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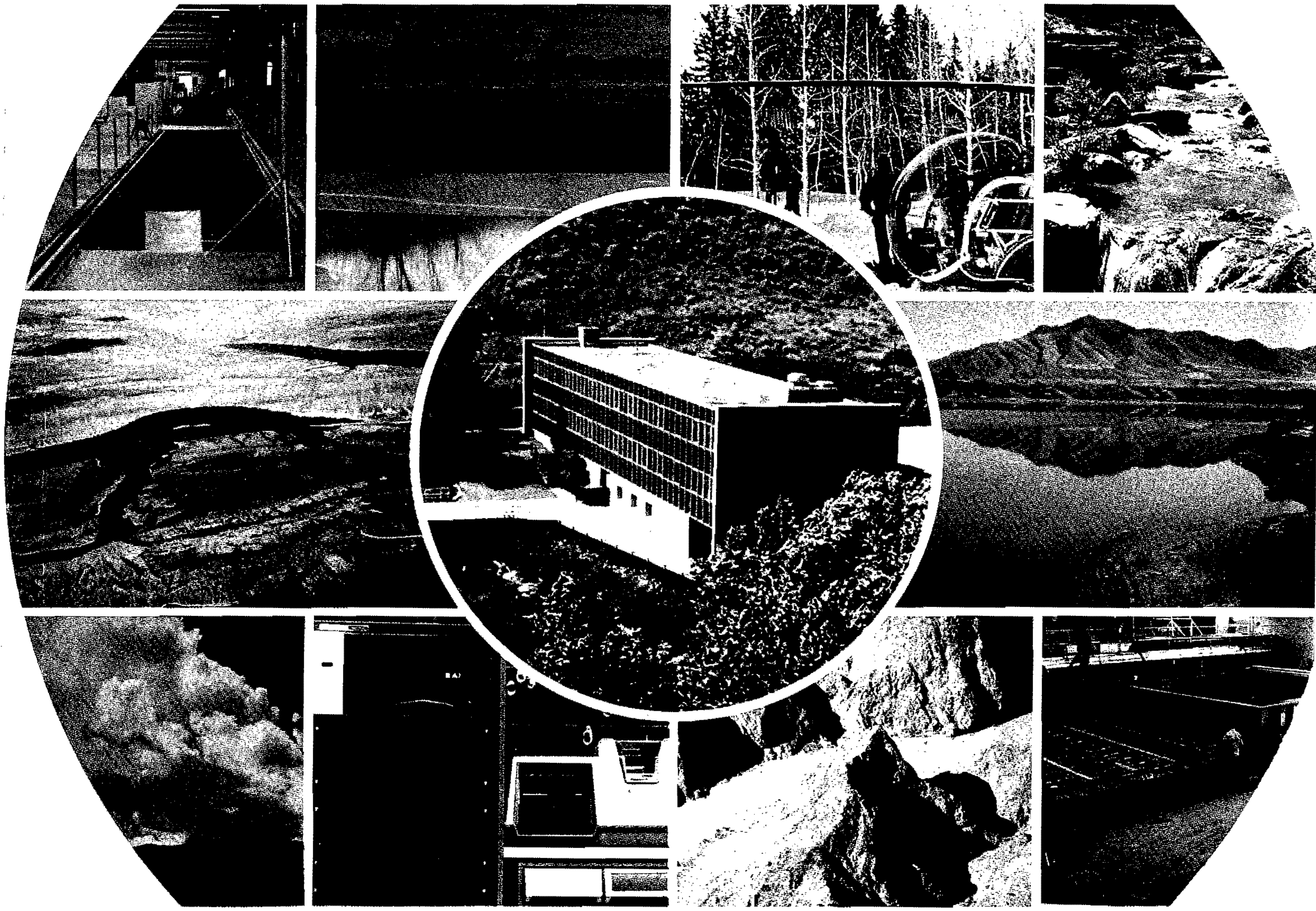

Utah Water Research Laboratory
College of Engineering
Utah State University
Logan, Utah 84322

December 1978

WATER QUALITY SERIES

UWRL/Q-78/02

EVALUATION AND COMPARISON OF OVERLAND FLOW AND SLOW RATE SYSTEMS TO UPGRADE SECONDARY WASTEWATER LAGOON EFFLUENT

by

Michael C. Kemp,
Daniel S. Filip,
and Dennis B. George

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ABSTRACT

To evaluate the effectiveness of overland flow treatment in upgrading secondary wastewater lagoon effluent, three 15 x 36 m plots on a 2.5 percent slope were constructed and sown for a high density vegetative cover using Reed Canary grass. Wastewater was applied to the upper end of each plot at rates of 7.5, 15, and 22.5 cm/wk. Results from the overland flow system investigation were compared with similar data obtained the preceding year from an existing slow rate land application system on an adjacent site. Secondary effluent from the same lagoon system was applied to the slow rate system study area. After evaluating influent and effluent water quality characteristics from both systems, site specific efficiencies were detailed.

Overland flow as a tertiary treatment process may not be suitable to satisfy future discharge standards because of the minimum biochemical oxygen demand and suspended solids effluent concentrations that are attainable. Overland flow could be used as a nitrification-denitrification process if land costs were sufficiently low. The slow rate system can be an excellent tertiary treatment method if the groundwater is protected and no subsurface water collection and discharge is required. If a discharge is required, organic carbon and nutrient concentrations might be unacceptable depending upon initial site soil conditions.

ACKNOWLEDGMENTS

The site preparation for the overland flow system and the analytical phases of research on both the overland flow and slow rate systems were funded by the Office of Water Research and Technology, U.S. Department of the Interior. OWRT contract numbers were: 14-34-0001-7093, 14-34-0001-7094, and 14-34-0001-8047. The authors sincerely appreciate this financial assistance.

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INTRODUCTION

Rationale

Many small communities in the United States use wastewater lagoon systems to treat domestic sewage. About 90 percent of the more than 5,000 existing lagoon systems are located in cities of 10,000 people or less. Low installation, operation, and maintenance costs are among the prime reasons for lagoon popularity in small communities.

The enactment of various state and federal water pollution control regulations has resulted in very stringent wastewater discharge standards. Most wastewater lagoon systems will not provide an adequate degree of treatment to meet future standards. Organic and suspended solids removal efficiencies are reduced by the presence of algae in lagoon discharge waters. Nutrients may also be released by decomposing algae, thereby accelerating the eutrophication of receiving waters.

Additional treatment may be needed to meet discharge standards, but the installation and operation costs for many tertiary treatment systems are prohibitive in small communities. A relatively inexpensive, easy to maintain system that requires little observation is necessary. Land application of secondary lagoon effluent is a potentially feasible method in many areas. Three alternative land application processes currently used include rapid infiltration (infiltration-percolation), slow rate system (spray irrigation), and overland flow. Slow rate systems and overland flow are receiving major interest for tertiary treatment because of their high nitrogen removal capabilities.

Treatment of wastewater by slow rate systems is an established practice in the United States. It is generally economical and has the additional benefit of aiding crop production when used for agricultural irrigation. Treatment efficiencies are very high, and surface discharge is eliminated or greatly reduced. Slow rate systems are most often used in areas having moderately permeable soils, and application rates are relatively low (1 to 20 cm/wk).

Overland flow can be used in areas having low permeability soils and at a higher wastewater application rate (7.5 to 30 cm/wk). It has been suggested that treatment efficiencies are sufficiently high and costs are low enough to make overland flow a practical alternative for tertiary treatment in small communities. Overland flow has been used for the treatment of cannery wastes and primary domestic sewage. Whereas slow rate systems have received considerable interest as a tertiary treatment process, little emphasis has been placed on the use of overland flow to upgrade secondary effluents, particularly those from wastewater lagoons.

Statement of Purpose

The purpose of this research was to study and compare the effectiveness of overland flow and slow rate systems in treating secondary lagoon effluent. All spray irrigation results were obtained in research conducted by Hicken (1978) one year prior to the operation and evaluation of the overland flow system.

Objectives

The objectives of this project were as follows:

1) Evaluate the effectiveness of overland flow and slow rate systems as upgrading processes for secondary lagoon effluent, with respect to application rates, system age, seasonal changes, and costs.

2) Determine the organic carbon, suspended solids, organic and inorganic nitrogen forms, and phosphorus removal efficiencies of overland flow and slow rate wastewater treatment systems treating secondary lagoon effluent.

3) Compare the performance of an overland flow and slow rate systems treating effluent from the same secondary wastewater lagoon system.

4) Develop tertiary treatment design criteria for future overland flow and slow rate system sites, including necessary site conditions and application rates.

REVIEW OF THE LITERATURE

Wastewater Lagoon Performance

General background

Over 5,000 wastewater lagoon systems are used to treat domestic and industrial wastes in the United States (Barsom, 1973). About 90 percent of these lagoon systems are located in communities of 10,000 people or less (Lewis and Smith, 1973). The primary reasons for the popularity of lagoon systems in small communities are the relative ease of design, construction, and operation and the moderate costs (McKinney, 1974).

Long hydraulic detention times allow lagoons to be stable treatment systems that are able to withstand wide diurnal fluctuations in wastewater flow and organic loading (Lewis, 1974). A nationwide survey on wastewater lagoon performance found that the average median effluent concentration of biochemical oxygen demand (BOD_5) ranged from 23 mg/l to 42 mg/l, and the average median suspended solids (SS) concentration ranged from 37 mg/l to 67 mg/l, depending upon whether the system was aerated, facultative, anaerobic, or tertiary (Barsom, 1973). Recent studies have further substantiated these data (Middlebrooks et al., 1978). The lagoon system in Logan, Utah, often yields BOD_5 concentrations of less than 10 mg/l and suspended solids concentrations of less than 30 mg/l (Reynolds et al., 1974). Even performances such as this, however, will not meet future 1980 water quality standardsfor the State of Utah and the federal government (Table 1).

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) promulgated guidelines for individual states to set wastewater discharge quality requirements. A summary of these requirements, comparing Environmental Protection Agency (EPA) and Utah limitations, is shown in Table 1. The EPA is currently allowing less restrictive suspended solids concentrations limitations for secondary wastewater lagoon effluents in many states. Utah requirements remain as stated for all secondary effluents, including those from lagoons (Smith, 1978). Many existing wastewater lagoon systems in Utah such as in Logan will be unable to meet 1980 and 1983 limitations.

Residual pollutants in wastewater lagoon effluents often include suspended solids, inorganic nutrients, organic compounds, heavy metals, pathogenic bacteria and viruses. Approximately 65 percent of the effluent BOD_5 is due to suspended solids, the majority of which are algae (Neel et al., 1961). Physical removal of the suspended solids should remove virtually all of the carbonaceous BOD_5 and much of the nitrogen BOD_5 (EPA, 1973).

Methods of upgrading secondary lagoon effluent

Several treatment methods are available for upgrading lagoon effluent. Process modifications such as deepening the pond, increasing the number of ponds, recirculating the effluent, improving feed and withdrawal methods, and supplemental aeration can be used to improve effluent quality (Lewis and Smith, 1973). To produce a high quality effluent, complex tertiary techniques are often necessary. Many of these techniques require significant capital investment, are costly to operate, and require highly skilled operators.

Centrifugation, microstraining, coagulation-flocculation, in-pond removal of particulates, total containment, biological harvesting, oxidation ditches, filtration, dissolved air flotation, controlled discharge, chlorination, and land disposal are some of the methods that can be used for tertiary treatment (Middlebrooks et al., 1974; Middlebrooks et al., 1978). Centrifugation, while effective, has a high operational cost that is incompatible with lagoon system economy. Microstraining may be practical and economical in larger communities. Some problems associated with microstrainers include incomplete solids removal and algal slime buildup. Coagulation-flocculation is effective in facilitating the removal of algae by sedimentation or dissolved air flotation (Friedman et al., 1977). The necessity of expert operating personnel and problems associated with

Table 1. Summary of waste discharge requirements (Horrocks, 1977).

Date for Compliance	Requirement	30 Day Limitation
June 30, 1977	State Interim Discharge Requirement	BOD_5 = 25 mg/l, 85% removal SS = 25 mg/l, 85% removal Fecal coliform = 200/100 ml
July 1, 1977	EPA Secondary Treatment	BOD_5 = 30 mg/l, 85% removal SS = 30 mg/l, 85% removal Fecal coliform = 200/100 ml
June 30, 1980	State Interim Discharge Requirement	BOD_5 = 10 mg/l, 90% removal SS = 10 mg/l, 90% removal Fecal coliform = 20/100 ml
July 1, 1983	EPA Best Practicable Treatment	Nitrification[a]
Dec. 31, 1983	State Class "C" Water Quality Standard	BOD_5 = 5 mg/l in receiving stream

[a] Possible exclusion for wastes with a temperature less than 20°C.

sludge disposal might make this method unacceptable for small communities (Middlebrooks et al., 1974).

Several problems are encountered with the in-pond removal of particulate matter. Settled material can decay and produce additional BOD_5 and the material may be subsequently re-suspended. Odors are produced by the anaerobic decomposition of the settled material, and the pond may eventually become filled with solids (Middlebrooks et al., 1978). Complete containment is impractical except where land is inexpensive and evaporation rates are high. Biological harvesting has been largely unsuccessful due to the excretion of fecal matter from the harvesting plant consumers producing a higher than acceptable BOD_5. Costs generally eliminate oxidation ditches as a means of polishing lagoon effluents.

Submerged rock filters may be effective in some cases. Major areas of concern for this process are sloughing, hydrogen sulfide production, and an increase in effluent ammonia nitrogen (O'Brien, 1974). Granular media filtration appears to be an effective and economically feasible alternative for lagoon upgrading when used with chemical addition. Operational expenses are high and filter runs are short, but treatment efficiencies are high. The use of intermittent sand filters for effluent polishing has been investigated on a pilot scale and field scale (Harris et al., 1977; Reynolds et al., 1974; Middlebrooks and Marshall, 1974). Results indicate that this method will meet 1980 standards economically. This has been further substantiated by preliminary results from a recently completed evaluation of full scale systems (Russell, 1978).

Land application of lagoon effluent is a viable approach for meeting current and future limitations. Spray irrigation, overland flow, and infiltration-percolation are among the several land application alternatives that are economically feasible for small communities (Thomas, 1974).

Land Application of Lagoon Effluent

Overview

Land application of wastewater has been practiced for many years throughout the United States and the world. Federal legislation now requires the consideration of land application as an alternative wastewater treatment method. Furthermore, the Environmental Protection Agency is directing that land treatment processes be preferentially considered (WPCF, 1977). A survey of several hundred municipal and industrial facilities using land application techniques concluded that land treatment is a workable alternative for advanced or tertiary wastewater renovation (Sullivan et al., 1973). Cost analyses have shown that depending upon local conditions, land treatment systems can be more economical than most other tertiary treatment alternatives (Young and Carlson, 1975; Pound et al., 1975). Increased interest is being expressed in the use of land application to upgrade secondary lagoon effluent (Thomas, 1974; Middlebrooks et al., 1974).

Rapid infiltration, slow rate, and overland flow systems are three land application methods currently used. A process diagram for each method is shown in Figure 1. The applicability of each method depends upon many factors such as wastewater characteristics, climate, geology, soils, vegetation, topography, and required application rates (Thomas, 1974; Thomas and Harlin, 1974; Pound et al., 1976; Powell, 1976; EPA, 1977). These general considerations are summarized in Table 2. Specific design considerations for each alternative are summarized in Table 3. Treatment efficiencies and objectives of the alternatives vary significantly (Table 4). As shown in Table 5, high quality effluent is expected from land application systems.

Rapid infiltration

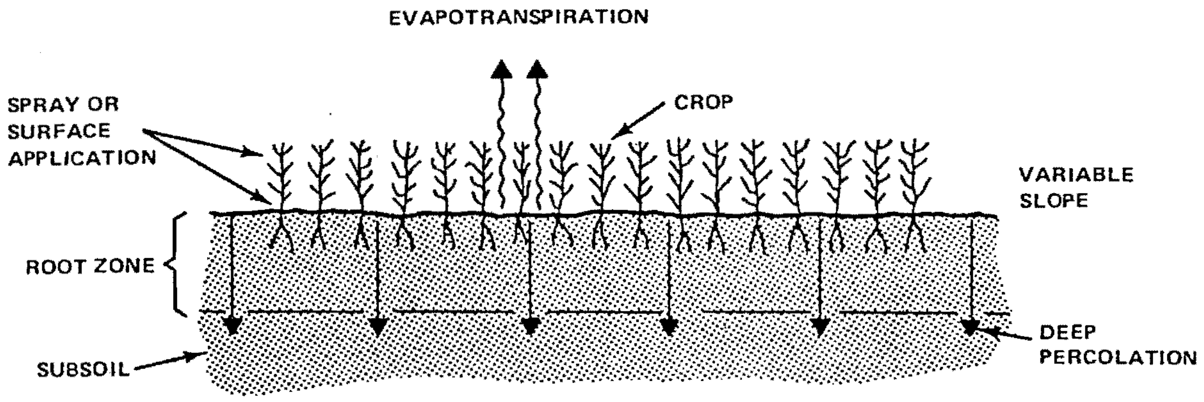
The use of rapid infiltration to dispose of wastewater has been widely accepted for decades (Thomas, 1974). Wastewater is applied at relatively high rates to a very permeable soil. Renovation is achieved by physical, chemical, and biological processes as the wastewater passes through the soil matrix. Since the wastewater is allowed to infiltrate at a high rate, less land is required for the same volume than with slow rate systems or overland flow.

Rapid infiltration systems may be designed for groundwater recharge, surface water recharge, or recovery of the renovated wastewater (Pound et al., 1976; EPA, 1975a). The potential for pollutant removal, however, is the lowest of the three major land application methods (Powell, 1976). At the Flushing Meadows, Arizona, rapid infiltration site, the average nitrogen effluent concentration was approximately 30 mg/l, and the orthophosphate phosphorus effluent was about 10 mg/l. The removal of BOD_5, suspended solids, and fecal coliforms was essentially complete (D'Itri et al., 1974). Even though the possibility of groundwater contamination is relatively high, rapid infiltration could be used in areas of low groundwater quality, for the purpose of limiting salt water intrusion, low water table areas, groundwater recharge, and properly drained areas.

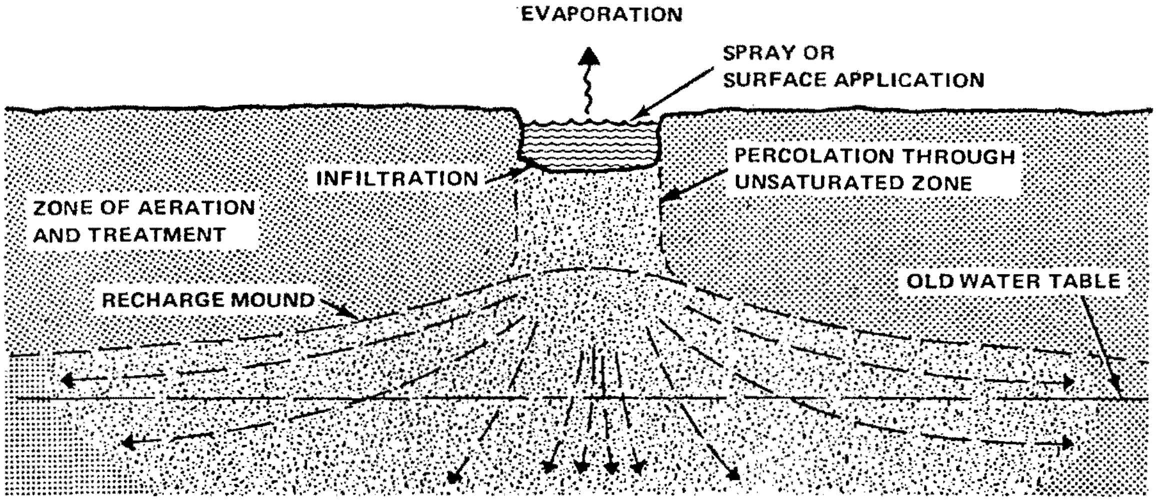
Slow rate

Slow rate application, usually in the form of spray irrigation, is the most widely used form of land application at the present time (Thomas, 1974; Pound et al., 1976). Wastewater is sprayed over a moderately permeable cropland with pollutant and nutrient removal resulting from soil mantle interaction and crop utilization (Middlebrooks et al., 1974; Pound et al., 1976; Powell, 1976; Bouwer, 1974). Periodic drying, resulting from intermittent operation and resting, is necessary for soil reaeration. This allows drying and decomposition of organic materials, nitrification of ammonium ions, and the prevention of crop flooding. In some cases, extended flooding can be used to facilitate ammonium adsorption (Bouwer, 1974).

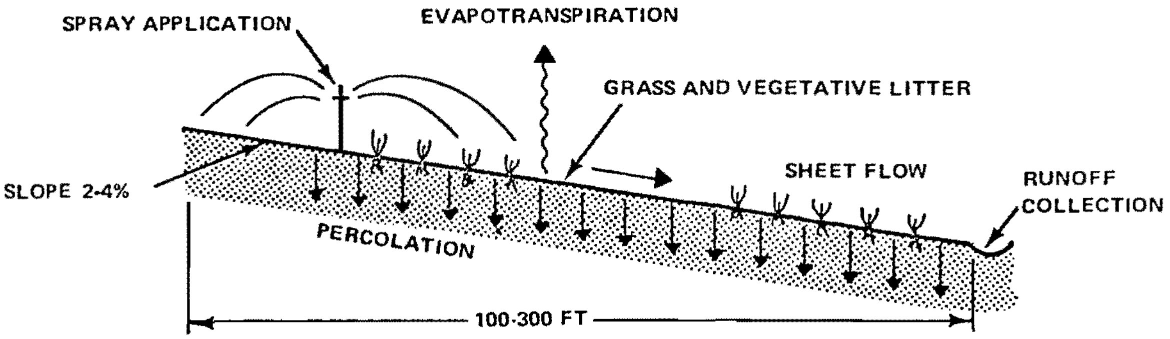
Advantages of slow rate systems include the maximization of crop production, high treatment efficiencies, the elimination of surface water discharges, potential economic return through crop production, and groundwater recharge. High treatment efficiencies and proper site selection greatly reduce the possibility of groundwater contamination (Powell, 1976; Pound et al., 1976). Disadvantages of slow rate systems include relatively low application rates,



(A) SLOW RATE



(B) RAPID INFILTRATION



(C) OVERLAND FLOW

Figure 1. Methods of land application (Pound et al., 1976).

possible increases in soil salt concentrations because of evapotranspiration, potential leaching of salts into the groundwater causing reuse limitations, and the formation of pathogenic aerosols (Bausum, Schaub, and Kenyon, 1978; Torpy et al., 1975; Webber and Leyshon, 1975).

Generally accepted wastewater application rates for slow rate systems range from 1 cm/wk to 10 cm/wk (Bouwer, 1974; Thomas, 1974; Pound et al., 1976; EPA, 1977). Although some seasonal variations occur, very high removal efficiencies for BOD_5 and suspended solids are common. Nutrient removal due to adsorption

Table 2. General land application design considerations (Pound et al., 1976).

Wastewater Characteristics	Climate	Geology	Soils	Plant Cover	Topography	Application
Flow volume	Precipitation	Groundwater	Type	Indigenous to region	Slope	Method
Constituent load	Evapotranspiration	Seasonal depth	Gradation	Nutrient removal capability	Aspect of slope	Type of equipment
	Temperature	Quality	Infiltration/ permeability	Toxicity levels	Erosion rate	Application rate
	Growing season	Points of discharge	Type and quantity of clay	Moisture and shade tolerance	Crop and farm management	Types of drainage
	Occurrence and depth of frozen ground	Bedrock	Cation exchange capacity	Marketability		
	Storage requirements	Type	Phosphorus adsorption potential			
	Wind velocity and direction	Depth	Heavy metal adsorption potential			
		Permeability	pH			
			Organic matter			

Table 3. Comparative design characteristics of land application alternatives (EPA, 1975a).

	Type of Alternative		
	Slow Rate	Overland Flow	Rapid Infiltration
Factor			
Liquid loading rate	1.3 to 10.2 cm/wk (0.5 to 4 in/wk)	5.1 to 14.0 cm/wk (2 to 5.5 in/w)	9.1 to 30.5 cm/wk (0.3 to 1.0 ft/wk)
Annual application	0.6 to 2.4 m/yr (2 to 8 ft/yr)	2.4 to 7.3 m/yr (8 to 24 ft/yr)	5.5 to 152 m/yr (18 to 500 ft/yr)
Land required for 1 MGD flow	25 to 263 hectares (62 to 650 acres) plus buffer zone	19 to 57 hectares (46 to 140 acres) plus buffer zone	1 to 25 hectares (2 to 62 acres) plus buffer zone
Application method	spray or surface	usually spray	usually surface
Soils	moderately permeable soils with good productivity when irrigated	slowly permeable soils such as clay or clay loams	rapidly permeable soils such as sands, loamy sands, and sandy loams
Probability of influencing groundwater quality	moderate	slight	certain
Needed depth of groundwater	about 1.5 m (5 ft)	undetermined	about 4.6 m (15 ft)

Table 4. Treatment comparison of land application alternatives (EPA, 1975b).

	Slow Rate	Type of Approach Overland Flow	Rapid Infiltration
Objective			
Recovery of renovated water[a]	0-70%	50-80%	Up to 97%
Treatment beyond secondary			
1. BOD_5 and suspended solids removal	98+%	92+%	85-99%
2. Nitrogen removal	85+%[b]	79-90%	0-50%
3. Phosphorus removal	80-99%	40-80%	60-95%
Grow crops for sale	excellent	fair	poor
Direct recycle to land	complete	partial	complete
Recharge groundwater	0-70%	0-10%	Up to 97%

[a] Percentage of applied water recovered depends upon recovery technique and climate.

[b] Depends upon crop uptake.

Table 5. Expected quality of treated water from land application processes, mg/l (EPA, 1977).

Constituent	Slow Rate[a]		Rapid Infiltration[b]		Overland Flow[c]	
	Ave	Max	Ave	Max	Ave	Max
BOD_5	<2	<5	2	<5	10	<15
Suspended Solids	<1	<5	2	<5	10	<20
Ammonia Nitrogen	<0.5	<2	0.5	<2	0.8	<2
Total Nitrogen	3	<8	10	<20	3	<5
Total Phosphorus	<0.1	<0.3	1	<5	4	<6

[a] Percolation of primary or secondary effluent through 5 ft (1.5 m) of soil.

[b] Percolation of primary or secondary effluent through 15 ft (4.5 m) of soil.

[c] Runoff of cominuted municipal wastewater over about 150 ft (45 m) of slope.

and crop utilization is also very high. At the Muskegon County slow rate system, lagoon effluent BOD_5 concentrations have been reduced from 20 mg/l to less than 3 mg/l. Suspended solids and phosphate are almost completely removed. Ammonia removal is about 83 percent, but an increase in nitrate is attributed to nitrification and the leaching of soil nitrates. Complete removal of coliforms and pathogenic organisms has been observed (Demirjian, 1975). At a slow rate site near Lake Tahoe, using activated sludge effluent, as much as 76 percent of the phosphate and 54 percent of the total nitrogen have been removed, with discharge concentrations of 4 mg/l and 12 mg/l respectively. The dominant nitrogen species changed from ammonia in the secondary effluent to nitrate in the discharge (Foster et al., 1965). Studies at a sewage farm in the Netherlands, using raw domestic sewage at an application rate of 20 cm/wk, showed a decrease in BOD_5 concentration from 381 mg/l to 9 mg/l and a total phosphorus reduction of 33 mg/l to less than 2 mg/l. Total nitrogen was reduced from 21 mg/l to 16 mg/l, with a high degree of nitrification (Beek et al., 1977).

Overland flow

The overland flow process provides physical, chemical, and biological treatment of wastewater as it passes over a soil surface and through a grass cover. Physical filtration of the suspended particles occurs as the water passes through the vegetation. Microbial activity significantly reduces BOD_5 concentrations, and along with soil interaction and plant assimilation, greatly reduces dissolved nutrients (Thomas, 1974; Powell, 1976; Carlson et al., 1974). Overland flow is used in areas having low soil permeability and a topography that can be shaped to produce a uniform flow distribution on the ground surface. More detailed explanations of constituent removal mechanisms are included in the discussion section.

Generally accepted design specifications for overland flow systems include a wastewater application rate of 7.5 cm/wk (3 in/wk) to 30 cm/wk (12 in/wk), plot lengths of 30 m (100 ft) to 9 m (300 ft), and slopes of 2 to 8 percent (Thomas, 1974; Thomas et al., 1974; Powell, 1976; Carlson et al., 1974).

Intermittent application periods of 6 to 10 hours per day, 4 to 6 days per week are common. As with slow rate systems, intermittent operation is necessary for soil drying and re-aeration. Reed Canary and Tall (Alta) Fescue are grasses that are considered very suitable for vegetative cover. They grow well under flooded conditions, and the nutrient uptake rates are relatively high (SCS, 1965; SCS, 1973; Law et al., 1970; Gilde et al., 1971).

