)

I_p = input P (kg/ha-yr)

H_p = harvest P (kg/ha-yr).

S_p can be estimated from laboratory sorption studies (Ryden et al. 1981). By using the procedure, they estimated that two soils in Hanover, New Hampshire, being used as slow rate prototype systems could remain effective for 50 to 140 years. A soil from Ft. Devens, Massachusetts, being used in a rapid infiltration system was estmated to have exceeded P removal capacity to 1.5 m, but the subsoil was still undersaturated.

It should be emphasized that estimation of soil removal capacity for P is very important and should be conducted during site selection and prior to construction of land treatment systems. Iskandar and Syers (1980) found that some soils have a very low capacity to sorb P from wastewater.

3-9 LAND TREATMENT MANAGEMENT

A. Objective

The objective of this task was to establish good management practices for land treatment systems.

B. Approach

Long- and short-term experiments were conducted at different locations in the United States to establish good management practices for crop production and soil amendments.

C. Research accomplishments and conclusions

1) Management of non-forested land

In the land treatment program, emphasis was placed on optimizing the application rate without sacrificing the quality of renovated water. Since crops are an integral part of the system, and in fact the most important renovating mechanism in slow rate and overland flow, proper methods for crop management were investigated at several locations in the United States.

At Apple Valley, Minnesota, corn was found to be less efficient in N removal than grasses but a more desirable cash crop. Hence, dual cropping was investigated and shown to be a good management practice (Linden et al. 1978, Marten et al. 1980). Since potassium is low in wastewater, additional fertilizer is required to enhance K in the soil. The amount of K to be added may be calculated from the following empirical equation:

$$K_f = 0.9\,U - K_w \qquad (7)$$

where K_f is the annual amount of K fertilizer to be added in the spring (kg/ha-yr), U is estimated N uptake (kg N/ha-yr) and K_w is the amount of K applied annually in wastewater (kg K/ha-yr). The effect of various cutting schemes on the persistence of eight forages at two levels of wastewater application was studied at the Apple Valley site. The results showed that, at the higher application rate (10 cm/wk), maximum persistence was obtained with quackgrass at two cuttings/year, quackgrass or Kentucky bluegrass at three cuttings/year, and either quackgrass, Kentucky bluegrass, orchardgrass, reed canarygrass or tall fescue at four cuttings/year. At the lower application rate (5 cm/wk), reed canarygrass gave the highest yield. Maximum persistence was found with Kentucky bluegrass, orchardgrass and reed canarygrass with two cuttings/year, and with Kentucky bluegrass and tall fescue with three cuttings/year. Alfalfa, smooth bromegrass and timothy did not perform well in this study.

Scheduling of wastewater application and type of pretreatment had little effect on crop yield and quality. However, residual chlorine (used in disinfection of wastewater) in excess of 1 mg/L decreased the plant yield.

Long-term application of wastewater containing NH_4 may decrease soil pH due to the production of H^+ from the nitrification of applied NH_4.

For proper management of land treatment sites, application of lime to raise soil pH is recommended. Soil pH should not be lower than 5.5 because of its effect on microbial activity, plant uptake of nutrients and transformations of heavy metals in the soil to mobile forms.

In some cases, application of wastewater containing high amounts of salts or high amounts of sodium (compared to calcium and magnesium) has the tendency to change the soil to saline or saline-alkali soil and thus decrease soil permeability and crop yield. Application of gypsum to these soils is recommended. The methods developed by the Department of Agriculture for reclaiming saline and saline-alkali soils and for determining gypsum requirements should be utilized.

In rapid infiltration systems, continuous application of wastewater for many years will result in a decrease in water infiltration rate because of clogging of the soil pores with particulate matter. To overcome this problem, removal of the top layer of the soil or drying and raking of the soil may be used.

2) Forest management options

a) Reforestation. Wastewater irrigation can be used very effectively to establish forests on barren land, abandoned farmland, and to regenerate clear-cut areas. The wastewater supplies the water and nutrients usually required for optimal survival and rapid growth of tree seedlings. Wastewater application will also stimulate growth of the herbaceous vegetation. This vegetation may compete with tree seedlings and require some type of cultural treatment for control. However, the herbaceous vegetation cover is necessary, especially during the early years of forest establishment, to achieve satisfactory wastewater renovation. The seedlings alone are not able to remove a sufficient amount of nitrogen to meet water quality standards until they are well established in the ecosystem. For poplar seedlings, this time period is two to three years.

Sudden removal of the herbaceous cover by spraying to remove grass and weeds can result in an immediate increase of nitrate in the soil leachate. With regrowth of the herbaceous vegetation, the nitrate concentration in the leachate will return to an acceptable level. Periodic mowing of the herbaceous vegetation will not ordinarily have a significant effect on the leachate quality.

b) Harvesting. Clear-cutting of an old forest that is no longer capable of sufficient nitrogen uptake to renovate wastewater to a satisfactory level and converting it to a stand of pioneer species of trees and herbaceous vegetation is an effective method for restoring the renovation efficiency of a site.

c) Slashing-burning. Nitrogen accumulation in the foliage reaches a steady-state condition with crown closure, and nitrogen accumulation in the understory vegetation actually starts to decrease. The accumulation of nitrogen in the forest floor continues throughout the first 80 to 100 years of the forest stand development, but nitrogen stored in the forest floor is immobilized and not readily available to the trees.

A very effective forest management option that can be considered is controlled burning to prevent nutrient leaching from the nitrogen-rich forest floor into the groundwater and to prepare sites for planting after harvesting. The combination of harvesting followed by slash-burning can remove nearly all of the above-ground stored nitrogen.

Removal of the most of the organic layer by burning results in a temporary loss of the ecosystem's buffering capacity against nitrogen leaching during the subsequent early stages of revegetation. With the establishment of pioneer vegetation or new tree seedlings, the development of herbaceous vegetation, buffering capacity, and total wastewater renovation capacity of the ecosystem are regained.

d) Short-term rotation. Short-term rotation forestry, involving irrigation and fertilization of fast-growing species for wood fiber and fuel, appears to be well suited for wastewater renovation. Studies have shown that poplar, sycamore, cottonwood and sweetgum have high nitrogen uptake capacity (frequently above 200 kg/ha-yr, when subjected to wastewater nitrogen loading in the 300 to 300 kg/ha-yr range). Biomass production has been observed to double under wastewater irrigation. Harvesting every five to eight years can remove more than 80% of the accumulated nitrogen stored in the aboveground biomass for these species.

Short-term rotation of hardwood forest systems can achieve wastewater renovation comparable to the renovation by annually harvested agriculture systems.

3-10. MONITORING REQUIREMENTS FOR LAND TREATMENT SYSTEMS

A. Objective

The objective of this task was to establish the monitoring requirements for well designed and constructed land treatment systems.

B. Approach

Monitoring is necessary to fulfill regulatory requirements and to obtain data for assessment of system effectiveness in renovating wastewater. Monitoring of land treatment for the purpose of R&D was beyond the scope of this task.

C. Research accomplishments and conclusions

1) Monitoring for regulatory requirements

Some regulatory monitoring reqiurements are placed on nearly all land treatment systems, but they may vary considerably from one project to another. The *Process Design Manual for Land Treatment of Municipal Wastewater* (1977) and its updated version (1981) contain guidance on pretreatment requirements. Criteria for protection of groundwater quality are presented in Federal Register 6190 (11 February 1976). In general, the preapplication treatment, determined by the designer, ranges from screening or comminution for isolated overland flow systems with no public access to biological treatment by lagoon or inplant processes with additional BOD or suspended solids control in public access areas such as parks and golf courses.

State agencies have frequently issued regulations more restrictive than those of the federal agencies. The majority of states have required secondary treatment of wastewater prior to application. Research data, however, have shown that there was usually no need for such treatment in order to achieve good quality of renovated water (Iskandar et al. 1976, Jenkins and Palazzo 1981). In some cases, poorer renovation of N occurred with secondary aerated wastewater than with primary wastewater.

2) Monitoring of soil and plant components

Keeney and Walsh (1978) proposed a two-step monitoring program for soil and plant and analysis. The first step, involving rather extensive sampling of the soil surface (0-15 cm) every year, monitors plant nutrient status and soil pH. The second part of the program, involving sampling soils at different depths every 3 to 5 years, evaluates the movement of P and heavy metals.

Due to the inherent variability in soil physical and chemical characteristics, soil sampling programs should give information not only on the changes in the soil but also on the variability of the soil. Soil sampling must be conducted according to soil types. A minimum of two samples per soil type must be taken and analyzed separately or mixed together prior to analysis. There is no universally accepted number of borings needed for a sample since this also is a function of field variability. Keeney and Walsh (1978) recommended 6 to 12 borings per sample. Samples should be air-dried, mixed thoroughly, sieved and stored in airtight containers. Subsamples may then be taken for analysis. The methods utilized in analyzing soils are those outlined in Iskandar et al. (1977).

Plants should also be sampled for two major purposes. The first is to collect a representative portion of all the harvested plants to determine either quality of the crop or nutrient removal. The second purpose is to sample a specific plant part (usually a recently matured leaf) at a given growth stage to evaluate potential deficiencies or toxicities. Sampling the leaves is relatively easy and can be done in time to correct difficiencies or toxicities. Considerable literature is now available to facilitate interpretation of the results, at least for most nutrient elements. From the program recommended by Keeney and Walsh (1978) and from the research data obtained at CRREL, a plant tissue monitoring program should include:

1. A yearly monitoring of crop yield and analysis for N, P, and K. The purpose is to establish removal efficiencies and plant nutrient difficiencies.
2. Analysis for NO_3-N in the forage to be used for livestock to determine if NO_3 is present in a level toxic to livestock (>1000 ppm NO_3-N on a dry weight basis).
3. Analysis every 3 to 5 years of plant tissue for heavy metals such as Cd, Zn, Cu, Ni to establish trends of metal uptake and possible food chain accumulation.

Table 11 summarizes the average composition range of selected elements in leaf tissue of common agronomic crops and the suggested tolerance level to be used in monitoring purposes.

3) Monitoring ground and soil water quality

Samples of groundwater may be obtained by the installation of monitoring wells or by removing water from the horizontal drains of the drainage system. Soil water may be obtained by suction lysimeters installed at different depths in the soil. The parameters include NO_3-N, Cl, P and fecal coliform bacteria. Groundwater should be sampled monthly or bimonthly and soil water should be sampled occasionally to establish an optimum application rate. Research studies have shown that other water quality values such as suspended solids and BOD effectively reach zero in slow rate systems. These parameters may be measured in groundwater samples from rapid infiltration systems.

4) Monitoring of microbiological aerosols

The application of wastewater to land by spray irrigation may generate aerosols containing pathogenic microorganisms which can migrate beyond the wetted zone. Schaub et al. (1978) reported a monitoring program for measuring the aerosols that may have usefulness in assessing the potential human risk relative to other sources of exposure. Sampling may be performed by a wide variety of samplers including initial impactors and impingers, electrostatic precipitators and scrubbers. They recommended that continuous metered information be required to ensure valid sampling and that a quality assurance program for sampling and microbiological assays should also be established. Because of the difficulty in collecting microbiological aerosols and the expertise required, these monitoring studies should be conducted to develop relationships and to evaluate mathematical models. Predictive models should be then utilized to evaluate possible risks associated with microbiological aerosols at land treatment sites.

3-11. HEALTH AND ENVIRONMENTAL ASPECTS

Protection of public health and the environment is the main objective of any waste treatment. Land treatment has undergone a tremendous amount of scrutinity in the past 10 years in regard to this objective.

A. Objectives

The objectives of this task were to assess potential health and environmental effects of land application of wastewater as compared to sewage treatment by conventional wastewater treatment plants.

B. Approach

Potential health and environmental effects of land treatment were identified to be associated with nitrogen, toxic metals and organics, and pathogens. Several existing and recently constructed land treatment systems were evaluated as to their performance in removing these substances. In addition, experiments were conducted on selected research facilities to study the fate of these constituents in land treatment. Mathematical models were developed and evaluated to describe the fate of some of these substances in the environment.

C. Research accomplishments and conclusions

1) Nitrogen

The health issue of concern for N is excess concentration of NO_3 in drinking waters for infants under 6 months of age, because of the danger of methemoglobinemia. The drinking water standard is set at 10 mg N/L to prevent this problem. In overland flow, the treated water is collected at the bottom of the slope for further treatment or discharge so that NO_3 levels may be decreased if required. In slow rate systems and rapid infiltration, accurate predictions of the NO_3-N in leachate must be known. Extensive research studies (Iskandar et al. 1976, Jenkins and Palazzo 1981, Iskandar and Selim 1981 and Selim and Iskandar 1981) have shown that it is possible to predict the concentration of NO_3-N in leachate within 15%. It was also concluded that the concentration of NO_3-N in leachate from land treatment depends on application rate, schedule of application, plant uptake, concentration of N in applied effluent and climate. With proper selection of crops and application regime, it should always be possible to achieve the target of 10 mg N/L in the leachate.

In rapid infiltration systems, the primary removal mechanism for applied N is denitrification. Experience of Phoenix, Arizona, showed that the removal of N could be as high as 80% of that applied by carefully controlling the application rates and schedules. However, in general practice, about 30 to 50% of applied N will be denitrified, depending on the temperature, organic carbon content, concentration of applied effluent and the rate and schedule of wastewater application. In Ft. Devens, Massachusetts, applied effluent contains about 40 to 50 mg N/L and leachate contains 15 to 20 mg/L (Satterwhite et al. 1976b). The high NO_3 concentrations in groundwater do not necessarily present public health problems because groundwater at Ft. Devens is not being used for drinking. Such water may be used for irrigation purposes. The emphasis on NO_3 concentrations in the leachate should be dependent on the ultimate potential use. Input to surface water could possibly enhance eutrophication, but eutrophication in many water bodies is a phosphorus-limiting, not an N-limiting, process (Lee 1970).

2) Trace metals

Of potential concern are movement of metals to drinking water and translocation of metals through the food chain to humans. However, while movement of metals through soils to drinking water can occur, it is highly improbable (Iskandar 1975, Lund and Page 1981, Page et al. 1981) due to the relatively low concentrations of metals in applied effluents and to the high capacity of soils to remove these metals from wastewater. Translocation of metals through the food chain is more critical. Studies conducted at CRREL (Iskandar 1975), in California (Page et al. 1981, Lund and Page 1981), and in several existing systems in other states (Iskandar et al. 1977, Uiga et al. 1977) and in Australia (Johnson 1974) have shown that metal uptake by plants from municipal wastewater irrigation soils was not high enough to cause toxicity to plants or to animals. Wastewater has been applied to soils in these systems for as long as 90 years.

The removal of metals by soils and subsequent transformation is complicated and involves several physical and chemical processes such as ion exchange, adsorption, complexation and precipitation. Studies have shown that the soluble forms of metals are the most important ones in terms of plant uptake and food chain accumulation (Iskandar 1975, Hinsely et al. 1978). In acid soils, substantial amounts of metals become soluble and hence plant uptake of metals increases under these conditions. Application of lime to raise soil pH was recommended in these cases.

3) Pathogens

The pathogens of concern in land treatment systems are bacteria, parasites and viruses. The major concerns are transmission to groundwaters, internal or external contamination of crops, translocation to grazing animals, and off-site transmission by aerosols or runoff (Reed 1979):

Parasites may be present in all wastewaters. Under optimum conditions, the eggs of these parasites, particularly *Ascaris*, can survive for many years in soils. However, due to their weight, parasite cysts and eggs will settle out in the preliminary treatment or storage ponds and most of them will be found in the sludge. There is no available evidence indicating transmission of parasitic disease from application of wastewater in land treatment systems.

Concerns with respect to crop contamination focus mainly on surface contamination and persistence of pathogens until consumed by man or animals or internal infection of the plant by root uptake. Turner et al. (1977) demonstrated the persistance of poliovirus on lettuce and radishes for up to 36 days. However, these crops are not among the recommended ones for land treatment. Also, 99% of the detectable viruses were inactivated within 5 to 6 days after application. Internal transmission of viruses from soils to plants was demonstrated only when soils were spiked with very high concentrations of virus. Criteria established for irrigating pasture with primary effluent suggest a period of 14 days rest prior to grazing.

Possible transmission of pathogens by runoff is only possible in overland flow systems. Again, in this system, runoff is collected and treated prior to discharge.

Possible contamination of groundwater by bacteria and viruses is not an issue in overland flow systems. In slow rate systems, a seven-year study (Iskandar et al. 1976, Jenkins and Palazzo 1981) showed that essentially complete removal of fecal coliform bacteria occurred within 150 cm in two different soils. The concentration of fecal coliforms in applied wastewater ranged from 10^3 to 10^5/100 mL. There is a debate on the issue of virus movement to groundwater in rapid infiltration systems. Some investigators feel that a single virus particle has the capability of initiating infection in man, while others argue that this concept is simplistic and misleading (Lennette 1976). The health threat of the indigenous virus transmission to groundwater users at some distance from the wastewater treatment facility seems to be almost non-existent compared to the impact of household septic tank leach field systems on groundwaters.

The potential for aerosol transport of pathogens from the land treatment has probably been the single most controversial health issue in recent years and has involved the broadest spectrum of participants. The issue goes beyond the technical and health aspects and involves aesthetics and emotions. Reed (1979) has recently reviewed the literature and discussed this issue.

4) Toxic organics

Concern has been expressed about transport of pesticides and trace organic compounds that may be present in wastewaters to the groundwater and uptake of these substances by crops. However, pesticides are effectively removed by soils and eventually biodegraded.

Studies conducted at CRREL (Jenkins et al. 1981) on the effectiveness of overland flow in removing toxic volatile organics from wastewater showed that from 80 to 100% of applied organics were removed. They believe that the removal mechanism is volatilization.

