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Roger Scott Tinkey

Utah State University

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LAGOON EFFLUENT POLISHING BY SOIL MANTLE TREATMENT USING VARIOUS UTAH SOIL TYPES

by

Roger Scott Tinkey

A thesis submitted in partial fulfillment of the
requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

[redacted]

UTAH STATE UNIVERSITY
Logan, Utah

1975

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I would also like to thank Dr. Fredrick Post of my Graduate Committee for his critical review of the thesis and for clearing up many difficult points; Professor Norman B. Jones for his helpful suggestions and advisement which directed me towards Environmental Engineering; and the Environmental Protection Agency for the Traineeship which enabled me to pursue this course of study.

Finally to my wife, Jolene, for her patience and support in fulfilling this assignment, I extend my sincere gratitude.

Roger Scott Tinkey

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ABSTRACT

Lagoon Effluent Polishing by Soil Mantle Treatment Using Various Utah Soil Types

by

Roger Scott Tinkey, Master of Science

Utah State University, 1975

Major Professor: Dr. Robert A. Gearheart
Department: Civil and Environmental Engineering

The purpose of this paper is to investigate the effectiveness of four Utah Great Basin soil types in removing particular chemical constituents and select enteric organisms from a sewage lagoon effluent. Sewage taken from the secondary oxidation pond in Logan, Utah was applied daily to lysimeters which allowed samples to be recovered at 7.6 and 38.1 centimeter soil depths. The texture of the soils was the most important physical property affecting their removal capacity. Drainage Farm soil (clay) provided the best bacteriological and overall chemical removal with Nibley (silty clay loam) second, then Draper (sandy loam) and Parleys (silty loam) last.

The soils were analyzed before and after the test period to determine any major change which would ultimately affect their removal capacity. Noticeable changes occurred in phosphorus, percent organic matter and cation exchange capacity. The changes that did occur had no apparent effect on the removal capacity of any of the soil during the test period.

The paper is dividen into three major parts: the bacteriological, the chemical, the initial and final soil comparison.

(192 pages)

INTRODUCTION

The rapid death of enteric organisms in soils has been well documented, but few investigations have attempted a detailed study of the characteristics of the soil that contribute to the decline in microbial numbers. In this study the writer will attempt to correlate the soils various characteristics with their effect on the removal and survival of the Total Coliform group, Fecal Coliform, and the Fecal Streptococcal group. These organisms were monitored because pathogens in water may be extremely diluted or occur intermittently so that when examination of a water supply is made, the pathogens may no longer be present. Therefore, laboratory analysis usually centers around the detection of fecal organisms associated with the pathogens, (Bryan, undated). Numerous chemical parameters will also be monitored to better evaluate the soils effect on the bacteria and to determine their effectiveness in removing chemical constitutents.

Four Utah Great Basin soils were chosen on the basis of major acreage, potential irrigated value and range in physical and chemical characteristics. The soils were studied in specially built lysimeters for ease of observation. Many objections have arisen to the use of lysimeters in field study comparisons. The most important dispute has been the assumption that the change in permeability which inevitably occurs when a soil is transferred from its natural bed into lysimeters would so alter its infiltration capacity that any results would be meaningless. However, it has been generally observed that it is the surface of a soil that limits infiltration rates, not the subsurface conditions. Only where some subsurface stratum exists should differences in degree of compaction and porosity be important (McGauhey and Krone, 1967). That this is indeed the case has been shown in several studies of field and lysimeter infiltration rates of various soils. When soil is used for disposal or treatment of wastewater, a system of inundation followed by drying and spading of the surface stratum is commonly used. This practice tends to disturb the soil in a manner comparable to that used in lysimeter operation (Orlob and Butler, 1955).

In this study suitable deep strata exists in the field. Therefore, the practicality of water reclamation or sewage disposal by surface spreading should be subject to determination by this lysimeter study.

There has been renewed interest in land disposal or treatment as evidenced by the numerous papers presented at recent conferences. The proceedings of the Pennsylvania State University Conferences were published and consisted of 32 papers (Sapper and Kardos, 1973). The proceedings of the Illinois Conference contained 26 papers (Proc. Joint Conf. Ill. 1973), while the proceedings of the Rutgers Conference consisted of 19 papers (Symp. at Rugers Univ., 1973).

Much of this renewed interest no doubt stems from the Federal Water Pollution Control Act calling for zero discharge by 1985 and the intermediate deadlines proposed in PL 92-500. Among the laws passed in the state of Utah is a law that will upgrade the water quality standards of most of the receiving waters in Utah from Class D to Class C (Table 1). As a result of this action, the effluent

Table 1. Specific standards established for class "C" and "D" water quality standards pertaining to waste water treatment plant effluents

Parameter	Concentration or Units Class "C"	Class "D"
pH	6.5 - 8.5	6.5 - 9.0
Coliform, monthly arithmetical mean	5,000/100 ml	5,000/100 ml
Fecal coliform, monthly arithmetical mean	2,000/100 ml	-
BOD_5, monthly arithmetical mean	5 mg/1	25 mg/1
Dissolved oxygen	5.5 mg/1	-
Chemical and radiological	PHS drinking water standards	PHS drinking water stndards

discharged into any of these receiving waters must meet a more rigid standard of quality.

There are certain rather important and in many cases critical considerations that arise from such a course of action. In many cases waste water treatment facilities have already been constructed and designed to meet only Class D standards. When the Class C standard becomes law, these facilities will no longer be allowed to discharge their effluents into any receiving water covered by the law. Therefore, either existing facilities must be improved to the point where the effluent can meet the new receiving water standard, or a different method of disposing of the effluent must be found.

As pointed out by Thomas (1973, p. 1476), the history of land disposal shows that the old systems were designed for "out of sight, out of mind," and the newer ones for treatment and reuse. Land disposal as a form of treatment or waste water renovation was used by 571 municipalities and 1300 industries in the U.S. in 1972. In addition to this there were over 50 million people using septic tanks.

The use of soil mantle disposal to upgrading lagoon effluent is limited by soil and ground water characteristics. However, most lagoons are constructed in areas where land is readily available and thus capital investment for soil mantle disposal is relatively low. Also, soil mantle disposal does not create a sludge disposal problem, has a low maintenance and operation cost, and may provide additional irrigation water in arid regions.

A case favoring land treatment over advanced biological waste treatment or physical chemical treatment is reported by Roper (1973). For the Chicago example, the land treatment cost was one-half and the energy usage one-third of that for the other two alternatives. Therefore, it is felt that soil mantle disposal is a viable alternative for upgrading lagoon effluents.

Objectives

The purpose of this research can be stated as follows: (1) to correlate the soil's various characteristics with their effect on the removal and survival of specific enteric organisms present in sewage lagoon effluents; (2) to investigate the effectiveness of each soil in removing various chemical constitutents in sewage lagoon effluent;

(3) to examine any change in the soil's characteristics after the test period.

REVIEW OF LITERATURE

History of Land Application of Sewage

A review of the history of sewage treatment indicates that land application of sewage is a very old practice. Developed in the early nineteenth century, waste water irrigation was used as a system of both treatment and disposal (Rudolfs, Willem and Cleary, E. J., 1956). Application of sewage effluent to the soil for the purpose of tertiary treatment has come along more recently, but is not a new idea. Wilcox (1948) reported that Tucson and Phoenix, Arizona; Lubbock, Texas; Denver, Colorado; and Pomona, Whittier and Riverside, California used sewage effluent for irrigation. Mentioned also in a report by Merz (1956) as having favorable results were Bakersfield, Fresno, Wasco and Tulare, California and Abilene, Kingsville and San Antonio, Texas. As of 1966, California had a total of 199 sewage plants that applied effluent to land, Texas had 40, Arizona 22, and New Mexico 21 (Eastman, 1967).

The practicality of using land application of sewage as a means of treatment and disposal has been proven feasible. Studies of land renovation of effluents with respect to sewage bacteria have also shown that soil is an effective medium for treating sewage. Using radioactive phosphorus to lable coliform bacteria, tests (Marculeseu, I. and Drucan, N., 1962) at the Tulza Collective farm in Rumania showed that 92-97 percent were retained in the uppermost 1 cm of the soil, with 3 to 5 percent retained in the 1 to 5 cm layer. An investigative study in Wisconsin observed that the return flow from the soil irrigated with sewage effluent did not increase the coliform index of the nearby creek. Also reports from 69 communities in California using sewage for irrigation indicate no ground water pollution or disease transmission occurring (Sepp, 1971).

The past and current uses of land treatment have been developed as a convenient and economical approach to wastewater disposal. The effect of land treatment techniques on animal life, plant life, soil and groundwater is presently being studied along with the engineering and economics of the system.

Mechanism of removal

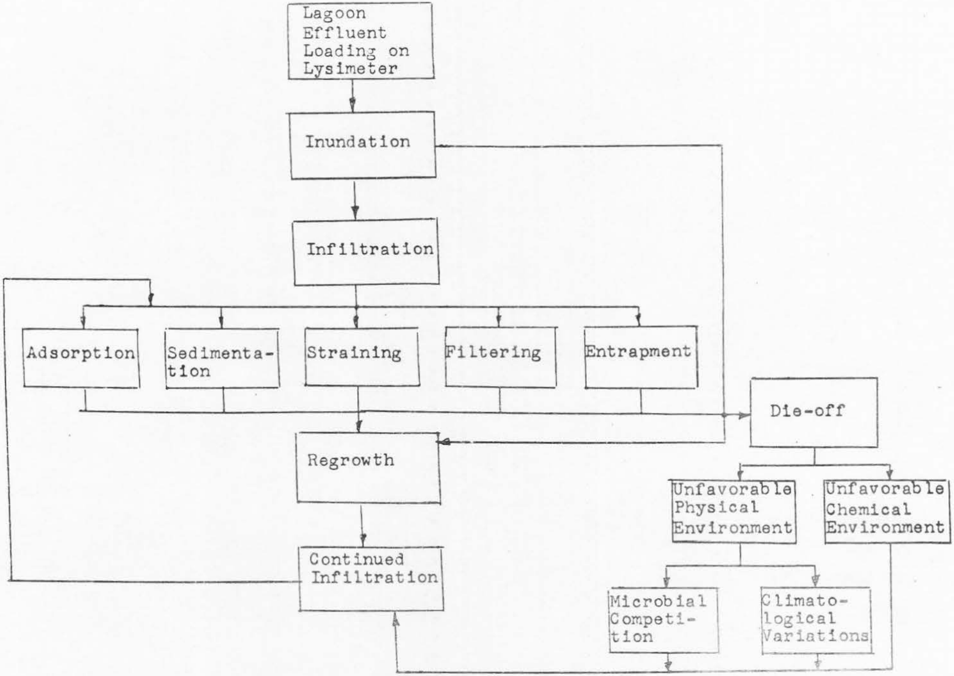
The application of soil mantle disposal to upgrading lagoon effluent is governered by soil and groundwater characteristics, as well as microbial activity. Soils have varying capacities to remove contaminants by filtering, adsorption, exchange and precipitation. As pointed out by McGauhy and Krone (1967, p. 146), "Bacteria behave like other particulate matter in soils and are removed by straining, sedimentation, entrapment, and adsorption. In addition, they are subject to die-away in an unfavorable environment." The other particulate matter as well as bacteria which McGauhey referred to is usually effectively removed in the top 12.5 or 15 centimeters of a soil system by one or more mechanisms: (a) straining at the soil surface, when the suspended particles build up on the soil surface and become part of the filter; (b) bridging, when suspended particles penetrate the soil surface until they reach a pore opening that stops their passage; (c) straining and sedimentation, which includes the conditions of (a) and (b) except that the suspended particles are finer than half of the smallest pore opening. Figure 1 shows a flow chart of the proposed mechanisms of removal and movement of bacertia in the lysimeter.

Soils effectiveness in water renovation is largely determined by the ability of microrganisms populating the first few feet of soil depth to convert the contaminants into innocuous volatile substances, into forms utilized by higher plants and to incorporate part of the materials into new protoplasm (Hinesly, 1974).

The soils ability to remove dissolved and particulate organics is concentration dependent. They may be supplied in concentrations inhibiting the growth of microorganisms, either directly as a toxicant or indirectly by adversely altering favorable soil chemical and physical properties, reducing the soils capacity to attenuate water pollutants (Hinesly, 1974). However, these wastes may also decrease the numbers of pathogenic bacteria ever present in municipal wastewaters. Also the presence of other microorganisms has an influence on the pathogenic organisms. This has been illustrated many times by longer survival after inoculation of a pathogen into a sterilized soil, sewage, or water then into a corresponding non-sterile substrate.

Some other factors that are important to the survival of intestinal pathogenic bacteria in soil, as stated by Rudolfs (1950) are as follows: (a) lower temperatures increase viability; (b) longevity is greater in moist soil than in dry soil; (c) neutral, high moisture-holding soil favors longevity; (d) the type and amount

Figure 1. Flow chart of proposed removal and movement of bacteria in the lysimeter.


Lagoon Effluent Loading on Lysimeter
Inundation
Infiltration
Adsorption
Sedimentation
Straining
Filtering
Entrapment
Die-off
Regrowth
Unfavorable Physical Environment
Unfavorable Chemical Environment
Continued Infiltration
Microbial Competition
Climatological Variations

of organic matter present may serve as a food and energy source to sustain or allow bacteria to increase.

The presence of members of the total coliform group has become the indicator of fecal pollution in water. As a group, coliforms are considered harmless, but their presence in a water sample indicates the possible presence of pathogenic enterobacteriaceae such as salmonella (Millipore, 1972). The fecal coliform group is specifically composed of those coliforms that enter water via fecal discharge of warm-blooded animals and man. The fecal streptococci bacterial group is also used as an indicator of fecal waste contamination in water. Fecal streptococci bacteria are especially native to the gut of warm-blooded animals, also man, and are considered typically non-pathogenic (Millipore, 1972).

The soils tested did not have a crop cover therefore the observed removal would be strictly due to soil characteristics as pointed out by Hinesly (1974, p. 64), "Once wastewater contaminants migrate below the biologically active root zone of plants their removal is mainly by adsorption and chemical precipiation reactions." Contamination of underground water supplies can be traced to situations where polluted water has been either injected directly below or has been allowed to circumvent the biologically active soil surface.

METHOD OF PROCEDURE

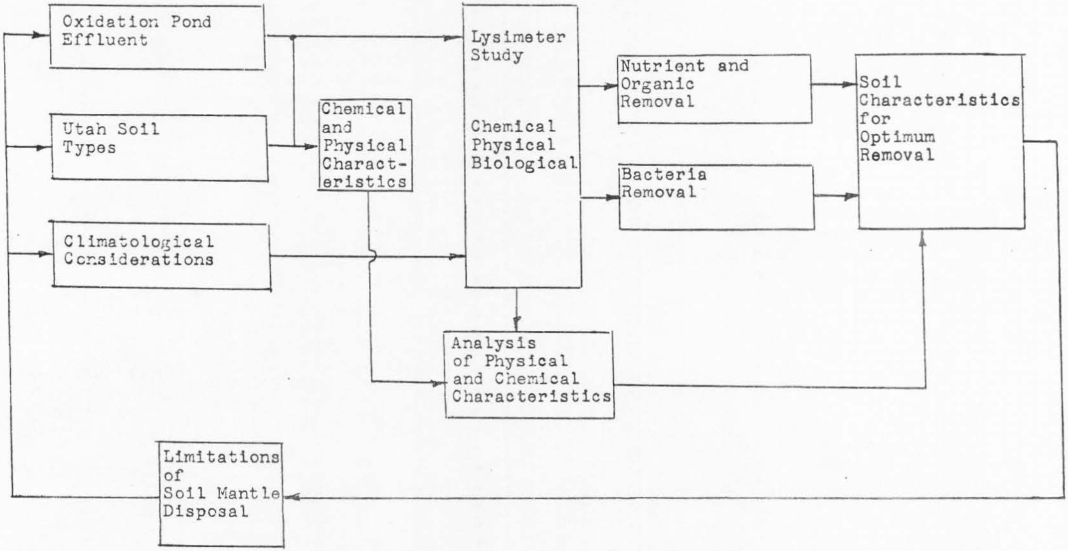
Methodology

This study was directed at correlating four different soils' various characteristics with their effect on the removal and survival of specific enteric organisms present in the sewage lagoon effluent. The soil characteristics of primary importance in bacterial removal are: texture, percent organic matter, cation exchange capacity, pH, and percent water saturation. The soils were analyzed to measure these properties before and after the test period which monitored the organism removal.

The bacteriological organisms studied were the total coliform group (TC), fecal coliform (FC), and fecal streptococci (FS). After monitoring the levels of these organisms in the sewage applied to the soils, and levels present in the sewage after percolating through the soils, the study attempts to single out individual soil characteristics contributing to varying degrees of removal.

It is also the interest of this study to investigate the effectiveness of each soil in removing the various chemical constituents in sewage lagoon effluent (see Chemical Analysis). Particular interest of this research was also given to note any change in the soils physical or chemical characteristics after the test period was complete. Figure 2 shows an information flow chart used in pursuing this study.

Figure 2. Information flow chart of research.


Oxidation Pond Effluent
Utah Soil Types
Climatological Considerations
Chemical and Physical Characteristics
Lysimeter Study
Chemical Physical Biological
Nutrient and Organic Removal
Bacteria Removal
Soil Characteristics for Optimum Removal
Analysis of Physical and Chemical Characteristics
Limitations of Soil Mantle Disposal

Experimental Design

Soil types

The four Utah Great Basin soil types chosen were Nibley, Parleys, Draper and soil typical to the Utah State University reclamation farm. These soils were chosen on the basis of major acreage, potential irrigated value and range in physical and chemical characteristics (Table 2).

Lysimeter design

A lysimeter is defined by Websters Dictionary as "a device for measuring percolation of water through soils and determining the soluble constituents removed in drainage." In this case eight lysimeters were constructed, 53 cm x 53 cm x 53 cm, with drains built at the 7.6 cm and 38.1 cm depth providing the two sample points, the bottom of the lysimeter has a two way slope which allows for complete and final drainage (Figure 3 and Photograph 1). The lysimeters were filled to 1.3 cm from the top, giving the drains mean depths of 7.6 cm and 38.1 cm with a 5% slope. The units were constructed of 5/8" exterior plywood, all corners reinforced with fiber stripping and the entire unit coated with marine glass resin. The drains are 3" Polyvinyl-chloride (PVC) with the top half cut out beginning 7.6 cm from each wall (Figure 3) to avoid picking up unfiltered samples due to possible sidewall channeling or short circuiting. Stainless steel wire mesh (16/inch) was placed over the drains in the PVC and over the bottom drain outlet to prevent clogging. Next, washed pea gravel was placed in the bottom to a layer 3.8-5 cm deep, the mid depth drains filled level with the cross section cut.

Table 2. Description, location and use of the four Utah Great Basin soils studied

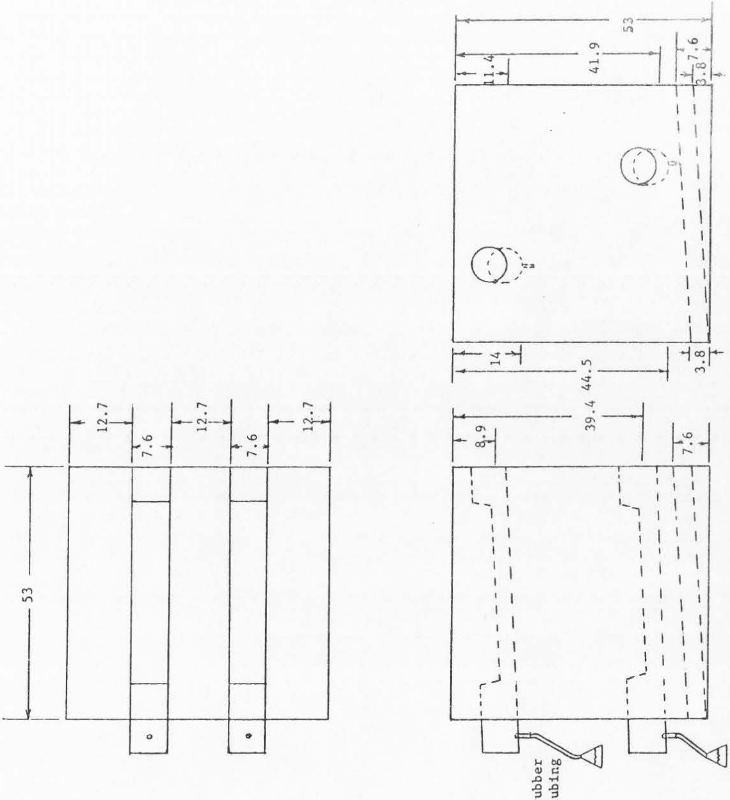
Soil Type	Texture	Sample Site Location	Use
Nibley	Silty Clay Loam	1.4 km S. 1 km E. of USU Animal Husbandry Farm	Irrigated Crops and natural pasture
Parleys	Silty Loam	2.4 km E. of Hyde Park on alluvial fan	Irrigated grain crops and natural pasture
Draper	Sandy Loam	2.4 km E. Perry on alluvial fan	Irrigated fruit crops and natural pasture
USU Reclamation Farm	Clay	4 km W. and and 1.6 km N. Logan	Irrigated grain crops and natural pasture

Each soil type occupied two lysimeters, thereby each lysimeter had only one sample point. For example, Nibley soil was loaded into two lysimeters, one of which was saturated from the bottom up to the 7.6 cm drain and sampled at the 7.6 cm level. The second lysimeter was saturated up to the 38.1 cm level and sampled at that point, giving two data points for each soil type.

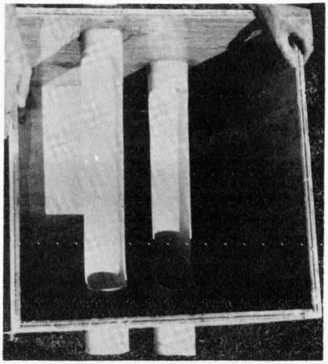
Soil preparation

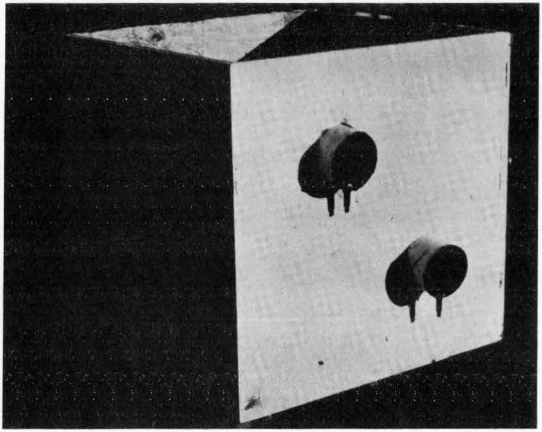
Field samples were taken with shovels as near as possible to the selected type locations and of horizons conforming to those of the original type profiles. The lysimeters were loaded in 10 cm lifts,

Figure 3. Design of lysimeter (all dimensions are centimeters).


53
12.7
7.6
12.7
7.6
12.7
41.9
11.4
7.6
3.8
14
44.5
3.8
39.4
8.9
7.6
rubber tubing
sample bottle

Photograph 1. Lysimeter.





each lift being rodded to attain a maximum and uniform compaction among all lysimeters filled.

A typical sample of each soil was submitted to the USU Soil, Plant and Water Analysis Laboratory for testing before and after this study to measure the following properties: pH, electric conductivity, phosphorus, potassium, texture, lime, organic matter, exchangeable sodium, total sodium, water soluble sodium, cation exchange capacity, and percent saturation.

Prior to the application of lagoon effluent, fresh water was applied to the soils for at least one month, three to four times weekly to aid settling and leach suspended solids from the filters. Five centimeters of lagoon effluent was then applied to the soils three times a week with a weekly determination of the specific conductance on the sewage applied and effluent from the filters to approximate the time the filters were approaching a steady-state condition. At the time an apparent steady-state condition was reached full chemical analysis began. The bateriological analysis started when the full chemical analysis began showing consistent results.

Sampling

Sampling schedule

Weekly determination of specific conductance started on September 5, 1974 and the full chemical analysis began on September 25, and was conducted weekly until November 25, 1974. On October 29, the bacteriological analysis began. The bacteriological tests were conducted daily on the sewage applied and the effluents recovered from the sample points until November 29. At this time consistent results were observed and chemical analysis also ceased.

Sampling procedure

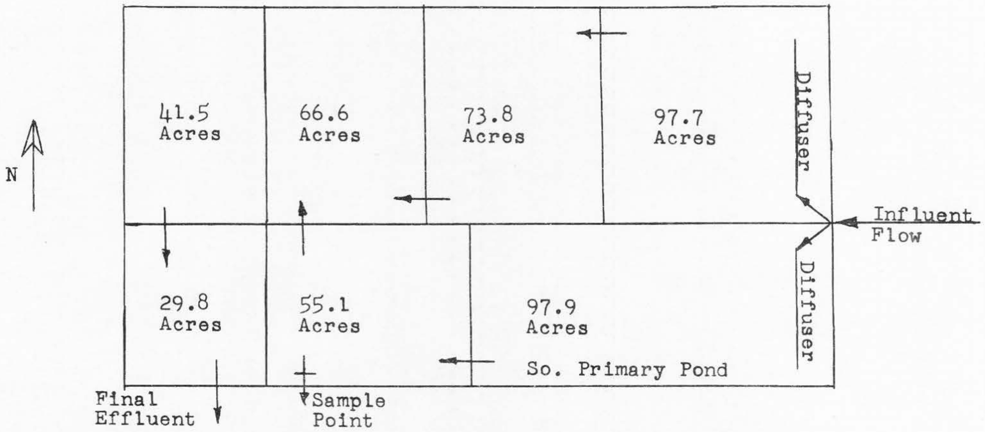
The sewage was collected each day from the secondary oxidation pond effluent port (Figure 4) in plastic five gallon containers. The sewage was then flooded onto the soils in 1.3 cm depths until 2.5 cm had been applied. Samples from the appropriate effluent port on each box were collected for the bacteriological analysis in sterile 500 ml erlenmeyer flasks (Figure 3). On days when samples were to be taken for the chemical analysis as well, the samples were first taken in the 500 ml flasks and then 2.5 liters were collected in washed four liter plastic containers to be used for the chemical analysis. The bacteriological and chemical analysis was conducted within six hours from when the sewage effluent was first applied to the lysimeters. Since the atmospheric temperature was always below 7°C, no further steps were taken to preserve the samples before analysis.