Some disadvantages associated with overland flow include a sensitivity to freezing temperatures, seasonal variations in nitrogen removal, and limited phosphorus removal (Thomas et al., 1974; Powell, 1976). Depending upon the intended effluent use, surface discharge may be a disadvantage. Groundwater recharge is limited.

Although not well developed in the United States, overland flow has been used for many years in other countries to treat primary domestic sewage. The Werribee sewage farm near Melbourne, Australia, has used the overland flow process for over 45 years. Removal efficiencies of 96 percent for BOD_5, 95 percent for suspended solids, 60 percent for total nitrogen, and 35 percent for total phosphorus have been observed at Werribee, with average influent concentrations of 578 mg/l BOD_5, 1788 mg/l total solids, 68 mg/l total nitrogen, and 34 mg/l total phosphorus (Seabrook, 1975).

Cannery wastes from food industries in the United States have been successfully treated using overland flow. Approximately 20 years ago, at a commercial soup producing plant in Ohio, wastewater discharged across a gently sloping field for a few hundred meters was observed to have a BOD_5 concentration reduction of more than 90 percent (Gilde et al., 1971). Using this information, an overland flow treatment system was developed for a cannery in Paris, Texas. Plot lengths of 67 m (220 ft) to 98 m (322 ft) and slopes of 2 to 6 percent resulted in average BOD and suspended solids removals of 99 and 98 percent, respectively, with effluent concentrations of 9 mg/l BOD_5 and 16 mg/l suspended solids (Law et al., 1970; Gilde et al., 1971).

Recent research in the United States has emphasized the treatment of primary domestic sewage. An overland flow system at Ada, Oklahoma, achieved BOD_5 and suspended solids removals exceeding 95 percent, with effluent concentrations of these constituents sometimes less than 10 mg/l. Phosphorus removal was about 50 percent, and nitrogen removal achieved a high of 90 percent during the summer (Thomas et al., 1974). Application rates of 7.5 cm/wk, 8.75 cm/wk, and 10 cm/wk (3 in/wk, 3.5 in/wk, and 4 in/wk) were used on plots 40 m (131 ft) long and sloped at 2 to 4 percent to obtain these results. In Vicksburg, Mississippi, a pilot scale study was conducted to determine the mechanisms involved in wastewater treatment by overland flow (Carlson et al., 1974). Removal efficiencies of 100 percent for ammonium, 95 percent for nitrate, 91 percent for organic nitrogen, and 75 percent for phosphorus were noted. Although recent interest has been focused on the development of overland flow as a tertiary process, little research has been conducted to prove its feasibility.

Environmental hazards of land application

The transmission of pathogenic bacteria and viruses, groundwater contamination, crop quality, and the propagation of insects are four major areas that influence the environmental and public health aspects of land application. Domestic sewage contains large numbers of enteric viruses and other organisms. Concentrations as high as 464,500 virus particles per liter have been detected in raw sewage (Gerba et al., 1975). Secondary sewage treatment removes a large portion of these organisms, but even chlorination does not provide complete disinfection (Sorber and Guter, 1971). A significant reduction of pathogenic organisms through land application has been noted by several researchers (Laverty et al., 1961; Amramy, 1964; Foster et al., 1965). Many of these organisms may not be inactivated for several months and may be eluted into the groundwater (Dunlop, 1968; Sepp, 1971; Gerba et al., 1975).

A major problem in many land application systems is the formation of pathogenic aerosols by sprinkler devices. Coliforms have been found as far as 350 m downwind from wastewater spray systems, and salmonella have been found as far as 60 m downwind (Katzenelson and Teltch, 1976). Although present evidence is not entirely conclusive, these aerosols may cause a significant health risk (Hickey and Reist, 1975a, 1975b). Use of an appropriately designed spray nozzle can reduce or eliminate aerosol formation (Thomas et al., 1974).

Nitrate nitrogen and total dissolved solids contamination can be major public health concerns, especially in areas where a groundwater aquifer is used for the potable water supply (Pound et al., 1976). Percolation and leaching through the soil column often results in undesirably high concentrations of these substances (Sorber and Guter, 1971).

Trace organics such as pesticides and heavy metals such as chromium, copper, cadmium, and zinc must also be considered. Usually, these materials are removed in the soil mantle by ion exchange and chemical precipitation. The concentrations of these materials are often below established limits even before being applied (Pound et al., 1976). The effects of heavy metal accumulations in the soil must be considered with respect to crop toxicity. Accumulations resulting from wastewater irrigation have not been found to be a severe problem (Pound et al., 1976; Johnson et al., 1974; Brown et al., 1978).

Wastewater ponding and increased wetness of the disposal area enhances the propagation of mosquitoes and flies which may create health hazards and nuisance conditions (Laverty et al., 1961; Kardos et al., 1974; Hicken, 1978). Periodic drying, however, reduces insect growth.

RESEARCH PROCEDURE

Site Description

The overland flow site consisted of three adjacent plots, each 15 m wide and 36 m long, with a slope of approximately 2.5 percent. A diagram of the site is shown in Figure 2. The plots were located about 2 km north of the Logan, Utah, wastewater lagoon system. Secondary effluent was pumped through 5.1 cm (2 inch) PVC pipe from the lagoons to a small holding pond located about 150 m southeast of the plots. A network of 6.4, 5.1, 3.2, 2.5, and 1.9 cm (2.5, 2, 1.25, 1, and 0.75 inch) PVC pipes was used to transport effluent from the holding pond to the treatment sites.

Wastewater was applied to the overland flow site using four evenly distributed fixed sprinklers on each plot (Figure 3). Fan spray nozzles produced by Bete Fog Nozzle, Inc.[1] and designed to reduce aerosol formation were mounted about 2 m above ground level. An impermeable barrier, constructed from sheet aluminum, was placed at the lower end of each plot to channel runoff into a 15.2 cm (6 inch) drain pipe (Figure 4). The drain pipe emptied into an existing drainage ditch located about 6 m from the plot ends.

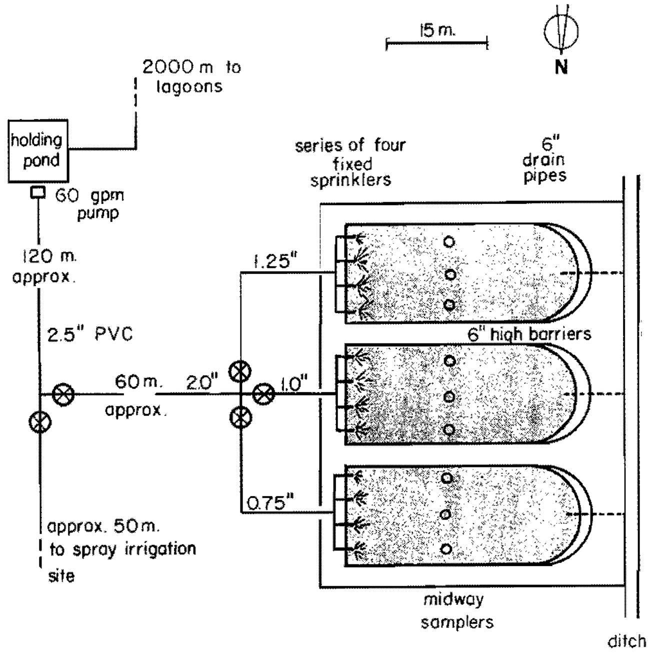


Figure 2. Overland flow site diagram.

Figure 3. Wastewater application sprinklers for the overland flow system.

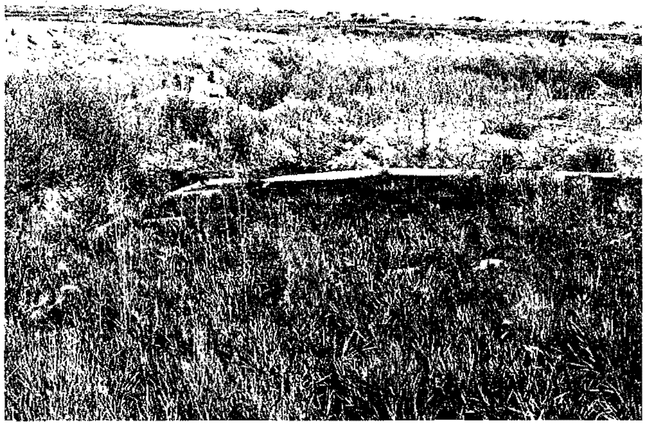


Figure 4. Runoff collection barrier for the overland flow system.

Each plot was seeded for a high density grass cover using a mixture of Reed Canary and Alta Fescue grasses. Growing conditions and the encroachment of local grasses and other plants resulted in a final cover consisting of 90 percent Reed Canary, 5 percent Alta Fescue, 3 percent Foxtail Barley, 1 percent alfalfa, and 1 percent miscellaneous plants. The grass cover was established before wastewater applications were begun (May 1976 to June 1977). Nonuniform flow paths, due to slight grading discrepancies, produced grass coverage on 90 to 98 percent of the total plot areas. A photograph of the entire site is shown in Figure 5.

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[1] Bete Fog Nozzle Inc., P.O. Box 311, Greenfield, Mass. 01301, Model Numbers FF250145, FF375145, and FF500145.

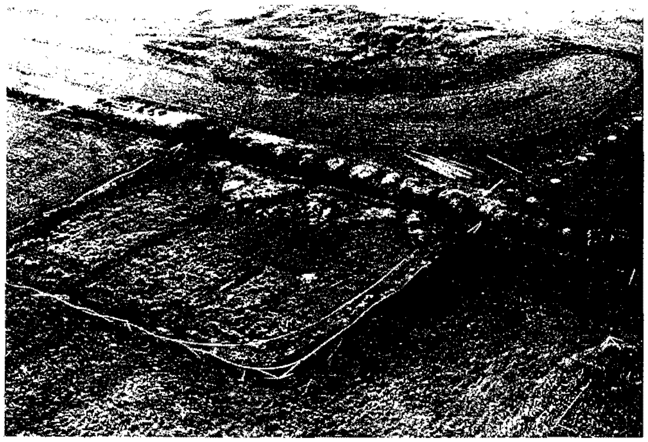

Figure 5. Overland flow site, overhead view.

Application and Sampling

Secondary effluent was pumped overnight from the Logan Municipal Wastewater Lagoon System, Logan, Utah, to the holding pond and applied to the treatment plots the following day. Effluent application rates of 7.5 cm/wk, 15 cm/wk, and 22.5 cm/wk were utilized. Wastewater was applied Monday through Thursday of each week from June 20, 1977, until September 31, 1977. The application period was 6 hours per day. Three days were allocated to drying and soil reaeration.

Samples were taken each week during the Thursday application period. After applying wastewater for approximately one hour, a grab sample was taken at a sprinkler orifice to examine influent conditions. Samples were then collected at each of the drain pipe outlets. Following the collection of effluent samples, runoff samples were obtained mid-way through each plot (Figure 2). A diagram of the mid-way sampling devices is shown in Figure 6. Three of these devices were evenly distributed in each plot. For each plot, water samples obtained from these devices were combined and used for laboratory analysis.

Samples were taken periodically in the region where the sprinkler discharge would have contacted the ground to estimate the air stripping of ammonia. Water samples were collected at the influent nozzle and at the soil surface. An adequate volume of sample required to conduct the ammonia analyses was collected at the soil surface within five minutes. There was no contact with the soil and water sample. Samples were collected on seven different dates during the wastewater application season (June 1977 through September 1977). Inflow and outflow rates under maximum runoff conditions were measured volumetrically to estimate evaporation and infiltration losses.

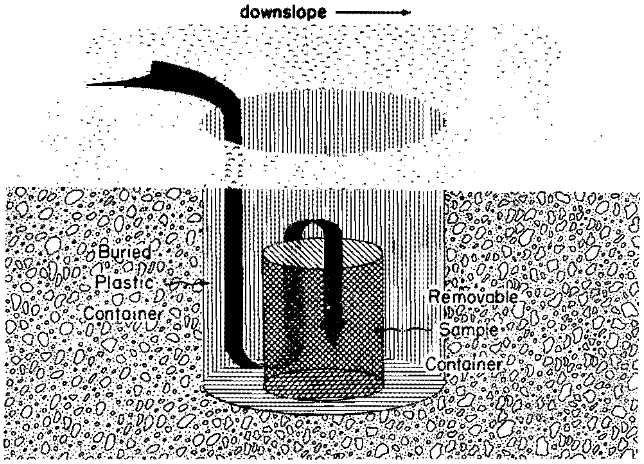

Figure 6. Midpoint runoff sampler for the overland flow system.

A fluorescene dye study was conducted to determine wastewater detention times for each plot under maximum runoff conditions. Fluorescene dye was added to the pump intake line at the holding pond. The dye traveled through 150 m of pipe prior to being applied to the overland flow plots. Effluent wastewater samples were collected every 2 minutes for first half hour and every 10 minutes thereafter. A spectrophotometer Model 70 was then used to determine concentrations of fluorescene dye in the discharged wastewater.

Two sets of soil samples were taken from each plot at depths of 15 cm and 100 cm to establish site chemical and physical conditions (Table 6). One set was taken in June prior to application of wastewater. The second set was collected at the end of September following completion of wastewater application to the land. Soil samples were analyzed by the Soil, Plant and Water Analysis Laboratory located at Utah State University, Logan, Utah.

Laboratory Analyses

Chemical and biological constituents used in obtaining meaningful and comparable data included total suspended solids, volatile suspended solids, BOD_5, total phosphorus, orthophosphate phosphorus, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total Kjeldahl nitrogen, sodium, hardness, and conductivity. Environmental Protection Agency approved laboratory procedures were used to obtain the results (EPA, 1974; APHA, 1975).

Slow Rate Site Description and Research Procedure (Hicken, 1978)

The slow rate site consisted of eight test areas, each approximately 15 m square, located almost adjacent to the overland flow site (Figure 7). Four of the test sites were covered with naturally occurring weeds and grasses, and the other four sites were bare. Secondary lagoon effluent was applied using a solid set sprinkler irrigation network at rates of 5.1, 10.2, and 15.3 cm/wk. Each application rate was used on one barren and one vegetated site. Additionally, one barren and one vegetated site received 10.2 cm/wk of well water to serve as experimental controls. A 15 m buffer zone was provided between each pair of vegetated and barren sites to reduce interference from adjacent irrigation activities.

The topsoil on the test sites was thin and composed of silty clay loam. Beneath the topsoil was a gley of mottled clay. Water movement through the clay was limited. A mole drain 10.2 cm in diameter located 1.2 m below the surface collected return flow from the sites. The sprinklers were spaced 9.15 m apart and were mounted 76 cm above the soil surface. The sprinklers were of the "Rainbird" type, having a full circle spray pattern. Wastewater and control

Table 6. Soil analysis results for the overland flow system.

	15 cm Depth					
	7.5 cm/wk		15 cm/wk		22.5 cm/wk	
	Start	Finish	Start	Finish	Start	Finish
Texture	SL[b]	SCL[c]	SL	SL	-	SC[d]
CEC, meg/100 g	18.5	21.2	17.4	23.8	-	17.2
pH	8.1	8.2	8.3	8.1	-	8.4
ECe	3.0	1.5	2.0	0.8	-	0.7
Sodium, meg/100 g[a]	1.0	0.6	0.9	0.3	-	0.3
Potassium, mg/l[a]	0.2	0.1	0.1	0.1	-	0.1
Chloride, meg/l	1.3	0.3	0.6	0.1	-	0.1
Phosphorus, mg/l	3.8	6.0	2.3	5.5	-	3.4
Nitrate, mg/l	43.0	2.9	13	3.3	-	0.4
Org. Carbon, percent	3.6	2.9	3.0	1.8	-	1.9
Bicarbonate, meg/l	0.1	0.2	0.1	0.3	-	0.3
Iron, mg/l	2.6	1.6	3.4	3.0	-	1.8
Zinc, mg/l	0.7	0.5	1.1	0.8	-	0.6
Copper, mg/l	0.8	0.7	1.0	1.2	-	0.5
Exch Sodium, meg/100 g	1.7	1.0	1.8	0.6	-	0.6
Exch Potassium, meg/100 g	1.3	1.3	1.3	1.4	-	1.2
Exch Calcium, meg/100 g	52.0	-	53.0	-	-	-
Exch Magnesium, meg/100 g	12.0	12.0	13.0	12.1	-	11.4

	100 cm Depth					
	7.5 cm/wk		15 cm/wk		22.5 cm/wk	
	Start	Finish	Start	Finish	Start	Finish
Texture	SCL	SC	C	C	-	C
CEC, meg/100 g	14.1	17.2	13.0	18.4	-	14.5
pH	8.4	8.5	8.6	8.6	-	9.2
ECe	11.0	0.8	7.0	0.9	-	2.0
Sodium, meg/100 g[a]	6.3	0.4	6.0	0.5	-	2.0
Potassium, mg/l[a]						
Chloride, meg/l	4.1	0.1	2.9	<0.1	-	0.5
Phosphorus, mg/l	2.3	2.6	8.6	2.6	-	2.2
Nitrate, mg/l	8.0	<0.1	2.0	<0.1	-	0.4
Org. Carbon, percent	1.1	1.4	0.7	1.2	-	0.6
Bicarbonate, meg/l	0.1	0.3	0.2	0.4	-	0.6
Iron, mg/l	3.2	1.2	5.6	2.0	-	6.0
Zinc, mg/l	0.8	0.6	2.0	0.8	-	10.4
Copper, mg/l	1.1	0.5	1.8	2.1	-	1.1
Exch Sodium, meg/100 g	4.9	0.6	5.5	1.9	-	6.3
Exch Potassium, meg/100 g	1.7	1.3	3.0	1.8	-	1.7
Exch Calcium, meg/100 g	48.0	-	45.0	-	-	-
Exch Magnesium, meg/100 g	12.0	12.4	13.0	12.5	-	11.1

[a] H_2O soluble.
[b] Silty loam.
[c] Silty clay loam.
[d] Silty clay.

water were applied to the sites on four successive days each week from June 28 through October 8, 1976. Application periods ranged from 2.5 to 7.5 hours to achieve the desired application rates.

Soil water sampling devices were installed at depths of 10, 30, 60, and 90 cm on each test site. Two sampling devices were installed at each depth. These devices consisted of a length of PVC pipe with a porous ceramic cup attached to the lower end and a stopper and tube arrangement used to collect water samples (Figure 8). The pore size of the ceramic cups was 2.9 microns. A partial vacuum was established in the sampling device 10 to 16 hours prior to the sample collection. Water samples were taken on the fifth day of each week from the holding pond, the control water, the return flow drainage, and the sampling devices located at various soil depths. The samples were analyzed for nitrogen forms, phosphorus forms, total organic carbon, specific conductance, and in some cases, total and volatile suspended solids.

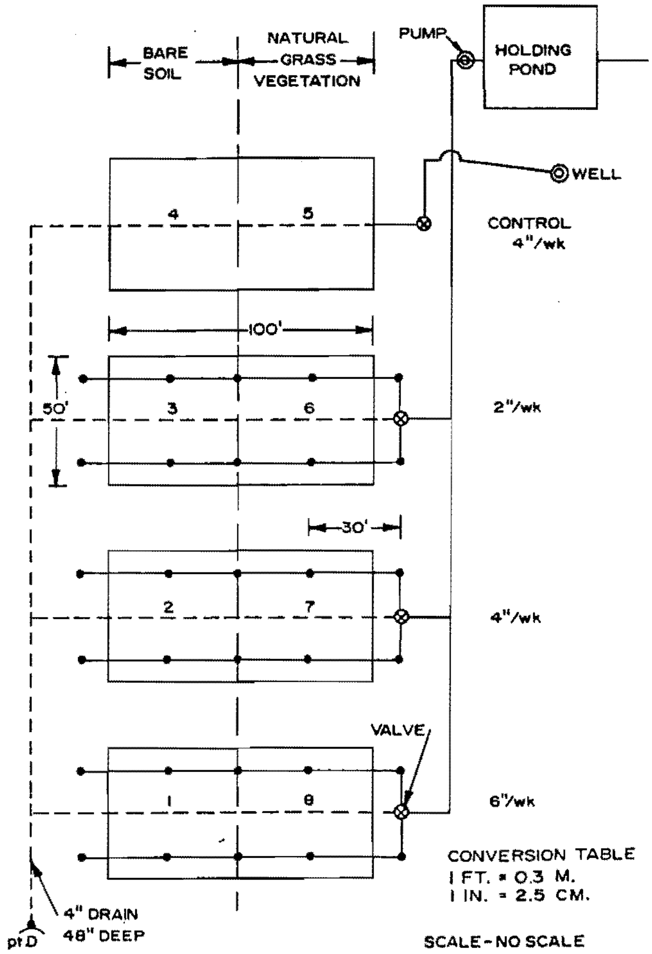

Figure 7. Test site diagram for the spray irrigation system (Hicken, 1978).

Soil samples were also analyzed by the Soil, Plant and Water Analysis Laboratory at Utah State University. Soil characteristics determined were nitrate-nitrogen (NO_3-N), sodium (Na), potassium (K), calcium (Ca), percent nitrogen, percent carbon, pH, phosphorus, specific conductance (ECe), and cation exchange capacity (CEC).

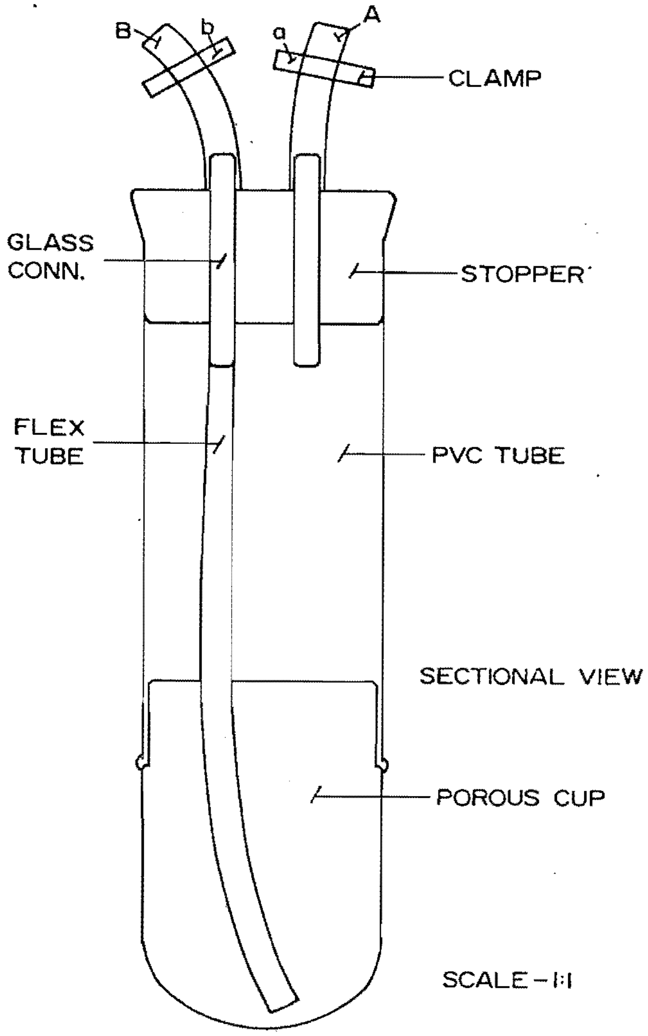

Figure 8. Soil moisture sampling device (after Hicken, 1978).

Vegetation samples were taken from each of the sites receiving wastewater effluent from the Logan lagoon system, the control site, and from an adjacent area that received no irrigation. From each site five separate 1 square meter areas were randomly chosen. The vegetation was removed near the soil surface from each area using electric clippers. the vegetation was air dried, weighed, and then each sample was ground into a homogeneous mass. Ten percent of each pulverized sample was ashed in a muffle furnace. The ashed weight of vegetation per acre was computed.

RESULTS AND DISCUSSION[1]

Overland Flow System Hydrology

Influent and runoff flow rates under peak flow conditions are presented in Table 7. In order to achieve the desired application rates, influent flows of 29, 58, and 87 l/min were required. Wastewater was applied to the overland flow plots 6 hours per day, Monday through Thursday. Runoff from each plot was measured periodically under peak flow conditions, i.e., after 3 to 4 hours of wastewater application on the third or fourth day of the week. Based on potential evapotranspiration rate data obtained for the Logan, Utah, area (Jeppson et al., 1978), the evapotranspiration rate was estimated to be approximately 2 l/min. The flow velocity in the 22.5 cm/wk plot probably exceeded the soil infiltration rate to such a degree that the percent runoff was higher than in the other plots. Water flow did not cover the 7.5 cm/wk plot completely. This could account for part of the reduced infiltration flow. Uneven wastewater distribution and severe channelization complicate infiltration rate and runoff comparisons.

Table 7. Hydrologic balance of overland flow plots.

	Application Rates, cm/wk 7.5	15	22.5
	Flow, l/min		
Influent	29	58	87
Mean Effluent Peak	21	42	74
Estimated Evapotranspiration	2	2	2
Net Infiltration	6	14	11
Percent Runoff	72	73	85
Percent Evapotranspiration	6	3	2
Percent Infiltration	22	25	13

It is physically impossible to attain a uniformly smooth surface on overland flow plots. Wastewater applied to the plots, travelling as thin sheets, will alter its flow pattern due to small changes in topography. Therefore, an even distribution of wastewater throughout the plot would be difficult to achieve.

Results of the dye study to determine plot wastewater detention times are shown in Figure 9. Fluorescene dye was added to the pump intake line and traveled through 150 m of pipe. The plot influent closely approximated a plug flow input. Average detention times for the 22.5 and 7.5 cm/wk plots were 30 and 45 minutes, respectively. Traces of dye were observed in the 7.5 cm/wk effluent after only 20 minutes, thereby indicating considerable short-circuiting. In the 15 cm/wk plot, water apparently flowed down one side at a much faster rate than the other, resulting in a double peak at 40 and 60 minutes. Average detention times were less than one hour regardless of flow rate.

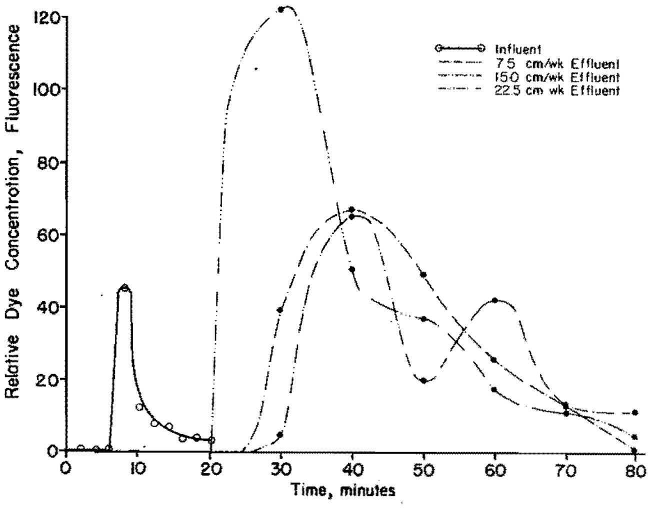

Figure 9. Dye study results to determine average detention times on the overland flow plots.

Organic Pollutants and Suspended Solids

Overland flow system

Mean influent and effluent concentrations of BOD_5, total suspended solids, and volatile suspended solids are shown in Table 8. Weekly variations of these constituents are shown in Figures 10, 11, and 12. At the 7.5 cm/wk application rate, the mean effluent BOD_5 concentration of 10.2 mg/l, the effluent total suspended solids concentration of 15.4 mg/l, and the effluent volatile suspended solids concentration of 9.0 mg/l are significantly higher (95 percent confidence level) than the respective influent concentrations. At the 15 cm/wk rate, the mean total suspended solids concentration of 13.0 mg/l is significantly higher than the influent concentration. At the 22.5 cm/wk rate, the volatile suspended solids concentration of 7.9 mg/l is significantly higher than the influent.

Table 8. Mean influent and effluent BOD_5 and suspended solids concentrations for the overland flow system, mg/l.[a]

	Influent	Effluents 7.5 cm/wk	15 cm/wk	22.5 cm/wk	Standard Deviation
Biochemical Oxygen Demand (BOD)[b]	7.8	10.2	8.0	8.6	0.5
Total Suspended Solids[c]	11.2	15.4	13.0	11.8	0.6
Volatile Suspended Solids[d]	6.5	9.0	7.4	7.9	0.4

[a] Statistical significance at 95 percent confidence level.

[b] 7.5 cm/wk > 15 cm/wk and influent 22.5 cm/wk > influent.

[c] 7.5 cm/wk > all others and 15 cm/wk > influent.

[d] 7.5 cm/wk > all others.

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[1] All results collected from the overland flow and the slow rate sites are presented in Appendices A and B, respectively.

