

EFFICIENCY OF A SEPTIC TILE SYSTEM
AS A TREATMENT PROCESS

by

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PREFACE

Septic tank systems have been used and generally recognized over the years as acceptable means for disposing of water-carried domestic wastes. In earlier years, these systems were principally used on farms and in rural areas of low-density residential development. Usage increased after the Second World War and about a million households are reported to be using septic tank systems in Canada today. Over the years, most concerns about septic systems have dealt with questions of public health. Recently, however, serious questions have been raised regarding the effects of nutrient-rich septic system effluents on water quality. In areas with extensive shoreland development as in Ontario, there is a mounting concern about the significance of nutrient contributions from these sources with regard to lake eutrophication. It is generally recognized that nitrogen and phosphorus are the key elements which control aquatic plant growth. Several studies suggest that when ammonia plus nitrate nitrogen is equal to or greater than 0.3 mg/l-N and orthophosphate levels exceed 0.01 mg/l-P, then a lake is likely to have excessive crops of algae and other aquatic plants.

This study was undertaken to evaluate how far a septic tile system is adequate as a treatment system for the reduction of many of the constituents of the septic tank effluent, especially the nutrients. A field investigation

was conducted with the primary objective of determining the efficiency of the septic tile system. "Efficiency" denotes the reduction achieved between the point at which the septic tank effluent was distributed to the tile and the various depths in the soil at which soil water samples were collected. The environmental effects of air and soil temperatures and unsaturated depth of the soil on the efficiency of the septic tile were determined to the extent possible.

This field study was conducted in a rural household in Quebec, about 15 miles north of Ottawa. A test tile 26 feet long was installed and a portion of the septic tank effluent entering the regular system was diverted to the test system. Zero-tension lysimeters were installed at 2'0", 3'6" and 4'6" depths to collect percolates. Chemical and bacteriological quality of the percolates and the groundwater adjoining the test tile were analyzed, along with the composition of raw sewage and septic tank effluent. This investigation was conducted over a period of 15 months from December, 1972 to March, 1974. An investigation was carried out to monitor horizontal travel of pollutants from the end of the septic tile. Chemical and bacteriological quality of the groundwater below four points in the existing tile field system was also studied during the summer of 1973. Certain studies were also made to examine any possible clogging that might have occurred in the tile trench. Soil studies were also done to get additional data on the transport of certain chemical constituents through the soil.

This study generally indicated that the soil had the ability to remove a high percentage of BOD, COD, TOC, $\text{NH}_3\text{-N}$, iron and indicator organisms present in the septic tank effluent. Removal of phosphates was generally lower, being in the 25-50% range. Relatively high levels of nitrate nitrogen were found in the percolate and the adjoining groundwater. The efficiency of the septic tile was found to be influenced by duration of loading and by seasonal variations. The depth to groundwater table was found to be the most important environmental factor. Generally, periods of higher air and soil temperatures showed better removal efficiencies. The pollutant concentrations in the groundwater were found to be quite high near the tile and these declined significantly farther downslope from the end of the tile. Ammonia nitrogen appeared to be oxidized in the initial ten feet from the end of the tile to nitrate nitrogen and reduction in nitrate nitrogen beyond this point was by dilution only.

These studies showed that on some occasions the concentrations of phosphates and nitrate nitrogen in the adjoining groundwater and below the existing system were in the range of 10 mg/l and 1.5 mg/l respectively, far exceeding the critical concentrations of such nutrients required to accelerate the eutrophication process. These conditions have special significance to lake shores where travel distances may be short between septic tile fields and local groundwater discharge points. On lake shores where septic

tank effluent is free to percolate into groundwater which discharges to the lake, significant additions of nitrogen in the form of nitrate may be made to the lake and substantial amounts of phosphorous in the form of phosphate may be added to it, especially in soils with a high water table or in soils with a low adsorptive capacity for phosphates.

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NOTATION

- A Cross-sectional area through which flow occurs.
- A_o Effective area (in square feet) of the soil liquid interface in the absorption system.
- ABS Alkyl benzene sulfonate.
- BOD Biochemical oxygen demand, 5 day, 20°C.
- BOD_e Biochemical oxygen demand of the effluent.
- BOD_i Biochemical oxygen demand of the influent.
- °C Degrees centigrade.
- COD Chemical oxygen demand.
- c Capacity of the septic tank in gallons/100.
- D_{10} Grain size, where 10% of the sample has grains smaller than this.
- D_{60} Grain size, where 60% of the sample has grains smaller than this.
- °F Degrees fahrenheit.
- fp "Equivalent" population load. p is the number of persons in the household; f is a factor reflecting the type of pretreatment of sewage and the presence or absence of food waste grinders or automatic washing machines.
- gpcd gallons per capita per day.
- gpd gallons per day.
- H Distance to impermeable stratum from original water level.
- h Head causing flow.
- h_o Distance to impermeable stratum from depressed water level.
- K Coefficient of permeability.
- k Specific permeability of the material.

L	Unit areal load capacity of the soil.
l	Distance.
M	Factor depending on percent saturation.
MPN	Most probable number.
m	Serial number assigned for probability plotting.
mg/l	Milligram per litre.
n	Any value of the parameter in the probability plot.
P	Probability.
p	Number of persons using
Q	Volume flow rate.
R	$\frac{\Delta T}{\Delta D}$
SPC	Standard Plate Count.
SS	Suspended solids.
T	Total elapsed time since the initial wetting.
TOC	Total organic carbon.
TSS	Total suspended solids
T _o	Useful life (in years) of the system.
t	Period of service in years.
V	Apparent velocity of flow.
VSS	Volatile suspended solids.
Y	Sludge and scum accumulation in cubic feet.
γ	Specific weight of the fluid.
ΔD	Measured drop in water level during the interval.
Δh	Difference in water level after bailing.
ΔT	Elapsed time since the preceding measurement.
μ	Viscosity.
μg	Microgram.

CHAPTER 1

INTRODUCTION

1.1 Historical Perspective

Historically, man has assumed that the land, water and air around him would absorb his waste products. He has viewed the land around him as a receptacle of infinite capacity. The technique of land disposal of domestic wastewaters is hardly new. In 1559, Bunslav, Prussia disposed of its sewage through land application and this operation continued for over 300 years (19)*. In 1857, Britain's Royal Commission on Sewage Disposal concluded that the right way to dispose of town sewage was to apply it continuously to land and that it was only by such application that the pollution of rivers could be avoided (36). Long time users of land disposal include some large municipalities such as Berlin (Germany), Paris (France) and Melbourne (Australia).

Apart from a number of municipalities using land treatment for their sewage, a large number of rural and suburban households, not connected to sanitary sewer systems, use individual septic tank-soil absorption systems for their sewage disposal. The first reported use of the household septic tank was in France about 100 years ago, where John Louis Mouras built his "Automatic Scavenger" utilizing a

* Numerals in parenthesis refer to corresponding items in the List of References.

cesspool for effluent disposal. Septic tanks were introduced in the United States in 1884 with the design of a two-chamber tank utilizing an automatic siphon for intermittent effluent disposal. The convenience of waterborne waste disposal in rural households and the difficulty of providing adequate sewerage systems for the large populations migrating to urban areas from rural centres led to widespread use of septic tank systems in North America. It is now estimated that about 50 million Americans use septic tank systems for household sewage disposal. According to the 1971 census report (49), out of 6,030,805 households in Canada, 1,022,265 households use septic tank systems for sewage disposal. On an average of 3.5 persons per household, about 3.6 million Canadians use septic tank systems for sewage disposal.

1.2 Septic Tank-Soil Absorption Systems

Septic tank systems are today essentially the same in design and construction as they were forty years ago. The method provides for the collection of waterborne household wastes in a buried vault where scum, grease and settleable solids are removed from the liquid by gravity separation. The retained solids are digested by bacterial action and partially liquefied. The effluent passes into the soil.

The effluent from a septic tank contains solids, many plant fertilizing nutrients, particularly nitrogen and

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phosphorous compounds, many microorganisms including pathogenic types as well as viruses. Disposal without further treatment would constitute a serious health and pollution hazard. Thus, in the usual septic tank system, an important role in the treatment of the wastewater is assigned to the soil through which the effluent percolates. Failure of a soil absorption system may cause bacterial contamination of ground and surface waters, objectionable odors, and pollution of recreational waters. The effectiveness of the soil as a treatment system may vary considerably with a number of changing environmental factors such as soil and air temperatures, amount of oxygen present and other factors. With continued application of the effluent, the ability of the soil to treat it may decline. Even with a soil absorption system operating well, it would appear that groundwater contamination is inevitable because the soil is not equally effective for the removal of all constituents of the percolate. Therefore it becomes necessary to evaluate how far a septic tile system is adequate as a treatment system for the reduction of many of the constituents of the septic tank effluent, especially the nutrients, as their release into a body of water may significantly contribute to enrichment and subsequent eutrophication. A recent Ontario study (83) has identified considerable lake pollution from the poor operating conditions and improper locations of waste disposal facilities (which are mostly septic tank systems) of lakeshore cottages.

Nassau County, Long Island, New York provides a large-scale, dramatic demonstration that septic tanks can pollute groundwater. Here, the daily discharge of 300 million litres of wastes into septic tanks and cesspools has caused increases in nitrate in individual and municipal wells above the present U.S. Public Health Service drinking water limit of 10 mg nitrate nitrogen per litre (108). The dissolved solids loads in the streams in the Boston area which receive septic tank effluent through percolation to groundwater reservoirs were found to increase by an amount that can be predicted from the housing density (81). Thus, land disposal as an effective means of water resources management will have to be viewed with consideration of possible pollution of ground and surface waters.

1.3. Canadian Practices in Using Septic Tank Systems

A report (123) based on a survey of provincial health agencies and a review of published regulations in Canada on septic tank design and installation criteria, showed that regulations governing their design and construction vary somewhat across the country; however, some requirements such as tank size and details, daily design flows and absorption trench sizes are fairly uniform throughout. Local factors will undoubtedly influence the values to be used for design particularly in a system which uses the soil for treatment. The survey shows that at least one province

(Saskatchewan) does not recommend absorption fields and that some municipalities formerly using them have changed to lagoon systems.

1.4 Objective of this Study

There is a lack of information on the reduction of pollutants of septic tank effluent by soil filtration, particularly in the form of field studies. This is the motivation for this research project. A field investigation of this type would impose certain limitations; for example, the various environmental factors like temperature and groundwater level cannot be controlled in the study to examine the specific effects, there is an absence of flexibility in modifying the set-up and there is the availability of essentially a single soil type. However, it has the important advantage over a laboratory set-up in that the system efficiency can be studied under the actual conditions which are quite difficult to simulate in a laboratory set-up.

The primary objective of this investigation is to determine the efficiency of the septic tile system. This will be evaluated with respect to the following parameters: reduction in total suspended solids (TSS), biochemical oxygen demand, 5 day 20°C (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total phosphates (PO₄-P), ammonia nitrogen (NH₃-N) and nitrification. "Efficiency" will be taken to mean the reduction achieved between the

point at which the septic tank effluent was distributed to the tile and the various depths at which the soil water samples were collected.

The environmental effects of soil temperature and unsaturated depth of soil, on the efficiency of the system, will be determined in so far as possible.

CHAPTER 2

LITERATURE REVIEW

2.1 Scope of the Review

There is a large amount of published material on the design and operation of septic tank systems. It is proposed to restrict the scope of the review to literature pertinent to the present investigation including such material for purposes of comparison and for the basic understanding of the process. The material is discussed in detail under the following subtitles:

- 1) Water use and wastewater flows in individual households,
- 2) The septic tank system,
- 3) Clogging of soils,
- 4) Influence of environmental factors on the performances of septic tank systems, and
- 5) Sewage treatment through soil with special reference to septic tank effluent treatment.

2.2 Water Use and Wastewater Flows in Individual Households

2.2.1 General

In view of the importance of water quantities in the planning of water and waste treatment facilities, many design estimates for the daily per capita water use are

contained in the literature. These estimates include leakage as well as miscellaneous non-household uses. Relatively few reports have been published on actual water usage in individual households and the distribution of water among the various uses. It is well recognized that per capita water use varies widely with the standard of living, the climate, personal habits and the number of persons per dwelling unit. In the review which follows gallons refers to U.S. gallons, unless noted otherwise.

2.2.2 Water Use and Wastewater Flows

Sernas (106) and Prescott (92) furnished data on mean water consumption rates in individual households. Subsequently the Ontario Department of Health (105) revised the design flows for the design of septic tank systems. The basis of their design as recommended in their publication is 60 gallons (Imperial) per capita per day (gpcd) for residences with automatic washing machine but no garbage grinder; they recommend a figure of 72 gpcd (Imperial) for dwellings with garbage grinder as well. Searcy and Furman (104) reported on the daily and hourly peaks of water consumption for institutions. Hubbell (50) suggested that the residential wastewater flow is 41.5 to 83 gpcd. Fair and Geyer (33) suggested a range of 15-70 gpcd for domestic water consumption.

The U.S. Department of Health, Education and

Welfare Manual No. 526 (76) presented a table showing 40 gpcd for rooming houses, 75 gpcd for single family dwellings and 150 gpcd for luxury residences and estates. Pond (90) presented data on per capita water use for one family houses. The water use ranged from 30.5 to 49.4 gpcd in 1937 for 4,899 homes. In a study of 18 homes (125), the average daily water use per person varied from 20 to 70 gallons and averaged 44 gallons. Public Health Service studies (117) to develop design criteria for soil absorption systems, revealed that the average daily water use was 56 gallons per person. The Public Health Service study also cited the results of an extensive water use study in Bethlehem, Pennsylvania which showed the average use to be 48 gpcd. A study at Johns Hopkins University also indicated an average per person use of 56 gpd (62). Both the study at Johns Hopkins and the study by the Public Health Service indicated that water use was inversely proportional to the number of persons per dwelling unit. Campbell and Smith (22) reported mean water consumption of 153.4 Imperial gallons per day for a family of four. The mean use of water for toilet flushing was 60.7% of the total intake. Laak (56) has stated that average sewage flow at his house was 155 gpd (Imperial) or 29 gpcd (Imperial). The daily flow from a single family dwelling adopted in the design of septic tank systems in Canadian provinces varies between 35 and 75 imperial gallons

per capita (Table 1). A figure in the range of 40 gpcd (Imperial) appears to be common. A recent investigation in Ontario revealed average figures (over 10 months) from 19.8 to 41.9 gpcd (Imperial) from 7 households, which are connected to a septic tank (25).

The water delivered to the households is divided among various uses. A few of the published estimates of water use are furnished in Tables 2, 3 and 4. After monitoring the wastewater flows from eighteen homes in Louisville, Ky., U.S.A. for 4 months, Carcich et al. (23) adopted an average figure of 60 gpcd sewage flow in the design estimates for pressure sewer systems.

2.2.3 Pollution Load

The design pollution load of 0.15 to 0.22 lbs of BOD per capita per day adopted for residential and community sewage treatment plants, with a sewage flow of about 100 gpcd is not realistic for an individual sewage disposal system. The average composition of domestic municipal sewage contains 100-500 mg/l of total suspended solids (4, 30, 33) and 100-360 mg/l of BOD (12, 73). Individual households in Ontario have shown an average of 255 mg/l of total suspended solids and 300 mg/l of BOD (12). A recent exhaustive study on three homes (125) showed average total suspended solids between 250-450 mg/l and average BOD between 325-475 mg/l. Zanoni and Rutkowski (133) report per capita loadings of

TABLE 1. Septic Tank Systems in Canada -
Design Daily Flows

Province	Particulars				
	Design Daily Flow-Imperial Gallons/cap/day				
	Single Family	Multiple Family	Day School	Hospital per bed	Motel
1. Alberta	50		10	100	
2. British Columbia	40		10	150	35
3. Manitoba					
4. New Brunswick	40		10	150	35
5. Newfoundland	35		10	100	35
6. Nova Scotia	75				
7. Northwest Territories					
8. Ontario	60		12	150- 250	35
9. Prince Edward Island					
10. Quebec	40	60	20	200	80 ^a - 100
11. Saskatchewan					
Dept. of National Health and Welfare, Canada	35				
Manual of Septic Tank Practice (USPHS No. 526)	75 ^b	60^b	20 ^b	250 ^b	50 ^b

^a per room

^b U.S. gallons

TABLE 2. Household Water Uses (43)

<u>Type of Use</u>	<u>Percentage</u>
Toilet Flush	45
Bathing	30
Kitchen	6
Drinking	5
Laundry	4
Cleaning	3
Sprinkling	3
Autowashing	1
Miscellaneous	3

TABLE 3. Estimated Distribution of Sewage (76)

<u>Waste</u>	<u>Volume of waste, gpcd</u>				
Total flow (gallons)	30	40	50	75	100
Kitchen wastes	0	7	10	10	15
Toilet wastes	15	15	20	25	30
Showers, wash basins, etc.	15	18	20	25	35
Laundry wastes	0	0	0	15	20

TABLE 4. Toilet Flushing (Family of Four) (22)

<u>Days of week</u>	<u>Water used for toilet flushing</u> <u>% of total daily intake</u>
Monday	44.7
Tuesday	66.9
Wednesday	47.0
Thursday	61.5
Friday	61.9
Saturday	68.5
Sunday	74.4

domestic wastewater, as below, based on a survey of 270 dwellings with a population of 1,207, in Milwaukee, Wisconsin.

BOD (5-day, 20°C)(lb/day/cap)	0.10
COD (lb/day/cap)	0.20
SS (lb/day/cap)	0.08
Wastewater flow (gpcd)	58

It would appear that the design BOD of 0.15 to 0.22 lbs per capita per day is too high for the design of individual household sewage disposal systems. Laak (56) has suggested an average figure of 0.06 lbs per day per capita of BOD.

2.3 The Septic Tank System

2.3.1 Septic Tanks

A septic tank provides a primary stage of sewage purification and is intended to overflow. The main purpose is to remove suspended matter and the separated material is retained as sludge and scum, until it can be pumped out. Its use is restricted to individual houses or groups of isolated dwellings and its use in large municipal sewage works is obsolete. The effluent from the septic tank contains much dissolved and colloidal organic matter and requires further treatment by aerobic biological processes before discharge to a water course.

A septic tank performs these main functions:

1. removes a good portion of the settleable and floatable matter by sludge and scum

2. effects reduction in settled and floating organic matter through anaerobic digestion, and
3. acts as storage for the remaining solids till removed.

There have been several investigations on the design of septic tanks. The best known studies were carried out by Weibel, Straub and Thoman (127), Bendixen et al. (8) and Weibel, Bendixen and Coulter (128), for the United States Public Health Service. Series of studies have also been made at the University of Toronto by Prescott (92), McGill (71) and Sernas (106). Baumann and Babbitt (6) investigated the performance of six small septic tanks at the University of Illinois.

2.3.2 Capacities of Septic Tanks

The total capacity of a septic tank is arrived at by making an allowance for storage of sludge and scum according to the interval between successive desludgings of the tank and an allowance of liquid space in which settlement of solid matter from sewage flowing through the tank can occur. Studies by Weibel, Bendixen and Coulter (128) showed that the annual rate of accumulation of sludge and scum was not affected by water consumption. According to them, three factors which may influence accumulation of sludge and scum, are time, persons and liquid capacity of the tank. They developed the following equation for estimating submerged accumulation when time in service,

number of persons and liquid capacity of tank are known:

$$Y = 3.4 (t) + 2.2 (p) + 4.0 (c) - 20.9 \quad (2.1)$$

where Y = accumulation in cubic feet

t = period of service in years

p = number of persons using

and c = capacity in gallons/100

The formula is applicable for a certain range indicated in the report. There are several publications which indicate the sizes, capacities and details of septic tanks, for individual households, etc. The "Manual of Septic Tank Practice" issued by the U.S. Public Health Service (76) is generally followed in U.S.A. Septic tank capacities based on the number of bedrooms, as recommended by various provinces in Canada are shown in Table 5. It may be seen that some provinces stipulate a minimum capacity of 400 gallons (imp.), while some indicate 500 gallons (imp.). This is evidently due to the differences in daily sewage flow adopted by them.

2.3.3 Anaerobic Process

Anaerobic digestion of organic sludge is the process that occurs in a septic tank. McKinney (73) suggested that the majority of microbial activity in a septic tank and cesspool occurs in the intermediate liquid zone and not in the settled sludge and floating scum, in contrast to an anaerobic digester. These differences make the sludge

TABLE 5. Septic Tank Requirements

No.	Province	Tank Capacity (Imp. Gals)					Minimum Capacity Gals	Minimum Liquid Depth in Feet	Minimum Detention time hours	Materials of Construction
		Number of Bedrooms								
		1	2	3	4	5				
1	Alberta		413 ^a	450 ^a	610 ^a	740 ^a	400	4	24	Concrete, fibre glass
2	British Columbia	500	500	600	750	-	500	4	-	Concrete, fibre glass
3	Manitoba						300	4	24	Concrete, fibre glass, coated metal
4	New Brunswick						300 ^b			
							500			
5	Newfoundland	413	413	450	612	737	413	4		Concrete, coated steel
6	Nova Scotia							4		Coated steel, concrete, fibre glass
7	Northwest Territories									
8	Ontario	500	500	600	720	900	500	4		Concrete, coated metal, fibre glass
9	Prince Edward Island							4		Concrete
10	Quebec	500	625	750	850	1050	400	4	24	
11	Saskatchewan							4		
	Dept. of National Health & Welfare, Canada	413	413	450	612	740	400	4		Concrete, coated metal
	Manual of Septic Tank Practice, (USPHS No. 526)	750 ^{c,d}	750 ^{c,d}	900 ^{c,d}	1000 ^{c,d}	1250 ^{c,d}	2-1/2			

^a with rate of sewage contribution at 35 gpcd, ^b for non-permanent residences, ^c garbage grinder and washers in use. ^d

digestion in a septic tank incomplete and the rate of digestion low. Two basic processes, liquefaction and gasification, are involved in anaerobic digestion of organic solids. The general theory of anaerobic sludge digestion is discussed in detail by McKinney (73) and Eckenfelder and O'Connor (30). According to Laak (56) the food supply, method of mixing, quality of water supply, pH and volatile acids content, all of which are uncontrolled in septic tanks, affect the process.

2.3.4 Treatment in Septic Tank

The following table lists a few treatment parameters for the experimental septic tank used in studies at the University of California (68) and the general performance of the same.

<u>Parameter</u>	<u>Raw Sewage</u>	<u>Septic Tank Effluent</u>	<u>% Removal</u>
	mg/l	mg/l	
BOD	150	75	50
COD	310	160	48.4
SS	185	50	73
Volatile Solids	265	160	39.6

Multiple compartment septic tanks remove BOD and SS better than a single compartment tank. McGill (71) developed the following equations for the effluent BOD and effluent SS from two compartment tanks with a 48 hour detention:

$$\text{BOD}_e = 4.10 \text{ BOD}_i^{0.658} \quad (2.2)$$

$$\text{SS}_e = 2.45 \text{ SS}_i^{0.713} \quad (2.3)$$

where e = effluent
and i = influent.

Coliforms including E. Coli are not removed enough in septic tanks according to Prescott (92). Weibel, Bendixen and Coulter (128) studied the effects of detergents, ground garbage and zeolite softener salts on the performance of septic tanks.

2.3.5 Septic Tank Effluent Disposal

Septic tank effluent is still a highly polluting liquid which requires further treatment before it can be safely disposed of. The effluent from a septic tank is usually treated in soil absorption systems like tile fields (absorption trenches), seepage beds, seepage pits or through sandfilter trenches, subsurface sand filters or above ground filters. Effluent treatment in trickling filters or in lagoons is also practised. Details of these arrangements are found in "Manual of Septic Tank Practice" (76), WHO Monograph "Excreta Disposal for Rural Areas" (124) and elsewhere (96, 97, 98). The investigations proposed in the project are restricted to absorption tile fields.

2.3.6 Absorption Tile Field

Details of absorption tile field design practised

by various provinces in Canada are shown in Table 6. The minimum width of trench is usually 18 inches and the maximum is either 24 or 36 inches. There is usually a gravel fill of 6 to 9 inches depth below the tile and a minimum of 2 inches fill above the tile. The minimum cover is usually 18 inches. The minimum pipe size is usually 4 inches, though some adopt 3-1/2 inches. The maximum length of lateral is 100 feet; some stipulate minimum length of trench in an installation at 150 to 180 feet.

Table 7 shows the absorption area or length of trench recommended for various percolation rates. The recommendations are in various units, making direct comparisons difficult. In many provinces, a soil with a percolation rate greater than 60 is judged not suitable, though in some, a soil with a rate greater than 30 is not recommended.