Analysis

Bacteriological analysis

The bacteriological analysis was conducted as prescribed in Standard Methods of the Examination of Water and Wastewater (APHA 1971). Total coliforms were analyzed by methods given in section 408 A (Standard Total Coliform Membrane Filter Procedure). Fecal coliforms were analyzed by methods given in section 408 B (Fecal Coliform Membrane Filter Procedure). Fecal Streptococcus was analyzed by methods given in section 409 B (Membrane Filter Technique for the Fecal Streptococcal Group).

Figure 4. Schematic drawing of Logan waste stabilization ponds.


N
41.5 Acres
66.6 Acres
73.8 Acres
97.7 Acres
Diffuser
Influent Flow
Diffuser
29.8 Acres
55.1 Acres
97.9 Acres
So. Primary Pond
Final Effluent
Sample Point

Chemical analysis

The applied lagoon effluent and each lysimeter sample port effluent was analyzed for: total carbon, total inorganic carbon, total organic carbon, suspended solids, volatile suspended solids, total unfiltered and filtered phosphate, ortho-phosphate, amonia, nitrite, nitrate, pH, specific conductance, total algae cell counts, chlorophyll "a" and pheophytin "a." Analysis technique followed that prescribed in APHA, 1971.

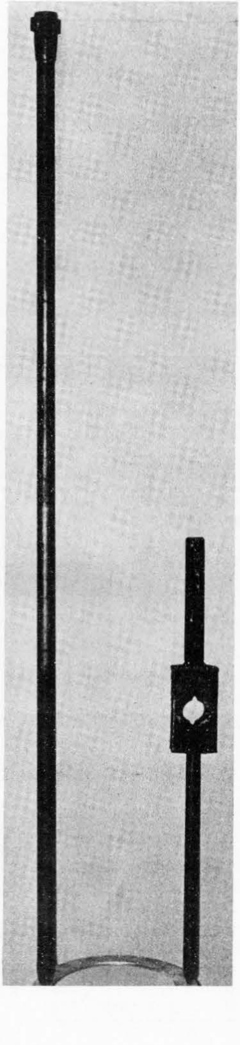
Final soil analysis

Upon completion of the testing period, the soils were allowed to freeze so that undisturbed core samples could be taken with a device known as a King tube (see below). The soil was analyzed at the top, 2.5 cm 5 cm 7.5 cm 12.5 cm 20 cm and 32.5 cm levels for remaining chlorophyll "a" and the presence of coliforms and fecal coliforms by the 3 tube-multi-dilution MPN method prescribed in APHA, 1971.

The King tube is a one inch (inside diameter) stainless steel pipe 183 cm long. On one end is a sharpened head (bottom left of Photograph 2) with an inside diameter slightly smaller than that of the remaining tube. The other end has a steel jacket reinforcing the end (Photograph 2). A hammer is used (bottom of Photograph 2) to drive the tube into a compacted soil to remove an undisturbed soil sample. The core is then removed from the upper end.

In the investigation to determine remaining coliform populations at different depths in the soil, the King tube and hammer were scrubbed and sterilized with methanol and flamed before each core

Photograph 2. King tube and driver.



was taken. The cores were then placed in sterile long plastic bags so as not to mix the soil horizons.

For the coliform determination the solid cores were aseptically separated into the desired levels. Approximately four grams were placed in a dilution bottle previously tared. Approximately the same amount from the same level was weighed, air dried and weighed again to determine the percent moisture. The soil suspension was then diluted to conduct the three tube multi-dilution coliform MPN and fecal coliform MPN test. The final results from the MPN determination for coliforms or fecal coliforms in the soil could then be reported as MPN per dry weight of soil.

Soil samples were also taken from the lysimeters at the top and 32.5 cm depth and analyzed by the U.S.U. Soil Plant and Water Analysis Laboratory. These results were compared to the soil properties before the test period.

Lagoon effluent characterization

The sewage used for this study was taken from the secondary oxidation pond of Logan's waste stabilization ponds. The test period was conducted from October through December. Average values over this time of various chemical and bacteriological parameters can be seen in Table 3. The hydraulic loading that these values produced on the lysimeters and would provide to an acre plot, are given in Table 4.

Table 3. Lagoon effluent characterization

Average Values Over Test Period	
Total algal cell counts No./ml	23,800.0
Total coliforms No./100 ml	160.0
Fecal coliform No./100 ml	64.0
Fecal Streptococci No./100 ml	100.0
Temp. ^{o}C	8.0
D.O. mg/1	19.0
Nitrate NO_3-N mg/1	0.15
Nitrite NO_2-N mg/1	0.04
Ammonia NH_3-N mg/1	4.1
B.O.D. mg/1	30.0
Specific conductance umhos/cm	640.0
Suspended solids mg/1	28.0
Volatile suspended solids mg/1	17.0
Total phosphate PO_4 mg/1	2.8
Ortho phosphate mg/1	2.1
PH	8.10
Total organic carbon mg/1	15.0
Total inorganic carbon mg/1	58.0
Total carbon mg/1	75.0

Table 4. Hydraulic loading characteristics

Parameter	Avg. Conc. mg/ℓ	Kg/day	Kg/Hectare/day	lbs/day	lbs/acre/day
B.O.D.	30.0	2.17×10^{-4}	7.56	4.78×10^{-4}	6.78
Nitrate	0.15	1.09×10^{-6}	3.82×10^{-2}	2.41×10^{-6}	3.41×10^{-2}
Nitrite	0.04	2.68×10^{-7}	9.35×10^{-3}	5.9×10^{-7}	8.35×10^{-3}
Ammonia	4.1	3.04×10^{-5}	1.05	6.7×10^{-5}	9.35×10^{-1}
Suspended Solids	28.9	2.09×10^{-4}	7.30	4.6×10^{-4}	6.54
Volatile Suspended Solids	17.0	1.23×10^{-4}	4.30	2.71×10^{-4}	3.84
Total Phosphate	2.81	2.03×10^{-5}	7.10×10^{-1}	4.48×10^{-5}	6.35×10^{-1}
Ortho-phosphate	2.09	1.51×10^{-5}	5.28×10^{-1}	3.33×10^{-5}	4.72×10^{1}
Total Organic Carbon	15.6	1.13×10^{-4}	3.94	2.49×10^{-4}	3.52
Total Inorganic Carbon	58.0	4.20×10^{-4}	1.46×10^{-2}	9.25×10^{-4}	1.31×10^{2}
Total Carbon	75.0	5.40×10^{-4}	1.91×10^{2}	1.19×10^{-3}	1.71×10^{2}

Microbial Characteristics*

Parameter	Avg. Conc. No./100mℓ	Organisms/Hectare/day	Organisms/acre/day
Total Coliform	160.0	3.95×10^{6}	1.6×10^{6}
Fecal Coliform	64.0	1.63×10^{6}	6.6×10^{5}
Fecal Streptococci	100.0	2.72×10^{6}	1.1×10^{6}
Total Algal Cells	23,800.0	5.93×10^{8}	2.4×10^{8}

*Loading rates based on 2.54 cm per day application.

RESULTS AND DISCUSSION

Method of Sampling

The lysimeters were set up to monitor the effluents from the soil at the 7.6 centimeter and 38.1 centimeter soil depths. Although there is much evidence to indicate the majority of bacteriological and chemical removal take place in the first few centimeters of soil, in this study it was very difficult to obtain reliable data at the 7.6 centimeter depth for a number of reasons.

Much of the data from the 7.6 centimeter sample points was invalid due to short circuiting occurring at the soil surface. This short circuiting was caused by the drying and cracking on the surface between sewage applications. In a lysimeter this large with so much surface area, surface disturbance as the sewage is applied would cause nonuniform soil depth which is very critical in evaluating removal in 7.6 centimeters of soil. Often times short circuiting was so extreme, samples were not obtained at all from the 7.6 centimeter level. However, much of the information gathered from the 7.6 centimeter level is valid and is very helpful in explaining some of the conditions that occurred.

In this study the objective was not so much to establish where the removal occurred but more to study which individual soil characteristics produced best removals. With this in mind the 38.1 centimeter sample points provided some very good information and lead to interesting conclusions.

Bacteriological Removal

The results of the bacteriological analysis for Total Coliform, Fecal Coliform, and Fecal Streptococcal Group for the 7.6 centimeter and 38.1 centimeter depths can be seen in Table 5. Due to an error in technique or use of an inferior method of determination in some cases the Fecal Coliform counts were very much higher than the Total Coliform which is unlikely. Therefore, in these cases we must assume the Fecal Coliform counts as minimum values for Total Coliforms. Table 6 shows the revised values for all three tests.

Since the sewage applied has ever changing levels of coliform populations, in order to obtain a reference by which to compare the removal of the various soils, the data has been converted to percent removal with respect to the sewage applied (Table 7).

Figures 5, 6, and 7 show percent removal plotted against each sample date for Total Coliform, Fecal Coliform and Fecal Streptococcus for all four soils at the 38.1 cm sample point. From these figures it is apparent that the Drainage farm soil (clay) produced consistently the best removal, showing 100% removal most of the time. Overall Nibley (silt clay loam) showed next best removal then Draper (sandy loam) and then Parleys (silty loam) showing poorest removal.

Figures 5 and 6 show common dips among all soils on November 9, 15, and 20. This indicates high levels of bacteria indicators in the effluent from the sample points. Figure 7 also shows these dips but lags the Total Coliform and Fecal Coliform by a couple of days each time. This observation would explain the much higher levels of Fecal

Table 5. Original counts for total coliform, fecal coliform, and fecal streptococcal group at the 7.6 and 38.1 centimeter depths.

	TOTAL COLIFORM									FECAL COLIFORM									FECAL STREPTOCOCCUS								
Sample Date	Sewage	Draper		Nibley		Parleys		Drainage Farm		Sewage	Draper		Nibley		Parleys		Drainage Farm		Sewage	Draper		Nibley		Parleys		Drainage Farm	
		7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm		7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm		7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm
10/31	OG	110	OG	NS	OG	NS	OG	NS	OG	13	OG	OG	NS	OG	NS	OG	NS	OG	94	44	75	NS	15	NS	OG	NS	OG
11/1	OG	1	OG	NS	40	OG	OG	OG	0	16	1	0	NS	3	10	6	17	0	166	47	19	NS	7	25	63	141	0
11/3	48	4	2	OG	24	OG	44	OG	0	7	2	0	13	0	3	2	2	0	12	20	9	111	3	90	0	335	0
11/5	76	0	0	4	4	OG	12	OG	5	7	3	0	NS	2	11	3	OG	0	104	22	4	NS	8	145	15	291	0
11/7	494	26	42	244	40	60	66	16	0	200	2	33	NS	6	130	13	157	0	187	26	80	98	4	217	2	302	0
11/9	800	40	33	NS	103	OG	400	486	0	TNTC	22	26	NS	20	TNTC	186	TNTC	0	285	30	3	NS	1	320	22	275	1
11/10	650	26	20	247	11	240	96	640	1	TNTC	30	18	141	4	TNTC	87	TNTC	0	274	23	16	65	5	188	42	324	0
11/11	720	7	145	304	12	20	88	40	4	135	2	51	130	10	110	14	115	0	135	19	18	52	15	155	6	152	0
11/12	200	6	0	44	7	0	20	60	3	95	7	8	NS	2	10	6	45	1	180	36	9	NS	3	0	0	211	0
11/13	60	0	0	NS	10	20	24	30	0	55	7	3	NS	0	1	2	40	0	137	28	8	NS	3	0	0	120	1
11/14	64	5	0	12	13	0	9	0	2	37	2	7	1	3	10	3	10	0	112	21	6	NS	1	51	0	362	0
11/15	13	0	0	NS	3	0	4	27	0	16	5	5	NS	1	20	1	10	1	78	24	3	NS	0	73	1	510	0
11/16	60	0	2	NS	10	0	0	0	0	46	6	4	NS	2	36	14	48	0	56	21	5	NS	2	27	0	112	0
11/17	48	0	OG	35	3	OG	2	OG	0	17	9	5	0	3	9	6	9	0	47	9	6	5	1	51	1	2000	0
11/18	65	OG	OG	NS	3	OG	OG	20	2	44	5	2	NS	3	24	7	31	0	50	16	4	NS	3	142	27	375	0
11/19	45	0	0	NS	3	0	1	0	0	32	3	1	NS	1	14	7	14	0	57	20	4	NS	3	62	1	50	0
11/20	25	OG	OG	20	6	OG	0	OG	0	5	1	3	68	2	11	7	OG	0	107	8	3	11	2	83	2	1205	0
11/21	20	OG	0	13	10	0	1	0	3	31	4	3	44	6	4	16	7	0	37	7	1	24	7	96	8	812	1
11/22	27	0	0	NS	6	0	0	20	0	26	5	2	NS	1	37	13	2	0	107	9	4	NS	3	122	26	4000	0
11/23	40	0	0	40	4	0	2	10	0	38	1	1	72	2	2	4	8	0	30	9	3	30	16	27	5	5700	0
11/24	10	0	0	20	3	30	2	10	0	19	2	1	11	1	27	7	29	0	52	2	2	0	14	30	4	630	1
11/25	33	2	0	32	3	0	0	0	2	92	2	3	14	1	203	9	27	0	85	5	1	26	14	80	3	2690	0
11/26	8	45	112	NS	264	146	195	1350	0	1000	200	70	NS	166	1000	200	1200	0	1000	48	11	NS	59	550	59	1530	0
11/27	60	21	0	NS	20	180	18	920	0	520	10	4	NS	32	80	150	95	0	600	31	5	NS	30	200	50	1000	0
11/29	50	29	0	NS	32	250	19	200	0	610	2	1	NS	47	50	145	42	0	165	2	1	NS	25	50	39	200	0

NS--No Sample OG--Overgrown TNTC--Too Numerous To Count

Table 6. Revised counts for total coliform, fecal coliform, and fecal streptococcal group at the 7.6 and 38.1 centimeter depths.

Sample Date	TOTAL COLIFORM								
	Sewage	Draper		Nibley		Parleys		Drainage Farm	
		7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm
10/30	OG	110	OG	NS	OG	NS	OG	NS	OG
11/1	16	1	0	NS	40	10	6	17	0
11/3	48	4	2	13	24	3	44	2	0
11/5	76	3	0	4	4	11	12	OG	5
11/7	494	26	42	244	40	130	66	157	0
11/9	800	40	33	NS	103	TNTC	400	486	0
11/10	650	30	20	247	11	240	76	640	1
11/11	720	7	145	304	12	110	88	115	4
11/12	200	7	8	44	7	10	20	60	3
11/13	60	7	3	NS	10	20	24	40	0
11/14	64	5	7	12	13	10	9	10	2
11/15	16	5	5	NS	3	20	4	27	1
11/16	60	6	4	NS	10	56	14	48	0
11/17	48	9	3	35	3	9	6	9	0
11/18	65	5	2	NS	3	24	7	31	2
11/19	45	3	1	NS	3	14	7	14	0
11/20	25	TNTC	3	20	6	11	7	OG	0
11/21	31	4	3	13	10	4	16	7	3
11/22	27	5	2	NS	6	37	13	20	0
11/23	40	1	1	72	6	2	4	16	0
11/24	19	2	1	20	3	30	7	29	0
11/25	92	2	3	32	3	230	9	27	2
11/26	1000	200	112	NS	264	1000	200	1350	0
11/27	520	21	4	NS	32	180	150	920	0
11/29	610	29	1	NS	47	250	145	200	0

Sample Date	FECAL COLIFORM								
	Sewage	Draper		Nibley		Parleys		Drainage Farm	
		7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm
10/30	13	NS	OG	NS	OG	NS	OG	OG	OG
11/1	16	1	0	NS	3	10	6	17	0
11/3	7	2	0	13	0	3	2	2	0
11/5	7	3	0	NS	2	11	3	OG	0
11/7	200	2	33	NS	6	130	13	157	0
11/9	200	22	26	NS	20	TNTC	186	TNTC	0
11/10	200	30	18	141	4	TNTC	87	TNTC	0
11/11	135	2	51	130	10	110	14	115	0
11/12	95	7	8	NS	2	10	6	45	1
11/13	55	7	3	NS	0	1	2	40	0
11/14	37	2	7	1	3	10	3	10	0
11/15	16	5	5	NS	1	20	1	10	1
11/16	46	6	4	NS	2	36	14	48	0
11/17	17	9	5	0	3	9	6	9	0
11/18	44	5	2	NS	3	24	7	31	0
11/19	32	3	1	NS	1	14	7	14	0
11/20	5	1	3	68	2	11	7	OG	0
11/21	31	4	3	44	6	4	16	7	0
11/22	26	5	2	NS	1	37	13	2	0
11/23	38	1	1	72	2	2	4	8	0
11/24	19	2	1	11	1	27	7	29	0
11/25	92	2	3	14	1	207	9	27	0
11/26	1000	200	70	NS	166	1000	200	1120	0
11/27	520	10	4	NS	32	80	150	95	0
11/29	610	2	1	NS	47	50	145	42	0

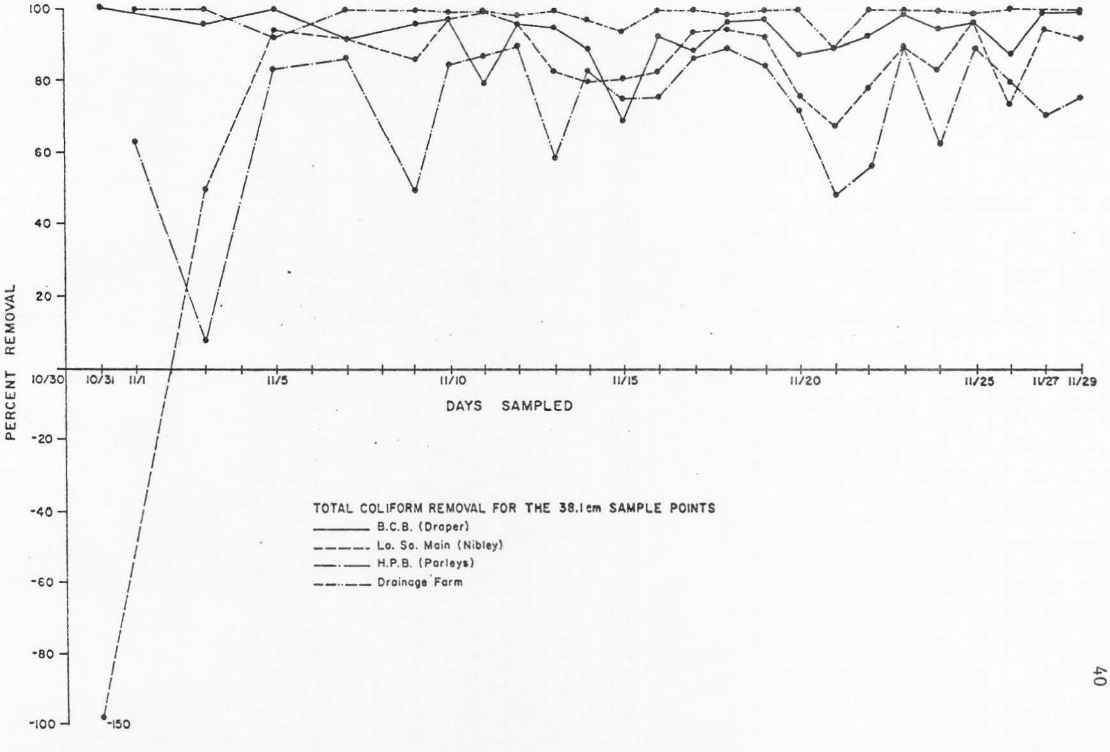
Sample Date	FECAL STREPTOCOCCUS								
	Sewage	Draper		Nibley		Parleys		Drainage Farm	
		7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm
10/30	94	44	75	NS	15	NS	OG	NS	OG
11/1	166	47	19	NS	7	25	63	141	0
11/3	12	20	9	111	3	90	0	335	0
11/5	104	22	4	NS	8	145	15	291	0
11/7	187	26	80	98	4	217	2	302	0
11/9	285	30	3	NS	1	320	22	275	1
11/10	274	23	16	65	5	188	42	324	0
11/11	135	19	18	52	15	155	6	152	0
11/12	180	56	9	NS	3	0	0	211	0
11/13	137	28	8	NS	3	0	0	120	1
11/14	112	21	6	NS	1	51	0	362	0
11/15	78	24	3	NS	0	73	1	510	0
11/16	56	21	5	NS	2	27	0	112	0
11/17	47	9	6	5	1	51	1	200	0
11/18	30	16	4	NS	3	142	27	375	0
11/19	57	20	4	NS	3	62	1	50	0
11/20	107	8	3	11	2	83	2	1205	0
11/21	37	7	1	24	7	96	8	812	1
11/22	107	9	4	NS	3	122	23	4000	0
11/23	30	7	3	30	16	27	5	5700	0
11/24	52	2	2	0	14	30	4	630	1
11/25	83	5	1	26	14	80	3	2690	0
11/26	1000	48	11	NS	59	550	59	1530	0
11/27	800	31	5	NS	30	200	50	1000	0
11/29	165	2	1	NS	25	50	39	200	0

NS - No Sample   OG - Overgrown   TNTC - Too Numerous To Count

Table 7. Percent removal of total coliform, fecal coliform and fecal streptococcal group with respect to sewage applied.

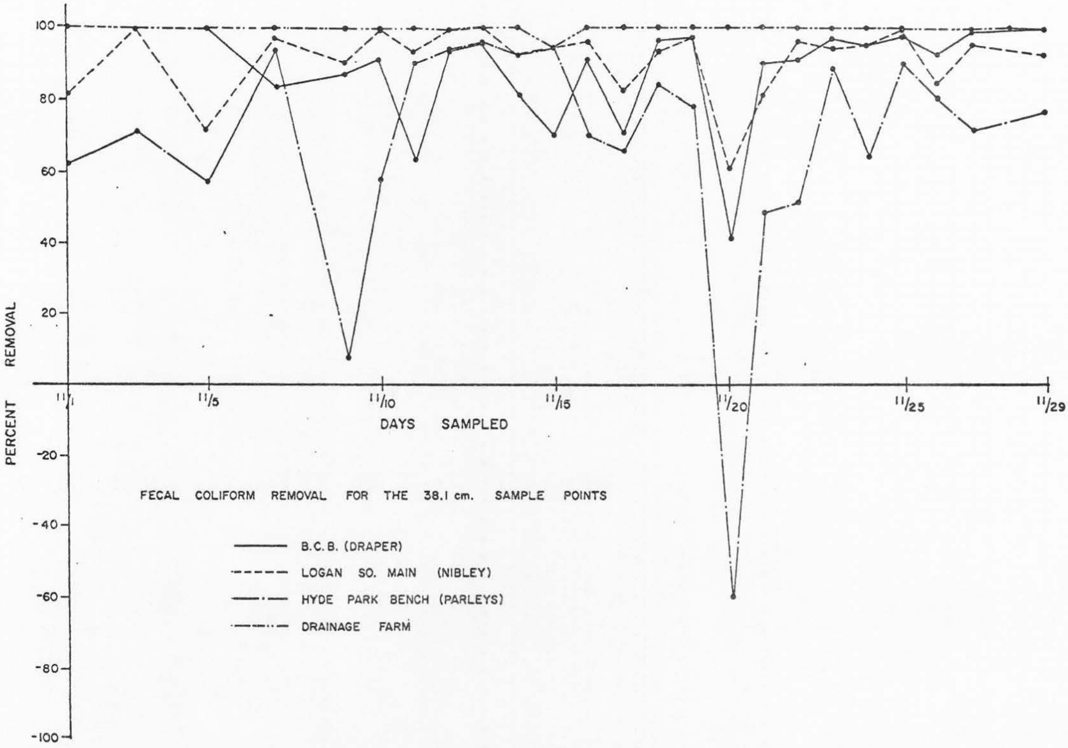
Sample Date	DRAPER						NIBLEY						PARLEYS						DRAINAGE FARM					
	T.C.		F.C.		F.S.		T.C.		F.C.		F.S.		T.C.		F.C.		F.S.		T.C.		F.C.		F.S.	
	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cm	7.6 cm	38.1 cn	7.6 cn	33.1 cm	7.6 cn	3?.1 cm	7.6 cm	38.1 cm
10/30					53	20						84												
11/1	94	100	99	100	72	89	94	-150	99	81	72	96	38	63	37	62	85	61	0	100	0	100	15	100
11/3	88	96	71	100	-67	25	73	50	-86	100	-830	75	94	83	57	71	-650	100	96	100	71	100	-2680	100
11/5	96	100	57	100	79	96	95	95		71		92	85	84	-57	57	-39	85		93		100	-173	100
11/7	95	92	99	83	86	52	51	92	48	97		98	74	87	35	94	-16	99	68	100	35	100	-80	100
11/9	95	96	89	87	89	99		87		90		99		50		7	-12	92	38	100		100	4	99
11/10	95	97	85	91	92	94	62	98	30	98	77	98	62	85		57	31	84	2	99		100	-18	100
11/11	99	80	93	63	78	88	52	98	4	93	59	89	85	87	19	90	-15	99	84	99	15	100	-13	100
11/12	96	96	93	93	80	95	78	96		98		98	95	90	89	94	100	100	70	98	53	99	-17	100
11/13	95	95	87	95	80	94		83		100		98	67	58	98	96	100	100	33	100	27	100	12	99
11/14	92	89	94	81	81	95	81	80	98	92		99	84	83	73	92	54	100	84	96	73	100	-224	100
11/15	69	69	69	69	69	96		81		94		100	-25	75	-25	94	5	99	-69	94	38	94	-555	100
11/16	90	93	87	91	62	91		83		96		96	40	76	22	70	52	100	20	100	-4	100	-100	100
11/17	81	89	48	70	81	87	27	94	100	82	89	98	81	87	48	65	-9	100	81	100	48	100	-312	100
11/18	92	97	89	96	68	92		95		93		94	63	89	45	84	-184	46	52	97	30	100	-650	100
11/19	93	98	91	97	65	93		93		97		95	69	88	56	78	-9	98	69	100	56	100	12	100
11/20		88	80	40	93	97	20	76	-1200	60	50	98	56	72	-120	-60	22	98		100		100	-1100	100
11/21	87	90	87	90	81	97	58	68	-42	81	35	81	87	48	87	48	-160	78	78	90	78	100	-2100	97
11/22	82	93	81	93	92	96		78		96		97	-37	56	-42	50	-14	76	26	100	93	100	-3900	100
11/23	98	98	97	97	70	90	-80	90	-89	94	0	47	95	90	94	89	10	84	60	100	99	100	-19000	100
11/24	90	95	90	95	96	96	-5	84	42	95	100	73	-57	63	-42	63	42	92	-52	100	-52	100	-1100	98
11/25	98	97	98	97	94	99	65	97	85	99	70	84	-120	90	-120	90	6	96	74	98	74	100	-3300	100
11/26	80	88	80	93	95	99		74		84		94	0	80	0	80	45	94	-35	100	-20	100	-53	100
11/27	96	99	97	99	95	99		95		95		95	66	71	84	71	67	92	-72	100	80	100	-67	100
11/29	95	99	99	99	99	99		92		92		88	59	76	91	76	70	76	67	100	93	100	-21	100

Figure 5. Total coliform percent removal at the 38.1 centimeter depth for all soils studied.