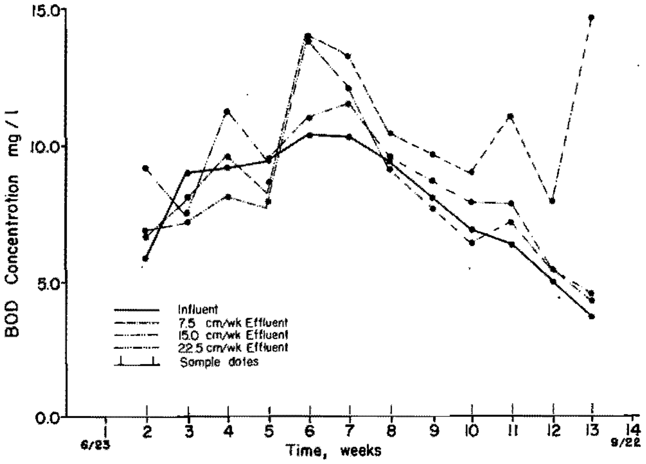

Figure 10. Influent and effluent BOD_5 concentrations for the overland flow system.

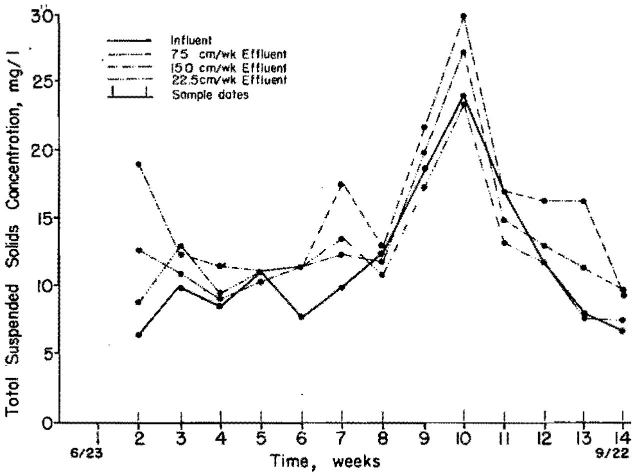

Figure 11. Influent and effluent total suspended solids concentrations for the overland flow system.

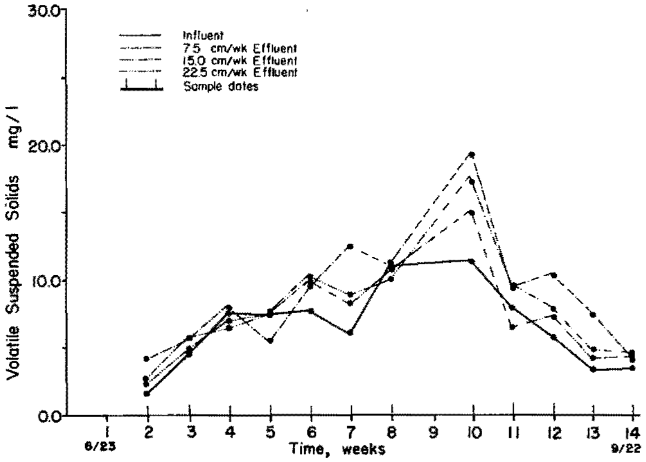

Figure 12. Influent and effluent volatile suspended solids concentrations for the overland flow system.

Physical filtration, sedimentation, and bio-oxidation are the predominant removal mechanisms for BOD_5 and suspended solids (Thomas et al., 1974; Powell, 1976). Considerable microbiological growth was observed on the soil surface of each plot. The increase in volatile and total suspended solids may be attributed to the scouring of algae, bacteria, fungi, and particulate debris from the soil surface. Factors that contributed to the lack of physical filtration may include the type of vegetation growth and the physical characteristics of the suspended solids in the lagoon effluent. Reed Canary, the predominant grass, is a bunch grass rather than a sod former. Although the grasses produced a fairly thick stand, the limited wastewater to grass contact may have hampered the filtration process. Also, the relatively small particle size and poor settling characteristics of the suspended matter remaining in the lagoon effluent decreased the removal capability of the overland flow plots.

Some of the BOD_5 concentration increases were probably due to the scouring of volatile suspended solids. No significant correlation was found, however, between BOD_5 and volatile solids concentrations. Therefore, much of the BOD_5 was in the form of soluble organics. Limited filtration, restricted wastewater contact with oxidizing organisms, and low influent BOD_5 concentrations probably reduced the organic removal efficiencies in the overland flow system. Some BOD_5 increase may have been caused by the dissolution of soluble organics.

Heterogeneous characteristics of the soil surface may be responsible for part of the difference in treatment efficiencies among the plots. Analyses showed that the soil characteristics in each plot were about the same at depths of 15 cm and 100 cm (Table 6). A looser soil texture was observed on the surface of the 7.5 cm/wk plot. This difference could explain the significantly higher effluent suspended solids concentrations, even though the flow rate was the lowest of all.

The mean weekly concentrations of all effluents for total and volatile suspended solids are shown in Figure 13. The mean concentrations of the influent and all effluents are also included. A significant correlation exists between volatile and total suspended solids at the 95 percent confidence level. Volatile suspended solids tended to increase during the middle of the summer because of longer photosynthetic periods and warmer temperatures. The high suspended solids concentration measured during week 10 was caused by the introduction of allochthonous material to the holding pond during severe storms that occurred the preceding week. As previously discussed, there was little difference in the influent and effluent concentrations. System age had no effect on removal efficiencies.

Figure 14 presents the variation in BOD_5 mean effluent concentrations. Although the volatile suspended solids concentrations increased significantly during week 10, the BOD_5 concentration did not. When this volatile suspended solids value is deleted, the correlation between BOD_5 and suspended solids is much higher, and the overall BOD_5 concentrations follow a similar seasonal pattern. Again, little change is observed in the influent and effluent concentrations, and seasonal changes and system age had no effect on treatment efficiencies.

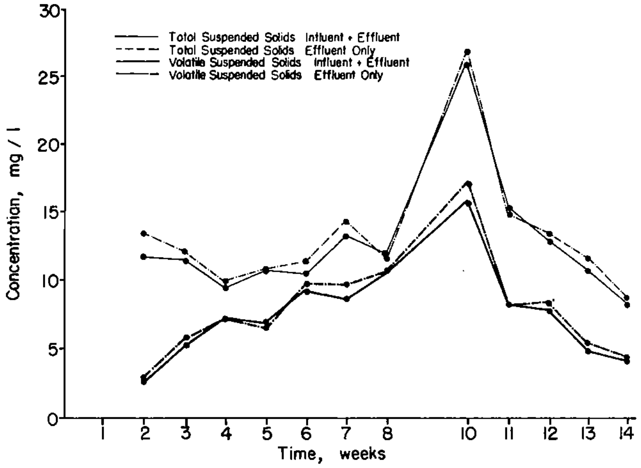

Figure 13. Weekly mean effluent concentrations of total and volatile suspended solids for all application rates used in the overland flow system.

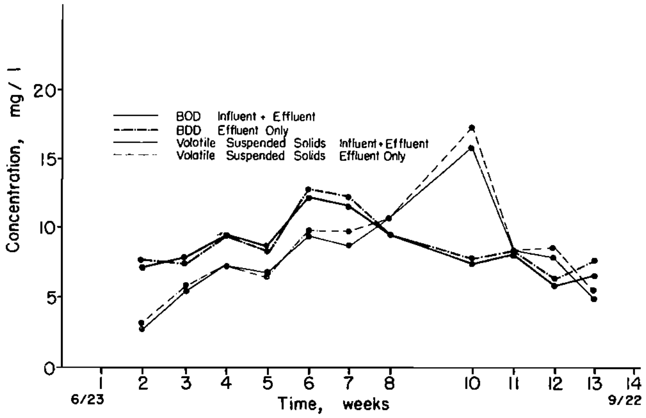

Figure 14. Weekly mean effluent BOD_5 concentrations for all application rates used in the overland flow system.

Slow rate system[2]

The total organic carbon (TOC) test was used to estimate the organic pollutional strengths of the slow rate groundwater samples. Physical filtration of the water sample through the porous ceramic cups necessitated the measurement of soluble organics and not the total organic carbon. For the same reasons, suspended solids could not be determined in the groundwater samples. Suspended solids concentrations were measured in the subsurface drainage, which represented a composite of the drainage from all test sites. Influent and effluent TOC and suspended solids concentrations for the slow rate system are presented in Table 9. Figure 15 shows the weekly lagoon effluent and mole drain suspended solids concentration variations.

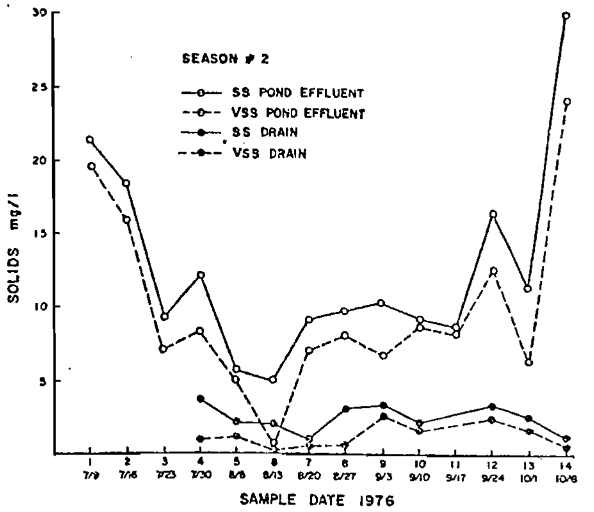

Figure 15. Mole drain volatile and total suspended solids concentrations for the slow rate system (Hicken, 1978).

The differences in TOC resulting from application rate, vegetation or non-vegetation, or the type of irrigation water applied are not significant at the 95 percent confidence level. There was a significant increase in percolate TOC concentrations as the sample depth in the soil increased because of the leaching of soil organic carbon. This increase appeared to stabilize at the 60 to 90 cm depth. Because the water in the drain system is a composite of all the test sites, it is impossible to relate suspended solids concentrations to cover type or application rates. A general observation, however, is that suspended solids concentrations in the drainage are consistently lower than in the wastewater applied to the soil. This is to be expected since soils are natural filters.

Comparison of Overland Flow With Slow Rate System

As indicated in Table 8, low concentrations of BOD_5 and suspended solids are not greatly changed by the overland flow process. Oftentimes, low level concentrations actually increased. Effluent BOD_5 and suspended solids concentrations less than 5 mg/l are very unlikely when using an overland flow system with the type of grass used in this study.

Although comprehensive suspended solids data were not obtained for the slow rate system, percolate concentrations of less than 5 mg/l seem relatively easy to obtain, even with slightly higher influent concentrations. Total organic carbon (TOC) concentrations in the percolate from the slow rate system were generally higher than those in the influent at all sample depths. Mean percolate concentrations ranged from 7 to 50 mg/l. Due to the soil characteristics at the USU Drainage Farm, discharge from the subsurface drainage probably would not meet effluent standards based on organic pollutants. After extended operation, the concentrations of leached organic carbon might become less than the standards.

Phosphorus

Overland flow system

Mean influent and effluent concentrations of total and orthophosphate phosphorus are presented in Table 10. Figures 16 and 17 show the weekly vari-

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[2] All slow rate results and conclusions contained in this report are derived from Hicken (1978). Only data obtained from the 1976 test season are used in this comparison.

Table 9. Mean influent and effluent total organic carbon and suspended solids concentrations for the slow rate system, mg/l (Hicken, 1978).

	Soil Depth, cm	Wastewater Sites						Control Site	
		5.1 cm/wk		10.2 cm/wk		15.3 cm/wk		10.2 cm/wk	
		Veg.	Bare	Veg.	Bare	Veg.	Bare	Veg.	Bare
Total organic carbon[a]	influent	11.5	11.5	11.5	11.5	11.5	11.5	4.33	4.33
	10	22.5	13.8	7.1	15.3	14.7	7.9	20.8	16.8
	30	33.7	19.8	11.2	24.1	17.5	15.9	23.3	23.5
	60	43.3	48.2	14.5	20.0	22.0	25.3	13.8	35.9
	90	34.0	29.2	23.1	25.1	25.5	17.9	32.5	31.6
Total suspended solids	influent			all sites	12.7				
	drain			all sites	2.4				
Volatile suspended solids	influent			all sites	9.8				
	drain			all sites	1.3				

Significance at 95 percent confidence level.

[a]No significant differences due to application rate, vegetative cover type, or water type. Significant difference is observed due to soil depth.

Table 10. Mean total and orthophosphate phosphorus concentrations for the overland flow system, mg/l.[a]

	Influent	Effluent			Standard Deviation
		7.5 cm/wk	15 cm/wk	22.5 cm/wk	
Total Phosphorus[b]	2.290	1.747	1.506	1.920	0.026
Orthophosphate Phorphorus[b]	1.927	1.372	1.194	1.534	0.017

[a]Statistical significance at 95 percent confidence level.

[b]All concentrations significantly different from each other.

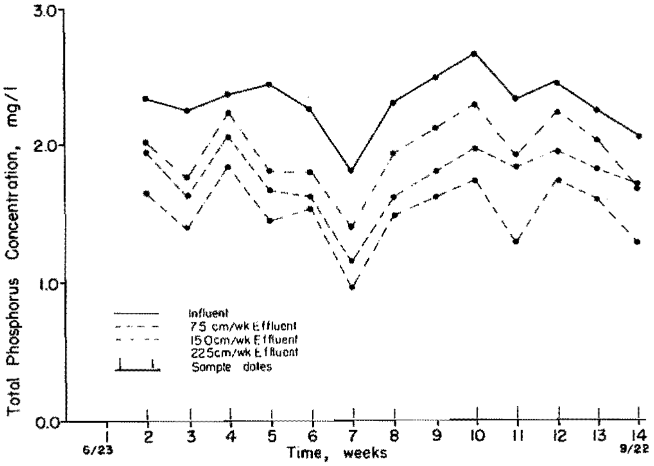

Figure 16. Influent and effluent total phosphorus concentrations for the overland flow system.

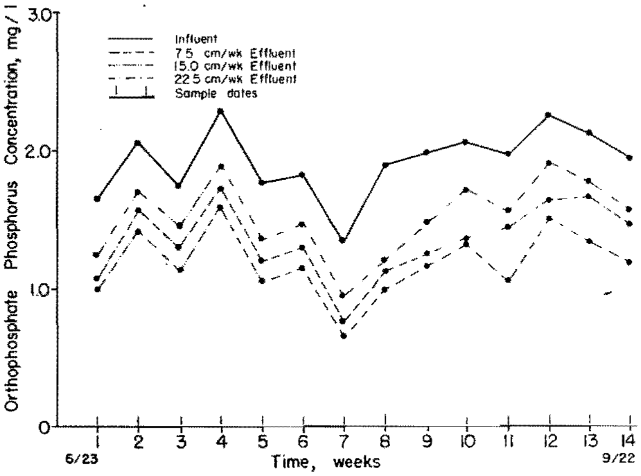

Figure 17. Influent and effluent orthophosphate phosphorus concentrations for the overland flow system.

ations. All effluent concentrations of total phosphorus are significantly less than the influent and significantly different from each other (95 percent confidence level). Orthophosphate phosphorus effluent concentrations are all significantly less than the influent and significantly different from each other. The lowest mean effluent concentrations of 1.50 mg/l total phosphorus and 1.19 mg/l orthophosphate phosphorus were observed in the 15 cm/wk effluent. The highest mean effluent concentrations of 1.92 mg/l total phosphorus and 1.53 mg/l orthophosphate phosphorus were found in the 22.5 cm/wk effluent. Weekly data followed the same distributional pattern as the means. The total mass of phosphorus removed in the 22.5 cm/wk plot was 21 g/day which was nearly as high as that of the 15 cm/wk plot (Figure 18). The mass removal in the 7.5 cm/wk plot was 11 g/day. The removal efficiency was nearly as high as that of the 15 cm/wk plot. A comparison of orthophosphate concentrations at the midpoint and discharge of each plot indicates that much of the phosphorus removal occurred in the upper half of each plot (Figure 19). In some cases, the orthophosphate concentration in the discharge was higher than that at the midpoint.

Phosphorus is removed by several mechanisms including chemical precipitation, adsorption, and

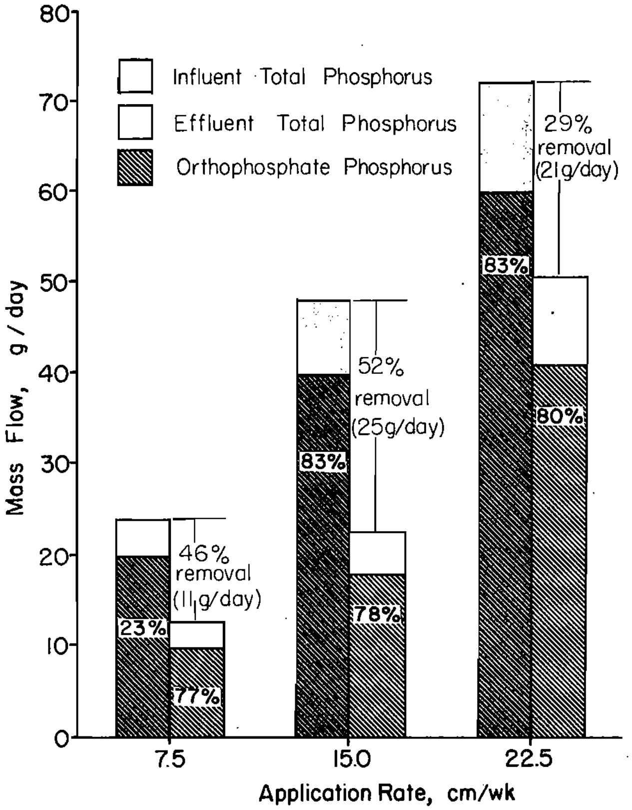

Figure 18. Total phosphorus mass balance for the overland flow system.

nutrient assimilation by the vegetation and microbial population on the soil surface (Powell, 1976; Carlson et al., 1974; Thomas et al., 1974). In overland flow systems, phosphorus removal by nutrient assimilation is considered to be relatively low compared to the removal due to soil interaction (Thomas et al., 1974). Opportunities for soil contact are limited and the overall phosphorus removal efficiencies are low. At the 22.5 cm/wk application rate, thicker sheet flows of wastewater and a shorter detention time reduce the opportunities for phosphorus to come in contact with the soils. This reduced contact results in the low total phosphorus removal efficiencies of 16 percent on a concentration basis and 29 percent on a mass basis. The 7.5 cm/wk application rate should theoretically produce the most efficient phosphorus removal. On a concentration basis, the total phosphorus removal efficiency for the plot receiving 7.5 cm/wk was only 24 percent compared to 34 percent at 15 cm/wk. On a mass basis, the removal efficiencies were 46 and 52 percent for the 7.5 and 15 cm/wk rates, respectively. The higher efficiency obtained on the 15 cm/wk plot might be explained by the previously discussed difference in surface soil texture. The soil on the 15 cm/wk plot contained more clay and therefore, more adsorption sites. Also, phosphorus dissolution may have been more prevalent in the 7.5 cm/wk plot because of the looser soil texture. Increased soil permeability would have allowed more solvent-ion contact.

Several factors must be considered in comparing midpoint and discharge orthophosphate concentrations. Phosphorus removal and the leaching of soluble phosphates occurred simultaneously throughout the entire length of each plot. Although nutrient assimilation is assumed to be of minor importance, a decrease in the density of grasses and microbial flora in the lower ends of the plots may have resulted in some decrease in phosphorus removal. During periods of low orthophosphate phosphorus concentrations such as those found in the lagoon effluent, phosphorus dissolution may severely limit the overall removal efficiency.

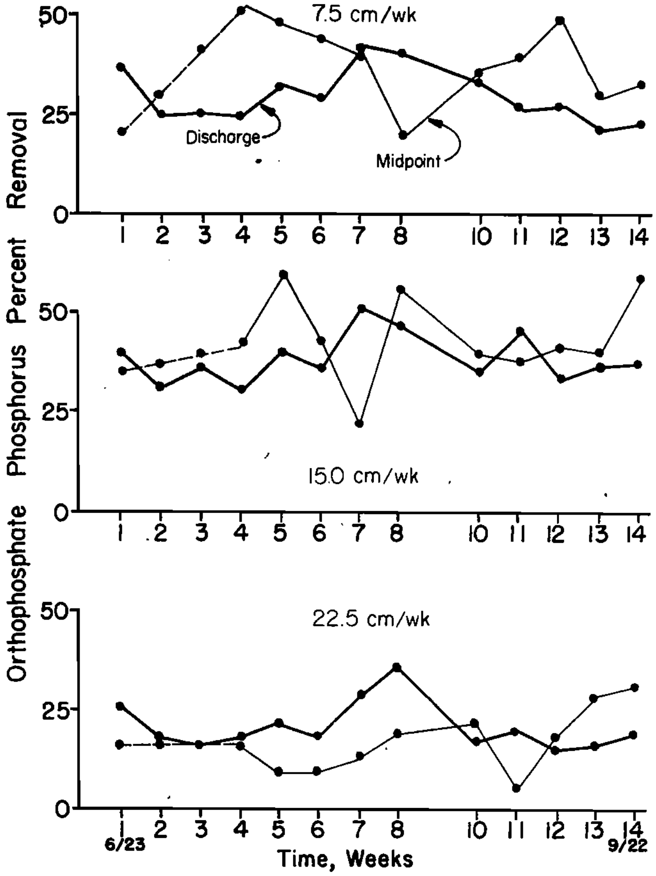

Figure 19. Comparison of orthophosphate phosphorus percent removals at midpoint and discharge of each plot in the overland flow system.

Overall weekly mean effluent concentrations for total and orthophosphate phosphorus are shown in Figure 20. Seasonal changes and system age had little effect on phosphorus removal capabilities. Therefore, in this study, soil interaction was more important than biological nutrient assimilation.

Slow rate system (Hicken, 1978)

Mean influent and percolate total phosphorus and orthophosphate phosphorus concentrations are presented in Table 11. Weekly orthophosphate phosphorus lagoon effluent and control water concentrations are shown in Figure 21. Figures 22, 23, 24, and 25 show weekly orthophosphate phosphorus concentrations at various soil depths. As a result of the sampling method, the total phosphorus concentration tends to represent only the soluble portion. No significant differences were observed due to the application rate, vegetation cover, or water type. Significant differences were found based on soil depth. Since the percolate

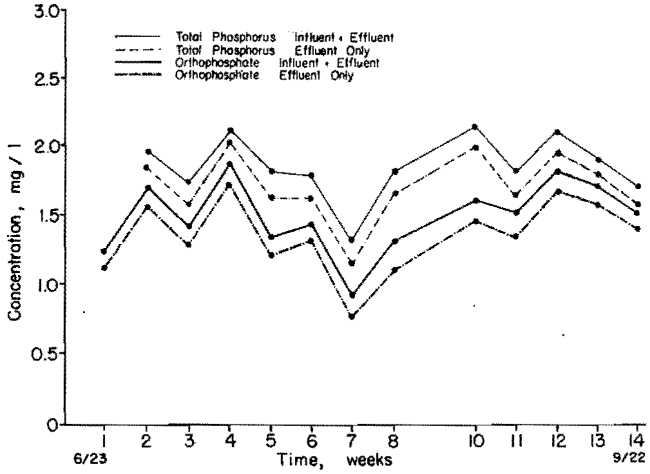

Figure 20. Weekly mean effluent total and orthophosphate phosphorus concentrations for all application rates used in the overland flow system.

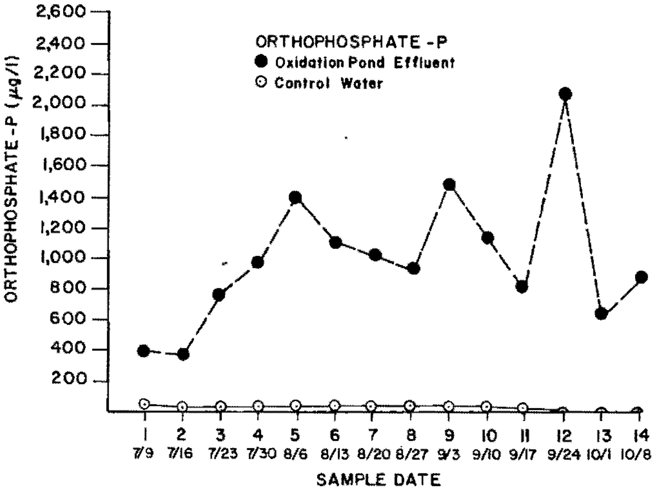

Figure 21. Orthophosphate phosphorus concentrations in the lagoon effluent and control water applied to the slow rate site (Hicken, 1978).

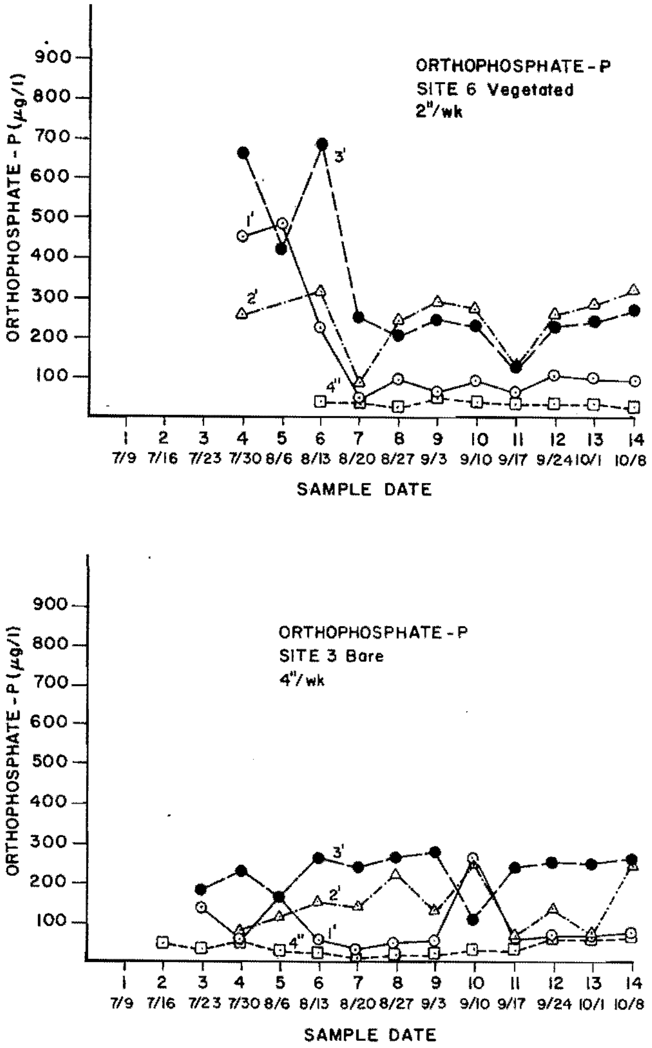

Figure 22. Orthophosphate phosphorus concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 5.1 cm (2 in) per week (Hicken, 1978).

Table 11. Mean influent and effluent total phosphorus and orthophosphate phosphorus concentrations from slow rate system, mg/l (Hicken, 1978).

	Soil Depth, cm	Wastewater Sites						Control Site	
		5.1 cm/wk		10.2 cm/wk		15.3 cm/wk		10.2 cm/wk	
		Veg.	Bare	Veg.	Bare	Veg.	Bare	Veg.	Bare
Total phosphorus[a]	influent	1.460	1.460	1.460	1.460	1.460	1.460	0.074	0.074
	10	0.094	0.100	0.098	0.271	0.116	0.142	0.157	0.152
	30	0.206	0.082	0.100	0.128	0.311	0.152	0.095	0.191
	60	0.363	0.149	0.111	0.123	0.535	0.365	0.196	0.215
	90	0.373	0.344	0.202	0.696	0.176	0.195	0.266	0.226
Orthophosphate phosphorus	influent	1.000	1.000	1.000	1.000	1.000	1.000	0.028	0.028
	10	0.031	0.033	0.053	0.180	0.079	0.061	0.045	0.026
	30	0.162	0.086	0.052	0.088	0.238	0.092	0.045	0.040
	60	0.224	0.140	0.069	0.126	0.348	0.204	0.107	0.154
	90	0.326	0.224	0.127	0.556	0.138	0.095	0.133	0.195

Statistical significance at 95 percent confidence level.

[a] No significant differences due to application rate, cover type, or water type. Significant differences due to soil depth.