In slow rate systems, removal of the toxic organics is also expected to be high. At Muskegon, Michigan, 56 organic compounds were identified (EPA 1976) in raw wastewater. However, only 17 of these compounds were present after aeration and detention in the storage ponds. Of these only 5 compounds were detected in the renovated water recovered from the site underdrains. More research is being conducted at the present time at the CRREL slow rate system and at Ontario, California.

In summary, the potential health and environmental effects of nitrogen and metals from land treatment are either nonexistent or can be managed by proper design and operation. Pathogens and organics are the greatest area of potential concern but proper design and management of land treatment systems provide for adequate protection of public health.

3-12. BENEFITS OF RESEARCH ON THE LAND TREATMENT OF WASTEWATER AND ECONOMIC ANALYSIS

A. Benefits of the research program

The research conducted by the Corps of Engineers and others has shown the land treatment of wastewater to be a cost-effective, energy-saving technology. Since the interactions of soil and vegetation with wastewater are now more clearly understood, cost-effective design optimization can now be accomplished.

A major accomplishment of the LTRP has been input to the 1977 *Process Design Manual for Land Treatment of Municipal Wastewater* (EM 110-1-501) issued jointly by the Corps of Engineers, the U.S. Environmental Protection Agency and U.S. Department of Agriculture, and to the revised *Process Design Manual*, published in 1981.

The LTRP research has also resulted in improved understanding of treatment responses of storage ponds and the capabilities of different plant types for wastewater renovation. Appropriate levels of preapplication treatment have now been identified, and overly stringent levels have been shown to be detrimental to the land treatment process.

Overland flow has been established as a practical technology, and a rational design procedure for this process has been established. The use of overland flow in cold regions has been investigated and shown to be a feasible treatment alternative.

Rapid infiltration's limitations have been defined and design precautions to protect drinking water aquifers have been developed. It has been shown that the recovered percolate from rapid infiltration systems is suitable for irrigation of crops.

Methods have been developed that can predict the water flow in various soils and the fate of pollutants such as nitrogen, phosphorus and heavy metals. Computer modeling techniques have been developed to optimize these methods of prediction.

The LTRP program has directly influenced the selection of land treatment of wastewater at several locations, including (see Reed and Bouzoun 1980):

- Land treatment at numerous Corps recreation sites: Arkabutla, Mississippi; Deer Creek, Ohio; Clarence Cannon Dam, Missouri; John Kerr Dam, Virginia; etc.
- Land treatment at Fort Meade, Maryland; Fort Ord, California; West Dover, Vermont; Greenville, Maine; Portland, Tennessee (Nashville Urban Study); and Clayton County, Georgia (Atlanta Urban Study).

B. Economic benefits

The economic benefits of the research efforts may be demonstrated through cost comparisons. Numerous comparisons have already documented the economic advantages of land treatment as compared to mechanical technologies. A rigorous economic analysis was made in a report by Reed and Bouzoun (1980). The approach that they used to conduct this analysis was to compare the cost of a hypothetical land treatment system that was designed using the criteria available in 1972-74 to a similar system designed with the 1980 criteria resulting from the LTRP.

In their hypothetical comparison for a slow rate system, Reed and Bouzoun (1980) estimated a difference in design costs of $12,193,000 (in 1980 dollars) for a 10-mgd system based on 1973 criteria and $10,174,000 for an identical system based on 1980 criteria. For a 3.68-mgd rapid infiltration system, the savings were even more substantial; the system would cost $12,194,000 using the 1973 criteria and only $5,603,000 with the improved (1980) design resulting from the LTRP. Similarly Bouzoun and Martel (1980) estimated a savings in the construction costs of a hypothetical 1-mgd overland flow system as $5,535,000 if 1980 design criteria were used rather than 1972 criteria.

Reed and Bouzoun (1980) conclude that the research on land treatment provided very significant benefits in "optimization of criteria, increased confidence of the profession in the reliability of the concepts, and use of the concepts where they were previously excluded." They point out that significant economic benefits from the research can be documented, and that these savings will be most significant in cold climates.

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APPENDIX A: Corps of Engineers Land Treatment of Wastewater Research Program: An Annotated Bibliography

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AVAILABILITY

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ABBREVIATIONS

BOD	Biological Oxygen Demand
CEC	Cation Exchange Capacity
FA	Fluorescent Antibody Technique for counting micro-organisms
GC-MS	Gas Chromatograph - Mass Spectrophotometer Analysis
M-FC	Membrane Fecal Coliform Procedure
MPN	Most Probable Number Technique for counting micro-organisms
SS	Suspended Solids
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids

C	Carbon
Ca	Calcium
Cd	Cadmium
Cl	Chloride
Cr	Chromium
Cu	Copper
Fe	Iron
Hg	Mercury
K	Potassium
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
NH_4^+	Ammonium
Ni	Nickel
N_2O	Nitrous Oxide
NO_2^-	Nitrite
NO_3^-	Nitrate
P	Phosphorus
Pb	Lead
PO_4^{2-}	Phosphate
Zn	Zinc
CAPDET	Computer Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems
COE	U.S. Army Corps of Engineers
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
CRREL TL	CRREL Translation
EPA	U.S. Environmental Protection Agency
NTIS	National Technical Information Service
SCS	Soil Conservation Service
USAEWES	U.S. Army Engineer Waterways Experiment Station
USDA	U.S. Department of Agriculture

1982 ENTRIES

Open Literature

Latterell, J.J., R.H. Dowdy, C.E. Clapp, W.E. Larson and D.R. Linden (1982) Distribution of phosphorus in soils irrigated with municipal wastewater effluent: A 5-year study. Journal of Environmental Quality, vol. 11, p. 124-128.

The specific objectives of this study are to determine the distribution of various P forms in soil irrigated 5 years with municipal wastewater and to measure the P-adsorption power of the soil following 5 years of P loading.

Martel, C.J. and C.R. Lee (1982) Overland flow: An alternative for wastewater treatment. The Military Engineer, vol. 74, p. 181-184.

This paper is intended to acquaint the military engineers who are unfamiliar with it with the overland flow technology. The research involved in developing the design criteria is discussed. The general construction characteristics and the necessary operation and maintenance procedures are also discussed.

Palazzo, A.J., T.F. Jenkins and C.J. Martel (1982) Vegetation selection and management for overland flow systems. In Land Treatment of Municipal Wastewater (F.M. D'itri, Ed.). Ann Arbor, Michigan: Ann Arbor Science Publishers Inc., p. 135-154.

This study has three objectives. The first is to determine which species of forage grasses should be used in overland flow systems, based on their speed of establishment and long-term persistance. The second is to obtain data on nutrient uptake by grasses in overland flow systems to be used to develop design criteria for nutrient removal. The final object is to determine forage grass yields and quality.

Schaub, S.A., H.T. Bausum and G.W. Taylor (1982) Fate of virus in wastewater applied to slow-infiltration land treatment systems. Applied and Environmental Microbiology, vol. 44, p. 383-394.

The removal of seeded coliphage f2 and indigenous enteroviruses from primary and secondary wastewaters applied by spray irrigation to sandy loam and silt loam soils in field test cells is examined. Sterilized soil core segments from different depths are studied to determine their virus adsorption capabilities when suspended in wastewater, test cell percolate water or distilled water containing divalent cations.

Technical Reports

Berggren, P.A. and I.K. Iskandar (1982) A users index to CRREL land treatment computer programs and data files. CRREL Special Report 82-26.

A users index is presented as a directory for the computer programs and data files developed at CRREL on land treatment. Two computers were used, one located at CRREL and the other at the Dartmouth Time Sharing System (DTSS), Dartmouth College, Hanover, New Hampshire. The objectives of this directory are to allow users to locate and use or request copies of desired programs or data files, to maintain a permanent record of programs and data files developed under the land treatment program, and to assist in technology transfer.

Bouzoun, J.R., D.W. Meals and E.A. Cassell (1982) A case study of land treatment in a cold climate: West Dover, Vermont. CRREL Report 82-44.

A slow rate land treatment system that operates throughout the year in a cold climate is described. Information on the geology, soils, vegetation, wildlife and the climate at the site is also presented. Winter operational problems such as ice formation on the elevated spray laterals, and freezing and plugging of the spray nozzles are discussed, as are their solutions. The results of a 1-year study to characterize the seasonal performance of the system, to develop N and P budgets for the system, to monitor specific hydrologic events on the spray field, to monitor shallow groundwater quality, to monitor the groundwater quality in off-site wells, and to monitor the water quality of two rivers that border the site are presented. Recommendations for the design and operation of other slow rate land treatment systems to be constructed in cold climates are included.

Iskandar, I.K. (1982) Overview of models used in land treatment of wastewater. CRREL Special Report 82-1.

This report summarizes the state-of-the-art of the modeling of wastewater renovation by land treatment. The models discussed are classified based on their use for planning, site selection and cost analysis, and for predicting 1) water and salt transport in soils, 2) N transport and transformations, 3) P transport and transformations, 4) virus movement in soils, and 5) toxic metal and trace organic movement in soils. This report compares the different models as to their purpose, input and output data, and status of validation. In addition, the report includes a section on research needs for modeling land treatment of wastewater.

Martel, C.J., T.F. Jenkins, C.J. Diener and P.L. Butler (1982) Development of a rational design procedure for overland flow systems. CRREL Report 82-2.

This report describes the development of a new design procedure for overland flow systems that is based on hydraulic detention time. A 2-year study was conducted on a full-scale overland flow site to obtain performance data in relation to detention time. Kinetic relationships are developed for removal of BOD, total SS, NH_4^+ and total P. Also, an empirical relationship is developed to predict hydraulic detention time as a function of application rate, terrace length and slope. These relationships are validated using published data from other systems. An example of how to use the new procedure and a comparison with the conventional design approach is included.

McKim, H.L., W.E. Sopper, D. Cole, W. Nutter, D. Urie, P. Schiess, S.N. Kerr and H. Farquhar (1982) Wastewater applications in forest ecosystems. CRREL Report 82-19.

This report summarizes the current state of knowledge concerning the application of municipal wastewater in forest ecosystems to assist in the design of such systems. This report supplements the Process Design Manual for Land Treatment of Municipal Wastewater.

Palazzo, A.J. (1982) Plant growth and management for wastewater treatment in overland flow systems. CRREL Special Report 82-5.

Domestic wastewater is applied over a 4-year period at various rates to three overland flow test slopes to study forage grass growth and nutrient removal. Plant yields, composition and uptake of nutrients are determined.

Ryden, J.C., J.K. Syers and I.K. Iskandar 1982. Evaluation of a simple model for predicting phosphorus removal by soils during land treatment of wastewater. CRREL Special Report 82-14.

This report evaluates a simple P balance model to predict site longevity with respect to P removal during land treatment. The model is based on measured inputs and outputs of P and on an estimate of the P storage capacity of the soil profile. Sorption of P by three soils used in land treatment is compared to the P sorption model.

Engineer technical letters

ETL 1110-2-525 (in prep.) Slow infiltration land treatment design criteria for plant uptake of nutrients.

This ETL presents guidance and recommendations for design and management of slow infiltration land treatment systems. This information is primarily related to forage grass growth and uptake of nutrients during the growing season.

ETL 1110-2-526 (1982) Crop management for overland flow wastewater treatment systems. 16 July.

Information and guidance for management of forage crops or vegetative cover on overland flow systems is presented in this ETL. Crop management aspects included in this study are 1) winter ryegrass overseeding, 2) frequency of harvesting, 3) intermittent and continuous wastewater application, 4) weed control and 5) insect control. These aspects re discussed in relation to runoff water quality, crop yield, crop nutrie t, heavy metal uptake and maintenance of the grass cover.

ETL 1110-2-529 (1982) Wastewater application in forest ecosystems.

See CRREL Report 82-19 by McKim et al. under 1982 Technical reports.

1981 ENTRIES

Publications in open literature

Bosatta, E., I.K. Iskandar, N.G. Juma, G. Kruh, J.O. Reuss, K.K. Tanji and J.A. van Veen (1981) Status report on modeling of processes: Soil microbiology. In Simulation of Nitrogen Behavior in Soil Plant Systems (M.J. Frissel and J.A. van Veen, Eds.). Wageningen, the Netherlands: Pudoc, Centre of Agricultural Publishing and Documentation, p. 38-44.

The N transformations of interest to this workshop are nitrification, denitrification, mineralization-immobilization and biological N_2-fixation. Each of the above microbially-mediated reactions are examined relative to modeling approaches, to appraisal of mathematical modeling and validation, and to the effect of environmental and soil factors.

Chen, R.L. and W.H. Patrick, Jr. (1981) Efficiency of nitrogen removal in a simulated overland flow wastewater treatment system. Journal of Environmental Quality, vol. 10, p. 98-103.

In a simulated overland flow system, vertical measurements of redox potential indicate the presence of both oxidized and reduced zones that provided favorable conditions for simultaneous nitrification-denitrification reactions. Addition of C sources can substantially reduce the redox potential and enhance the rate of NO_3^- reduction. N transformation rates are examined by the use of labeled ^{15}N under controlled laboratory conditions.

Greene, S.M., M. Alexander and D.C. Leggett (1981) Formation of N-Nitrosodimethylamine during treatment of municipal wastewater by simulated land application. Journal of Environmental Quality, vol. 10, p. 416-421.

This study establishes the potential for nitrosamine formation under conditions resembling land treatment. Dimethylnitrosamine (DMNA) is selected for investigation because of its high toxicity and the ubiquity of its precursor, dimethylamine (DMA). The extent of DMNA formation and the behavior of its precursors are examined in soils incubated with sewage and in effluent from soil columns percolated with sewage.

Iskandar, I.K. (Ed.) (1981) Modeling Wastewater Revovation - Land Treatment. New York: John Wiley and Sons.

This book is written by a multidisciplinary group of scientists and engineers to fill a need for information on mathematical modeling of land treatment of liquid waste. Both research personnel and decision makers should find it useful in planning, designing and managing modern land treatment systems.

Iskandar, I.K. (1981) Introduction. Chap. 1. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 3-19.

This chapter gives general information on land treatment, characteristics of wastewater, mechanisms of wastewater renovation by land treatment, health aspects of land treatment and the need for mathematical models in land treatment plans, design, management and operation.

Iskandar, I.K. and H.M. Selim (1981) Validation of a model for predicting nitrogen behavior in slow infiltration systems. Chap. 18. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 508-533.

This chapter presents data for N model validation. The data come from a lysimeter study using two different soils and ^{15}N as a tracer. The N concentration in soil solution at different soil depths and in the leachate, plant uptake of N, and root distribution are monitored. Water flow, and N transport and transformation submodels are discussed.

Iskandar, I.K. and H.M. Selim (1981) Modeling nitrogen transport and transformations in soils: 2. Validation. Soil Science, vol. 131, p. 301-312.

This paper is a condensed version of chapter 18 by Iskandar and Selim (1981) in Modeling Wastewater Renovation - Land Treatment.

Iskandar, I.K., K.K. Tanji, D.R. Nielsen and D.R. Keeney (1981) Concluding remarks and research needs. Sec. 6. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 767-772.

This chapter makes concluding remarks and summarizes the research needs in modeling wastewater renovation.

Keeney, D.R. (1981) Soil nitrogen chemistry and biochemistry. Chap. 10. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 259-276.

This chapter presents general background on soil N chemistry and biochemistry as related to land treatment, with specific reference to mineralization-immobilization, nitrification, denitrification and crop removal. Critical review of N transformations in slow and rapid infiltration systems and overland flow systems is presented. Research needs are also discussed.

Leggett, D.C. and I.K. Iskandar (1981) Evaluation of a nitrification model. Chap. 12. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 313-358.

This chapter reviews the literature on modeling nitrification in soils and presents a model based on Michaelis-Menten kinetics. The effects on nitrification of soil pH, temperature and dissolved oxygen content are discussed. Model validation using laboratory data is also included.

Linden, D.R., C.E. Clapp and J.R. Gilley (1981) Effects of municipal wastewater effluent irrigation scheduling on nitrogen renovation, reed canarygrass production and soil water conditions. Journal of Environmental Quality, vol. 10, p. 507-510.

A 2-year field experiment is conducted to test the performance of reed canarygrass and the removal of N from wastewater under varying irrigation schedules.

Lund, L.J., A.L. Page, C.O. Nelson and R.A. Elliott (1981) Nitrogen balances for an effluent irrigation area. Journal of Environmental Quality, vol. 10, p. 349-352.

An 8.5-ha pasture irrigated with secondary sewage effluent is studied to determine the fate of N applied in the effluent. Soils of the Corralitos Series (Typic Xeropsamment) in nine plots were sampled twice to evaluate the variations in the field water contents and NO_3^--N and Cl^- concentrations in the unsaturated zone below the root zone. Crop removal, leaching and gaseous losses were evaluated for their role in N removal.

Mansell, R.S. and H.M. Selim (1981) Mathematical models for predicting reactions and transport of phosphorus applied to soils. Chap. 21. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 600-646.

This chapter reviews existing mathematical models for P transport and transformations in soils. Mathematical models that assume chemical equilibrium for reactions of P applied to soil, those that assume non-equilibrium, and those that assume a reversible P removal from solution to occur simultaneously by equilibrium and nonequilibrium reactions are discussed. Also discussed are mechanistic multiphase models for reactions and transport of P applied to soils and transport models for preferential movements of water and P through soil channels.

Mehran, M., K.K. Tanji and I.K. Iskandar (1981) Compartmental modeling for prediction of nitrate leaching losses. Chap. 16. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 444-477.

This chapter presents a simple N model for land treatment. This model consists of two submodels: a water-flow submodel and an N-flow submodel. The underlying principles of compartmental modeling are discussed. The model was evaluated with field data from Davis, California, and Hanover, New Hampshire.

Nakano, Y., R.L. Chen and W.H. Patrick Jr. (1981) Nitrogen transport and transformation in overland flow land treatment. Chap. 19. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 534-568.

This chapter presents a mechanistic N model for overland flow. Water movement and N transport and transformation are discussed. The model is validated with data from a laboratory scale model using ^{15}N as a tracer.