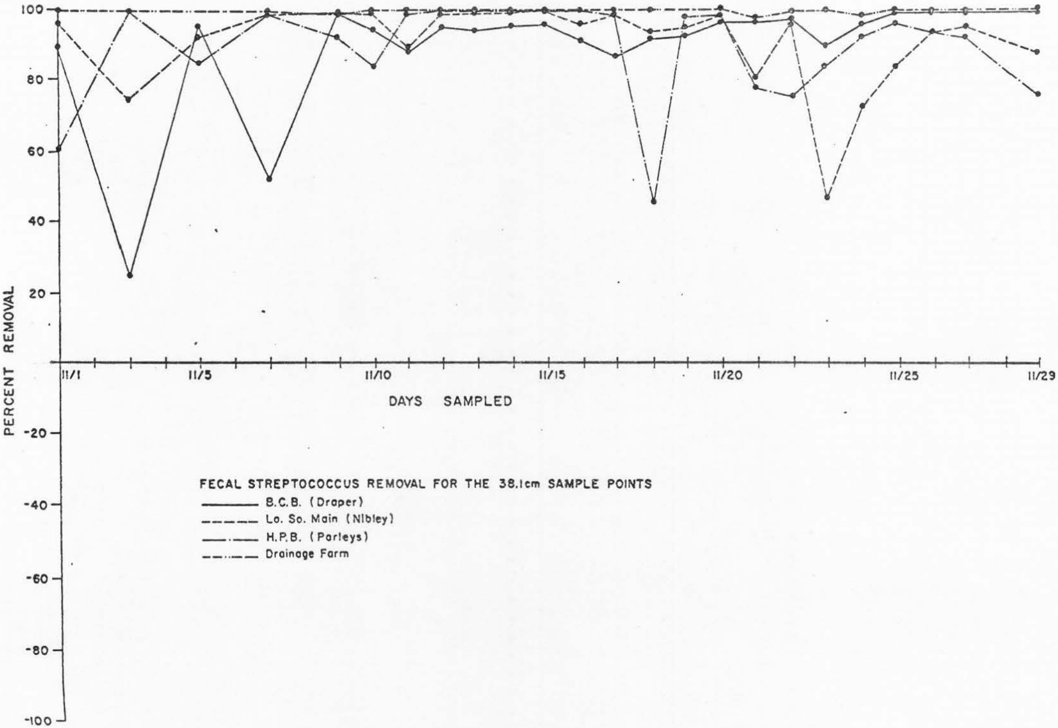
TOTAL COLIFORM REMOVAL FOR THE 38.1cm SAMPLE POINTS

Figure 6. Fecal coliform percent removal at the 38.1 centimeter depth for all soils studied.



FECAL COLIFORM REMOVAL FOR THE 38.1 cm. SAMPLE POINTS

Figure 7. Fecal Streptococcus percent removal at the 38.1 centimeter depth for all soils studied.


FECAL STREPTOCOCCUS REMOVAL FOR THE 38.1cm SAMPLE POINTS

Streptococcus in the 38.1 cm level over the Total Coliform. The Fecal Streptococcus found the soil favorable for growth. After a few days the higher population began washing through and showing up in a decrease in percent removal.

Although all soils proved effective for the removal of these bacterial indicators there is a marked difference in the degree of removal between the Drainage Farm soil and Parleys. Draper and Nibley fall between these two, with some variability shown between these two. Table 8 shows the average bacterial counts obtained at the various effluent ports over a 21 day period. Table 9 gives the removal rates of the four soils with depth for the three bacterial indicators. These rates clearly show which soils produced best removals. Drainage Farm was most efficient, then came Nibley, Draper and Parleys. The graphs for these rates can be found in the appendix (Figures 21-24). The primary reasons for the much better removal by Drainage Farm soil over the other three is the texture. The Drainage Farm soil was by far the most dense, therefore provided for removal by the three mechanisms of straining, bridging, and straining and sedimentation. It appears that the texture is indeed the most important factor in these four soils.

Figures 8, 9, and 10, show Total Coliform, Fecal Coliform and Fecal Streptococcus removal at the 7.6 cm levels for the four soils. It is quite evident from these that short circuiting was occurring. These figures suggest that the bacteria may have been growing. Negative removal indicates higher counts in the effluent from the lysimeters than were in the sewage applied. The Fecal Streptococcus grew most readily and apparently best in the Drainage Farm soil which has the

Table 8. Average bacterial counts over a 21-day period

Soil Type	Level	Total Coliform	Fecal Coliform	Fecal Streptococcus
Drainage Farm	Sew. (Top)	160	64	100
	7.6 cm	92	34	860
	38.1 cm	1	0	0
Nibley	Sew. (Top)	160	64	100
	7.6 cm	81	50	42
	38.1 cm	15	3	6
Draper	Sew. (Top)	160	64	100
	7.6 cm	9	6	20
	38.1 cm	7	8	10
Parleys	Sew. (Top)	160	64	100
	7.6 cm	47	34	94
	38.1 cm	41	20	11

Table 9. Removal rates of individual organisms for the four soils

Soil Type	Total Coliform	Fecal Coliform	Fecal Streptococcus
	Bacterial Organisms		
Drainage Farm	.091	.083	.088
Nibley	.050	.068	.060
Draper	.062	.051	.052
Parleys	.015	.031	.050

$$\text{Rates} = \frac{\text{Log organisms removed}}{\text{cm. of soil}}$$

Figure 8. Total coliform percent removal at the 7.6 centimeter depth for all soils studied.

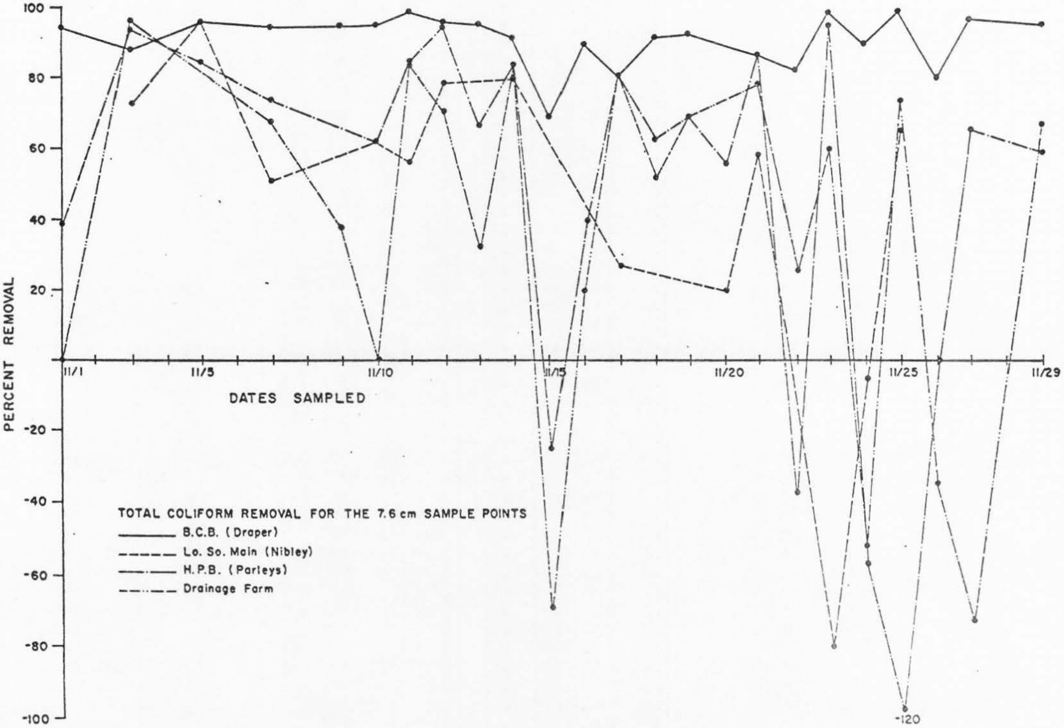

100
80
60
40
20
-20
-40
-60
-80
-100
PERCENT REMOVAL
11/1
11/5
11/10
11/15
11/20
11/25
11/29
DATES SAMPLED
-120
TOTAL COLIFORM REMOVAL FOR THE 7.6 cm SAMPLE POINTS
B.C.B. (Draper)
Lo. So. Main (Nibley)
H.P.B. (Parleys)
Drainage Farm

Figure 9. Fecal coliform percent removal at the 7.6 centimeter depth for all soils studied.

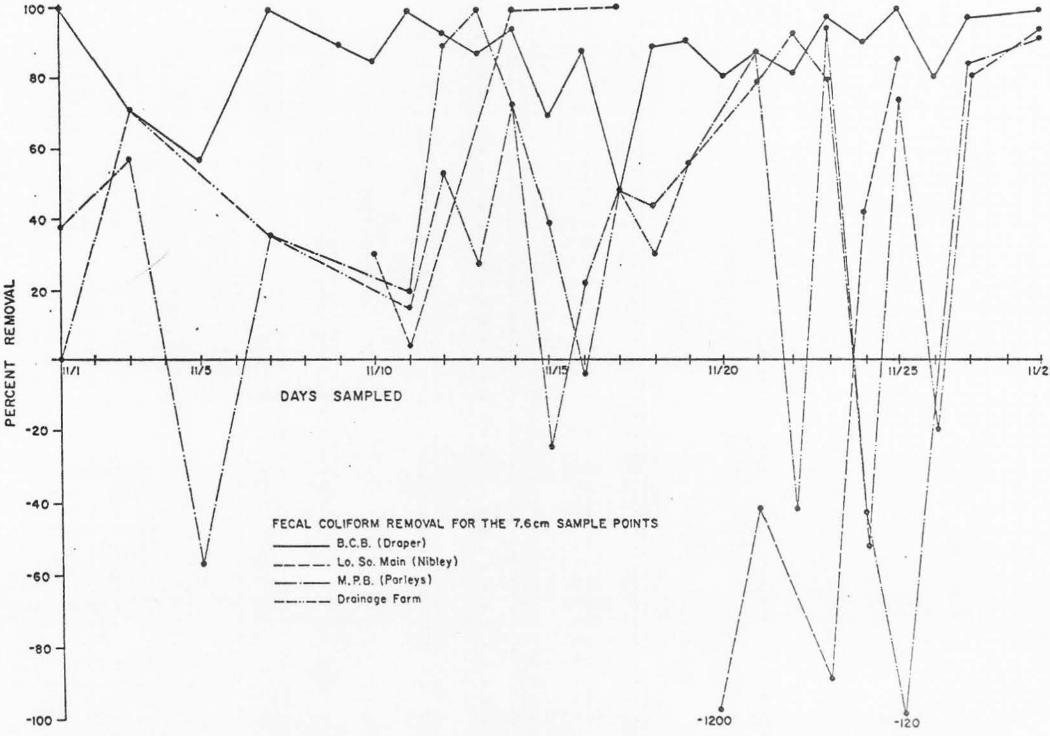
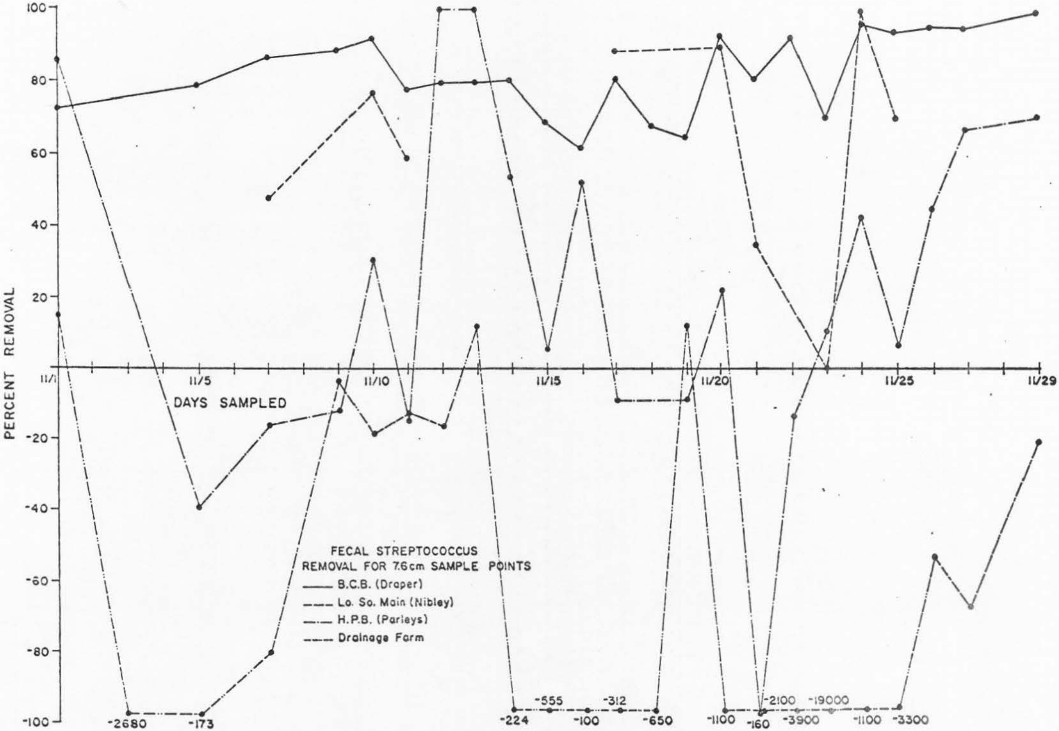

FECAL COLIFORM REMOVAL FOR THE 7.6cm SAMPLE POINTS

Figure 10. Fecal streptococcus percent removal at the 7.6 centimeter depth for all soils studied.


FECAL STREPTOCOCCUS REMOVAL FOR 7.6cm SAMPLE POINTS

greatest amount of organic matter and highest moisture holding capacity. It could also be assumed this soil had the greatest amount of short circuiting. The total coliforms did not thrive quite as well as the fecal streptococcus but better than the fecal coliforms.

It can be concluded that these bacterial indicators do grow in soil near the surface but are readily removed at least below 38.1 cm in degrees proportional to the soil texture or type. The bacteriological analysis of the soil after the test period failed to show any significant levels of bacterial indicators present at any level (Table 10). The fact that the soils were frozen and had been for approximately two weeks prior to taking the core sample could account for the limited survival of the coliforms. The soil (Nibley) in which some survival occurred had a fairly high moisture holding capacity as indicated in Table 11. This may account for the lack of survival. As pointed out by Hugo (1971) at temperatures just below zero a high proportion of coliform bacilli and other organisms were killed. However, when cells were suspended in distilled water prior to freezing survival greatly increased. It was also discovered that survival decreases as a function of the storage and temperature. It is suggestive from the data that the organisms near the top of the soil died quickly while those within the soil or the area last to freeze lasted longest.

Table 10. Results of a three tube, three dilution M.P.N. determination for for coliforms and fecal coliforms at various depths.

		NUMBER OF TUBES POSITIVE USING THREE TUBES PER DILUTION																			
		DRAINAGE FARM					DRAPER					PARLEYS					NIBLEY				
		Coliforms			Fecal Coliforms		Coliforms			Fecal Coliforms		Coliforms			Fecal Coliforms		Coliforms			Fecal Coliforms	
Level	Dilutions (ml)	Pres.	Conf.	MPN Org./gm. (Dry Wt.)	Conf.	MPN Org./gm. (Dry Wt.)	Pres.	Conf.	MPN Org./gm. (Dry Wt.)	Conf.	MPN Org./gm. (Dry Wt.)	Pres.	Conf.	MPN Org./gm. (Dry Wt.)	Conf.	MPN Org./gm. (Dry Wt.)	Pres.	Conf.	MPN Org./gm. (Dry Wt.)	Conf.	MPN Org./gm. (Dry Wt.)
TOP	1 -1 -2 -3	0 0 0 0					0 1 0 0	0		0		0 0 0 0					0 0 0 0				
1"	1 -1 -2 -3	0 0 0 0					0 0 0 0					0 0 0 0					2 1 0 0	0 0		0 0	
2"	1 -1 -2 -3	0 0 0 0					0 0 0 0					0 0 0 0					0 1 0 0	0		0	
3"	1 -1 -2 -3	0 0 0 0					0 0 0 0					0 0 0 0					2 0 0 0	0		0	
5"	10 1 -1 -2	0 0 0 0					1 1 0 0	0 0		0 0		0 0 0 0					3 3 3 3	3 1 1 0	28	0 0 0 0	
8"	10 1 -1 -2	0 0 0 0					0 0 0 0					1 0 0 0	0		0		1 1 0 0	0 0		0 0	
13"	10 1 -1 -2	1 0 0 0	0		0		1 0 0 0	0		0		1 0 0 0	0		0		3 1 0 0	1 0	2	0 0	

Table 11. Results of a before and after analysis of the four soils' chemical and physical properties.

	DRAPER			NIBLEY			PARLEYS			DRAINAGE FARM		
	Before Test Period	After Test Period		Before Test Period	After Test Period		Before Test Period	After Test Period		Before Test Period	After Test Period	
		Top	32.5 cm		Top	32.5 cm		Top	32.5 cm		Top	32.5 cm
pH	7.1	8.4	7.8	7.4	8.1	7.7	7.6	8.1	7.7	8.1	8.2	8.3
ECe mmhos/cm	1.1	.7	.5	.5	.7	.5	.6	.9	.6	.9	.7	.5
P ppm	13.0	21.0	19.0	27.0	31.0	26.0	4.5	11.0	3.9	7.1	32.0	6.4
K ppm	171.0	81.0	110.0	490.0	378.0	408.0	398.0	315.0	389.0	490.0	399.0	450.0
Texture	Sandy Loam	Sandy Loam	Silt Loam	Silt Loam	Clay	Clay	Silt Loam	Silt Loam	Silt Loam	Clay	Silty Clay Loam	Silty Clay Loam
Lime	+	+	+	+	++	++	++	++	++	++	++	++
Org. Matter %	2.3	.5	1.2	3.7	1.0	1.1	1.9	1.1	1.2	5.5	2.2	2.8
Exch. Na me/100g	.2	.2	.2	.3	.4	.3	.2	.4	.4	.8	.4	.4
Total Na me/100g	.2	.2	.3	.3	.5	.4	.2	.5	.4	1.2	.5	.6
Water Sol. Na. me/100g	.1	.1	.1	.1	.1	.1	.1	.1	.1	.3	.2	.1
Cation Exch. Capacity me/100g	9.9	5.1	8.8	23.6	19.6	21.2	17.7	11.8	12.2	19.7	12.0	15.7
Water Saturation %	28.0	21.0	29.0	56.0	60.0	66.0	42.0	42.0	44.0	83.0	81.0	90.0
Moisture Storage Capacity cm/cm	2.54/34	2.54/34	4.45/34	4.45/34	5.70/34	5.70/34	4.45/34	4.45/34	4.45/34	5.70/34	5.08/34	5.08/34

Chemical Removal

Nitrogen

Figures 11, 12, and 13 of Drainage Farm soil show the values resulting from the analysis of the influent and effluents from the 38.1 cm sample points for nitrate, nitrite and ammonia. Graphs of these parameters for Draper, Nibley, and Parleys are given in the Appendix, Figures 25-33. Due to the short circuiting which occurred data from the 7.6 cm sample points cannot be considered reliable. These graphs show an appreciable increase in nitrate over the amounts present in the sewage applied. The source of this increase must come from the production of ammonia from the decomposition of organics present in sewage and trapped on the filter and that already present in the soil as well as the oxidation of ammonia present in the sewage.

Figures 11, 12 and 13 show the level of nitrate remaining relatively steady in the sewage and the levels of ammonia increasing towards the end of the testing period. The values of nitrate from the 38.1 cm sample points were declining sharply at this time however. This can be attributed to the drop in temperature which may have affected the nitrifying bacteria. Little ammonification and nitrification take place in reduced temperatures during the winter. On the other hand the rate of activity of microorganisms above 7°C increases two fold or three fold for each rise of 10°C if moisture is adequate and the soil is not highly acid.

The tests indicate that the soils could have contained a fairly high amount of nitrogen initially due to the much higher values of nitrate coming out, over the nitrate levels in the sewage applied.

Figure 11. Nitrate levels in the influent and effluent from 7.6 and 38.1 centimeter depths for Drainage Farm soil.

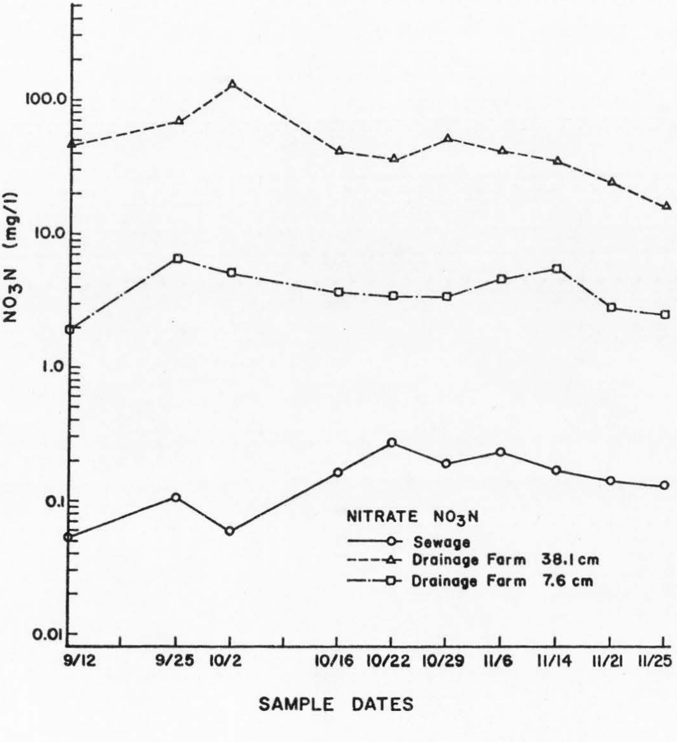

100.0
10.0
1.0
0.1
0.01
NO$_3$N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
NITRATE NO$_3$N
Sewage
Drainage Farm 38.1 cm
Drainage Farm 7.6 cm

Figure 12. Nitrite levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.

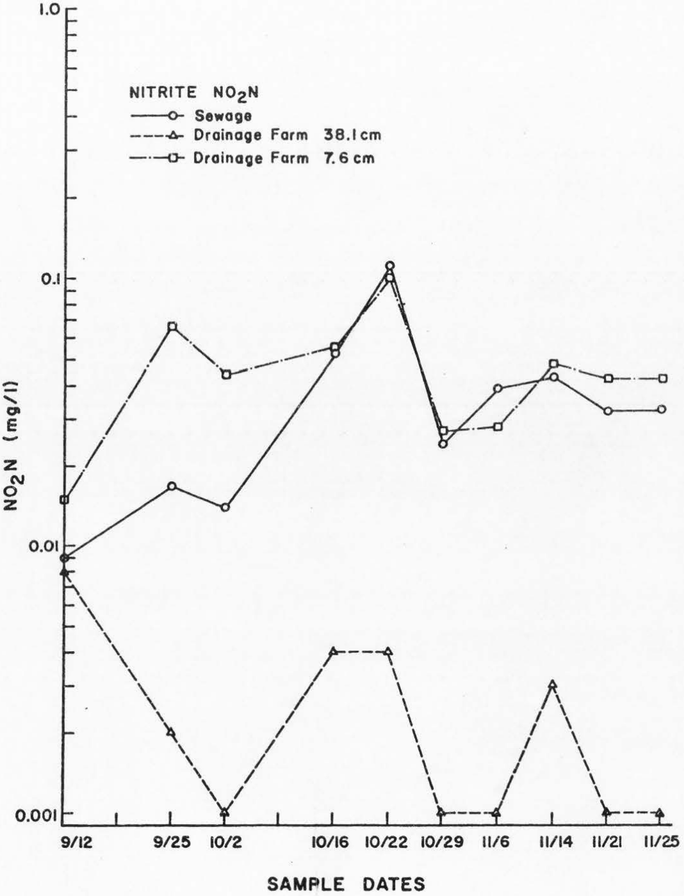
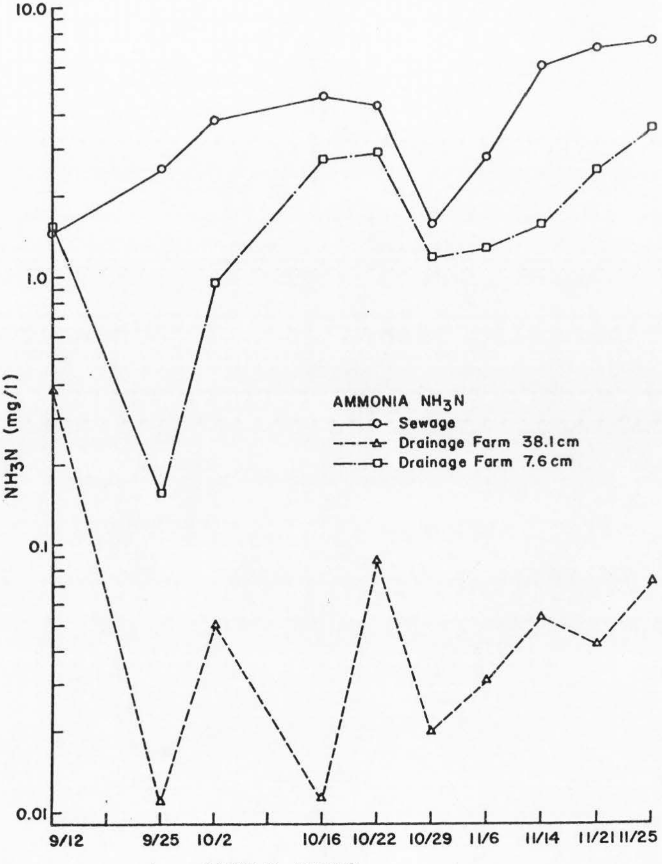

1.0
0.1
0.01
0.001
NO$_2$N (mg/l)
NITRITE NO$_2$N
Sewage
Drainage Farm 38.1 cm
Drainage Farm 7.6 cm
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure 13. Ammonia levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.