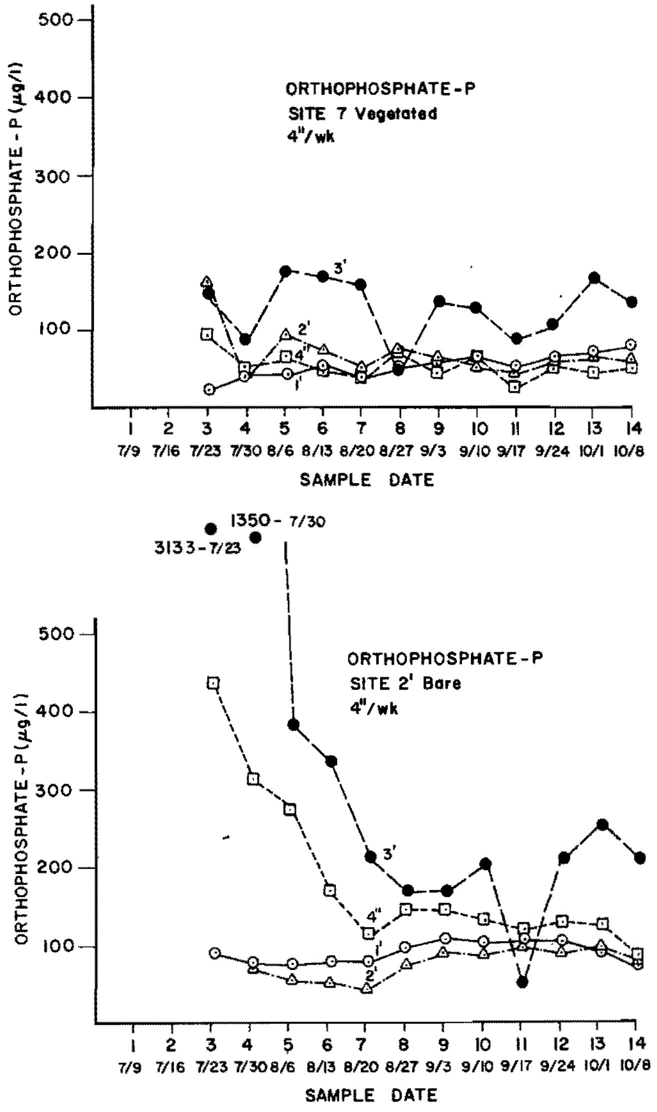

Figure 23. Orthophosphate phosphorus concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

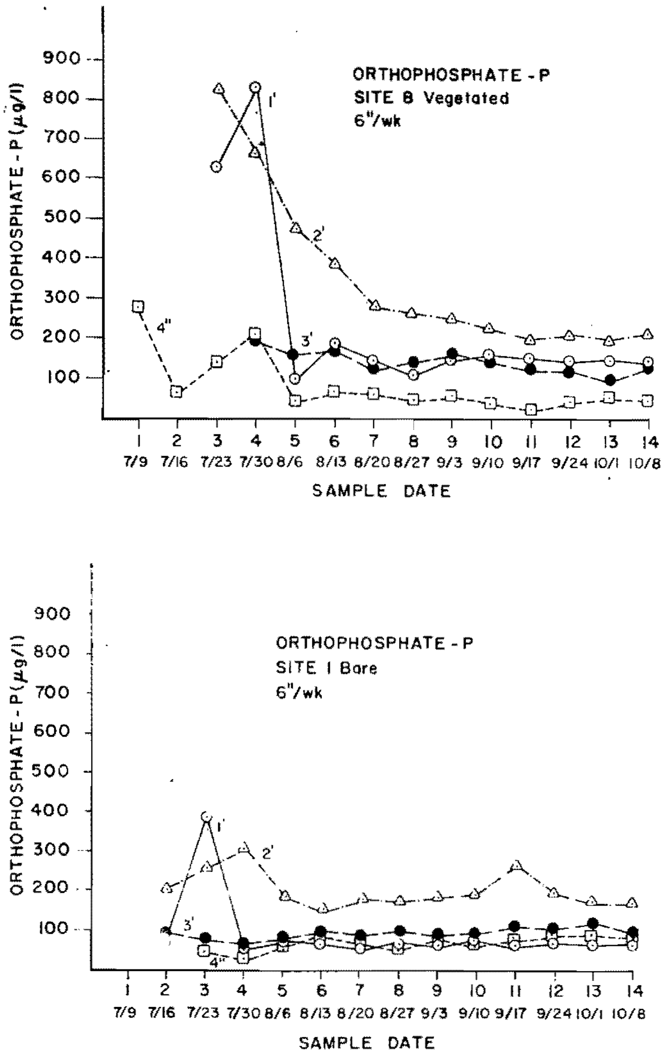

Figure 24. Orthophosphate phosphorus concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 15.3 cm (6 in) per week (Hicken, 1978).

concentrations were essentially the same regardless of whether control or wastewater was applied, the concentrations represented conditions inherent to the soil system. After a large decrease in phosphorus concentrations near the surface of each plot, an increase with depth is indicated. Leaching of soluble phosphates probably caused this increase. Generally, phosphorus removal efficiencies exceeded 80 percent at all depths and exceeded 93 percent at the 10 cm depth. Figure 26 shows the percent orthophosphate phosphorus removal at the 10 cm depth for all application rates. Vegetative uptake was not found to be a significant phosphorus removal mechanism. Adsorption and ion exchange were the major removal mechanisms.

Comparison of Overland Flow With Slow Rate System

Phosphorus removal in the overland flow system is limited (Table 10). The best total phosphorus concentration removal efficiency recorded was only 35 percent, with an effluent concentration of 1.5 mg/l. Removal rates are much higher in the spray irrigation system (Table 11), with percolate total phosphorus concentrations ranging from 0.09 to 0.54 mg/l. Influent concentrations were somewhat higher for the overland flow system, but the independence of removal efficiency and influent concentrations for the slow

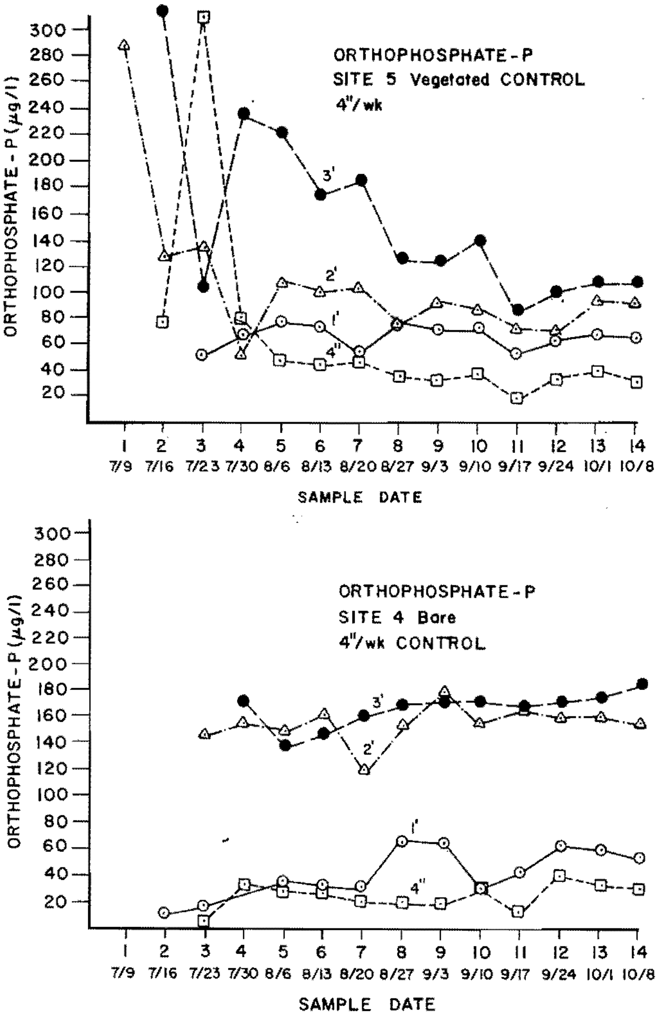

Figure 25. Orthophosphate phosphorus concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of control water to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

rate system has been established (Hicken, 1978). The highest phosphorus removal in the slow rate system was observed at a depth of 10 cm, where total phosphorus concentrations exceeded 0.09 mg/l and orthophosphate concentrations exceeded 0.03 mg/l. Although these concentrations represented removal efficiencies of over 95 percent, discharge of these levels of phosphorus could still lead to accelerated eutrophication in some receiving waters.

Nitrogen

Overland flow system

Mean influent and effluent ammonia, nitrite, nitrate, and organic nitrogen concentrations are presented in Table 12. Weekly variations of these constituents are shown in Figures 27, 28, 29, and 30. Ammonia nitrogen removal and conversion was fairly

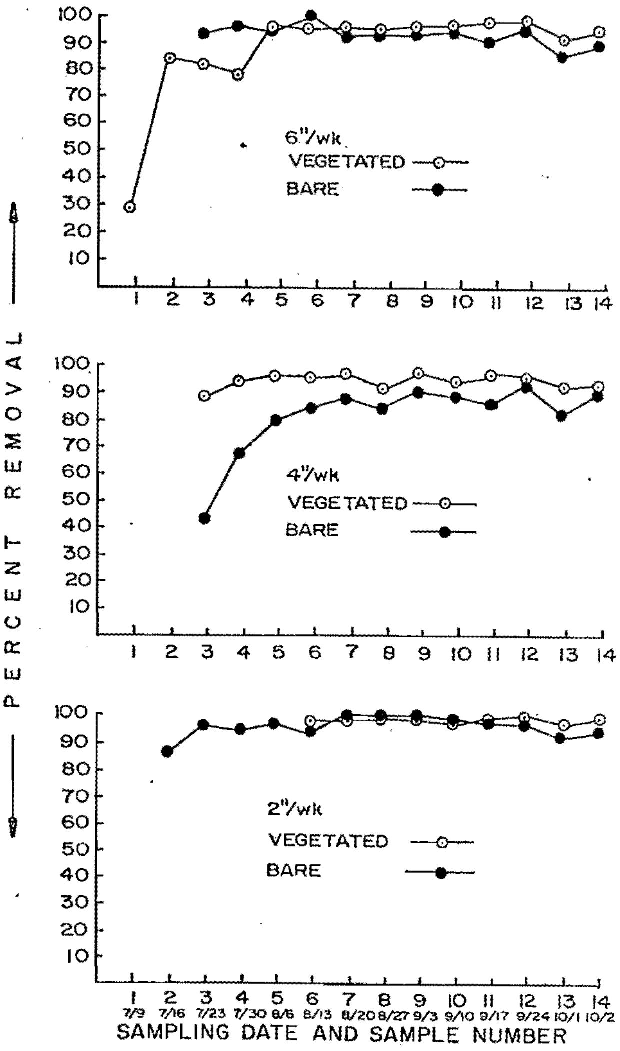

Figure 26. Orthophosphate phosphorus percent removals at a soil mantle depth of 10 cm (4 in) following lagoon effluent application to the slow rate site of 5.1 cm (2 in), 10.2 cm (4 in), and 15.3 cm (6 in) per week (Hicken, 1978).

Table 12. Mean ammonia, nitrite, nitrate and organic nitrogen concentrations for the overland flow system, mg/l.[a]

	Influent	Effluents 7.5 cm/wk	15 cm/wk	22.5 cm/wk	Standard Deviation
Ammonia nitrogen[b]	2.331	0.306	0.135	0.591	0.136
Nitrite nitrogen[c]	0.070	0.058	0.033	0.075	0.008
Nitrate nitrogen[d]	0.065	0.110	0.042	0.121	0.013
Organic nitrogen[e]	2.213	2.403	2.017	2.321	0.150

[a] Statistical significance at 95 percent confidence level.

[b] All effluents < influent, 15 cm/wk < 22.5 cm/wk.

[c] 15 cm/wk < all others.

[d] 7.5 cm/wk and 22.5 cm/wk > influent and 15 cm/wk.

[e] No significant differences between each concentration value.

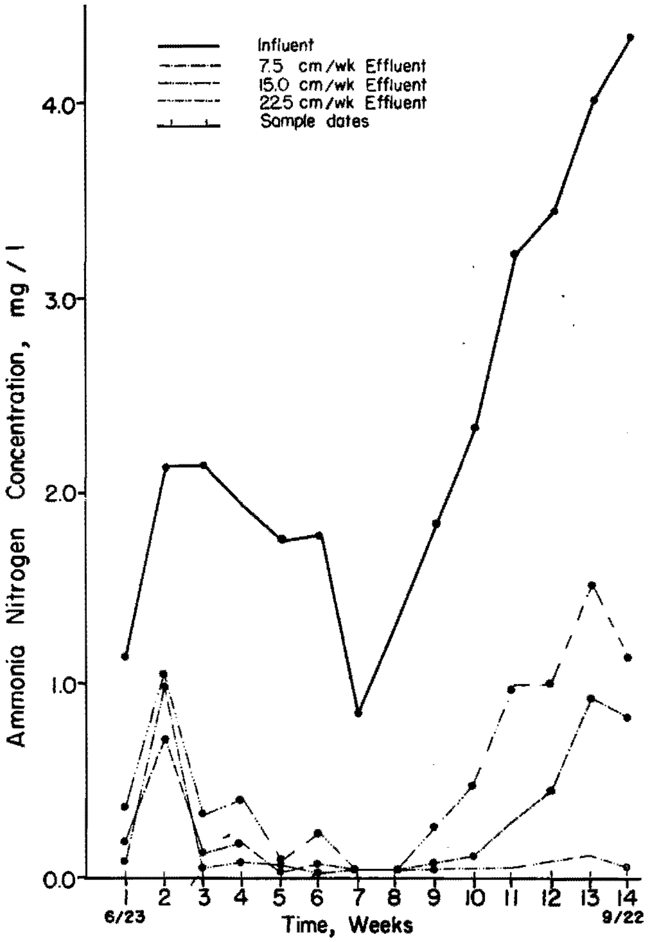

Figure 27. Influent and effluent ammonia nitrogen concentrations for the overland flow system.

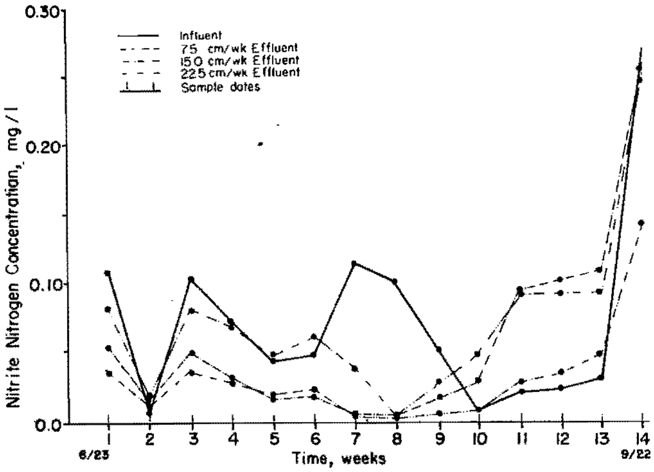

Figure 28. Influent and effluent nitrite nitrogen concentrations for the overland flow system.

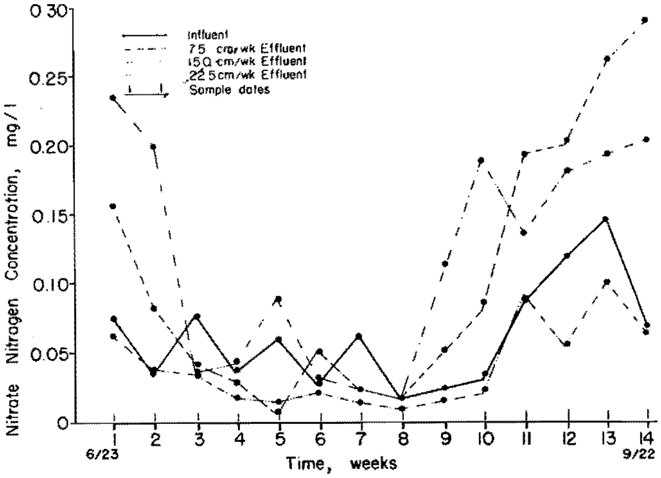

Figure 29. Influent and effluent nitrate nitrogen concentrations for the overland flow system.

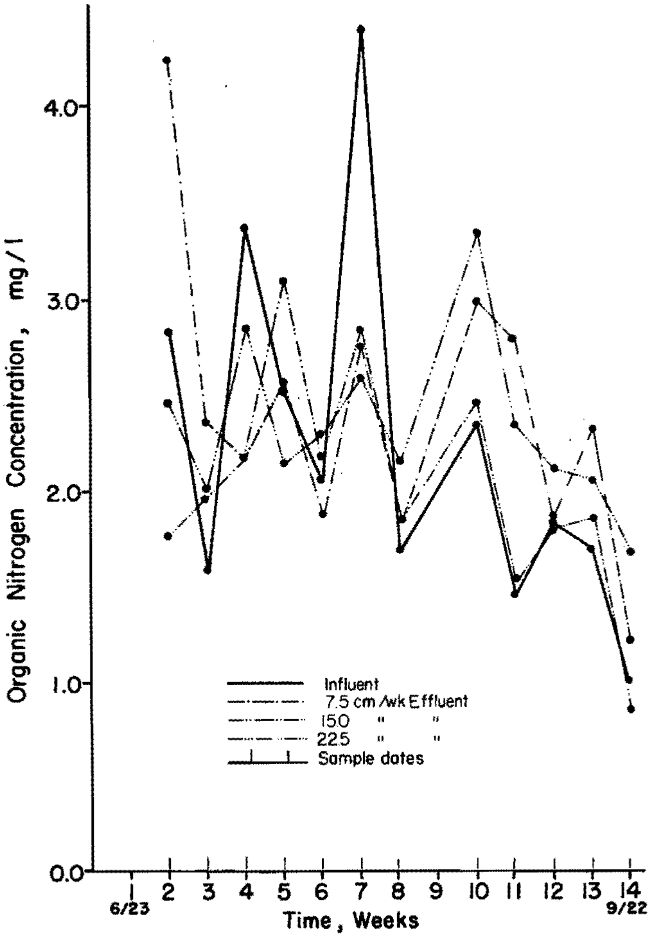

Figure 30. Influent and effluent organic nitrogen concentrations for the overland flow system.

high, with the best removal efficiency of 94 percent observed at the 15 cm/wk application rate and the lowest removal efficiency of 75 percent found in the 22.5 cm/wk effluent. Small changes were noted in the nitrite and nitrate nitrogen concentrations. The effluent nitrite nitrogen concentration of 0.033 mg/l from the plot receiving 15 cm/wk was significantly less than the influent concentration. The 7.5 and 22.5 cm/wk effluent nitrate nitrogen concentrations of 0.110 and 0.121 mg/l were significantly higher than the influent concentration of 0.042 mg/l. The 15 cm/wk effluent concentration of nitrate nitrogen did not significantly differ from the influent. No significant differences were observed in the influent and effluent organic nitrogen concentrations at all application rates. On a mass basis (Figure 31), a nitrogen removal of 64 g/day was noted at the 15 and 22.5 cm/wk application rates. More nitrogen remained in the ammonia form in the 22.5 cm/wk effluent (19 percent compared to 6 and 9 percent on the 15 and 7.5 cm/wk plots respectively). The mass of nitrogen removed in the 7.5 cm/wk plot was much less. Nevertheless, the removal efficiencies were all similar (44 to 65 percent). Essentially all of the ammonia removal occurred in the upper half of each plot (Figure 32).

Mechanisms for removing nitrogen in overland flow systems include ammonia volatilization, adsorption and fixation of ammonium ions, nitrification-denitrification, and nutrient assimilation by the grasses and microbial population in the soil (Thomas et al., 1974; Carlson et al., 1974; EPA, 1977). Nitrification-denitrification may be the major removal mechanism (Thomas, 1974). Applied wastewater is well aerated as it flows across the soil surface, and nitrification occurs. This film of water limits oxygen transfer into the soil, and reducing conditions develop. Plants provide organic debris and root secretions that can be used as a substrate by denitrifying bacteria. Organic material is also present in the wastewater and soil. Nitrate nitrogen formed in the aerated surface water diffuses into the soil and is denitrified to nitrous oxide or nitrogen gas.

Approximately 10 percent of the influent ammonia was removed by stripping during the sprinkler application (Table 26). Equilibrium between ammonia and ammonium ions in a water solution can be described by the following stoichiometric relationship:

$$NH_4 + OH^- \rightleftharpoons NH_3 + H_2O$$

Based on the above relationship the equilibrium coefficient (Kb) can be defined by the following equation:

$$\frac{[NH_4^+][OH^-]}{[NH_3]} = K_b = 1.8 \times 10^{-5} \text{ at } 25^\circ C$$

$$\text{or} \quad \frac{[NH_4^+]}{[NH_3]} = \frac{1.8 \times 10^{-5}}{[OH^-]}$$

in which

$[NH_4^+]$ = ammonium ion molar concentration (moles/liter)

$[OH^-]$ = hydroxyl ion molar concentration (moles/liter)

$[NH_3]$ = ammonia molar concentration (moles/liter)

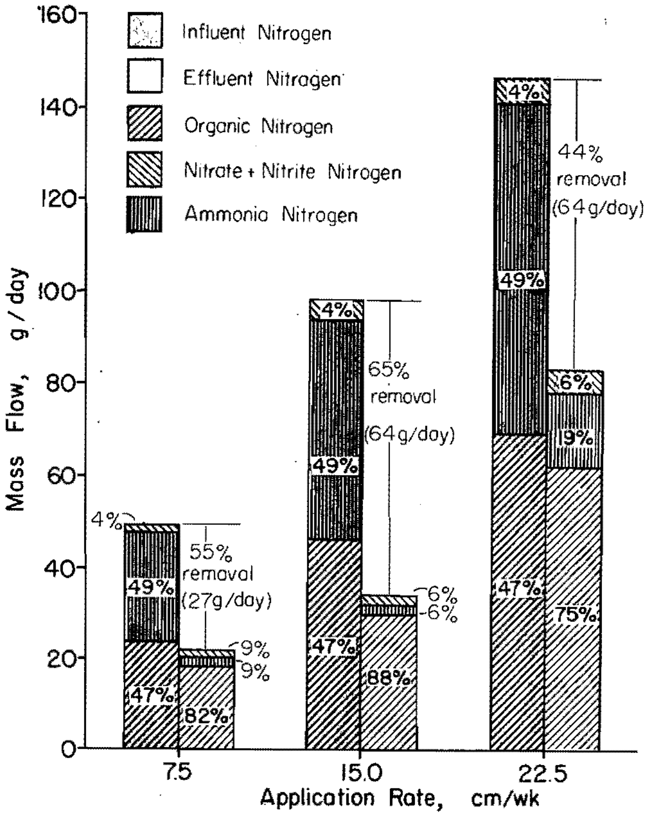

Figure 31. Nitrogen mass balance for the overland flow system.

The percent of theoretically available volatile ammonia of the total ammonia present in the water solution is derived by the following expression:

$$\text{Percent Ammonia} = \frac{[NH_3]\ (100)}{[NH_4^+] + [NH_3]}$$

$$= \frac{[NH_3]\ (100)}{\frac{1.8 \times 10^{-5}}{[OH^-]}[NH_3] + [NH_3]}$$

$$\text{or Percent Ammonia} = \frac{[OH^-]\ (100)}{1.8 \times 10^{-5} + [OH^-]}$$

Based on the observed range of pH values of 7.6 to 8.9, the stripping removed a significant amount of the 2 to 31 percent theoretically available volatile ammonia. Higher influent pH values generally result in increased ammonia stripping (Hicken, 1978). Some volatilization may occur as the wastewater flows over the overland flow plots. Ammonia may also be removed by the fixation of ammonium ions in the crystal lattice of certain clays and by adsorption onto clay particles and colloids (Lance, 1972). Fixed ammonium ions are not accessible to nitrifying bacteria and are not easily exchanged (Nommik, 1965). Adsorbed ammonium

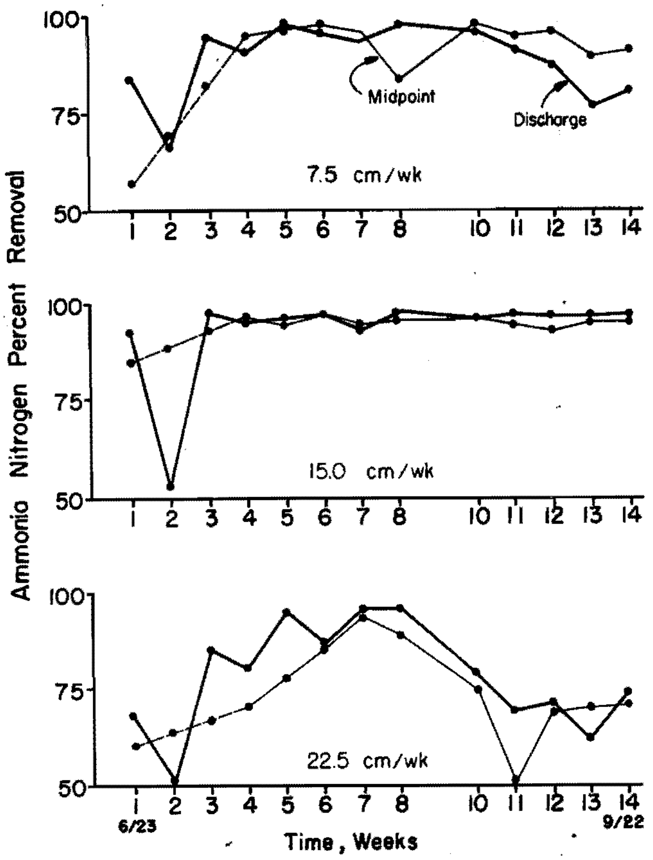

Figure 32. Comparison of ammonia nitrogen percent removals at midpoint at discharge of each plot in the overland flow system.

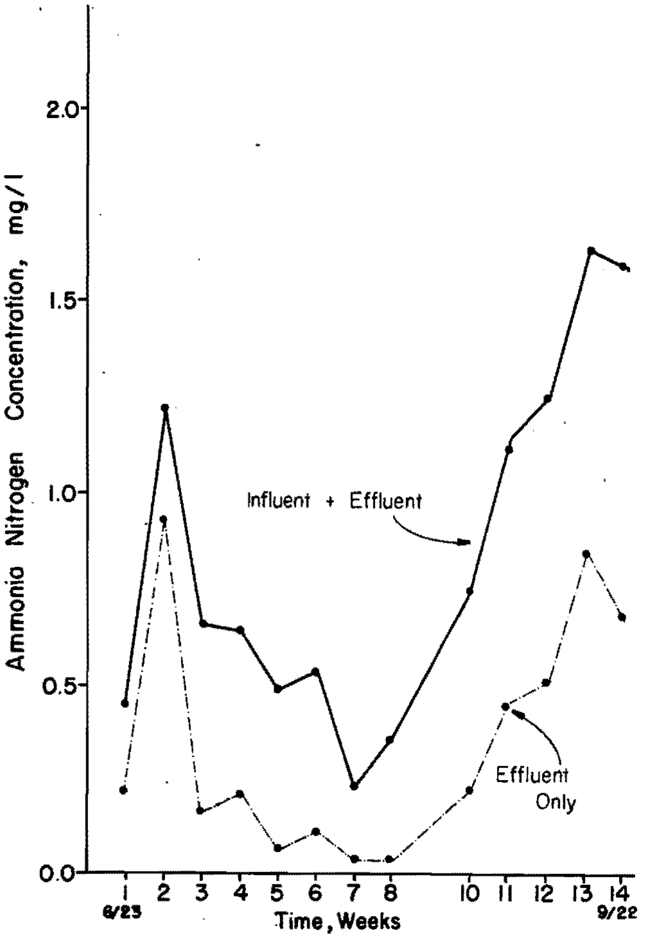

Figure 33. Weekly mean effluent ammonia concentrations for all application rates used in the overland flow system.

ions are nitrified during drying periods when the soil becomes aerobic. Subsequent denitrification occurs under flooded, anaerobic conditions (Hicken et al., 1978; EPA, 1977; Carlson et al., 1976). Nutrient assimilation by the organic mat and root zone is the remaining primary mechanism for nitrogen removal (Carlson et al., 1976). Theoretical uptake rates cannot be used to evaluate the relative importance of nutrient assimilation because much of the wastewater never comes in contact with the root zone and the soil surface microbial population. All of the previously discussed mechanisms are undoubtedly involved in nitrogen removal.

Figure 33 shows the overall weekly mean effluent concentrations of ammonia nitrogen. A general increase in influent concentrations near the end of the summer was probably due to the advent of cooler weather resulting in reduced biological activity in the lagoons. Effluent concentrations also increased, but the removal rate remained essentially constant. Therefore, soil interaction may have played a major role in ammonia removal. This is particularly evident considering the ammonia nitrogen effluent concentration from the 15 cm/wk plot (Figure 27), which has already been described as having more adsorption sites available. Higher nitrate and nitrite nitrogen concentrations in the 22.5 cm/wk effluent resulted directly from increases in these constituents in the influent flow. The thicker water film and faster flow resulted in inefficient diffusion of nitrate into the soil. Also, less time was available for nutrient utilization. A potential increase of oxygen transfer into the soil in the 7.5 cm/wk plot due to looser soil texture and thinner water film may have reduced denitrification efficiency. Increased scouring and dissolution of soluble nitrogen forms probably occurred on this plot. A definite gradient in grass density and height was observed in each plot. One study attributed a similar gradient to the high removal of ammonia in the upper half of the plots resulting in availability limitations in the lower end (Carlson et al., 1974).