It is interesting to note that absorption tile fields are no longer recommended in Saskatchewan for two reasons: 1) The soil in most areas is clay and the trenches would require considerable enlargement and filling with gravel and 2) where there is light gravel or light sandy soil, there is invariably an underground water supply and this type of disposal is not recommended for such areas. Freezing of the fields in cold weather has also created a problem. The practice at present is to provide septic tanks and pump-out chambers for the disposal of sewage from

TABLE 6. Absorption Field Design

No.	Province	Min. Spacing of tiles ft.-in.	Min. Pipe dia. in.	Slope of tile in/100'	Max. length of tile ft.	Max. length of lateral ft.	Min. cover in	Trench width in		Min. gravel fill		Remarks
								Min	Max	Above tile	Below tile	
1	Alberta	5	4	2-4		100	18	18		6		
2	British Columbia	6	3-1/2	2-4	150		16	18		2	9	
3	Manitoba	5-8	4		180		18	1				
4	New Brunswick	6	3-1/2	4		100	14	18		2	9	
5	Newfoundland	6	4	2-4	150		18	18	24	2	6	
6	Nova Scotia	4	4	2-4		100	12					
7	Northwest Territories											
8	Ontario	6	4	4		100	12	18	36	2	6	
9	Prince Edward Island											
10	Quebec	6	4	2-4		100	12	18	36	2	6	
11	Saskatchewan											Absorption fields not recommended
	Dept. of National Health and Welfare, Canada	3-6	4	2-4		100	18	18		2	12	
	Manual of Septic Tank Practice (USPHS No. 526)	6	4			100	12	18	36	2	6	

TABLE 7. Soil Percolation Test and Absorption Area Recommended

No.	Province	Required Absorption Area or Length of Trench						Remarks
		Percolation Rate						
		Time in minutes for water to fall 1 inch						
		1	2	5	10	30	60	>60
1.	Alberta							
2	British Columbia	30	53	70	107	>30,	unsuitable	length in feet of trench/bedroom
3	Manitoba							
4	New Brunswick	180	320	420	645	>30,	unsuitable	length in feet trench/dwelling
5	Newfoundland	-	100	100	175	325		length in feet of trench/2 bed-rooms or less
6	Nova Scotia			0.40	0.55	unsuitable		length of trench in feet/gallon/day
7	Northwest Territories							
8	Ontario	20	44	64	110	154		unsuitable length of trench in feet/bedroom
9	Prince Edward Island							
10	Quebec							
11	Saskatchewan							Absorption fields not recommended
	Dept. of National Health and Welfare, Canada							
	Manual of Septic Tank Practice (USPHS No. 526)	70	85	125	165	250	330	unsuitable Area in square feet per bedroom

private buildings not connected to a municipal sewage works.

2.4 Clogging of Soils

2.4.1 General

Clogging of a soil is a physical phenomenon, an increase in physical resistance to flow resulting from changed friction or viscosity coefficients or reduction in size and volume of pore spaces (45). The factors contributing to soil clogging are usually classified as physical, chemical and biological (66, 68).

2.4.2 Physical Factors in Soil Clogging

There are several ways in which clogging may result from predominantly physical phenomena, according to McGauhey and Winneberger (68). They are:

1. Compaction of soil by superimposed loads.
2. Smearing of soil surfaces by excavating equipment.
3. Migration of fines by vibration of dry soil during preparation of site area.
4. Migration of fines due to rainfall beating against surface.
5. Washdown of fines perched on larger particles.

Coulter et al. (26) and Bendixen et al. (9) in field observations of construction of septic tank percolation systems report many instances of compaction of soil during construction. Smearing of the sidewall surface by worn rotary blade-

type buckets is also a common cause of physical clogging. An important physical factor in soil clogging which has implications in the operation of aerobic soil systems is the retention of soil moisture by capillarity (66). Experiments by Klein and McGauhey (53), Bendixen et al. (10) and Winneberger et al. (130, 131) show that for each soil of grain size small enough to make surface tension and capillary major forces, there is a minimum length of soil column necessary to produce draining of the soil when application is stopped. This factor represents the minimum distance between the soil surface and underlying water table. Though this is a physical phenomenon, it leads to biological clogging under anaerobic conditions.

2.4.3 Chemical Factors in Clogging of Soils

Of the factors that might be classed as "Chemical", ion exchange is by far the most important. Its best known action is the deflocculation of soils, resulting in decreased permeability when sodium represents a high percentage of the cationic content of the water. Fifty percent Na is the generally accepted critical point beyond which deflocculation becomes progressively greater (66). Fireman (35) found that soils high in organic matter have higher permeabilities than normal soils when irrigated with waters of low-sodium percentage, and vice versa with waters of high-sodium percentages.

2.4.4 Biological and Organic Clogging of Soil

Clogging of soil by biological agents and their activities is by far the most important cause of loss of infiltrative capacity. Allison's (2) work identified microbial action as the cause of decreased permeability under prolonged submergence and sealing up. McCalla (64) felt that there are two ways by which microorganisms may reduce water movement through the soil under prolonged submergence -

- 1) The microorganisms may produce gases or highly hydrated organic materials such as slimes that might interfere with water movement.
- 2) Microorganisms may reduce water percolation by decomposing or changing the structure of stabilizing agents, resulting in structure deterioration.

Thomas et al. (118) investigated the site and nature of soil-pore clogging under sewage spreading using laboratory and field lysimeters. Their studies showed three phases in the infiltration rate loss: phase I, a slow reduction under aerobic conditions; phase II, a rapid reduction under anaerobic conditions. The primary site of clogging was found to be the 0- to 1 cm depth of soil. They found that though sulfide was an indicator of anaerobic conditions, it was not a primary cause of clogging. Clogging under anaerobic conditions evidenced in many field installations, obviously resulted from two principal factors, the biological slimes, including residues of incompletely degraded organic matter and particulate matter which had penetrated the soil surface. Anaerobic conditions,

incidentally, were the natural outcome of continuous application of effluent to the system. Winneberger et al. (129) observed that the black layer at the surface was precipitated by anaerobic degradation of sulfates and penetrated downward a short distance into the soil. The organic mat is confined to a thinner layer at the surface, i.e. 0.5 to 1 cm, in contrast with the 5 to 10 cm penetration of ferrous sulfide. When the system was allowed to drain, ferrous sulfide clogging was quickly overcome by the oxidation of sulfide to sulfate in the presence of atmospheric oxygen.

Studies of the mechanism of biological clogging of the surface zone of sand during prolonged percolation of water containing high levels of organic matter were made at the Weisman Institute in Israel. Mitchell and Nevo (79) found that polysaccharide-producing microorganisms predominated in the clogged layers of sand. A positive correlation was observed between accumulation in the profile of polysaccharides and clogging of columns of sand in permeameters. Further studies by Nevo and Mitchell (82) showed correlations between clogging of sand beds by microbial polysaccharides and decline in measured potential in the sand, which inhibits the degradation of the polysaccharide. Sudden changes in permeability of the sand when the water temperature changes during infiltration can also be predicted. If the temperature were below 20°C, the rate of clogging should occur between 20°-30°C and at 37°C little or no

clogging should be detected. Studies by Laak (57) showed that the clogging zone was in the upper 0-2" (5 mm) of the soil surface and that the clogging material consisted of about 90 percent bacteria cells. Iron and sulfate analyzed from clogged sand was not sufficient to indicate that ferrous sulfide was the major cause of clogging.

2.4.5 Effect of Loading on Soil Clogging

Continuous inundation of an infiltrative surface, creating anaerobic conditions, will result in soil clogging. Both duration of continuous application and the organic and other content of the applied liquid are factors involved. Little useful information concerning the optimum cycle of loading and resting for trench or other subsurface systems can be obtained from septic tank percolation field experience, as such systems operate with virtually no control of the loading pattern. The random intermittency of loading that results from household wastewater discharges appears to be a factor in the survival of those systems that have not failed. Much more data on loading and clogging are drawn from surface infiltration ponding systems than septic tank systems. Winneberger et al. (130, 131) found the resting to be beneficial in restoring the infiltrative capacity of subsurface trenches and seepage beds used in septic tank installations. They report that partial recovery of the initial infiltrative capacity of a soil does not require

drying, but that draining is necessary to reestablish the required aerobic system. DeVries (29) found that the physical condition of sand filters did not deteriorate as a result of daily application of primary treatment plant effluent for 2 hours, for 240 days, with filters drained during the rest period of 22 hours. But this application at a temperature of $4^{\circ} \pm 3^{\circ}\text{C}$ resulted in failure in 10 days because of pore clogging. The clogged pores were on the soil surface and the failed filters recovered in 8 days at room temperature.

It has been shown (128) that reduced concentration of total suspended solids resulted in less soil clogging and that increased substrate concentration with constant total suspended solids (TSS) increased soil clogging. In another study (129), it was shown that anaerobic pretreatment, did not sufficiently change the clogging rates of soil when the sum concentrations of TSS and BOD in the load remained about the same. Laak (57) found that soil columns loaded with septic tank effluent and extended aeration plant effluent clogged at different rates. Studies at the University of California (67) show that in the design of percolation fields, the bottom area is of little or no practical value in long term infiltration because it soon becomes clogged and ponding results. Narrow trenches in which a large percentage of side wall area is wetted by a given volume of applied effluent are found to be far more satisfactory than wide bottom

trenches of the same depth. Recent studies by Popkin and Bendixen (91) have shown that continued hydraulic acceptance as measured by the rate of wetting new surface area in a progressive ponding situation is influenced directly by the frequency of applying waste, the volume of waste applied and the quality of waste applied. The rate of development of wetted absorption area is decreased by reducing the frequency of application and by a combination of the two methods. Their studies suggest that a vastly improved design and operation of soil absorption system can be obtained without affecting ground water quality through use of once-a-week dosing alone or combined with the use of improved pretreatment. The following mathematical formulation developed by Thomas et al. (116) describes the capacity of soil for receiving wastes before becoming clogged.

$$L = \frac{fpT_o}{A_o} \quad (2.4)$$

where fp = the "equivalent" population load. p is the number of persons in the household; and f is a factor reflecting the type of pretreatment of sewage and the presence or absence of food waste grinders or automatic washing machines.

T_o = the useful life (in years) of the system.

A_o = the effective area (in square feet) of the

soil liquid interface in the absorption system.

and S = unit areal load capacity of the soil.

2.5 Influence of Environmental Factors on the Performance of Septic Tank Systems

2.5.1 General

Many environmental factors influence the operation and performance of septic tank systems. The factors that are considered here are: temperature, snow cover and depth to ground water.

2.5.2 Temperature

The biological and chemical reduction of organic material proceed very slowly under low temperatures. Organic materials exposed on the surface of the ground or placed within the shallow top layers of seasonally thawed ground, decompose slowly. Slow decomposition of organic matter tends to maintain a greater supply of food for many forms of life and it is presumed that this may account for the reported abundance of life (3). Under low temperature conditions, biological processes appear to offer the most promise, although biological reactions are influenced by temperature. It would however appear that aerobic processes in general may be more efficient than anaerobic processes since heat appears to affect the latter much more than the former. If the soil is

permanently frozen as in certain cold areas, then it has a marked effect on the infiltration and dissipation of liquid wastes. Drainage is severely affected and is mostly horizontal rather than vertical (3). Small waste disposal systems such as septic tanks and subsurface tile fields or sand filters, as ordinarily constructed for use in temperate climates, are reported to be impractical in the continuous permafrost or on ice (3). Septic tanks are used in cold regions to serve 25 to 100 persons or more; these are usually enclosed in the heated buildings. Alter (3) recommends that septic tanks for cold regions should be approximately twice as large as is necessary where sewage temperatures are 55° to 60°F.

Laboratory studies performed in Cincinnati by the United States Public Health Service using a two-day detention time and temperatures of 40°-50°F (4°-10°C) gave 31-41 percent removal of total solids, 68-89 percent of suspended solids and 70-77 percent of BOD (127). Similar tests performed at Washington State University using a detention time of 4.5 days and temperatures of 33°F, 40°F and 59°F (0.6°C, 4.4°C, and 15°C) showed removals of 31 percent of the total solids, 83-86 percent of the suspended solids, and 49-52 percent of BOD (47).

In the field studies conducted by the Manitoba Department of Health (1), it was observed that under severe winter conditions, temperatures in the septic tank remained

at or about 50°F, in the siphon chamber around 40°F and in the tile of the disposal field, about 32°F in a satisfactory installation, under a snow cover of 5 to 22 inches. Laak (56) mentions that Professor Graham's observations in 1921 revealed that septic tank temperatures varied between 7° to 22°C in the first chamber and 2° to 14°C in the second chamber, while the air temperatures varied between -20°C and 6°C. Hickey and Duncan (46) measured the temperatures inside 20 septic tank systems in Anchorage and Fairbanks in Alaska and their results and analyses reveal the following interesting facts:

1) The average temperatures of the septic tank contents during the coldest months ranged between 52° and 54°F (11.1° and 12.2°C) for Anchorage and 48° and 50°F (8.9° and 10°C) for Fairbanks, while the average nearby ground temperatures remained below 35°F (1.7°C) for several months in both areas.

2) In Anchorage, the concrete tanks apparently provided better insulation than the steel tanks, as they were 10.5°F (5.8°C) warmer inside than outside, as opposed to a temperature differential of 3.5°F (2.0°C) in the steel tanks; no such differential was observed at Fairbanks.

3) In Anchorage, the liquid temperature in the seepage pits ranged from 4° to 16°F (2.2° to 9°C) colder than in the septic tanks, with an average difference of 8°F (4.4°C), while in Fairbanks, the seepage pit temperatures

ranged from 2° to 9°F (1.1° to 5°C) colder than the septic tanks, with an average difference of 6°F (3.3°).

4) The studies generally indicated that septic tank-soil absorption systems perform satisfactorily in the climates of Fairbanks and Anchorage, Alaska, and that the large amount of heat provided to the septic tank by the wastewater from the residence (due to domestic hot water system) may be a significant factor in maintaining the disposal system at an operable temperature. Field studies on the performance of septic tanks at certain remote air force installations in Alaska (114), revealed that in unheated tanks, the temperature ranged from 2°C to 27°C for the influent and from 2° to 29°C for the effluent, with the average temperatures of 17°C for both the influent and effluent. The BOD removals averaged only 14 percent in the unheated tanks, while the total suspended solids were reduced 38 percent. Schwartz and Bendixen (103) confirmed the earlier observations of Robeck et al. (100) on the need to avoid starting at or under 40°F (4°C). Schwartz and Bendixen noted that the early days of operation are critical for the rate of biological development, that the extended longevities for the units started in summer ran through the following winter without any difficulty. They stressed that the start up period is critical and cold weather operation per se is not necessarily restrictive on the performance of a soil systems. Their studies indicate that hydraulic longevity of systems

started in summer was better by a factor of about 3 than that of systems started in winter.

Brink (16) stated that low temperatures have no effect on ultimate results of filtration because soil adsorption increases with decrease in temperature. Studies by Laak (56) showed that a decrease of mean liquid temperature from 23°C to 8.5°C caused by a temperature of -17°C on the top of the soil columns did not affect the clogging rate for each system as to be of significance and that it did not significantly affect the BOD removal and suspended solids removal on three different soils.

Thus it may be seen that temperature of air, liquid and soil are important environmental factors that have to be taken into account in the operation of the septic tank-soil absorption systems. Smith (107) observed a general seasonal wave effect of soil temperature; in California, he found that the soil is warmer than the atmosphere throughout the year. Hickey and Duncan (46) observed this for most of the year. Smith (107) also found that temperature changes with depth, with the magnitude of variations decreasing with depth. This sets in motion heat movement upward and downward, depending on the season (air temperature).

2.5.3 Snow Cover

A cover of snow on the soil during winter acts as an efficient insulator to rapid and extensive temperature

changes. . . Bayer (7) reports that all experimental data on the effect of snow cover on soil temperature and the penetration of frost show relatively shallow freezing under snow, unless the air temperature sinks very low for long periods. . . In the Manitoba field studies (1), it was found that the snow cover varied between 5" to 22", with the temperature differential between air and soil (2.5' depth) varying between 6° to 61° F.

2.5.4 Depth to Ground Water

Greater unsaturated depth of soil increases the adsorptive capacity of the soil system by helping contact of the greater mass of soil material with the infiltrating water. The reaeration capacity of the active biological zone at the soil surface is influenced by unsaturated depth. Studies by Schwartz and Bendixen (103) showed that a minimum critical depth of unsaturated zone exists, somewhere between 2 feet and 4 feet; they suggest an optimum depth of at least 5 feet. Hydraulic longevity is reported to be restricted in shallower systems, as limited reaeration permits more rapid accumulation of soil-pore clogging materials. Their study indicated that adequate draining of the unsaturated zone and of the biologically active zone at the surface is necessary to ensure an optimal retention time for biological treatment and to avoid restricting reaeration of the active zone.

2.6 Sewage Treatment Through Soil With Special Reference to Septic Tank Effluent Treatment

2.6.1 General

Septic tank-soil absorption systems have an expected life of 15 to 20 years if installed properly at an acceptable location and if the user follows a few simple rules. According to the U.S. Department of Agriculture (109) the factors that affect soil absorption fields are: Soil permeability, ground water level, depth to rock or sand and gravel, slope of the ground surface, nearness to a stream or body of water, and changes in the soil type. These characteristics are determined by field observations and the soil permeability or rate of water movement through the soil is measured by percolation tests at the site. It is recommended that the ground surface slope not exceed 10 percent, the depth to rock or sand not less than 4 feet from the bottom of the tile distribution lines and the distance to a surface water course be a minimum of 50 feet.

The features of the hydrologic cycle that are of particular interest with respect to the disposal of wastewater on land are infiltration, percolation (both saturated and unsaturated flow), evapotranspiration and runoff. These fundamental concepts are discussed below briefly.

2.6.2 Infiltration

The term infiltration is used to describe the entry phase of the movement of water into soil and the term percolation is used with reference to all movement of water that occurs below the ground surface but above the water table. The primary factors which affect infiltration are the character and porosity of the soil, the moisture content, the degree of compaction of the soil surface and the presence and the type of vegetation. The character of a soil includes its porosity, the pore-sizes and the pore-size distribution. Beyond the above factors, constituents in the wastewater (organic and inorganic) have an effect on infiltration, as viscosity is dependent on temperature. Greater infiltration occurs during the warmer periods of the year than during the cooler periods.

McGauhey and Krone (69) have reported the variation of infiltration rates during long periods of continuous water application and three distinct phases of infiltration are discussed. In the first phase, the infiltration rate decreases with time and this decrease is attributed to the progressive slaking or wetting of the soil. The second phase shows an increase in the infiltration rate, due to the absorption of entrapped air by the water, which has the effect of increasing the porosity of the soil. In the third phase, the infiltration rate decreases as a result of the eventual clogging of the soil through microbial activity and the

development of anaerobic organisms in the upper few inches of the soil. This long-term infiltration behaviour is depicted in Fig. 1. Experiments on the effect of cyclical loading show that in contrast with the typical time-rate of Fig. 1, periods of rest and loading will reproduce the upper section of phase 3 in a pattern as shown in Fig. 2, thus permitting long-time use of an infiltrative surface at acceptable infiltration rates (70). The optimum cycle of resting and loading must be determined by experiment with the finished installation. The curve shown in Fig. 2 is typical of the horizontal surface of spreading ponds, where both draining and drying of the soil may occur during resting period. In septic tank percolation trenches, a much more complex situation develops, where vertical sidewalls represent the infiltrative surface. McGauhey (70) discusses in detail the theoretical infiltration rate curve pattern for the trench sidewall, in which successive curves are lower in elevation and steeper in descent (Fig. 3).

2.6.3 Percolation

The movement of water in the soil beneath the ground surface but above the water table is referred to as percolation and is distinct from the flow that occurs at and beneath the water table, which is regarded as ground water flow. Percolation may take place as either saturated flow or unsaturated flow. Saturated flow is governed by

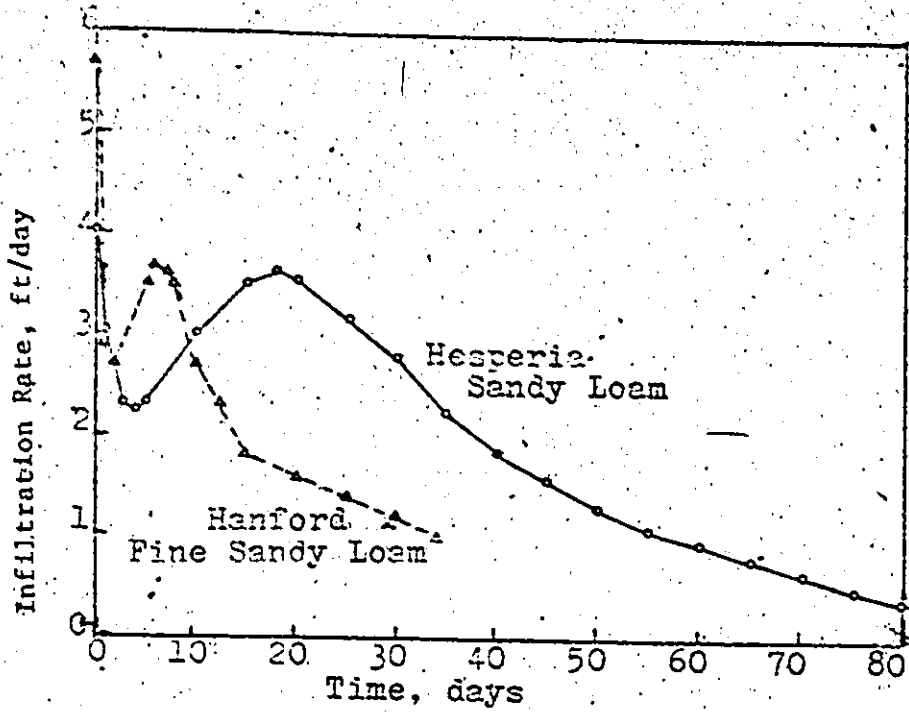


Fig. 1. Long-term Infiltration

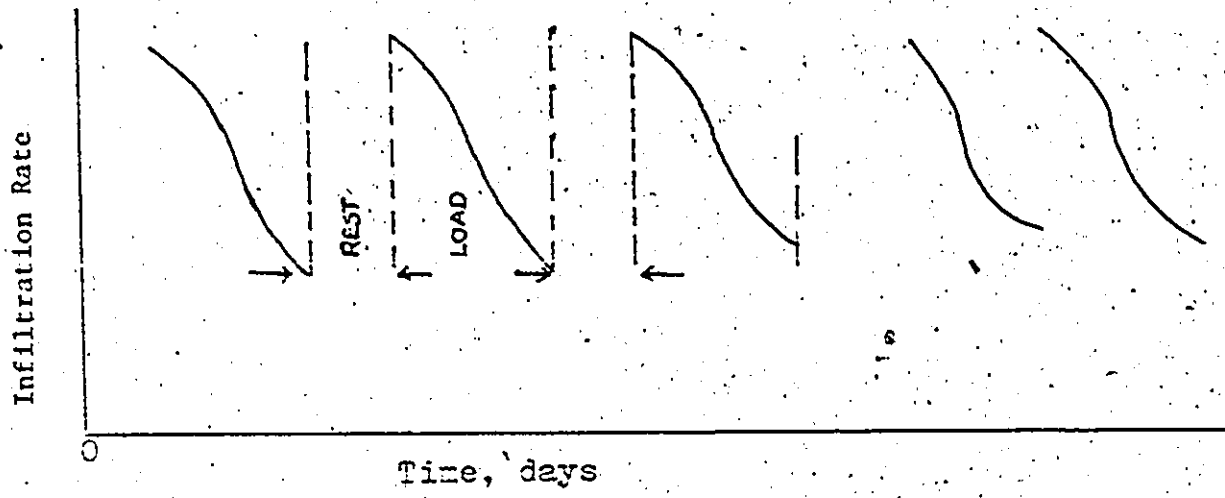


Fig. 2. Typical Restoration of Infiltrative Capacity by Cyclical Operation.

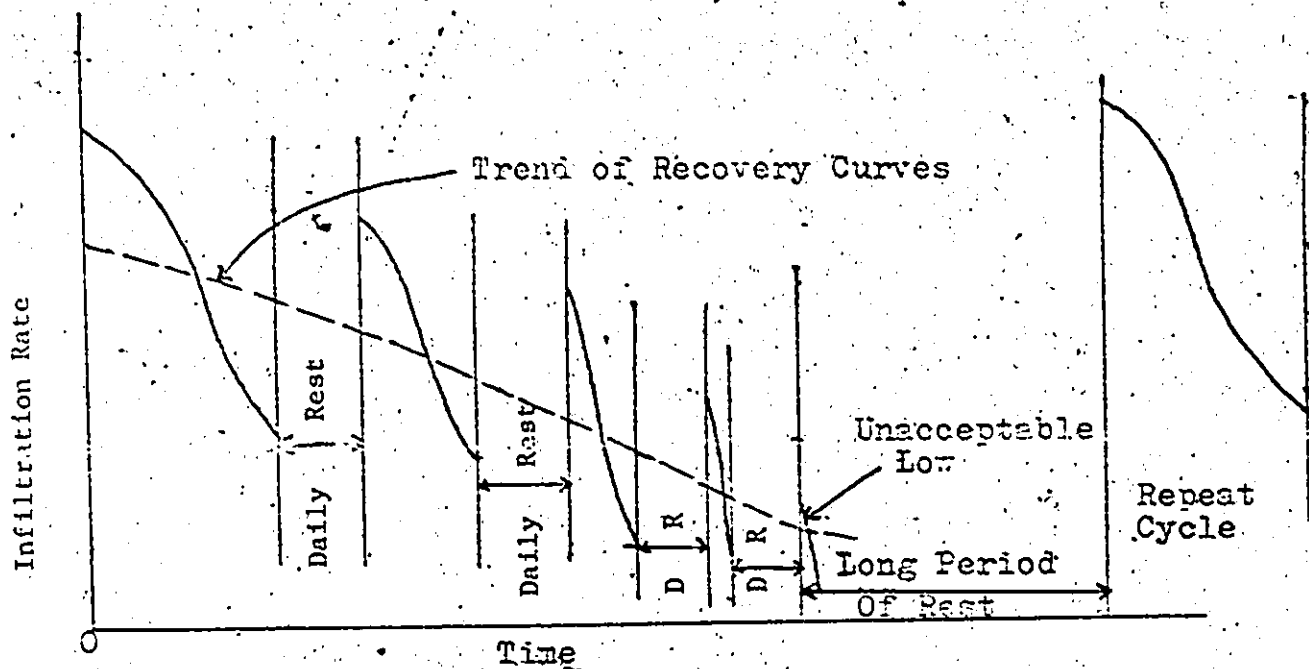


Fig. 3. Theoretical Pattern of Restoration of Infiltrative Capacity of a Trench Sidewall.

the same parameters as ground water flow and is described by the well-known Darcy equation,

$$V = \frac{Q}{A} = K \frac{dh}{dl} \quad (2.5)$$

where V is the apparent velocity of flow, Q is the volume flow rate, A is the cross-sectional area through which flow occurs, K is the "coefficient of permeability" and $\frac{dh}{dl}$ is the hydraulic gradient or the change in head (h) with respect to distance (l). The coefficient of permeability is a function of the soil type and also is a function of the fluid.