10.0
1.0
0.1
0.01
NH3N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
AMMONIA NH3N
Sewage
Drainage Farm 38.1cm
Drainage Farm 7.6cm

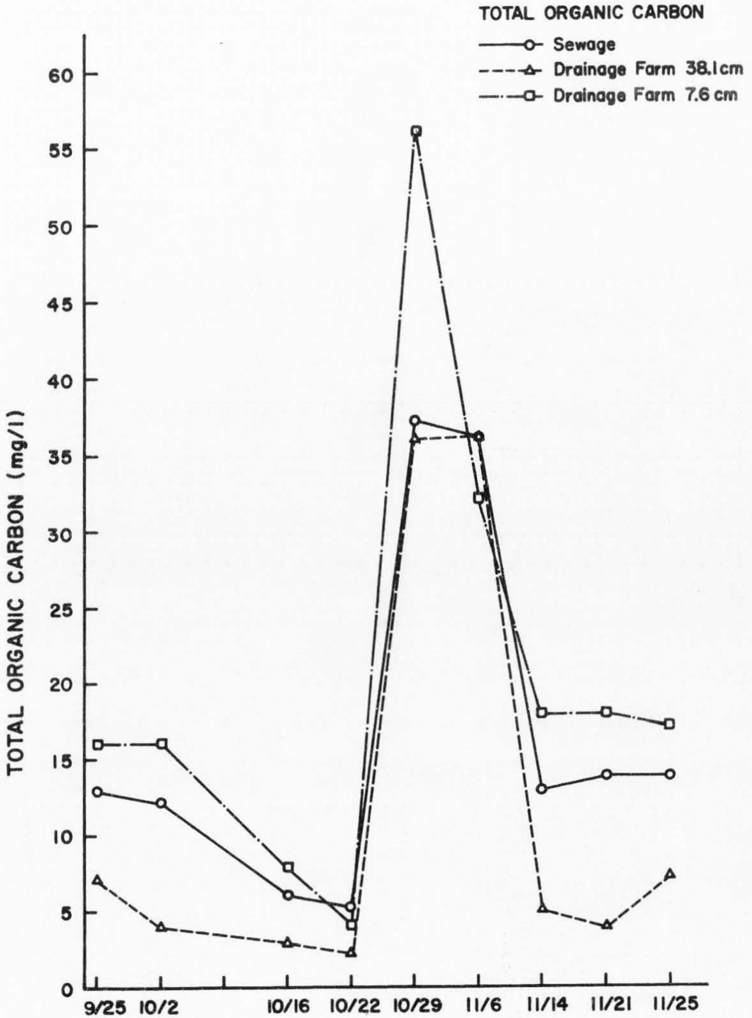
Leaching removes large amounts of nitrates from soils but not more than traces of other forms of nitrogen.

Nibley (silty clay loam) and Drainage Farm (clay) produced appreciably higher levels of nitrate in the 38.1 cm effluents than the Parleys (silty loam) and Draper (sandy loam) soils. This suggests that the tighter soils or those producing a longer residence time allow nitrification to proceed longer, therefore, the higher nitrate levels. Although sandy soils will leach what nitrates are present in the soil faster, the denser or more clay-like will produce higher levels of nitrate if the organics are available, as is the case here. Figures 12 and 13 also show this case to be true. The Drainage Farm and Nibley soils produced lowest levels of ammonia and nitrite indicating that these primary and intermediate forms are not as readily leached out and that nitrification has had more time, therefore we see less nitrite and ammonia and more nitrates.

Total organic carbon

To explain the extreme nitrate build-up in the soils, a high quantity of ammonia and/or organic nitrogen would be expected. As the ammonifiers comprise a large percentage of the bacteria and fungi that live in soil, decomposing soil organic matter to obtain a supply of energy or carbon for growth, a large supply of organics would explain alot. Figure 14 shows levels of T.O.C. in the influent and effluents from the sample points for Drainage Farm soil. Graphs of T.O.C. for Draper, Nibley and Parleys are given in the Appendix, Figures 34-36. Figure 14 shows the levels of T.O.C. in the effluents correspond fairly close to the concentration of T.O.C. in the

Figure 14. Total organic carbon levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.


TOTAL ORGANIC CARBON
Sewage
Drainage Farm 38.1cm
Drainage Farm 7.6 cm
TOTAL ORGANIC CARBON (mg/l)
0
5
10
15
20
25
30
35
40
45
50
55
60
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

sewage applied. The graph indicates some removal through the soils, however not enough to support the assumption that the organics are supplying the source of nitrates, if the soils did not contain a high amount of organics initially.

In examining the data from the before and after analysis of the soils (Table 11), it shows a marked decrease in the organic material present in the soils. The clay-like soils, Nibley and Drainage Farm, again show the greatest decrease in organic matter, 70% and 50% respectively, where Draper had a 48% reduction and Parleys was reduced by 37% (all figures from the 38.1 cm levels).

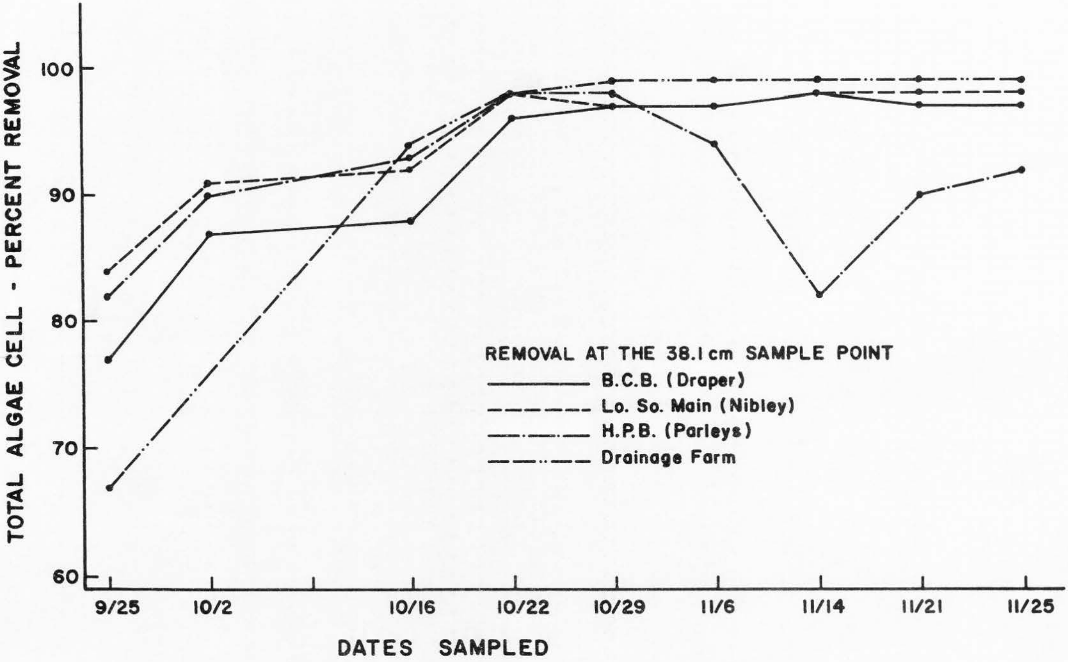
Figure 14 then, indicates organics being leached or passed through the soils, but also being replenished by the source in the sewage. There is an overall net loss in organic matter in each soil, which may account for some of the nitrate excess.

The four soils show that they have the potential of acting effectively in the removal of organic matter. The factors contributing to the degree of organic uptake would be the soil characteristics and the microbial activity. In this study where the atmospheric conditions were uniform for all soils, differences in degree of removal would be dependent solely on the soil characteristics. The more clay-like soils (Drainage Farm and Nibley) provided better removal than the sandy or silt loam soils. Figure 15 showing the percent removal of total algal cells suggests a possible source of organic material.

Algal cells

Figure 15 supports the observation already made that the Drainage Farm soil provides the best removal followed by Nibley,

Figure 15. Total algal cell percent removal at the 38.1 centimeter depth for all soils studied.


TOTAL ALGAE CELL - PERCENT REMOVAL
100
90
80
70
60
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
DATES SAMPLED
REMOVAL AT THE 38.1 cm SAMPLE POINT
B.C.B. (Draper)
Lo. So. Main (Nibley)
H.P.B. (Parleys)
Drainage Farm

Draper and Parleys. In the removal of algal cells it would be expected that the three mechanisms of removal; straining, bridging, and straining and sedimentation would govern the percent removal achieved by each soil. At the beginning of the testing period the removal appears much lower than toward the end. This condition could have been caused by the buildup of a film on the soil surface. The condition could also have been caused by the soil cracking between sewage applications. Before the biological analysis began, the sewage applications were only three times weekly as opposed to every day later on. In the soils with a higher percent clay, the cracking would be expected to be more severe thereby explaining the much lower removal of the Drainage Farm (clay) soil initially. As the algal cells begin to build up on the soil surface, the removal would be expected to increase as is observed here. The large drop in percent removal by Parleys must have occurred after the soil surface of this lysimeter was re-leveled on October 29. This act drastically disturbed the clogged pores, decreasing the filterability. At this time the suspended solids and volatile suspended solids shot up enormously for this soil as shown in Figures 39 and 42 in the Appendix.

Suspended solids

As Figures 16 and 17 for Drainage Farm Soil indicate, the volatile suspended solids concentration in the influent is slightly lower than the suspended solids, as is to be expected. Graphs of suspended solids and volatile suspended solids for Draper, Nibley and Parleys are given in the Appendix, Figures 37-42. The level of suspended solids in the influent is fairly steady without drastic

Figure 16. Suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.

SUSPENDED SOLIDS

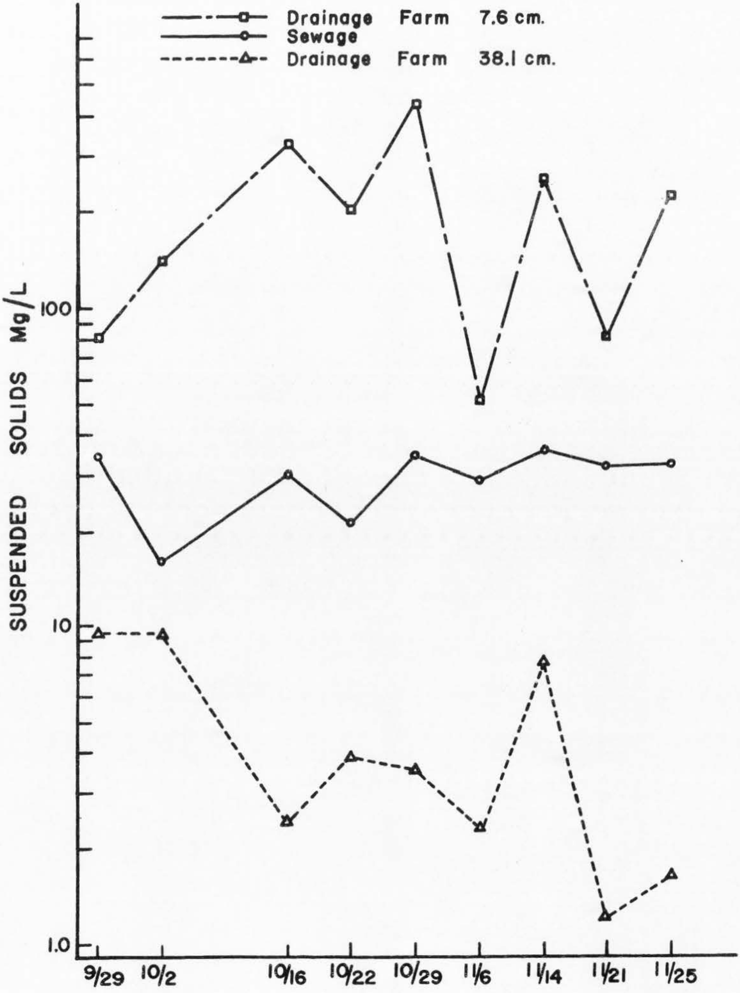
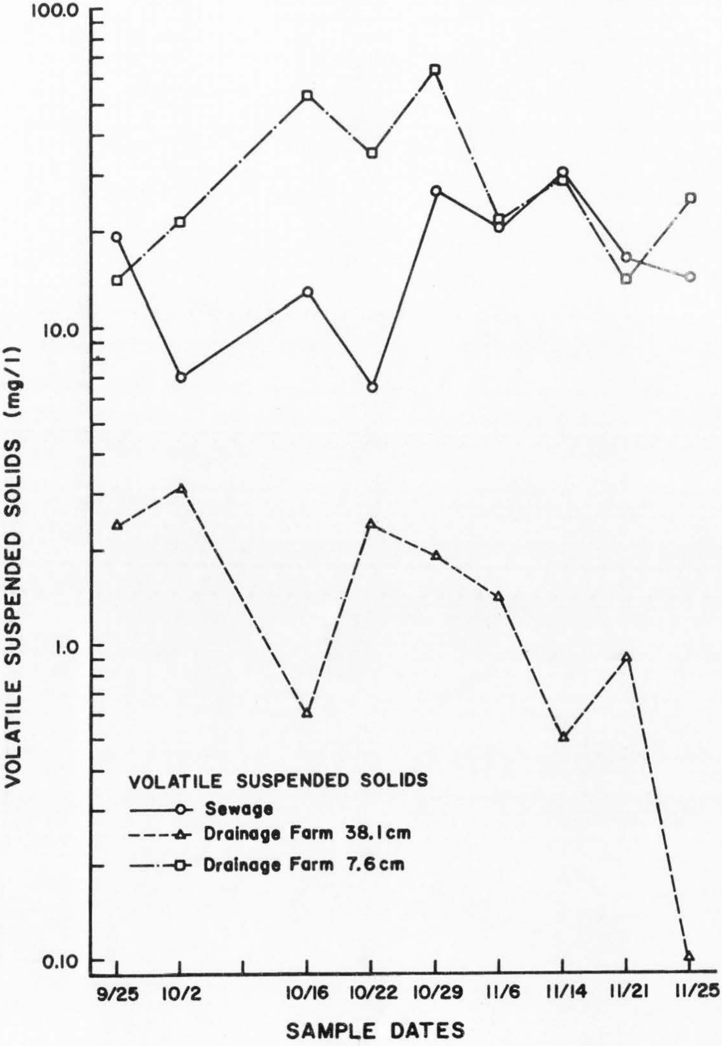


Figure 17. Volatile suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.


100.0
10.0
1.0
0.10
VOLATILE SUSPENDED SOLIDS (mg/l)
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
VOLATILE SUSPENDED SOLIDS
Sewage
Drainage Farm 38.1 cm
Drainage Farm 7.6 cm

changes reflecting a stable turbid condition. The volatile suspended solids, however have some large fluxuations caused by unsettled algal populations. The level of suspended solids in the influent remains fairly constant while the levels in the effluents at the 38.1 cm sample points are constantly decreasing. This is also the condition for the volatile suspended solids. The increasing removal toward the end of the period show an increased filtering effect caused by straining and sedimentation and also utilization of the volatile or organic matter present. Drainage Farm soils shows the best removal with Nibley second. These soils with tighter pore space and longer residence time provide best removal by a filtration effect and utilization of the organic matter. The removals provided by Draper and Parleys are close to the other two soils. The average removals provided by these soils for suspended and volatile suspended solids are approximately 85% once the sewage had been applied for a time.

Phosphorus

The phosphate removal capacity of a soil is a result of a combination of adsorption of phosphate and precipitation of compounds of phosphorus. As stated by Shewman (1973), it was found the soil properties most likely correlated with adsorption would be surface area and the related properties, percent clay and cation exchange capacity. The amount and condition of lime present probably influences both precipitation and adsorption.

Figures 18 and 19 of the Drainage Farm soil show that most all of the phosphate exists as ortho-phosphate. Graphs of total and ortho-phosphate for Draper, Nibley and Parleys are given in the Appendix,

Figure 18. Total phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.

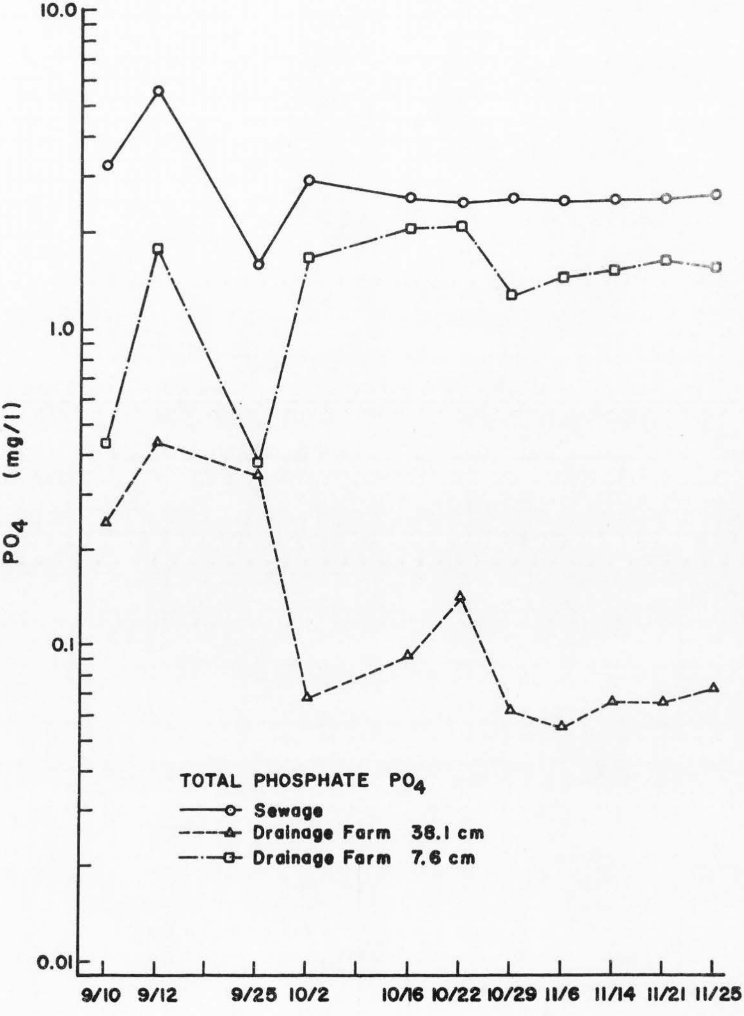
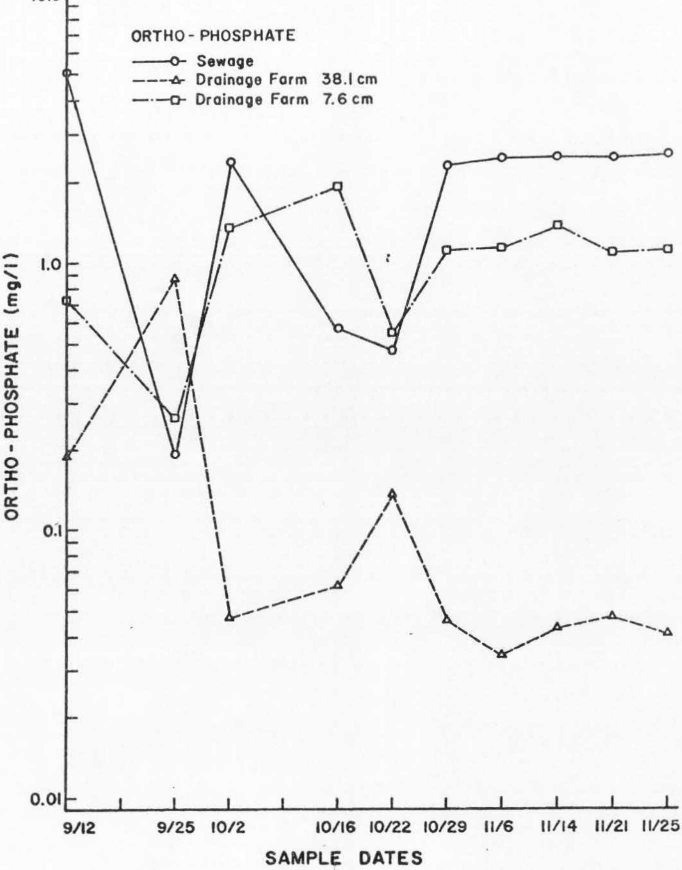

10.0
1.0
0.1
0.01
PO4 (mg/l)
9/10
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
TOTAL PHOSPHATE PO4
Sewage
Drainage Farm 38.1 cm
Drainage Farm 7.6 cm

Figure 19. Ortho-phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.


ORTHO - PHOSPHATE
Sewage
Drainage Farm 38.1 cm
Drainage Farm 7.6 cm
10.0
1.0
0.1
0.01
ORTHO - PHOSPHATE (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figures 43-48. The total phosphate concentrations from the 38.1 cm sample point show very consistent results, fluctuating only when the influent concentration varies. The removal of total phosphate appears dependent a great deal on adsorption. Ortho-phosphate influent concentrations are a little less than the total phosphate influent but the concentrations of ortho-phosphate from the 38.1 cm sample points are at about equal levels with the total phosphate, suggesting a change of form or increase from another source. The erratic fluctuations of the ortho-phosphate effluent levels indicate probable microbial activity breaking down phosphate or organics initially present in the soil to show an increase. The fluctuations could have been caused by the severe temperature variation which occurred during the testing period, affecting the amount of microbial activity.

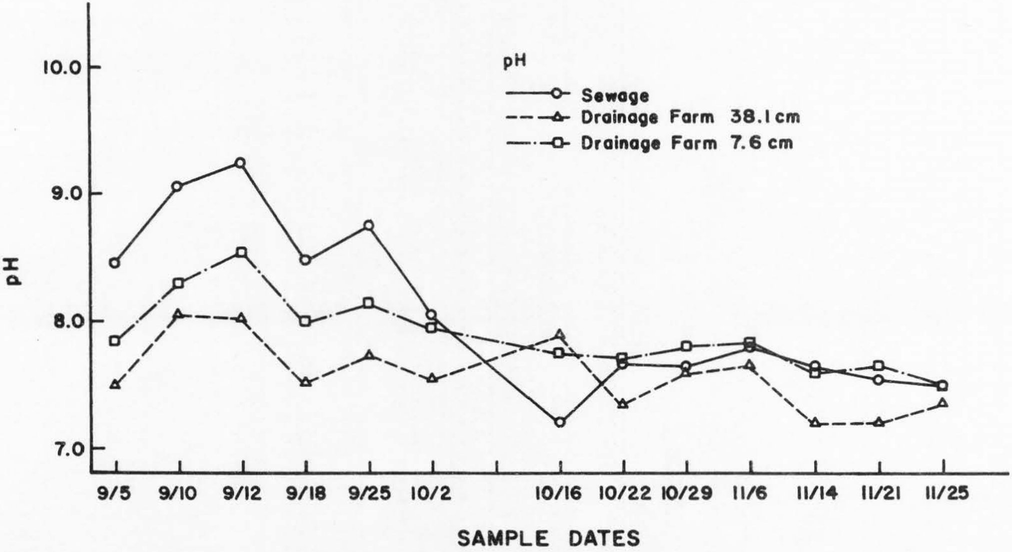
The degree of removal by the different soils are consistent between the total phosphate and ortho-phosphate. Drainage farm soil was again the most effective treatment media followed by Parleys, Draper and Nibley. As stated earlier, removal capacity is based on surface area and these soils show this to be true; Drainage Farm (clay), Parleys (silt loam), Draper (sandy loam), however, Nibley should not have been the poorest. Being a siltly clay loam, Nibley should have shown removal comparable to the Drainage Farm. Also in studying the cation exchange capacity (C.E.C.; see Table 11) the order again occurs from high to low--Drainage Farm (19.7), Parleys (17.7) and Draper (9.9), however Nibley has the highest (23.6), justifying a better removal. It can be concluded that either Nibley soil does not have the capacity for removal under these loading rates or there was some short circuiting involved. In the case of phosphorus removal where there is only 2-4 ppm to begin with, slight short circuiting would have a large effect. The percent of clay and amount of lime present (Table 11) also supports the observed results, however here again Nibley does not follow the rule so we must conclude, a small degree of channeling may have occurred in this lysimeter.

pH

Figure 20 shows the pH values for the lagoon effluent applied to the soils and the effluent pH values for the Drainage Farm soil at the 7.6 centimeter and 38.1 centimeter depths. Graphs of pH for Draper, Nibley and Parleys are given in the Appendix, Figures 49-51. The 7.6 centimeter pH values are generally lower than the sewage lagoon effluent applied but not as low as the effluent from the 38.1 centimeter depth. This condition supports an interesting and expected observation.

The pH of the lagoon effluent was usually in the range of 7.8 to 8.5. The pH values from the 7.6 centimeter depths averaged around 7.5-8 while the 38.1 centimeter depths produced pH values around 7.0 to 7.25. The drop in pH may have been caused by production of CO_2 and organic acids resulting from bacterial action in the soil. Nitrification of the ammonium and removal of carbonate also reduces pH. These factors would almost all be dependent on the detention time for their degree of effect. Therefore, it is generally observed that those samples from the 38.1 centimeter depth or effluent which had the longest detention time produced the greatest reduction in pH values.

Figure 20. pH values of the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.


pH
Sewage
Drainage Farm 38.1 cm
Drainage Farm 7.6 cm
10.0
9.0
8.0
7.0
pH
9/5
9/10
9/12
9/18
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Changes in soil properties

The soils studied provided a great deal of removal of various constituents and bacteria, but their individual characteristics did not change drastically as Table 11 indicates. As in the determination of chlorophyll "a" and pheophytin "a" in the sewage, the analysis of the core samples for chlorophyll "a" did not turn up levels high enough to be of significant value. The noticeable changes occurred in phosphorus, percent organic matter and cation exchange capacity.