Slow rate system

Mean influent and percolate concentrations of ammonia, nitrite, and nitrate nitrogen are presented in Table 13. Ammonia concentrations in the lagoon effluent, control water and at various soil mantle depths are shown in Figures 34, 35, 36, 37, and 38. Nitrite and nitrate nitrogen concentrations are shown in Figures 39 through 48. Approximately 35 percent of the ammonia was removed by stripping as the influent was applied. This high degree of stripping resulted from a high pH value of approximately 9.0. No significant difference was observed due to cover type,

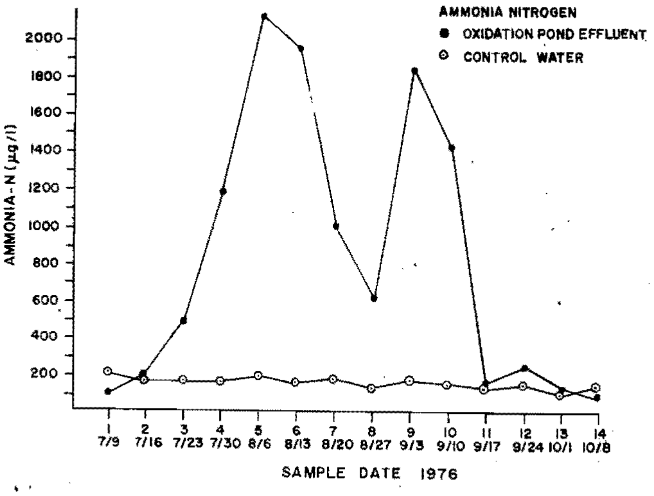

Figure 34. Ammonia nitrogen concentrations in the lagoon effluent and control water applied to the slow rate system (Hicken, 1978).

which implies that nutrient uptake was not a major ammonia removal mechanism. Nitrification of ammonia was probably inhibited by anaerobic conditions caused by the flooded conditions. Adsorption may have been the major removal mechanism. No significant difference was observed due to the type of water applied. As in the case of phosphorus, the ammonia concentration at any particular depth in the soil seems to be a function of the background levels. The highest ammonia removal (95 percent) occurred after only 10 cm of percolation. The concentration then tended to increase with depth. Explanations for this include the release of adsorbed ammonia, the denitrification of nitrates and nitrites to ammonia which occurs in some cases, and the anaerobic decomposition of organic matter (Powell, 1975). Application rates had no significant effects on percolate ammonia concentrations.

Significant differences in nitrate nitrogen concentrations were observed due to water type, cover type, application rate, and sample depth. The leaching of soil nitrates seemed to be the predominant factor resulting in the percolate concentrations (Corey, McWorter, and Smith, 1976; and Pratt, Biggar, and Broadbent, 1977). Vegetative uptake accounted for some of the large nitrate differences between vegetated and bare sites, but in almost every case, initial soil nitrate concentrations were higher in the bare site locations. At the site receiving 15.3 cm/wk of wastewater, nitrate concentrations in the vegetated and non-vegetated percolates were approximately the same. Initial soil nitrate levels were about the same at this site also. As the application rate increased, percolate concentrations decreased. Nitrate was leached faster as the application rate increased.

Comparison of Overland Flow With Slow Rate System

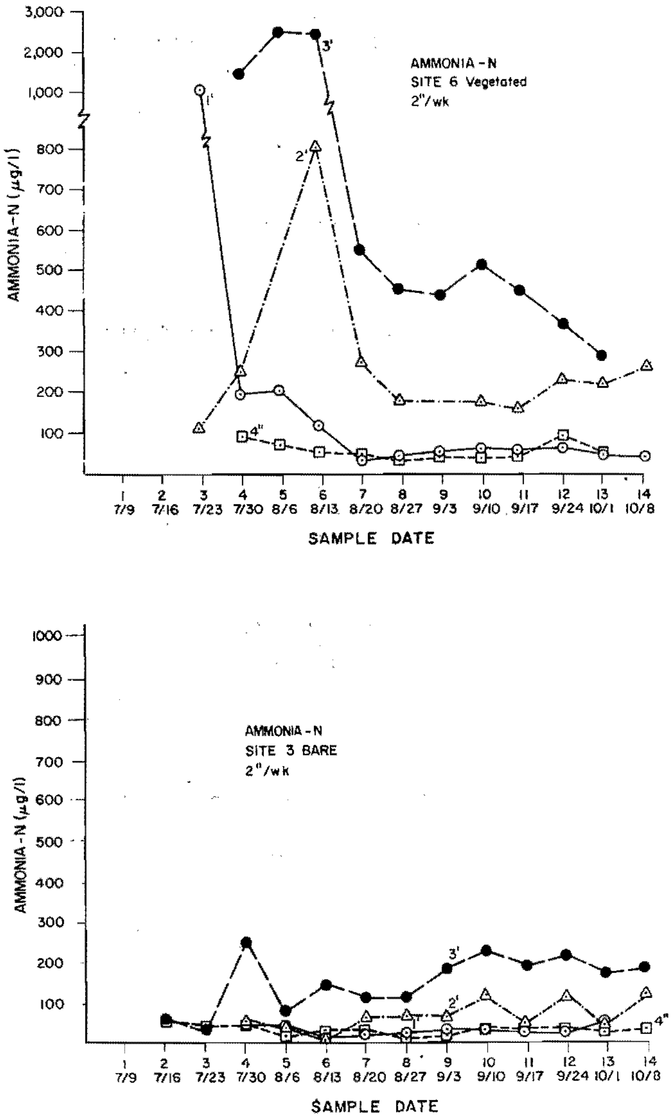

Figure 35. Ammonia nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 5.1 cm (2 in) per week (Hicken, 1978).

Ammonia removal in the overland flow system was good, with the mean influent concentration of over 2.3 mg/l being reduced to less than 0.15 mg/l at the most efficient application rate (Table 12). Nitrate and nitrite nitrogen levels in the effluent differed only slightly from the influent, with all effluent concentrations less than 0.2 mg/l. Ammonia removal in the slow rate percolate was also very high, especially at the 10 and 30 cm depths (Table 13). Some increases were noted, particularly at the 90 cm depth. The mean influent concentration of 0.832 mg/l applied to the slow rate sites was much lower than the concentration applied to the overland flow site, but the percolate concentrations did not appear to depend on influent conditions. Nitrate nitrogen in the slow rate percolate seemed to depend on initial soil conditions. Many of the percolate concentrations were approximately the same as the overland flow effluent concentrations, but some were considerably higher and exceeded drinking water standards of 10 mg/l. Therefore the percolate water from the system could impair local potable groundwater supplies.

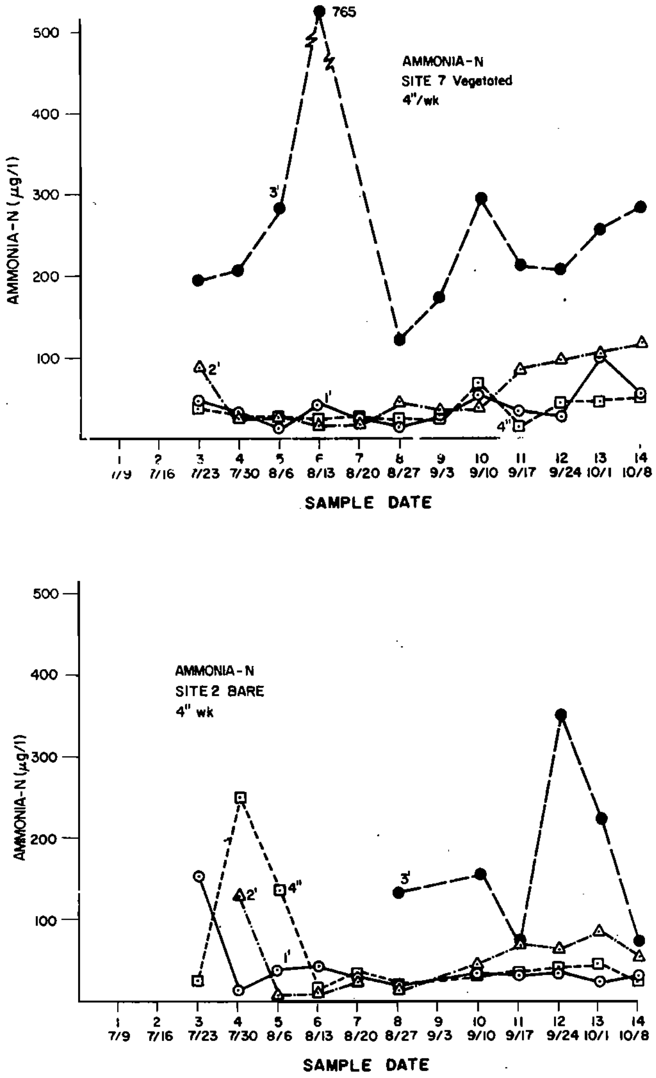

Figure 36. Ammonia nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

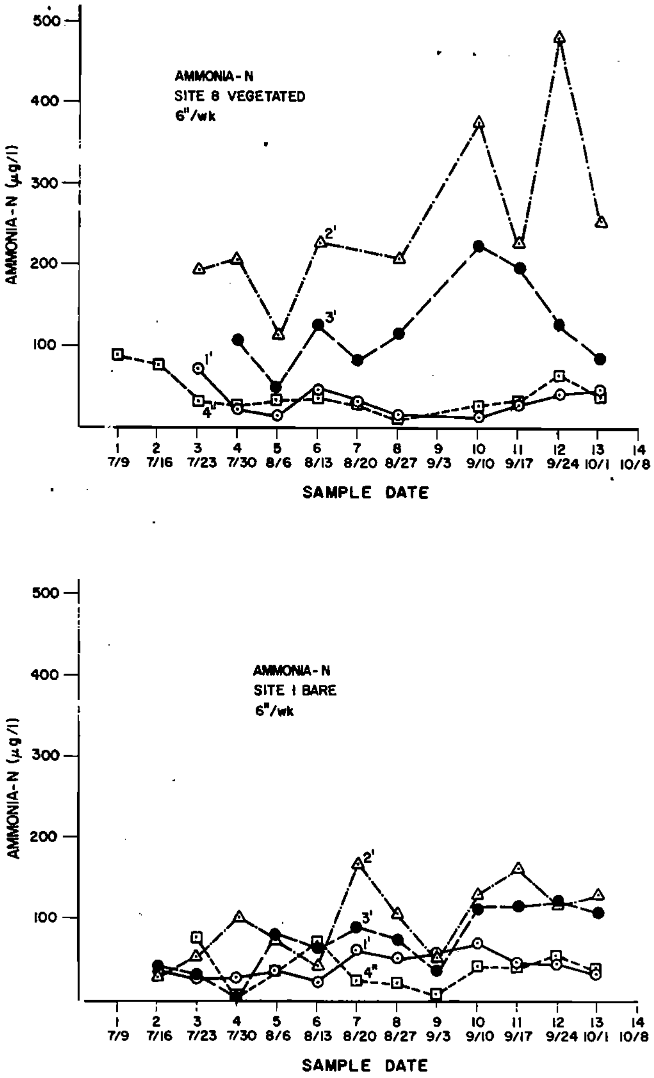

Figure 37. Ammonia nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 15.3 cm (6 in) per week (Hicken, 1978).

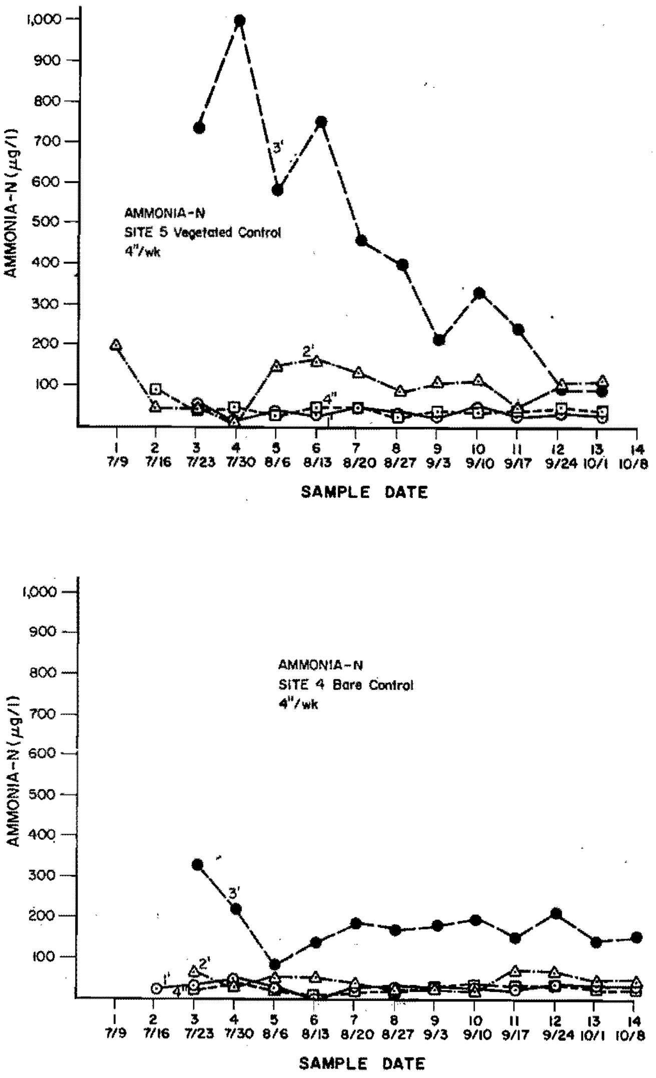

Figure 38. Ammonia nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of control water to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

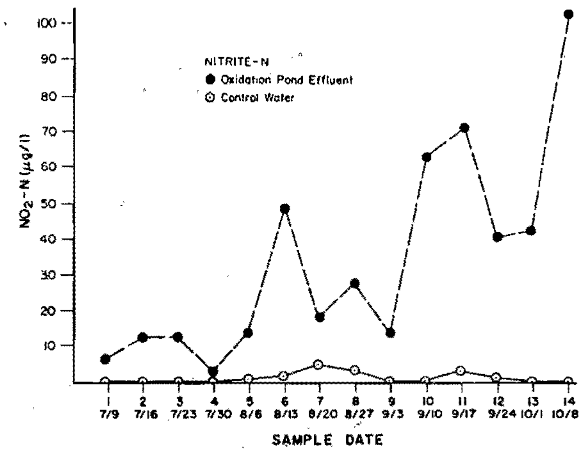

Figure 39. Nitrite nitrogen concentrations in the lagoon effluent and control water applied to the slow rate system (Hicken, 1978).

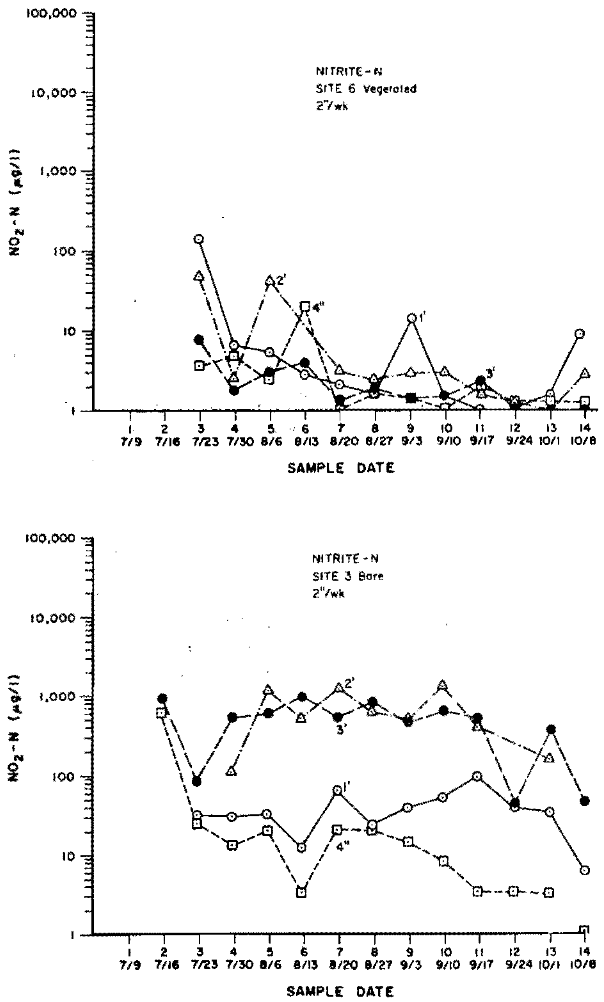

Figure 40. Nitrite nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 5.1 cm (2 in) per week (Hicken, 1978).

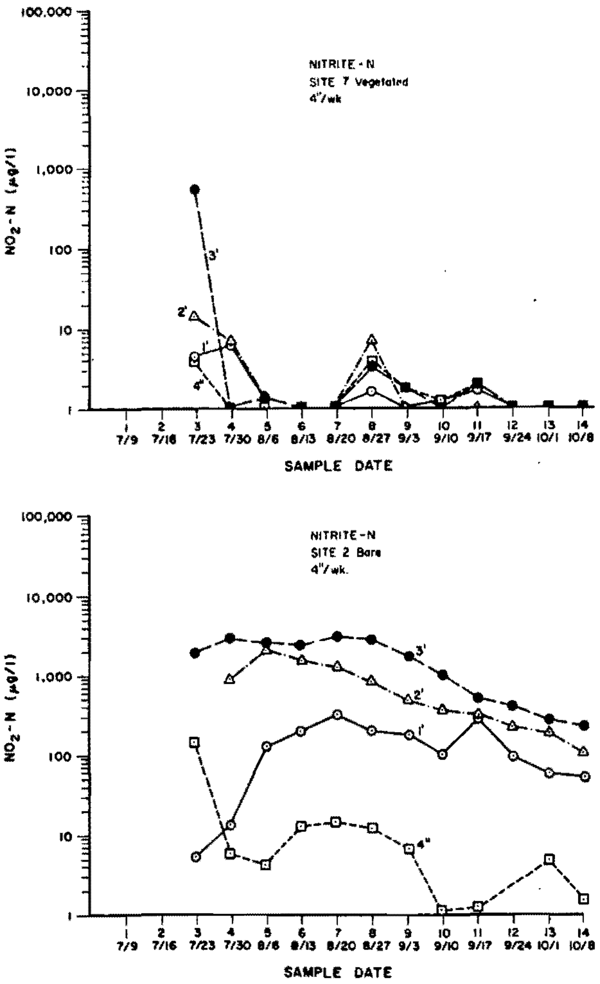

Figure 41. Nitrite nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

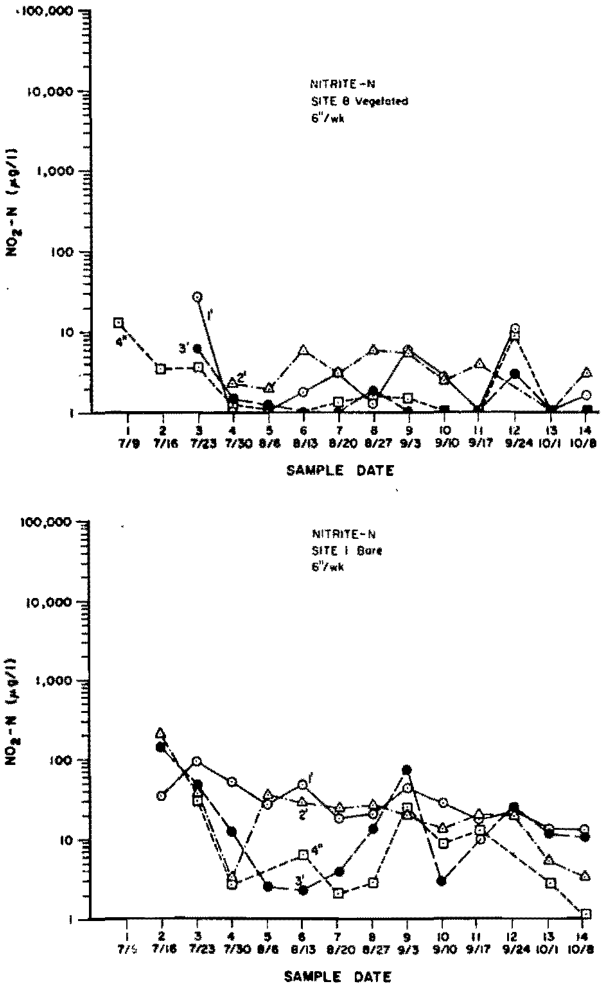

Figure 42. Nitrite nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 15.3 cm (6 in) per week (Hicken, 1978).

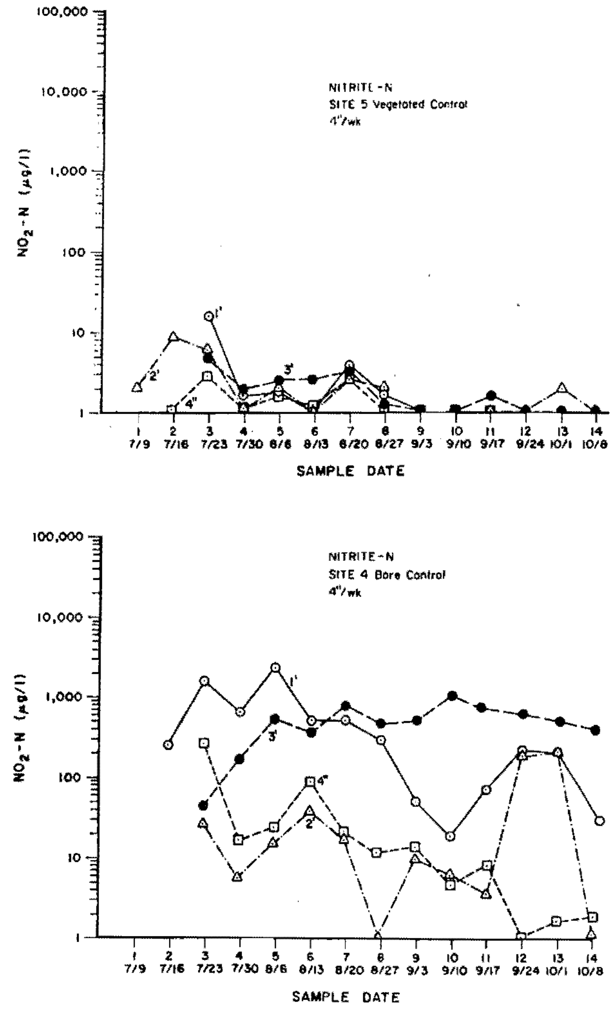

Figure 43. Nitrite nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of control water to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

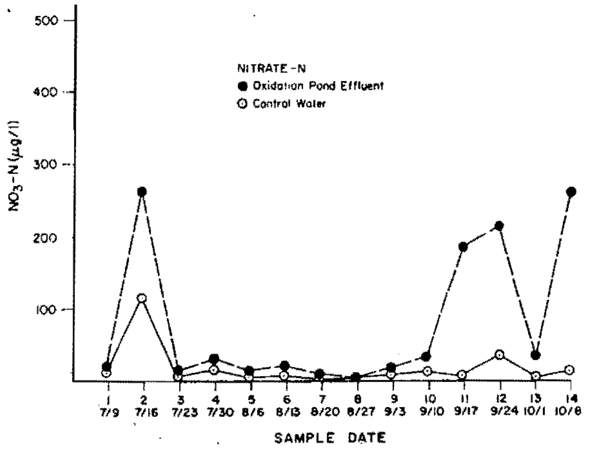

Figure 44. Nitrate nitrogen concentrations in the lagoon effluent and control water applied to the slow rate system (Hicken, 1978).

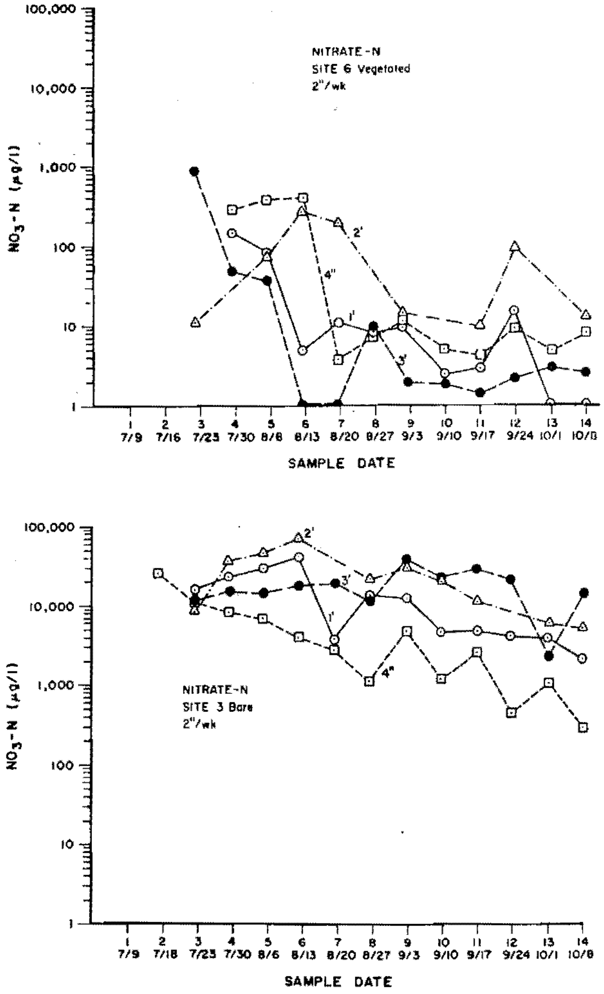

Figure 45. Nitrate nitrogen concentrations at the soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 5.1 cm (2 in) per week (Hicken, 1978).

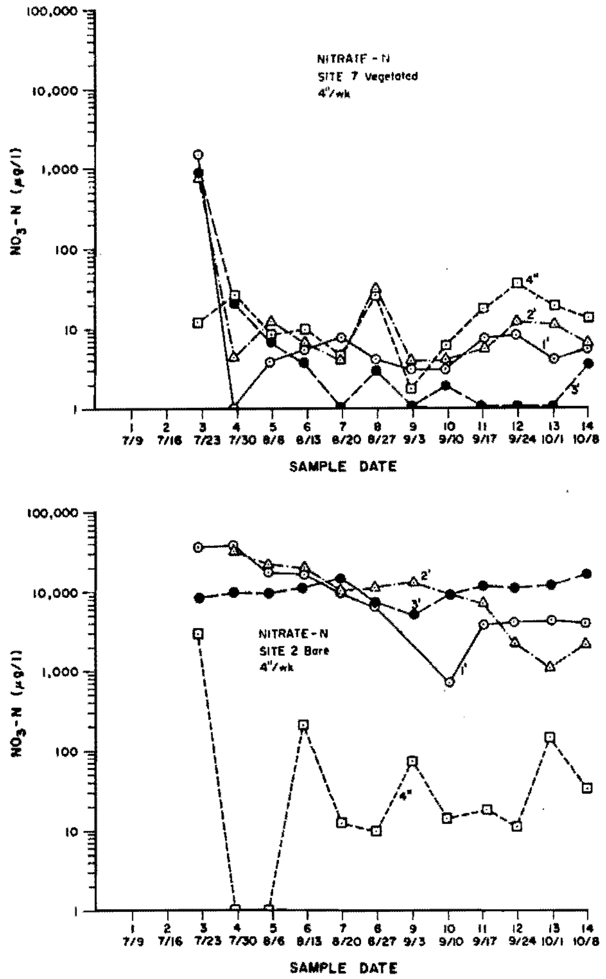

Figure 46. Nitrate nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

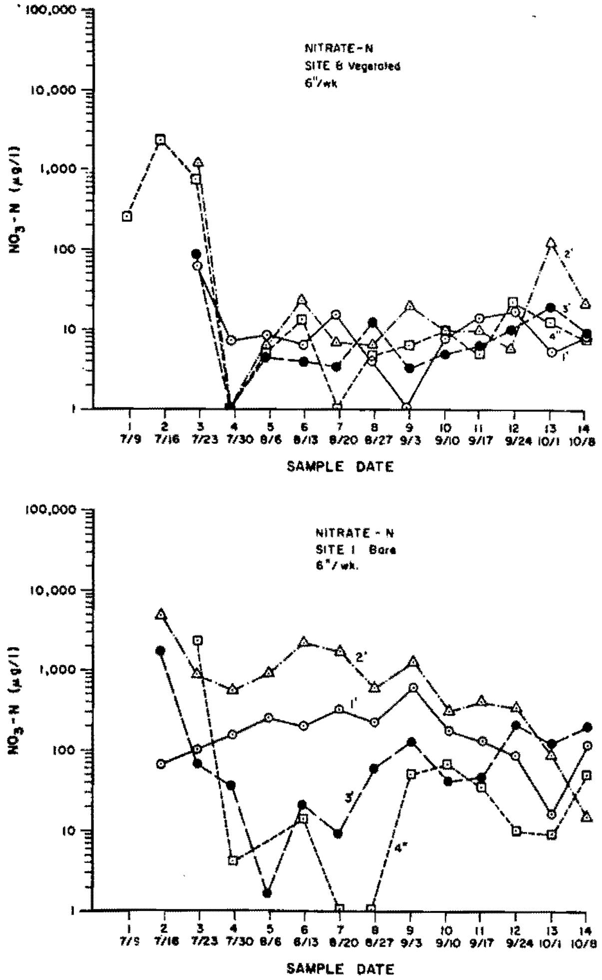

Figure 47. Nitrate nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 15.3 cm (6 in) per week (Hicken, 1978).