Separating the properties of the percolating fluid from the properties of the permeable medium leads to the definition of the specific or intrinsic permeability of a material:

$$k = K \frac{\mu}{\gamma} \quad (2.6)$$

where μ and γ are the values of viscosity and specific weight of the fluid for which K is applicable. The value of " k " has been found experimentally to remain constant for a given soil for different liquids or gases.

In the case of septic tank effluent application into the soil through tile fields, the percolation would be generally a case of unsaturated flow with ground water level at least 4 to 5' below the tile level. Percolation that occurs as unsaturated flow is essentially two-phase flow, since both liquid and gas (usually water and air) occupy the pores of the soil. Experimental work has indicated that for

the one-dimensional flow case, a modification of the Darcy equation may be used with good results (24). The modification consists of introducing a factor that reduces the specific permeability; this factor is a function of the percentage of saturation of the soil by the liquid. The Darcy equation written with the specific permeability instead of the coefficient of permeability for saturated flow is

$$v = k \frac{\gamma}{\mu} \frac{dh}{dl} \quad (2.7)$$

For unsaturated flow, the Darcy equation may be stated as

$$v = M k \frac{\gamma}{\mu} \frac{dh}{dl} \quad (2.8)$$

where M , varying between 0 and 1.0 (i.e. between 0% and 100%), depends on percent saturated. The typical nature of the dependence of M on percent saturation may be seen in Fig. 4. It can be seen for example that for these sands, with 50% saturation, M would have a value of less than 10% or 0.1. Not until the material was over 80% saturated, would the unsaturated specific permeability (Mk) reach 50% of the saturated value. With percolation (both saturated and unsaturated) dependent on permeability, and permeability dependent on pore size and soil structure, percolation is almost exclusively dependent on soil type. Freeze (37) developed equations for the unsaturated and saturated flows (both steady and unsteady), keeping the physical continuity

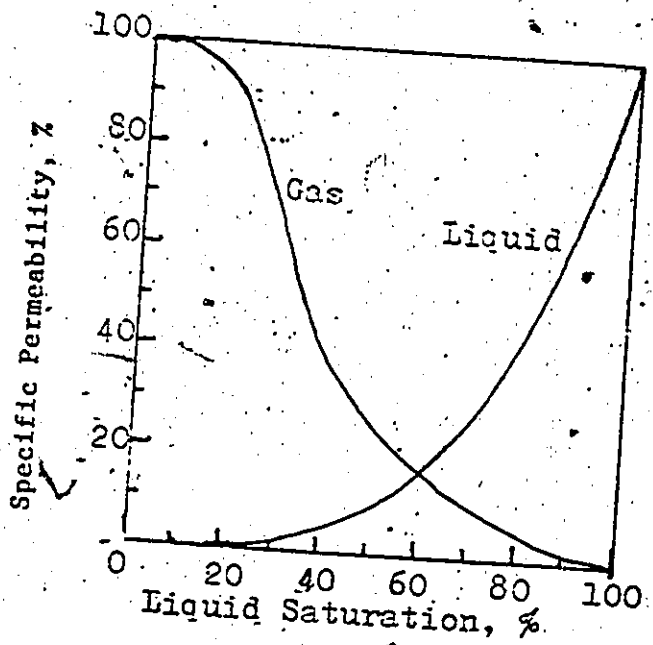


Fig. 4. Typical Dependence of Permeability to Unsaturated Gas or Liquid Flow in Sand (as a percentage of specific permeability) upon the Degree of Liquid Saturation

between the unsaturated flow systems and ground water flow systems, and presented a numerical finite-difference solution for the one-dimensional, vertical flow problem involving saturated-unsaturated systems. Unsaturated two-phase flow is comprehensively treated by Stallman (110).

Brown (17) stated that the flow in the unsaturated region is affected by the following factors:

- 1) The rate and manner in which fluid is introduced
- 2) The extent and geometry of the pore spaces in the material
- 3) The magnitude and direction of temperature and chemical gradients
- 4) The fluid properties such as density, viscosity and surface tension

Hoopes and Harleman (48) developed mathematical equations for wastewater discharge and dispersion in porous media.

Bruch and Street (18) studied mixing of pollutants in recharge water with the ground water, with a model study set-up representing a two-dimensional seepage flow.

2.6.4 Evapotranspiration

Evapotranspiration represents the net combined effect of evaporation from soil and transpiration by plants in reducing the water in a soil system. When compared to the infiltrative capacity of the soil, however, evapotranspiration values are generally quite modest. Evapotranspira-

tion is estimated by means of lysimeters, soil-moisture measurements, ground water level variations and the use of the basic hydrology continuity equation. Several equations exist for calculating evapotranspiration. Among these, the Thornthwaite equation is probably the most widely used.

2.6.5 Runoff

Runoff is the residual of precipitation after interception, infiltration, evapotranspiration and storage in surface depressions, if any, have been satisfied. Its magnitude and distribution in time are dependent on these factors, plus the physical characteristics of the watershed: size, shape, slope, roughness, type and density of vegetation, etc. Since the septic tank effluent is to be applied 2' below the ground and not as an overland runoff, this aspect is not discussed in detail.

2.6.6 Physical, Chemical and Biological Actions in the Soil

These help to remove the pollutants as they travel through the soil. The actions are individually analyzed in the following paragraphs.

Physical Actions

Preul (93) indicated that the physical action of the soil in removing pollutants is limited to filtration. Not only is filtration important for removing suspended

particles from wastewater, but it is also the mechanism that retains microorganisms and facilitates biological treatment of dissolved and suspended organic matter. Even though the removal of suspended particles from water flowing through soils is easily observed, the processes involved are difficult to describe except in simple cases. McGauhey and Krone (69) discuss in detail the various mechanisms involved in the filtration process. The cases are: 1) straining at the soil surface, 2) bridging and 3) straining and sedimentation. There are also cases with cohesive particles. Sakthivadivel and Irmay (101) have reviewed the filtration theories extensively and the filter equation that has been presented for removal within the filter matrix.

Since the soil grain size is usually much larger than the molecular size of the ions related to pollution, filtering may not be effective (88). However, entrapped particles cause a filtering effect in excess of that provided by the soil. Soils with fine clay particles which provides pores small enough to filter contaminants do not allow the percolation of water. Conversely, soils that allow acceptable soil percolation rates for absorption systems are not too effective at filtering out pollutants.

Chemical Actions

Chemical actions in the soil which are effective in the removal of pollutants are adsorption and ion exchange.

Adsorption of a liquid on a solid phase is defined by Glasstone (40) as the concentration in the form of a film of molecules of a dissolved substance upon the surface of a solid. The surface of the liquid is in a state of strain and that of the solid has similarly a residual field of force; there will be, consequently, a tendency for the free energy of any surface to decrease and it is this tendency that is ultimately responsible for the phenomenon of adsorption. In ion exchange, the cations and anions pass between the liquid and solid phase. Adsorption is dependent upon the available surface area of the soils. Smaller soil particles have larger surface areas per gram of soil and consequently can adsorb certain nitrogen compounds and ABS contaminants to a greater degree. The soils are limited, however, by percolation rates or the amount of contaminant bearing water to which they can be subjected. The rate of adsorption according to Joyce and Sukemik (52) is a linear function of the square of the concentration, i.e., the greater the fraction of the solute adsorbed per unit of time, the more dilute the solution, which implies that the process favours the removal of trace quantities. Hajek (42) has illustrated the methods that soil scientists have employed successfully to predict the assimilative capacity of the soil for chemically contaminated wastewater. He has also characterized those chemical interactions which are likely to be important under the above circumstances.

Biological Actions

Most of the soil bacteria and therefore the biological action is in the upper 2 feet of the soil in the zone of higher oxygen content. There are three principal methods for reaeration of soil: a) dissolved air carried into the soil by the percolating water, b) the hydrodynamic flow of air resulting from the "piston-like" movement of a slug of water through the soil and c) diffusion of air into the soil body when there is no standing or ponded water on the ground surface. Strictly speaking, the biochemical soil system is not concerned with air in general but rather with the exchange of oxygen and carbon dioxide, the two principal gases involved in aerobic stabilization. The diffusion of oxygen through the soil system is discussed in detail by Pincince and McKee (87) and by McMichael and McKee (74). The oxygen content of the soil gases decreases with increased depth below the soil surface and the carbon dioxide content usually increases. Under wet conditions, a silt loam soil was reported by Preul (78) to be anaerobic at a depth of 6 feet with gas containing 15.5% CO_2 and 0.2% O_2 . For the same soil at 2 feet depth, the gas had an oxygen content of 11.6% and a CO_2 content of 2.4%. In the case of septic tank effluent applied at about 2' below ground level, soil reaeration could occur only by the process of molecular diffusion of oxygen from the atmosphere, through the soil, as the septic tank effluent will have practically no dissolved

oxygen. The oxygen content of the soil near a soil absorption system is adequate to sustain the presence of nitrifying bacteria, Nitrosomonas and Nitrobacter and Preul (93) found that they are so effective that within a few feet from the soil absorption trench, the nitrogen was nearly all in the form of nitrate.

2.6.7 Water Quality Changes in Soil System

Typical septic tank effluent characteristics are presented in Table 8. These indicate the composition of the liquid overflowing the tank and entering the soil absorption field. Van Kleck (120) reported that the average total suspended solids (TSS) entering an individual septic tank system is about 150 mg/l. About 50-60 percent of the TSS are removed in the septic tank itself as seen from the average figures in Table 8. A large fraction (75-85%) of suspended solids is volatile. Influent BOD to septic tanks usually ranges from about 150-325 mg/l (86, 46). Typically, very little BOD reduction occurs in the septic tank because of its anaerobic nature and short detention time. Reductions in BOD of 25-50% are characteristic (46). Table 8 indicates average effluent BOD concentrations of 90-130 mg/l. Other features of the tank effluents are zero dissolved oxygen, high inorganic ion content and high coliform counts. Significant quantities of nitrogen and phosphorous compounds are also released from septic tanks. Quality changes that occur

Table 8. Average Composition of Septic Tank Effluent

Parameter	Preul (1965)	Robeck et al (1964)	Polkowski & Boyle (1970)
Total Susp. Solids, mg/l	40	46	74
Vol. Susp. Solids, mg/l	—	36	60
BOD ₅ , mg/l	130	90	102
Dissolved Oxygen, mg/l	0	—	—
pH	7.0-7.5	7.5-8.1	—
Alkalinity, mg/l	300	400	—
Organic Nitrogen, mg/l	10	5.4	16.2
NO ₂ -N, mg/l	0.003	0.008	.065
NO ₃ -N, mg/l	0.15	0.11	0.13
NH ₃ -N, mg/l	25	22	14.0
Phosphates*, mg/l	20	—	—
K, mg/l	10-15	—	—
Na, mg/l	100	—	—
Sulphates, mg/l	50	—	—
Chlorides, mg/l	70	75	43.0
Coliform Bacteria/ 100 ml	—	5 million	93 million

* As P

during the passage of the wastewater through the soil with respect to specific pollutants (chemical and microbiological) are discussed below.

Bacteria and Viruses

Bacteria and other microorganisms present in excreta, pass easily through the septic tanks and into the soil around the absorption field. These microorganisms are not capable of migration, but are carried along by the liquid flowing through the soil (20, 113). In a new soil absorption bed, the transport of microorganisms through the unclogged soil may be rapid and quite far. Restriction of transport in new systems is due primarily to the straining action of the soil, and possibly to adsorption of bacteria on the soil particles (16). As the soil becomes clogged with the sewage solids over a period of use, the transport of sewage microorganisms becomes more restricted (21). The survival period for these organisms in nature and the distance to which they can be transported in soil, based on the work of many investigators, as summarized by Patterson et al. (85), are shown in Tables 9a and 9b. The distance of travel depends upon the porosity of the soil and the rate of ground water flow. Malin and Snellgrove (75) reported that, in clay, coliform bacteria were not found below 2 feet of soil. In more permeable soils, coliform bacteria were observed at greater depths.

Table 9a. Distance of Travel of Microorganisms

Type of Organism	Distance Transported, ft.		Investigators
	Vertical	Horizontal	
E. coli		232	Warrick and Muegge, 1930
E. coli	10-30		Mom and Schaafama, 1933
E. coli		80	Caldwell, 1937
E. coli		400	Dappert, 1932
Coliform bacteria		10-400	Miller et al, 1957
Coliform bacteria	2-3		Malia and Snellgrove, 1958
Coliform bacteria		180	Randall, 1970
Coliform bacteria	150		Hickey and Duncan, 1966
Clostridium welchii	7-8		Hickey and Duncan, 1966
"Lactose Fermenters"	2.5	2.0	Ciovanardi, 1938
"Bacteria"	6	1.5	Szoplak and Milkowska, 1961
"Bacteria"		2000	Walker, 1969

Table 9b Time of Survival of Fecal Bacteria

Type of Organism	Survival Time			Investigators
	Septic Tank	Soil	Other	
Salmonella typhosa			52 days	Caldwell, 1933
Salmonella typhosa			165 days	Warrick & Muegge, 1930
Salmonella typhosa	27 days	25-41 days		Beard, 1938
Salmonella typhosa	24 days			Green & Beard, 1938
E. coli			2 yr. 8 mo.	Warrick & Muegge, 1930
E. coli		2 yr.		Mom & Schaafama, 1933
Coliform bacteria		3 months		Malin & Snellgrove, 1958
Coliform bacteria		4-7 days		Subrahmanyam & Bhaaskaran, 1950

It is agreed that there is a gradual die off of bacteria with time. Table 9b shows that fecal organisms may survive for quite long periods in the septic tank and the soil, during which time, they may be transported by ground water movement over relatively long distances. As the bacterial concentration in septic tank effluent is quite high, large quantities of fecal organisms are carried each day into the soil absorption field. The data presented by McMichael and McKee (74) showed that the percolates at the two test basins under investigation contain sizeable concentrations of coliform organisms, an almost complete absence of fecal coliforms and measurable but low concentrations of fecal streptococci.

Viruses

More than 100 kinds of viruses are known to be excreted by man and approximately 70 of these have been found in sewage. Those that appear to be transmitted through wastewaters are the enteroviruses poliomyelitis, coxsackie and infectious hepatitis. There are a limited number of studies of the movement of viruses through granular media. Field tests were conducted by Merrell et al. (77) at the Santee Water Reclamation Project near San Diego, California, for the purpose of evaluating the treatment used to upgrade municipal sewage for recreation purposes. The treatment included an activated sludge plant followed by an oxidation pond with a

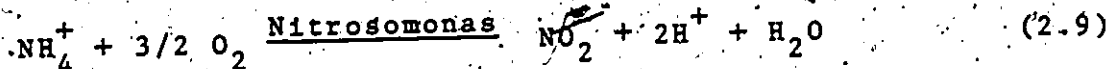
retention time of 20 to 30 days. The effluent of the oxidation pond was discharged into percolation basins and allowed to travel 1,500 feet through sand and gravel, overlaying a clay stratum, to a collection ditch. The ditch water was chlorinated before the water was used for recreational lakes. Mass immunizations against polio were being made at the time and there were high concentrations of polio viruses in the sewage. Viruses could be found in the effluent of the activated sludge unit, but none were found in the effluent of the oxidation pond. In order to test the efficacy of the percolation beds, a high concentration of poliomyelitis viruses was added directly to one of the percolation ponds. The average velocity of water flow through the aquifer was estimated to be 100 feet per day. Samples were collected from observation wells located 200 feet and 400 feet down flow from the bed and from the ditch for a two-month period. No viruses were found. Eliassen et al. (32) developed tracer and analytical techniques for bacterial viruses and studied their movement through five soils under saturated flow conditions. The removal of virus from percolating water was found to be due to sorption on the soil particles. Soils having a higher clay content sorbed virus more rapidly than those with less clay. Prolonged application of high concentration of viruses to even clayey soils will eventually result in a breakthrough of organism. There is very little information on virus removal during unsaturated flow. Filmer

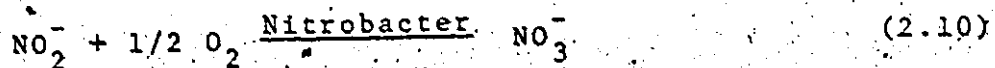
and Coree (34) investigated the removal of virus size albumin particles through partially saturated soil. They found that soils with a higher clay content provided better removal and that decreasing the degree of water saturation of the soil increased the retention capacity. Studies by Laak (56) showed that soil columns of medium sand, garden soil and sandy loam transferred recoverable polio virus-3 until the initial fluorescein sodium dose was diluted to about $1:10^4$ for each type of soil. Virus titres were diminished mainly because of dilution. His studies also showed that polio virus-3 was recovered from sample cores in the sand columns after the infectivity of virus in the column effluents was undetectable. Studies at Whittier Narrows (74) indicated the following results: (a) Though viruses (Polio type III and type I) were identified and enumerated in the settled sewage sample (82 PFU/800 ml) and in the activated sludge effluent (202 PFU/800 ml), no enteric viruses were detected in 800 ml of the sample of water that had percolated through two feet of soil. b) The results of virological assay on samples from the test basin (2 ft and 4 ft) showed no viruses in one litre, during August 1964 and Feb.-March 1965. c) After adding virus (1011PFU) Sabin Type III Poliovirus vaccine, to 191.1 cubic meters of effluent, none of the samples from the 2, 4, 6, and 8 ft pans after an interval of few hours to a few days (3 days) showed any entero-viruses in the dilutions tested.

Specific Chemical Contaminants

Nitrogen

Nitrogen compounds contribute to the problem of excessive growths in lakes and streams that may be fed by ground water; in addition one form - nitrate nitrogen - has a public health significance, as it is the cause of the disease "Methemoglobinemia" in infants. The two main factors affecting the movement of nitrogen compounds in soil are 1) adsorption-ion exchange phenomenon exhibited by the soils and 2) the action of the nitrifying and denitrifying bacteria. Most soils in nature possess a net negative charge which means that they have the capacity to attract and hold cations out of solution. The magnitude of this capacity depends on many variables including: soil type, pH, cation type and concentration, anions present, ions previously adsorbed, etc. As indicated earlier, most of the nitrogen in septic tank effluents is in the ammonia form. At normal effluent pH (less than 8.5) most of this is in the form of the ammonium ion, NH_4^+ . The combination of the negative charge on the soil particle and the positive charge on the ammonium ion lead to an efficient nitrogen fixing mechanism. However the nitrifying bacteria of most importance are Nitrosomonas and Nitrobacter. In a simplified form, microbial nitrification proceeds as follows:





The nitrate ion has a negative charge and therefore is not adsorbed to any appreciable extent by the soil. However it is very soluble in the percolating water and is therefore carried down to the ground water table where it is free to move with the ground water flow. Under anaerobic conditions some bacteria can utilize nitrates, along with organic carbon compounds as a source of energy. The end products of the reaction are molecular nitrogen, nitric oxide and nitrous oxide. Under the optimum conditions considerable quantities of nitrate may be removed from the percolating water through this process.

Preul (93) conducted a two-year laboratory and field study concerned primarily with the travel of the various forms of nitrogen in the ground water flow in the vicinity of sewage ponds and septic tank-soil absorption systems. Ammonia was found to be the predominant form of nitrogen in septic tank effluent wherein the values averaged 60 mg/l. The ammonia was rapidly converted to nitrate nitrogen and an average level of 2 mg/l was found at 100 feet from the source, when the background level of ammonia-N was 0.5 mg/l. Nitrate nitrogen which was found to be essentially zero with septic tank effluent was as high as 40 mg/l in the ground water at 20 feet from the absorption system. It was normally less than 10 mg/l at 100 feet from the source of pollution. The nitrate nitrogen background level was 0.1 mg/l. Preul and

Schroepfer (94) in a laboratory study with soil columns demonstrated that ammonium ion is strongly adsorbed by soil. Nitrate ion, on the other hand, was not readily adsorbed to the soil at normal pH values. Preul (93) found that biological oxidation was the dominant mechanism occurring in soil to reduce ammonia concentration and the oxidation occurred near the tile field. Studies by Polkowski and Boyle (88) indicated that the average ammonia nitrogen concentration in the septic tank effluent was 14.0 mg/l and the nitrate nitrogen was 0.13 mg/l. At a well located 15 feet downstream from the tile field, the concentrations had reversed in relative magnitude with the ammonia nitrogen dropping to an average of 1.34 mg/l and the average nitrate nitrogen concentration increasing to 7.0 mg/l. Figure 5 depicts a curve of average nitrate nitrogen concentrations versus distance from soil absorption systems based on the values reported by Preul (93) and Polkowski and Boyle (88). Though the soils were different and the ground water flow is unknown, it is interesting to observe that the reduction of nitrate nitrogen concentration in the ground water appears nearly the same. This may support the view that nitrate nitrogen is not adsorbed effectively by the soil and that dilution by the ground water is the major cause of the reduction of concentration. In a Minnesota study (89), Polta reported that a significant concentration of nitrate nitrogen was detected in the shallow ground water at a

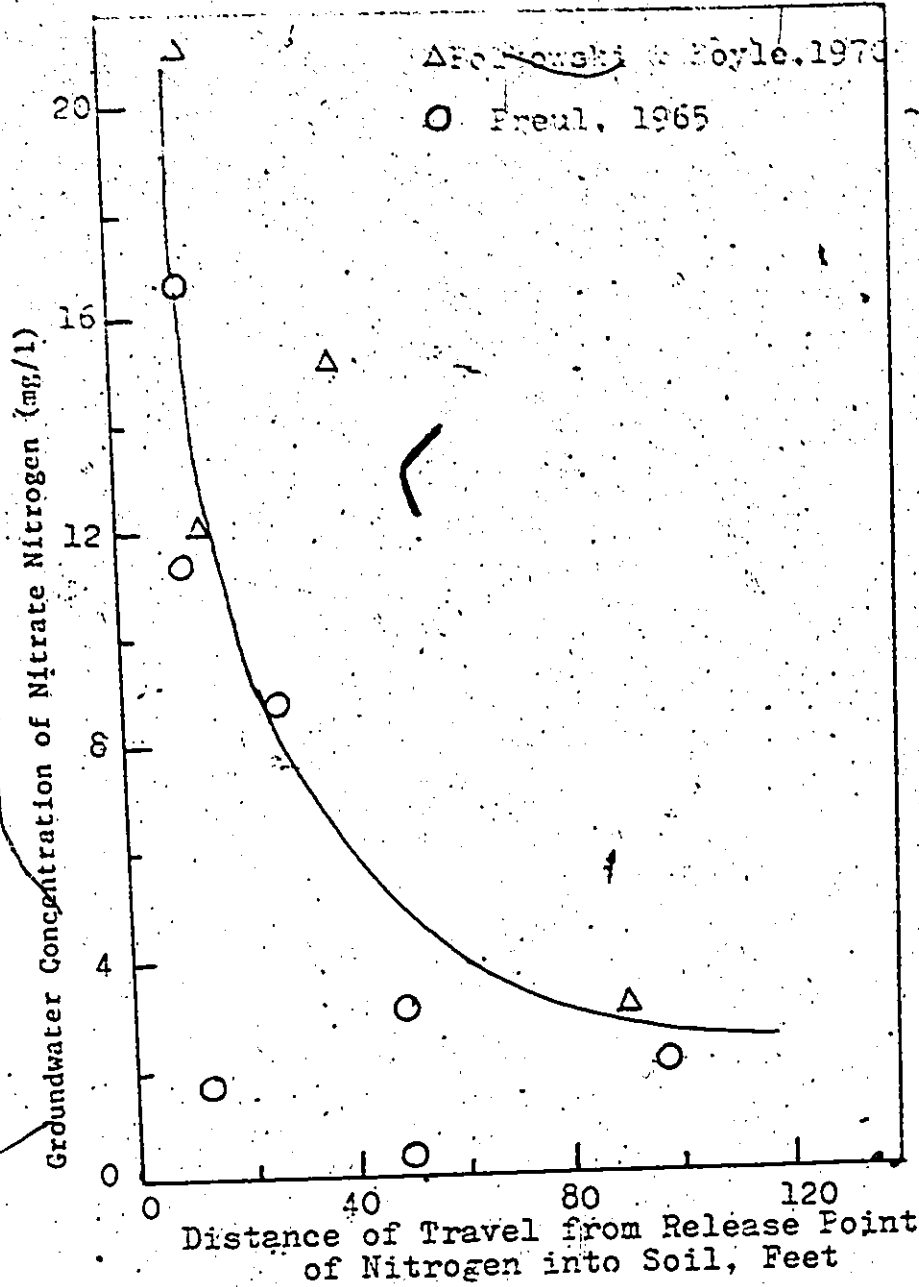


Fig. 5. Nitrate Nitrogen Concentration in Groundwater Downstream from Septic-Tank Soil Absorption Systems

distance of 140 feet downstream of the seepage pit. At a distance of 70 feet downstream, the $\text{NO}_3\text{-N}$ concentration was approximately 10 mg/l. The concentration close to seepage pit was about 30 mg/l. In the Pennsylvania study (84), Parizek et al found that the reduction of nitrate nitrogen concentration ranged from 68 to 82 percent in the upper 12 inches of the soil profile.