Palazzo, A.J. (1981) Seasonal growth and accumulation of nitrogen, phosphorus, and potassium by orchardgrass irrigated with municipal wastewater. Journal of Environmental Quality, vol. 10, p. 64-68.

This 2-year field study determines the seasonal growth and nutrient accumulation of a forage grass receiving 7.5 cm/week of domestic primary-treated wastewater. An established sward of Pennlate orchardgrass is managed on an annual three-cutting system. Grass samples are taken periodically during the growing season to determine the plant dry matter accumulation and uptake of N, P and K.

Palazzo, A.J., T.F. Jenkins and C.J. Martel (1981) Vegetation selection and management for overland flow systems. Public Works, vol. 112, no. 8, p. 49-52.

This paper details the usefulness of several forage grasses on an overland flow system operated in Hanover, New Hampshire. Also discussed are the problems encountered with invading species and winter operation, how to maintain the cover crop prior to land treatment, and the yield that may be expected. General recommendations include the specific grass mixes to use, when to fertilize and proper weed control.

Riggan, P.J. and D.W. Cole (1981) Simulation of forest production and nitrogen uptake in a young Douglas Fir ecosystem. Chap. 15. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 410-443.

This chapter presents a model for biomass production and N uptake in a Douglas fir ecosystem. The model is evaluated with field data from Pack Forest experimental site near Seattle, Washington.

Ryden, J.C., L.J. Lund and S.A. Whaley (1981) Direct measurement of gaseous nitrogen losses from an effluent irrigation area. Journal of the Water Pollution Control Federation, vol. 53, p. 1677-1682.

This study measures the extent and nature of gaseous N loss from an effluent disposal area following irrigation with secondary-treated effluent. Gaseous N losses from field plots within the disposal area are estimated from measurements of NH_4^+ volatilization and total denitrification N loss using a field adaptation of the acetylene-inhibition technique.

Ryden, J.C., J.K. Syers and I.K. Iskandar (1981) Evaluation of a simple model for predicting phosphorus removal by soils during land treatment of wastewater. Chap. 22. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 647-667.

This chapter describes a simple model that evaluates soils' ability to remove wastewater P, and predicts P movement in soils and site longevity. The model is evaluated with field data; advantages and limitations of the model are discussed.

Selim, H.M. and I.K. Iskandar (1981) WASTEN: A model for nitrogen behavior in soils irrigated with liquid waste. In Simulation of Nitrogen Behavior of Soil-Plant Systems (M.J. Frissel and J.A. van Veen, Eds.). Wageningen, the Netherlands: Pudoc, Centre for Agricultural Publishing and Documentation.

This model 1) simulates the physical, chemical and biological processes of N transformation and transport in multilayered soil profiles for slow and rapid infiltration systems, 2) enables prediction of NO_3^--N concentrations in soil solution and leachate in time and space, and 3) assists in esti-

mating the application rate and schedule of water and N to a land treatment system.

Selim, H.M. and I.K. Iskandar (1981) A model for predicting nitrogen behavior in slow and rapid infiltration systems. Chap. 17. In *Modeling Wastewater Renovation - Land Treatment* (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 478-507.

This chapter presents a mechanistic N model that includes a water submodel and an N submodel. The effects of nitrification rate, NH_4^+ exchange, plant uptake, wastewater application rate and schedule, and rainfall are discussed in terms of the models' sensitivity.

Selim, H.M. and I.K. Iskandar (1981) Modeling nitrogen transport and transformation in soils: 1. Theoretical considerations. *Soil Science*, vol. 131, p. 233-241.

This paper is a condensed version of Chapter 17 by Selim and Iskandar in *Modeling Wastewater Renovation - Land Treatment*.

Shaffer, M.J. and S.C. Gupta (1981) Hydrosalinity models and field validation. Chap. 7. In *Modeling Wastewater Renovation - Land Treatment* (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 136-181.

This chapter presents a review of hydrosalinity models for land treatment and discusses the Bureau of Reclamation model. Model sensitivity analysis and evaluation are also included using data from three different systems and simulated field applications.

Smith, C.J., R.L. Chen and W.H. Patrick, Jr. (1981) Nitrous oxide emission from simulated overland flow wastewater treatment systems. *Soil Biology and Biochemistry*, vol. 13, p. 275-278.

This study looks at N_2O evolution from overland flow prototypes receiving daily applications of municipal wastewater with NH_4^+-N concentrations of 10 to 47 µg/mL. The effect of liming the soil and increasing the NH_4^+ concentration in the wastewater is also studied.

Stanley, P.M. and E.L. Schmidt (1981) Serological diversity of *Nitrobacter* spp. from soil and aquatic habitats. *Applied and Environmental Microbiology*, vol. 41, p. 1069-1071.

This study examines the serological diversity among *Nitrobacter* spp. Fluorescent antibodies prepared against 11 *Nitrobacter* spp. cultures isolated from soil and water are placed in six serogroups. These fluorescent antibodies are compared with a group of 16 additional isolates.

Syers, J.K. and I.K. Iskandar (1981) Soil phosphorus chemistry. Chap. 20. In Modeling Wastewater Renovation - Land Treatment (I.K. Iskandar, Ed.). New York: John Wiley and Sons, p. 571-599.

This chapter reviews the literature on soil P chemistry as related to land treatment. Emphasis is given to sorption-desorption reactions since these have direct bearing on the movement of P within soils and influence the longevity of sites for wastewater renovation.

U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Interior and U.S. Department of Agriculture (1981) Process Design Manual for Land Treatment of Municipal Wastewater. EPA 625/1-81-013 (COE EM 1110-1-501).

This manual provides criteria and supporting information for the planning and process design of land treatment systems. Recommended procedures for planning and design are presented along with state-of-the-art information on treatment performance, energy considerations, and health and environmental effects. This document is a revision of the Process Design Manual for Land Treatment of Municipal Wastewater sponsored by EPA, COE and USDA, and published in 1977. The scope of this manual is limited to the three major land treatment processes: slow rate, rapid infiltration and overland flow.

Technical reports

Abele, G., H.L. McKim, D.M. Caswell and B.E. Brockett (1981) Hydraulic characteristics of the Deer Creek Lake land treatment site during wastewater application. CRREL Report 81-7 (ADA 103 732).

The objectives of this study are to determine the infiltration and drainage rates at the Deer Creek Lake land treatment system outside of Columbus, Ohio, and the total water mass balance during wastewater application. Previous soil water-content data were conflicting so the wastewater distribution on the application area is examined in this report.

Jenkins, T.F. and A.J. Palazzo (1981) Wastewater treatment by a slow rate land application system. CRREL Report 81-14 (ADA 106 975).

Six slow rate land treatment prototypes, three containing a sandy loam and three containing a silt loam, are studied from June 1974 to May 1980. The systems are spray-irrigated with either primary or secondary wastewater at varying application rates. The performance of forage grasses is studied to determine the yield and nutrient uptake under the various application regimes.

Jenkins, T.F., D.C. Leggett, C.J. Martel and H.E. Hare (1981) Removal of volatile trace organics from wastewater by overland flow. CRREL Special Report 81-1 (ADA 097 576).

A prototype overland flow land treatment system is studied to determine its effectiveness in reducing the levels of volatile trace organics in municipal wastewater. Chlorinated primary wastewater, water collected from the surface at various points downslope, and runoff are analyzed by GC-MS using a purge and trap sampler.

Jenkins, T.F., A.J. Palazzo, P.W. Schumacher, H.E. Hare, P.L. Butler, C.J. Diener and J.M. Graham (1981) Seven-year performance of CRREL slow-rate land treatment prototypes. CRREL Special Report 81-12 (ADA 103 739).

Water quantity and quality data are presented for the wastewater applied to and the percolate leaving the 5-ft soil profiles of six outdoor test cells that were operated from June 1973 through May 1980. Average concentration, mass loading, mass removal and percentage removal of wastewater constituents are presented for each year. Nutrient balance sheets summarize the relative amounts removed by plant uptake, deep percolation and other N and P removal mechanisms.

Palazzo, A.J. and J.M. Graham (1981) Seasonal growth and uptake of nutrients by orchardgrass irrigated with wastewater. CRREL Report 81-8 (ADA 101 613).

This 2-year field study determines the seasonal growth and nutrient accumulation of a forage grass receiving primary treated domestic wastewater. An established sward of Pennlate orchardgrass is managed on an annual three cutting system. Grass samples are periodically analyzed to determine plant dry matter accumulation and uptake of N, P and K. Changes in nutrient uptake with harvest period are related to both changes in dry matter accumulation and plant nutrient concentration. Estimates of monthly plant removal for N and P are presented as a guide in designing land treatment systems according to the procedures given in the Process Design Manual for Land Treatment of Municipal Wastewater (EM 1110-1-501).

Parker, L., I.K. Iskandar and D.C. Leggett (1981) Effect of soil temperature and pH on nitrification kinetics in soils receiving a low level of ammonium enrichment. CRREL Special Report 81-33 (ADA 090 575/2).

Two studies investigate the effect of soil temperature and pH on nitrification kinetics in soils receiving a low level of NH_4^+ enrichment. Soil samples are analyzed for NH_4^+, NO_2^- and NO_3^-. In the temperature study the number of NH_4^+ and NO_2^- oxidizers is also determined. In this study two soils from a slow infiltration land treatment test facility are used. The three incubation temperatures selected mimic field conditions at the test site. Soils that had received prior treatment with dolomitic limestone to raise the pH are used in the second study to determine the effect of pH on nitrification kinetics. The three pHs used in this study are 4.5, 5.5 and 7.0.

Peters, R.E., C.R. Lee and D.J. Bates (1981) Field investigation of overland flow treatment of municipal lagoon effluent. USAEWES Technical Report EL-81-9.

Overland flow treatment of municipal lagoon effluent is studied in a field environment near Utica, Mississippi. The ability of overland flow to renovate municipal wastewater with respect to BOD, TSS, nutrients, fecal coliforms and heavy metals is studied over an approximately 3-year period. The roles played by soil, soil temperature, vegetative cover and management in wastewater renovation are investigated.

Ryan, J.F and R.C. Loehr (1981) Site selection methodology for the land treatment of wastewater. CRREL Special Report 81-28 (ADA 108 636).

This report presents a methodology that covers various facets of site selection, from preliminary screening to field data acquisition for the preparation of a final design for a land treatment system. The methodology is presented in three stages or levels.

1980 ENTRIES

Publications in open literature

Belser, L.W. and E.L. Schmidt (1980) Growth and oxidation kinetics of three genera of ammonia oxidizing nitrifiers. FEMS Microbiology Letters, vol. 7, p. 213-216.

This article presents data on parameters that characterize the growth and kinetics of substrate oxidation for three genera of NH_4^+ oxidizers (Nitrosomonas, Nitrosospira, Nitrosolobus). Comparative studies based on the MPN and FA enumeration techniques in pure culture are used to obtain the results.

Chen, R.L. and W.H. Patrick, Jr. (1980) Nitrogen transformations in a simulated overland flow wastewater treatment system. Water Research, vol. 14, p. 1041-1046.

In this study physical scale models of plant-soil systems and labeled ^{15}N-NH_4^+ are used to determine the fate of applied N during overland flow. Of special interest is the N removal efficiency and the amount of applied N incorporated into the plant-soil system.

Iskandar, I.K. and J.K. Syers (1980) Effectiveness of land application for phosphorus removal from municipal waste water at Manteca, California. Journal of Environmental Quality, vol. 9, no. 4, p. 616-621.

This study evaluates the effectiveness of P removal by a slow infiltration system that has been in operation for several years and discusses the results obtained in terms of the soil characteristics. The effects of crop removal, infiltration rate and the P sorption capacity of the soil are discussed.

Jacobson, S.N. and M. Alexander (1980) Relation of temperature, carbon source, and denitrifier population to nitrate loss from soil. Soil Biology and Biochemistry, vol. 12, p. 501-505.

This study develops practical means for the use of soil in removing NO_3^- and organic matter from wastewater. The soils and conditions are selected to estimate the likely effect of environmental or operating conditions in the field on the rate of NO_3^- removal. In addition, a quantitative relation is sought between the numbers of denitrifiers and the extent of NO_3^- reduction in the soil.

Jenkins, T.F., D.C. Leggett and C.J. Martel (1980) Removal of volatile trace organics from wastewater by overland flow treatment. Journal of Environmental Sciences and Health, vol. 15, no. 3, p. 211-224.

A prototype overland flow land treatment system is studied to determine its effectiveness in reducing the levels of volatile trace organics in municipal wastewater. Chlorinated primary wastewater, water collected from the surface at various points downslope and runoff are analyzed by GC-MS using a purge and trap sampler.

Jenkins, T.F., D.C. Leggett, C.J. Martel, R.E. Peters and C.R. Lee (1980) Toxic volatile organics removal by overland flow land treatment. In Proceedings, 53rd Annual Conference of Water Pollution Control Federation, September 28-October 3, Las Vegas, Nevada. Washington, D.C.: Water Pollution Control Federation.

This study determines the degree and rate of removal by overland flow for a number of toxic organic substances and develops relationships for predicting removals. Two sites were used in this study, one in Hanover, New Hampshire, and the other in Utica, Mississippi. This study is a follow-up to the one published in the Journal of Environmental Sciences and Health (1980).

Martel, C.J., D.D. Adrian, T.F. Jenkins and R.E. Peters (1980) Rational design of overland flow systems. Proceedings, 1980 American Society of Civil Engineers National Conference on Environmental Engineering, July 8-10, New York. New York: ASCE.

This paper presents a design procedure based on hydraulic detention time (the average time a particle of water takes to travel from the top to the bottom of the slope). The authors theorize that any desired level of treatment can be achieved by controlling the length of time wastewater remains on the slope.

Marten, G.C. and A.W. Hovin (1980) Harvest schedule, persistence, yield, and quality interactions among four perennial grasses. Agronomy Journal, vol. 72, p. 378-387.

This paper determines whether harvest schedule under weed-free conditions differentially influences persistence, hay yield and forage quality for orchardgrass, tall fescue, reed canarygrass and smooth bromegrass.

Marten, G.C., W.E. Larson and C.E. Clapp (1980) Effects of municipal wastewater effluent on performance and feed quality of maize vs. reed canarygrass. Journal of Environmental Quality, vol. 9, p. 137-141.

This study compares the feed quality and yields of maize fodder and reed canarygrass when managed by conventional practices and when treated with municipal wastewater during four growing seasons.

Marten, G.C., D.R. Linden, W.E. Larson and C.E. Clapp (1980) Maize culture in reed canarygrass sod to renovate municipal wastewater effluent. Agronomy Journal, vol. 73, p. 293-297.

These two experiments are conducted over a 3-year period on effluent-treated soils and assess the effects of suppressing reed canarygrass with several types and rates of herbicides on 1) yields of interplanted maize grain and fodder, 2) total crop yields and N removal by maize-reed-canarygrass combinations, 3) feed quality of interplanted maize, 4) water infiltration capacity of Typic Hapludoll soil, and 5) the N concentration in the soil water at the bottom of the root zone (just above the water table).

Meals, D.W., Jr., E.A. Cassell, J.R. Bouzoun and C.J. Martel (1980) Spray application of wastewater effluent in West Dover, Vermont. Journal of the New England Water Pollution Control Association, vol. 14, no. 1, p. 38-53.

This paper evaluates performance of the land treatment process in West Dover, including considerations of the hydrologic behavior of the site, treatment effectiveness, patterns of seasonal variation and off-site effects. This treatment plant disposes of chlorinated effluent by spraying on forested land and is one of the few in the U.S. that operates year-round in a cold climate.

Nakano, Y. (1980) Application of recent results in functional analysis to the problem of wetting fronts. Water Resources Research, vol. 16, no. 2, p. 314-318.

Some recent results in nonlinear functional analysis are presented as evidence supporting the new viewpoint that wetting fronts with a finite propagating speed are generally singular surfaces.

Palazzo, A.J., C.J. Martel and T.F. Jenkins (1980) Forage grass growth on overland flow systems. In Proceedings of the 1980 American Society of Civil Engineers National Conference on Environmental Engineering, July 8-10, New York. New York: ASCE, p. 347-354.

This study 1) determines plant growth and nutrient removal on an overland flow slope receiving primary or secondary effluent, 2) provides information for the improvement of plant management procedures for maintaining maximum plant uptake of N and P, and 3) ascertains the feed quality and value of the plant material grown.

Stark, S.A. and C.E. Clapp (1980) Residual nitrogen availablity from soils treated with sewage sludge in a field experiment. Journal of Environmental Quality, vol. 9, no. 3, p. 505-512.

The residual N available from sewage sludges applied to a sandy loam soil is determined in this study. In study I, three sludge types--anaerobically digested, aerobically digested, and mixed primary-settled and waste-activated--are applied over a 3-year period. Soil samples are collected 2 years after the final sludge application. Study II samples are obtained from plots of a field experiment in which an anaerobically digested sludge had been applied 4 years earlier. Several biological and chemical characteristics are examined as indexes of N availability.

Technical Reports

Abele, G., H.L. McKim, B.E. Brockett and J. Ingersoll (1980) Infiltration characteristics of soil at Apple Valley, Minnesota, Clarence Cannon Dam, Montana, and Deer Creek Lake, Ohio. CRREL Special Report 80-36 (ADA 093 350).

Three land treatment sites at Apple Valley, Minnesota, Clarence Cannon Dam, Missouri, and Deer Creek Lake, Ohio, are used to collect and evaluate field infiltration data. This study also evaluates the installation and operation of the test equipment and instrumentation, as well as data collection schedule and analysis techniques.

Chen, R.L. and W.H. Patrick, Jr. (1980) Nitrogen transformation in a simulated overland flow wastewater treatment system. CRREL Special Report 80-16 (ADA 084 280).