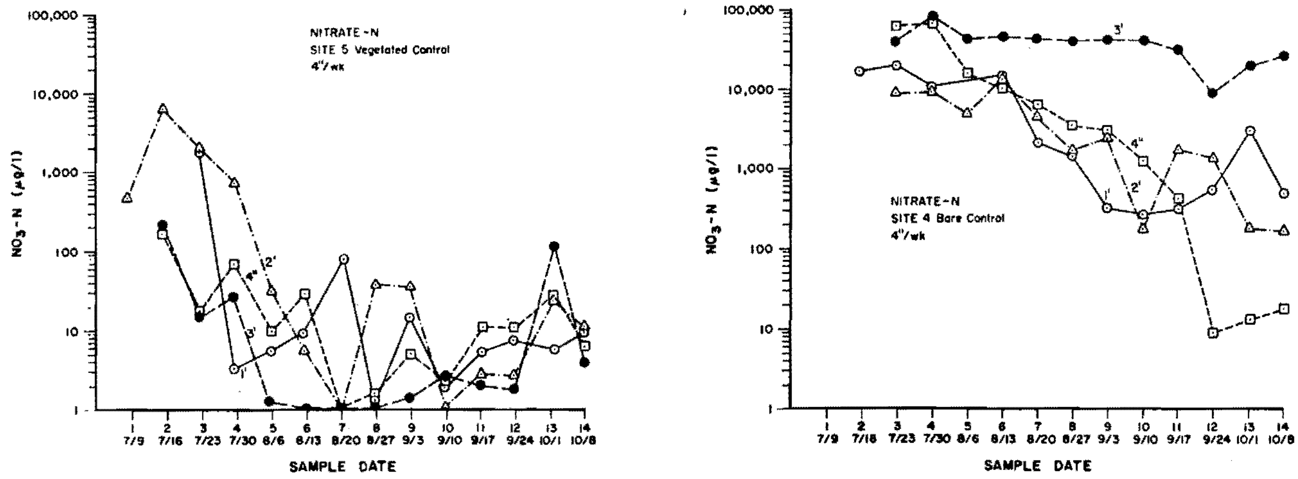

Figure 48. Nitrate nitrogen concentrations at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of control water to the slow rate site at 12.2 cm (4 in) per week (Hicken, 1978).

Table 13. Mean influent and effluent ammonia, nitrite, and nitrate nitrogen concentrations for the slow rate system, mg/l (Hicken, 1978).

	Soil Depth, cm	Wastewater Sites						Control Site	
		5.1 cm/wk		10.2 cm/wk		15.3 cm/wk		10.2 cm/wk	
		Veg.	Bare	Veg.	Bare	Veg.	Bare	Veg.	Bare
Ammonia nitrogen[a]	influent	0.832	0.832	0.832	0.832	0.832	0.832	0.181	0.181
	10	0.050	0.031	0.034	0.061	0.041	0.039	0.041	0.027
	30	0.076	0.031	0.038	0.042	0.034	0.043	0.031	0.027
	60	0.261	0.064	0.057	0.051	0.255	0.098	0.101	0.045
	90	0.935	0.151	0.274	1.330	0.122	0.074	0.449	0.182
Nitrite nitrogen	influent	0.058	0.058	0.058	0.058	0.058	0.058	0.001	0.001
	10	0.004	0.066	0.001	0.031	0.003	0.009	0.001	0.034
	30	0.018	0.040	0.002	0.150	0.005	0.036	0.002	0.592
	60	0.013	0.689	0.003	0.841	0.004	0.035	0.003	0.015
	90	0.002	0.517	0.055	1.900	0.002	0.030	0.002	0.589
Nitrate nitrogen[b]	influent	0.069	0.069	0.069	0.069	0.069	0.069	0.020	0.020
	10	0.110	5.530	0.018	0.303	0.010	0.026	0.018	13.300
	30	0.029	14.600	0.005	13.000	0.014	0.202	0.015	5.360
	60	0.093	24.100	0.010	32.200	0.022	0.734	0.018	4.150
	90	0.010	19.000	0.004	10.900	0.014	0.081	0.016	38.000

Statistical significance at 95 percent confidence level.

[a] No significant difference due to cover, water type, application rate. Significant difference due to soil depth.

[b] Significant differences due to cover, water type, application rate, and soil depth.

Salinity and Sodic Hazard

Overland flow system

Weekly variations in specific conductance and sodium adsorption ratios (SAR) are shown in Figures 49 and 50. Very little change was observed in either of these parameters as the wastewater flowed through the overland flow plots. The specific conductance of all influent and effluent samples did not exceed 750 μmho/cm. SAR values did not exceed 1.0. Crop irrigation is a potential use of effluent from overland flow sites. Waters with high salinity and high sodium adsorption ratios can limit irrigation usage. A classification chart for the evaluation of irrigation waters is shown in Figure 51 and explained in Table 14. All data from the overland flow effluents fall in the C2-S1 category. The effluents could be used on most soils, with little danger of the development of harmful exchangeable sodium levels. Vegetation with a moderate salt tolerance could be grown without special salinity control measures. Since overland flow treatment has little effect on salinity and sodium adsorption ratio values, the use of the effluent for irrigation depends on the quality of the secondary effluent.

Slow rate system

Mean specific conductance and sodium adsorption ratios are presented in Table 15. No significant differences were noted in the specific conductance values, with respect to water type, cover, application rate, or soil depth. Figures 52, 53, 54, 55, and 56 show weekly lagoon effluent and percolate conductance results. Percolate samples did have higher values than the influent. Sodium adsorption ratios in most of the percolate samples were higher than the influent, especially at the 60 and 90 cm soil depths. Specific conductance values range from about 1000 to 17,000 μmho/cm in the percolate, with the majority being around 1000 to 2000 μmho/cm. SAR values range from 1 to 25, with the majority less than 5 above the 30 cm depth and greater than 10 below 30 cm. Reuse of the subsurface drainage would be limited to well drained soils and crops with a high salt tolerance.

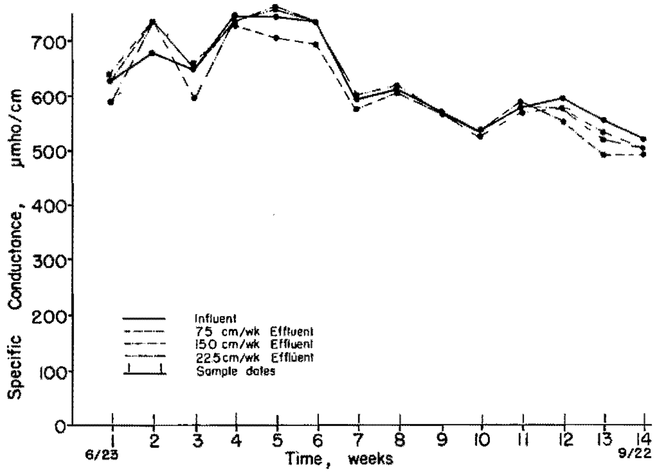

Figure 49. Influent and effluent electroconductivity data for the overland flow system.

Influent and effluent sodium adsorption

System comparison

Almost no change is observed in specific conductance and SAR values as wastewater passes through the overland flow plots (Figures 49 and 50). As previously discussed, all of the results fall into the C2-S1 category on the classification chart (Figure 51) and could be used for irrigation under most circumstances

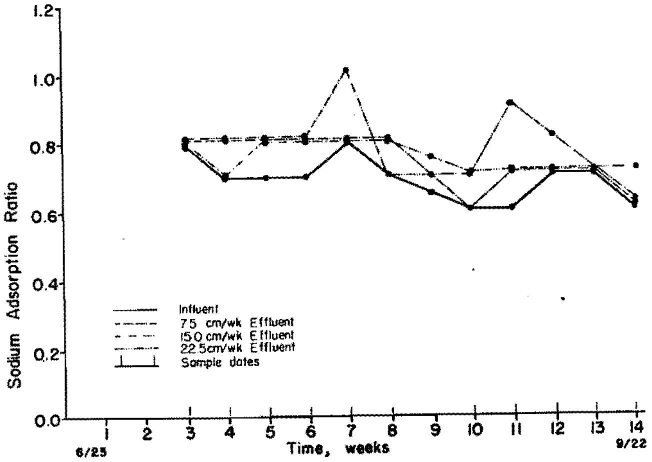

Figure 50. ratios (SAR) for the overland flow system.

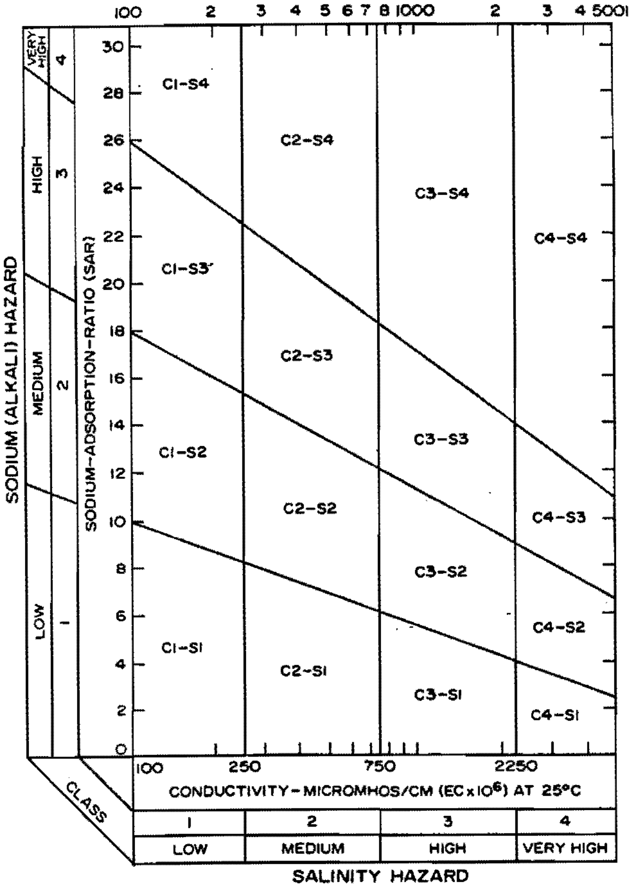

Figure 51. Diagram for the classification of irrigation waters (USDA, 1954).

Table 14. Description of classification scheme shown in Figure 51 (USDA, 1954).

Conductivity

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management--good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with water of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Table 15. Mean electroconductivity data and sodium adsorption ratios for the slow rate system (Hicken, 1978).

	Soil Depth, cm	Wastewater Sites						Control Sites	
		5.1 cm/wk		10.2 cm/wk		15.3 cm/wk		10.2 cm/wk	
		Veg.	Bare	Veg.	Bare	Veg.	Bare	Veg.	Bare
Specific conductance[a] (μmho/cm)	influent	570	570	570	570	570	570	483	483
	10	2560	1030	970	1010	1350	910	1210	1170
	30	3060	1830	1060	1860	1240	1090	1500	1810
	60	6470	6260	1420	1590	1710	1970	1640	3020
	90	16900	12100	3770	9180	5140	1940	3290	12100
SAR	influent	1	1	1	1	1	1	2	2
	10	1	3	2	3	1	3	1	2
	30	1	2	6	5	1	2	2	3
	60	8	11	7	21	8	11	6	6
	90	11	13	21	25	11	13	15	15

Significant at 95 percent confidence level.
[a]No significant differences due to cover, water type, application rate, or soil depth.

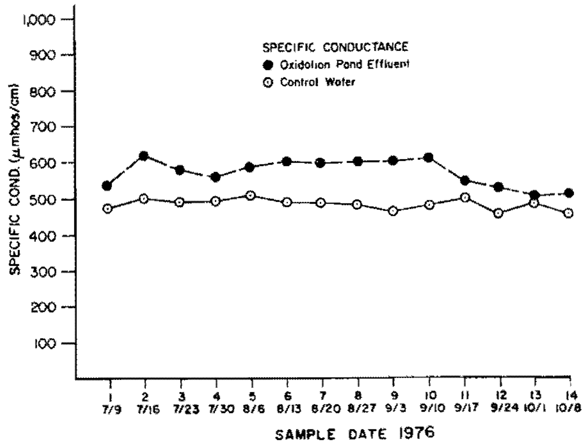

Figure 52. Specific conductance values of the lagoon effluent and control water applied to the slow rate system (Hicken 1978).

with little or no problem. Further irrigation with the slow rate system return flow would be difficult. Percolate specific conductance values (Table 15) fall in the C3 category most often and sometimes in the C4 category. This water could not be used on soils with restricted drainage, special salinity controls might be required, and crops would have to be very salt tolerant. SAR values remained in the S1 category until the 60 cm depth was reached. Most of the values at the 60 and 90 cm depths remained in the S2 category, but some were included in the S3 classification. This water could be used with appropriate soil conditions and special management.

Operational Difficulties

Overland flow system

Operation of the overland flow system was relatively simple, but several problems were encountered. Data were collected for the period from the week of June 20-24 through the week of September 19-23. No

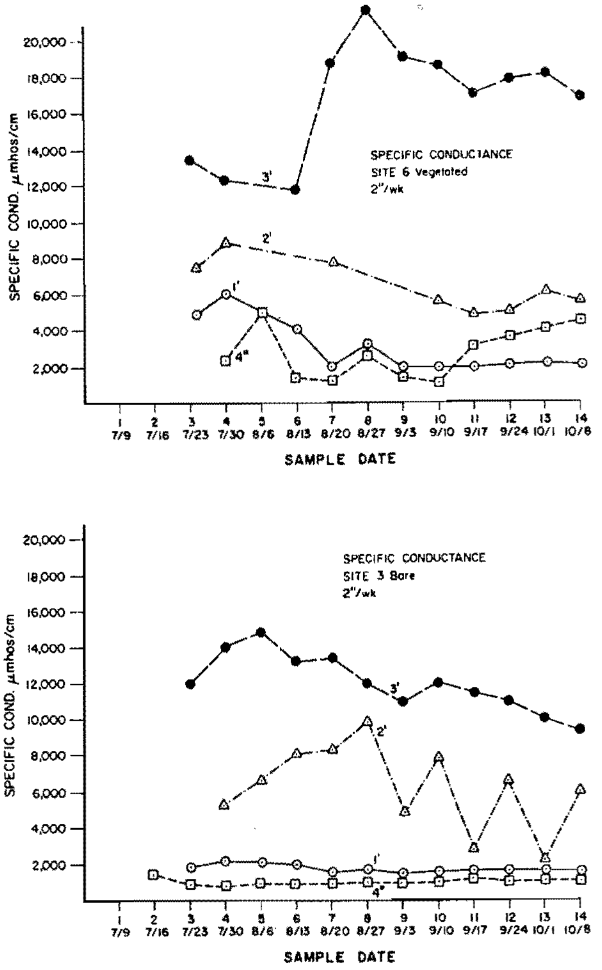

Figure 53. Specific conductance values at the soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 5.1 cm (2 in) per week (Hicken, 1978).

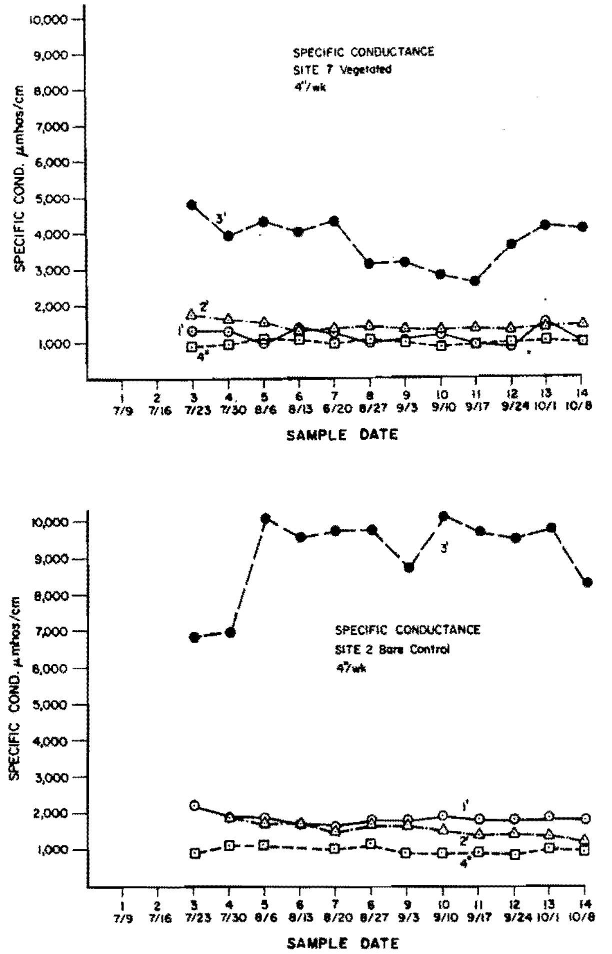

Figure 54. Specific conductance values at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

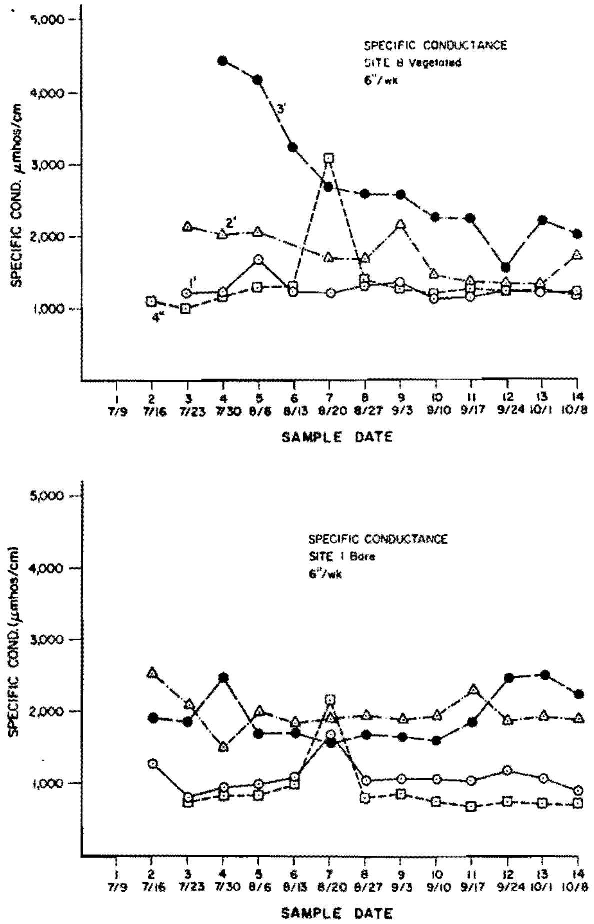

Figure 55. Specific conductance values at soil mantle depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of lagoon effluent to the slow rate site at 15.3 cm (6 in) per week (Hicken, 1978).

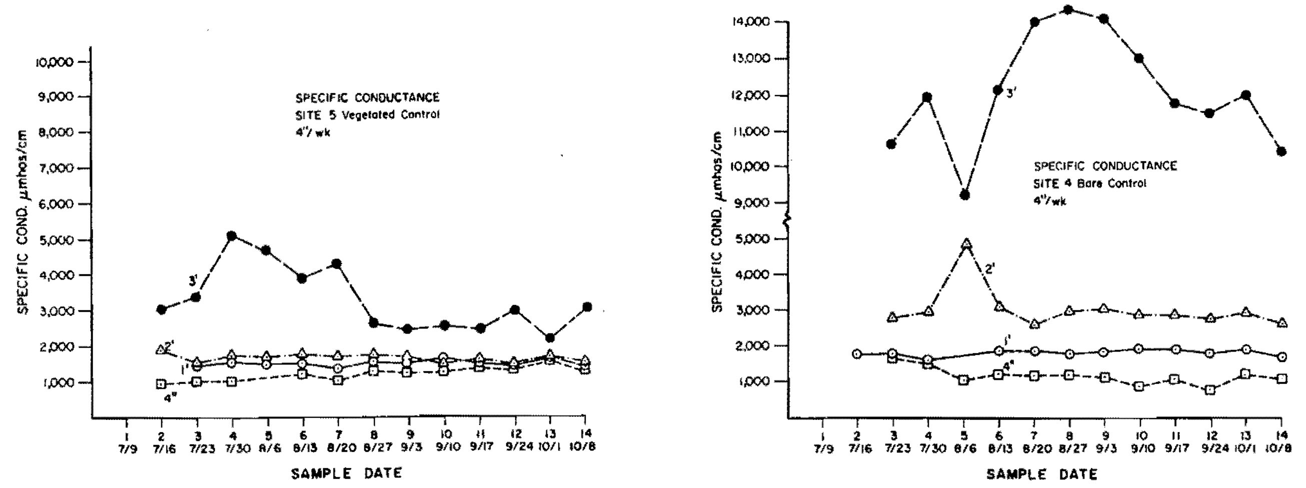

Figure 58. Specific conductance values at soil mantel depths of 10 cm (4 in), 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) following the application of control water to the slow rate site at 10.2 cm (4 in) per week (Hicken, 1978).

data were collected for the week of August 15-19 because of an electrical pump failure caused by wet circuits produced during extremely heavy precipitation. Daily pump operation was hampered by priming difficulties resulting from hydraulic grade line discontinuities in the intake line. These discontinuities were due to a change in the pump location for security reasons. With only a few exceptions, the length of application period and the time of day for each application remained consistent throughout the season. Filamentous growth in the holding pond caused severe intake line clogging near the end of the summer. The problem was temporarily controlled by periodic cleaning of the intake and the construction of a large basket enclosure.

Major problems associated with the plots themselves included nonuniform plant and wastewater coverage, channelization, and mosquito propagation. Applications of grass seed exceeding three to four times the recommended dosage were necessary to establish an adequate grass cover. Even then, soil conditions inhibited growth in some sections of the plots (Figure 57). Although a great deal of care was used in site preparation, small inconsistencies in the site grading resulted in nonuniform flow distributions. Aluminum baffles and lateral troughs were used to distribute the flow more evenly. In the 7.5 cm/wk plot wastewater flow did not cover approximately 10 percent of the total available area. Coverage in the other two plots was nearly complete after baffles were incorporated. On the 22.5 cm/wk plot the wastewater tended to flow on a diagonal from right to left because of a lateral pitch of approximately 1.5 percent near the lowest end. Channelization was a severe problem in all three plots (Figure 58). This caused short circuiting and a high degree of scouring in the channels. Also, it was difficult to establish a dense grass cover in the channels. The use of baffles and periodic filling of the channels helped to control this problem to a certain extent, but not completely. Similar erosion problems have been observed in overland flow sites at Vicksburg, Mississippi, and Paris, Texas (Peters, 1978).

Large mosquito populations were observed at the overland flow site. Moist conditions in the plots following the application periods and sometimes stagnant conditions in the drainage ditch undoubtedly facilitated mosquito propagation. The problem was primarily due to inadequate drainage resulting from insufficient slope in the effluent drainage ditch. The mosquitoes were bred in the drainage ditch and subsequently migrated to the overland flow site which provided an ideal habitat.

Spray irrigation system

Some difficulties were encountered in operating at the application rates used in this study. At the 15.3 cm/wk application rate, severe ponding occurred on the soil surface of both the bare and vegetated plots. The soil eventually became saturated to the point that water was still standing after the three day drying period. At the 10.2 cm/wk rate, ponding also occurred, but not until mid-season. On the vegetated site receiving 10.2 cm/wk, no ponding was observed until the last three or four weeks of the irrigation season. No ponding occurred on the vegetated site receiving 5.1 cm/wk of wastewater. Some ponding was observed on the bare site at the end of the season. Algal growth appeared on the soil surface of all the bare sites receiving wastewater and control water. The growth on the control surface was very minute compared to that on the other sites. Ponding on the control site, however, was similar to the degree of ponding on the 10.2 cm/wk wastewater site. This indicates that algal growth apparently did not affect the infiltration rates.

Figure 57. Grass distribution at the lower end of an overland flow plot.

Figure 58. Channelization and baffles in an overland flow plot.

Large mosquito populations were observed at the spray irrigation site. Moist conditions resulting from ponding enhanced insect propagation. The number of mosquitoes seemed to increase as the application rate increased (i.e., as more ponding occurred).

Comparison of Overland Flow With Slow Rate System

Major problems associated with the overland flow system included nonuniform plant and wastewater coverage, channelization and the resulting short circuiting, and mosquito propagation. The mosquito problem would be greatly alleviated by proper drainage ditch construction. Great care in site preparation and the establishment of vegetation might reduce some of the problems associated with the overland flow system. Major problems observed at the slow rate site included severe ponding and mosquito propagation. A lower application rate of approximately 5 cm/wk could solve the ponding problem and reduce mosquito propagation under similar conditions. The spray irrigation site was not properly drained. Soil permeability was apparently too low to allow wastewater irrigation at economical application rates.

Economic Considerations and Design Criteria

Overland flow system

The overland flow system evaluated in this study was not effective in providing the degree of treatment necessary to meet future wastewater discharge standards. Before tertiary treatment design criteria for overland flow systems can be formulated, more research must be conducted. Vegetative cover density and uniformity requirements must be established. The flow length necessary for optimum nutrient removals should be determined. Treatment efficiencies on soils with various surface characteristics need to be compared.

Qualitatively, it appears that overland flow treatment efficiencies will be optimal on soils with a high surface clay content and using a very dense, uniform grass cover approaching that of a lawn. Bunch grasses, such as Reed Canary, were shown in this and other studies to promote channeling of the wastewater (Peters, 1978). Sod forming grasses would likely be more applicable. Initial site preparation is of utmost importance. The slopes must be graded to a very high uniformity to reduce erosion problems and aid in the even distribution of wastewater. A dense grass cover can also reduce many of the erosion problems. The vegetation should be completely established before wastewater applications proceed. Flow lengths necessary for the removal of low level nutrient concentrations may be much shorter than previously suspected. In this study nutrient concentrations in the applied wastewater after 18 m of flow were as low as or lower than concentrations in the effluent (36 m of flow). Few differences in treatment efficiencies were noted as a result of the varying application rates used in this study. Any application rates in the range specified in the literature (Pound et al., 1976; EPA, 1977) may be suitable from the standpoint of treatment efficiency.

Estimated costs for overland flow systems are presented in Table 15. Overland flow could be an economical means of tertiary treatment, if adequate degrees of treatment can eventually be obtained. The costs shown do not include land costs. These would have to be evaluated on a site specific basis. Site grading, preparation, and maintenance costs might increase substantially in tertiary treatment systems because of the extraordinary care that apparently must be taken. Depending on the type of grass cover and soil, periodic grading and earthwork to maintain even slopes and remove erosion channels might be required. Extensive site maintenance might significantly increase overland flow costs.

Slow rate system

Initial soil conditions at proposed slow rate sites are extremely important. Soil permeability will determine if an economical application rate can be utilized. Adequately designed subsurface drainage systems can be used to increase allowable irrigation application rates in soils with relatively low permeabilities. High initial concentrations of nitrate nitrogen, phosphorus, and organic carbon can severely limit treatment efficiencies for a number of years, especially if percolate collection and discharge is required. Various application rates within the range of those listed in the literature (Pound et al., 1976; EPA, 1977) appear to result in essentially the same treatment efficiencies. Generally, the suitability of slow rate for tertiary treatment must be evaluated on a site specific basis.

Estimated costs for wastewater irrigation systems using various application methods are presented in Table 16. Ordinarily, capital and operational costs are less in systems using center pivot sprinkler systems. Other methods, however, appear to be economical. Land costs are not included and might be prohibitive because of the relatively low application rates that can be utilized. Crop harvesting however can provide additional revenue to offset the total cost of the system.

System comparison

Costs are highly variable for slow rate and overland flow systems and depend upon specific site conditions and land costs. The costs presented in Table 16 indicate that overland flow treatment can be more economical than slow rate. Due to the variety of local site conditions and costs, engineering judgment and evaluation must be used to select a suitable tertiary treatment process.

Table 16. Comparative costs for land application alternatives (Middlebrooks et al., 1978).