Phosphates

Many soils are capable of fixing large quantities of phosphorous making it not available to plants as a nutrient. The mechanism of phosphorous fixation is quite complicated. The processes include 1) adsorption, 2) replacement reactions, possibly involving changes in the mineral crystalline structure, and 3) precipitation reactions through which the soluble phosphates react with iron, aluminium or calcium to form insoluble compounds. The most important mechanism is adsorption by soil colloids. The phosphorous fixation capacity of soils have been reported to be as high as 8000 lb P/acre to a depth of 6 inches. The surface soils generally have the greatest fixing capacity; the capacity of the sub-surface soils is also high. Land having a high phosphorous fixation capacity, though not good for plant cultivation, is ideally suited for wastewater soil absorption systems in view of its capacity to remove soluble phosphates from the percolating water and prevent contamination of ground waters thus avoiding water pollution.

Polkowski and Boyle (88) in a study of septic tank absorption field drainage, found orthophosphate to be reduced from 5.15 mg/l in the septic tank effluent to 0.04 mg/l in a shallow well located only 15 feet downstream of the absorption field. These results agreed with the findings of a study conducted at Penn State University, (84) in which sewage effluent was applied to soil by spraying. Phosphates were found to be 99% removed in the top 12 inches of soil. In the study by Preul (93), phosphates in the septic tank effluent were found to be significantly removed upon entering the soil and at 100 feet from the source of pollution, the level of PO_4 dropped from 20 mg/l in the septic tank effluent to less than 1.0 mg/l. Similar results were reported in another study (95) by Preul, when he studied ground water contamination due to infiltration from waste stabilization ponds. Results of several field experiments cited by Stanford and Pierre (112) show no more than slight downward movement of phosphorous following surface applications of phosphate. Furthermore, a review of the results of lysimetry experiments by different workers over a period of 250 years cited by Bailey (5) show that only trace amounts of phosphorous had ever been found in the percolate. Mack (72) found that the amount of water-soluble phosphorous leached from a soil system increased with increase in temperature.

It is generally estimated that less than 20% of the phosphorous applied is utilized by the crop and the

remainder stays in the soil. The removal efficiency for some of the waste constituents, like phosphates, applied to a land disposal site does have a finite limit due to inherent site capacity. This time period, strongly dependent on concentration applied and soil type, might be many decades, but a finite limit does exist. These constraints would primarily apply to those compounds which depend on adsorption as a key removal mechanism.

Surfactants

Synthetic detergents at one time were considered to be serious soil and water contaminants. Klein and McGahey (54) reported in a study on septic tank removal of alkyl benzene sulfonate (ABS) that only 10% of the ABS entering the septic system was removed in the tank itself and this removal was due solely to adsorption. Suess (115) measured the adsorption of ABS on 10 different soil types by batch technique in laboratory tubes. The ABS concentrations were determined by the methylene blue test and a radioactive isotope S^{35} served as a tracer. The adsorption per gram of soil was found to increase with decreasing grain size, but the intensity of the ABS adsorption increased with increasing grain size. No soil was found to be completely covered by a monomolecular layer and the percentage of coverage was proportional to the grain size. ABS adsorption was found to be affected by mineralogical composition of the soil and adsorption was

higher in limestone than in sandstone. Since the introduction of biodegradable detergents such as linear alkylated sulfonate (LAS) in 1965, consideration of ABS data is appropriate only in so far as it indicates the extreme distances that nondegradable contaminants can travel through soil. ABS was shown to be in ground water up to 200 ft from the source of contamination (95). The biodegradable detergents such as LAS and sulfate esters of tallow and coconut oils were found by Klein and McGauhey (54) to be removed in septic tanks to the extent of 9-15% and 61-63% respectively. Because LAS is not degradable under the normal anaerobic conditions of a septic tank, only 0.6-2.5% of LAS removed was attributed to biodegradation. In contrast 40-43% biodegradation was reported for the sulfated natural oils. Provided that the soil absorption field is maintained aerobic, breakdown of LAS and the sulfated oil compounds in a complete way would occur in the soil. Polkowski and Boyle (88) confirm the rapid degradation in reporting low methylene blue active substances (e.g. detergents) in an absorption field ground water plume.

Chloride

Of the common chemical constituents in absorption field effluents, nitrogen and chloride are the most mobile. Chloride was frequently used earlier as a tracer of ground water flow. Dappert (28) reported chlorides to have travelled more than 1,500 feet. Miller (78) reported that chloride from

an oil field brine travelled 1,300 feet in one instance. Polkowski and Boyle (88) found chloride contamination easily detectable 250 feet down stream from a septic tank absorption field.

Other Chemical Characteristics

Easily-degraded organic compounds in the waste are indicated by BOD, COD and TOC. For a particular waste, a correlation can be established between the three. Both COD and TOC include organic fractions that cannot be easily degraded by aerobic organisms. The microbial life in the soil system is the major responsible mechanism for removal of BOD, COD, and TOC. Initial uptake of organic matter might be through adsorption and/or filtration but the metabolic processes of the organisms provide the final pathway. Significant removals of BOD and COD (80-90%) have been reported when septic tank effluent is allowed to percolate through sand columns (11, 99). Thomas and Bendixen (119) have reported that soil microorganisms digested about 80 percent of organic carbon from septic tank effluents and that large variations in temperature, the loading rate and duration of dosing, had no effect on the percentage of organic carbon degraded.

CHAPTER 3

EXPERIMENTAL SET UP AND STUDIES

3.1 Experimental Set Up and Instrumentation

3.1.1 Experimental Site

The experimental site is located in Cantley, Municipality of Touraine, Gatineau County, Province of Quebec, about 15 miles north of Ottawa. The site is located in a valley within the Gatineau Hills. The test site is situated between two small streams which cut through the valley. The site is about 30 feet higher in elevation than the streams and located about 200 feet south of one of them and about 400 feet north of the other. The soil map (59) of the region shows that the soil in this area is a mixture of Piedmont (sandy loam texture) and Portiac (silt loam to silty clay loam texture) soils and that the terrain is undulating land with steeply sloping banks, stone and outcrop-free.

A subsurface tile field system was already in operation at this site since June, 1970, treating the effluent from a septic tank of 1,250 gallons (imperial) capacity, receiving raw sewage from an individual household. It has 10 laterals, each 56 feet long. Five of these laterals were in use until June, 1973, when all the laterals were brought into use. Figure 6 shows the map of the site

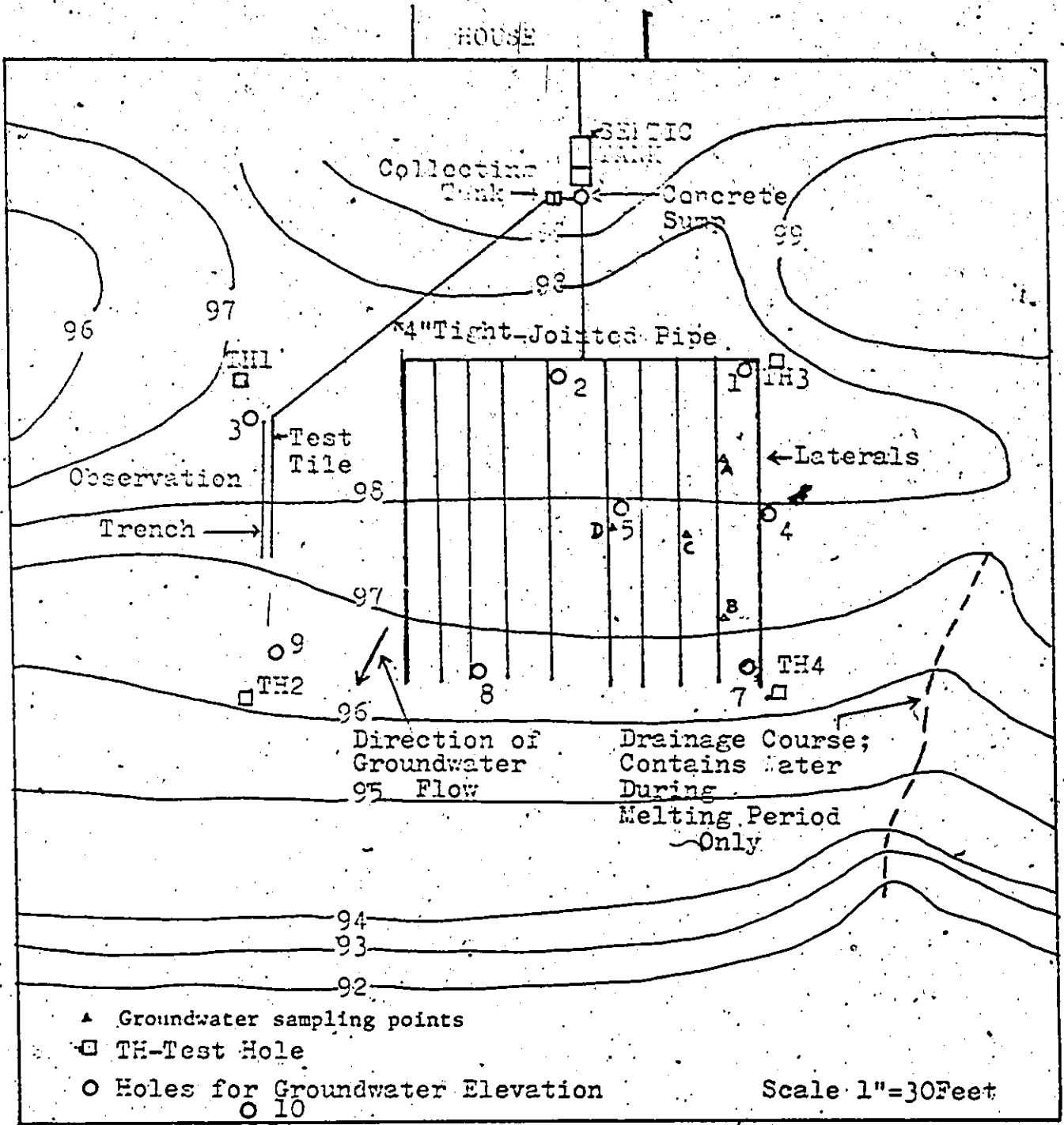


Fig. 6. Layout of Existing Tile Field and The Test Tile

with the existing tile field. It was decided to make a site evaluation before installing an experimental tile field at this site. The results of the site evaluation are discussed in the following paragraph.

3.1.2 Site Evaluation

A test pit 5 feet deep was dug near the proposed experimental tile field and soil samples from each foot depth were collected and grain size analyses by mechanical and hydrometer methods were carried out as recommended by Bowles (15). Grain-size distribution curves for the five samples taken at various depths are shown in Figs. A-1 to A-5 in Appendix A, page 240. A visual examination of the samples indicated that the soil is sandy clay for the initial depth of 2 feet, followed by clay with less sand at depths of 2 to 5 feet. D_{10} and D_{60} sizes and the uniformity coefficient ($\frac{D_{60}}{D_{10}}$) of the five samples are given in Table 10. The moisture content of the soil samples collected at various depths of 0 (surface), 1.0, 2.0, 3.0, 3.5, 4.0 and 4.5 feet were determined on a day in October, 1972, in the field by the calcium carbide gas pressure method described by Blystone et al (13). Results are shown in Table 11 and in Fig. 7. The moisture content was found to be between 20 and 30 percent at depths of 2 to 5 feet.

Four test holes were dug at the places shown in Fig. 6, and percolation tests were conducted as recommended

Table 10. Grain-Size Distribution Characteristics
of Soil Samples

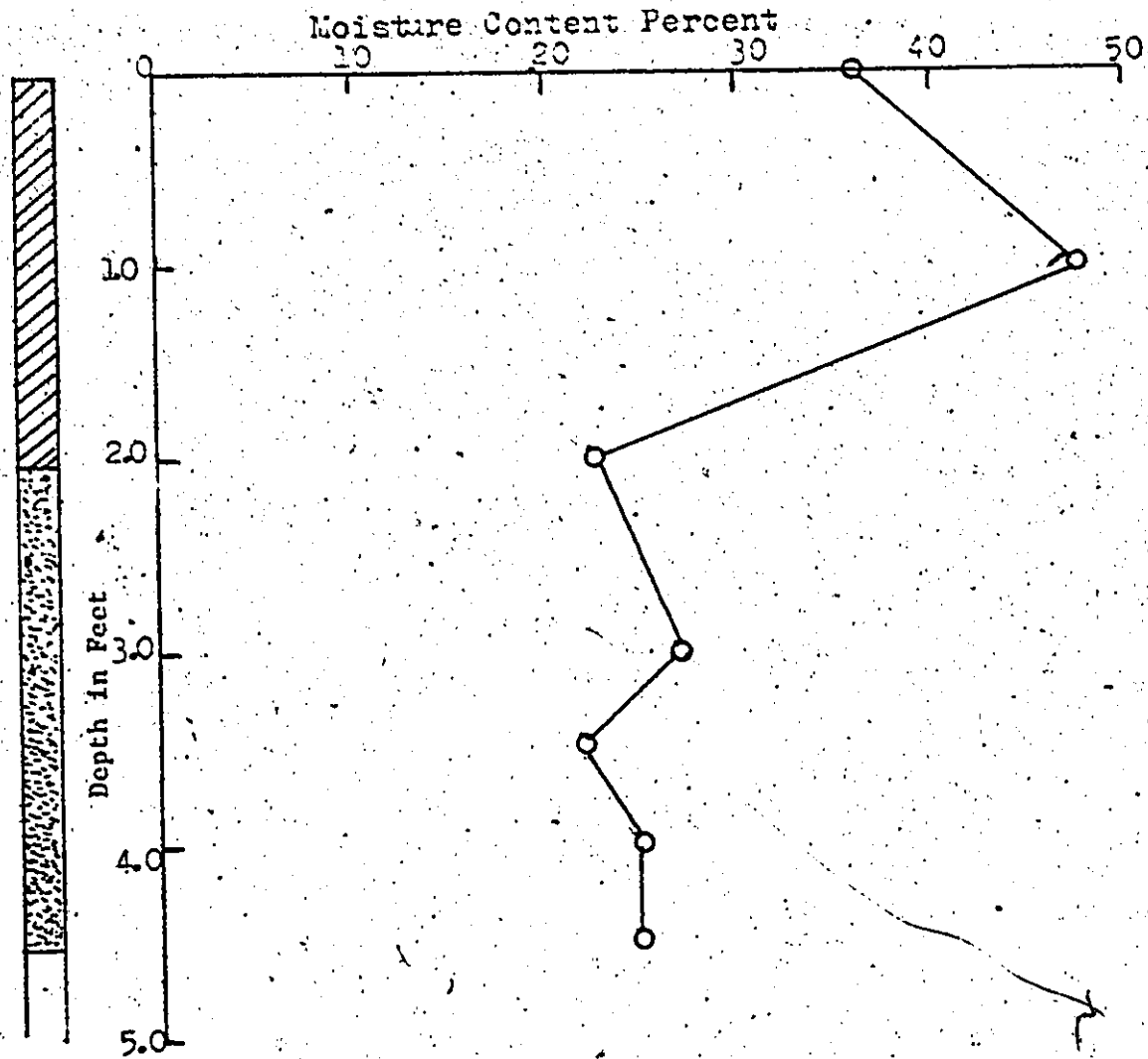
Sample Number	Depth of Collection feet	D ₁₀ size. mm	D ₆₀ size mm	Uniformity Coefficient $\frac{D_{60}}{D_{10}}$
1	0-1	0.0028	0.1100	39.2
2	1-2	0.0062	0.0510	8.2
3	2-3	0.0020	0.1000	50.0
4	3-4	0.0010	0.4100	410.0
5	4-5	0.0025	0.2000	80.0

Table 11. Moisture Content of Soil at Various Depths

Date: 25.10.72

Depth in feet	Moisture Content	
	Percent of wet wt (w')	Percent of dry wt (w)
0.0	26.6	36.4
1.0	32.4	48.0
2.0	18.6	22.8
3.0	21.2	27.0
3.5	18.0	22.0
4.0	20.2	25.2
4.5	21.4	25.0

Note: $w = \frac{w'}{(1 - \frac{w'}{100})}$



Note:



Sandy Clay

Clay with very little Sand

Fig. 7. Moisture Content at Various Depths
(25-10-72)

in the "Manual of Septic Tank Practice" (76). The percolation test details are given in Appendix A (Table A1, page 240). The percolation rate (time in minutes for water to drop 1 inch) was calculated by the usual method and by the method of Ludwig and Ludwig (63) and details are furnished in Appendix A (Table A2 and Figs. A6 to A9, page 240). The percolation test results are furnished in Table J2. Test holes 1 and 2 lie on both ends of the experimental tile field, with soils showing relatively differing percolation rates.

Information obtained on the ground water level at the site indicated that the water level fluctuated between near ground level condition during spring snowmelt period to a depth of 8 to 10' during late summer and early fall periods. Ground water level observations made at the site as part of information on the environmental conditions at the site are discussed later in this chapter and the data are furnished in Chapter 4. Some observations of ground water level in boreholes at the site indicated tentatively that the movement of ground water was from north to south. Further measurements of ground water elevations and also of the permeability of the soil were carried out subsequent to the initial site evaluation. Ground water level elevations were taken at various locations on May 16, 1974, and the elevations are shown in Table 13. The locations are shown in Fig. 6 (page 67). It may be seen that the groundwater movement was in a northeast to southwest direction, as indicated in Fig. 6.

Table 12. Percolation Test Results

Test Hole No	Percolation Rate*		Allowable Rate of Sewage Application gpd per sq.foot
	By usual method	By the method of Ludwig & Ludwig	
1	12	12	1.40
2	56	56	0.70
3	15	15	1.30
4	11	12	1.5

* Time in minutes for water to drop 1 inch.

Table 13. Groundwater Elevations at Various Points
at the Site (16-5-74)

Location	Ground level	Depth to water level from ground		Groundwater Elevation
		inches	feet	
1	97.96	25.0	2.08	95.88
2	97.88	-	-	-
3	96.86	-	-	-
4	97.36	17.5	1.46	95.90
5	97.46	23.0	1.92	95.54
6	96.18	17.5	1.46	94.72
7	96.55	9.0	0.75	95.80
8	94.44	0.0	0.00	94.44
9	95.08	13.5	1.12	93.96
10	84.80	8.0	0.67	84.13
11	81.04	12.0	1.00	80.04

For permeability tests, two-inch diameter undisturbed samples were taken vertically from the bottom of a two-foot deep test pit as well as horizontally into the sides of the pit using five-inch long tubing. The permeability tests were done using the sample tubes as permeameters, with a constant head of water. Two vertical and two horizontal samples were collected and tested for permeability. Calculations were done on the lines indicated by Bowles (15). The results are given in Table 14. The horizontal permeability is found to be 60 times greater than the vertical permeability. Though the horizontal permeability could be expected to be greater in sandy clay soils, the greater margin may be due to the fact that the vertical samples penetrated a layer between 2 feet and 2 feet 6 inches while the horizontal samples were taken at the two feet layer; the soil characteristics differ somewhat beyond the 2-foot depth.

A bailing test was also conducted by digging a test pit 2 feet square and 2 feet deep. The water level was lowered by bailing and the rate at which it rose was measured. Calculations for permeability were made on the lines suggested by Healy and Laak (44) based on conventional well theory. The radius of drawdown was assumed equal to ten times the effective radius of the test pit. The approximate depth to impermeable strata in this case was 90 feet. These calculations for permeability are shown in Fig. A-10.

Table 14. Permeability of Soil Samples Taken
at 2' 0" Depth

Sample description	Permeability	Arithmetic mean permeability
Vertical sample 1	1.1×10^{-6} cm/sec	
Vertical sample 2	3.4×10^{-5} cm/sec	1.8×10^{-5} cm/sec or 3.6×10^{-5} ft/min
Horizontal sample 1	1.8×10^{-3} cm/sec	
Horizontal sample 2	4.0×10^{-4} cm/sec	1.1×10^{-3} cm/sec or 2.2×10^{-3} ft/min

(Appendix A, page 240). The calculated value of permeability was 2.6×10^{-5} ft/min which is comparable to the vertical permeability obtained through laboratory experiments.

3.1.3 Field Experimental Installation

The septic tank effluent discharged at the top of a vertical one foot diameter concrete sump, with an outlet pipe at the bottom 2' below which is connected to the existing tile field system. It was decided to divert a portion of the septic tank effluent at this small sump for experimental purposes. A 90° bend was fitted to the effluent pipe at its entry point into the vertical sump; a slit one inch wide and three inches long was made at mid depth in the middle length of the bend, so that the flow not diverted for experimental purposes fell into the sump to discharge into the existing system. A horizontal pipe was fitted to the other end of the bend and this pipe discharged into the farther compartment of a two-compartment collecting tank. Figure 8 shows a sketch of the arrangement. Each compartment had internal dimensions of 46-3/4 inches wide and 35 inches long with a depth of 33 inches. Only the farther compartment was used for collecting the effluent, in this study. Higher loadings could be adopted by removing the partition between the compartments thereby making use of the capacity of both the compartments. One-foot depth of effluent in this collecting chamber was equivalent to 71 imperial gallons. The horizontal

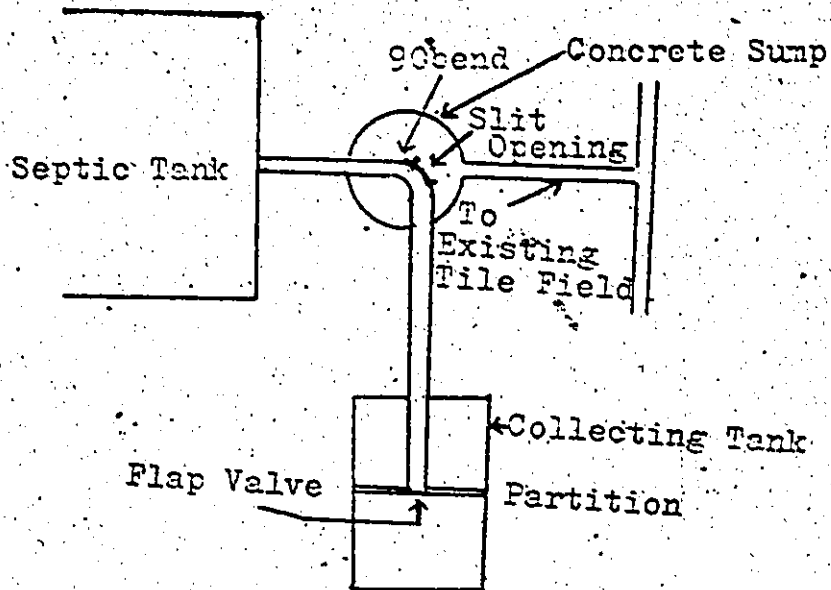


Fig. 8. Arrangements for Diverting Septic Tank Effluent.

entry pipe to this collecting chamber was fitted with a flap valve that was operated by a vertical sliding mechanism. The method of operation was to close the flap valve after a particular depth of effluent was collected in the collecting tank, so that the remainder of the flow passed on to the existing system through the slit in the bend located in the vertical sump. The outlet from the tank was fitted with a valve for controlling the flow into the experimental tile field. Figure 9 shows a photograph of the collecting tank and the control valve. A tight-jointed 4-inch pipeline 80 feet long conveyed the effluent from the collecting tank to the beginning of the test tile which was about 25 feet away from the nearest existing lateral. The experimental tile was 4-inch diameter, 26 feet long and open jointed with perforations. The installation followed closely the specifications laid down in the "Manual of Septic Tank Practice" (76). The details of the test tile arrangement are shown in Fig. 10. The salient levels of the various pipe arrangements are given below:

Invert level of septic tank outlet - 97.92
Invert level of outlet from collecting tank - 95.48
Invert level of the tile (north end) - 94.88
Invert level of the tile (south end) - 94.80
Ground level (north end) - 97.41
Ground level (south end) - 96.54

There was a drop of 0.60 feet in the 80 foot length of tight

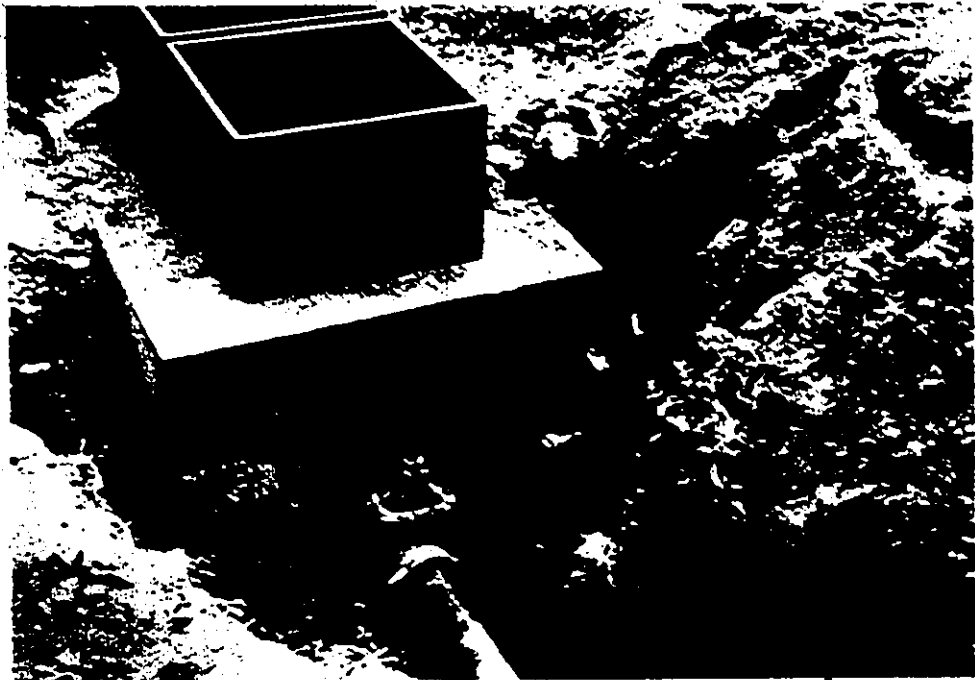


Fig. 9. Collecting Tank and Control Valve.