This research employs scale models of plant-soil systems in which labeled ^{15}N (as NH_4^+-N) is used to trace applied N during overland flow. The N removal efficiency and the amount of applied N incorporated in the plant-soil system are of special interest.

Hoeppel, R.E., R.G. Rhett and C.R. Lee (1980) Fate and enumeration problems of fecal coliform bacteria in runoff waters from terrestrial ecosystems. USAEWES Technical Report EL-80-9 (ADA 090 719).

Field and greenhouse model tests are conducted, using both natural wastewater and tracer fecal coliform bacteria. Greenhouse models use soils that are either uncontaminated or contaminated by human wastes; application rates are varied to determine best treatment conditions. The standard method for fecal coliform testing is modified to develop improved testing methodology.

Iskandar, I.K., L. Parker, K. Madore, C. Gray and M. Kumai (1980) Disinfection of wastewater by microwaves. CRREL Special Report 80-1 (ADA 082 174).

This report explores microwave radiation as a possible alternative for disinfection of wastewater and investigates the rate and extent of disinfection and possible mechanisms of bacterial destruction.

Iskandar, I.K., L. Parker, C. McDade, J. Atkinson and A.P. Edwards (1980) Dynamics of NH_4 and NO_3 in cropped soils irrigated with wastewater. CRREL Special Report 80-27 (ADA 090 575).

This field study 1) obtains information on the dynamic behavior of wastewater NH_4^+ and NO_3^- in soils, 2) determines the relative abundance of NH_4^+ and NO_3^- in soils receiving wastewater, and 3) evaluates any seasonal effect on the fate of wastewater NH_4^+ applied to soils in a slow infiltration system. The study is conducted using an on-going test plot with two soil types and a forage grass cover.

Leggett, D.C. and I.K. Iskandar (1980) Improved enzyme kinetic model for nitrification in soils amended with ammonium: I. Literature review. CRREL Report 80-1 (ADA 082 303).

This work synthesizes reported temperature and pH effects on nitrification and nitrifier growth rates. The principles of microbial kinetics are extended to soils.

Martel, C.J., T.F. Jenkins and A.J. Palazzo (1980) Wastewater treatment in cold regions by overland flow. CRREL Report 80-7 (ADA 084 489).

In this study primary effluent, secondary effluent and tapwater are applied to separate sections of a pilot-scale overland flow site in a cold regions environment. Performance is evaluated for 1 year, May 1977 to June 1978.

Nakano, Y. (1980) Propagating velocity of singularity occurring in certain degenerate parabolic equations. Transactions of the Twenty-fifth Conference of Army Mathematicians. Research Triangle Park, N.C.: Army Research Office, ARO Report 80-1.

The conditions that determine the propagating velocity of a wetting front and also serve as the moving boundary conditions at the wetting front are presented. These conditions are shown to hold true for particular solutions reported in the literature.

Selim, H.M. and I.K. Iskandar (1980) Simplified model for prediction of nitrogen behavior in land treatment of wastewater. CRREL Report 80-12 (ADA 085 191).

A simplified model for simulation of N transformations and transport in land treatment is presented. The purpose of the model is to predict the behavior of NH_4^+-N and NO_3^--N in the soil profile in land treatment systems. The model is based on the simultaneous solution of the transient soil water flow equation with the equations describing the transformation, transport and plant uptake of N in the soil. The model is valid for uniform as well as multilayered soil profiles and can be adapted to incorporate various N transformation mechanisms and boundary conditions.

Theses and dissertations

Gasiorowski, S.A. (1980) Phosphate adsorption and desorption on two contrasting soils used for land treatment of wastewater. Ph.D. Dissertation, University of New Hampshire, Durham.

This research involves the phosphate adsorption-desorption behavior of two soils: Charlton silt loam, a typical acid soil from New England which is being used in experimental wastewater treatment, and Tujunga coarse sandy loam from a wastewater treatment facility located at Manteca, California, which has failed to remove phosphate from wastewater efficiently. The effects of altering the pH and phosphate content of municipal wastewater on adsorption and desorption are determined. Radioactive ^{32}P is used to follow the adsorption and desorption rate in suspensions of soil and wastewater. Parallel experiments are conducted where phosphate is also monitored by conventional spectrophotometric analyses. The complementary use of ^{32}P and non-radioactive phosphate permits the evaluation of adsorption and desorption of freshly sorbed and native phosphate independently, as well as evaluation of the degree of exchange.

Greene, S.M. (1980) Formation of dimethylnitrosamine during treatment of municipal wastewater by simulated land application. M.S. Thesis, Cornell University, Ithaca, New York.

This study is designed to establish the potential risk of nitrosamine formation during land treatment. Dimethylnitrosamine (DMNA) is selected because of its extreme toxicity and the ubiquity of its precursor amine. The behavior of NO_2^- and dimethylamine (DMA) in relation to DMNA formation is studied. The yield of DMNA is examined in two acidic, sewage amended soils: Arkport fine sandy loam and Lake George sand. The latter soil is obtained from a site that had received amendments of municipal wastewater for 20 years. DMNA levels are also measured in sewage that had been percolated through 15-cm soil columns, and predictions are made from these data about the possibility of nitrosamine contamination of groundwater. Factors that might contribute to the risk of nitrosamine formation during land application of wastewater are examined.

Presentations

Adams, J.R. and C.J. Merry (1980) Application of a land resource information system (LRIS) and the CAPDET model to facilities planning and land treatment of municipal wastewater. Presented at the 14th International Symposium on Remote Sensing of Environment, 23-30 April, San Jose, Costa Rica.

This paper discusses the combined use of a large computer database (LRIS) and a computer model (CAPDET). The LRIS allows the rapid evaluation of very large land areas for suitability for any land use that can be evaluated in terms of physical soil properties. (CAPDET provides information for evaluation of the economics of a variety of wastewater treatment systems.) In this study, the portion of the Lake Erie drainage basin located in the U.S. is evaluated to determine whether it contains potential sites for land treatment.

Cole, D.W. (1980) Response of forest ecosystems to sludge and wastewater applications - A case study in western Washington. Presented at the Symposium on Utilization of Municipal Wastewater and Sludge for Land Reclamation and Biomass Production, September 16-18, Pittsburgh, Pennsylvania.

The purpose of the program at the University of Washington is to investigate the feasibility of applying municipal wastewater and dewatered sludge to established forests and new plantations. This paper addresses the three major goals of this program: 1) to determine the environmental soundness of the program, 2) to determine changes in forest productivity, 3) and to establish the economic aspects, including both costs and benefits.

Jenkins, T.F., D.C. Leggett and C.R. Lee (1980) Toxic volatile organics removal by overland flow land treatment. Presented at the 53rd Annual Conference of the Water Pollution Control Federation, September 28 - October 3, Las Vegas, Nevada.

The ability of overland flow systems to treat and remove toxic volatile organics from wastewater is studied at sites in Utica, Mississippi, and Hanover, New Hampshire. The percent removal is found to be a function of detention time. Biodegradation, sorption on suspended matter and volatilization are discussed as possible mechanisms of removal.

Martel, C.J., D.D. Adrian and R.E. Peters (1980) Design of overland flow systems--A rational approach. Presented at the 53rd Annual Conference of the Water Pollution Control Federation, September 28 - October 3, Las Vegas, Nevada.

This paper presents a rational procedure for design of overland flow systems. With this procedure, overland flow systems can be designed to meet discharge permit requirements.

Martel, C.J., J.R. Bouzoun and T.F. Jenkins (1980) Removal of organics by overland flow. Presented at the U.S. Environmental Protection Agency National Seminar on Overland Flow Technology for Municipal Wastewater, September 16-18.

This study is conducted to better understand the behavior of and possible mechanisms for selected removal of organics in overland systems, and the kinetics of their removal. This paper focuses on the BOD, TOC and trace organic removal findings.

Palazzo, A.J. and J.R. Bouzoun (1980) Long-term plant nutrient removal using the nutrient film technique for wastewater treatment. Proceedings, 72nd Meeting, American Society of Agronomy, November 30 - December 5, Detroit, Michigan, p. 33.

This study determines the effectiveness of the nutrient film technique as a wastewater treatment system. Primary domestic wastewater is applied continuously for 190 days to mature reed canarygrass. The N, P, K, crude protein and dry matter yield of the plants are examined along with the N and P levels in the applicant and runoff (abstract only).

Parker, L. and I.K. Iskandar (1980) Effects of temperature and pH on nitrification kinetics in soils. Proceedings, 72nd Annual Meeting, American Society of Agronomy, November 30 - December 5, Detroit, Michigan, p. 34.

The effect of temperature on nitrification kinetics in soils at a low N concentration is monitored microbiologically and chemically. This study is performed on two New Hampshire soils. The effect of pH is tested in three Wisconsin soil samples. The microbiological population is not monitored in this experiment (abstract only).

1979 ENTRIES

Publications in open literature

Breuer, D.W., D.W. Cole and P. Schiess (1979) Nitrogen transformation and leaching associated with wastewater irrigation in Douglas-fir, poplar, grass and unvegetated systems. In Municipal Wastewater and Sludge Recycling on Forest Land and Disturbed Land (W.E. Sopper, Ed.). University Park: Pennsylvania State University Press, p. 19-33.

This study evaluates the N transformations and transport process in coniferous and deciduous forests. The study includes an experimental system at Pack Forest near Seattle, Washington, and gives an overview of the site and initial results on the nitrification process and N leaching characteristics.

Hunt, P.G., R.E. Peters, T.C. Sturgis and C.R. Lee (1979) Reliability problems with indicator organisms for monitoring overland flow treated wastewater effluent. Journal of Environmental Quality, vol. 8, p. 301-304.

A 2-year study (1975-76) on the response of indicator organisms in wastewater from faculative lagoons treated by overland flow is conducted in Utica, Mississippi. Fecal streptococci and fecal coliforms are enumerated in the wastewater before it is applied to the plots, as it flows downslope and as it is discharged from the plots.

Johnson, D.W., D.W. Breuer and D.W. Cole (1979) The influence of anion mobility on ionic retention in wastewater-irrigated soils. Journal of Environmental Quality, vol. 8, no. 2, p. 146-250.

This paper offers a conceptual model of soil leaching mechanisms and provides baseline information that may be used to develop land treatment design guidelines incorporating total environmental fluxes. All the major anions are considered collectively. Their production and mobility are related to the total ionic leaching following irrigation of municipal wastewater on a forest soil.

Lee, C.R. and R.E. Peters (1979) Overland flow treatment of a municipal lagoon effluent for reduction of nitrogen, phosphorus, heavy metals, and coliforms. Journal of Progress in Water Technology, vol. 11, p. 175-183.

Overland flow treatment of municipal facultative lagoon effluent is studied on 24 research plots at Utica, Mississippi. The study evaluates factors such as the amount of wastewater applied, length of application period, slope of treatment area, crop management, and reduction in BOD, SS, N, O, heavy metals and coliforms.

Marten, G.C., C.E. Clapp and W.E. Larson (1979) Effects of municipal wastewater effluent and cutting management on persistence and yield of eight perennial forages. Agronomy Journal, vol. 71, p. 650-658.

The persistence and yields of dry matter and feed nutrients of seven cool-season perennial grasses and alfalfa are determined using three cutting schedules. Two levels of effluent treatment plus one control treatment--commercial fertilizer--are used in this study, which covers a 5-year period.

McKim, H.L., T.F. Jenkins, C.J. Martel and A.J. Palazzo (1979) International and national developments in land treatment of wastewater. In Symposium on Effluent Irrigation Under Prairie Conditions, 24-25 January, Regina, Saskatchewan. Environment Canada.

This paper documents the national and international history and scope of land treatment. The types of land treatment discussed are rapid infiltration, slow infiltration and overland flow. Specific examples are used. The primary design criteria, management practices and treated water quality characteristics are discussed.

Nakano, Y. (1979) Application of recent results in functional analysis to the problems of water tables. Advances in Water Resources, vol. 2, p. 185-190.

The traditional viewpoint in hydrology and soil physics purports that water tables appearing in porous media described by Darcy's law and the extended Darcy's law are not singular surfaces. Several particular solutions in which singularities occur are presented as counter-examples to the traditional viewpoint and as evidence supporting the new theory that water tables are generally singular surfaces.

Nakano, Y., R.A. Khalid and W.H. Patrick Jr. (1979) Water movement in a land treatment system of wastewater by overland flow. Progress in Water Technology, vol. 11, no. 4-5, p. 185-206.

Water movement in an overland flow land treatment system is studied experimentally and theoretically. A small-scale physical model is used to obtain experimental data. The theoretical analysis is based upon the shallow water equation for overland flow and the Darcy-Richards law for soil water flow.

Palazzo, A.J. and T.F. Jenkins (1979) Land application of wastewater: Effect on soil and plant potassium. Journal of Environmental Quality, vol. 8, p. 309-312.

This study reports on the removal of K by a forage grass mixture from soil that received applications of wastewater over a 5-year period. The forages were grown on either sandy loam or silt loam soil.

Technical Reports

Abele, G., H.L. McKim and B.E. Brockett (1979) Mass water balance during spray irrigation with wastewater at Deer Creek Lake land treatment site. CRREL Special Report 79-29 (ADA 080 649).

The water mass balance for a 3.6-ha test area is calculated during and two days after wastewater application. The total water mass balance is calculated by use of soil water contents, underdrain flow rates and calculated values for evapotranspiration.

Bausum, H.T., R.E. Bates, H.L. McKim, P.W. Schumacher, B.E. Brockett and S.A. Schaub (1979) Bacterial aerosols from a field source during multiple sprinkler irrigation: Deer Creek Lake State Park, Ohio. CRREL Special Report 79-32 (ADA 077 632).

Quantitative data on the strength, dispersion, particle size and decay of bacterial aerosols produced downwind from a spray irrigation land treatment system are presented in this study.

Bouzoun, J.R. (1979) Freezing problems associated with spray irrigation of wastewater during the winter. CRREL Special Report 79-12 (ADA 070 031).

This report assesses the problems associated with applying wastewater by spray irrigation during the winter in a cold climate. The system discussed in this report is the wastewater treatment facility in West Dover, Vermont.

Cassell, E.A., D.W. Meals, Jr. and J.R. Bouzoun (1979) Spray application of wastewater effluent in West Dover, Vermont: An initial assessment. CRREL Special Report 79-6 (ADA 068 534).

This study assesses the performance of the land treatment system in West Dover, Vermont. This 6-week monitoring program is designed to determine the amounts of N, P and other constituents applied to the eastern slope of the effluent spray field and to determine the amounts of these constituents in drainage from the spray field. Site performance is assessed in terms of mass balance of various nutrient forms across the eastern slope. In addition, data on site groundwater and adjacent streams are collected and examined to provide an initial estimate of the impact of effluent application.

Elgawhary, S.M., I.K. Iskandar and B.J. Blake (1979) Evaluation of nitrification inhibitors in cold regions land treatment of wastewater: Part 1. Nitrapyrin. CRREL Special Report 79-18 (ADA 071 077).

A series of laboratory and field tests are conducted to investigate the possibility that nitrapyrin could be useful as a nitrification inhibitor in land treatment. Laboratory tests included soil incubation and soil column studies. Variables were soil type, temperature, nitrapyrin concentration and method of application to the soil. Experimental designs included two soils, three temperatures and three levels of inhibitors in a complete factorial. Forage grasses were present in all treatments, and wastewater containing NH_4^+ was used.

Iskandar, I.K., S.T. Quarry, R.E. Bates and J. Ingersoll (1979) Documentation of soil characteristics and climatology during five years of wastewater application to CRREL test cells. CRREL Special Report 79-23 (ADA 074 712).

This report is a collection of information gathered during 5 years of a field study on slow infiltration land treatment. Emphasis is on presenting actual data as well as detailed descriptions of the methods used. Very little discussion is included.

Jacobson, S.N. and M. Alexander (1979) Preliminary investigations of the kinetics of nitrogen transformation and nitrosamine formation in land treatment of wastewater. CRREL Special Report 79-4 (ADA 086 169).

Denitrification of NO_3^- in wastewater is monitored in soils with pHs of 4.2, 5.5 and 6.8. The effects of C sources on the denitrification rates (glucose, methanol, succinate or secondary effluent) are monitored in a sandy loam and a silty loam soil.

Jenkins, T., H. Hare, A. Palazzo, R. Bates, C. Martel, I. Iskandar, D. Fisk, D. Gaskin, P. Shumacher, J. Bayer, S. Quarry, J. Ingersoll, L. Jones and J. Graham (1979) Prototype overland flow test data: June 1977 - May 1978. CRREL Special Report 79-35 (ADA 078 734).

This study presents data from a 1-year study on a prototype overland flow land treatment system. Water quantity and quality data are presented as well as plant yields and nutrient uptake. The soil chemical and physical parameters measured are also presented along with a table of initial site characteristics. The meteorological measurements obtained in support of this effort are included to complete the data base.

Jenkins, T.F., S.T. Quarry, I.K. Iskandar, A.P. Edwards and H.E. Hare (1979) Use of ^{15}N to study nitrogen transformations in land treatment. CRREL Special Report 79-31 (ADA 077 583).

This study compares different strategies of using ^{15}N as a tracer in describing the fate of wastewater N in land application. Four soil columns are packed with a sandy loam soil and covered with forage grass. The columns are treated with tapwater or wastewater according to four experimental strategies. The strategies vary the treatment given the soil prior to application of the ^{15}N label, the schedule and amounts of the applied ^{15}N label, and the type of water used for subsequent column leaching.

Theses

Cantor, R.R. (1979) Denitrification studies at Deer Creek State Park wastewater renovation site. M.S. Thesis, Ohio State University, Columbus.

This study employs the acetylene inhibition technique as a laboratory and in situ method of measuring denitrification. Laboratory studies include 1) checks on the accuracy of lab studies, and 2) tests to determine the effects of glucose, NO_3^- and moisture content on denitrification and the effect of headspace N_2O on N_2O evolution. In situ denitrification studies are performed on tilled alfalfa and reed canarygrass plots. The effect of soil organic levels on denitrification is determined for these plots. The relative effects that plant uptake and denitrification have on wastewater renovation is determined for each plot. The exudation of carbonaceous material by each crop is also assessed for its effect on denitrification.