The phosphorus as would be expected showed a build up on the surface of all soils especially on the clay (Drainage Farm). Because phosphate does not move readily through the soil we see an increase on the surface and a slighter increase at the 32.5 cm depth. As indicated by Table 11, the removals by Parleys and Draper were also noticeable.

The organic matter decreased considerably as was discussed earlier, however, it is apparent that this may have had some effect on the cation exchange capacity. The soils with a higher percentage of organic matter at the start, i.e., Nibley and Drainage farm had a higher C.E.C. "Soils high in organic matter have substantial cation exchange capacities because of the large negative charge developed by the humus" (N. T. Coleman, 1957, p. 73). Therefore, the C.E.C. is observed to decrease proportionally with the decreased organic material in the final analysis.

SUMMARY AND CONCLUSIONS

Summary

The objectives of this investigation were to: (1) correlate the soils' various characteristics with their effect on the removal and survival of specific enteric organisms present in a sewage lagoon effluent; (2) to investigate the effectiveness of each soil in removing various chemical constituents in sewage; (3) to examine any change in the soils' characteristics after the test period.

All soils provided very good removal of the three bacterial indicators. There was a definite difference in the degree of removal between the Drainage Farm soil and Parleys. Draper and Nibley fell between these two, but also showed some discrepancy. The primary reason for the much better removal by Drainage Farm soil over the other three was the texture. This soil was by far the most dense, therefore providing for removal by the three mechanisms of straining, bridging, and straining and sedimentation. Drainage Farm soil (clay) provided the best bacteriological removal with Nibley (silty clay loam) second, then Draper (sandy loam) and Parleys (silty loam) last.

An increase in nitrate over the amounts present in the sewage was observed. The source of this increase came from the decomposition of organics present in the sewage and initially in the soils. Another source was the oxidation of ammonia present in the sewage resulting from organic degradation in the oxidation ponds.

Tighter soils or those producing a longer residence time allowed nitrification to proceed longer, therefore produced higher nitrate levels in the effluents from the lysimeters. Nibley (silty clay loam) showed highest levels, Drainage Farm (clay) was next, then Parleys (silty loam) and Draper (sandy loam) showed the lowest levels.

The four soils show that they have the potential of acting as an effective filter in the removal of organic matter. The more clay-like soils (Drainage Farm and Nibley) provide better removal than the sandy or silt loam soils.

In respect to volatile suspended solids and suspended solids, Drainage Farm soil shows the best removal with Nibley second. These soils with tighter pore space and longer residence time provide best removal by a filtration effect and utilization of the organic matter. The removals provided by Draper and Parleys are close to the other two soils. The average removals provided by these soils for suspended and volatile suspended solids are approximately 85%.

The phosphate removal capacity of the soils was a result of a combination of adsorption of phosphate and precipitation of compounds of phosphorus. Drainage Farm soil was the most effective treatment media followed by Parleys, Draper and Nibley.

The soils studied provided a great deal of removal of various constituents and bacteria, but their individual characteristics did not change drastically. The noticeable changes occurred in phosphorus, percent organic matter and cation exchange capacity. The changes that did occur had no apparent effect on the removal capacity of any of the soils during the test period.

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Thomas, R. E. 1973. Land disposal II: an overview of treatment methods. Journal WPCF 45: 1476-1483.

Tofflemire, T. J & F. E. VanAlstyne. 1974. Land Disposal of Wastewater. Journal Water Pollution Control Federation. 46:1201-1209.

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Warrington, Sam L. 1952. "Effects of using lagooned sewage effluents on farmland." Sewage and Industrial Wastes 24(10):1243-1247.

Wilcox, L. V. 1948. Agr. uses of reclaimed sewage effluents. Sewage Works Journal 20:24-33.

Wilson, C. W. & F. E. Beckett (1968) Editors, Municipal Sewage Effluent for Irrigation. Proceedings of a symposium held at Louisiana Polytechnic Institute, July.

APPENDIX

Figure A21. Average bacterial populations at points within Draper soil during test period.

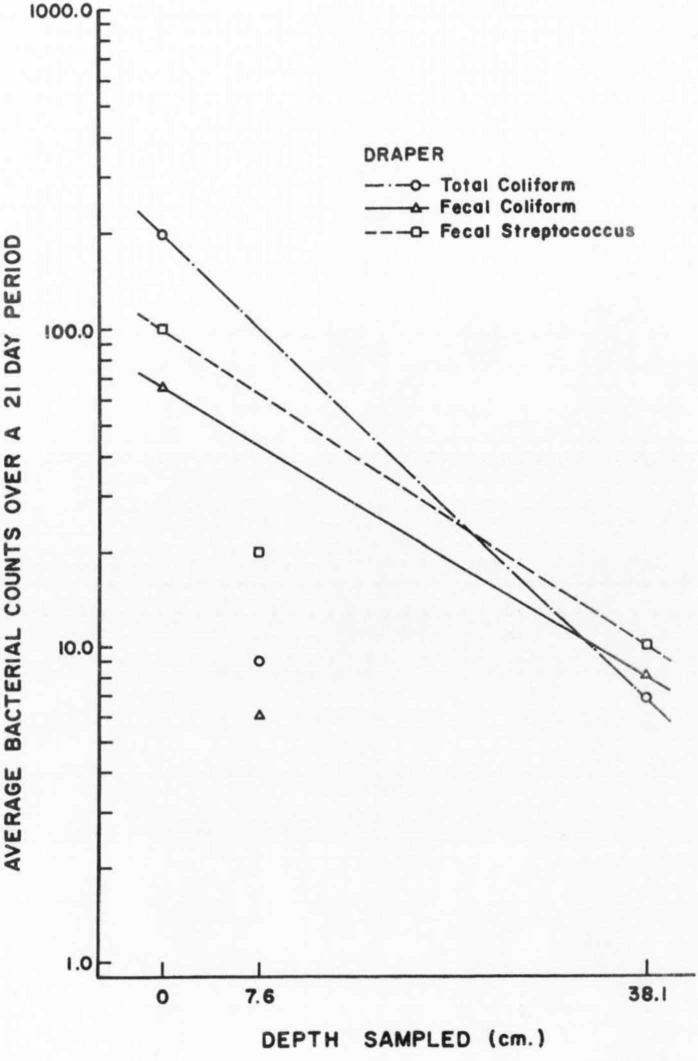

DRAPER
Total Coliform
Fecal Coliform
Fecal Streptococcus
1000.0
100.0
10.0
1.0
0
7.6
38.1
DEPTH SAMPLED (cm.)
AVERAGE BACTERIAL COUNTS OVER A 21 DAY PERIOD

Figure A22. Average bacterial populations at points within Nibley soil during test period.

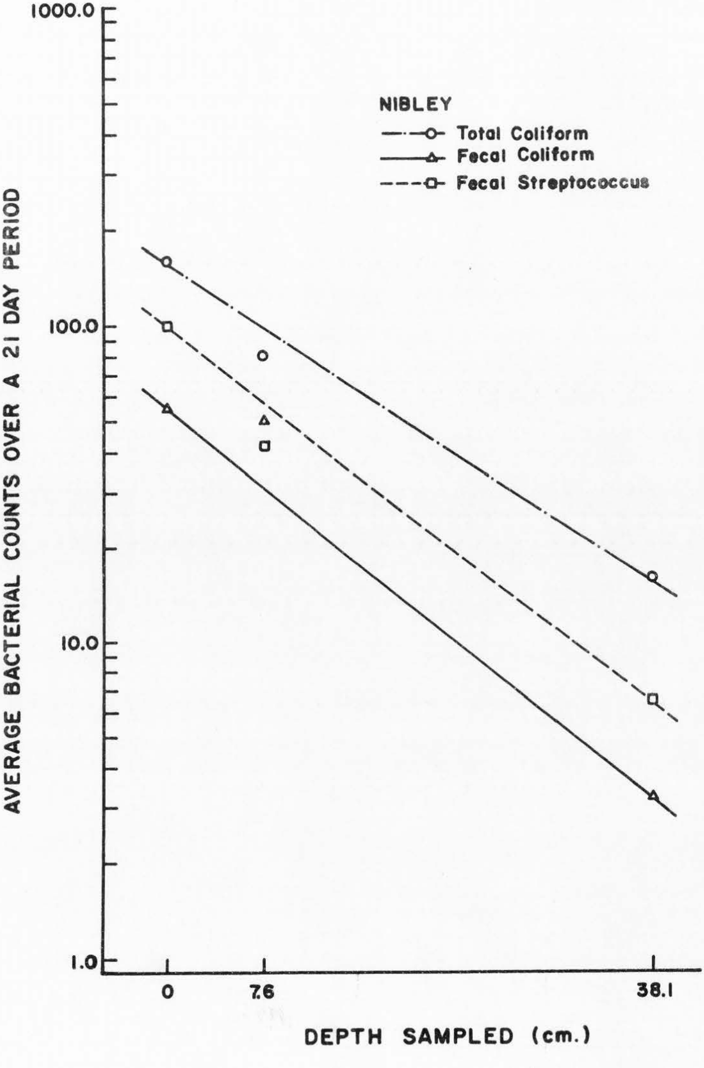

NIBLEY
Total Coliform
Fecal Coliform
Fecal Streptococcus
AVERAGE BACTERIAL COUNTS OVER A 21 DAY PERIOD
1000.0
100.0
10.0
1.0
0
7.6
38.1
DEPTH SAMPLED (cm.)

Figure A23. Average bacterial populations at points within Parleys soil during test period.

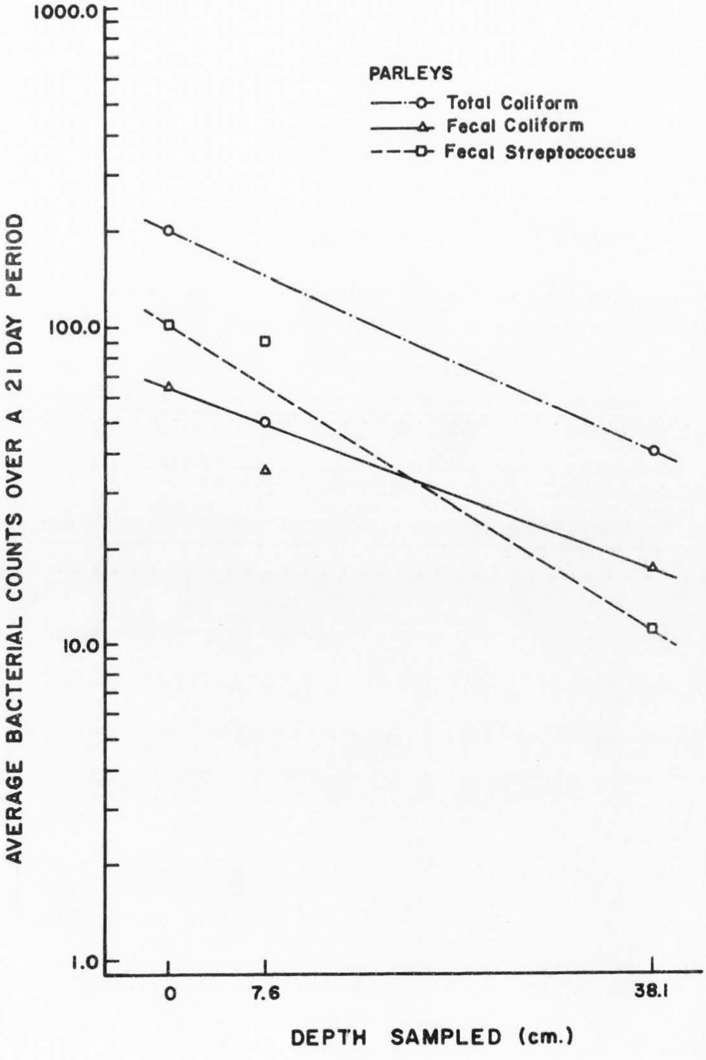

PARLEYS
Total Coliform
Fecal Coliform
Fecal Streptococcus
AVERAGE BACTERIAL COUNTS OVER A 21 DAY PERIOD
1000.0
100.0
10.0
1.0
0
7.6
38.1
DEPTH SAMPLED (cm.)

Figure A24. Average bacterial populations at points within Drainage Farm soil during test period.

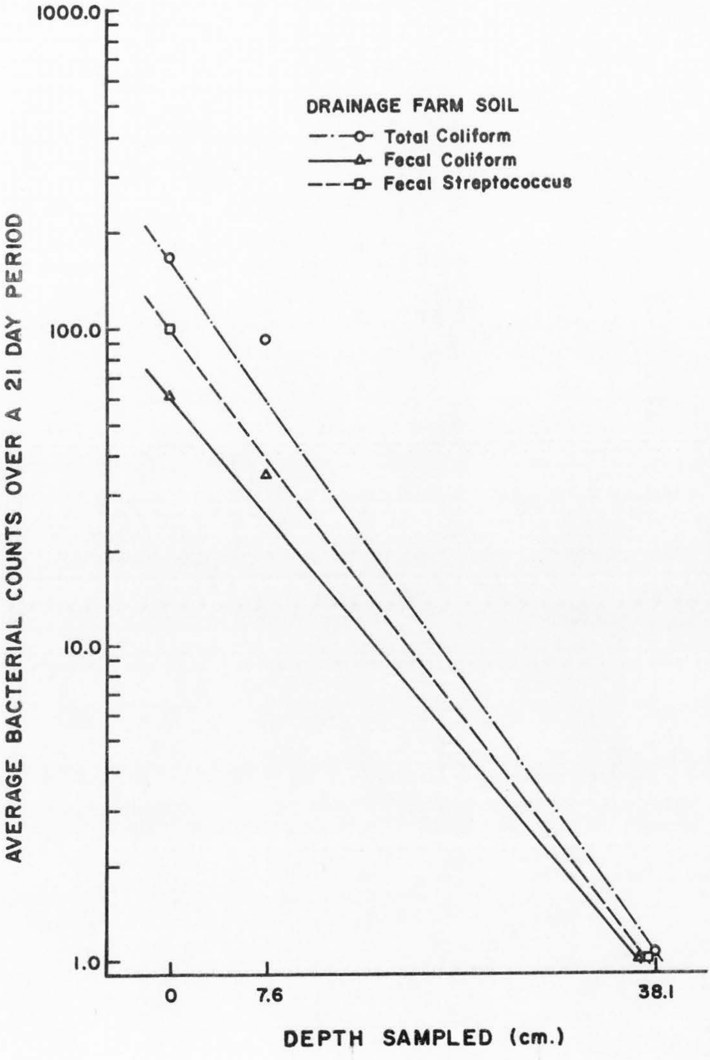

1000.0
100.0
10.0
1.0
AVERAGE BACTERIAL COUNTS OVER A 21 DAY PERIOD
DRAINAGE FARM SOIL
Total Coliform
Fecal Coliform
Fecal Streptococcus
0
7.6
38.1
DEPTH SAMPLED (cm.)

Figure A25. Nitrate levels in the influent and effluent from 7.6 and 38.1 centimeter depths for Draper soil.

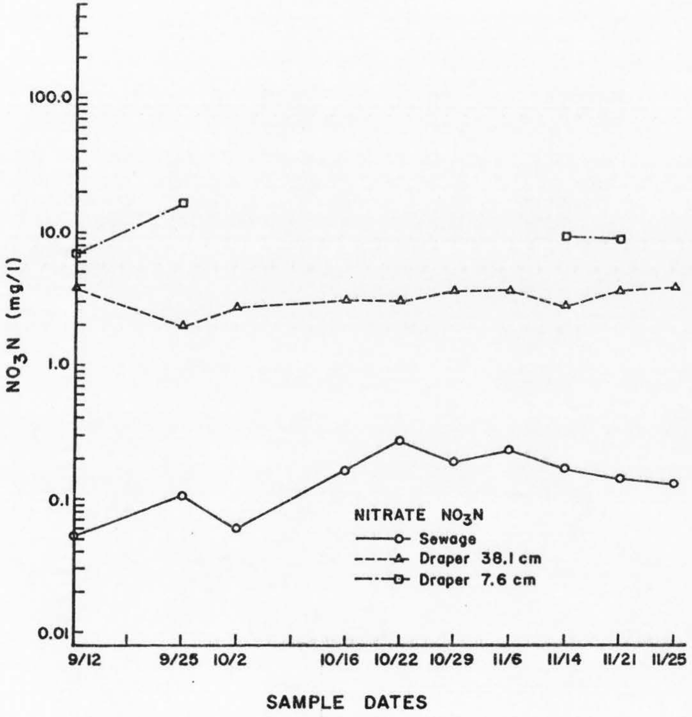

100.0
10.0
1.0
0.1
0.01
NO_3N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
NITRATE NO_3N
Sewage
Draper 38.1 cm
Draper 7.6 cm

Figure A26. Nitrate levels in the influent and effluent from 7.6 and 38.1 centimeter depths for Nibley soil.

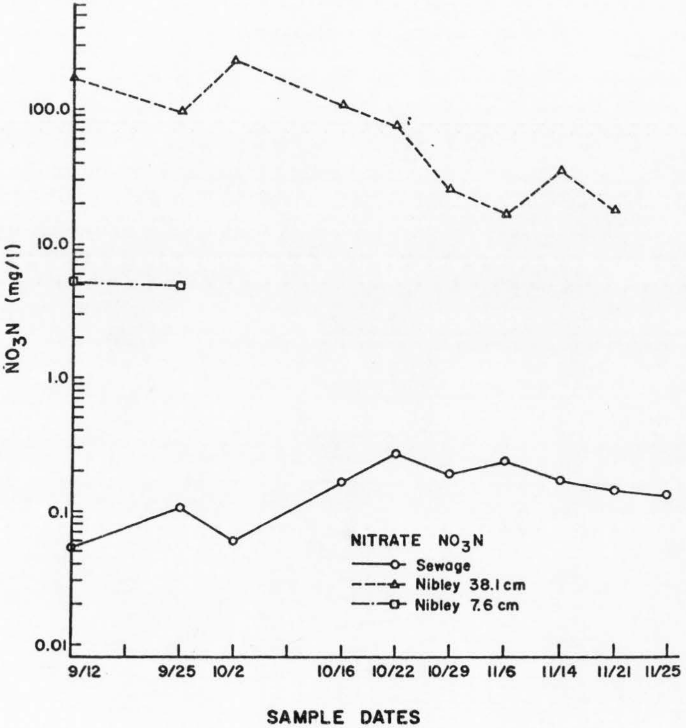

100.0
10.0
1.0
0.1
0.01
NO_3N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
NITRATE NO_3N
Sewage
Nibley 38.1 cm
Nibley 7.6 cm

Figure A27. Nitrate levels in the influent and effluent from 7.6 and 38.1 centimeter depths for Parleys soil.

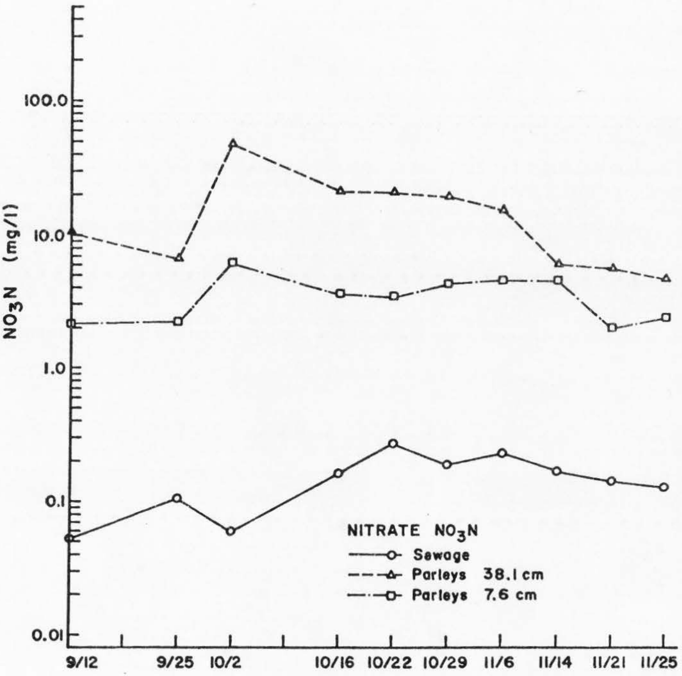

100.0
10.0
1.0
0.1
0.01
NO_3N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
NITRATE NO_3N
Sewage
Parleys 38.1 cm
Parleys 7.6 cm

Figure A28. Nitrite levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

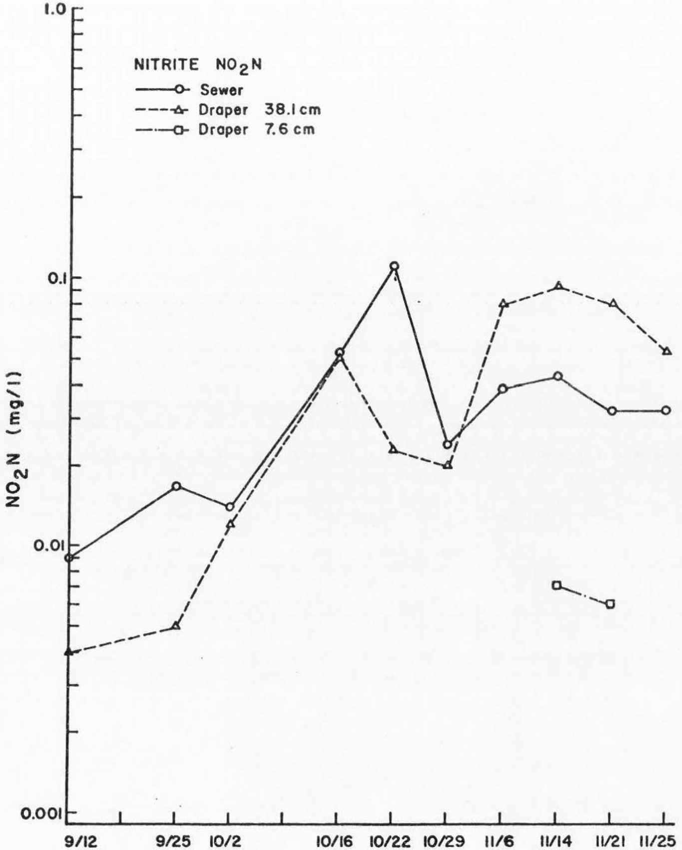

NITRITE NO_2N
Sewer
Draper 38.1 cm
Draper 7.6 cm
NO_2N (mg/l)
1.0
0.1
0.01
0.001
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A29. Nitrite levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

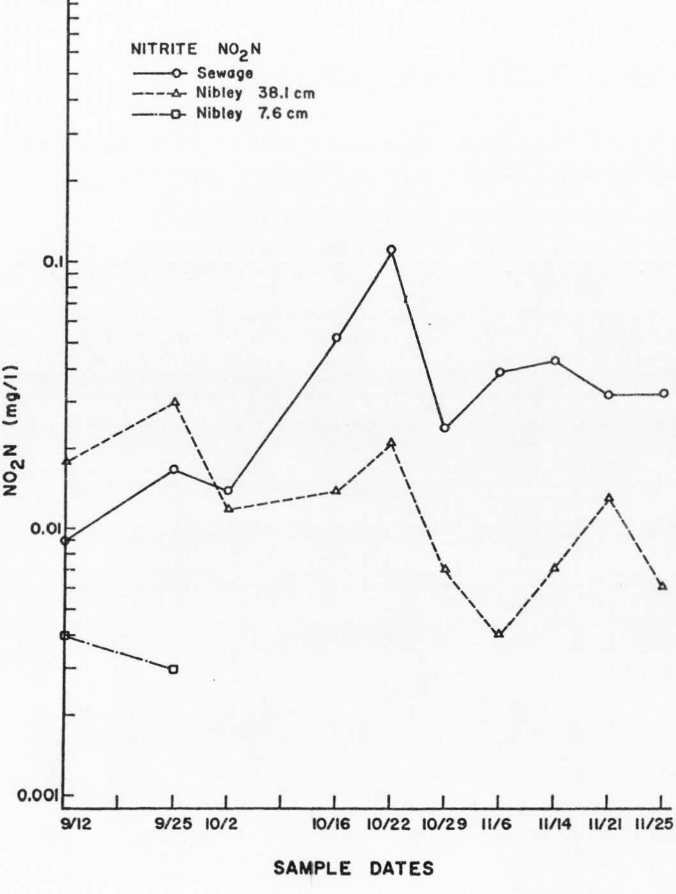

1.0
0.1
0.01
0.001
NO$_2$N (mg/l)
NITRITE NO$_2$N
Sewage
Nibley 38.1 cm
Nibley 7.6 cm
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A30. Nitrite levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

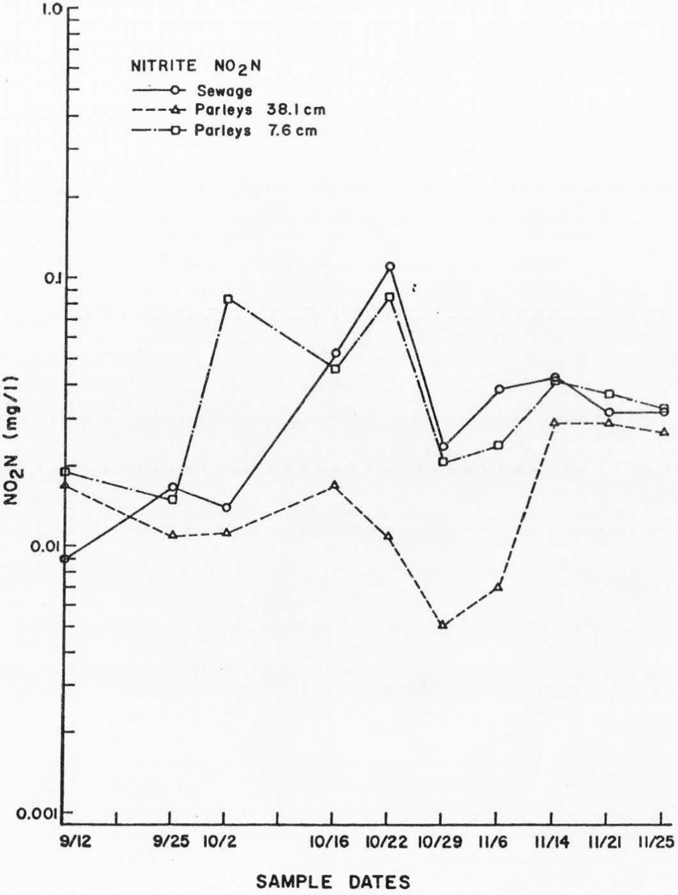

NITRITE NO2N
Sewage
Parleys 38.1 cm
Parleys 7.6 cm
1.0
0.1
0.01
0.001
NO2N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A31. Ammonia levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

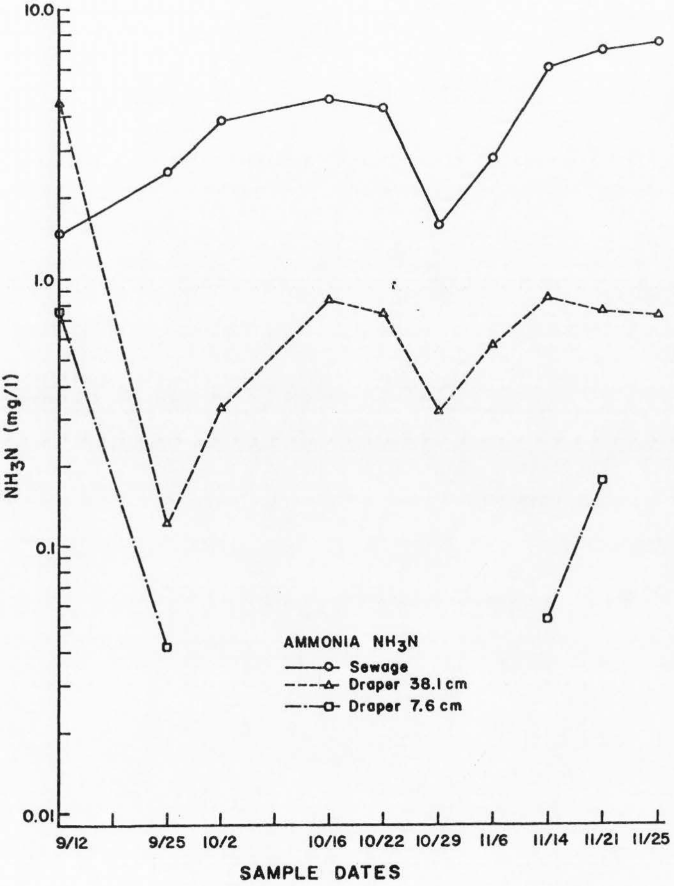

10.0
1.0
0.1
0.01
NH$_3$N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
AMMONIA NH$_3$N
Sewage
Draper 38.1 cm
Draper 7.6 cm

Figure A32. Ammonia levels in the influent and effluent from the 7.6 and 38.1 centimeter depth for Nibley soil.