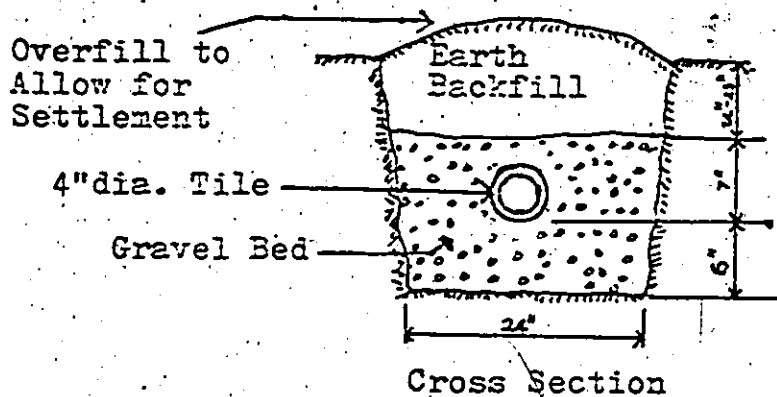
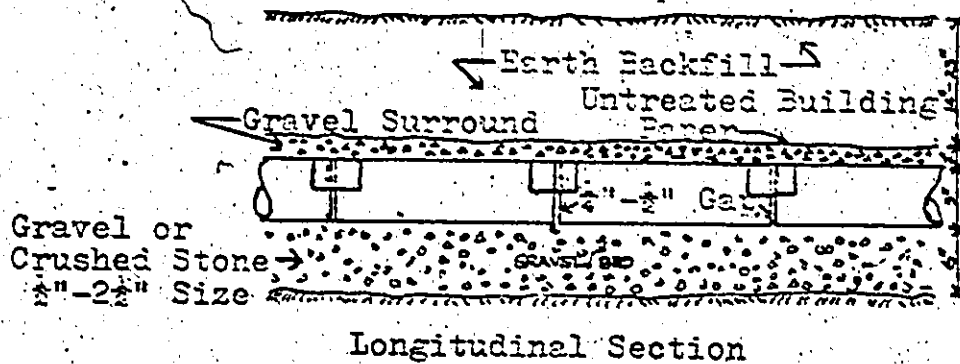


Fig. 10. Details of Test Tile

jointed pipe, sufficient for the flow conditions contemplated. The test tile had a drop of 0.08 feet or about 1 inch in a distance of 26 feet following the usual practice of allowing 4 inches per 100 feet. The ground level at the site sloped 0.87 feet over 26 feet. The invert level of the tile at the northern end was 2.53 feet below ground level and the invert level of the test tile at the southern end was 1.74 feet below ground level. The test tile was at an average depth of 2.13 feet or 26 inches below the ground level.

The test tile trench was 2 feet wide and graded gravel (1/2" to 2-1/2" size) was spread for a depth of 6 inches below the tile and for a depth of two inches above the top of the tile. The top of the stone layer was covered with untreated building paper and the trench backfilled with earth. Figure 11 shows a photograph of the test tile trench with the tile placed on gravel during construction.

A parallel observation trench 30 feet long, 2 feet wide and 6 to 8 feet deep was constructed 2'6" from the test tile trench. Shoring and strutting of the trench were done to prevent its collapse especially at periods of high groundwater level during spring snowmelt. The observation trench was covered on the top by boards and an opening with a removable cover was left at the southern end for getting inside the trench for collecting percolates from lysimeters and for collecting groundwater samples. The observation trench was required in connection with the installation of



Fig. 11. Test Tile on Gravel Bed During Construction

lysimeters and for collecting the percolate obtained through the lysimeters. The original idea was to install twelve zero-tension lysimeters, three each at depths of 2 feet, 4 feet, 6 feet and 8 feet in order to collect the percolates. However, after constructing the trench, it became difficult to install all these due to high groundwater level and so it was decided to install seven zero-tension lysimeters at depths of 2' 0", 3' 6" and 4' 6" only as shown in Table 15.

Choice of the Lysimeter, Its Preparation and Installation

Lysimeters are usually used for field collections of soil water, but all lysimeters are reported to have certain limitations (55). A lysimeter, which combines the advantages of several types of lysimeters, was developed and described by Jordan (51). This lysimeter is essentially of the Ebermayer type. The basic lysimeter is a 2x12 inch stainless steel trough. Simple troughs fail to collect a portion of the water since water tends to cling to the surface of the installation tunnel rather than drip from the top; unless the edges of a lysimeter trough are in firm contact with the soil for the entire perimeter of the trough, water will tend to run out through spaces between lysimeter and soil. To overcome this problem, a fibreglass screen lined with glasswool is suspended inside the trough and soil is tamped on top of the screen until the soil is even with the top of

Table 15. Location Details of Lysimeters

Lysimeter Number	Distance from northern end of trench, in feet	Depth from ground level in feet	Penetration into side wall in inches
1	2.0	2.0	19
2	4.0	3.5	24
3	6.0	4.5	22
4	9.0	2.0	30
5	11.0	3.5	20
6	16.0	2.0	26
7	18.0	3.5	18

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the trough. Thus, this lysimeter is designed to eliminate the surface tension that occurs when water moving through the soil meets an interface at the screen. This lysimeter is therefore called a "Zero-Tension" lysimeter. Zero-Tension lysimeters manufactured by New Jersey Scientific Supply Co. Incorporated were used in the investigation to collect the percolates seeping from the test tile. A photograph of the zero-tension lysimeter and supporting wedges is shown in Fig. 12. Figure 13 shows a perspective view of the zero-tension lysimeter.

Lysimeters were positioned in tunnels dug laterally from the observation trench. The tunnels extended from the same observation trench and these were located in such a way that they were at least 18" apart horizontally and were not directly above each other. To insure complete drainage of the trough, the top of the tunnel was sloped slightly downward towards the pit as shown in Fig. 14.

The screening inside the lysimeter was lined with a blanket of glasswool approximately 1/8" to 1/16" thick. The glasswool prevented the soil from falling through the screen and also improved the wetting characteristics of the screen. The glasswool was trimmed neatly along the edges of the lysimeter. The cradle-like space inside the lysimeter (on top of the glasswool) was filled with soil removed from the tunnel. The soil was tamped down so that it was even

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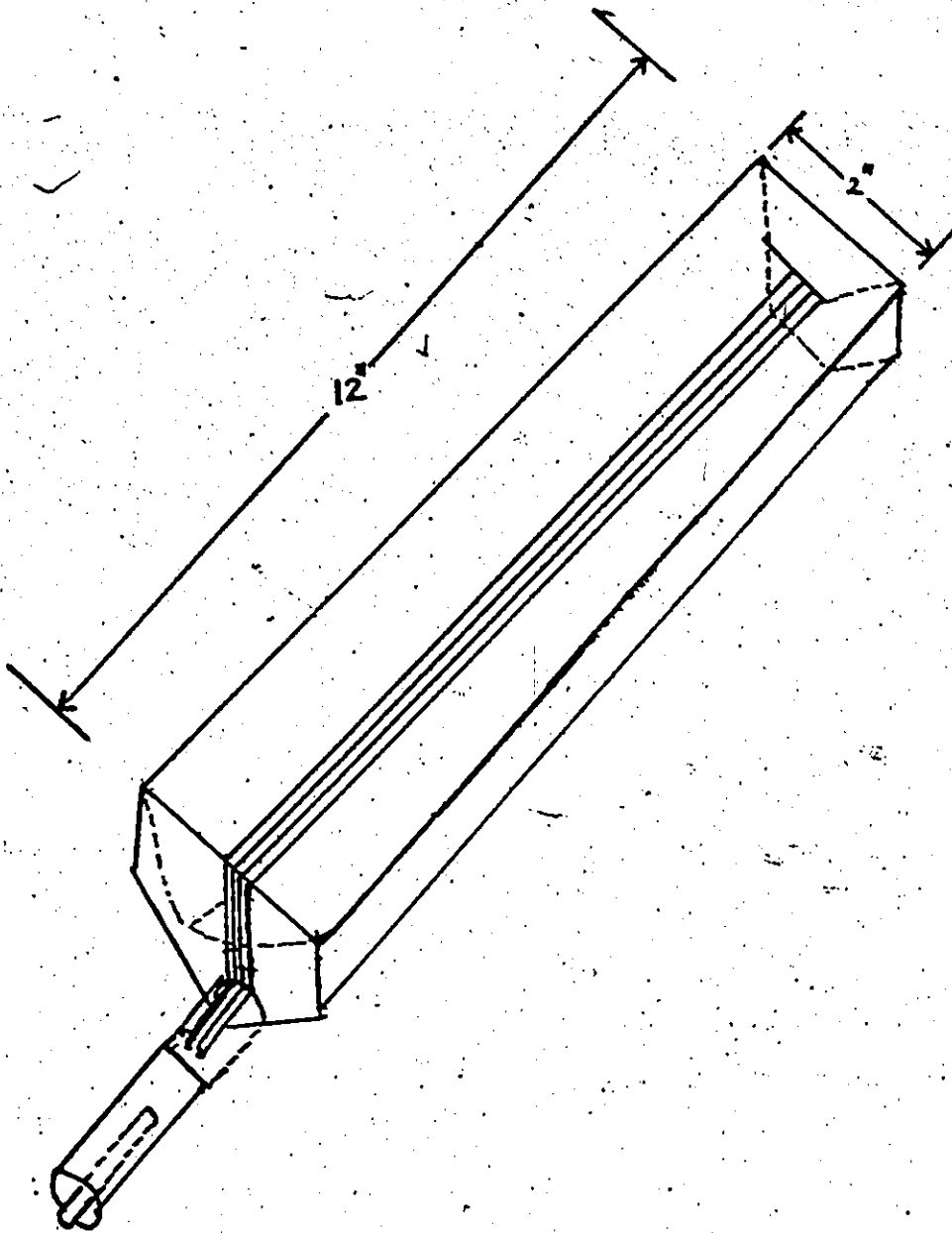


Fig. 13. Perspective View of the Zero-Tension Lysimeter



Fig. 14. Cross Section of Trench and Tunnel

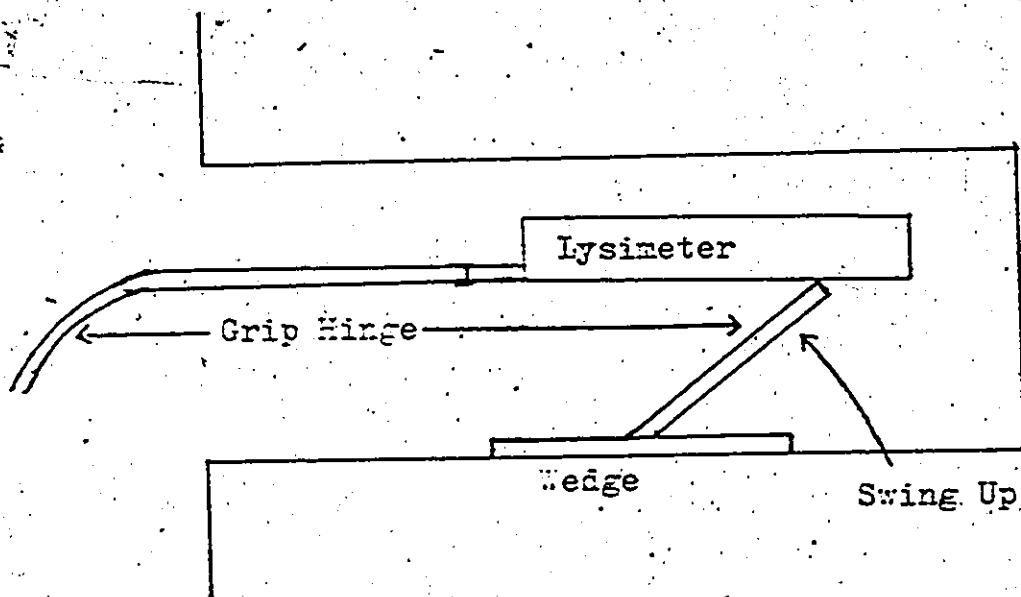


Fig. 15. Bracing of Lysimeter

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CORPORATION, FORT MONMOUTH, NEW JERSEY

with the top of the lysimeter. The wedge was adjusted so that it was the right height to support the trough firmly against the top of the tunnel. Then the wedge was laid in the folded position so that it can swing upward and towards the entrance of the tunnel (Fig. 15). To complete the installation the wedge was gripped as shown by reaching into the tunnel with one arm. The collection tube was held with the other hand so as to balance the lysimeter on top of the wedge. The swinging portion of the wedge was gradually pulled outward until the lysimeter was wedged firmly against the roof of the tunnel. This insured firm contact between the soil in the trough and the roof of the tunnel. Lack of firm contact would result in malfunction of lysimeters while excessive upward force could cause the screen inside the lysimeter to break away from the trough. Once the lysimeter was firmly wedged in place, a check was made for holes between the lysimeter wall and the soil above by passing a finger around the upper edge of the lysimeter. The holes, if any, were filled by tamping in small lumps of soil. The tunnel was refilled by packing in the soil which was previously removed. A lysimeter installation usually took about one hour. The collection tubes led to sample bottles kept either at the bottom of the trench or hung from braces. Seven lysimeters were placed in position as described above at depths and distances indicated in Table 15 (page 85). Figure 16, is a photograph showing collection tubes from the lysimeters in the observation trench.



Fig. 16. Collection Tubes from the Lysimeter

3.2 Details of Experimental Studies

The various studies carried out during 1972, 1973 and 1974 are broadly classified under the following six categories:

1. Drinking water quality, water use, raw sewage and septic tank effluent characteristics and scum and sludge accumulation in the septic tank.
2. Lysimeter studies.
3. Groundwater quality investigations.
4. Collection of data on environmental conditions.
5. Studies conducted in relation to possible clogging of the experimental tile.
6. Other soil studies.

These are discussed in detail in the succeeding paragraphs.

3.2.1 Water and Wastewater Quality and Quantity and Septic Tank Effluent Quality and Sludge and Scum Accumulations in the Septic Tank

The household draws its drinking water supply from a tube well, sunk to a depth of about 90 feet. Analyses of sample water collected during two occasions were carried out to determine the following characteristics:

pH, total solids, total suspended solids (TSS), volatile suspended solids (VSS), fixed suspended solids, total organic carbon (TOC), total phosphates (PO_4-P), ammonia nitrogen (NH_3-N), nitrate nitrogen

(NO₃-N), total soluble iron, hardness as CaCO₃, chlorides, total coliform, fecal coliform, fecal streptococci, and Pseudomonas aeruginosa.

The analytical procedures for these parameters of interest are discussed in the latter part of this chapter.

Water used by the household during December, 1972, January, February, March, and December, 1973, was measured using a Neptune water meter. During this period, the number of toilet flushings each day was counted and recorded to estimate the quantity used for toilet flushing. Diurnal fluctuations in water use were also recorded for three different days.

Raw sewage samples were usually collected from the vertical pipe in the basement of the household leading to the septic tank. Composite samples were collected only on two occasions, as manual collection and compositing in the basement of the house could be possibly hazardous if it were to be done regularly. Hence, only grab samples of raw sewage were collected around 10:00 a.m. on eleven occasions during the period of investigation. The composite samples as well as the grab samples were analyzed for the following parameters:

pH, TSS, VSS, BOD, COD, TOC, PO₄-P, NH₃-N, NO₃-N, total soluble iron, chlorides, total coliform, fecal coliform, fecal streptococci, and Pseudomonas aeruginosa.

The analytical procedures for these parameters are discussed

in the latter part of this chapter. Four grab samples of raw sewage at different periods of the day were collected on one day, for analysis to determine the diurnal fluctuations in the chemical characteristics of raw sewage.

Grab samples of the septic tank effluent were collected around 10:00 a.m. on twenty different days during the period of investigation; the samples were collected from the pipe at the collecting tank after allowing the effluent to flow for some time. The samples were analyzed for the following parameters:

pH, TSS, VSS, fixed SS, BOD, COD, TOC, total PO_4 -P, NH_3 -N, NO_3 -N, total soluble iron, chlorides, total coliform, fecal coliform, fecal streptococci, and Pseudomonas aeruginosa.

Sludge and scum accumulations in both the compartments of the septic tank were carried out on three different occasions (30-10-72, 1-6-73 and 18-9-73). The scum and sludge-measuring devices were similar to those described in the "Manual of Septic Tank Practice" (76). Scum was measured with a stick to which a weighted flap was hinged. The stick was forced through the mat, the hinged flap fell into a horizontal position and the stick was raised until resistance from the bottom of the scum was felt. Measurements were made from the top of the tank wall for the top of the scum, bottom of the scum and the liquid level, to determine the floating, submerged and the total

scum. A long stick wrapped with rough, white towelling lowered to the bottom of the tank was used to get the depth of sludge and liquid depth of the tank. The sludge line could be distinguished by sludge particles clinging to the towelling. All measurements were again taken from the top of the tank wall.

3.2.2 Lysimeter Studies

The installation of the experimental tile and of the lysimeters was completed in November, 1972. The percolation test results for the test holes 1 and 2 (Table 12, page ~~50~~ Fig. 6, page 67) near the experimental tile, revealed that the allowable rates of sewage application were 1.40 U.S. gpd/sq.ft. and 0.70 U.S. gpd/sq.ft. respectively for the soils at test holes 1 and 2. It was decided to adopt an average rate of 1 (Imperial) gpd/sq.ft. This worked out to a loading of 52 gallons (Imp.) per day for the experimental tile bed 2 feet wide and 26 feet long.

The septic tank effluent required for loading the tile was collected in the collecting tank by opening the flap valve at the mouth of the inlet pipe. Measurement of the depth indicated the amount of effluent collected since one-foot depth of the effluent in the collecting tank was equivalent to 71 gallons (Imperial). An intermittent system of loading was adopted because it was found to be more beneficial by earlier investigators. The collected effluent

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each day was discharged to the system in 2 to 3 hours by adjusting the valve. This type of intermittent operation was continued from the start in December, 1972 to late June, 1973. Then it was found convenient to modify the intermittent loading pattern, loading the required amount in a day over a period of 2 to 3 hours, resting it for two days and loading it again. This pattern was generally followed with certain exceptions. A complete record of loading operation is furnished in Table B-1, Appendix B. The mean loadings of the experimental tile every month from December, 1972 to March, 1974 are shown in Table 16. It may be seen that the mean loading rate was between 45 and 65 gallons per day for most of the months with the exception of March, 1973, June, 1973, February, 1974 and March, 1974. In the case of March, 1973 and March, 1974, the loading was very low as it was discontinued for a greater part of the month due to high groundwater level. Higher loadings witnessed in June, 1973 and February, 1974 were due to accidental greater diversions. It was rather difficult to maintain the correct loading rate precisely due to manpower limitations essentially as the system was manually operated. The mean loading rate over the entire period of investigation worked out to 53.7 gpd.

As described earlier, seven zero-tension lysimeters were installed, three at 2' 0" depth, three at 3' 6" depth and one at 4' 6" depth. The loading of the tile started in middle of December, 1972. Percolates from lysimeters 3

Table 16. Mean Monthly Loading of the Experimental Tile

Month	Loading Imp. gallons per day	Remarks
December 1972	57.8	
January 1973	50.1	
February 1973	62.4	
March 1973	18.8	No loading from 12.3.73
April 1973	50.4	No loading till 11.4.73
May 1973	50.2	
June 1973	90.3	
July 1973	63.2	
August 1973	45.9	No loading from 16.8.73 to 23.8.73
September 1973	57.9	No loading from 10.9.73 to 19.9.73
October 1973	60.0	
November 1973	58.0	
December 1973	61.4	
January 1974	44.0	No loading from 6.1.74 to 10.1.74
February 1974	79.5	
March 1974	10.0	No loading from 6.3.74

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(4'6" depth) and 7 (3'6" depth) were collected in early January, 1973. The groundwater level in the observation trench in the months of January (latter part) to May, 1973 was quite high, with mean values between 15 and 24 inches from ground level. This made collection of any percolate sample virtually impossible due to the height of water in the observation trench. Also percolate samples had no meaning during these months, as most often the groundwater level was either very close to the tile or above it. When the groundwater level receded in the month of June, 1973 and thereafter, attempts were made to collect the percolates from the lysimeters. There were no percolates in the sample bottles during June, July and August, 1973. Percolates were collected twice in September, 1973, once in October, November and December, 1973 and again in January and February, 1974. The collection details are shown in Table 17. It may be seen that no sample was collected from lysimeters 1 and 4 (2'0" depth) during the entire period of investigation. Only one sample was collected from lysimeter 2 (3'6" depth) and four samples were collected from lysimeters 3, 5 and 6, while three samples were collected from lysimeter 7. In all, 16 samples were collected. The collection pattern appeared to be quite erratic, though it was not unexpected. The percolates from the lysimeters were analyzed for the following parameters:

pH, TSS, VSS, fixed suspended solids, BOD, COD, TOC,

Table 17. Collection Details of Lysimeter Percolates

Date of Collection	Lysimeter Numbers						
	1	2	3	4	5	6	7
4- 1-73							x
11- 1-73			x				
18- 9-73			x		x		
27- 9-73			x		x	x	x
11-10-73			x		x		
29-11-73					x		x
18-12-73						x	
30- 1-74		x				x	
21- 2-74						x	

x - indicates collection.

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total $\text{PO}_4\text{-P}$, $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, total soluble iron and chlorides.

Bacteriological examination of the samples were not carried out, as it was felt that it would not be possible to leave a sterile collecting tube each time. Also the long time taken for accumulation of each sample would leave collecting tubes with bacterial growths, vitiating results by sudden flushings. Procedures for analysis are discussed in the latter part of this chapter.

3.2.3 Groundwater Quality Investigations

Due to the rapid rise in the groundwater level in the observation trench soon after completion of the installation, it was possible to collect only a few samples of percolates in the early stages. It was decided to analyze the groundwater samples in the trench periodically from the start of loading of the experimental tile in order to determine the fate of the pollutants under adverse groundwater conditions. Groundwater in the trench was also analyzed before the start of loading of the tile to find the background concentrations. The groundwater samples were collected and analyzed continuously for nearly every week from the start of loading in December, 1972 till the end of July, 1973 for a period of 9 months until the groundwater level dropped below the trench bottom level (65" below ground). The samples were again collected and analyzed once every month

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from December, 1973 through March, 1974 after the level rose in December, 1973. These groundwater samples were analyzed for these parameters:

pH, TSS, VSS, fixed SS, BOD, COD, TOC, total PO_4 -P, NH_3 -N, NO_3 -N, total soluble iron, chlorides, total coliform, fecal coliform, fecal streptococci and Pseudomonas aeruginosa.

An investigation was carried out to examine the horizontal travel of BOD, COD, TOC, NH_3 -N, NO_3 -N, total PO_4 -P, total soluble iron, chlorides and bacterial indicator organisms down slope from the end of the test tile in the general direction of the groundwater flow. This was done in May and June, 1973 after about 6 months of loading the septic tile to allow enough time lag for pollutants to reach the sampling point 50 feet away. Groundwater samples were collected on these two occasions at distances 10, 20, 30, 40 and 50 feet from the end of the septic tile in addition to the sample from the trench.

Groundwater samples at four locations by the side of three laterals (2, 3 and 5) of the existing tile field system (Fig. 6, page 67) were collected during the summer of 1973 for chemical and bacteriological analyses. The existing system had been in operation for three years, when these samples were collected. The parameters analyzed are those already indicated.

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3.2.4 Collection of Data on Environmental Conditions

The environmental factors considered in this study were air and soil temperatures, snow cover and un-saturated depth of soil.