Chopp, K.M. (1979) Microbial populations and activity in soil irrigated with municipal wastewater effluent. M.S. Thesis, University of Minnesota, St. Paul.

Nitrification in soil and the conditions that affect it are discussed. The following topics are covered: 1) the best procedure for extracting NH_4^+ oxidizing bacteria from soil, 2) the optimum method of enumerating NH_4^+ oxidizing bacteria, 3) the effects of treatment, season, crop and crop residue on soil microbe numbers and activity, with an emphasis on NH_4^+ oxidizing bacteria, 4) the relationships that exist between microbial numbers and activity, especially the relationship of nitrifying bacteria with soil and water N concentrations.

Moser, M.A. (1979) Methodology for assessing soil series suitability for land treatment of wastewater. M.S. Thesis, Cornell University, Ithaca, New York.

Methodology is developed to rate soil series suitability for slow rate, overland flow and rapid infiltration land treatment based on soil information available in soil surveys. Soil properties affecting wastewater transmission and pollutant attenuation are reviewed and summarized. Commonly available information on soil properties is characterized for importance to assessing soil suitability for land treatment processes.

Presentations

Clapp, C.E., G.C. Marten, D.R. Linden and W.E. Larson (1979) Nutrient uptake by crops irrigated with municipal wastewater effluent. Proceedings, 71st Annual Meeting, American Society of Agronomy, 5-10 August, Fort Collins, Colorado, p. 27.

Plant nutrient uptake by corn and forage grasses is compared when these crops are irrigated with secondary municipal wastewater or treated with inorganic fertilizer for a 4-year period. Total seasonal N uptake curves for crops irrigated with effluent, including corn, reed canarygrass and other selected forage grasses, are presented. N uptake with time within seasons by corn and forage grasses are graphically illustrated. Plant uptake of P, Ca, Mg and Na is also discussed (abstract only).

Dowdy, R.H., C.E. Clapp, W.E. Larson and D.R. Duncomb (1979) Runoff and soil water quality as influenced by five years of sludge applications on a terraced watershed. Proceedings, 71st Annual Meeting, American Society of Agronomy, 5-10 August, Fort Collins, Colorado, p. 28.

The effects of applying municipal sewage sludge on a terraced watershed over a 5-year period are examined. The heavy metal content (Zn, Cr, Cu, Pb, Ni and Cd) the runoff and soil water at depths of 60 and 150 cm is determined. The area cropped with corn receives liquid sludge by surface injection and the area cropped with reed canarygrass receives it by sprinkler irrigation (abstract only).

Iskandar, I.K. (1979) Selected design parameters of existing systems for land application of liquid waste: A computer file. Presented at the 2nd Annual Conference on Municipal Waste Management, September 17-21, Madison, Wisconsin.

This computer file and accompanying programs store and retrieve information on design parameters, performance characteristics and published information on existing land treatment systems. This file should assist design engineers during the planning of new land treatment systems.

Iskandar, I.K. and H.M. Selim (1979) Validation of a mathematical model for nitrogen transformations and transport in land treatment of wastewater. Proceedings, 71st Annual Meeting, American Society of Agronomy, 5-10 August, Fort Collins, Colorado, p. 30.

Soil lysimeters are used to investigate the effectiveness of N removal. These results are used as a data base for the validation of a simplified N model. The model predicts the transport and transformations of NH_4^+ and NO_3^- in a multilayered soil profile under transient water flow conditions. The model also includes water and N uptake by plants (abstract only).

Iskandar, I.K., C. McDade, L.V. Parker and A.P. Edwards (1979) Inorganic nitrogen and forage root distribution in soils irrigated with wastewater. Proceedings, 71st Annual Meeting, American Society of Agronomy, 5-10 August, Ft. Collins, Colorado, p. 30.

This field study determines the dynamics of NH_4^+ and NO_3^- in soils irrigated weekly with domestic wastewater. Soil cores, to 60-cm deep, are collected from two plots containing different soil types. The samples are collected in July and October for NH_4^+ and NO_3^- analyses. Root length, diameter and distribution with soil depth are determined in samples collected in July, October and December. The effect of soil depth and temperature (season) on NH_4^+, NO_3^- and root distribution is discussed (abstract only).

McKim, H.L. and G. Abele (1979) Performance of a slow infiltration land treatment system at Deer Creek Lake, Ohio. Proceedings, 71st Annual Meeting, American Society of Agronomy, 5-10 August, Fort Collins, Colorado, p. 33.

This study examines the effect of application of wastewater from a holding pond to three 1.2-ha test sites having reed canarygrass, alfalfa and oat-soybean rotation. The P and NO_3^- concentrations in the applied wastewater and percolate are examined. The dry yields and N removal by the plant species are also examined (abstract only).

Palazzo, A.J., H.L. McKim and J.M. Graham (1979) Seasonal accumulation of nitrogen, phosphorus and potassium by a forage grass irrigated with wastewater. Proceedings, 71st Annual Meeting, American Society of Agronomy, 5-10 August, Fort Collins, Colorado, p. 35.

The seasonal accumulation of N, P and K in a forage grass is studied to determine the peak nutrient uptake periods during a single growing season. An established sward of Pennlate orchardgrass is used in this experiment and is sprayed weekly with domestic primary wastewater. The grass is harvested three times per season. Treatments include periodic sampling (four times per harvest period) during the growing season (abstract only).

Peters, R.E., C.R. Lee, D.J. Bates and B.E. Reed (1979) Influence of storms on nutrient runoff from an overland flow land treatment system. Presented at the Hydrologic Transport Modeling Symposium, December, New Orleans, Louisiana. St. Joseph, Michigan: American Society of Agricultural Engineers.

This paper presents results from a study of rainfall-runoff relationships and nutrient content of storm water runoff from an overland flow system near Utica, Mississippi. The implications of such runoff relative to the discharge permit are discussed.

Reed, S.C. (1979) Health aspects of land treatment. Presented at the Technology Transfer Seminars, Land Treatment of Municipal Wastewater Effluents. U.S. Environmental Protection Agency and U.S. Army Corps of Engineers.

The health aspects of major concern are N, metals, organics and pathogens. Parasites, crop contamination, runoff, groundwater contamination and aerosols are discussed in relation to pathogens.

1978 ENTRIES

Publications in open literature

Aulenbach, D.B., R.R. Harris and R.C. Reach (1978) Purification of secondary effluent in a natural sand filter. Journal of the Water Pollution Control Federation, vol. 50, p. 86-94.

The Lake George Village Rapid Infiltration Sewage Treatment Plant has been discharging the settled trickling filter effluent onto natural delta sand beds and allowing the sand system to purify the effluent for 37 years. This study determines the quality of the effluent as it passes through the sand bed.

Bausum, H.T., B.E. Brockett, P.W. Schumacher, S.A. Schaub, H.L. McKim and R.E. Bates (1978) Microbiological aerosols from a field source during sprinkler irrigation with wastewater. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL, p. 273-280.

This paper presents measurements of the strength, dispersion, decay and particle size characteristics of bacterial aerosols generated by spray irrigation. This study provides simultaneous source strength and meteorological data adequate for predictive modeling of aerosol plume dispersion.

AD-A134 540 LAND TREATMENT RESEARCH AND DEVELOPMENT PROGRAM SYNTHESIS OF RESEARCH RESULTS(U) COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH I K ISKANDAR ET AL. 2/2

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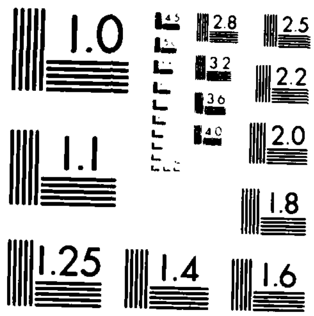

MICROCOPY RESOLUTION TEST CHART
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Belser, L.W. and E.L. Schmidt (1978) Diversity in the ammonia-oxidizing nitrifier population of a soil. Applied and Environmental Microbiology, vol. 36, no. 4, p. 584-588.

Multiple genera of NH_4^+-oxidizing chemoautotrophic nitrifiers in a soil are detected, isolated and studied by means of modified MPN techniques. The soil examined is a silt loam treated with NH_4^+ + NO_3^- or sewage effluent. Three different MPN media are compared for total count and species selectivity. The selectivity and counting efficiency of MPN media are also studied by observing the growth response of representative pure cultures isolated from the soil.

Belser, L.W. and E.L. Schmidt (1978) Serological diversity within a terrestrial ammonia-oxidizing population. Applied and Environmental Microbiology, vol. 36, no. 4, p. 589-593.

Fluorescent antibodies prepared against 16 NH_4^+-oxidizing nitrifying bacteria are examined as to cross reactivity. Isolates obtained from a single soil are stained to examine the effectiveness of the suite of fluorescent antibodies for study of a given NH_4^+-oxidizing population.

Clapp, C.E., A.J. Palazzo, W.E. Larson, G.C. Marten and D.R. Linden (1978) Uptake of nutrients by plants irrigated with municipal wastewater effluent. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL, p. 395-404.

This paper presents comparisons of plant nutrient uptake by corn and forage grasses irrigated with secondary municipal wastewater or treated with inorganic fertilizer. Characteristics of effluent from various locations are given for the plant nutrients as well as for quality indicators. The importance of the presence of varying amounts of N, P and K in effluent is discussed. This paper graphically presents total seasonal N uptake by corn, reed canarygrass and other selected forage grasses. N uptake with time within seasons by reed canarygrass during the normal first cutting period is also illustrated.

Cole, D.W. and P. Schiess (1978) Renovation of wastewater and response of forest ecosystems: the Pack Forest Study. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL, p. 323-331

Wastewater from a secondary treatment facility is applied to seedlings, an established 45-year-old Douglas fir forest, a barren plot and a grass plot. Ion fluxes within the soil and nutrient use by the vegetation are monitored monthly. The efficiencies of these systems in renovating applied wastewater are calculated.

Dowdy, R.H., W.E. Larson, J.M. Titrud and J.J. Latterell (1978) Growth and metal uptake of snap beans grown on sewage sludge amended soil: A four-year field study. Journal of Environmental Quality, vol. 7, p. 252-257.

The long-term trace metal accumulations in edible snap bean tissue are measured over a 4-year period to determine the effect of annual sludge applications on trace metal uptake, and the residual effect on metal uptake by subsequent crops of a single large sludge application.

Dowdy, R.H., G.C. Marten, C.E. Clapp and W.E. Larson (1978) Heavy metals content and mineral nutrition of corn and perennial grasses irrigated with municipal wastewater. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL, p. 175-181.

This paper reports the effect of 4 years of high effluent loading on the trace metal and mineral composition of corn and selected perennial forage grasses. This field study is conducted on a well-drained silt loam soil.

Gaseor, R.A. and L.J. Biever (1978) Use of wastewater in turf irrigation. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL, p. 165-173.

The use of wastewater for turf irrigation is investigated at the U.S. Air Force Academy's Eisenhower Golf Course, which has been irrigated with secondary wastewater since 1960. The soil is sampled at 7.6 cm increments to a depth of 45.7 cm and tested for elevated levels of K, Cu, Fe and Zn. The turf is checked for any changes in species composition and any other adverse effects.

Gupta, S.C., M.J. Shaffer and W.E. Larson (1978) Review of physical-chemical-biological models for a prediction of percolate water quality. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL p. 121-132.

Differences and similarities among various models are pointed out in terms of 1) type of flow, 2) initial and boundary conditions, 3) presence of plant roots, 4) type of salt flow mechanisms, 5) initial condition of salt flow models, and 6) various interactions with soil particles or with other salts in solution. The models can be classified as 1) analytical solutions, 2) numerical solutions, or 3) a combination of analytical and numerical solutions. An illustration of predicted water quality using the Bureau of Reclamation's combination-type model versus measured values from an experiment at Apple Valley, Minnesota, is included.

Ham, G.E. and R.H. Dowdy (1978) Soybean growth as influenced by soil amendments of sewage sludge and heavy metals: Field studies. Agronomy Journal, vol. 70, p. 326-330.

The objectives of this field research are to compare soybean plant growth and metal uptake of salt- and sludge-borne metals and to determine the partitioning of these heavy metals into the various plant parts.

Iskandar, I.K. (1978) The effect of wastewater reuse in cold regions on land treatment systems. Journal of Environmental Quality, vol. 7, p. 361-368.

Six outdoor test cells are used to investigate the effect of land treatment in a cold region on groundwater quality, soils and vegetation. The organic C, BOD, SS, fecal coliform and P levels are determined for the two soils used. The principal mechanisms for N removal are discussed. The movement of applied heavy metals is also monitored.

Iskandar, I.K. (1978) History of land treatment of wastewater. In Proceedings, Land Treatment of Waste Effluent Symposium, 26-28 April, College Park, Maryland. University of Maryland, p. 6-11.

This report summarizes the history of the use of the natural soil-plant system for purifying wastewater. The reasons for the success or failure of these old systems are documented.

Iskandar, I.K. (1978) Overview of existing land treatment systems. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL p. 193-200.

This paper reviews existing systems of land application. Particular emphasis is placed upon the historical philosophy of the use of the natural soil-plant system for purifying wastewater, reasons for the success or failure of the older systems, and experience gained from their design, construction and operation.

Iskandar, I.K. and H.M. Selim (1978) Evaluation of N models for prediction of NO_3-N in percolate water in land treatment. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL, p. 163-169.

This paper reviews existing N models for use with agricultural soils and determines their applicability in land treatment systems. Three processes are considered critical: 1) chemical and biological transformations of N species, 2) transport of water and soluble N species, 3) plant uptake of water and N species.

Jenkins, T.F. and C.J. Martel (1978) Pilot scale study of overland flow land treatment in cold climates. Journal of Progress in Water Technology, vol. 11, no. 4-5, p. 207-214.

This study is designed to investigate the treatment effectiveness of overland flow over 12 months of continuous use in a cold climate. Primary and secondary wastewaters are applied to an overland flow site. Applied wastewater as well as surface and subsurface flows are monitored for NO_3^-, NH_4^+, TKN, BOD, SS, pH, conductivity and total P.

Jenkins, T.F., C.J. Martel, D.A. Gaskin, D.J. Fisk and H.L. McKim (1978) Performance of overland flow land treatment in cold climates. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL, p. 61-70.

This study evaluates the performance of overland flow systems, especially during the winter months. Primary wastewater, secondary wastewater, and tapwater are applied to a prototype overland flow site. Composite water samples are analyzed for pH, BOD, TOC, SS, NO_3, TKN, NH_4, total P, major cations, fecal coliform, conductivity and Cl.

Latterell, J.J., R.H. Dowdy and W.E. Larson (1978) Correlation of extractable metals and metal uptake of snap beans grown on soil amended with sewage sludge. Journal of Environmental Quality, vol. 7, p. 435-440.

In this field study anaerobically digested sludge was applied to a sandy soil as single applications or as three annual sludge applications. In both cases sludge-borne trace metals removed by several chemical extractants are correlated to trace metal uptake by snap beans and soil organic matter.

Linden, D.R., W.E. Larson and R.E. Larson (1978) Agricultural practices associated with land treatment of domestic wastewater. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL, p. 313-322.

This paper outlines field management practices and how they are used to maximize the nutrient renovation of wastewater when it is recycled through a soil-crop system. Crop selection, soil drainage, methods of irrigation, close-seeded forages and row-crop management are discussed.

Marten, G.C., R.H. Dowdy, W.E. Larson and C.E. Clapp (1978) Feed quality of forages irrigated with municipal sewage effluent. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, Hanover, New Hampshire, vol. 2. CRREL, p. 183-190.

In this study municipal sewage effluent is applied to five persistent perennial forage grasses, corn grown for silage and grain during each of 3 years. The effect of the effluent on digestibility, and protein, Ca and P contents of each crop is discussed.

McKim, H.L. (Coordinator) (1978) State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire. CRREL.

This symposium summarizes the state of knowledge of the practical aspects of land treatment and identifies the suitable approaches for the design of such systems. The topics include: site selection considerations, national and international case studies, health effects, pretreatment considerations, uses of wastewaters in agricultural and forest systems, monitoring, modeling and design criteria. The Proceedings are published in two volumes. Volume I contains the invited papers presented and discussed at the conference; volume II contains shorter papers about on-going research.

McKim, H.L., J.R. Bouzoun, C.J. Martel, A.J. Palazzo and N.W. Urban (1978) Land treatment systems and the environment. Proceedings, American Society of Civil Engineers National Convention, 16-20 October, Chicago, Illinois. New York: ASCE, p. 201-225.

The design and performance of rapid infiltration, slow infiltration and overland flow technology is discussed. The efficiency of N and P removal, factors controlling treatment efficiency and management practices are discussed, as well as the degree of pretreatment necessary.

Merry, C.J. (1978) The use of remote sensing techniques and other information sources in regional site selection of potential land treatment areas. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL, p. 107-120.

This paper demonstrates the use of satellite and aircraft data products in the mapping of regional land use. In addition, available sources for hydrologic, geologic, soils and topographic information are discussed for use in evaluating sites for land treatment potential.

Nakano, Y. (1978) Evaluation of the moving boundary theory in Darcy's flow through porous media. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL, p. 143-151.

Using continuum physics, this paper shows that across both the water table and the wetting front local acceleration generally suffers a non-zero jump, and these two boundaries can be interpreted as acceleration waves. This interpretation is found to be consistent with reported regularity results obtained from a purely mathematical viewpoint.

Nakano, Y. (1978) Theory and numerical analysis of moving boundary problems in the hydrodynamics of porous media. Water Resources Research, vol. 14, no. 1, p. 125-134.