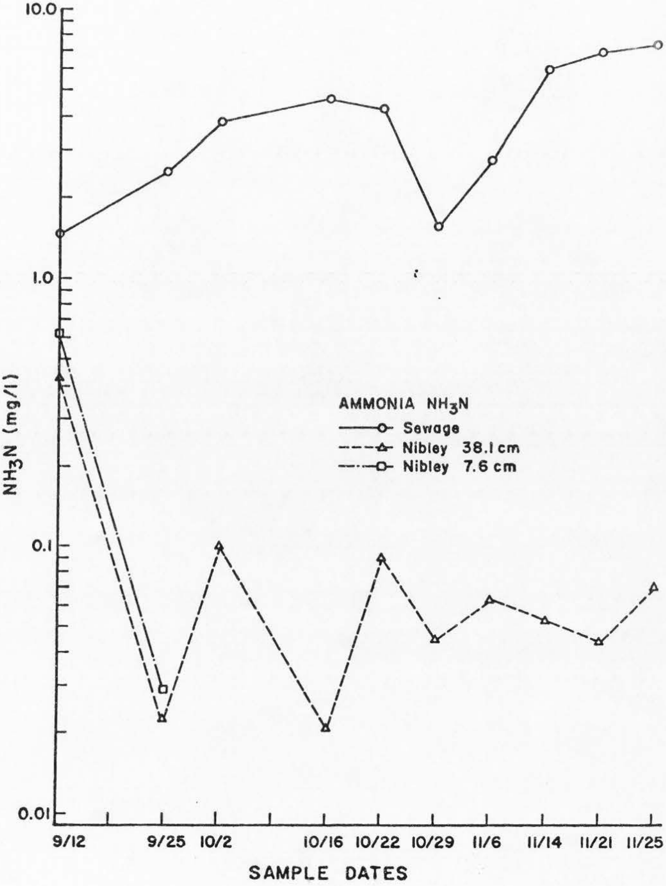

10.0
1.0
0.1
0.01
NH3N (mg/l)
AMMONIA NH3N
Sewage
Nibley 38.1 cm
Nibley 7.6 cm
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A33. Ammonia levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parley soil.

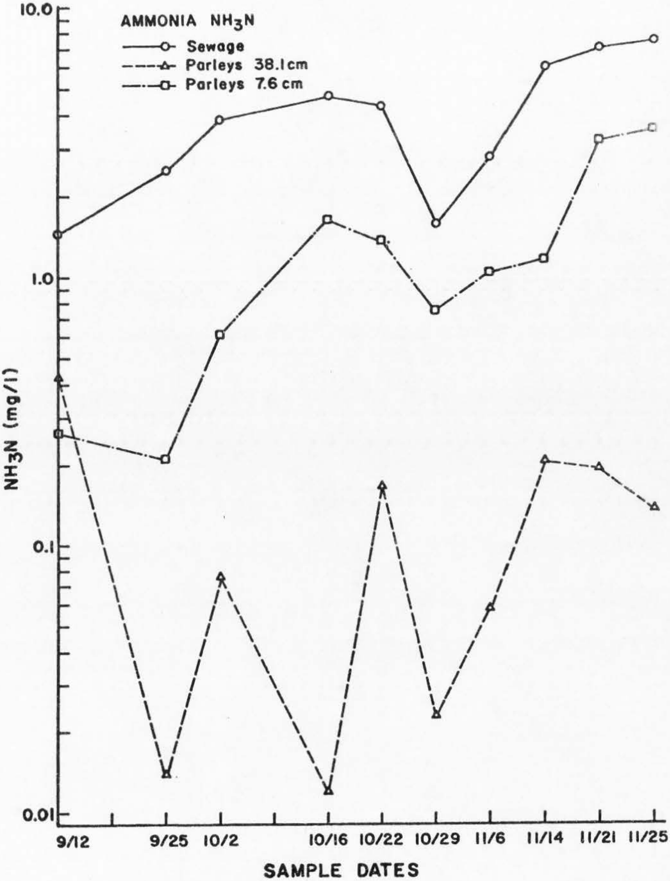

AMMONIA NH_3N
Sewage
Parleys 38.1cm
Parleys 7.6 cm
10.0
1.0
0.1
0.01
NH_3N (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A34. Total Organic Carbon levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

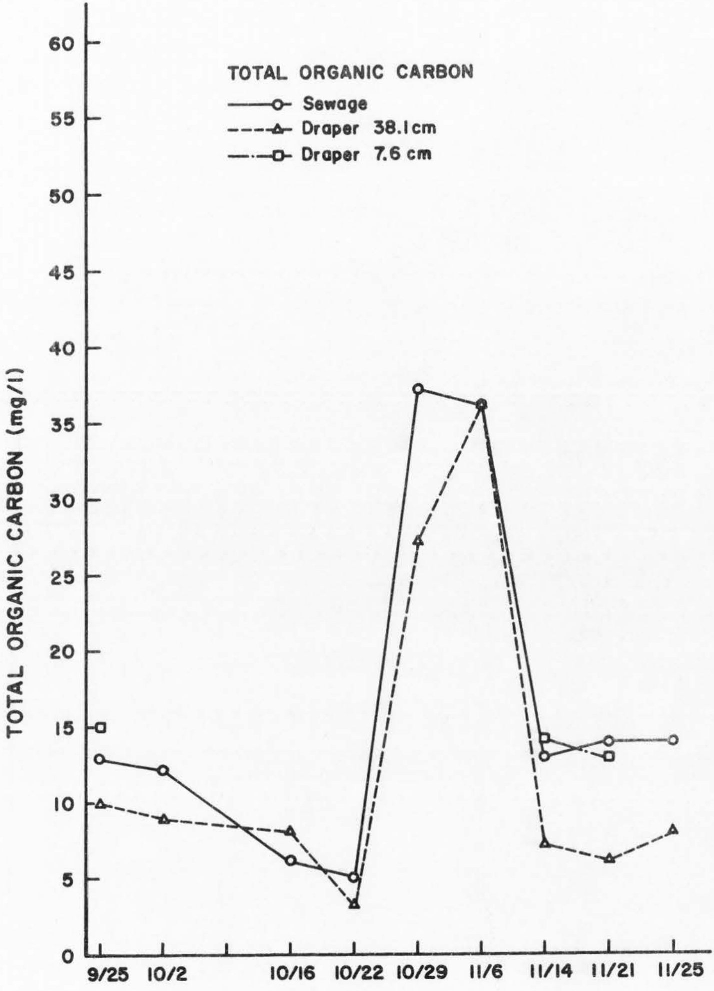

TOTAL ORGANIC CARBON
Sewage
Draper 38.1 cm
Draper 7.6 cm
TOTAL ORGANIC CARBON (mg/l)
0
5
10
15
20
25
30
35
40
45
50
55
60
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A35. Total Organic Carbon levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

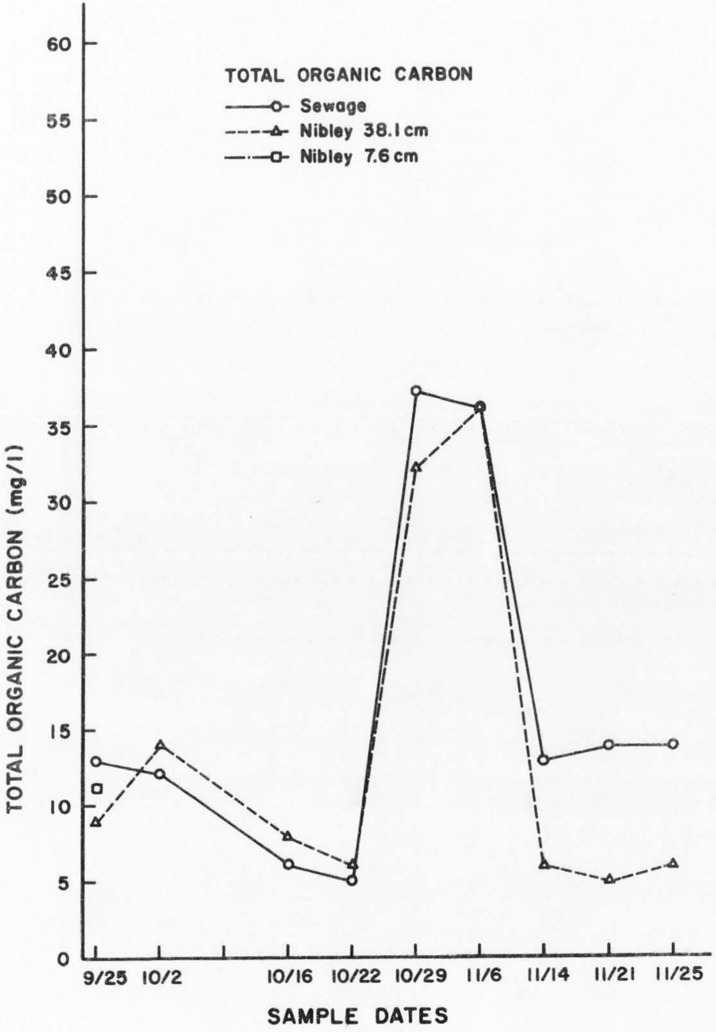

TOTAL ORGANIC CARBON
-o- Sewage
-△- Nibley 38.1 cm
-□- Nibley 7.6 cm
TOTAL ORGANIC CARBON (mg/l)
0
5
10
15
20
25
30
35
40
45
50
55
60
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A36. Total Organic Carbon levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

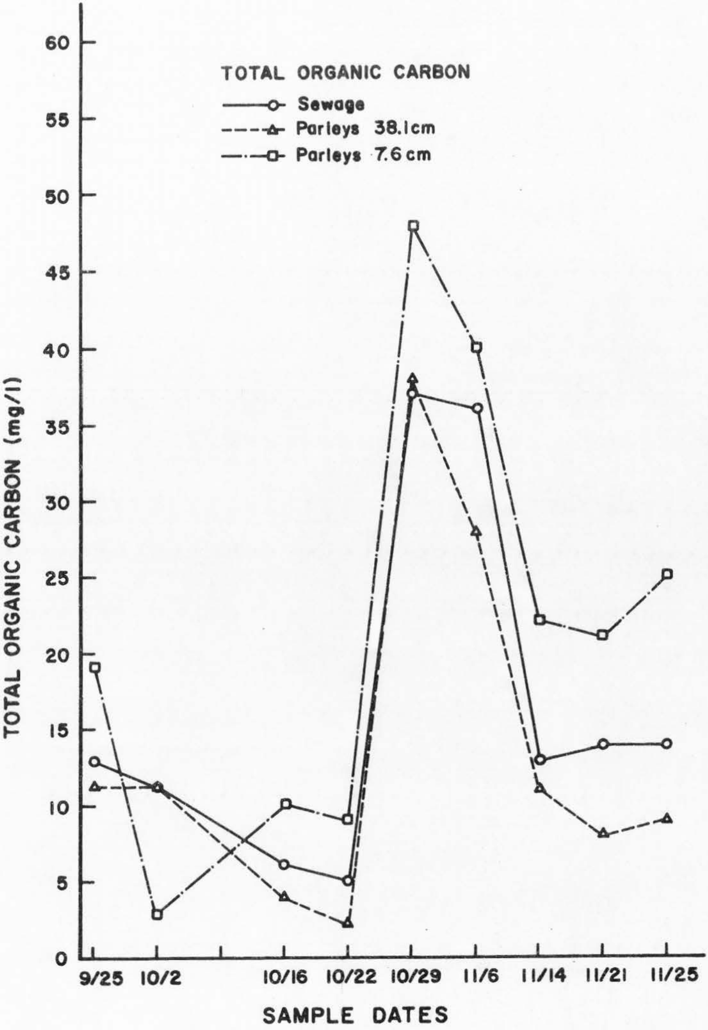
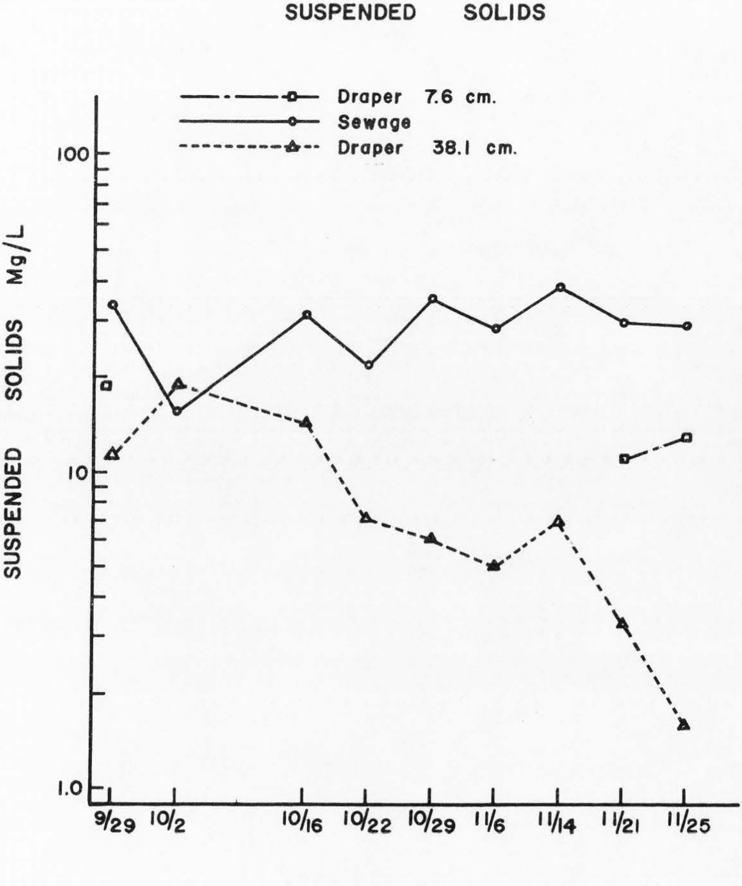

TOTAL ORGANIC CARBON
Sewage
Parleys 38.1cm
Parleys 7.6 cm
TOTAL ORGANIC CARBON (mg/l)
60
55
50
45
40
35
30
25
20
15
10
5
0
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A37. Suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.



SAMPLE DATES

Figure A38. Suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

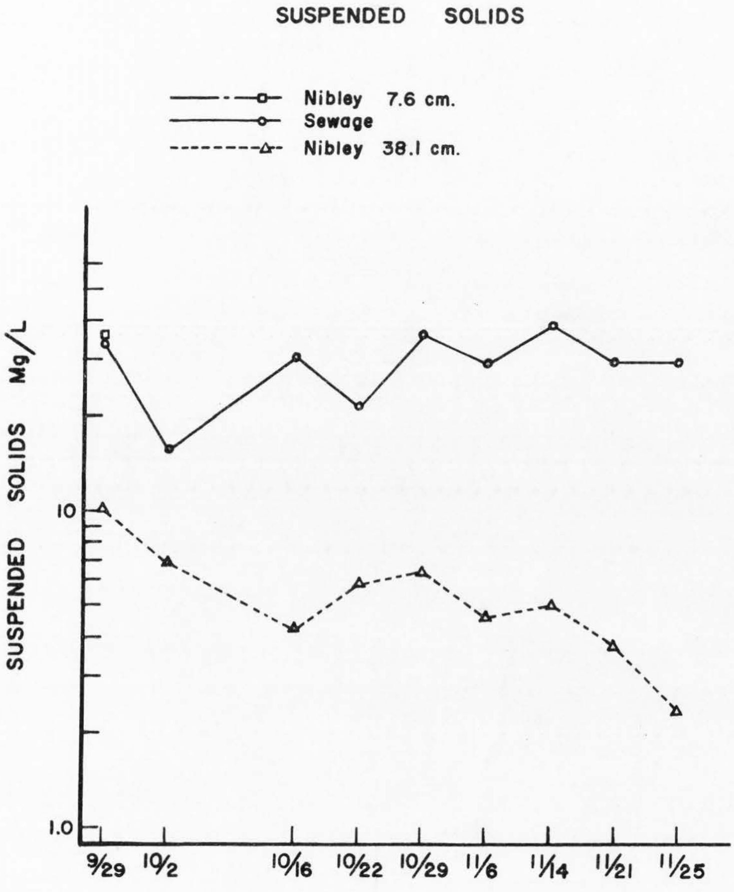

SUSPENDED SOLIDS
Nibley 7.6 cm.
Sewage
Nibley 38.1 cm.
SUSPENDED SOLIDS Mg/L
10
1.0
9/29
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A39. Suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

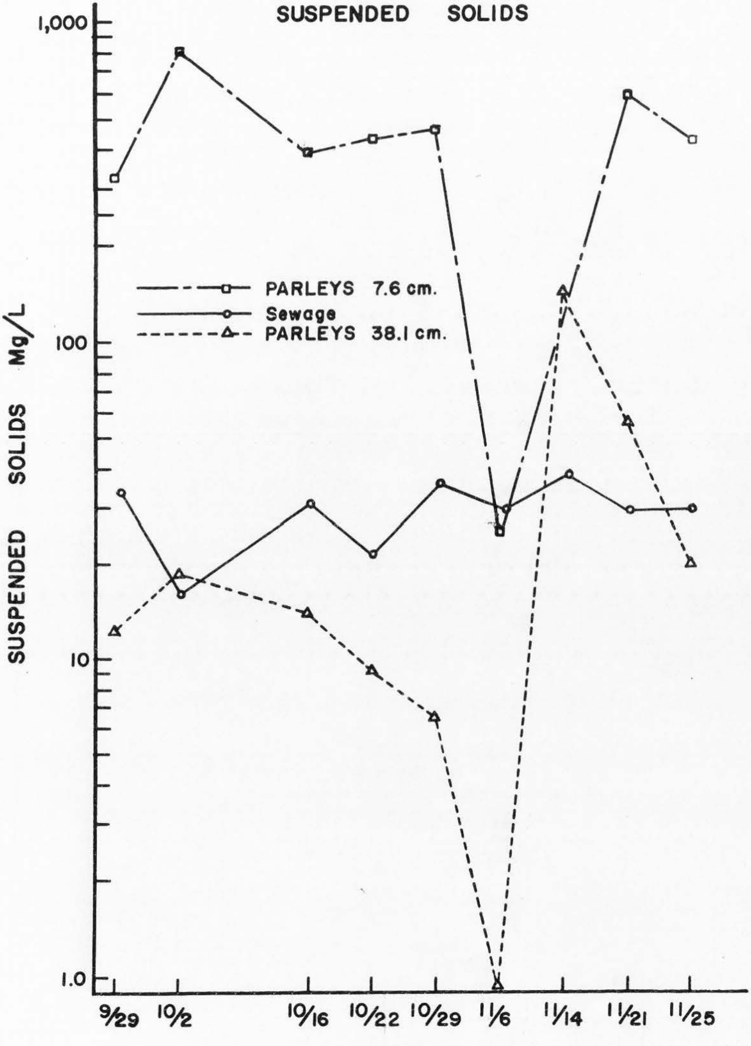

SUSPENDED SOLIDS
1,000
100
10
1.0
SUSPENDED SOLIDS Mg/L
PARLEYS 7.6 cm.
Sewage
PARLEYS 38.1 cm.
9/29
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A40. Volatile suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

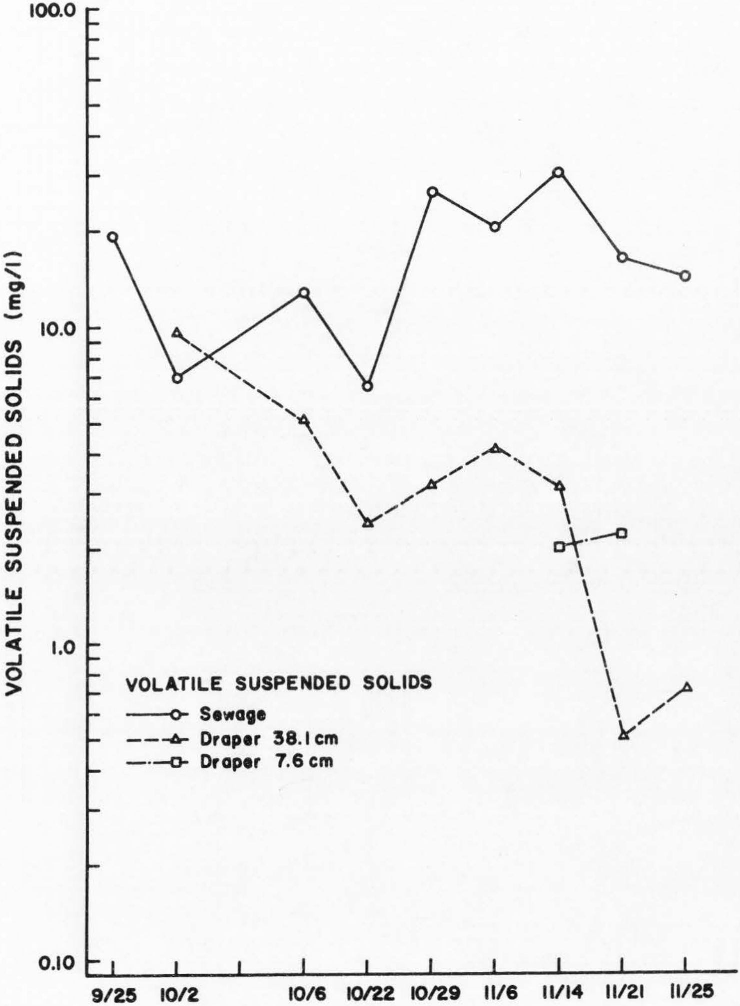

100.0
10.0
1.0
0.10
VOLATILE SUSPENDED SOLIDS (mg/l)
VOLATILE SUSPENDED SOLIDS
Sewage
Draper 38.1 cm
Draper 7.6 cm
9/25
10/2
10/6
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A41. Volatile suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

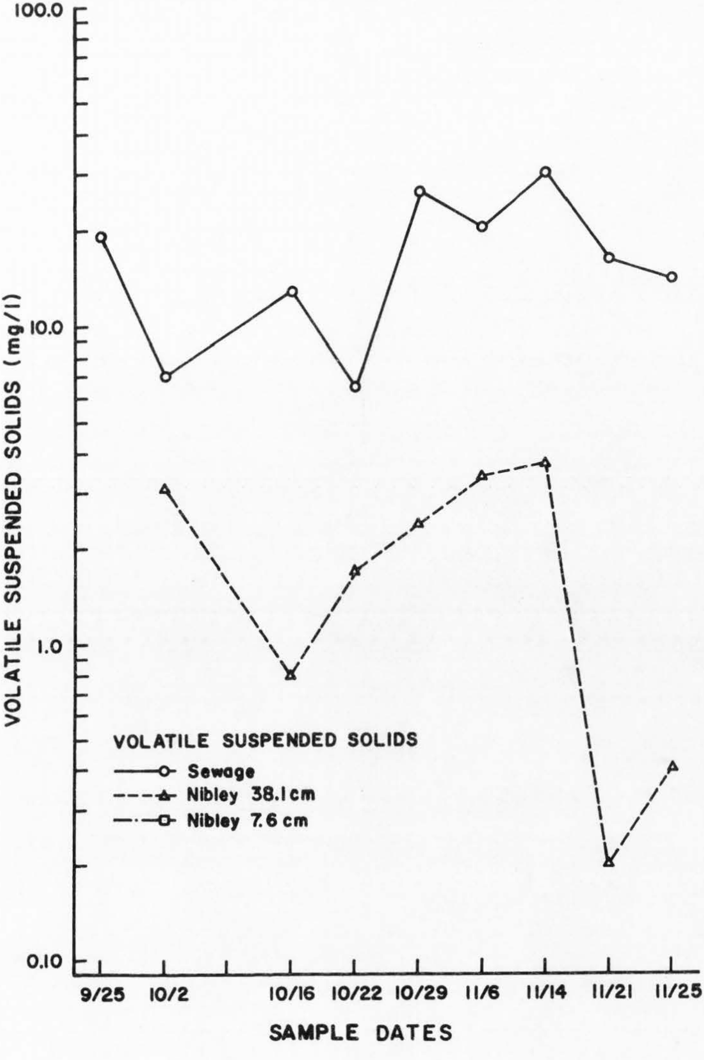

100.0
10.0
1.0
0.10
VOLATILE SUSPENDED SOLIDS (mg/l)
VOLATILE SUSPENDED SOLIDS
Sewage
Nibley 38.1 cm
Nibley 7.6 cm
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A42. Volatile suspended solids concentration in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