Air Temperature

Air temperature measurements at the site between December, 1972 and May, 1973 were made using a direct recording hygrothermograph. The air temperatures during summer went beyond 70°F and the equipment was not able to record temperatures beyond 70°F. Hence temperature data was obtained from the Weather Office, Ottawa for the period of the study from June, 1973 to March, 1974. It was observed by a comparison to earlier figures that the difference is not considerable.

Soil Temperature

Temperature probes were installed at the following locations: 1) inside the test tile, 2) in the soil at 2'6" depth, 3) in the soil at 3'6" depth, 4) in the soil at 4'6" depth, 5) in the septic tank midway below the liquid level, 6) in the soil at a depth of 2'6" close to the septic tank and 7) in the collecting tank. Thermistor probes 2, 3 and 4 were embedded in the soil close to the septic tile.

Temperature measurements at these seven locations were made manually using a Yellow-Springs Telethermometer. Temperature

readings were taken around 10:00 a.m. daily for a period between middle of December, 1972 and February, 1973 to examine the effect of lower atmospheric temperatures on the soil temperatures. Thereafter temperature readings were taken once a week or sometimes even longer intervals, till January, 1974.

Snow Cover

Some observations on the depth of snow on ground at the site during the winter period did not materially differ from the data on this issued by the Weather Office, Ottawa. It was decided therefore to use the daily data collected by the Weather Office, Ottawa for this purpose. During the period of study, there was no snow on the ground from May, 1973 to October, 1973.

Unsaturated Depth of Soil

Measurements were made on the depth to groundwater level in the observation trench from the ground, at times of sample collection, which was weekly, except during December, 1973 to March, 1974 when there were fewer observations.

3.2.5 Studies Relating to Possible Clogging of the Experimental Tile

An attempt was made to investigate the extent of clogging that might have occurred below the tile trench. The

test tile trench was exposed for a length of two feet and the soil below the gravel was examined. Tube samples from this soil were collected and permeability tests were carried out. Samples were also collected from this site and analyzed for ferrous sulphide. Samples of a soil close by not subject to the influence of the tile system were collected and analyzed for ferrous sulphide for comparison purposes. The samples at the bottom of the tile trench were also analyzed qualitatively for polysaccharides. These samples at the bottom of the tile trench were also collected and examined microscopically for microbial activity. Initial infiltration rates at this location and the unclogged soil close by were determined by filling with water for a depth of 12", the exposed 2' length part of the tile bed and a test pit 2' square respectively.

3.2.6 Other Soil Studies

Soil samples (duplicate) from two locations, one farther from the tile (away from its influence) and the other 12" from the edge of the tile trench were taken from various depths (0, 2'6", 3'6", 4'0"). These samples were analyzed for PO_4 -P, NO_3 -N and chlorides to determine the influence of the effluent on the soil and the possible retention of pollutants in the soil.

A soil moisture content study was carried out before and after loading the test tile to examine the seepage

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pattern. Moisture content determinations were made on soil samples taken before loading at various depths of 0', 2'0", 3'0", and 3'3" from ground level at distances of 0, 15" and 30" from the edge of the test tile. Similar determinations were made on samples taken after 3 hours from loading at a location quite close to the original location. This location was at a distance of 16 feet from the northern end; the lysimeter 6 (at 2'0" depth) was located on the other side of the test tile at this location.

3.3 Analytical Procedures

The study involved analytical determinations of the concentrations of various parameters with respect to the water used for drinking, raw sewage, septic tank effluent, percolates from the lysimeters and groundwater adjacent to the tile. The parameters determined were: pH, TSS, VSS, fixed SS, BOD, COD, TOC, total PO_4 -P, NH_3 -N, NO_3 -N, total soluble iron, chlorides, total solids (for drinking water only), hardness as $CaCO_3$ (for drinking water only), total coliforms, fecal coliforms, fecal streptococci and Pseudomonas aeruginosa. Generally, methods outlined in "Standard Methods" (111) were followed for the chemical and bacteriological analyses. The methods used in the determination of each parameter are indicated below.

3.3.1 Methods Adopted

pH was determined electrometrically using a digital pH meter (Section 221 of "Standard Methods") manufactured by Orion Research (Model 801). Total suspended solids were determined by the glass fiber filter (Reeves Angel, 4.25 cm dia) method (Section 224c of "Standard Methods"). The glass fiber filter with the suspended solids was ignited in a muffle furnace at 600°C for 10 minutes (132) and the weight loss was reported as volatile suspended solids. BOD was measured using iodometric method with azide modification for dissolved oxygen (Sections 218A, 218B and 219 of "Standard Methods"). The dichromate reflux method (Section 220 of "Standard Methods") was adopted for COD. TOC was measured using Beckman Model 915, TOC Analyzer (80, 102) (Section 138 of "Standard Methods"). Only filtrates of the samples were analyzed for TOC. The total phosphate concentration was found by preliminary acid digestion with sulphuric acid-nitric acid (Section 223C, Method II of "Standard Methods") thereby converting all the phosphates to orthophosphates and following the standard procedure for the stannous chloride method (Section 223E of "Standard Methods") for the determination of orthophosphates. A spectrophotometer (Bausch and Lomb Spectronic 20) with a 1 cm light path was used in this estimation at 690 mμ. Calibration data and curves are furnished in Appendix C, page 264. Ammonia nitrogen was determined by Kjeldahl method (Section 132 of "Standard Methods"). Distillation, followed by nesslerization or tri-

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ration was adopted in the estimation. In the nesslerization method, a spectrophotometer (Bausch and Lomb Spectronic 20) with a 1 cm light path was used at 450 m μ . Calibration data and curve are furnished in Appendix C, page 264. The nitrates in the samples were determined by the zinc reduction method (Section 213A of "Standard Methods"). Colour comparison of the samples with the standards was made using a spectrophotometer (Bausch and Lomb Spectronic 20) with a 1 cm light path, at 520 m. Total soluble iron (total iron in the filtrate) was estimated by atomic absorption spectrophotometer (Unican SP 90A) for the greater part of the study and by phenanthroline method in the latter part of the study (Sections 129A and 124A of "Standard Methods"). Calibration data and curve for the estimation of total soluble iron by atomic absorption method are furnished in Appendix C, page 264. Mercuric nitrate method (Section 112B of "Standard Methods") was used in the estimation of chlorides. The EDTA titrimetric method (Section 122B of "Standard Methods") was adopted in the estimation of the hardness of water samples. Standard plate counts at 20°C and 35°C were estimated as per "Standard Methods" (Section 406). Total coliforms, fecal coliforms and fecal streptococci were evaluated adopting the membrane filter technique described in the "Standard Methods" (Sections 408A, 408B and 409B). The multiple-tube technique described in the "Standard Methods" (Section 413B) was adopted in the estimation of Pseudomonas aeruginosa.

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3.3.2 Sampling, Transport and Storage

All the samples for chemical and bacteriological analyses were transported to the laboratory within one hour of collection. The bacteriological examination was conducted on the same day. The samples were stored in a refrigerator (0°C) before analysis. The unstable parameters were analyzed within 12 hours, and the entire analyses were completed within 48 hours of sample collection. No specific sample preservation methods were adopted in the study.

3.3.3 Analysis of Soil Samples for Certain Chemical Parameters

Certain soil samples were analyzed for ferrous sulphide, nitrate nitrogen, total phosphates and chlorides. Preliminary sample preparation steps adopted by Crosby et al (27) were used in the study. 250 grams of soil were shaken on a rotary shaker for 1 hour with 200 ml distilled water. The extract was centrifuged at a high speed for 10 minutes and the supernatant liquid was used for the chemical analysis. The ferrous sulphide was estimated stoichiometrically after individual estimations of total iron and sulphide in the sample. Nitrate nitrogen, total phosphates and chlorides were estimated following procedures mentioned earlier. The results are reported for gram of dry soil, after making necessary correction for the moisture content.

A qualitative test for the presence of polysaccharides in the soil beneath the septic tile was conducted by acid hydrolysis of the sample and confirmation using Benedict's solution.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Efficiency of the Septic Tile

The efficiency of the septic tile system has been evaluated with respect to the following parameters: TSS, BOD, COD, TOC, total phosphates (PO_4 -P), NH_3 -N and nitrification. Reductions achieved in respect of indicator organisms and Pseudomonas aeruginosa were evaluated to the extent feasible. "Efficiency" refers to the reductions achieved between the point at which the septic tank effluent was distributed to the tile and the various depths at which the soil water samples were collected. Results of lysimeter studies and of investigations on groundwater quality adjacent to the test tile and below the existing tile field system have been examined to determine the efficiency of the septic tile as a treatment process.

4.1.1 Results of Lysimeter Studies

Chemical characteristics of the percolates collected from the seven lysimeters installed (16 samples in all) are shown in Table 18. Three lysimeters were at 2'0" depth, three were at 3'6" depth and one was at 4'6". Two lysimeters at 2'0" depth did not collect any percolate during the entire investigation.

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Table 18. Chemical Characteristics of Percolates Collected using Lysimeters

No	Characteristics	4-1-73		11-1-73		18-9-73		27-9-73		11-10-73		29-11-73		18-12-73		30-1-74		21-2-74	
		Ly 7	Ly 3	Ly 3	Ly 5	Ly 5	Ly 6	Ly 7	Ly 3	Ly 5	Ly 5	Ly 7	Ly 6	Ly 7	Ly 6	Ly 2	Ly 6	Ly 6	Ly 6
1	pH	7.0	7.3	7.79	8.30	7.12	7.2	7.1	6.75	6.9	6.85	6.90	6.80	6.90	6.60	6.70	6.65		
2	TSS, mg/l	28	20	82	256	132	158	68	62	90	140	-	46	44	18	24	40		
3	VSS, mg/l	24	-	74	152	106	112	60	54	50	60	-	38	38	14	16	34		
4	Fixed SS, mg/l	4	-	8	104	26	46	8	8	40	80	-	8	6	4	8	6		
5	BOD, mg/l	33	26	140	473	110	200	40	40	43	47	-	57	71	38	31	59		
6	COD, mg/l	58	53	242	585	182	260	121	113	50	150	-	112	143	55	172	65		
7	TOC, mg/l	17	14	20	28	32	25	34	28	6	2	26	20	12	12	34	22		
8	PO ₄ -P, mg/l	15	7.9	12.5	16.0	6.0	9.0	1.0	2.50	8.7	11.0	18.0	1.0	2.50	9.0	11.0	6.0		
9	NH ₃ -N, mg/l	30	42	97	-	93	85	34	73	83	80	-	15	11	63	23	83		
10	NO ₃ -N, mg/l	0.22	0.18	0.04	0.20	0.00	0.00	0.26	1.40	0.08	0.18	-	1.50	0.30	1.2	0.5	0.3		
11	Total Soluble Fe mg/l	0.30	0.0	3.6	5.74	0.96	0.93	0.10	0.60	0.70	0.02	-	-	-	0.1	0.2	0.1		
12	Chlorides, mg/l	-	-	47	51	50	47	54	58	49	45	-	52	49	45	43	50		

Note: Ly - Lysimeter

Variation of Parameter Reduction with Depth and Time

An analysis was made to determine the variation in the efficiency for various parameters at the three depths noted above, with time. The mean values of the parameters relating to the septic tank effluent as calculated (Tables 19 and 20) were taken for the analysis. Tables 21 to 29 show the variation in efficiencies for various parameters with soil depth and time. Figures 17 to 20 also depict the variations in efficiency for the parameters with time. An analysis of the results presented in Tables 21 to 29 and Figs. 17 to 20 show that generally the efficiency of the septic tile reached low levels at the end of 40 weeks from start of loading in respect to the reduction of various parameters TSS, BOD, COD, TOC, PO_4 -P, NH_3 -N, and total soluble iron for depths of 3'6" and 4'6". Results for 2'0" depth were available only beyond 40.5 weeks. The efficiencies at the depths of 3'6" and 4'6" increased after about 40 weeks and remained relatively higher for another 21 weeks up to which period the study was made. Assuming that the system would have gotten fairly stabilized at this stage, after 40 weeks of operation, an examination of the efficiencies for this period (40 to 61 weeks) revealed that the efficiencies in respect of TSS, BOD, COD, TOC, and total soluble iron and nitrification were relatively higher for the 3'6" depth as compared to 2'0" depth. However, in respect of NH_3 -N, and total phosphates, the reductions at 2'0" depth appeared to

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Table 19. Chemical Characteristics of Septic Tank Effluent

Date of Sample	pH	TSS mg/l	VSS mg/l	Fixed SS mg/l	BOD mg/l	COD mg/l	TOC mg/l	PO ₄ -P mg/l	NH ₃ -N mg/l	NO ₃ -N mg/l	Total Soluble Fe mg/l	Chlorides mg/l
21-01-73	7.14	204	136	68	167	525	58	12.2	100	-	0.0	-
12-03-73	7.00	204	132	72	296	734	90	23.0	93	0.04	20.0	-
19-03-73	7.04	624	540	84	478	2026	160	11.0	100	0.00	0.5	53
26-03-73	6.80	116	100	16	318	536	190	11.0	80	0.04	0.5	52
02-04-73	6.85	296	236	60	448	336	114	8.0	77	0.02	0.5	85
16-04-73	6.80	88	75	13	268	380	76	7.5	100	0.01	0.7	56
23-04-73	6.96	96	44	52	304	368	60	7.5	83	0.00	0.5	52
04-05-73	6.95	116	96	20	247	346	64	6.5	100	0.00	0.3	45
14-05-73	6.97	68	56	12	288	254	60	6.3	83	0.00	3.0	38
28-05-73	7.00	124	90	34	270	240	80	14.3	105	0.00	3.5	42
01-06-73	6.91	120	108	12	166	372	50	11.3	105	0.02	0.0	37
11-06-73	6.89	80	74	6	666	290	42	7.5	108	0.02	0.0	37
18-06-73	6.86	126	48	78	180	1331	24	15.0	105	0.04	5.0	40
25-06-73	6.76	90	78	12	208	676	64	30.0	105	0.04	0.2	53
13-07-73	6.70	92	78	14	200	668	64	9.0	95	0.08	0.76	67
23-07-73	6.53	162	126	36	205	354	68	9.0	97	0.02	0.94	56
10-08-73	6.82	376	292	84	380	660	64	8.2	100	0.00	1.10	42
18-09-73	7.45	142	112	30	200	520	48	13.5	100	0.06	5.0	40
27-09-73	6.9	102	86	16	160	303	44	10.0	97	0.00	0.56	101
11-10-73	6.7	294	234	60	140	440	32	11.2	110	0.10	0.46	53
Mean	6.90	176	137	39	280	568	73	11.6	97	0.026	2.63	

Table 20. Bacteriological Characteristics of Septic Tank Effluent

Date	Coliform MF count/100 ml	Fecal Coliform MF count/100 ml	Fecal Streptococci MF count/100 ml	SPC per ml		Pseudomonas Aeruginosa MPN/100 ml
				35°C	20°C	
19-02-73	1,200,000	500,000	26,000	650,000	1,400,000	79
09-03-73	24,000,000	1,200,000	250,000	100,000	850,000	17
19-03-73	240,000	4,100	80,000	84,000	940,000	2
02-04-73	11,000,000	5,200,000	210,000	310,000	930,000	16,000
16-04-73	2,700,000	320,000	44,000	200,000	620,000	2,200
04-05-73	1,300,000	14,000	14,000	2,200,000	680,000	110
28-05-73	3,300,000	380,000	740,000	450,000	850,000	<2
01-06-73	1,300,000	480,000	590,000	90,000	370,000	<0.2
18-06-73	920,000	14,000	79,000	1,400,000	3,900,000	4
23-07-73	4,200,000	200,000	120,000	170,000	270,000	39
Mean (Geometric)	2,278,000	176,400	110,800	305,900	824,500	30

Table 21. Removal of Suspended Solids with Soil Depth and Time

TSS of Septic Tank effluent (mean) mg/l	Weeks from start of loading	TSS of the percolate at 2'0" depth mg/l	Percentage removal at 2'0" depth	TSS of the percolate at 3'6" depth mg/l	Percentage removal at 3'6" depth	TSS of the percolate at 4'6" depth mg/l	Percentage removal at 4'6" depth
176.0	2.5	28	79	20	88		
	3.5						
	39.0	256	-	82	53		
	40.5	110	38	132	25		
	42.5	90	49	90	49		
	49.0	46	74				
	52.0	44	75				
	58.0	24	86	18	90		
	61.0	40	77				

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Table 22. Variation of pH with Soil Depth and Time

Weeks from start of loading	pH of the percolate at 2'0" depth	pH of the percolate at 3'6" depth	pH of the percolate at 4'6" depth
2.5		7.0	
3.5			7.3
39.0		8.3	7.8
40.5	7.1	7.0	7.1
42.5		6.9	6.9
49.0		6.9	
52.0	6.9		
58.0	6.7	6.6	
61.0	6.7		

Table 23. Reduction of BOD with Soil Depth and Time

BOD of septic tank effluent (mean) mg/l	Weeks from start of loading	Percentage reduction at		BOD of the percolate at		Percentage reduction at		BOD of the percolate at		Percentage reduction at 4'6" depth
		2'0" depth	3'6" depth	2'0" depth	3'6" depth	3'6" depth	4'6" depth	4'6" depth	4'6" depth	
mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
280	2.5		33		89		26		91	
	3.5		473		-		140		50	
	39.0		120		57		110		61	
	40.5	40		85			43		85	
	42.5		47		83					
	49.0		57		80					
	52.0	71		75						
	58.0	31		89		38		86		
	61.0	59		79						

Table 24. Reduction of COD with Soil Depth and Time

COD of septic tank effluent (mean) mg/l	Weeks from start of loading	COD of the percolate at		Percentage reduction at		COD of the percolate at		Percentage reduction at	
		2'0" depth mg/l	2'0" depth mg/l	2'0" depth	3'6" depth	3'6" depth mg/l	4'6" depth	4'6" depth mg/l	4'6" depth
568	2.5				58	90	53	91	
	3.5				585	-	242	58	
	39.0				187	67	182	68	
	40.5	121	80		150	74	50	91	
	42.5				112	80			
	49.0								
	52.0	143	75						
	58.0	172	70		55	90			
	61.0	65	89						

Table 25. Reduction of TOC with Soil Depth and Time

TOC of septic tank effluent (mean) mg/l	Weeks from start of loading	TOC of the percolate at reduction at 2'0" depth mg/l	Percentage reduction at 2'0" depth	TOC of the percolate at reduction at 3'6" depth mg/l	Percentage reduction at 3'6" depth	TOC of the percolate at reduction at 4'6" depth mg/l	Percentage reduction at 4'6" depth
73	2.5	17	77	14	81		
	3.5						
	39.0	28	62	20	73		
	40.5	34	54	27	63	32	56
	42.5			2	97	6	90
	49.0			23	69		
	52.0	12	83				
	58.0	34	54	12	83		
	61.0	22	70				

Table 26. Reduction of Total Phosphates (PO₄-P) with Soil Depth and Time

Total Phosphates (PO ₄ -P) of septic tank effluent (mean) mg/l	Weeks from start of loading	Total Phosphates (PO ₄ -P) in the percolate at 2'0" depth mg/l	Percentage reduction at 2'0" depth	Total Phosphates (PO ₄ -P) in the percolate at 3'6" depth mg/l	Percentage reduction at 3'6" depth	Total Phosphates (PO ₄ -P) in the percolate at 4'6" depth mg/l	Percentage reduction at 4'6" depth
11.6	2.5	15.0	-	7.9	32	119	-
3.5	3.5	16.0	-	12.5	-	47	-
39.0	40.5	5.8	91	6.0	47	25	-
42.5	49.0	11.0	5	8.7	25	-	-
52.0	58.0	9.5	18	-	-	-	-
61.0	61.0	9.0	22	-	-	-	-

Table 27. Reduction of Ammonia Nitrogen with Soil Depth and Time

Ammonia nitrogen in septic tank effluent (mean) mg/l	Weeks from start of loading	Ammonia nitrogen in the percolate at 2'0" depth mg/l	Percentage reduction at 2'0" depth	Ammonia nitrogen in the percolate at 3'6" depth mg/l	Percentage reduction at 3'6" depth	Ammonia nitrogen in the percolate at 4'6" depth mg/l	Percentage reduction at 4'6" depth
97	2.5	30	69	42	57		
	3.5	-	-	97	0		
	39.0	79	19	93	4		
	40.5	34.4	65	80	18		
	42.5			15	85		
	49.0						
	52.0	11.5	90				
	58.0	23.3	76	63	35		
	61.0	83.3	14				

Table 28. Variation of Nitrates with Soil Depth and Time

Weeks from start of loading	Nitrate in the percolate at 2'0" depth mg/l	Nitrate in the percolate at 3'6" depth mg/l	Nitrate in the percolate at 4'6" depth mg/l
2.5		0.22	
3.5			0.18
39.0		0.20	0.04
40.5	0.26	0.70	0.00
42.5		0.18	0.08
49.0		1.50	
52.0	-		
58.0	0.20	1.20	
61.0	0.10		

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Table 29. Reduction of Total Soluble Iron with Soil Depth and Time

Total iron in septic tank effluent (mean)	Weeks from start of loading	mg/l			Total soluble iron in the percolate at 4'6" depth
		Total Soluble Percentage iron in the percolate at 2'0" depth	Total Soluble Percentage iron in the percolate at 3'6" depth	Total Soluble Percentage iron in the percolate at 4'6" depth	
2.63	2.5	0.30	89	0.0	100
3.5	3.5	5.74	-	3.6	-
39.0	39.0	0.80	70	0.96	63
40.5	40.5	0.10	97	0.02	73
42.5	42.5	-	-	-	-
49.0	49.0	-	-	-	-
52.0	52.0	-	-	-	-
58.0	58.0	0.20	92	0.10	96
61.0	61.0	0.10	97	-	-