The exact mathematical descriptions of a boundary between unsaturated flow and saturated flow as well as a wetting front are obtained. A new concept for numerical analysis of flow in a partly unsaturated and a partly saturated porous medium is introduced.

Nakano, Y. and I.K. Iskandar (1978) Simulation of the movement of conservative chemicals in soil solution. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL, p. 371-380.

A numerical method is introduced to simulate the movement of conservative chemicals in soil by water. The method is essentially based upon a finite element approximation to the equation of continuity, and each element constitutes a complete mixing cell. The theoretical justification of the method is presented and the accuracy of the method is examined using experimental data obtained from a large lysimeter.

Palazzo, A.J. and H.L. McKim (1978) The growth and nutrient uptake of forage grasses when receiving various application rates of wastewater. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL p. 157-163.

The growth and nutrient removal of forage grasses that received 3 years of wastewater application are reported. The forages received wastewater at various application rates and schedules and grew in either a sandy loam or a silt loam soil. Plant and soil analyses are presented.

Peters, R.E. and C.R. Lee (1978) Field investigations of advanced treatment of municipal wastewater by overland flow. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL, p. 45-50.

Overland flow treatment of municipal facultative lagoon effluent is studied using research plots at Utica, Mississippi. The factors evaluated include the amount of wastewater applied, length of application period, slope of treatment area, crop management and reduction in BOD, SS, N, P, heavy metals and coliforms.

Selim, H.M. and I.K. Iskandar (1978) Nitrogen behavior in land treatment of wastewater: A simplified model. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 1. CRREL, p. 171-179.

A simplified mathematical model is developed that describes transformations and transport of N under transient soil water flow conditions. Kinetic reactions are assumed to govern the nitrification and denitrification processes. A macroscopic approach is used to incorporate plant uptake of water as well as NO_3^--N and NH_4^+-N from the soil solution. The sensitivity of the model to changes in rate of N transformation, N uptake by plants, and schedule and amounts of N application are also investigated. The model can be used as a tool to predict the fate of N in land treatment systems.

Sletten, R.S. (1978) Land application of wastewater in permafrost areas. In Proceedings, Third International Conference on Permafrost, 10-13 July, Edmonton, Alberta, Canada. National Research Council of Canada, p. 911-917.

An experimental study conducted near Fairbanks, Alaska, investigates both high-rate and low-rate systems for polishing aerated lagoon effluent to meet secondary infiltration treatment criteria. The two systems are compared for feasibility in cold climates based on N removal, winter storage needs, vegetative uptake and availability of required soil type.

Spaine, P.A. and C.J. Merry (1978) Computer procedure for comparison of land treatment and conventional treatment: preliminary designs, cost analysis and effluent quality predictions. In State of Knowledge in Land Treatment of Wastewater, Proceedings of an International Symposium, 20-25 August, Hanover, New Hampshire, vol. 2. CRREL, p. 335-340.

During 1972, a manual for the design of wastewater treatment facilities was developed by USAEWES. To complete the manual and to assist the design engineer, the computer model CAPDET was developed. The CAPDET program provides planning level design and cost evaluations for any wastewater treatment system. CAPDET can be used as a planning tool to estimate the costs and designs of land treatment systems and as a screening tool to compare a wide range of alternative designs.

Uiga, A. and R.S. Sletten (1978) An overview of land treatment from case studies of existing systems. Journal of the Water Pollution Control Federation, February, p. 277-285.

The operations of four full-scale land treatment systems are investigated for treatment performance, cost (capital, and operation and maintenance), and soil chemistry changes that may halt application or decrease performance. The four sites are Livermore, California (8 years of operation), Manteca, California (11 years), Quincy, Washington (20 years), Calumet, Michigan (88 years). Each system is described separately (history and current operations), then compared with the other three sites. CRREL research studies are used to explain observed differences. This paper summarizes the previously reported data and develops a comparative cost analysis for the sites.

Technical reports

Bilello, M.A. and R.E. Bates (1978) Climatic survey at CRREL in association with the land treatment project. CRREL Special Report 78-21 (ADA 062 518).

Six test cells at CRREL are used to study the effect of wastewater application on various types of soil and vegetation. This paper reports basic information about the climate proximate to these test cells and provides summarized results of the collected climatic data. Meteorological considerations for the operation of wastewater treatment systems are presented in reference to the CRREL test program.

Blake, B.J., B.E. Brockett and I.K. Iskandar (1978) Construction and performance of platinum probes for measurements of redox potential. CRREL Special Report 78-27 (ADA 062 426).

A simple method is described for constructing and testing platinum oxidation-reduction probes in the laboratory. The probes are "blacked" with platinum chloride to increase their lifetime. Methods of standardization and problems encountered are discussed.

Edwards, A.P. (1978) A guide to the use of ^{14}N and ^{15}N in environmental research. CRREL Special Report 78-18 (ADA 060 385).

This study uses natural or artificial stable isotopic labeled mineral N to determine the fate of N in wastewater. The possibilities and problems associated with the small amounts of N normally present after secondary waste treatment are assessed. The methods minimize analytical errors and are applicable to other types of environmental research involving isotope ratio analysis as a means of tracing N in the biosphere.

Iskandar, I.K. and Y. Nakano (1978) Soil lysimeters for validating models of wastewater renovation by land application. CRREL Special Report 78-12 (ADA 059 994).

This report describes the construction, operation and performance of large-scale lysimeters. These lysimeters continuously monitor soil moisture flow, soil temperature and redox potential with depth, and sample soil water and soil air with depth. The rate of soil water movement to the groundwater is continuously monitored by a rain gage and a recorder.

The automatic spray system simulates field conditions and is described in this report.

Iskandar, I.K., D. Robinson, W. Willcockson and E. Keefauver (1978) Computer file for existing land application of wastewater systems: A user's guide. CRREL Special Report 78-22 (ADA 062 658).

This computer program, written in BASIC, stores and retrieves information on existing wastewater land treatment systems. This program provides assistance to design engineers during the planning of new land treatment systems by making available the design criteria and performance characteristics of operating systems. The SEARCH program locates systems with specific design parameters, such as flow rate, waste type, application rate and mode, ground cover and length of operation. The printout from SEARCH includes a list of articles on similar systems in addition to the design parameters.

Jenkins, T.F. and S.T. Quarry (1978) Methodology for nitrogen isotope analysis at CRREL. CRREL Special Report 78-8 (ADA 054 939).

This report documents the chronology of events and the procedures employed in developing an N isotope analysis capability at CRREL. Both the instrumental and wet chemistry procedures are reported to enable others interested in the procedures to obtain useful data. The procedures described have resulted in the ability to measure the ^{15}N - ^{14}N ratio to a precision of 0.001 atom %, a value easily within the acceptable range for tracer experiments.

Jenkins, T.F., A.J. Palazzo, P.W. Schumacher, D.B. Keller, J.M. Graham, S.T. Quarry, H.E. Hare, J.J. Bayen and E.S. Foley (1978) Five-year performance of CRREL land treatment test cells. CRREL Special Report 78-26 (ADA 086 172).

The performance of the six land treatment test cells is summarized over a 5-year period from June 1973 through May 1978. The data presented include quality and volume of wastewater applied and percolate resulting from application of primary and secondary wastewater by spray irrigation. Mass loadings and removals are presented as well as crop production and nutrient uptake. Nutrient balance sheets are shown that demonstrate the percentage of N and P that is attributed to crop uptake and leachate over this period.

Nakano, Y. (1978) The mathematical description of a moving boundary problem in an elliptic-parabolic system of partial differential equations in the hydrodynamics of porous media. In Transactions of the 23rd Conference of Army Mathematicians, Hampton, Virginia. Research Triangle Park, North Carolina: Army Research Office, ARO Report 78-1, p. 11-20.

The simultaneous solution of two types of partial differential equations, a parabolic equation for unsaturated flow and an elliptic equation for saturated flow, is required for analysis of water movement in partly unsaturated and partly saturated porous media. A new and complete mathematical description of the boundary is obtained.

Nylund, J.R., R.E. Larson, C.E. Clapp, D.R. Linden and W.E. Larson (1978) Engineering aspects of an experimental system for land renovation of secondary effluent. CRREL Special Report 78-23 (ADA 062 923).

A research system was designed and installed at the Apple Valley Wastewater Treatment Plant in Rosemount, Minnesota, to develop agricultural management practices for removal of N from municipal wastewater effluent.

Palazzo, A.J. (1978) Effects of wastewater sewage sludge on the growth and chemical composition of turfgrasses. CRREL Special Report 78-20 (ADA 061 878).

This greenhouse study determines the effects of wastewater and sewage applications on the growth and chemical composition of two turfgrass mixtures. A mixture of tall fescue and annual ryegrass is compared to a mixture of Kentucky bluegrass, red fescue and annual ryegrass.

Theses

Jacobson, S.N. (1978) Preliminary investigations of the kinetics of nitrogen transformation and nitrosamine formation in land treatment of wastewater. M.S. Thesis, Cornell University, Ithaca, New York.

Laboratory experiments test the effect of soil pH, C source and temperature on denitrification rates in two soils, a silt loam and a sandy loam. The active denitrifiers in the test soils are characterized. Comparisons are made between the NO_3^--N per cell needed for four strains of denitrifiers and the NO_3^--N per cell consumed by the countable numbers of denitrifiers.

Presentations

Edwards, A.P. and I.K. Iskandar (1978) Assumption and errors in the use of ^{15}N as a tracer in N-balance studies. Poster session at 70th Annual Meeting, American Society of Agronomy, 3-8 December, Chicago, Illinois.

Nine major sources of error leading to low values for the percentage or equivalents of applied labeled-N recovered in balance-sheet studies are given (abstract only).

Jenkins, T.F., I.K. Iskandar and S.T. Quarry (1978) ^{15}N as a tracer for nitrogen transformation and transport in land treatment. Proceedings, 70th Annual Meeting, American Society of Agronomy, December 3-8, Chicago, Illinois, p. 27.

This study determines the best procedure for documentation of the transformation and transport of N under wastewater irrigation using an ^{15}N tracer. Four columns, packed with silty loam and covered with grass, are treated with 7.5 cm of water or wastewater weekly. Soil solution at d[illegible]pth and leachate are analyzed weekly for concentration and ^{15}N ratios of [illegible] and NH_4^+. Four strategies for applying the ^{15}N tracer are tested (abstract only).

Jenkins, T.F. and C.J. Martel (1978) Pilot scale study of overl[illegible] flow land treatment in cold climates. Presented at the International Conference on Developments in Land Treatment and Utilization, October 23-27, Melbourne, Australia.

For text see Journal of Progress in Water Technology, vol. 11, no. 4-5, p. 207-214.

Leggett, D.C. and I.K. Iskandar (1978) Computer model for nitrification in soils under nitrogen-limiting conditions. Proceedings, 70th Annual Meeting, American Society of Agronomy, 3-8 December, Chicago, Illinois, p. 29.

A Michaelis-Menten-Monod kinetic model is developed to predict nitrification in soils. Application of the model requires the assumption that N is the sole limiting nutrient. A further assumption is that pH dependence can be described in terms of active site dissociation and non-competitive inhibition by nitrous acid and NH_4^+. All rate and Michaelis constants are approximated by values from the literature. Some features of the model and examples of its prediction are compared with experimental data (abstract only).

Marten, G.C., C.E. Clapp and W.E. Larson (1978) Wastewater effluent influence on persistence, quality, and yield of perennial forages and maize. Proceedings, 70th Annual Meeting, American Society of Agronomy, 3-8 December, Chicago, Illinois, p. 23.

The effect of municipal wastewater application on eight perennial forages and maize is examined over a 4-year period. The effect of effluent quantity on persistence and digestibility of each species is determined.

The crude protein and silica contents of each species is examined (abstract only).

McKim, H.L. and I.K. Iskandar (1978) Land treatment of wastewater in the northern United States. Proceedings, 70th Annual Meeting, American Society of Agronomy, 3-8 December, Chicago, Illinois, p. 31.

This 4-year study determines if land treatment is a viable method for treating primary and secondary wastewater. Grass, legumes, forests or row crops are tested as possible vegetative covers. The effect of application rate, irrigation schedule and specific soil information on water quality is discussed (abstract only).

Peters, R.E. and C.R. Lee (1978) The potential of overland flow to treat runoff in the Kissimmee River Valley and Taylor Creek-Nubbin Slough Watersheds. In Presented at the Symposium on Environmental Quality Through Wetlands Utilization, February 28 - March 2, Tallahassee, Florida.

The use of overland flow in the Kissimmee Valley for renovation of dairy lagoon wastes through spray irrigation, and recycling of nutrients for crop production from nonpoint agricultural runoff are discussed.

Peters, R.E., C.R. Lee and F. Hall, Jr. (1978) Nutrient content of stormwater runoff from overland flow land treatment systems. Proceedings, 70th Annual Meeting, American Society of Agronomy, 3-8 December, Chicago, Illinois, p. 33.

Flow activated automatic water samplers are used to sample stormwater runoff from grassed field plots irrigated with domestic sewage lagoon effluent. Several storms of various intensities and durations are sampled and the runoff is analyzed for total N, NH_4, NO_3, total P and ortho-P (abstract only).

Draft translations

Abramov, B.A. and V.I. Korobov (1978) Use of outflow for tree and bush species irrigation. CRREL TL 690 (ADA 055 747).

This paper discusses the results of studies initiated in Volgogradskaya Oblast on the use of industrial wastewater for the irrigation of tree and bush species.

CRREL (1978) Neutralization of organic substances in wastewater by plants, 1975. CRREL TL 676 (ADA 053 435).

This report discusses the neutralization of 21 organic chemicals in treatment plants determined by analyses using a flame ionizing detector (author unknown).

CRREL (1978) Collection of articles on the utilization of animal waste for irrigation. CRREL TL 688 (ADA 055 779).

This collection of papers discusses animal wastewater uses in irrigation. Methods for prevention of contamination of water bodies, assessment of treatment of the outflow from animal husbandry complexes, uses for liquid manure, and effects of irrigation on crops are given in this report (author unknown).

CRREL (1978) Algolization of wastewater with subsequent use for irrigation, 1975. CRREL TL 689 (ADA 069 854).

The use of Biological Oxidation Contact Stabilization (BOCS) ponds to purify wastewater for use in irrigation is discussed in this report (author unknown).

CRREL (1978) Collection of articles on wastewater and its uses for irrigation in the Soviet Union. CRREL TL 692 (ADA 069 857).

This collection of articles covers a wide spectrum of subjects related to the use of wastewater in irrigation. Topics include: soil purification of wastewater, biological oxidation as a pretreatment and optimization of BOCS pond construction, a method for determining the usefulness of irrigation, permissible substance contents of feedcrops, effects on perennial grass yield, effectiveness of supplementation with fertilizers, and health effects on animals raised on irrigated crops.

Dodolina, V.T. (1978) Irrigation use of food industry wastewater, 1976. CRREL TL 675 (ADA 053 434).

This study is conducted by the All-Union Scientific Research Institute for the Agricultural Utilization of Waste Water (VNIISSV). It establishes that the wastewater of starch plants and sugar refineries can be used for irrigation of meadows, pastures and fodder, grain and industrial crops. This wastewater has a high fertilizing value and is chemically characterized in this report.

Dodolina, V.T. (1978) Wastewater classification by fertilizing value. CRREL TL 691 (ADA 055 748).

This report, prepared by VNIISSV, classifies wastewater by its fertilization values. Wastewater from cities, settlements, industrial enterprises and animal husbandry complexes are classified.

Kovaleva, N.A., L.F. Mikheeva and M.I. Demina (1978) Wastewater use for feed crop land, 1976. CRREL TL 673 (ADA 053 432).

This report discusses experiences of various Soviet farms using wastewater irrigation for feed crop land.

Saiapin, V.P. (1978) Nutrition value and fodder harmlessness of plant output grown with textile industry wastewater irrigation, 1976. CRREL TL 671 (ADA 035 225).

This paper discusses the effect of irrigation with wastewater from the textile industry upon fodder crops and animal feeding. The effects on the animals' health, the productivity and nutritive value of their milk and meat, and their capacity for reproduction are discussed.

Shcherbakov, A.S. et al. (1978) Method of wintertime sprinkler distribution of wastewater, 1978. CRREL TL 674 (ADA 053 433).

This paper presents a method for the distribution of wastewater through a sprinkler system in wintertime by reducing the outflow of thawed wastewater from the irrigated lot. This method ensures the even penetration of the thawed water into the soil along the entire irrigated sector.

1977 ENTRIES

Publications in open literature

Baillod, C.R., R.G. Waters, I.K. Iskandar and A. Uiga (1977) Preliminary evaluation of 88 years of rapid infiltration of raw municipal sewage at Calumet, Michigan. In Land as a Waste Management Alternative, Proceedings of the 1976 Cornell Agricultural Waste Management Conference (R.C. Loehr, Ed.). Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., p. 489-510.

This study investigates the long-term influence of land treatment on the soil-groundwater environment. This article is concerned with a rapid infiltration system that has served the Village of Calumet, Michigan, for the past 88 years and may be the oldest land treatment site currently in use in the U.S.

Clapp, C.E., D.R. Linden, W.E. Larson, G.C. Marten and J.R. Nylund (1977) Nitrogen removal from municipal wastewater effluent by a crop irrigation system. In Land as a Waste Management Alternative, Proceedings of the 1976 Cornell Agricultural Waste Management Conference (R.C. Loehr, Ed.). Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., p. 139-150.

The objective of this study is to develop agronomic practices for maximum N use by crops irrigated with municipal wastewater. The N in the soil-water-crop system is accounted for by measuring the characteristic components in the field experiment.

Dowdy, R.H. and G.E. Ham (1977) Soybean growth and elemental content as influenced by soil amendments of sewage sludge and heavy metals: Seedling studies. Agronomy Journal, vol. 69, p. 300-304.

Many research studies substitute soluble metal salts for sludge-borne metals in attempts to define heavy metal uptake by plants. Soybean uptake of sludge and salt-borne heavy metals is measured to assess this experimental approach and determine the effect of sewage sludge on the availability of soluble metals.