Process or System and Location	Design Flow MGD	Design Loading	Annual Costs[a] $/1000 Gallons Capital	O&M	Total	Cost Base	Reference
Overland Flow[b]							
EPA Estimate	0.3	2 in/wk	0.27	0.14	0.41	1973	EPA, 1975b
EPA Estimate	0.3	8 in/wk	0.19	0.10	0.29	1973	EPA, 1975b
Davis, California	5.0	8 in/wk	0.10	0.05	0.15	1976	Brown and Caldwell, 1976
Slow Rate[b]							
EPA Estimate	0.3	2 in/wk	0.20	0.19	0.39	1973	EPA, 1975b
EPA Estimate	0.3	4 in/wk	0.17	0.15	0.32	1973	EPA, 1975b
Slow Rate-Center Pivot[b]							
EPA Estimate	0.3	2 in/wk	0.19	0.18	0.37	1973	EPA, 1975b
EPA Estimate	0.3	4 in/wk	0.16	0.13	0.29	1973	EPA, 1975b
Slow Rate-Solid Set[b]							
EPA Estimate	0.3	2 in/wk	0.26	0.15	0.41	1973	EPA, 1975b
EPA Estimate	0.3	4 in/wk	0.19	0.12	0.31	1973	EPA, 1975b
Rapid Infiltration							
EPA Estimate	0.3	8 in/wk	0.17	0.10	0.27	1973	EPA, 1975b
EPA Estimate	0.3	24 in/wk	0.13	0.08	0.21	1973	EPA, 1975b

[a] Costs amortized at 7 percent and a 20 year life.
[b] Values can vary by 50 percent and do not include land costs.

SUMMARY AND CONCLUSIONS

In order to evaluate the effectiveness of overland flow in upgrading secondary wastewater lagoon effluent, three 15 x 36 m plots on a slope of approximately 2.5 percent were constructed and sown for a high density grass cover. Wastewater was applied at the upper end of each plot at rates of 7.5, 15, and 22.5 cm/wk from June 20 through September 22, 1977. Influent and effluent samples were analyzed for concentrations of BOD_5, suspended solids, nitrogen forms, phosphorus forms, and salinity. Water balances were conducted and a dye study was used to determine plot detention times. Ammonia stripping from the sprinklers was also determined. Results from the overland flow system were compared to similar results obtained from a slow rate project conducted the preceding year on an adjacent site and using a similar effluent.

The slow rate site consisted of eight test areas, each approximately 15 m square. Four sites were vegetated and four were bare. Wastewater was applied to each pair of vegetated and bare areas from July 5 until October 7, 1976. Application rates of 5.1, 10.2, and 15.3 cm/wk were utilized. Additionally, one pair received 10.2 cm/wk of well water to serve as an experimental control. Test parameters were similar to those used in the overland flow system evaluation. Based on the data obtained and pertinent observations, the following conclusions can be made.

Overland Flow System

1. Low level concentrations of BOD_5 and suspended solids were not reduced by overland flow treatment. Concentrations of these constituents tended to increase slightly.

2. Concentrations of less than 5 mg/l BOD_5 and suspended solids were not obtained at average influent concentrations of BOD_5 and suspended solids of 7.8 and 11.2 mg/l, respectively.

3. A very tight surface soil texture is needed to prevent excessive scouring of particulate matter.

4. In this study Reed Canary grass, a bunch former, did not provide a dense enough cover for the filtration of low level suspended solids concentrations.

5. System age had no effect on the removal of BOD and suspended solids.

6. Phosphorus removal did not exceed 40 percent in the overland flow system on a concentrations basis and 55 percent on a mass basis.

7. Mean effluent total phosphorus concentrations exceeded 1.5 mg/l. Orthophosphate phosphorus mean effluent concentrations exceeded 1.1 mg/l for all hydraulic loading rates.

8. The majority of phosphorus removal occurred in the upper half of each plot. Concentrations tended to increase in the lower half.

9. Surface soil characteristics were a major factor in the removal of phosphorus. As the clay content increased, phosphorus removal increased.

10. System age had little effect on phosphorus removal efficiencies.

11. Mean ammonia removal efficiencies ranged from 75 to 94 percent in the overland flow system, with effluent concentrations of 0.135 to 0.391 mg/l.

12. Nitrite and nitrate nitrogen concentrations in the effluents were only slightly different from the influent, with all mean concentrations less than 0.13 mg/l. The mean influent concentrations of nitrite and nitrate were 0.07 and 0.065 mg/l, respectively.

13. Significant differences (95 percent confidence level) were not observed between influent and effluent organic nitrogen concentrations.

14. Essentially all of the ammonia nitrogen removal occurred in the upper half of each plot.

15. Stripping of ammonia nitrogen at a pH of 7.5 to 8.5 as the wastewater was applied accounted for approximately 10 percent of the total ammonia removal.

16. Soil interaction may be a major factor in ammonia nitrogen removal. The effluent concentration remained essentially constant in the 15 cm/wk effluent regardless of influent concentration. The soil on this plot had a high clay content and therefore provided many ion adsorption sites.

17. System age did not affect ammonia removal efficiencies.

18. Specific conductance and SAR values were not changed as the wastewater passed through the overland flow sites. The effluent was suitable for irrigation under most circumstances.

19. Infiltration and evapotranspiration accounted for 15 to 30 percent of the applied wastewater, with the remainder being discharged.

20. Average plot detention times in the overland flow system were 30 minutes, 45 minutes, and 40 minutes at application rates of 22.5 cm/wk, 7.5 cm/wk, and 15 cm/wk, respectively.

21. Short circuiting was evident on all treatment sites.

22. Non-uniform flow distributions, channelization, and mosquito propagation were the major problems associated with the system operation.

23. The best degree of treatment for all parameters was obtained at the 15 cm/wk application rate. Surface soil conditions, and not application rate, appeared to account for most of the differences among the plots.

Slow Rate System

1. No significant differences were observed in total organic carbon (TOC) concentrations with respect to application rate, vegetation, or type of irrigation water.

2. TOC concentrations increased with increasing soil depth because of the soil organic carbon content.

3. Suspended solids concentrations in the subsurface drainage were consistently lower than in the influent and averaged less than 3 mg/l.

4. No significant differences in orthophosphate phosphorus concentrations were observed with respect to application rate, vegetation, or water type.

5. A large decrease in orthophosphate phosphorus concentration was observed near the soil surface. Influent or the phosphate phosphorus concentrations were 1 mg/l. Effluent orthophosphate concentrations exceed 0.03 mg/l at 10 cm depth. The concentration then increased with increasing soil depth, because of the leaching of soluble phosphates.

6. Orthophosphate phosphorus removal efficiencies exceeded 80 percent at all depths and 93 percent at the 10 cm depth.

7. Stripping accounted for approximately 35 percent of the ammonia nitrogen removal as the wastewater was applied to the soil at initial pH values of about 9.0.

8. Nutrient assimilation was not a significant ammonia nitrogen removal mechanism. Adsorption may have been the major mechanism.

9. Application rate had no significant effect (95 percent confidence level) on percolate ammonia nitrogen concentrations.

10. The greatest ammonia nitrogen removal occurred in the upper 10 cm of soil. The concentration then increased with increasing soil depth.

11. Significant differences (95 percent confidence level) in nitrate nitrogen concentrations were observed with respect to water type, vegetation, application rate, and soil depth.

12. The leaching of soil nitrates is the predominant factor resulting in percolate concentrations.

13. Nitrate nitrogen concentrations decreased with increasing application rate.

14. Nitrate nitrogen concentration differences between the vegetated and nonvegetated sites may be due to initial soil levels and not nutrient assimilation.

15. Specific conductance values in the percolate ranged from 1000 to 17,000 µmho/cm, with the majority less than 2000 µmho/cm.

16. Sodium adsorption ratios were generally less than 5 above the 30 cm depth and greater than 10 below 30 cm.

17. Ponding and mosquito propagation were major operational difficulties. No ponding occurred on the vegetated site receiving 5.1 cm/wk of wastewater. The mosquito population appeared to be reduced at this application rate.

Comparison of Overland Flow and Slow Rate Systems

1. Slow rate lagoon effluent treatment can result in a high degree of suspended solids removal. Suspended solids removal in the overland flow system used in this study was not sufficient to meet future 1980 discharge standards of 10 mg/l, approximately 90 percent of the operational time.

2. Neither the slow rate system nor the overland flow system used in this study reduced organic pollutants.

3. Phosphorus removal in the overland flow system was relatively low (29 to 52 percent). The removal in the slow rate system was much higher (i.e. exceeded 80 percent at all depths). Effluent samples collected at any depth from the USU Drainage Farm slow rate system would still exceed 0.03 mg/l orthophosphate phosphorus and 0.09 mg/l total phosphorus.

4. Ammonia nitrogen removal and conversion was high (exceeding 80 percent) for both systems. The increase in ammonia nitrogen with depth can be a disadvantage in the slow rate system.

5. Nitrate nitrogen concentrations in the discharge from the slow rate system depended on initial soil conditions and sometimes exceeded drinking water standards of 10 mg/l. Very low concentrations (less than 0.3 mg/l) were found in the overland flow effluent.

6. It would be difficult to use effluent from the slow rate system for further irrigation unless appropriate soil and vegetation were provided. There should be no problem in using overland flow effluent for irrigation purposes.

7. Mosquito propagation was a problem in both land application systems.

RECOMMENDATIONS FOR FUTURE RESEARCH

1. Overland flow BOD and suspended solids removals should be more fully evaluated with respect to the relative importance of physical and biological mechanisms and the density or type of grass cover.

2. A study to determine the relative importance of ammonia nitrogen removal mechanisms in overland flow systems should be undertaken. In particular, a comparison of soil adsorption efficiencies and removal resulting from the nitrification-denitrification cycle should be made.

3. The flow length necessary to produce an effluent containing low levels of nutrients should be determined.

4. Pathogenic virus and bacteria removal efficiencies using overland flow and slow rate should be evaluated. The ultimate fate of these organisms should be determined.

5. Various wastewater application methods for overland flow and slow rate systems should be studied to determine the most efficient method with respect to aerosol formation and treatment efficiencies.

6. Slow rate and overland flow treatment efficiencies in various climatic zones should be evaluated and compared.

APPLICATION OF RESULTS

This research demonstrated that land treatment by overland flow and slow rate application is potentially limited as a "polishing" treatment mechanism for lagooned wastewater effluent. This specific conclusion is based on conditions at the specific site studied, namely the relatively high quality of the wastewater produced by the lagoon, the type and density of vegetative cover, the soil characteristics, the site preparation, and other local factors.

In spite of the fact that other previously noted studies have demonstrated similar limits for the removal of organic and inorganic constituents when they used different quality influents at various geographically separated sites, the use of land application of wastewater is a proven technique for renovation and productive reuse of wastewater. This research and other related work does indicate that the rate of application by the slow rate process may need to be balanced by crop uptake to avoid residual organic and inorganic nutrient discharge. In the case of overland flow, where the lower limit for removal of organic constituents was reached, the further renovation of the effluent by such methods as slow rate application or advanced waste treatment may be required to completely preclude introduction of residual organic and inorganic constituents into the receiving watercourse.

Overland flow sites must be carefully prepared to produce a uniform flow across the plot and preclude channeling. The species of grass should also be carefully chosen to produce a dense sod-type vegetative cover. Irregularities in preparation of the site such as grading errors, differential compaction, inappropriate or inconsistent soil types, etc., likely will result in a decreased wastewater-to-grass contact and associated deterioration of effluent quality. If such potential problems are not considered during system development and early implementation, the integrity of the entire treatment facility may degenerate and the maintenance costs will be excessive.

Planners considering use of land treatment must consider these limitations, but they must also consider the desired or mandated water quality in the receiving stream. Properly designed and operated land application systems do produce a very high quality effluent. Such systems may also provide returns through the sale of cash crops or animals fed with the crop yield. It is this return and the availability of large amounts of inexpensive land that permits the large scale overland flow-slow rate application-lagoon system in Melbourne, Australia, to treat municipal wastewater for 2 cents per 1000 liters compared to the cost of 7.5 cents per 1000 liters at a nearby activated sludge facility. The Melbourne land treatment site was constructed in the late nineteenth century.

If these factors seem favorable, the prospective user of land application should consider a limited scale field test to determine the efficiency of the proposed system with the specific wastewater. In this manner the appropriate design for the site characteristics, the need for pretreatment, and effluent quality will be evident before installation of the full scale process.

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APPENDICES

Appendix A: Overland Flow Data

Table 17. Weekly BOD5 concentration data for the overland flow system, mg/l.

Week	Influent	Effluents 7.5 cm/wk	Effluents 15 cm/wk	Effluents 22.5 cm/wk
1 (6-23)	-	-	-	-
2	5.8	6.6	6.8	9.2
3	9.0	7.9	7.1	7.4
4	9.1	9.6	8.1	11.3
5	9.4	8.2	7.7	9.4
6	10.4	14.0	13.8	11.0
7	10.3	13.3	12.1	11.5
8	9.4	10.4	9.1	9.5
9	-	-	-	-
10	6.9	8.9	6.4	7.8
11	6.4	11.0	7.2	7.8
12	5.0	7.8	5.4	5.4
13	3.6	14.6	4.5	4.3
14 (9-22)	-	-	-	-

Table 19. Weekly volatile suspended solids concentration data for the overland flow system, mg/l.

Week	Influent	Effluents 7.5 cm/wk	Effluents 15 cm/wk	Effluents 22.5 cm/wk
1 (6-23)	-	-	-	-
2	1.6	4.0	2.8	2.2
3	4.4	5.6	5.8	4.8
4	7.6	8.0	6.4	7.0
5	7.4	5.4	7.4	7.4
6	7.8	9.4	10.0	10.2
7	6.0	12.6	8.2	8.8
8	11.0	11.2	10.8	10.0
9	-	-	-	-
10	11.4	19.4	15.2	17.8
11	8.0	9.4	6.6	9.6
12	5.8	10.6	7.4	8.0
13	3.3	7.8	4.2	4.8
14 (9-22)	3.6	4.2	4.3	4.6

Table 18. Weekly total suspended solids concentration data for the overland flow system, mg/l.

Week	Influent	Effluents 7.5 cm/wk	Effluents 15 cm/wk	Effluents 22.5 cm/wk
1 (6-23)	-	-	-	-
2	6.4	19.0	12.8	8.8
3	10.0	12.4	11.0	13.0
4	8.6	11.6	9.0	9.4
5	11.0	11.0	10.4	11.2
6	7.8	11.4	11.8	11.6
7	10.0	17.6	12.4	13.6
8	12.6	12.8	11.8	10.8
9	-	-	-	-
10	24.0	29.8	27.2	23.6
11	17.0	17.0	15.0	13.2
12	11.8	16.2	13.0	11.8
13	8.0	16.2	11.4	7.8
14 (9-22)	6.8	9.2	9.8	7.4

Table 20. Weekly total phosphorus concentration data for the overland flow system, mg/l.

Week	Influent	Effluents 7.5 cm/wk	Effluents 15 cm/wk	Effluents 22.5 cm/wk
1 (6-23)	-	-	-	-
2	2.319	1.933	1.660	2.003
3	2.241	1.613	1.394	1.753
4	2.364	2.073	1.859	2.222
5	2.432	1.674	1.437	1.803
6	2.258	1.613	1.535	1.794
7	1.802	1.155	0.955	1.392
8	2.303	1.606	1.490	1.923
9	-	-	-	-
10	2.665	1.984	1.727	2.293
11	2.308	1.819	1.286	1.908
12	2.463	1.968	1.746	2.235
13	2.258	1.817	1.603	2.025
14 (9-22)	2.072	1.707	1.386	1.691

Table 21. Weekly orthophosphate phosphorus concentration data for the overland flow system, mg/l.

Week	Influent	7.5 cm/wk Midpoint	7.5 cm/wk Effluent	15 cm/wk Midpoint	15 cm/wk Effluent	22.5 cm/wk Midpoint	22.5 cm/wk Effluent
1 (6-23)	1.672	1.345	1.076	1.092	1.005	1.395	1.240
2	2.083	-	1.587	-	1.428	-	1.712
3	1.760	-	1.313	-	1.126	-	1.476
4	2.303	1.092	1.745	1.363	1.601	1.912	1.896
5	1.780	0.951	1.211	0.724	1.073	1.618	1.382
6	1.825	1.048	1.317	1.041	1.168	1.667	1.492
7	1.345	0.710	0.774	1.060	0.647	1.187	0.964
8	1.896	1.533	1.146	0.842	1.011	1.533	1.206
9	-	-	-	-	-	-	-
10	2.073	1.331	1.385	1.272	1.338	1.618	1.719
11	1.984	1.206	1.463	1.222	1.074	1.883	1.580
12	2.263	1.165	1.651	1.321	1.510	1.863	1.925
13	2.125	1.506	1.678	1.278	1.349	1.537	1.780
14 (9-22)	1.938	1.289	1.484	1.148	1.195	1.328	1.578

Table 22. Weekly ammonia nitrogen concentration data for the overland flow system, mg/l.

		7.5 cm/wk		15 cm/wk		22.5 cm/wk	
Week	Influent	Midpoint	Effluent	Midpoint	Effluent	Midpoint	Effluent
1 (6-23)	1.146	0.489	0.183	0.164	0.082	0.452	0.370
2	2.131	-	0.726	-	1.000	-	1.069
3	2.147	-	0.116	-	0.044	-	0.316
4	1.930	0.105	0.171	0.055	0.077	0.584	0.395
5	1.747	0.052	0.038	0.081	0.056	0.096	0.082
6	1.794	0.040	0.076	0.037	0.031	0.255	0.231
7	0.818	0.031	0.048	0.044	0.046	0.045	0.033
8	1.312	0.228	0.030	0.042	0.029	0.150	0.054
9	-	-	-	-	-	-	-
10	2.308	0.056	0.102	0.074	0.062	0.585	0.483
11	3.203	0.162	0.284	0.147	0.056	1.703	1.008
12	3.453	0.140	0.445	0.252	0.091	1.057	1.004
13	3.996	0.384	0.926	0.151	0.113	1.189	1.516
14 (9-22)	4.320	0.336	0.832	0.193	0.071	1.274	1.120

Table 23. Weekly nitrite nitrogen concentration data for the overland flow system, mg/l.

		7.5 cm/wk		15 cm/wk		22.5 cm/wk	
Week	Influent	Midpoint	Effluent	Midpoint	Effluent	Midpoint	Effluent
1 (6-23)	0.108	0.101	0.054	0.089	0.037	0.138	0.083
2	0.006	-	0.014	-	0.011	-	0.018
3	0.103	-	0.050	-	0.038	-	0.081
4	0.072	0.044	0.031	0.080	0.029	0.124	0.069
5	0.044	0.013	0.017	0.007	0.020	0.040	0.047
6	0.049	0.007	0.019	0.029	0.023	0.078	0.062
7	0.115	0.010	0.007	0.030	0.005	0.075	0.039
8	0.010	0.047	0.005	0.004	0.003	0.027	0.004
9	-	-	-	-	-	-	-
10	0.008	0.008	0.029	0.017	0.009	0.063	0.049
11	0.022	0.056	0.097	0.065	0.029	-	0.094
12	-	-	-	-	-	-	-
13	0.032	0.066	0.110	0.045	0.049	0.098	0.096
14 (9-22)	0.270	0.270	0.260	0.265	0.146	0.345	0.255

Table 24. Weekly nitrate nitrogen concentration data for the overland flow system, mg/l.

		7.5 cm/wk		15 cm/wk		22.5 cm/wk	
Week	Influent	Midpoint	Effluent	Midpoint	Effluent	Midpoint	Effluent
1 (6-23)	0.075	0.111	0.158	0.181	0.063	0.086	0.237
2	0.033	-	0.082	-	0.037	-	0.199
3	0.078	-	0.041	-	0.034	-	0.033
4	0.037	0.287	0.029	0.077	0.018	0.086	0.041
5	0.060	0.089	0.005	0.020	0.014	0.122	0.090
6	0.028	0.012	0.052	0.041	0.021	0.046	0.032
7	0.061	0.033	0.025	-	0.013	0.054	0.026
8	0.017	0.054	0.017	0.039	0.009	0.034	0.015
9	-	-	-	-	-	-	-
10	0.030	0.020	0.080	0.020	0.020	0.120	0.190
11	0.088	0.074	0.193	0.085	0.091	-	0.136
12	0.119	-	0.200	-	0.055	-	0.180
13	0.148	0.094	0.260	0.165	0.101	0.182	0.194
14 (9-22)	0.070	0.140	0.290	0.195	0.064	0.255	0.205

Table 25. Weekly organic nitrogen concentration data for the overland flow system, mg/l.

		Effluents		
Week	Influent	7.5 cm/wk	15 cm/wk	22.5 cm/wk
1 (6-23)	-	-	-	-
2	2.820	4.225	1.759	2.461
3	1.579	2.361	1.959	1.989
4	3.362	2.138	2.136	2.828
5	2.507	2.553	3.007	2.122
6	2.035	1.858	2.173	2.283
7	4.378	2.743	2.831	2.587
8	1.682	1.831	1.831	2.131
9	-	-	-	-
10	2.344	2.985	2.460	3.343
11	1.494	2.767	1.480	2.322
12	1.813	1.854	1.790	2.089
13	1.692	2.321	1.844	2.059
14 (9-22)	0.898	1.204	0.862	1.638

Table 26. Weekly pH data for the overland flow system.

		Effluents		
Week	Influent	7.5 cm/wk	15 cm/wk	22.5 cm/wk
1 (6-23)	8.7	8.7	8.7	8.6
2	8.2	8.5	8.5	8.4
3	8.4	8.4	8.5	8.5
4	8.2	8.4	8.5	8.4
5	8.3	8.8	8.7	8.6
6	8.2	8.4	8.4	8.4
7	8.7	8.9	8.9	8.8
8	7.7	7.6	7.6	7.6
9	-	-	-	-
10	8.2	8.6	8.6	8.5
11	8.0	8.6	8.8	8.6
12	8.1	8.6	8.6	8.5
13	8.0	8.5	8.5	8.4
14 (9-22)	7.8	8.3	8.3	8.2

Table 27. Ammonia nitrogen stripping in the overland flow system, mg/l.

		Effluents		
Week	Influent	7.5 cm/wk	15 cm/wk	22.5 cm/wk
7	0.818	0.769	0.875	0.718
8	1.312	1.130	1.160	1.152
10	2.308	2.150	2.278	2.043
11	3.203	2.797	3.083	2.947
12	3.453	3.037	2.873	3.012
13	3.996	-	2.873	3.791
14	4.320	3.895	-	3.692

Table 28. Weekly specific conductance data for the overland flow system, μ mho/cm.

		Effluents		
Week	Influent	7.5 cm/wk	15 cm/wk	22.5 cm/wk
1 (6-23)	625	618	585	628
2	675	730	725	735
3	643	649	589	644
4	743	724	726	738
5	746	704	749	752
6	729	667	726	725
7	589	570	590	596
8	608	604	607	613
9	-	-	-	-
10	532	532	532	522
11	575	586	575	565
12	593	553	573	573
13	550	490	530	520
14 (9-22)	520	490	500	500

Table 29. Weekly sodium adsorption ratio (SAR) data for the overland flow system.

		Effluents		
Week	Influent	7.5 cm/wk	15 cm/wk	22.5 cm/wk
1 (6-23)	-	-	-	-
2	-	-	-	-
3	0.8	0.8	0.8	0.8
4	0.7	0.8	0.8	0.7
5	0.7	0.8	0.8	0.8
6	0.7	0.8	0.8	0.8
7	0.8	0.8	1.0	0.8
8	0.7	0.8	0.7	0.8
9	-	-	-	-
10	0.6	0.6	0.7	0.7
11	0.6	0.7	0.9	0.7
12	0.7	0.7	0.8	0.8
13	0.7	0.7	0.7	0.7
14 (9-22)	0.6	0.6	0.6	0.7

Table 30. Dye concentration data for the overland flow system detention time study, fluorescene.

		Effluents		
Time, min.	Influents	7.5 cm/wk	15 cm/wk	22.5 cm/wk
0	0	0	0	0
2	0	-	-	-
4	0	-	-	-
6	0.2	-	-	-
8	45.0	-	-	-
10	12.0	0	0	0
12	8.0	-	-	-
14	7.2	-	-	-
16	4.2	-	-	-
18	4.7	-	-	-
20	3.6	0.2	0	0
25		1.5	0	112
30		40	4	123
40		67	66	47
50		45	66	47
60		24	43	16
70		13	12	12
80		1	12	5

Table 31. Influent-effluent flow data for the overland flow system, l/min.

	Application Rate		
	7.5 cm/wk	15 cm/wk	22.5 cm/wk
Influent	29	58	87
Effluents			
Week			
10	22	48	82
12	19	38	72
14	22	40	70

Table 32. Soil analysis results for the overland flow system.

	15 cm Depth					
	7.5 cm/wk		15 cm/wk		22.5 cm/wk	
	Start	Finish	Start	Finish	Start	Finish
Texture	SL	SCL	SL	SL	-	SC
CEC, meg/100 g	18.5	21.2	17.4	23.8	-	17.2
pH	8.1	8.2	8.3	8.1	-	8.4
ECe	3.0	1.5	2.0	0.8	-	0.7
Sodium, meg/100 g[a]	1.0	0.6	0.9	0.3	-	0.3
Potassium, mg/ℓ[a]	0.2	0.1	0.1	0.1	-	0.1
Chloride, meg/ℓ	1.3	0.3	0.6	0.1	-	0.1
Phosphorus, mg/ℓ	3.8	6.0	2.3	5.5	-	3.4
Nitrate, mg/ℓ	43.0	2.9	13	3.3	-	0.4
Org. Carbon, percent	3.6	2.9	3.0	1.8	-	1.9
Bicarbonate, meg/ℓ	0.1	0.2	0.1	0.3	-	0.3
Iron, mg/ℓ	2.6	1.6	3.4	3.0	-	1.8
Zinc, mg/ℓ	0.7	0.5	1.1	0.8	-	0.6
Copper, mg/ℓ	0.8	0.7	1.0	1.2	-	0.5
Exch Sodium, meg/100 g	1.7	1.0	1.8	0.6	-	0.6
Exch Potassium, meg/100 g	1.3	1.3	1.3	1.4	-	1.2
Exch Calcium, meg/100 g	52.0	-	53.0	-	-	-
Exch Magnesium, meg/100 g	12.0	12.0	13.0	12.1	-	11.4

	100 cm Depth					
	7.5 cm/wk		15 cm/wk		22.5 cm/wk	
	Start	Finish	Start	Finish	Start	Finish
Texture	SCL	SC	C	C	-	C
CEC, meg/100 g	14.1	17.2	13.0	18.4	-	14.5
pH	8.4	8.5	8.6	8.6	-	9.2
ECe	11.0	0.8	7.0	0.9	-	2.0
Sodium, meg/100 g[a]	6.3	0.4	6.0	0.5	-	2.0
Potassium, mg/ℓ[a]					-	
Chloride, meg/100 g	4.1	0.1	2.9	< .1	-	0.5
Phosphorus, mg/ℓ	2.3	2.6	8.6	2.6	-	2.2
Nitrate, mg/ℓ	8.0	< .1	2.0	< .1	-	0.4
Org. Carbon, percent	1.1	1.4	0.7	1.2	-	0.6
Bicarbonate, meg/ℓ	0.1	0.3	0.2	0.4	-	0.6
Iron, mg/ℓ	3.2	1.2	5.6	2.0	-	6.0
Zinc, mg/ℓ	0.8	0.6	2.0	0.8	-	10.4
Copper, mg/ℓ	1.1	0.5	1.8	2.1	-	1.1
Exch Sodium, meg/100 g	4.9	0.6	5.5	1.9	-	6.3
Exch Potassium, meg/100 g	1.7	1.3	3.0	1.8	-	1.7
Exch Calcium, meg/100 g	48.0	-	45.0	-	-	-
Exch Magnesium, meg/100 g	12.0	12.4	13.0	12.5	-	11.1

[a] H_2O soluble.

Appendix B: Spray Irrigation Data

Table 33. Total organic carbon data for the spray irrigation system, mg/l (Hicken, 1978).