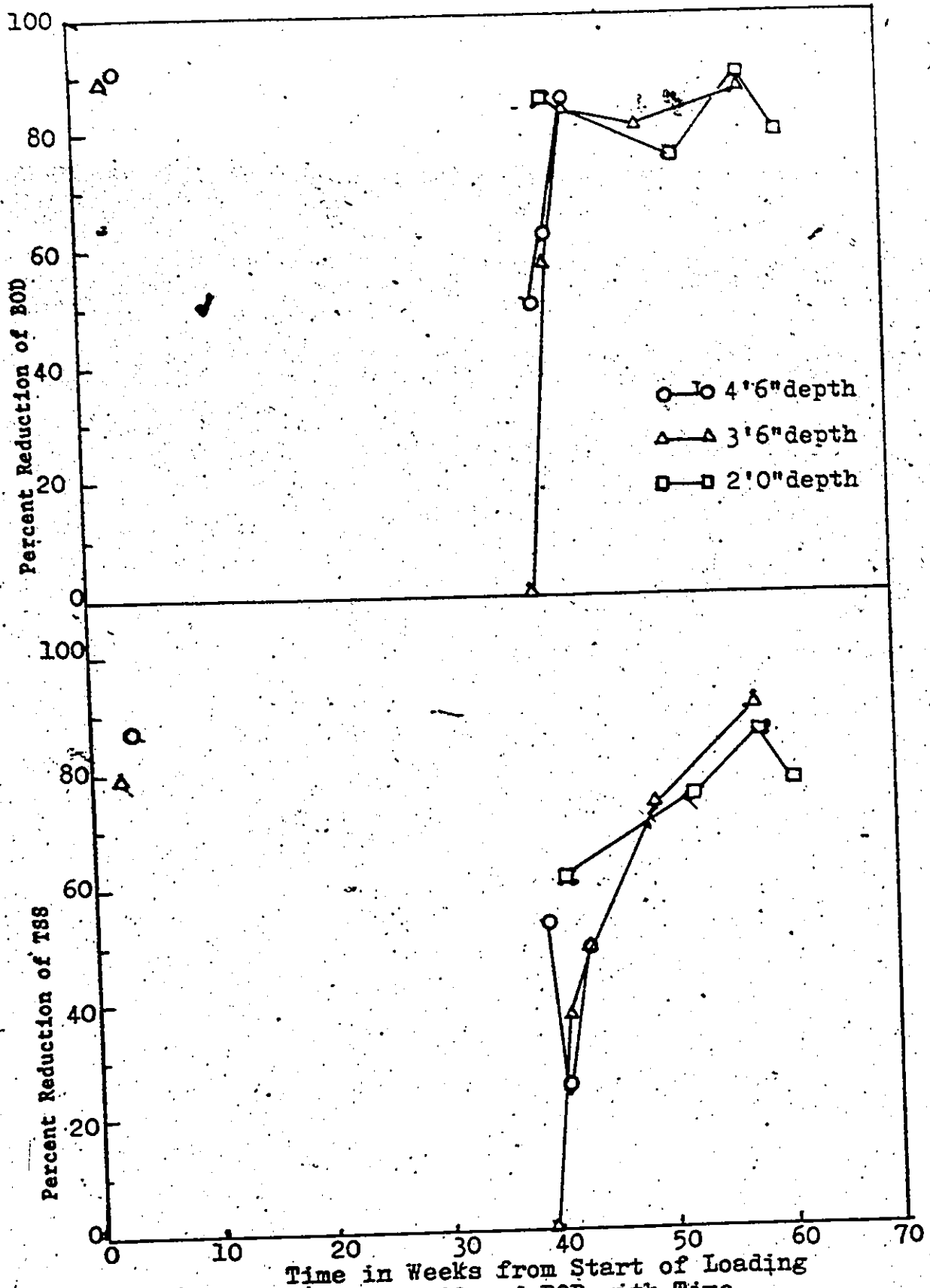


Fig.17. Reduction of TSS and BOD with Time

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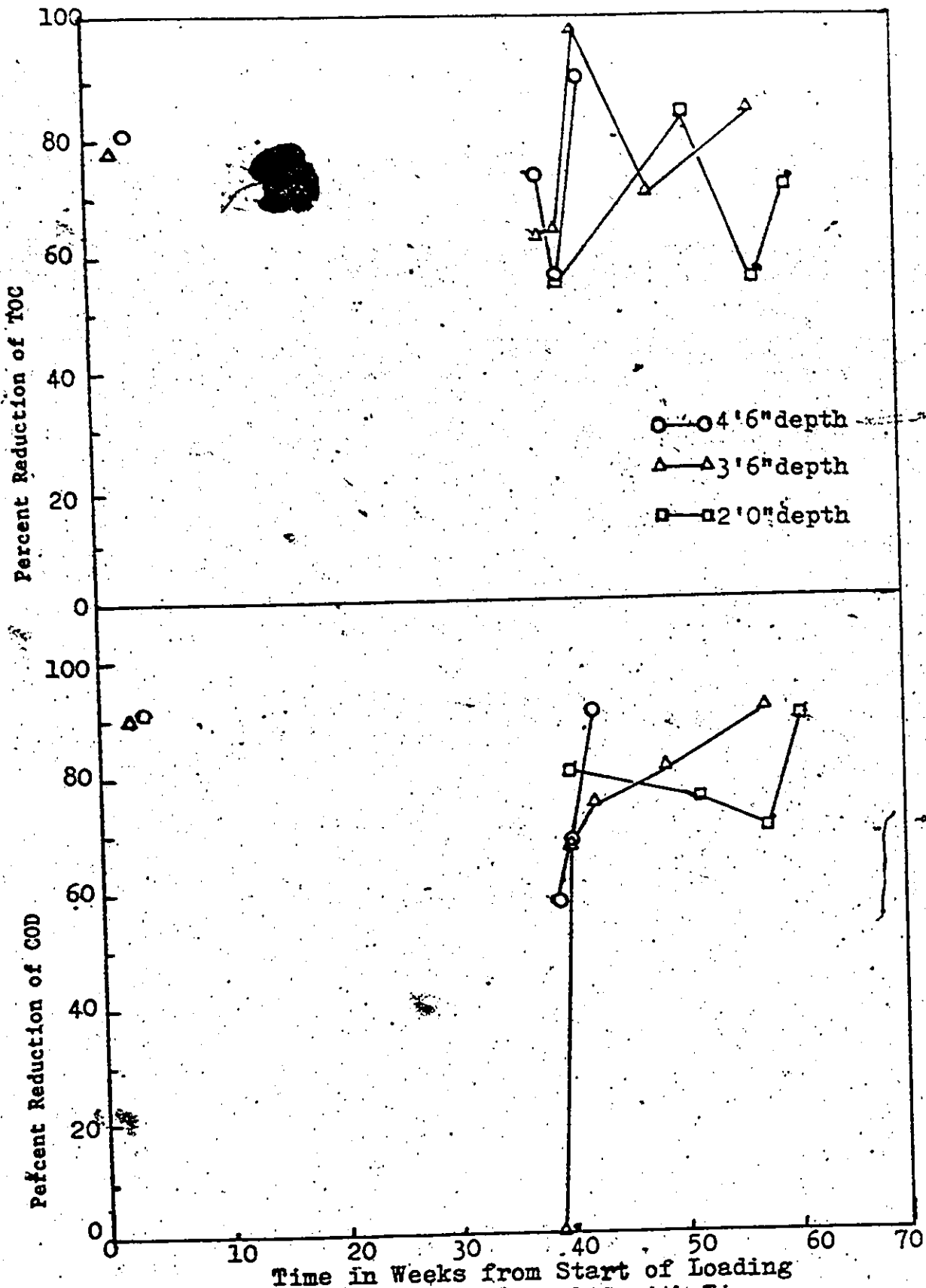


Fig.18. Reduction of COD and TOC with Time

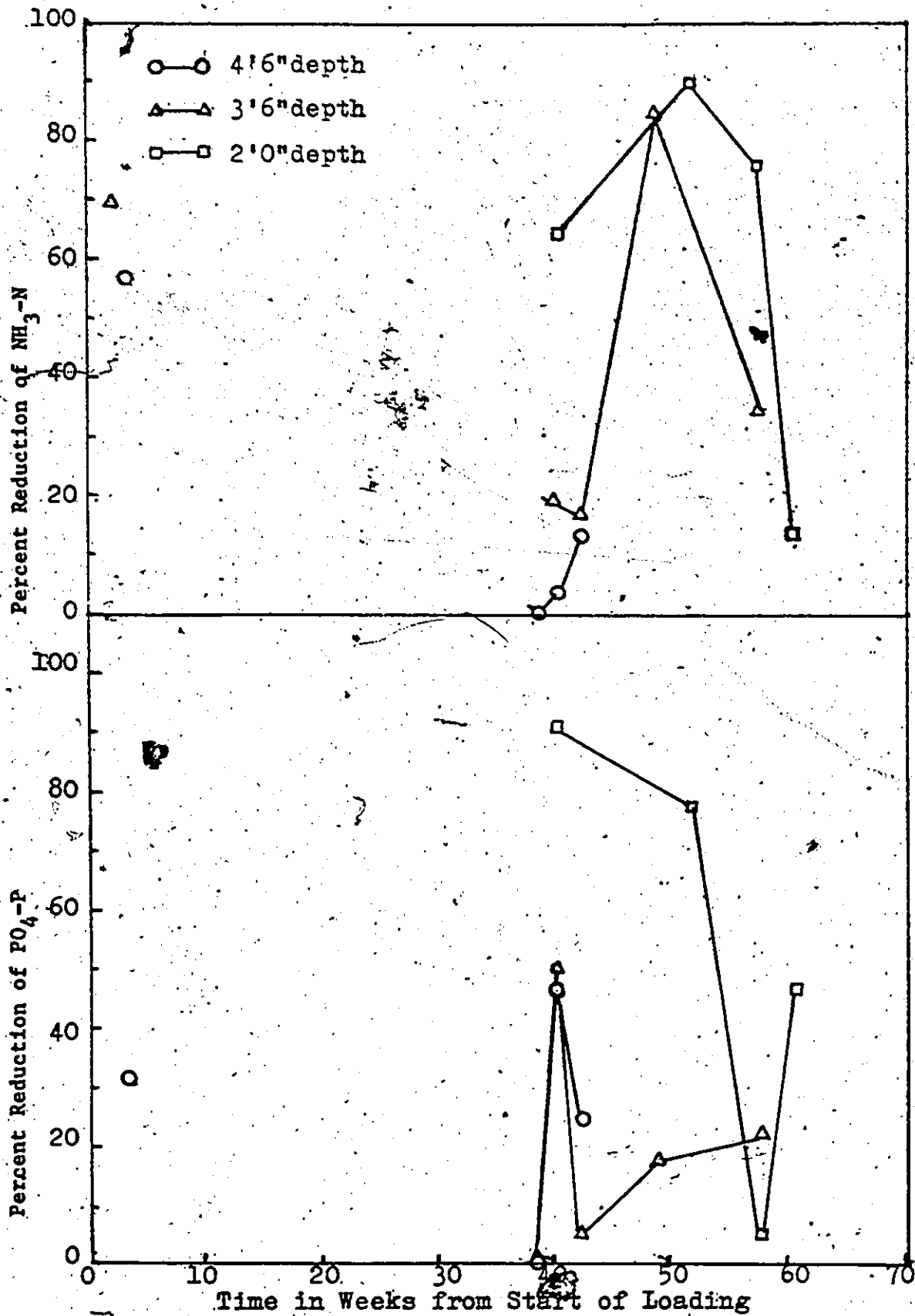


Fig. 19. Reduction of Po₄-P and NH₃-N with Time

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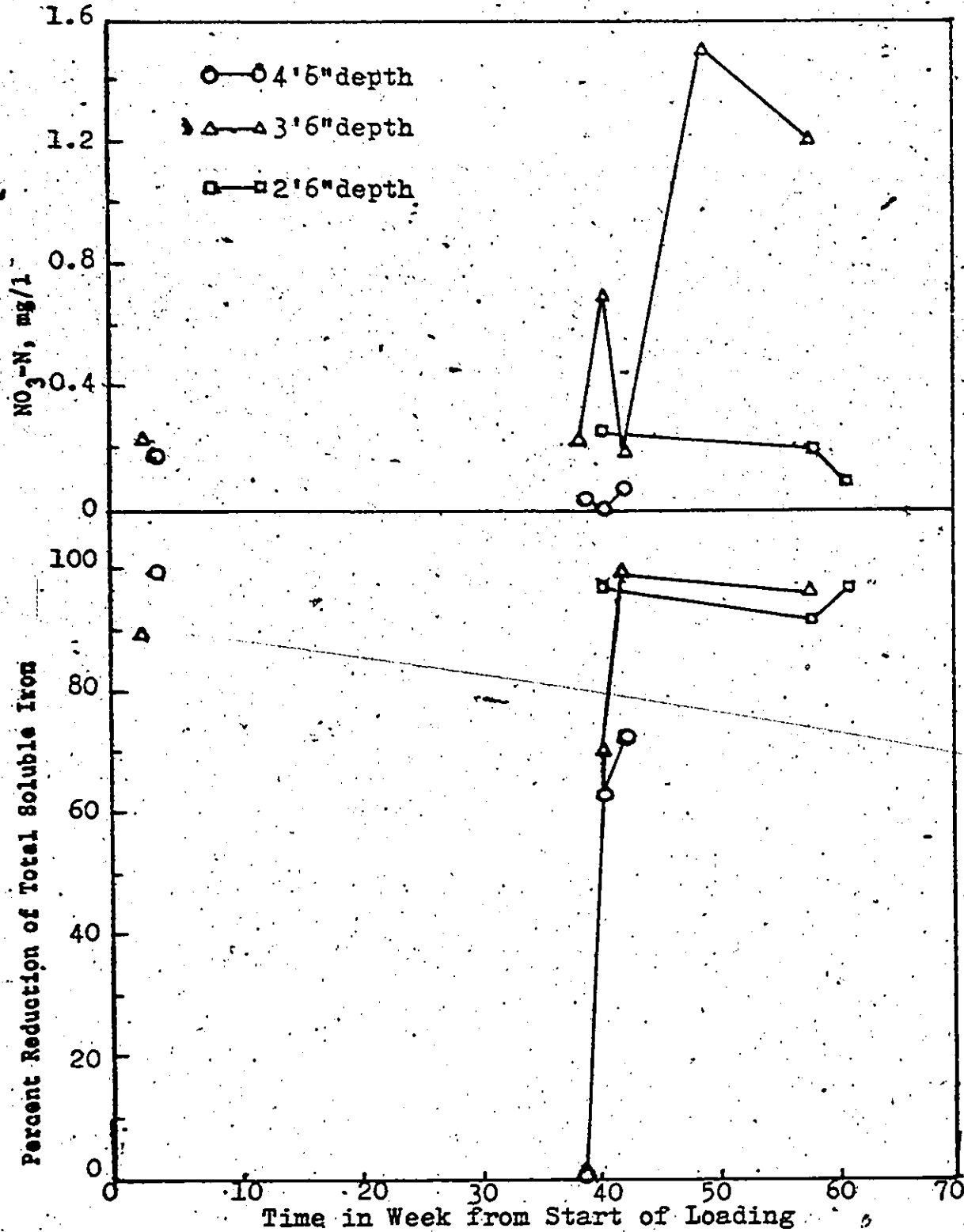


Fig.20. Reduction of Iron with Time and The Nitrification Trend with Time

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be greater than at 3'6" depth. Results for 4'6" depth beyond 42.5 weeks of operation of the tile were not available. However, when results for a particular day in September, 1973 were analyzed, it was found that on this occasion the reductions achieved (Figs. 21 to 23) in respect of TSS, BOD, COD, total phosphates, $\text{NH}_3\text{-N}$ and total soluble iron showed a generally declining trend with depth, while in the case of TOC and nitrates alone, there was an increase at 3'6" depth declining again at 4'6" depth. These observations were made at the end of 40.5 weeks from the start just after the period when efficiencies touched the lowest mark. It is probable that the system had not achieved stability by that time due to an abnormal environmental condition created by a very high water table.

It may be of interest to examine in detail the specific efficiencies for the various parameters at different depths. TSS reductions were in the 40-90% range for the 2'0" and 3'6" depths beyond 40 weeks. The reductions for 3'6" depth were relatively higher after 49 weeks of operation. The reductions for the 4'6" depth were significantly lower. BOD, COD and TOC reductions during this period were usually in the 75-90% range, with reductions at 3'6" depth generally greater than those at 2'0" depth. $\text{NH}_3\text{-N}$ reductions showed an upward trend (85-90%) at about 50 weeks, declining thereafter to rather low levels (15-35%) for both the depths of 2'0" and 3'6". With increase in ammonia reduction, there

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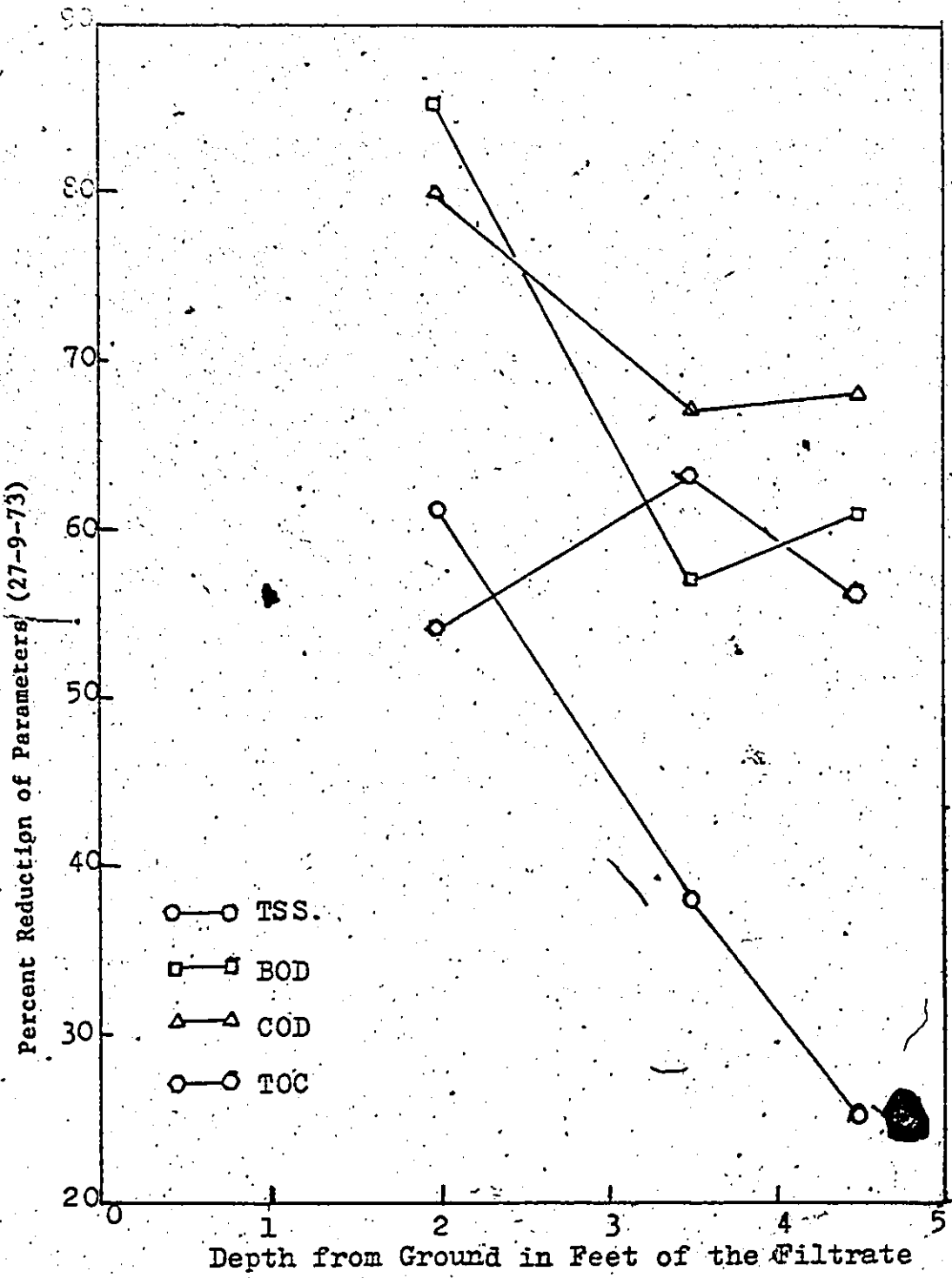


Fig. 21. Effect of Depth of Soil on TSS, BOD, COD and TOC Reduction

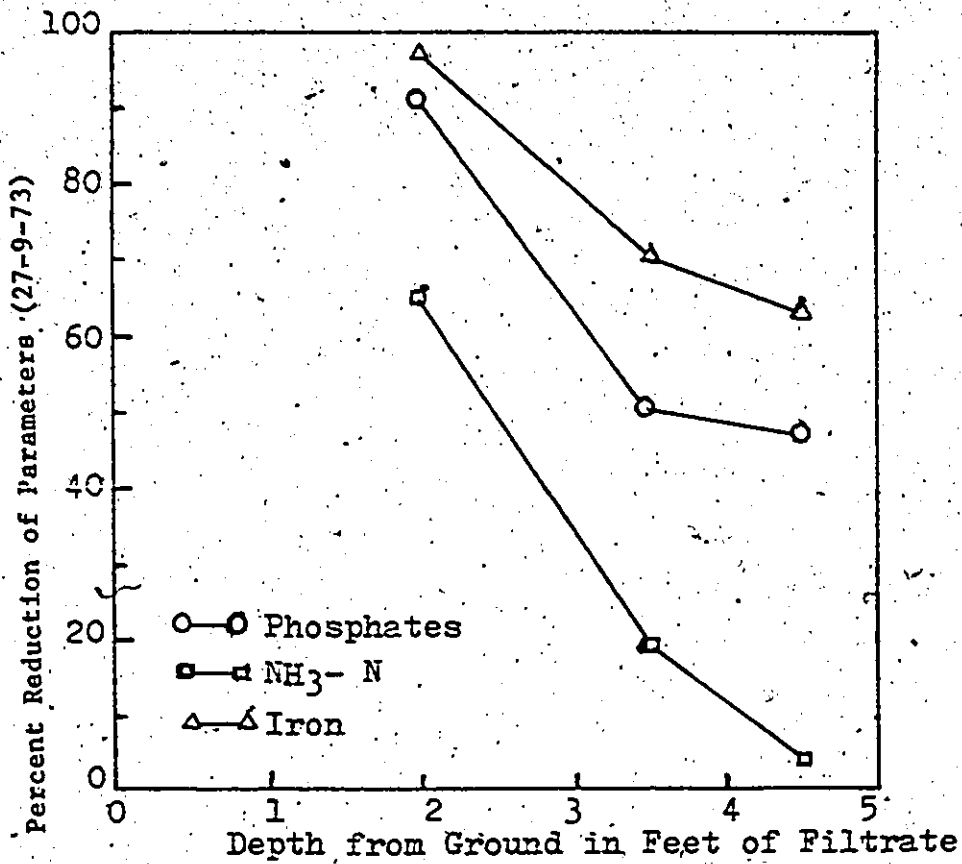


Fig. 22. Effect of Depth of Soil on PO₄-P, NH₃-N and Fe Reduction

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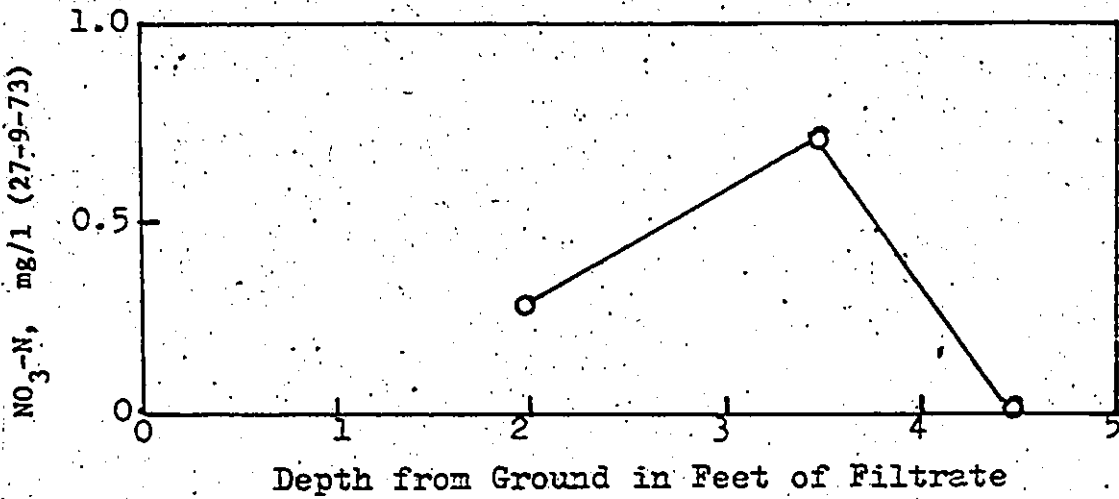


Fig. 23. Effect of Soil Depth on Nitrification,

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had been corresponding increases in nitrification during this period, showing clearly the adsorption of ammonia by the soil and biological nitrification occurring together. In the case of total phosphates, the trend was not very clear. Reductions at 2'0" depth were rather erratic and reductions at 3'6" depth and at 4'6" depth were only in the 25-50% range, leaving a sizeable amount of total phosphates, sometimes as high as 11 mg/l in the percolate, at various depths. Nitrification trends witnessed in this study revealed that nitrate levels of the percolate at 3'6" depth could be as high as 1.50 mg/l, though at 4'6" depth they were much lower probably due to denitrification occurring because of lack of oxygen supply at that depth.

Data examined so far still left unanswered two important questions:

1) Why were there relatively very high reductions (80-90%) of the various parameters near the start of the operation (2.5-3.5 weeks from the start) at 3'6" and 4'6" depths?

2) Why were the reductions achieved at 2'0" depth on many occasions higher than those obtained at depths of 3'6" and 4'6", contrary to normal expectations?

These high reductions witnessed near the start of operation may be due to the dilution of the percolate due to rather heavy rain that fell on the area during the last day of December 1972 and some rainfall thereafter.

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along with some snowmelt water due to above freezing temperatures during the latter part of the days in late December and early January. Since the groundwater was also fluctuating up and down during this time, some dilution by groundwater in addition to percolating rain water was also possible.

As regards reductions at 2'0" depth, percolates were collected at 2'0" depth from only one lysimeter, as the other two kept at 2'0" depth did not collect any percolate during the entire investigation. This lysimeter No. 6, was placed at a distance of 16' from the northern end and it penetrated 26" into the common wall from the observation trench, 4" from the side of tile trench. The top of the tile at this location was 1.71 feet from ground level and the bottom 2.04 feet from ground level. The bottom of the trench was 2.54 from ground level. At the usual loading rate and assuming poor infiltration due to clogging, the depth of the effluent may be expected to reach 6.5 inches in the tile trench; the top of the water level could be 2.0 feet from ground, the same level as the lysimeter. It would be rather improbable for all the effluent to reach this lysimeter, as it involved horizontal travel only. Though it was 4" away from the side of the trench, there was possibility of only a fraction of the effluent reaching the lysimeter, that too, due to the fact that the horizontal permeability at this depth was significantly higher than vertical permeability. Thus a strong possibility existed for the soil water sample

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obtained through the lysimeter to be made up of a greater amount of infiltrated rain water and a lesser amount of the filtered effluent.

In this connection, the flow pattern from a tile trench to an existing groundwater system was considered. The pattern of flow assumed by Healy and Laak (44) is shown in Fig. 24. In the case of dry soils Healy and Laak (45) have further stated that the flow results primarily from capillarity in all cases except sand and gravel, while examining the flow pattern from a percolation hole. If flow results from capillarity, a saturation front may be expected to move away from the hole in a form that could be represented by a cylinder and a hemisphere. With the lysimeter only 4" from the side wall of the tile trench, the saturation front would probably reach the lysimeter without difficulty; however this depends upon the fact that the effluent in the trench would have to be at least 6" deep. If it were not so, the lysimeter would not catch the filtered effluent seeping through the soil, either by capillary action or by gravity flow. Situations wherein that depth of effluent in the trench was not obtained existed many times as the loading rate was sometimes smaller due to other factors.