Gupta, S.C., R.H. Dowdy and W.E. Larson (1977) Hydraulic and thermal properties of a sandy soil as influenced by incorporation of sewage sludge. Soil Science Society of America Journal, vol. 41, p. 601-605.

The effects of sewage sludge additions on hydraulic and thermal properties of sandy soil are studied. The soil-water retention, hydraulic conductivity, soil-water diffusivity, soil temperature and heat capacity for the treated and untreated soils are compared.

Hunt, P.G., C.R. Lee and R.E. Peters (1977) Update: overland flow. Water Spectrum, vol. 9, no. 2, p. 23-29.

This paper presents a general discussion of the reseach needs for overland flow technology. Topics that are discussed include: P removal and the long-term effect of aluminum sulfate treatment, heavy metal removal, pathogen transmission, quality of runoff during rainfall and effect of plant composition.

Iskandar, I.K., R.S. Sletten, T.F. Jenkins and D.C. Leggett (1977) Wastewater treatment alternative needed. Water and Wastes Engineering, vol. 14, no. 11, p. 82-87.

Wastewater application rate, effect of preapplication treatment, soil type and seasonal effects are considered in this study by use of prototype test cells.

Larson, W.E. and G.E. Schuman (1977) Problems and need for high utilization rates of wastes. In Proceedings, Symposium on Soils and Management of Organic Wastes and Waste Waters, Madison, Wisconsin, chap. 23. Soil Science Society of America, p. 587-604.

This chapter describes situations where large amounts of organic wastes and wastewaters can be used successfully without environmental deterioration and discusses some of the requirements for site selection, necessary properties of the waste and management of the area.

Murrmann, R.P. and I.K. Iskandar (1977) Land treatment of wastewater: Case studies of existing disposal systems at Quincy, Washington, and Manteca, California. In Land as a Waste Management Alternative, Proceedings of the 1976 Cornell Agricultural Waste Management Conference (R.C. Loehr, Ed.). Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., p. 467-488.

This paper discusses the findings obtained for two slow infiltration sites located at Manteca, California, and Quincy, Washington.

Palazzo, A.J. (1977) Land application of wastewater: Forage growth and utilization of applied nitrogen, phosphorus and potassium. In Land as a Waste Management Alternative, Proceedings of the 1976 Cornell Agricultural Waste Management Conference (R.C. Loehr, Ed.). Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., p. 171-180.

This 2-year study characterizes the effectiveness of a forage mixture in renovating wastewater when the waste is applied to land at several rates. Nutritional changes through soil and plant analysis are determined to permit correction, where necessary, through proper management procedures.

Sletten, R.S. and A. Uiga (1977) Feasibility study of land treatment at a subarctic Alaskan location. In Land as a Waste Management Alternative, Proceedings of the 1976 Cornell Agricultural Waste Management Conference (R.C. Loehr, Ed.). Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., p. 533-547.

This paper discusses the feasibility of land application in artic and subartic Alaska so that EPA secondary effluent standards may be met. This investigation is conducted at Eielson Air Force Base during the summers of 1974 and 1975.

Uiga, A., I.K. Iskandar and H.L. McKim (1977) Water reuse at Livermore, California. In Land as a Waste Management Alternative, Proceedings of the 1976 Cornell Agricultural Waste Management Conference (R.C. Loehr, Ed.). Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., p. 511-531.

This study compares multiple reuse practices for treated wastewater effluent, and evaluates short-term (annual) and long-term (8 years) effects of the wastewater reuse options.

Technical reports

Bouzoun, J.R. (1977) Land treatment of wastewater at West Dover, Vermont. CRREL Special Report 77-33 (ADA 046 300).

A general description of a wastewater land treatment system located in a "cold" climatic region is given. Secondary wastewater is sprayed on a forested knoll. The system is operated during the winter when the ambient air temperature is as low as 10°F (-12.2°C). Spray nozzles have been developed that ensure rapid drainage of the spray laterals after each spray cycle and, therefore, prevent freezing.

Iskandar, I.K., R.P. Murrmann and D.C. Leggett (1977) Evaluation of existing systems for land treatment of wastewater at Manteca, California, and Quincy, Washington. CRREL Report 77-24 (ADA 045 357).

Wastewater treatment sites at Manteca, California, and Quincy, Washington, are evaluated for their performance and long-term impact. These sites have been operated as slow-infiltration systems for up to 20 years. Performance is evaluated in terms of water quality, while soil chemical parameters are measured to determine the effects of prolonged wastewater application at the sites.

Johnson, D.W. and D.W. Cole (1977) Anion mobility in soils: Relevance to nutrient transport from terrestrial to aquatic ecosystems. Ecological Research Series, EPA 600 3-77-068 (distributed by NTIS as no. PB-271 725).

This report reviews the current knowledge of soil anion adsorption reactions and their effects on leaching, and suggests a simple model, based on anion production and adsorption considerations, to predict and explain nutrient transport. The relationship of this approach to that based on cation production and adsorption is discussed.

Linden, D.R. (1977) Design, installation, and use of porous ceramic samplers for monitoring soil water quality. USDA Technical Bulletin 1562.

This report describes how to use porous ceramic samplers, how to construct a soil-water sampling system, how and where to install samplers, and how to obtain samples. It is intended as a guide for users of porous ceramic samplers who have little or no background knowledge of soil, hydrology or geology.

Palazzo, A.J. (1977) Reclamation of acidic dredge soils with sewage sludge and lime at the Chesapeake and Delaware Canal. CRREL Special Report 77-19 (ADA 041 636).

This field study assesses the effects of sewage sludge and lime on the revegetation and reclamation of acidic and infertile dredge soils.

Presentations

Clapp, C.E., D.B. White and M.H. Smithberg (1977) Yields and composition of turf grasses fertilized with sewage sludge. Proceedings, 69th Annual Meeting, American Society of Agronomy, 13-18 November, Los Angeles, California, p. 110.

Liquid and dried anaerobically digested sewage sludge is applied to field plots of Kentucky bluegrass and creeping bentgrass and cropped over two growing seasons. Four N application rates as liquid sludge and two rates as dried sludge are compared with an NH_4-NO_3 control. The dry matter yields, N, P, K and heavy metal contents of each species are compared between sludge treatments and season (abstract only).

Cole, D.W. (1977) Ecosystem research in the natural managed forest: application of wastewaters and dewatered sludges to forest ecosystems. Presented at IUFRO Division I Meeting, September, Ossiach, Austria.

This paper examines the problems that can arise from tending managed forests in light of information derived from studies of forest ecosystems in the Pacific Northwest of the U.S. Of particular concern is the use of a forest as a site for disposal of municiple wastewaters and sludges.

Dowdy, R.H., C.E. Clapp and W.E. Larson (1977) The effect of wastewater treatment on sludge-borne metal accumulation in corn leaf and grain tissue. Proceedings, 69th Annual Meeting, American Society of Agronomy, 13-18 November, Los Angeles, California, p. 24.

This 4-year study assesses the plant availability of tracer metals from sewage sludge. The sewage sludge is applied annually at three rates for the highest treatments of waste-activated, anaerobic and aerobic treated material. Leaf and grain Zn and Cd levels are compared. Tissue Cu, Pb, Cr and Ni levels are also determined (abstract only).

Leggett, D.C. and I.K. Iskandar (1977) Mathematical modeling of nitrification in land treatment of wastewater. Proceedings, 69th Annual Meeting, American Society of Agronomy, 13-18 November, Los Angeles, California, p. 30.

A mechanistic model of nitrification is presented that is based on Michaelis-Menten kinetics. It initially considers soil temperature, pH and concentration of added NH_4^+. The pH dependency is expressed in terms of empirical proton dissociation constants on the active site of the enzyme. The temperature dependance is based on literature data for the

Arrhenius law effect on both the maximum velocity and Michaelis constants. Estimates of population size and specific rates per microorganism are taken from the literature and used to test the model's general validity (abstract only).

Linden, D.R., C.E. Clapp, G.C. Marten and W.E. Larson (1977) Nutrient balance in corn and forage systems fertilized with municipal wastewater effluent. Proceedings, 69th Annual Meeting, American Society of Agronomy, 13-18 November, Los Angeles, California, p. 30.

The removal of N by the forage crops and retention of P and K in the soil rooting zone, and the subsequent levels of N, P and K in the leachate are discussed (abstract only).

McKim, H.L. (1977) Corps of Engineers land treatment program--An overview of four years' research accomplishments. Presented at the 8th Annual Symposium on Military Applications of Environmental Research and Engineering, 7-8 December, Edgewood, Maryland.

This paper addresses the objectives of the land treatment program: evaluating preapplication requirements, optimizing the renovation capacity of land treatment systems, monitoring groundwater quality, and constructing and validating a mathematical model to predict the quality of percolate water from treatment systems.

McKim, H.L. and I.K. Iskandar (1977) Corps of Engineers Land Treatment Program--An overview of four years' research accomplishments. Proceedings, 69th Annual Meeting, American Society of Agronomy, 13-18 November, Los Angeles, California, p. 31.

This paper addresses the objectives of the land treatment program: evaluating preapplication requirements, optimizing the renovation capacity of land treatment systems, monitoring groundwater quality, and constructing and validating a mathematical model to predict the quality of percolate water from treatment systems (abstract only).

Merry, C.J. and P.A. Spaine (1977) The land treatment module of the CAPDET program. Presented at the 8th Annual Symposium on Military Applications of Environmental Research and Engineering, 7-8 December, Edgewood, Maryland.

The computer model CAPDET is developed to complement the Process Design Manual for Land Treatment of Municipal Wastewater and to assist the field engineer. The CAPDET program provides planning level design and cost evaluations of any wastewater treatment system.

Palazzo, A.J. and H.L. McKim (1977) The chemical analysis of forage grasses receiving four years of wastewater applications. Proceedings, 69th Annual Meeting, American Society of Agronomy, 13-18 November, Los Angeles, California, p. 33.

The effect of 4 years of wastewater application on forage crops and their soils is examined. Six outdoor test cells containing sandy loam or silty loam are used. The plant and soil levels of N, P and K are examined. Supplemental greenhouse studies are performed to determine the effect of P and K fertilizers on plant yield (abstract only).

Peters, R.E. and C.R. Lee (1977) Field investigations on overland flow for advanced treatment of municipal wastewater. Proceedings, 69th Annual Meeting, American Society of Agronomy, 13-18 November Los Angeles, California, p. 34.

Land treatment of wastewater by overland flow is studied at a field installation with use of facultative lagoon effluent. Reductions of applied N and P, BOD, SS and fecal coliforms are determined. The effect of aluminum sulfate on P removal is also determined (abstract only).

Draft translations

Wierzbicki, J. (1977) Effect of geography on the extensive agricultural use of sewage, 1950. CRREL TL 642 (ADA 044 765).

This article considers the causes for the elimination of many irrigated fields in England. The importance of climate and soil is discussed.

Wierzbicki, J. (1977) Sewage farming at Ostrow Wielkopolski, 1949. CRREL TL 643 (ADA 044 746).

The sewage from Ostrow Wielkopolski has been purified since 1911 by agricultural use on irrigated fields. This report discusses the method of sewage purification used.

Wierzbicki, J. (1977) Disadvantages and advantages of sewage disposal in connection with agricultural utilization, 1949. CRREL TL 645 (ADA 044 767).

This report details some of the disadvantages and advantages of sewage disposal by agricultural utilization.

Wierzbicki, J. (1977) Supplying water table intake through agricultural use of urban sewage, 1957. CRREL TL 652 (ADA 046 304).

This work presents two basic advantages of agricultural use of urban sewage: the levels of the water table and surface waters in the vicinity of the waterworks intakes rose considerably, and largely fallow land was transformed into fruitful meadows, pastures and arable land.

Wierzbicki, J. (1977) Irrigated fields for urban sewage, 1952. CRREL TL 653 (ADA 046 305).

This report discusses the advantages of using a gravity flow system for transporting wastewater. Cost comparisons are given. Also the effects of irrigation on soils and crop yield are discussed.

1976 ENTRIES

Publications in open literature

Dowdy, R.H., R.E. Larson and E. Epstein (1976) Sewage sludge and effluent use in agriculture. In Land Application of Waste Materials. Ankeny, Iowa: Soil Conservation Society of America, p. 138-153.

This paper suggests guidelines for sludge application on crop land with minimal site monitoring or environmental degradation. This discussion covers potential hazzards, problems and possible solutions, and agricultural benefits. The parameters used for the guidelines include: site selection, N, metals and pathogens. The degree of monitoring required is also discussed.

Hunt, P.G. and C.R. Lee (1976) Land treatment of wastewater by overland flow for improved water quality. In Biological Control of Water Pollution (J. Tourbier and R.W. Pierson, Jr., Eds.). University of Pennsylvania Press, p. 151-160.

This paper presents an overview of land treatment of wastewater, a development of the overland flow system of treatment, and possible modifications of current concepts of overland flow treatment for improved water quality.

Iskandar, I.K. and D.C. Leggett (1976) Reclamation of wastewater by application on land. In Proceedings, Army Science Conference, June 22-25, Research Triangle Park, North Carolina. Army Research Office, p. 199-213.

This paper discusses the results of 2 years of operation of prototype slow-infiltration land treatment systems. Information derived from this work can provide guidance to Corps of Engineers Division and District sanitary engineers on design, operation and management of land treatment systems.

Larson, W.E. and J.R. Gilley (1976) Soil-climate-crop considerations for recycling organic wastes. In Transactions of the ASAE, American Society of Agricultural Engineers, vol. 19, no. 1, p. 85-89,96.

This paper discusses land application of sewage sludges and effluent by considering waste, soil, crop and climatic factors. Soil physical considerations include: hydraulic properties, surface seals, topography and saturation of the soil profile. Soil chemical and biological considerations include: chemical properties of soil, chemical adsorption by soil, effects of Na, K, P on soil exchange, N transformations and NO_3^- leaching, and toxic chemicals and metals in the applicant. The effects of temperature and crop cover are also discussed.

Uiga, A. (1976) Let's consider land treatment, not land disposal. Civil Engineering, American Society of Civil Engineers, vol. 46, no. 3, p. 60-62.

This paper considers land treatment of wastewater as an alternative to land disposal. Pretreatment and disinfection requirements, groundwater and surface water degradation, application rates, hydraulic considerations and economic considerations for land treatment are discussed.

Technical Reports

Iskandar, I.K., R.S. Sletten, D.C. Leggett and T.F. Jenkins (1976) Wastewater renovation by a prototype slow infiltration land treatment system. CRREL Report 76-19 (ADA 029 744).

The feasibility of a slow-infiltration land treatment system as an alternative to advanced waste treatment is studied using six outdoor test cells. Wastewater is applied to forage grasses by spray irrigation. The parameters studied are wastewater application rate, effect of pretreatment, and soil type and seasonal effects on the treatment system.

Lee, C.R., P.G. Hunt, R.E. Hoeppel, C.A. Carlson, T.B. Delaney, Jr. and R.N. Gordon, Sr. (1976) Highlights of research on overland flow for advanced treatment of wastewater. USAEWES Miscellaneous Report Y-76-6 (ADA 033 864).

Greenhouse grass-soil models are used to study overland flow treatment of municipal wastewater. The response of overland flow treatment of N, P and heavy metals to various operating conditions is determined.

Palazzo, A.J. (1976) The effects of wastewater application on the growth and chemical composition of forages. CRREL Report 76-39 (ADA 032 774).

The data presented in this report are related to the capabilities of vegetation in renovating wastewater. Also included are results that reflect on the management of a system for sustained plant performance and N removal.

Satterwhite, M.B., B.J. Condike and G.L. Stewart (1976) Treatment of primary sewage effluent by rapid infiltration. CRREL Report 76-49 (ADA 035 390).

The effectiveness of inundation of a rapid infiltration basin for 7 days followed by a 14 day recovery period is compared with secondary and tertiary treatment in this study.

Satterwhite, M.B., G.L. Stewart, B.J. Condike and E. Vlach (1976) Rapid infiltration of primary sewage effluent at Fort Devens, Massachusetts. CRREL Report 76-48 (ADA 035 730).

This study compares the water quality of unchlorinated primary effluent that has undergone rapid infiltration land treatment with the quality of wastewater that has undergone conventional tertiary treatment. This study is performed at Fort Devens, Massachusetts, and tests the effectiveness of rapid infiltration in a northern environment.

Presentations

Murrmann, R.P. and I.K. Iskandar (1976) Land treatment of wastewater: Case studies of existing disposal systems at Quincy, Washington, and Manteca, California. Presented at the 8th Annual Waste Management Conference, April 28-30, Rochester, New York.

Evaluation of these two systems is presented. Factors considered include site history, operational characteristics, current performance and impact on soil characteristics. At both sites a control field and two disposal fields are compared. Soil samples are analyzed for 30 chemical parameters. Soil solution samples collected at 80- and 160-cm depths, pretreatment water samples, and peripheral drainage water and groundwater samples are analyzed for pH, NH_4^+, NO_3^- and ortho-P.

Nakano, Y. and I.K. Iskandar (1976) Validation of mathematical models of land treatment of wastewater via slow infiltration. Proceedings, 68th Annual Meeting, American Society of Agronomy, 28 November - 3 December. Houston, Texas, p. 29.

The objective of this study is to experimentally validate a mathematical model simulating bio-physical processes in the land treatment of wastewater by slow infiltration. This presentation summarizes the results of investigations in soil water movement and dispersion of Cl in the soil, and a *preliminary study* on nitrification and Eh measurements. Experimental data obtained from lysimeters and supplemented by data from test plots are used to evaluate the accuracy of the model simulations (abstract only).

Palazzo, A.J. (1976) Land application of wastewater: Forage growth and utilization of applied N, P, and K. Presented at the 8th Annual Waste Management Conference, April 28-30, Rochester, New York.