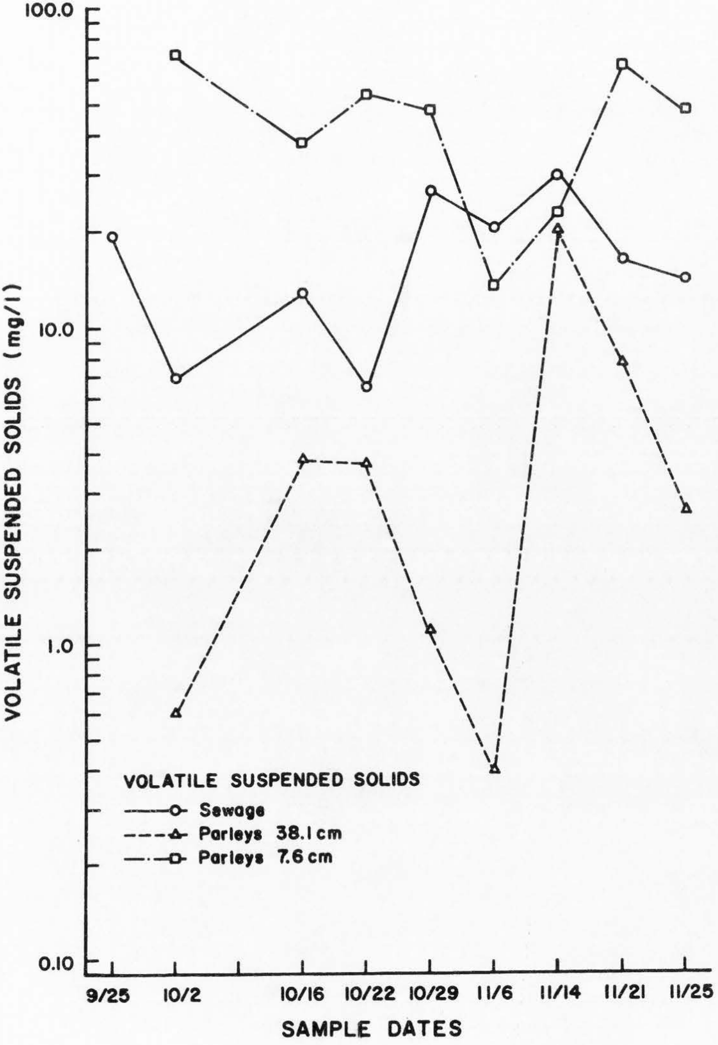

VOLATILE SUSPENDED SOLIDS (mg/l)
100.0
10.0
1.0
0.10
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
VOLATILE SUSPENDED SOLIDS
Sewage
Parleys 38.1 cm
Parleys 7.6 cm

Figure A43. Total Phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

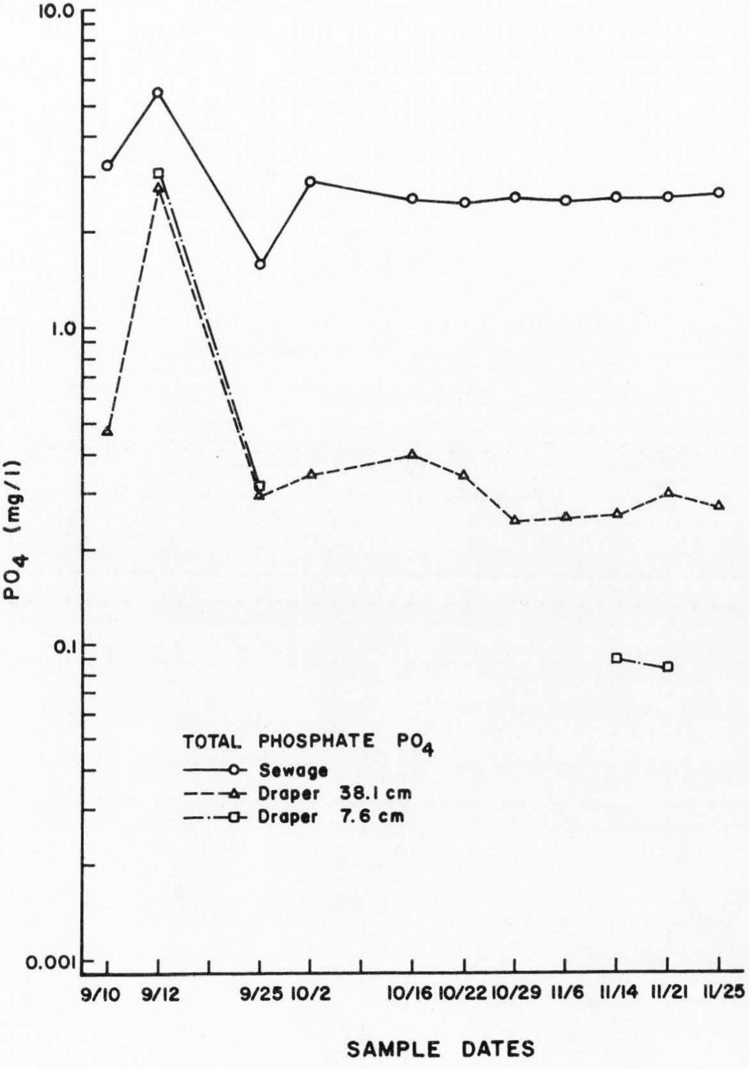

10.0
1.0
0.1
0.001
PO$_4$ (mg/l)
9/10
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
TOTAL PHOSPHATE PO$_4$
Sewage
Draper 38.1 cm
Draper 7.6 cm

Figure A44. Total Phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

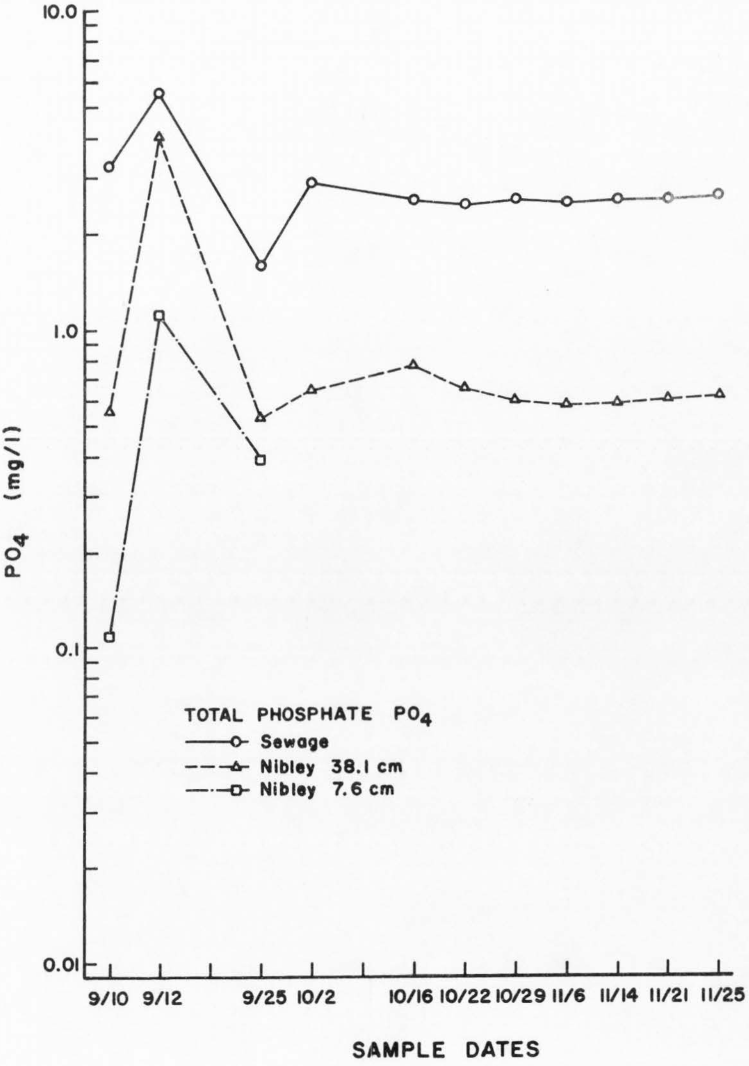

10.0
1.0
0.1
0.01
PO4 (mg/l)
TOTAL PHOSPHATE PO4
Sewage
Nibley 38.1 cm
Nibley 7.6 cm
9/10
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A45. Total Phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

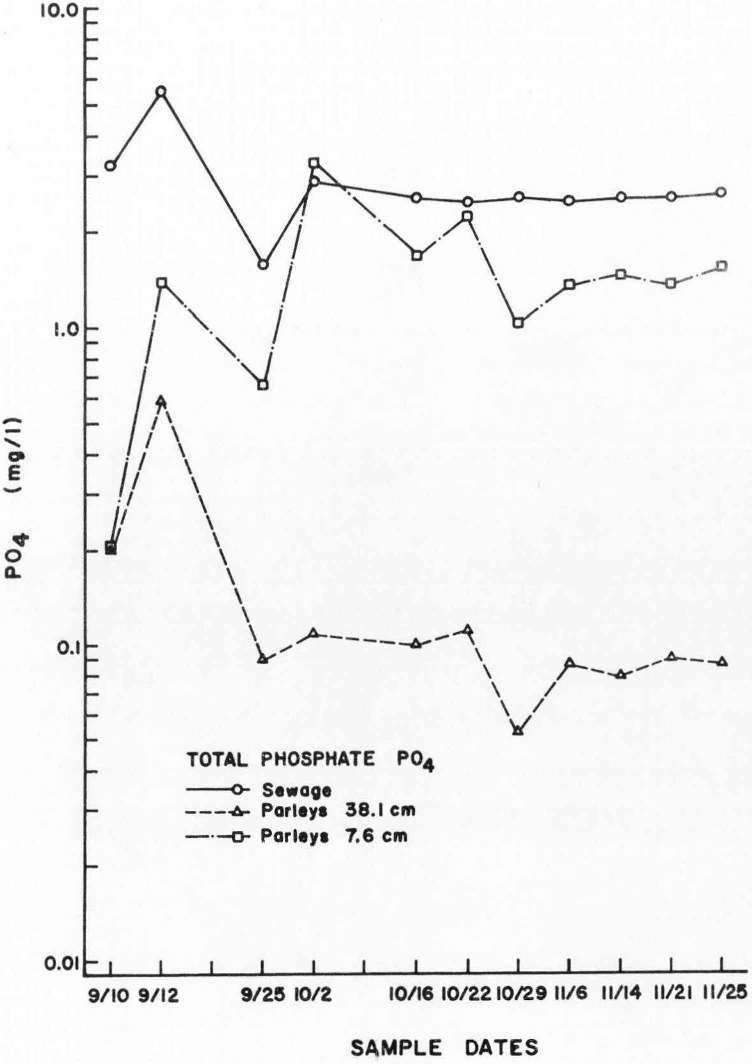

10.0
1.0
0.1
0.01
PO$_4$ (mg/l)
9/10
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
TOTAL PHOSPHATE PO$_4$
Sewage
Parleys 38.1 cm
Parleys 7.6 cm

Figure A46. Ortho-Phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

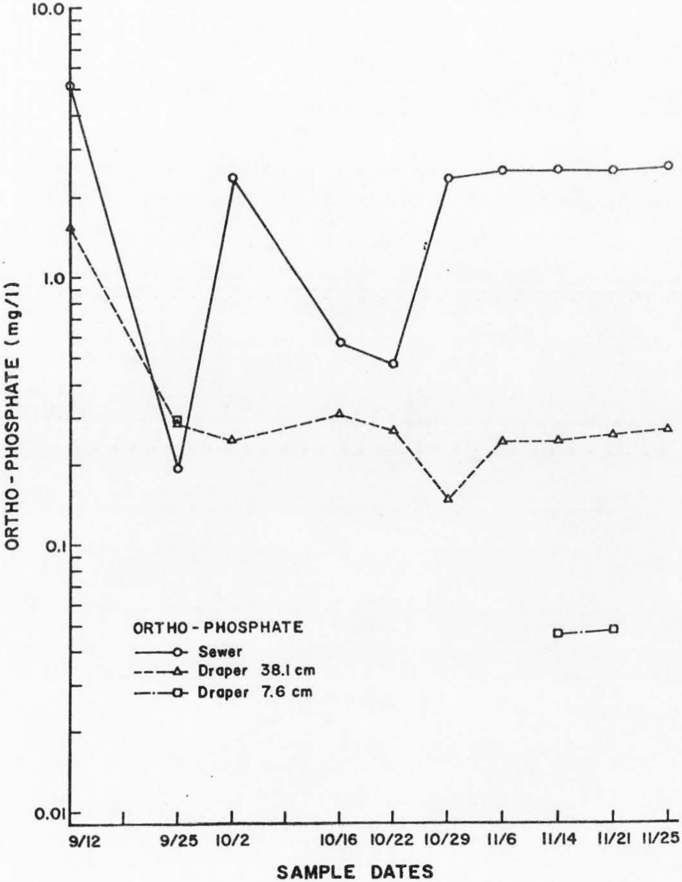

10.0
1.0
0.1
0.01
ORTHO - PHOSPHATE (mg/l)
ORTHO - PHOSPHATE
Sewer
Draper 38.1 cm
Draper 7.6 cm
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A47. Ortho-Phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

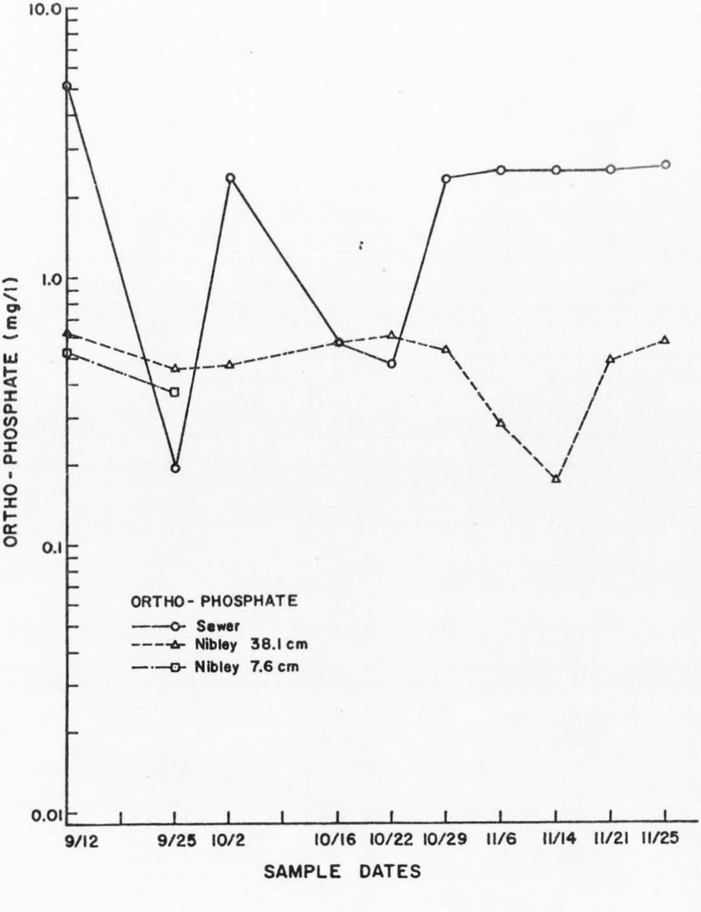

10.0
1.0
0.1
0.01
ORTHO - PHOSPHATE (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
ORTHO - PHOSPHATE
Sewer
Nibley 38.1 cm
Nibley 7.6 cm

Figure A48. Ortho-Phosphate levels in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

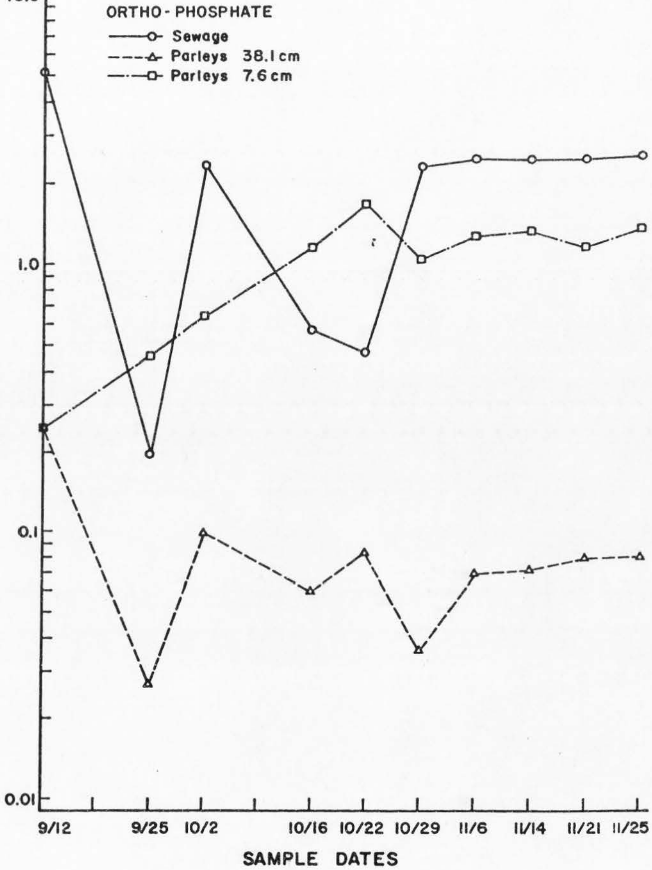

ORTHO - PHOSPHATE
Sewage
Parleys 38.1 cm
Parleys 7.6 cm
10.0
1.0
0.1
0.01
ORTHO - PHOSPHATE (mg/l)
9/12
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A49. pH values of the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

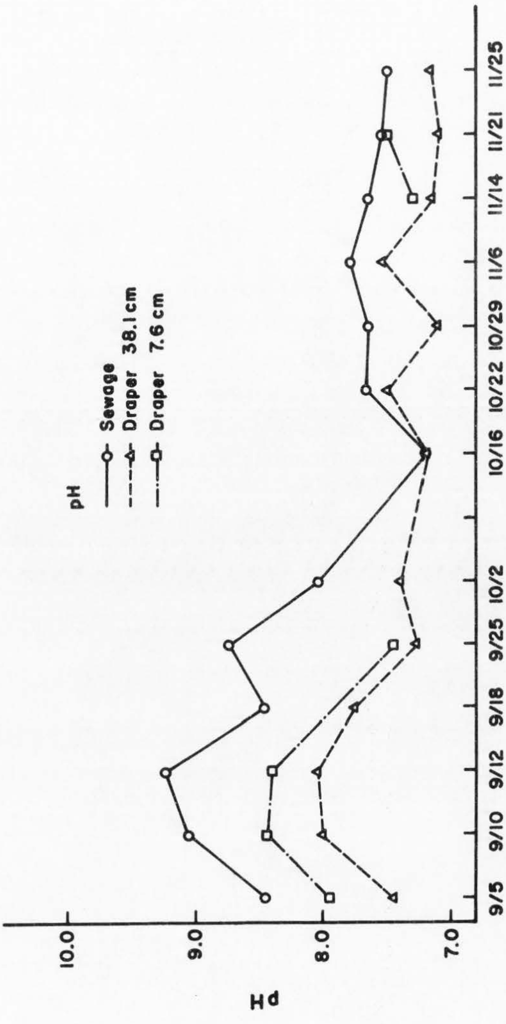

pH
-○- Sewage
-△- Draper 38.1 cm
-□- Draper 7.6 cm
pH
10.0
9.0
8.0
7.0
9/5
9/10
9/12
9/18
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A50. pH values of the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

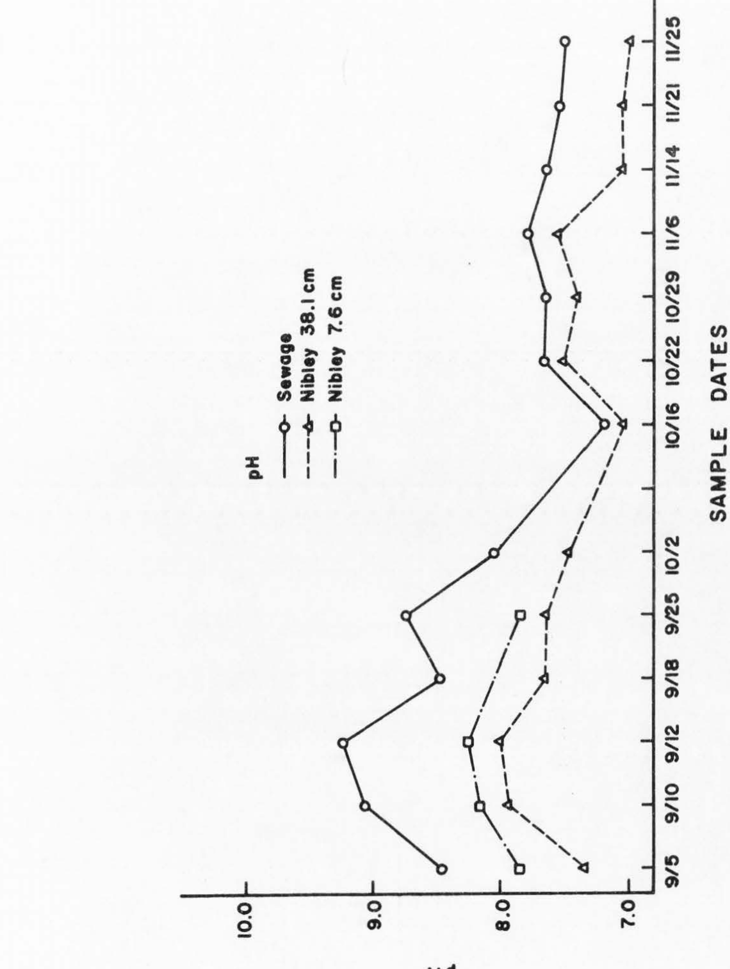

pH
Sewage
Nibley 38.1 cm
Nibley 7.6 cm
pH
10.0
9.0
8.0
7.0
9/5
9/10
9/12
9/18
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A51. pH values of the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

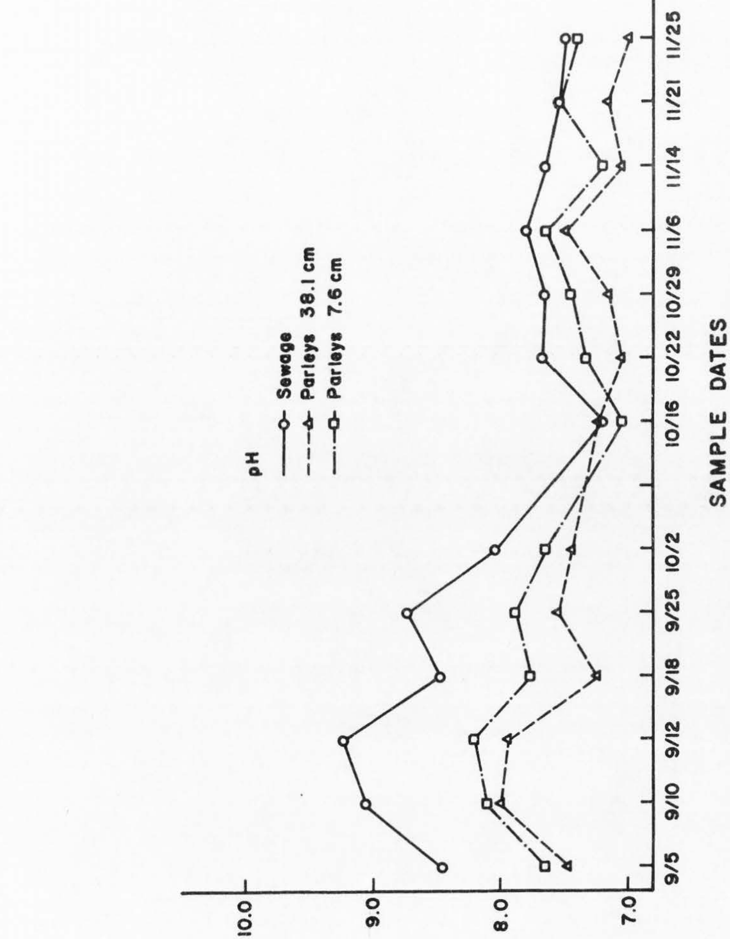

pH
10.0
9.0
8.0
7.0
9/5
9/10
9/12
9/18
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES
pH
Sewage
Parleys 38.1 cm
Parleys 7.6 cm

Figure A52. Specific conductance values in the influent and effluent from the 7.6 and 38.1 centimeter depths for Draper soil.