Test Site	Depth	Date–1976										
		7/16	7/23	8/13	8/20	8/27	9/3	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"		21	<1	32	17	18	18	15	12	<1	15
	1'		8	11	41	6	11	<1	10	27	47	18
	2'	40	3	20	70	4	15	<1	8	33	27	22
	3'		7	32	74	<1	35	48	10	12	11	26
Bare 6"/wk	4"		5	6	23	<1	7	18	<1	12	<1	8
	1'	16	14	10	32	29	14	18	25	<1	<1	16
	2'		3	37	67	12	31	18	5	18	37	25
	3'		<1	31	55	1		18	5	9	23	18
Vegetated 4"/wk	4"	22	<1	4	9	<1	15	6	10	3	2	7
	1'	24	<1	25	18	3	12	6	10	12	2	11
	2'		6	18	41	11	15	6	20	6	8	14
	3'	27	5	30	98	16	22	<1	<1	18	15	23
Bare 4"/wk	4"	26	8	<1	44	3	21	30	15	<1	5	15
	1'		21	40	65	2	22	30	5	18	14	24
	2'			36	54	<1	36	6	5	18	5	20
	3'	25	<1	21	83	25	37	12	10	18	20	25
Vegetated 2"/wk	4"		8	33	41	8	24	<1	50	24	15	22
	1'		<1	64	62	19	95	18	10	6	29	34
	2'	17	44	105	127	30	39	<1	25	30	16	43
	3'		<1	54	56	17	105	29	8	15	28	34
Bare 2"/wk	4"	<1	7	<1	19	2	12	36	45	<1	17	14
	1'	28	22	27	51	11	26	<1	15	<1	18	20
	2'	48		34	104	58	46	66	35	<1	43	48
	3'	6	<1	23	105	<1	48	48	20	12	30	29
Vegetated Control 4"/wk	4"	39	5	13	64	<1	12	36	<1	6	34	21
	1'		3	29	57	<1	21	54	15	9	22	23
	2'	6	2	<1	72	<1	22	<1	15	12	9	14
	3'	<1	<1	63	119	<1	109	<1	5	12	17	32
Bare Control 4"/wk	4"	4	10	29	49	<1	14	6	<1	36	20	17
	1'	32	1	32	67	7	30	30	12	<1	23	24
	2'		18	62	97	24	78	18	<1	<1	26	36
	3'		8	48	62	14	39	24	42	12	35	32
Oxidation Pond Effluent		21	12	<1	22	5	15	18	8	12	1	12
Control Water		19	15	<1	6	<1	<1	<1	<1	3	<1	4

Table 34. Vegetation data for the spray irrigation system, kg/hectare (Hicken, 1978).

	Second Season				
Irrigation Water Type	E	E	E	C	N
Irrigation Rate (cm/wk)	5.1	10.2	15.2	10.2	0.0
Volatile Vegetable Matter (kg/ha)	1040	1190	1120	1260	937

E = stabilization pond effluent
C = control well water
N = nonirrigated.

Table 35. Suspended solids data for the spray irrigation system, mg/l (Hicken, 1978).

		Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
In Stabilization Pond Effluent	Total Suspended Solids	21.3	18.3	9.13	12.0	5.70	4.19	9.14	9.56	10.2	9.2	8.56	16.5	11.3	32.6	12.7
In Drain	Total Suspended Solids				3.55	2.15	2.20	1.05	2.14	3.42	2.19		3.40	2.63	1.11	2.38
In Stabilization Pond Effluent	Volatile Suspended Solids	19.5	15.8	7.00	8.30	5.00	0.65	6.09	8.29	6.62	8.60	8.24	12.7	6.15	24.1	9.79
In Drain	Volatile Suspended Solids				0.75	1.20	0.36	0.72	0.61	2.78	1.89		2.55	1.78	0.69	1.33

Table 36. Orthophosphate phosphorus data for the spray irrigation system, μg/l (Hicken, 1978).

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"	276	58	134	212	44	56	50	44	52	40	16	36	48	46	79
	1'			631	830	91	179	143	104	150	153	149	142	149	140	238
	2'			820	665	473	385	280	264	248	224	203	210	195	215	348
	3'				189	156	163	120	137	156	141	118	121	92	126	138
Bare 6"/wk	4"			44	26	63	74	67	60	78	61	74	85	91	89	61
	1'		71	385	46	77	71	58	66	82	64	70	72	76	78	92
	2'		206	252	307	185	151	180	177	184	192	271	199	174	172	204
	3'		94	72	61	81	99	95	101	92	92	110	109	121	103	95
Vegetated 4"/wk	4"			92	52	62	42	39	69	44	63	26	54	45	54	53
	1'			22	41	42	50	35	49	58	63	51	69	71	80	52
	2'			160	36	94	71	49	73	66	51	48	58	60	60	69
	3'			143	86	175	166	157	41	134	129	90	106	165	135	127
Bare 4"/wk	4"			435	310	272	166	111	145	142	130	119	125	121	85	180
	1'			86	70	73	78	79	95	108	101	102	100	89	69	88
	2'				67	54	52	43	73	91	86	96	90	92	83	126
	3'			3133	1350	382	335	210	169	170	204	48	210	254	206	556
Vegetated 2"/wk	4"						36	32	20	45	37	28	30	30	20	31
	1'				453	484	225	38	93	59	87	57	106	94	92	162
	2'				257		323	82	249	297	278	118	255	287	323	224
	3'				670	423	693	251	202	246	233	115	230	243	275	326
Bare 2"/wk	4"		45	29	49	28	21	8	15	16	28	26	54	53	58	33
	1'			137	57	169	58	21	49	50	262	53	55	53	63	86
	2'				78	112	148	135	221	125	242	61	125	54	242	140
	3'			179	229	168	261	234	262	278	109	236	245	240	251	224
Vegetated Control 4"/wk	4"		78	258	83	49	46	48	37	36	38	19	30	41	32	45
	1'			53	69	78	74	54	76	72	74	53	63	68	65	66
	2'	286	127	136	52	108	101	104	76	94	87	73	70	94	91	107
	3'		260	86	197	184	145	154	105	102	116	71	98	107	106	133
Bare Control 4"/wk	4"			8	33	29	25	20	18	27	40	11	39	30	29	26
	1'		9	17	24	38	33	30	64	62	29	42	61	59	54	40
	2'			144	154	148	161	118	151	178	155	166	158	160	155	154
	3'			523	171	136	145	160	168	172	172	169	172	174	185	195
Oxidation Pond Effluent		391	369	768	988	1400	1100	1030	927	1480	1230	829	2090	642	881	1000
Control Water		47	34	41	28	21	30	21	28	29	31	22	19	18	25	28

Table 37. Ammonia nitrogen data for the spray irrigation system, μg/l (Hicken, 1978).

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated	4"	90	79	30	25	31	37	29	10	<1	28	34	62	40		41
6"/wk	1'			73	21	17	45	30	15	<1	12	26	41	48	49	34
	2'			193	209	113	224		208	<1	378	228	484	254		255
	3'				106	49	124	80	115	<1	223	195	127	85		122
Bare	4"			77	<1	36	73	27	22	9	42	44	60	35		39
6"/wk	1'		40	30	28	36	24	60	53	56	72	45	47	33		44
	2'		32	55	101	75	43	170	109	51	131	164	120	129		98
	3'		43	31	<1	82	66	90	78	38	116	119	121	108		74
Vegetated	4"			37	28	24	23	21	22	22	69	17	42	45	52	34
4"/wk	1'			48	34	12	42	21	15	24	51	32	28	101	54	38
	2'			89	26	24	18	17	41	34	39	84	97	104	114	57
	3'			195	208	286	765		120	175	292	222	209	254	283	274
Bare	4"			24	251	138	15	38	22	<1	31	40	43	46	24	61
4"/wk	1'			155	16	40	40	29	20	<1	32	33	40	25	32	42
	2'				129	8	7	21	15	<1	47	74	65	83	59	51
	3'				7320	2710	887		134	<1	159	76	356	224	74	1330
Vegetated	4"				89	64	44	39	29	34	32	36	88	44		50
2"/wk	1'			1060	190	197	113	28	32	43	51	50	58	42	32	76
	2'			108	246		799	268	171		168	151	222	214	261	261
	3'				1450	2450	2410	549	454	431	515	445	366	283		935
Bare	4"		53	35	43	16	29	29	12	20	36	32	30	28	36	31
2"/wk	1'				54	38	9	26	21	32	31	27	29	41		31
	2'				58	30	4	64	64	64	111	47	111	35	119	64
	3'		54	30	254	79	144	110	122	185	227	190	213	171	183	151
Vegetated	4"		90	36	44	27	36	44	22	38	34	34	48	36		41
Control	1'			52	<1	30	27	43	28	24	48	29	33	29		31
4"/wk	2'	196	47	38	<1	145	163	133	90	106	117	60	102	112		101
	3'			739	1020	581	756	459	402	216	337	243	90	90		449
Bare	4"			29	39	24	12	23	28	21	32	30	34	25	26	27
Control	1'		26	32	49	28	4	29	22	24	25	24	35	28	29	27
4"/wk	2'			69	28	55	52	30	28	28	25	70	66	43	40	45
	3'			333	222	87	141	189	173	186	199	150	216	141	152	182
Oxidation Pond Effluent		82	178	492	1170	2160	1950	1020	640	1830	1450	170	279	131	99	832
Control Water		218	168	168	170	204	178	201	159	197	185	153	189	168	173	181

Table 38. Nitrite nitrogen data for the spray irrigation system, μg/l (Hicken, 1978).

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"	14	3	4	1	<1	<1	1	2	1	<1	<1	9	<1	<1	3
	1'			29	<1	<1	2	3	1	6	3	<1	12	1	2	5
	2'			4	2	2	6	3	6	6	3	4		<1	3	4
	3'			7	1	1	<1	<1	2	<1	<1	1	3	<1	<1	2
Bare 6"/wk	4"			32	3		6	2	3	27	8	14		3	<1	9
	1'		38	103	58	30	56	20	19	46	29	19	24	14	14	36
	2'		201	41	3	39	31	27	29	19	14	20	20	5	3	35
	3'		151	54	12	2	2	4	15	85	3	10	24	13	10	30
Vegetated 4"/wk	4"			4	<1	<1	<1	<1	4	2	1	2	<1	1	<1	1
	1'			5	7	1	<1	1	2	<1	1	2	<1	<1	<1	2
	2'			14	7	1	<1	<1	8	<1	<1	1	<1	<1	<1	3
	3'			644	<1	1	<1	1	<1	2	<1	2	<1	<1	<1	55
Bare 4"/wk	4"			155	6	5	13	17	13	7	119	1		5	2	31
	1'			6	16	148	204	325	218	198	112	340	107	67	60	150
	2'				960	2510	1760	1270	897	527	380	377	243	200	129	841
	3'			2160	3390	3060	2820	3440	3200	1970	1130	589	453	297	256	1900
Vegetated 2"/wk	4"			4	5	2	21	<1	2	1	<1	2	1	1	1	4
	1'			170	7	6	3	2	2	14	2	<1	<1	2	10	18
	2'			58	3	48		3	2	3	3	2		<1	3	13
	3'			7	2	3	4	1	2	1	2	3	<1	1	<1	2
Bare 2"/wk	4"		720	26	14	22	4	24	22	14	8	4	4	3	<1	66
	1'			32	32	35	11	75	22	41	59	10	40	33	6	40
	2'				112	1210	580	1220	658	537	1260	444		183		689
	3'		951	80	658	681	1000	602	934	509	780	572	49	442	53	517
Vegetated Control 4"/wk	4"		<1	3	1	2	1	3	<1	<1	<1	1	<1	<1	<1	1
	1'			17	2	2	<1	4	2	<1	<1	<1	<1	<1	<1	2
	2'	2	8	6	1	2	<1	3	2	9	<1	<1	<1	2	<1	3
	3'		<1	5	2	3	3	3	1	<1	<1	2	<1	1	<1	2
Bare Control 4"/wk	4"			290	17	25	9	24	12	14	5	8	<1	2	2	34
	1'		280	1910	761	2960	606	610	333	59	21	79	24	22	32	592
	2'			29	6	17	44	20	<1	10	7	4	21	22	1	15
	3'			50	188	643	402	879	572	613	1130	835	700	590	472	589
Oxidation Pond Effluent		7	13	12	3	14	49	19	28	14	64	71	40	43	428	58
Control Water		<1	<1	<1	<1	<1	2	5	4	<1	<1	3	1	<1	<1	1

Table 39. Nitrate nitrogen data for the spray irrigation system, μg/l (Hicken, 1978).

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"	265	2450	814	<1	5	14		5	6	11	5	26	15	8	10
	1'			64	7	9	6	17	5	<1	8	16	19	6	8	14
	2'			1210	<1	7	27	7	6	20	10	10	6	124	28	22
	3'			88	<1	5	4	4	14	3	5	6	10	21	8	14
Bare 6"/wk	4"			2540	4		13	<1	<1	54	77	35	12	9	54	26
	1'		70	104	167	244	219	353	260	661	197	131	88	15	117	202
	2'		5190	989	600	981	2620	<1	628	1750	352	405	376	91	14	734
	3'		1930	72	35	2	21	10	62	159	44	43	204	121	195	81
Vegetated 4"/wk	4"			12	29	9	10	5	28	2	6	38	39	19	16	18
	1'			1170	<1	4	6	8	4	3	3	8	9	4	6	5
	2'			855	5	13	7	5	31	4	5	11	14	12	7	10
	3'			916	22	6	4	<1	3	<1	2	1	1	1	3	4
Bare 4"/wk	4"			3110	<1	<1	213	14	9	75	13	17	11	136	32	303
	1'			34600	37200	18300	16000	9980	7370		763	4270	4420	4820	4740	13000
	2'				29800	22000	20700	10300	13300	14500		7650	2010	1100	2470	32200
	3'			8640	9910	9840	11100	14300	7900	5620	10200	11500	12400	12500	17400	10900
Vegetated 2"/wk	4"				310	397	448	4	7	12	5	5	10	5	9	110
	1'				178	86	5	14	8	11	2	3	18	<1	<1	29
	2'			12		78	290	224		14		10	102		14	93
	3'			935	54	38	<1	<1	10	2	1	1	3	3	3	10
Bare 2"/wk	4"		26300	11300	8470	6920	4030	2860	1160	5240	1110	2800	438	1030	262	5530
	1'			16200	25300	30000	40000	3710	15200	16900	5040	5490	4310	4650	2350	14600
	2'			8900	38900	46400	69200		24300	29000	21300	12600	5960	6490		24100
	3'			11500	15100	14400	18000	19200	13600	39800	22700	29400	25900	2450	15600	19000
Vegetated Control 4"/wk	4"		186	18	70	10	32	<1	2	5	3	14	13	38	8	18
	1'			2090	3	6	9	92	1	14	2	6	9	6	13	15
	2'	508	7060	2110	769	36	6	<1	42	40	<1	3	3	37	14	18
	3'		221	16	28	1	<1	<1	<1	1	3	2	2	130	5	16
Bare Control 4"/wk	4"			59000	61500	15300	9810	6410	3330	3060	1280	405	8	14	16	13300
	1'		19500	21300	1040		13900	2080	1550	324	285	321	519	2950	493	5360
	2'			9500	9680	4930	13600	4460	1680	2420	172	1710	1430	171	1	4150
	3'			40900	71400	40400	43500	42900	39800	42200	39800	34200	9020	23600	28100	38000
Oxidation Pond Effluent		18	226	13	32	11	19	8	3	18	33	185	218	34	262	69
Control Water			117	8	18	6	5	1	2	10	13	5	37	4	16	20

Table 40. Sodium adsorption ratios for the spray irrigation system (Hicken, 1978).

Test Site	Depth	Date–1976										
		7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/10	9/17	9/24	Avg.
Vegetated 6"/wk	4"	2	1	1	1	1	1	1	1	1	1	1
	1'			1		1		2	2	1		1
	2'		36	10	9	9				3		8
	3'			13	13	12	11	10	9	8		11
Bare 6"/wk	4"		4			3	2					3
	1'	2		2	2	2	2	2	2	2		2
	2'		31	15	7	5		8	6	11	7	11
	3'		21	9	12	14		15	13	13	10	13
Vegetated 4"/wk	4"			2	1	2	2	2	2	2	1	2
	1'		16	10	6	6		4	2	2	2	6
	2'		8	8	7	8	7	7	6	5	5	7
	3'		5	36	29		37	20	18	13	15	21
Bare 4"/wk	4"		4	4	3	2	3	3	4	2	3	3
	1'		7	4	6	5	5	7	5	4	5	5
	2'		16	11	24	20		29	25	22	19	21
	3'			22	18		8	10	39	47	29	25
Vegetated 2"/wk	4"				2	2	2	3	1	3	4	2
	1'				12	14	5	7	4	3	3	7
	2'									12		12
	3'			20	21		23	20	25	34	27	24
Bare 2"/wk	4"			3	2	2	2	3	2	2	2	2
	1'			11	12	12	9	10	10	6	7	10
	2'			15	20	9	11	27	39	16		19
	3'			25	23	6	13	15	46	46	26	25
Vegetated Control 4"/wk	4"		1	2	1	1	2	2	1	1	1	1
	1'		3	3	2	1	1	2	1	1		2
	2'		17	5	5	4	4	5	3	3	3	6
	3'		20	15	18	17	19	13	12	9	14	15
Bare Control 4"/wk	4"		3	2	2	2			2			2
	1'			4	3	2	3	2	3	2	2	3
	2'			7	8	5	7	8	5	5	5	6
	3'			23	17	11	6	7	17	20	22	15
Oxidation Pond Effluent			1	1	1	1	1	2	2	2	2	1
Control Water			1	2	2	1	2	2	2	2	2	2
Drain				10	12	4	3		14			9

Table 41. Specific conductance values for the spray irrigation system, µmho/cm (Hicken, 1978).

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated	4"		1100	980	1150	1290	1290	3070	1390	1230	1180	1260	1210	1230	1160	1350
6"/wk.	1'			1200	1490	1180	1260	1200	1290	1320	1140	1170	1210	1210	1180	1240
	2'			2110	2010	2050		1690	1680	2130	1450	1310	1310	1250	1770	1710
	3'			31700	4430	4170	3220	2680	2590	3550	2260	2220	1560	2220	2030	5140
Bare	4"			726	830	824	790	2150	791	856	725	672	730	717	720	910
6"/wk.	1'		1270	760	920	970	1090	1690	1040	1050	1050	1030	1280	1080	900	1090
	2'		2520	2090	1500	2000	1830	1900	1940	1890	1940	2300	1850	1950	1880	1970
	3'		1910	1860	2490	1700	1710	1590	1690	1650	1600	1870	2470	2500	2230	1940
Vegetated	4"			920	970	1050	1070	950	1020	1010	858	950	906	994	936	970
4"/wk.	1'			1300	1300	1030	960	854	1000	1120	909	944	893	1490	942	1060
	2'			1790	1610	1560	1350	1320	1440	1350	1280	1360	1260	1322	1420	1420
	3'			4840	3950	4370	4050	4320	3120	3220	2830	2610	3610	4180	4130	3770
Bare	4"			961	1140	1110		1070	1120	953	903	933	910	1050	992	1010
4"/wk.	1'			2270	1930	1910	1711	1690	1790	1730	1940	1810	1840	1930	1800	1860
	2'			—	1930	1740	1720	1560	1730	1600	1530	1480	1500	1440	1250	1590
	3'			6920	7020	10200	9640	9390	9850	8810	10200	9820	9600	9900	8310	9180
Vegetated	4"			—	2450		1360	1220	2590	1480	1180	3030	3640	4050	4580	2560
2"/wk.	1'			4520	6040	5000	4050	2280	2600	2000	1940	1850	2040	2290	2140	3060
	2'			7560	8930			7810			5630	4890	5050	6230	5670	6470
	3'			13300	12300		11800	18900	21700	19200	18700	17200	17900	18200	17000	16900
Bare	4"		1420	922	806	916	950	932	990	987	1010	1170	1000	1150	1100	1030
2"/wk.	1'			1920	2290	2250	2070	1540	1870	1630	1640	1710	1700	1700	1670	1830
	2'				5320	6720	8200	8280	9930	4840	7880	2870	6600	2220	6040	6260
	3'			12000	14100	14900	13300	13500	12100	11000	12000	11500	11000	10700	9410	12100
Vegetated	4"		976	1040	1050		1200	1040	1290	1220	1220	1360	1360	1520	1270	1210
Control	1'			1500	1590	1510	1540	1360	1570	1540	1620	1490	1430	1630	1320	1500
4"/wk.	2'		1910	1560	1770	1680	1790	1690	1730	1680	1550	1550	1470	1530	1360	1640
	3'		3060	3410	5120	4700	3940	4360	2610	2470	2550	2400	2950	2210	3020	3290
Bare	4"			1670	1540	1050	1230	1190	1240	1125	864	1100	726	1220	1100	1170
Control	1'		1810	1720	1560		1940	1880	1780	1820	1940	1860	1870	1940	1650	1810
4"/wk.	2'			2780	3000	4900	3100	2600	2970	3000	2810	2810	2770	2900	2600	3020
	3'			10700	12000	9280	12200	14100	14400	14100	13000	11800	11500	12000	10400	12100
Oxidation Pond Effluent		536	623	567	561	592	600	599	603	602	610	546	526	502	508	570
Control Water		474	500	490	496	514	486	487	481	463	479	502	455	484	455	483

Table 42. Soil sample analyses results for the spray irrigation system (Hicken, 1978).

Sample Site	Sample Depth (Inches)	Na meq/l			K meq/l			Ca meq/l			% C			% N		
		Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2
Vegetated 6"/wk	0-6	0.4	0.2	0.2	< 0.1	0.1	< 0.1	< 0.1	0.1	0.2	4.1	3.6	4.2	0.3	0.4	0.4
	9-15	0.5	0.3	0.1	< 0.1	0.1	< 0.1	< 0.1	0.1	0.1	3.2	2.7	3.4	0.3	0.3	0.3
	30-36	4.2	1.0	0.6	0.2	0.1	< 0.1	0.3	< 0.1	< 0.1	0.7	0.8	0.9	0.1	0.1	0.1
Bare 6"/wk	0-6	< 0.1	0.9	0.2	< 0.1	0.1	< 0.1	< 0.1	0.1	0.1	2.7	3.6	3.6	0.3	0.3	0.3
	9-15	< 0.1	1.0	0.2	< 0.1	0.1	< 0.1	< 0.1	< 0.1	0.1	1.9	1.5	3.4	0.2	0.2	0.3
	30-36	4.2	4.9	0.8	0.2	0.1	< 0.1	0.1	0.1	< 0.1	0.7	0.5	0.8	0.1	0.1	0.1
Vegetated 4"/wk	0-6	1.0	0.1	0.2	0.1	0.1	< 0.1	< 0.1	0.1	0.2	2.3	4.4	4.4	0.2	0.4	0.4
	9-15	4.0	0.2	0.1	0.3	< 0.1	< 0.1	< 0.1	0.1	0.1	1.3	2.6	2.3	0.2	0.3	0.2
	30-36	4.3	1.4	0.8	0.2	0.1	< 0.1	0.1	0.1	< 0.1	0.5	0.5	0.6	0.1	0.1	0.1
Bare 4"/wk	0-6	0.2	0.2	0.3	0.1	0.1	< 0.1	0.2	0.1	0.2	6.0	3.9	3.8	0.4	0.3	0.3
	9-15	0.3	0.4	0.4	< 0.1	0.1	< 0.1	< 0.1	0.1	< 0.1	3.0	2.3	1.8	0.2	0.2	0.2
	30-36	8.5	3.3	2.9	0.3	0.1	< 0.1	0.2	< 0.1	< 0.1	0.4	0.5	0.5	0.0	0.1	0.1
Vegetated 2"/wk	0-6	0.7	0.2	0.2	0.1	0.1	< 0.1	0.1	0.1	0.1	3.6	2.4	2.2	0.4	0.2	0.2
	9-15	1.2	0.8	0.4	< 0.1	0.1	0.1	0.2	0.1	< 0.1	2.7	1.4	1.2	0.3	0.1	0.1
	30-36	3.0	4.0	10.5	< 0.1	0.2	0.4	< 0.1	0.1	0.6	0.4	0.5	0.5	0.1	0.1	0.1
Bare 2"/wk	0-6	1.0	1.0	0.3	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	5.1	4.4	4.4	0.3	0.4	0.4
	9-15	8.4	2.3	0.8	0.4	0.1	< 0.1	0.7	0.1	< 0.1	3.1	2.8	2.8	0.3	0.3	0.3
	30-36	10.4	10.4	2.3	0.3	0.4	< 0.1	0.3	0.4	< 0.1	0.5	0.5	0.5	0.1	0.1	0.1
Vegetated Control 4"/wk	0-6	0.2	0.2	-0.2	< 0.1	< 0.1	< 0.1	0.1	0.2	0.1	4.8	4.4	3.8	0.3	0.4	0.3
	9-15	0.2	0.2	-0.2	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	2.1	2.0	1.8	0.2	0.2	0.2
	30-36	1.0	0.7	0.9	< 0.1	0.1	< 0.1	< 0.1	0.1	< 0.1	0.4	0.5	0.4	0.1	0.1	0.1
Bare Control 4"/wk	0-6	0.2	0.2	0.3	< 0.1	0.1	< 0.1	0.1	0.1	< 0.1	4.4	4.0	3.4	0.3	0.4	0.3
	9-15	0.5	0.2	0.7	< 0.1	0.1	< 0.1	< 0.1	0.1	0.8	2.7	2.6	2.5	0.3	0.2	0.3
	30-36	6.7	0.7	1.8	0.2	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.5	0.6	0.8	0.1	0.1	0.1
Non-irrigated	0-6															
	9-15															
	30-36															

Table 42. Continued.

Sample Site	Sample Depth (Inches)	NO_3-N, mg/l			P Available, mg/l			EC_e, mmhos/cm			pH			Cation Exchange Capacity meq/100 g	Deviation from Non-irrigated meq/100 g
		Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2		
Vegetated 6"/wk	0-6	2.7	2.5	1.3	6.9	5.6	7.2	0.7	0.7	0.8	8.4	8.4	8.0	24.8	+1.2
	9-15	2.8	2.6	2.0	4.7	4.0	4.5	0.8	0.6	0.5	8.7	8.5	8.5	22.1	+1.9
	30-36	0.7	0.2	0.6	3.0	4.8	2.8	6.2	1.4	0.7	8.3	8.7	8.8	18.7	- 0.5
Bare 6"/wk	0-6	4.4	18.9	4.3	14.0	8.3	14.4	0.6	1.7	0.6	8.3	8.5	8.1	24.8	+1.2
	9-15	2.2	13.4	5.4	6.4	5.5	7.2	0.6	1.0	0.7	8.7	8.9	8.2	21.7	+1.5
	30-36	1.5	3.5	1.4	3.3	3.4	2.7	5.0	6.9	0.9	8.5	8.7	8.8	17.2	- 2.0
Vegetated 4"/wk	0-6	0.6	4.2	0.3	25.0	5.9	7.3	1.0	0.5	0.8	8.5	8.3	8.0	24.8	+1.2
	9-15	0.6	0.9	0.6	13.0	3.5	4.4	2.7	0.5	0.5	8.8	8.4	8.4	19.2	- 1.0
	30-36	1.2	< 0.1	0.5	4.4	4.0	3.1	4.2	2.0	1.0	8.4	8.6	8.9	17.2	- 2.0
Bare 4"/wk	0-6	37.7	4.0	7.3	12.0	11.5	15.2	0.8	0.6	0.8	8.1	8.5	8.2	22.7	- 0.9
	9-15	17.2	9.1	4.1	6.3	4.6	7.9	0.7	0.8	0.7	8.3	8.4	8.6	17.7	- 2.5
	30-36	1.7	7.6	4.0	1.4	3.2	5.7	18.9	2.5	2.2	8.3	9.1	9.0	21.2	+2.0
Vegetated 2"/wk	0-6	1.6	1.0	0.6	6.0	19.0	8.7	1.5	0.7	0.8	7.9	8.4	8.3	22.7	- 0.9
	9-15	1.3	0.9	0.7	5.0	6.8	5.0	2.5	0.9	0.7	8.3	8.9	8.6	18.7	- 1.5
	30-36	3.3	0.8	0.6	1.3	3.9	6.9	2.3	4.5	1.2	8.8	8.7	9.2	17.7	- 1.5
Bare 2"/wk	0-6	38.7	3.8	5.8	7.8	9.1	10.6	1.9	1.7	0.6	8.3	8.5	8.3	23.8	+0.2
	9-15	18.2	18.4	3.5	4.6	5.8	5.2	15.0	3.2	1.0	8.0	8.4	8.8	21.7	+1.5
	30-36	1.5	6.2	5.9	3.4	2.9	3.8	18.2	16.3	2.1	8.2	8.4	8.9	18.2	- 1.0
Vegetated Control 4"/wk	0-6	3.3	0.6	0.9	4.1	3.2	3.6	0.7	0.7	0.5	8.2	8.3	8.3	21.2	- 1.4
	9-15	2.2	0.1	0.9	1.6	1.8	2.4	0.4	0.5	0.4	8.6	8.5	8.6	18.7	- 1.5
	30-36	0.6	0.1	0.2	1.5	1.7	3.7	0.9	0.8	0.9	8.8	9.0	8.9		
Bare Control 4"/wk	0-6	26.0	10.9	4.2	10.0	12.3	9.1	0.7	0.8	0.6	8.1	8.3	8.5	22.7	- 0.9
	9-15	6.6	3.3	2.2	4.8	4.9	3.1	0.7	0.7	1.4	8.6	8.4	8.6	26.3	+6.1
	30-36	4.2	3.8	5.7	2.0	2.6	5.0	5.7	1.0	1.6	8.5	8.9	9.0	16.3	- 2.9
Non-irrigated	0-6													23.6	
	9-15													20.2	
	30-36													19.2	