The contribution of a forage mixture in the renovation of wastewater by a prototype slow infiltration system is studied. The forage is grown in three outdoor cells containing a sandy loam soil. The forages received domestic wastewater at three rates. Crop yields, soils and tissue analyses, plant removal efficiency and the total uptake of N and P are examined for their relation to the rate of wastewater applied.

Peters, R.E., P.G. Hunt and C.R. Lee (1976) Overland flow treatment of municipal facultative lagoon wastewater. Proceedings, 68th Annual Meeting, American Society of Agronomy, 28 November - 3 December, Houston, Texas, p. 30.

This field test evaluates the advanced treatment of municipal wastewater from a facultative lagoon by overland flow. Various slopes are tested. The extent of N, P, fecal coliform and fecal streptococci removal is determined. The effect of aluminum sulfate is also considered with respect to P removal.

Sletten, R.S. and A. Uiga (1976) Feasibility study of land treatment of wastewater at a subarctic Alaskan location. Presented at the 8th Annual Waste Management Conference, April 28-30, Rochester, New York.

The feasibility of land treatment to meet 1977 secondary treatment standards at Eielson Air Force Base near Fairbanks, Alaska, is discussed. Three test plots, 25 ft square, are sprayed with aerated lagoon effluent at three different rates. Weekly water quality samples are taken from the applied lagoon effluent, from catchment lysimeters at a depth of 6 in., and from well points 4.5 ft deep. Weather and soil data are also collected.

1975 ENTRIES

Publications in open literature

Dowdy, R.H. and W.E. Larson (1975) Metal uptake by barley seedlings grown on soils amended with sludge. Journal of Environmental Quality, vol. 4, p. 229-233.

The removal of metals by 30-day-old barley seedlings from two soils having pHs of 5.9 and 7.9 is studied following the application of sewage sludge. One set of soil-sludge samples was incubated for 1 year before cropping to study the effect of sludge degradation on metal availability.

Dowdy, R.H. and W.E. Larson (1975) The availability of sludge-borne metals to various vegetable crops. Journal of Environmental Quality, vol. 4, p. 278-282.

The uptake of metals by seven vegetable crops is studied after sewage sludge is applied to a coarse sandy soil. The metal contents of the vegetative, fruiting, root and tuber tissues are determined.

Iskandar, I.K. (1975) Urban waste as a source of heavy metals in land treatment. In Proceedings, International Conference on Heavy Metals in the Environment, 27-32 October, Toronto, Ontario, Canada. Ottawa: National Research Council of Canada, p. 417-432.

Heavy metal accumulation in soils and forages of a slow infiltration land treatment system during a 2-year period is discussed. Uptake of heavy metals by plants and soils is compared with the amounts applied, soil type and mode of wastewater application.

Larson, W.E., J.R. Gilley and D.R. Linden (1975) Consequences of waste disposal on land. Journal of Soil and Water Conservation, vol. 30, p. 68-71.

This paper discusses benefits of land disposal, compositition of the wastes, precautions to prevent N-overloading, proper handling of heavy metals and toxic chemicals, and movement of runoff waters.

Technical reports

Schaub, S.A., E.P. Meier, J.R. Kolmer and C.A. Sorber (1975) Land application of wastewater: The fate of viruses, bacteria and heavy metals at a rapid infiltration site. U.S. Army Biomedical Research and Development Laboratory Technical Report 7504 (ADA 011 263).

Rapid infiltration treatment of wastewater is studied to determine if significant quantities of specific microbiological and chemical wastewater constituents could percolate into groundwater. The site selected for study has been in operation for over 30 years. Primary sewage effluent is used for rapid infiltration-percolation.

U.S. Army Corps of Engineers (1975) Status report: Corps of Engineers wastewater management via land treatment research program, July 1974 - January 1975.

This report summarizes the the Corps of Engineers research program on land treatment and related topics. The program includes projects sponsored by both the Civil Works and Military Construction Directorates.

Theses

Archer, S.L. (1975) Characterization of the effluent from a metropolitan Seattle, Washington, treatment facility. M.S. Thesis, University of Washington, Seattle.

This thesis characterizes the organic constituents of the Seattle metropolitan wastewater treatment facility and uses this information to formulate a model.

Presentations

Clapp, C.E., W.E. Larson and M.M. DuBois (1975) Soil carbon and nitrogen changes after field application of sewage sludge. Proceedings, 67th Annual Meeting, American Society of Agronomy, 24-30 August, Knoxville, Tennessee, p. 131.

In this 4-year study, aerobic, anaerobic and waste activated sludges are applied at three rates with fertilized and unfertilized controls. Soil C and N levels and decomposition rates for the sludges are compared for each treatment (abstract only).

Hunt, P.G., C.R. Lee and R.E. Hoeppel (1975) Removal of nitrogen, phosphorus, and trace elements by overland flow treatments of wastewater. Proceedings, 67th Annual Meeting, American Society of Agronomy, 24-30 August, Knoxville, Tennessee, p. 27.

The removal of N, P and heavy metals (Zn, Cu, Mn, Pb, Ni and Cd) from secondary wastewater by overland flow is tested ovei a 3-year period using greenhouse models. Differing application rates are used. The effect of aluminum sulfate on P removal is also examined (abstract only).

Iskandar, I.K. and H.L. McKim (1975) The effect(s) of two years of wastewater application on soil characteristics. Proceedings, 67th Annual Meeting, American Society of Agronomy, 24-30 August, Knoxville, Tennessee, p. 27.

The effects of application of domestic wastewater enriched with heavy metals to sandy loam and silty loam soils in six test cells over 1 year are examined. The wastewater is enriched with Cu, Zn, Cd, Pb, Hg, Ni and Cr to simulate industrial wastewater. The heavy metal, P, organic C and free iron oxide contents and CEC are determined throughout the soil profile (abstract only).

Leggett, D.C., I.K. Iskandar, T.F. Jenkins and H.L. McKim (1975) Seasonal variation in water quality from a controlled slow infiltration treatment system. Proceedings, 67th Annual Meeting, American Society of Agronomy, 24-30 August, Knoxville, Tennessee, p. 28.

The ability of six outdoor test cells containing silty or sandy loam soils to renovate primary and secondary sewage effluents is discussed. Water quality parameters (nutrients, BOD, SS, heavy metals, coliform bacteria, pH, electrical conductivity and Cl) are monitored at 6-, 18- and 60-in. depths, daily to weekly. The importance of seasonal effects is also considered (abstract only).

Palazzo, A.J., R.S. Sletten and H.L. McKim (1975) The effects of wastewater disinfection on crop yields and tissue analysis of four forage grasses. Proceedings, 67th Annual Meeting, American Society of Agronomy, 24-30 August, Knoxville, Tennessee, p. 30.

This greenhouse study assesses the effects of wastewater disinfection on the yield and chemical composition of four forage grasses--orchardgrass, lincoln smooth bromegrass, reed canarygrass and climax timothy--grown in either sandy loam or silty loam soil. The N, P, K and heavy metal content of the grasses are compared (abstract only).

Uiga, A., M.A. Bilello and A.J. Palazzo (1975) The effects of wastewater management on the water budget of a land treatment system. Proceedings, 67th Annual Meeting, American Society of Agronomy, 24-30 August, Knoxville, Tennessee, p. 35.

A water budget is measured in situ for three test cells containing a sandy loam soil and planted forages. The amount of the daily application and the number of daily applications are varied to determine their effect on the water budget. On-site weather observations include continuous monitoring of precipitation, air and soil temperature, pan evaporation, and several other parameters. Water loss as evapotranspiration and change in soil water are calculated by measuring the amounts of water applied, rainfall, and the amounts of water percolated (abstract only).

Draft translations

Dodolina, V.T. (1975) Sugar plant wastewater suitable for irrigation, 1974. CRREL TL 501 (ADA 017 305).

This report presents information on the suitability of wastewater from a sugar plant for irrigation by studying soil, climate, hydrogeology and the composition of the wastewater. The effects on productivity and water quality are examined.

Dodolina, V.T., V.M. Novikov and A.A. Sollogub (1975) Sugar plant wastewater utilized for irrigation. CRREL TL 500 (ADA 017 306).

This paper discusses the use of sugar plant wastewater for irrigation of agricultural crops. Soil types, water quality of the filtered and unfiltered wastewater, and crop yields are discussed.

Dolivo-Dobrovol'skii, L.B., L.A. Kul'skii and V.F. Nakorchevskaia (1975) Chemistry and microbiology of water, 1971. CRREL TL 506 (ADA 027 708).

This report discusses the chemical and microbiological characteristics of natural and sewage waters, and the chemical and microbiological processes that take place during their purification. Particular attention is devoted to problems of chemical and biological purification, intensification of the methods of treating natural and sewage waters, new reagents and improvement of the treatment method.

L'vovich, A.I. (1975) Natural methods of purifying wastewaters and utilizing them in agriculture: Bibliography, parts 1 and 2, 1971. CRREL TL 505 (ADA 019 105).

This bibliography gives a list of published Soviet material on agricultural use of wastewater and natural methods of purifying it on agricultural and municipal irrigation fields. Material on self-purification of the soil and sanitary and hygenic evaluations of soil methods are presented.

Novikov, V.M. (Ed.) (1975) Natural methods of purifying sewage and its utilization in agricultural management, 1972. CRREL TL 488 (ADA 014 971).

This collection of articles discusses the theoretical and practical aspects of the agricultural use of sewage. The results of research on irrigation with sewage in various types of soil and the effects of sewage on the yield and quality of fodder crops are presented. The suitability of various kinds of sewage for irrigation is evaluated.

Novikov, V.M. (Ed.) (1975) Natural purification of sewage and the economic effectiveness of its utilization for irrigation: A collection of articles, 1975. CRREL TL 491 (ADA 055 636L).

This collection discusses effective use of sewage in agriculture. The report is divided into three sections: irrigation by wastewater, the sanitary-hygenic aspects of irrigated fields, and the economic effectiveness of this process.

Novikov, V.M. (Ed.) (1975) Use of sewage in agriculture, 1969. CRREL TL 499 (ADA 017 303).

This collection of articles, prepared by the Central Scientific Research Station for the Agricultural Utilization of Sewage (TsNISSV), covers existing achievements in the use of sewage for irrigation and the prospects of its development.

1974 ENTRIES

Publications in open literature

Hunt, P.G. and C.R. Lee (1974) Overland flow treatment of waste-water--a feasible approach. In Land Application of Wastewater, Proceedings of a Research Symposium, November 20-21. EPA 903 9-75-017 (NTIS PB-241 438), p. 71-85.

This paper presents an overview of system operation and theory of a limited number of overland flow systems and the research models that respond as predicted by theory for overland flow treatment.

Larson, W.E. (1974) Cities' waste may be soils' treasure. Crops and Soils, vol. 27, p. 9-11.

This paper discusses the use of sludge for fertilizer. The nutrient content of sludge, crop response to sludge, drawbacks and methods of application are discussed.

Larson, W.E., J.R. Gilley and D.R. Linden (1974) Consequences of waste disposal on land. In Land Use: Persuasion or Regulation? Proceedings, 29th Annual Meeting, Soil Conservation Society of America, Syracuse, New York, p. 127-132.

This work is primarily concerned with the potential for use of plant nutrients in wastes on land and some of the precautions needed for successful management.

Technical Reports

Carlson, C.A., P.G. Hunt and T.B. Delaney, Jr. (1974) Overland flow wastewater. USAEWES Miscellaneous Paper Y-74-3 (ADA 008 371).

This study determines the mechanisms involved in wastewater treatment by overland flow so that operational feasibility, design and performance criteria can be more accurately evaluated.

Hoeppel, R.E., P.G. Hunt and T.B. Delaney, Jr. (1974) Wastewater treatment on soils of low permeability. USAEWES Miscellaneous Paper Y-74-2 (ADA 008 370).

This study consists of two experiments. In the first, a clay-soil-reed-canarygrass system is used to study nitrification and denitrification in overland flow; it represents a small-scale simulation of a cannery wastewater disposal system. The second examines the effects of adding sewage sludge to the upper few centimeters of an overland flow system. The levels of N, P, K, Na, Ca, Mg, Cd, Cu, Mn, Pb, Zn and N are examined.

Jellinek, H.H.G. (1974) Soil organics. I. Complexation of heavy metals. II. Bound water. CRREL Special Report 212 (ADA 008 868).

Humic substances (e.g. fulvic and humic acids) are discussed. Complexation of these acids with heavy metal ions is emphasized and the fundamental background of multiple equilibria is presented. Ion exchange and titrate methods are considered with respect to their use for the determination of complex stability constants. The relative importance of organic and inorganic matter in soils is emphasized. The composition of wastewaters with a view to their purification by soil irrigation is indicated. The role of organic matter with respect to water retention is discussed.

Presentations

Hoeppel, R.E., P.G. Hunt and T.B. Delaney, Jr. (1974) Nitrogen removal from wastewater by overland flow mode of land treatment. Proceedings, 66th Annual Meeting, American Society of Agronomy, 10-15 November, Chicago, Illinois, p. 29.

The removal of NH_4^+ and NO_3^- from wastewater is tested in a simulated overland flow system. Greenhouse models containing a mixture of grasses are used. The effect of rate and period of application are examined. The yield of grass and the N gradient is observed down the length of the model (abstract only).

Larson, W.E. and J.R. Gilley (1974) Soil and crop considerations for recycling wastes. Presented at 1974 Winter Meeting of the American Society of Agricultural Engineers, December 10-13. St Joseph, Michigan: ASAE.

The hydraulic and chemical properties of soil are considered important in the design of waste recycling systems. Crop considerations include yield potential, amount of nutrients and elements taken up by a crop, and adaptability of the crop to conditions imposed by the waste, such as insects and diseases.

Lee, C.R., C.A. Carlson and P.G. Hunt (1974) Wastewater phosphorus and heavy metal retention by overland flow land treatment systems. Proceedings, 66th Annual Meeting, American Society of Agronomy, 10-15 November, Chicago, Illinois, p. 31.

The advanced treatment of municipal wastewater by overland flow is monitored with greenhouse models, each containing mixture of grasses. Wastewater is applied at varying hydraulic loading rates. The efficiency of removal of P, Cd, Ni, Cu, Pb and Mn is discussed (abstract only).

McKim, H.L., T.D. Buzzell, R.P. Murrmann, S.C. Reed and W. Rickard (1974) Use of land treatment in wastewater management. Proceedings, 66th Annual Meeting, American Society of Agronomy, 10-15 November, Chicago, Illinois, p. 34.

This long-term research program was initiated in 1973 to develop management practices for economical renovation of municipal wastewater by application to land. An experimental facility is used that includes six prototypes containing sandy loam or silty loam seeded with a grass mixture. Volumes and chemical quality of wastewater and percolate water are monitored. Physical and chemical analyses of soils as well as plant production and nutrient uptake are also evaluated (abstract only).

1973 ENTRIES

Publication in open literature

Hunt, P.G. (1973) Overland flow. Water Spectrum, vol. 5, no. 4, p. 16-21.

This paper answers some of the questions a municipality might have concerning overland flow treatment of wastewater. The concept of wetland agriculture in conjunction with overland flow treatment is also discussed.

Larson, W.E., C.E. Clapp and R.H. Dowdy (1973) Research efforts and needs in using sewage wastes on land. Proceedings, 28th Annual Meeting, Soil Conservation Society of America, 30 September to 3 October, Hot

Springs, Arkansas. Ankeny, Iowa: Soil Conservation Society of America, p. 142-147.

This paper discusses the N, P and trace metal contents of sewage sludge and effluent, field application of sewage wastes, the spread of diseases, soil and crop management, and surface water control systems.

Reed, S.C. and T.D. Buzzell (1973) A sewage treatment concept for permafrost areas. In Permafrost: The North American Contribution to the Second International Conference. Washington, D.C.: National Academy of Sciences, p. 706-712.

A sewage treatment concept developed by CRREL is described. It is compatible with the permafrost environment and offers a substantial savings in construction costs. The concept adopts the passive approach to construction in permafrost by protecting the supporting material from thermal stress.

Presentations

Reed, S.C. (1973) Land disposal of wastewaters: State-of-the-art. Presented at the National Symposium on Ultimate Disposal of Wastewaters and their Residuals, 26-27 April 1973, Durham, North Carolina.

This paper represents a brief summary of the comprehensive report issued and still available, CRREL Special Report 171, Wastewater Management by Disposal on the Land.

Reed, S.C. and T.D. Buzzell (1973) Land treatment of wastewaters for rural communities. Presented at the Rural Environmental Engineering Conference, 27-28 September, Warren, Vermont.

Land treatment of wastewater is presented as an acceptable, economical alternative. Concepts and constraints, design criteria, land requirements and cost comparisons, as well as research needs, are outlined.

1972 ENTRIES

Technical reports

Reed, S.C. (Coordinator) (1972) Wastewater management by disposal on the land. CRREL Special Report 171. (ADA 752 132).

This overview discusses disposal techniques and ecosystem responses. The nine essentially independent chapters present technical assessments of critical operational parameters and ecosystem components for land disposal concepts. Three basic techniques of land disposal are considered in this report: spray irrigation, overland runoff and rapid infiltration.

SUBJECT INDEX

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Remote sensing

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Water quality

A facsimile catalog card in Library of Congress MARC format is reproduced below.

Iskandar, I.K.
Land treatment research and development program: Synthesis of research results / by I.K. Iskandar and E.A. Wright. Hanover, N.H.: U.S. Army Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1983.
vii, 150 p., illus.; 28 cm. (CRREL Report 83-20.)
Prepared for Office of the Chief of Engineers by Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory.
Bibliography: p. 58.
1. *Land treatment of wastewater.* 2. *Sanitary engineering.* 3. Wastewater treatment. I. Wright, E.A. II. United States. Army. Corps of Engineers. III. Cold Regions Research and Engineering Laboratory, Hanover, N.H. IV. Series: CRREL Report 83-20.

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