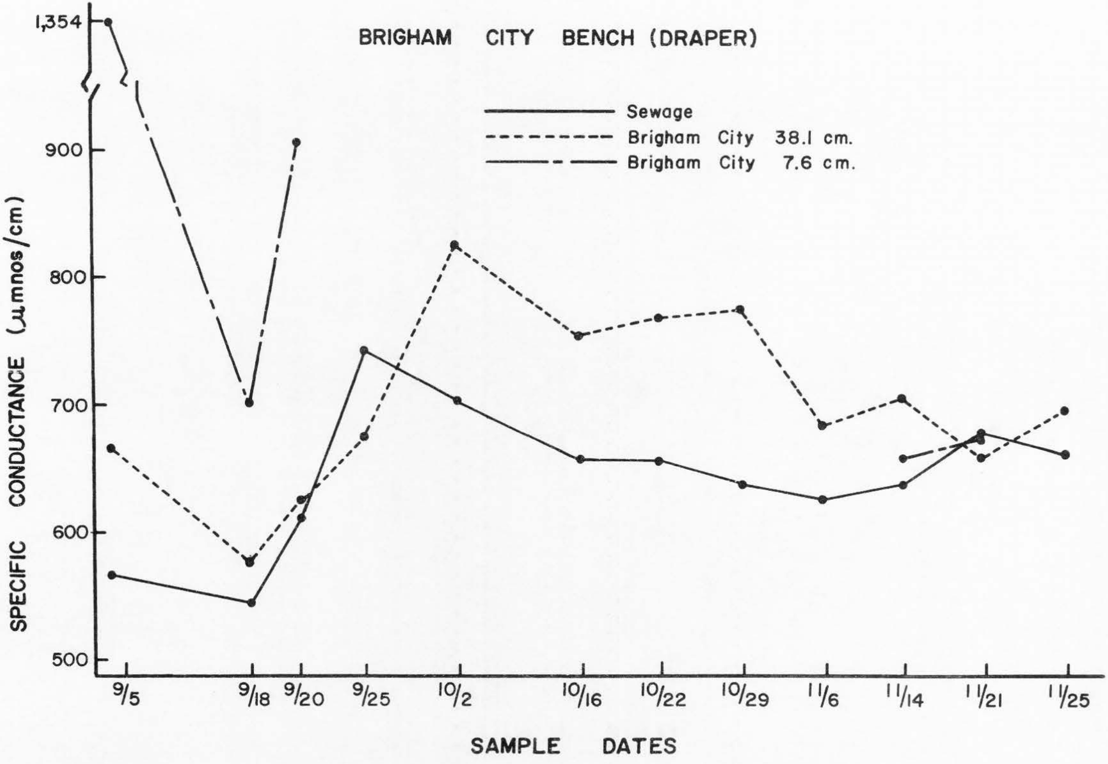

BRIGHAM CITY BENCH (DRAPER)
Sewage
Brigham City 38.1 cm.
Brigham City 7.6 cm.
1,354
900
800
700
600
500
SPECIFIC CONDUCTANCE (μ mnos/cm)
9/5
9/18
9/20
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A53. Specific conductance values in the influent and effluent from the 7.6 and 38.1 centimeter depths for Nibley soil.

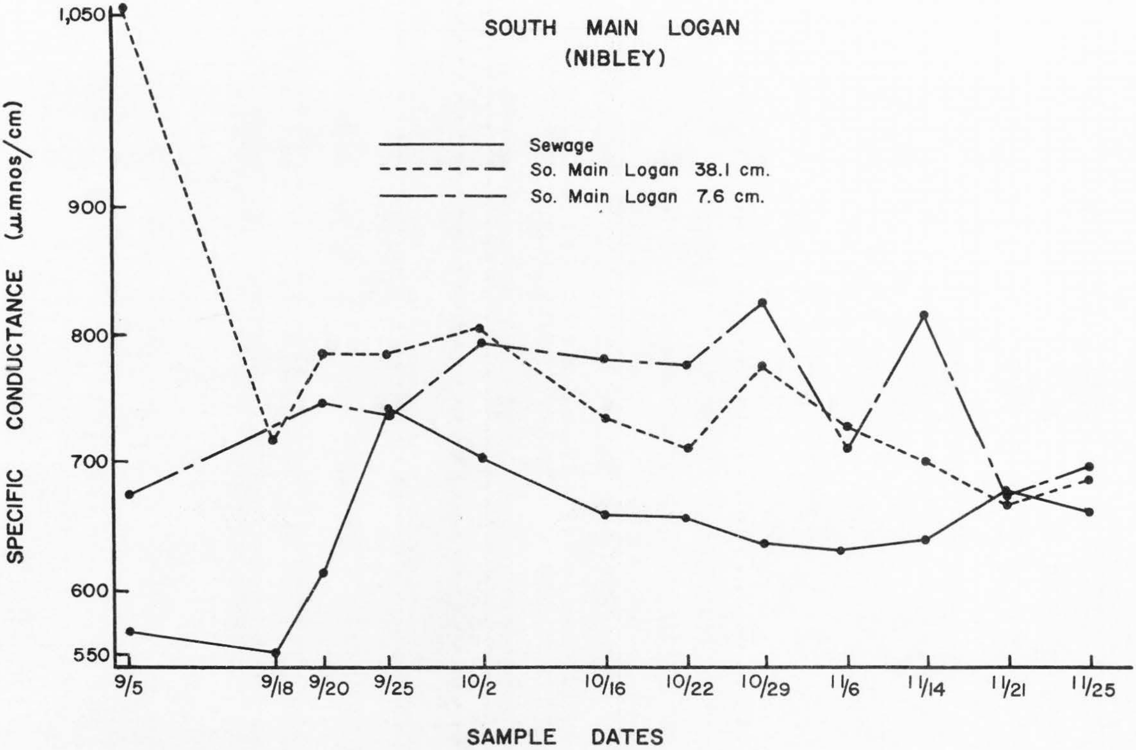

SOUTH MAIN LOGAN
(NIBLEY)
Sewage
So. Main Logan 38.1 cm.
So. Main Logan 7.6 cm.
SPECIFIC CONDUCTANCE (μmnos/cm)
1,050
900
800
700
600
550
9/5
9/18
9/20
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A54. Specific conductance values in the influent and effluent from the 7.6 and 38.1 centimeter depths for Parleys soil.

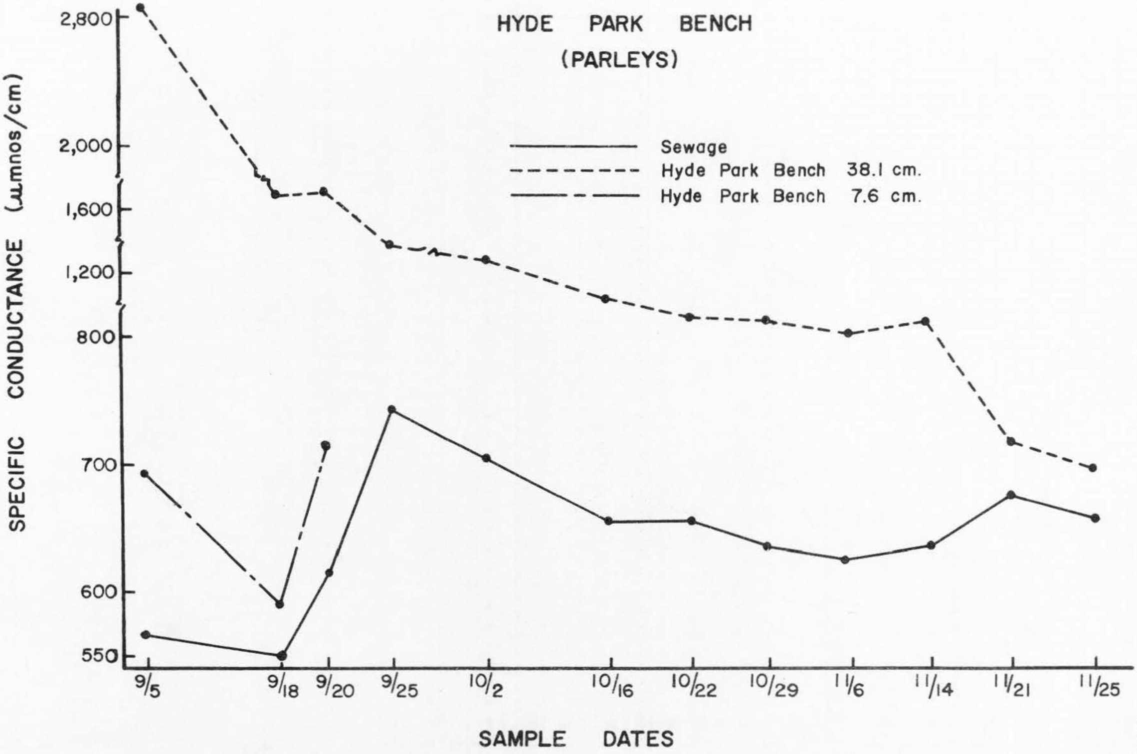

HYDE PARK BENCH
(PARLEYS)
Sewage
Hyde Park Bench 38.1 cm.
Hyde Park Bench 7.6 cm.
SPECIFIC CONDUCTANCE (µmnos/cm)
2,800
2,000
1,600
1,200
800
700
600
550
9/5
9/18
9/20
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Figure A55. Specific conductance values in the influent and effluent from the 7.6 and 38.1 centimeter depths for Drainage Farm soil.

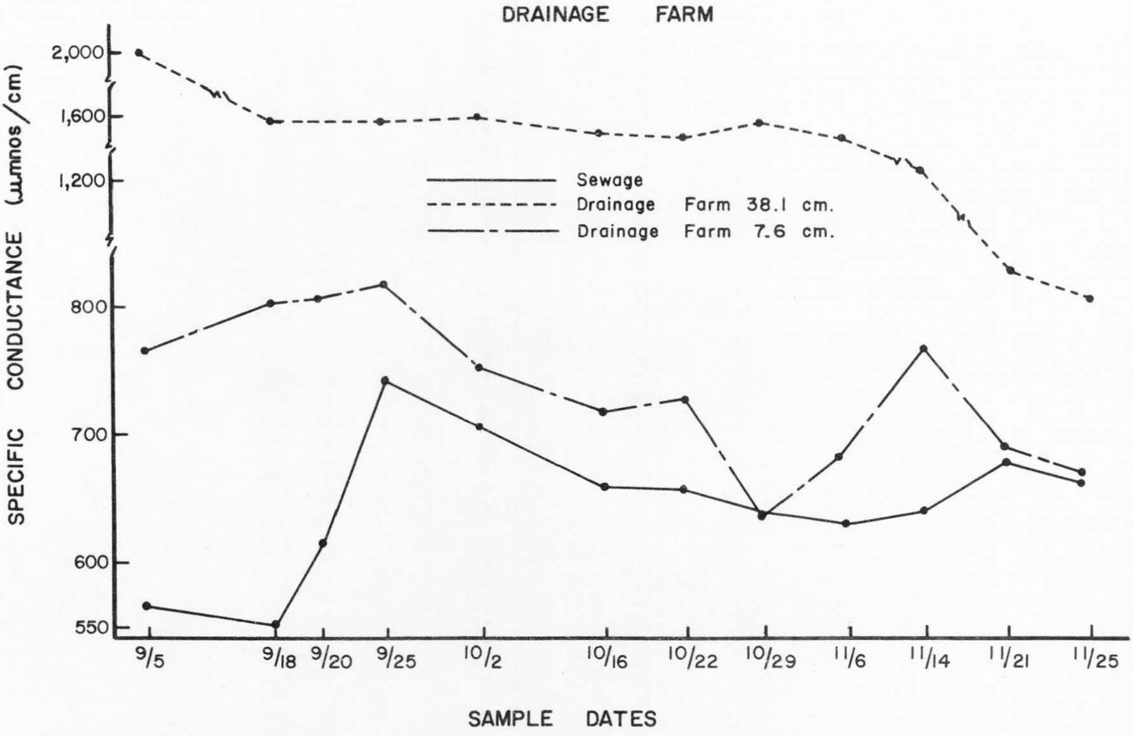

DRAINAGE FARM
SPECIFIC CONDUCTANCE (µmhos/cm)
2,000
1,600
1,200
800
700
600
550
Sewage
Drainage Farm 38.1 cm.
Drainage Farm 7.6 cm.
9/5
9/18
9/20
9/25
10/2
10/16
10/22
10/29
11/6
11/14
11/21
11/25
SAMPLE DATES

Table A12. Results of nitrate (NO_3 - N mg/ℓ) analyses

	Sample Date									
	9/12/74	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage									
	0.053	0.106	0.060	0.162	0.272	0.184	0.225	0.172	0.140	0.129
Draper										
7.6 cm.	7.025	17.792						9.068	8.784	
38.1 cm.	3.922	2.041	2.713	3.073	3.043	3.627	3.753	2.850	3.545	3.766
Nibley										
7.6 cm.	5.194	4.970								
38.1 cm.	175.417	98.745	230.376	101.132	74.860	25.840	17.500	34.554	28.368	25.452
Parleys										
7.6 cm.	2.177	2.237	6.105	3.706	3.487	4.271	4.655	4.564	1.998	2.392
38.1 cm.	11.422	6.759	48.195	21.830	21.423	19.075	16.200	5.984	5.410	4.667
Drainage Farm										
7.6 cm.	1.961	6.482	5.185	3.744	3.546	3.458	4.568	5.227	2.813	2.471
38.1 cm.	48.272	69.225	125.976	40.976	36.260	50.200	40.755	34.451	24.365	17.147

Table A13. Results of nitrite (NO_2 - N mg/ℓ) analyses

	Sample Date									
	9/12/74	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/2574
	Sewage									
	0.009	0.017	0.014	0.052	0.112	0.024	0.039	0.043	0.032	0.032
Draper										
7.6 cm.		0.009						0.007	0.006	
38.1 cm.	0.004	0.005	0.012	0.051	0.023	0.020	0.080	0.092	0.080	0.053
Nibley										
7.6 cm.	0.004	0.003								
38.1 cm.	0.018	0.030	0.012	0.014	0.021	0.007	0.004	0.007	0.013	0.006
Parleys										
7.6 cm.	0.019	0.015	0.084	0.046	0.086	0.021	0.024	0.042	0.037	0.033
38.1 cm.	0.017	0.010	0.011	0.017	0.010	0.005	0.007	0.029	0.029	0.027
Drainage Farm										
7.6 cm.	0.015	0.066	0.044	0.055	0.100	0.027	0.028	0.048	0.042	0.042
38.1 cm.	0.008	0.002	0.001	0.004	0.004	0.001	0.001	0.003	0.001	0.001

Table A14. Results of ammonia (NH_3 - N mg/ℓ) analyses

	Sample Date									
	9/12/74	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage									
	1.496	2.506	3.847	4.680	4.290	1.600	2.769	5.936	6.943	7.420
Draper										
7.6 cm.	0.755	0.042						0.053	0.175	
38.1 cm.	4.538	0.121	0.331	0.832	0.741	0.321	0.564	0.843	0.753	0.726
Nibley										
7.6 cm.	0.620	0.029								
38.1 cm.	0.436	0.025	0.100	0.021	0.090	0.045	0.063	0.053	0.044	0.070
Parleys										
7.6 cm.	0.269	0.211	0.611	1.625	1.352	0.753	1.022	1.145	3.159	3.519
38.1 cm.	0.436	0.014	0.076	0.012	0.165	0.023	0.058	0.208	0.191	0.134
Drainage Farm										
7.6 cm.	1.531	0.157	0.946	2.743	2.899	1.179	1.278	1.548	2.491	3.507
38.1 cm.	0.383	0.011	0.050	0.012	0.087	0.020	0.031	0.053	0.042	0.072

Table A15. Results of total organic carbon (unfiltered mg/ℓ) analyses

	Sample Date								
	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage								
	13	12	6	5	37	36	13	14	14
Draper									
7.6 cm.	15						14	13	
38.1 cm.	10	9	8	4	27	36	7	6	8
Nibley									
7.6 cm.	11								
38.1 cm.	9	14	8	6	32	36	6	5	6
Parleys									
7.6 cm.	19	3	10	9	48	40	22	21	25
38.1 cm.	12	12	4	2	38	28	11	8	9
Drainage Farm									
7.6 cm.	16	16	8	4	56	32	18	18	17
38.1 cm.	7	4	3	2	36	36	5	4	7

Table A16. Results of total carbon (unfiltered mg/ℓ) analyses

	Sample Date								
	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage								
	67	69	56	55	103	106	69	75	72
Draper									
7.6 cm.	79						78	81	
38.1 cm.	72	80	68	64	107	106	70	73	73
Nibley									
7.6 cm.	70								
38.1 cm.	89	82	72	67	116	112	87	89	91
Parleys									
7.6 cm.	93	88	77	72	134	108	94	97	100
38.1 cm.	82	68	58	58	102	100	82	83	86
Drainage Farm									
7.6 cm.	82	76	72	63	144	104	85	87	88
38.1 cm.	127	102	98	96	118	162	123	125	128

Table A17. Results of total inorganic carbon (unfiltered mg/ℓ) analyses

	Sample Date								
	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage								
	54	57	50	50	66	70	56	61	58
Draper									
7.6 cm.	64						64	68	
38.1 cm.	62	71	60	60	80	70	63	67	65
Nibley									
7.6 cm.	59								
38.1 cm.	80	68	64	61	84	76	81	84	85
Parleys									
7.6 cm.	74	85	67	63	86	68	72	76	75
38.1 cm.	70	56	54	56	64	72	71	75	77
Drainage Farm									
7.6 cm.	66	60	64	59	88	72	67	69	71
38.1 cm.	120	98	95	94	152	126	118	121	121

Table A18. Results of suspended solids (mg/ℓ) analyses

	Sample Date								
	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage								
	33.2	15.6	30.6	21.4	35.6	28.3	37.7	29.4	29.0
Draper									
7.6 cm.	18.6						11.0	12.5	
38.1 cm.	11.1	19.1	14.4	7.1	6.1	4.9	6.8	3.3	1.6
Nibley									
7.6 cm.	35.0								
38.1 cm.	10.1	6.8	4.3	5.8	6.3	4.4	4.9	3.6	2.4
Parleys									
7.6 cm.	322.8	800.0	387.8	422.7	458.3	24.8	130.7	587.5	422.9
38.1 cm.	12.2	18.8	13.8	9.0	6.2	0.9	144.3	54.5	19.8
Drainage Farm									
7.6 cm.	80.0	141.8	327.5	208.0	443.1	56.1	246.2	81.5	211.7
38.1 cm.	9.6	9.5	2.4	3.8	3.3	2.3	7.7	1.1	1.7

Table A19. Results of volatile suspended solids (mg/ℓ) analyses

	Sample Date								
	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
Sewage	19.2	7.0	13.0	6.5	26.8	20.4	30.0	16.2	14.2
Draper									
7.6 cm.	0						2.0	2.2	
38.1 cm.	0	9.7	5.1	2.4	3.2	4.1	3.1	0.5	0.7
Nibley									
7.6 cm.	0								
38.1 cm.	0	3.1	0.8	1.7	2.4	3.4	3.7	0.2	0.4
Parleys									
7.6 cm.	0	70.2	37.8	53.1	47.6	13.3	22.7	65.6	45.7
38.1 cm.	0	0.6	3.8	3.7	1.1	0.4	19.9	7.6	2.6
Drainage Farm									
7.6 cm.	14.2	21.4	52.7	35.2	63.1	21.4	29.2	13.9	25.0
38.1 cm.	2.4	3.1	0.6	2.4	1.9	1.4	0.5	0.9	0.1

Table A20. Results of total phosphate (PO_4 mg/ℓ) analyses

	Sample Date										
	9/10/74	9/12/74	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage										
	3.283	5.460	1.590	2.907	2.550	2.448	2.546	2.477	2.546	2.511	2.580
Draper											
7.6 cm.		3.047	0.318						0.089	0.083	
38.1 cm.	0.479	2.793	0.293	0.349	0.398	0.340	0.241	0.248	0.255	0.275	0.268
Nibley											
7.6 cm.	0.109	1.124	0.392								
38.1 cm.	0.559	4.030	0.531	0.650	0.765	0.646	0.599	0.578	0.585	0.599	0.612
Parleys											
7.6 cm.	0.208	1.397	0.658	3.215	1.673	2.217	1.032	1.342	1.445	1.376	1.513
38.1 cm.	0.200	0.597	0.090	0.109	0.099	0.119	0.052	0.086	0.079	0.089	0.086
Drainage Farm											
7.6 cm.	0.438	1.790	0.378	1.676	2.057	2.074	1.273	1.445	1.514	1.617	1.548
38.1 cm.	0.245	0.444	0.345	0.068	0.092	0.143	0.062	0.055	0.065	0.065	0.072

Table A21. Results of ortho-phosphate (O - PO_4 mg/ℓ) analyses

	Sample Date									
	9/12/74	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage									
	5.126	0.196	2.309	0.578	0.476	2.305	2.459	2.477	2.459	2.512
Draper										
7.6 cm.		0.297						0.046	0.048	
38.1 cm.	1.563	0.286	0.248	0.309	0.265	0.148	0.241	0.241	0.254	0.264
Nibley										
7.6 cm.	0.527	0.377								
38.1 cm.	0.625	0.456	0.472	0.570	0.604	0.533	0.281	0.172	0.481	0.567
Parleys										
7.6 cm.	0.248	0.458	0.641	1.166	1.675	1.030	1.273	1.307	1.153	1.358
38.1 cm.	0.248	0.027	0.099	0.060	0.083	0.036	0.069	0.071	0.079	0.080
Drainage Farm										
7.6 cm.	0.730	0.262	1.365	1.921	0.554	1.109	1.127	1.393	1.101	1.109
38.1 cm.	0.190	0.806	0.048	0.063	0.139	0.046	0.034	0.043	0.047	0.041

Table A22. Results of pH analysis

	Sample Date												
	9/5/74	9/10/74	9/12/74	9/18/74	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage												
	8.47	9.08	9.25	8.48	8.74	8.04	7.20	7.68	7.65	7.80	7.65	7.55	7.50
Draper													
7.6 cm.	7.94	8.45	8.40		7.45						7.30	7.50	
38.1 cm.	7.45	8.00	8.05	7.76	7.28	7.39	7.20	7.50	7.10	7.52	7.15	7.10	7.15
Nibley													
7.6 cm.	7.84	8.16	8.25		7.85								
38.1 cm.	7.34	7.93	7.99	7.65	7.64	7.48	7.05	7.51	7.40	7.55	7.05	7.05	7.00
Parleys													
7.6 cm.	7.65	8.11	8.21	7.77	7.89	7.64	7.05	7.33	7.45	7.65	7.20	7.55	7.40
38.1 cm.	7.48	8.00	7.94	7.25	7.56	7.46	7.25	7.05	7.15	7.50	7.05	7.15	7.00
Drainage Farm													
7.6 cm.	7.84	8.30	8.52	8.00	8.13	7.95	7.75	7.70	7.80	7.82	7.60	7.65	7.50
38.1 cm.	7.50	8.04	8.02	7.51	7.72	7.55	7.90	7.35	7.60	7.65	7.20	7.20	7.35

Table A23. Results of specific conductance (μmhos/cm) analyses

	Sample Date											
	9/5/74	9/18/74	9/20/74	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage											
	566	545	610	742	702	655	653	639	626	637	676	660
Draper												
7.6 cm.	1,354	697		903						658	670	
38.1 cm.	662	578	627	672	828	751	759	761	683	704	668	647
Nibley												
7.6 cm.	691	596		712								
38.1 cm.	2,880	1,717	1,725	1,428	1,314	1,047	979	935	851	935	712	698
Parleys												
7.6 cm.	672		747	726	793	784	779	821	713	812	672	698
38.1 cm.	1,056	717	786	784	804	733	711	773	725	701	670	687
Drainage Farm												
7.6 cm.	768	808	813	947	750	717	724	646	680	763	689	666
38.1 cm.	2,016	1,515	1,497	1,549	1,565	1,456	1,442	1,503	1,438	1,215	1,060	840

Table A24. Total algal cell counts (number/mℓ)

	Sample Date								
	9/25/74	10/2/74	10/16/74	10/22/74	10/29/74	11/6/74	11/14/74	11/21/74	11/25/74
	Sewage								
	3,378	5,226	5,889	17,476	57,684	37,365	34,874	19,140	23,496
Draper									
7.6 cm.	2,706						894	690	
38.1 cm.	792	725	712	713	1,626	1,115	562	545	682
Nibley									
7.6 cm.	2,746								
38.1 cm.	554	462	461	396	1,770	1,327	528	418	316
Parleys									
7.6 cm.	1,664	1,135	1,056	1,477	15,897	10,568	11,766	12,411	15,768
38.1 cm.	607	529	422	449	895	2,313	6,436	1,931	1,905
Drainage Farm									
7.6 cm.	4,249	4,314	1,622	1,387	47,856	54,901	18,182	23,427	27,855
38.1 cm.	1,121		370	343	401	316	367	307	247

Table A25. Results of pheophytin "α" (mg/ℓ) analyses

	Sample Date			
	9/25/74	10/2/74	10/16/74	10/22/74
Sewage	0	0	0	0
Draper				
7.6 cm.	0			
38.1 cm.	0	0	0	0
Nibley				
7.6 cm.	0			
38.1 cm.	0	0	0	0
Parleys				
7.6 cm.	0	.016	0	0
38.1 cm.	0	0	0	0
Drainage Farm				
7.6 cm.	0	0	0	0
38.1 cm.	0	0	0	0

Note.--Pheophytin "α" tests were not conducted further because levels were too low to make the data reliable.

Table A26. Results of chlorophyll "α" (mg/ℓ) analyses

	Sample Date			
	9/25/74	10/2/74	10/16/74	10/22/74
	Sewage			
	0.057	0.026	0.045	0.026
Draper				
7.6 cm.	0			
38.1 cm.	0	0	0.003	0.002
Nibley				
7.6 cm.	0			
38.1 cm.	0	0	0.001	0.001
Parleys				
7.6 cm.	0.010	0.003	0.025	0.012
38.1 cm.	0	0	0.002	0.002
Drainage Farm				
7.6 cm.	0	0.025	0.012	0.007
38.1 cm.	0	0	0.001	0.002

VITA

Roger Scott Tinkey

Candidate for the Degree of

Master of Science

in

Civil and Environmental Engineering

Thesis: Lagoon Effluent Polishing by Soil Mantle Treatment Using Various Utah Soil Types.

Major Field: Civil and Environmental Engineering

Biographical Information:

Personal Data: Born at Eureka, California, March 19, 1949, son of Victor W. and Mary R. Tinkey; married Jolene Roberson June 5, 1973.

Education: Attended elementary school in Freshwater, California; graduated from Eureka High School in 1967; received the Bachelor of Science degree from Utah State University, with a major in Civil Engineering, in 1972; Completed requirements for the Master of Science degree in Civil and Environmental Engineering at Utah State University in 1975.

Professional Experience: 1973-74, research engineer, Utah State University; 6/72 - 10/72, civil engineer, Windzler and Kelly Consulting Engineers, Eureka, California; summer 1971, engineering aide, Department of Public Works, County of Humboldt, Eureka, California; summer 1970, engineering aide, Larson and McMillian, Consulting Engineers and Land Surveyors, Eureka, California; summers 1969, 1968, 1967, engineering aide, Department of Public Works, County of Humboldt, Eureka, California.