The results of an investigation of the moisture content in the soil before and after loading the test tile (3 hours later) which was conducted at the site 16' from the northern end opposite lysimeter 6, at various depths

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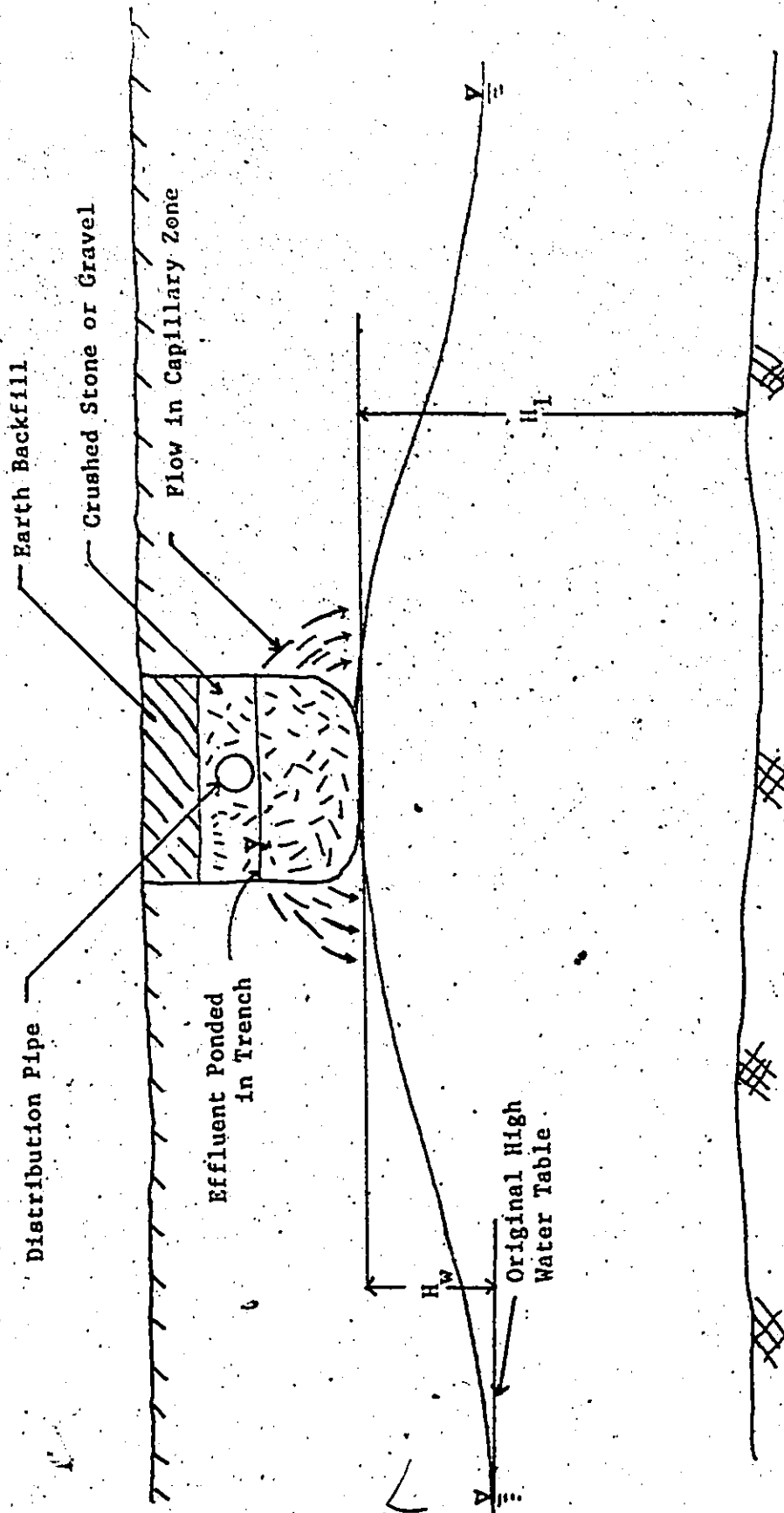
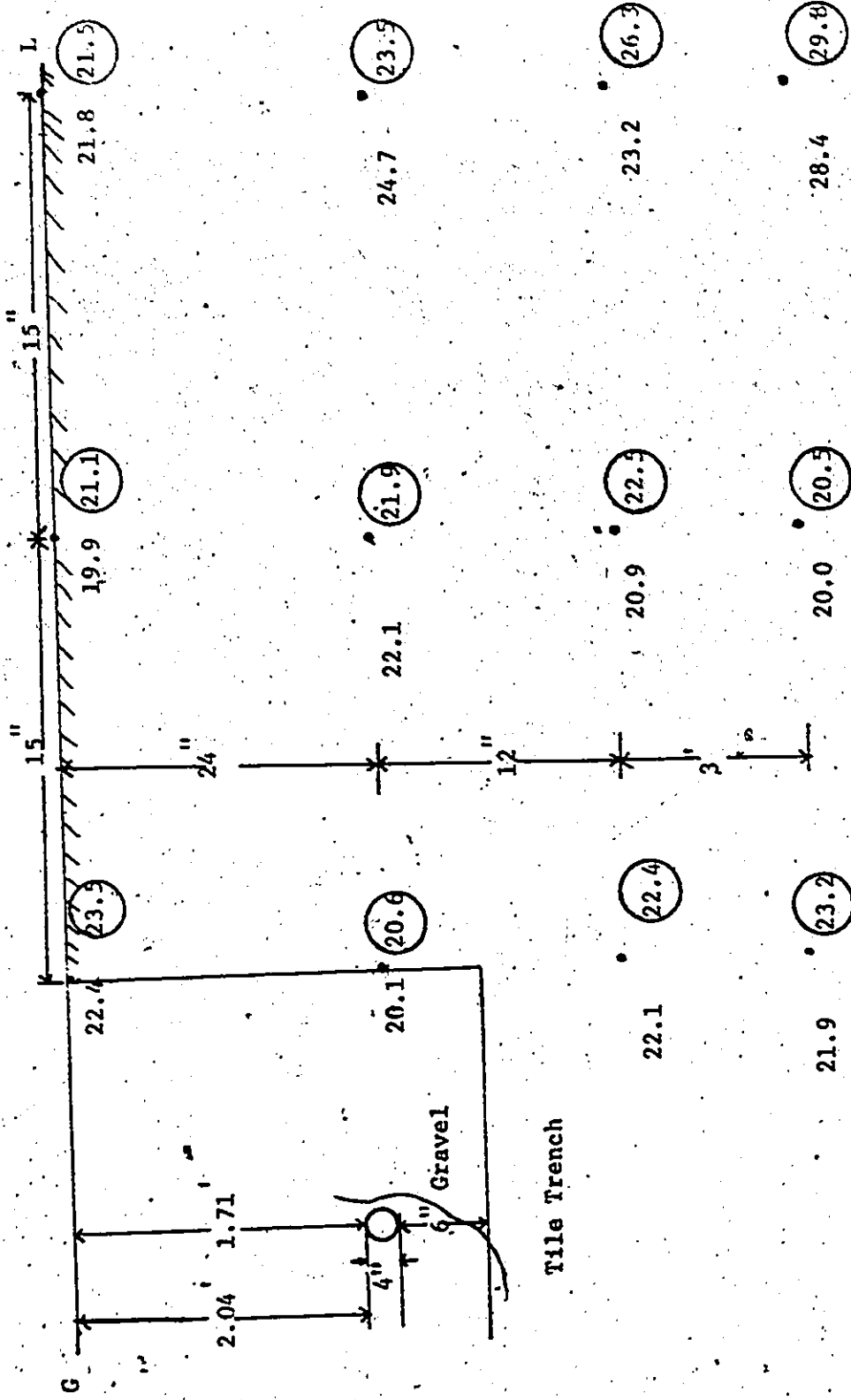


Fig. 24. Assumed Pattern of Flow from Tile Trench

of 2'0", 3'0" and 3'3" (close to the trench 15" and 30" from the trench side wall) are shown in Fig. 25. Although the results about the seepage pattern are not conclusive the points at 36" and 39" depth showed increases in moisture content while the points at 24" depth showed decreases in moisture content or in one case only a small increase. The elapsed time was probably not adequate for increases in moisture content comparable to those resulting from operation to be reflected. Judging from the fact that the percolate from the lysimeter at 2'0" depth, did contain pollutant parameters like BOD, COD, $\text{NH}_3\text{-N}$ in concentrations higher than that we could expect from only rainwater-infiltrated percolate, it was reasonable to assume that some effluent had reached the lysimeter 6 but possibly got more diluted by proportion, being closer to the top, than the ones below. It was also possible that the uptake by plants, which would also reduce concentrations of pollutants, may be more significant at 2'0" depth than at lower depths. No detailed investigation was however carried out on the evapotranspiration aspects of pollutant removal from soils.

It was found that the high reductions of COD, BOD, TOC and ammonia nitrogen to some extent observed in the present study are in agreement with the earlier findings reported in the literature (11, 99, 119). The main exception would appear to be in the reduction of total phosphates; in the present study the reductions were usually in the 25-50%



Note: Circled Values are after loading

Fig. 25. Moisture Content of Soil Before and After Loading

range other than on two occasions when the values exceeded 75%, compared to very high reductions (99%) reported in the literature (84) for shallow depths of a few feet.

Variation of Efficiency with Unsaturated Depth

An examination of Fig. 26 showing the mean unsaturated depth of soil during the various months as well as Figs. 17 to 20 (p.123-264) showing efficiencies with time, revealed that efficiencies were greater in respect of various parameters during the summer and early fall extending from August to November, when the unsaturated depth of soil was more than 65 inches. When the unsaturated depth decreased in the winter period, there was a tendency for the efficiency to decrease to some extent in respect of BOD and TSS, but more in the case of ammonia nitrogen. Nitrate nitrogen levels also showed a declining trend during the winter months. These findings generally agree with the observations made by Schwartz and Bendixen (103) under laboratory conditions.

Variation of Efficiency with Soil Temperature

An attempt was made to determine the influence of soil temperature on the efficiency in respect of various parameters. The mean monthly soil temperatures for the various depths are shown in Table 30. Soil temperatures which were depth dependent were plotted against reduction of various parameters (Figs. 27 to 32) ignoring the effect of

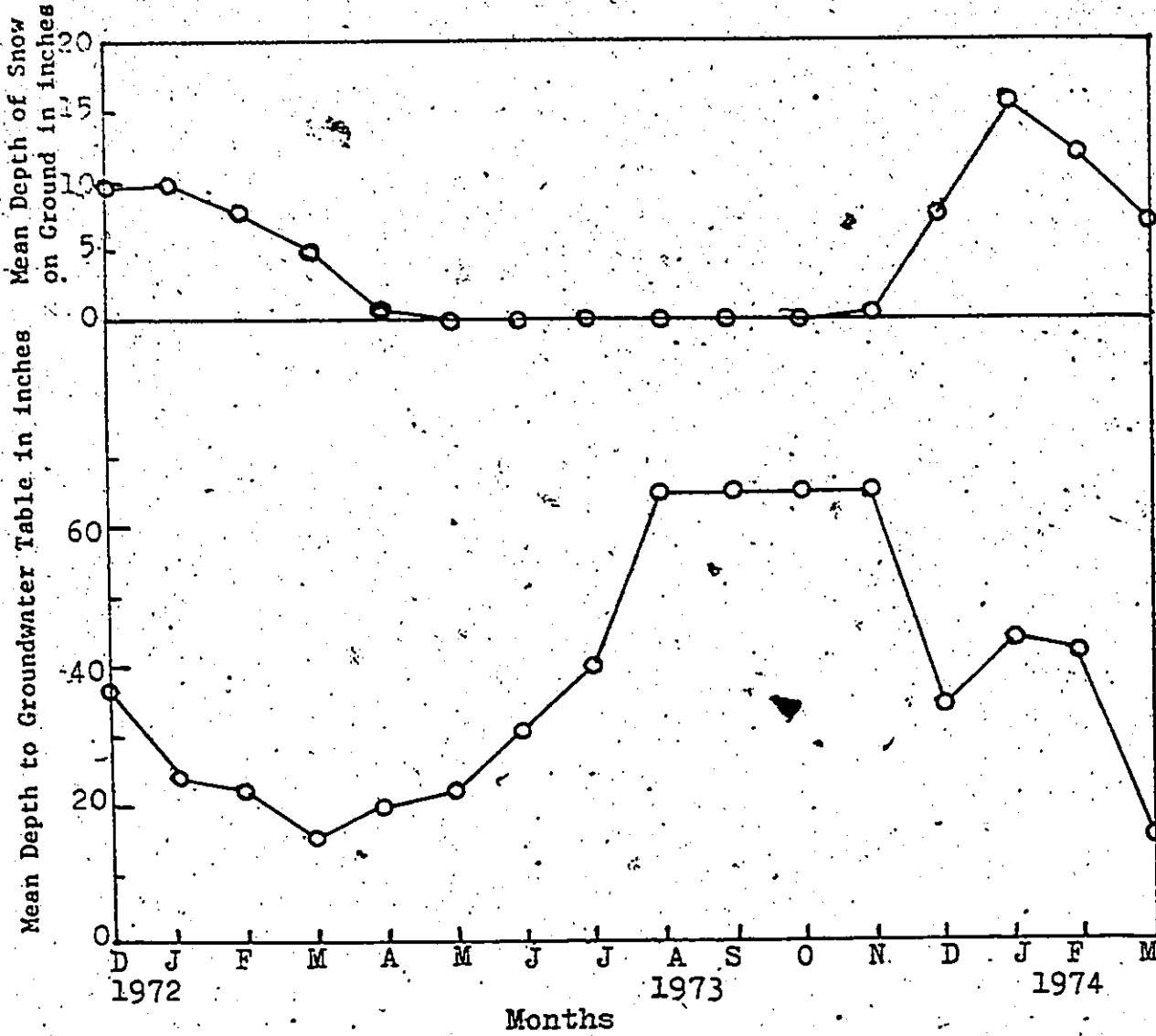


Fig. 26. Mean Monthly Unsaturated Depth of Soil and Snow Cover

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Table 30. Mean Soil Temperatures at Various Depths

Date of Sample	Weeks from start to loading	Mean monthly soil temperature (°F)		
		2'6" depth	3'6" depth	4'6" depth
04-01-73	2.5		38.1	
11-01-73	3.5			39.7
18-09-73	39.0		56.6	56.8
27-09-73	40.5	54.8	56.6	56.8
11-10-73	42.5		53.1	53.6
29-11-73	49.0		48.5	
18-12-73	52.0	40.3		
30-01-74	58.0	39.1	41.1	
21-02-74	61.0			

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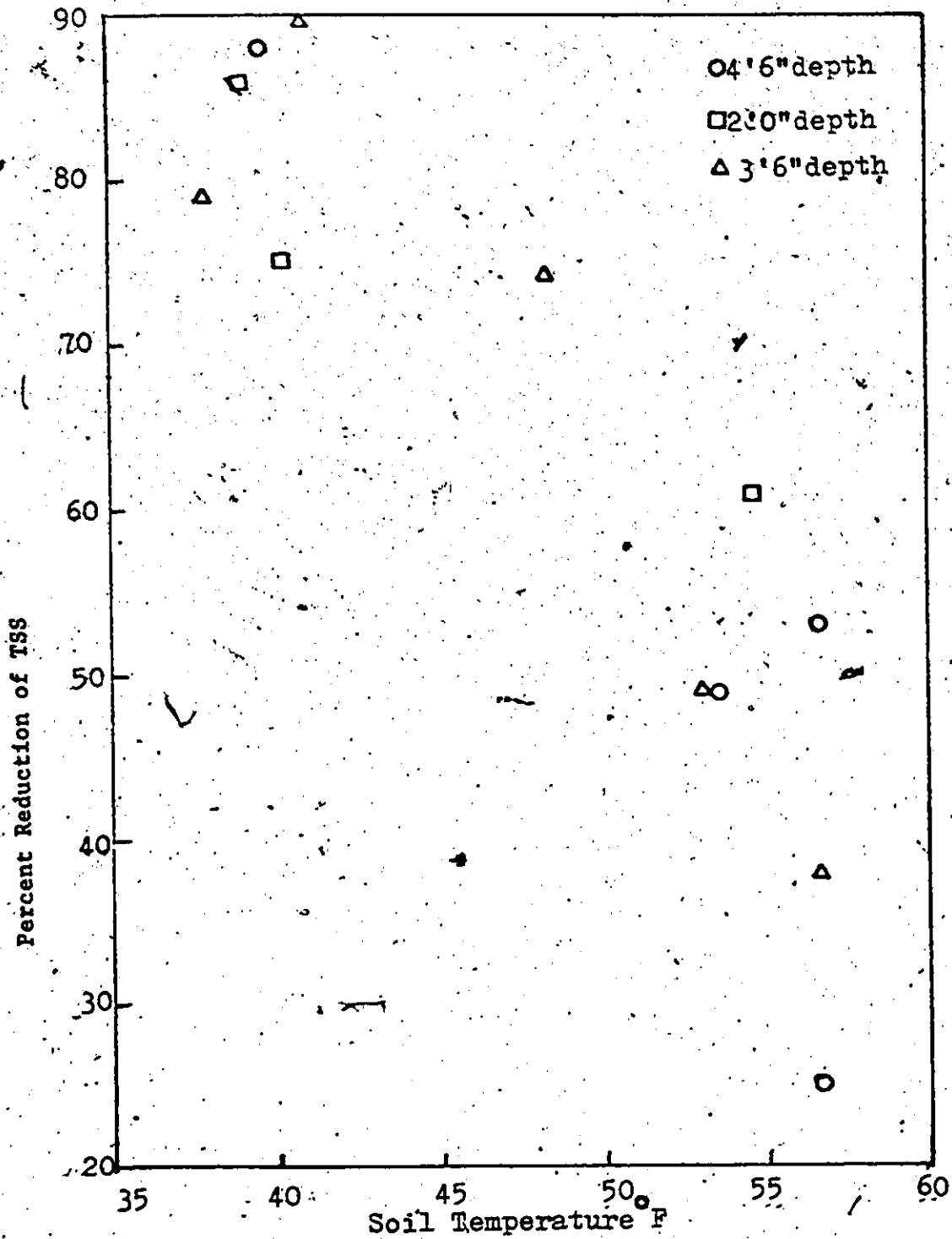


Fig. 27. Effect of Soil Temperature on TSS Reduction

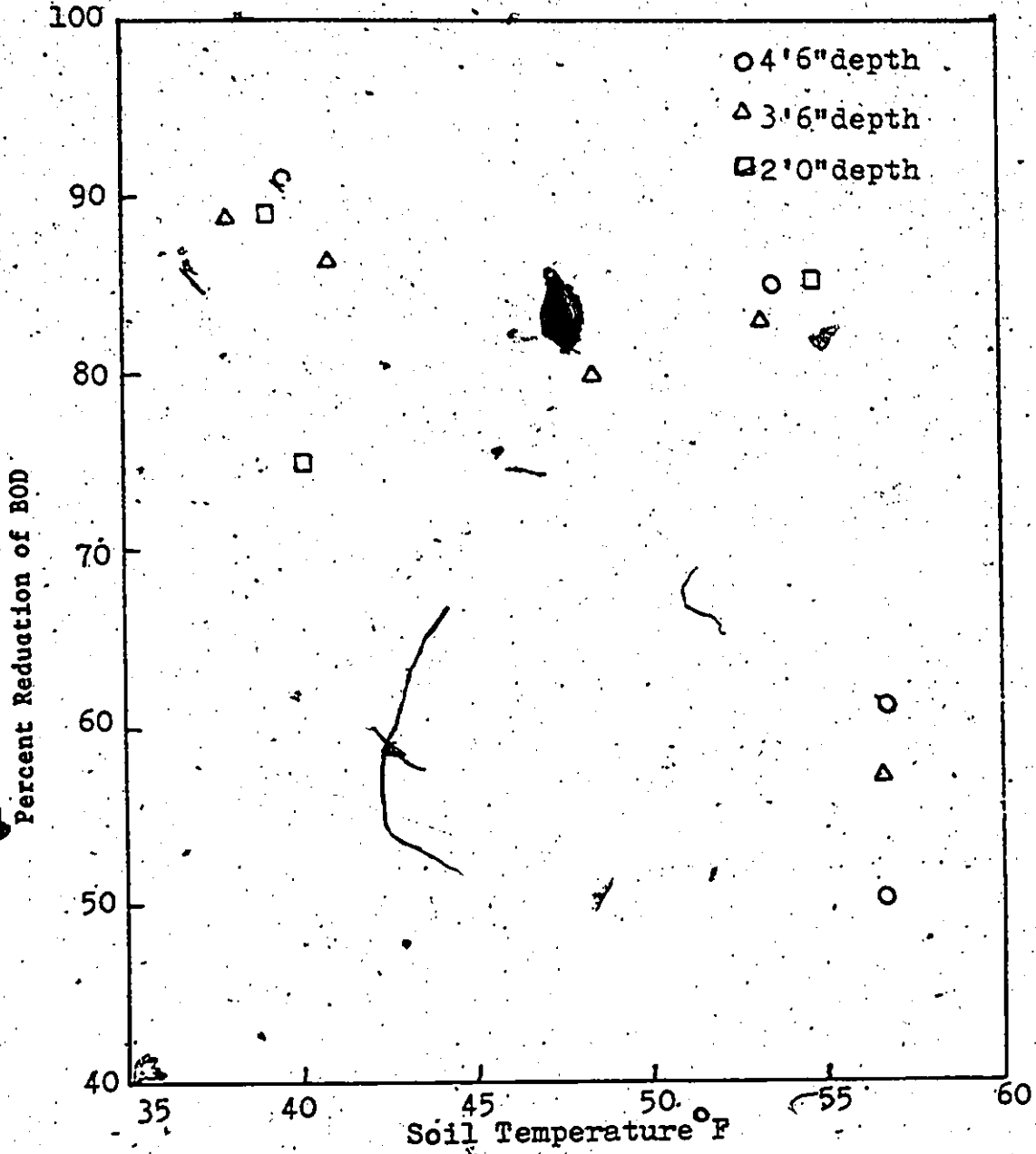


Fig. 28. Effect of Soil Temperature on BOD Reduction.

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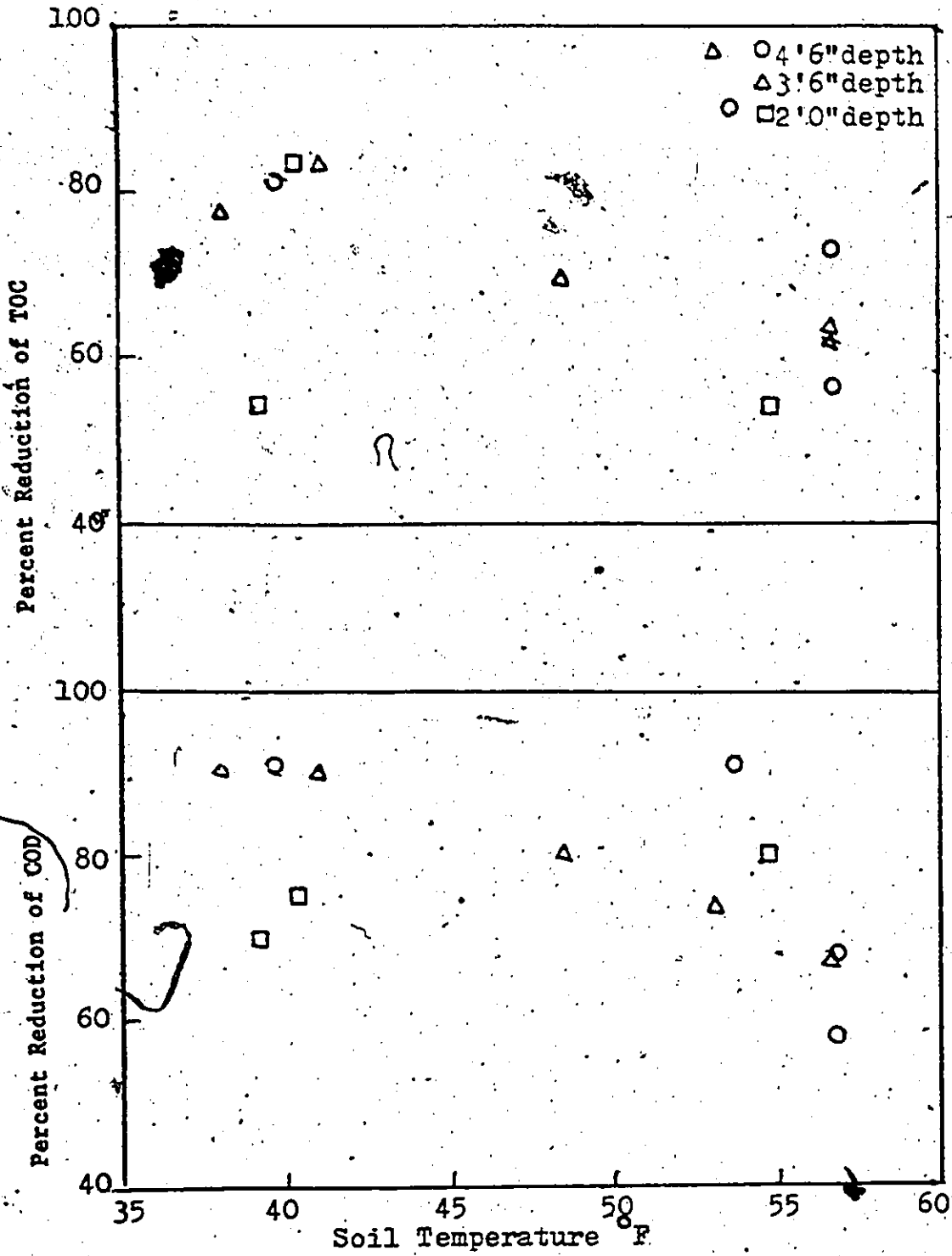


Fig. 29. Effect of Soil Temperature on COD and TOC Reduction

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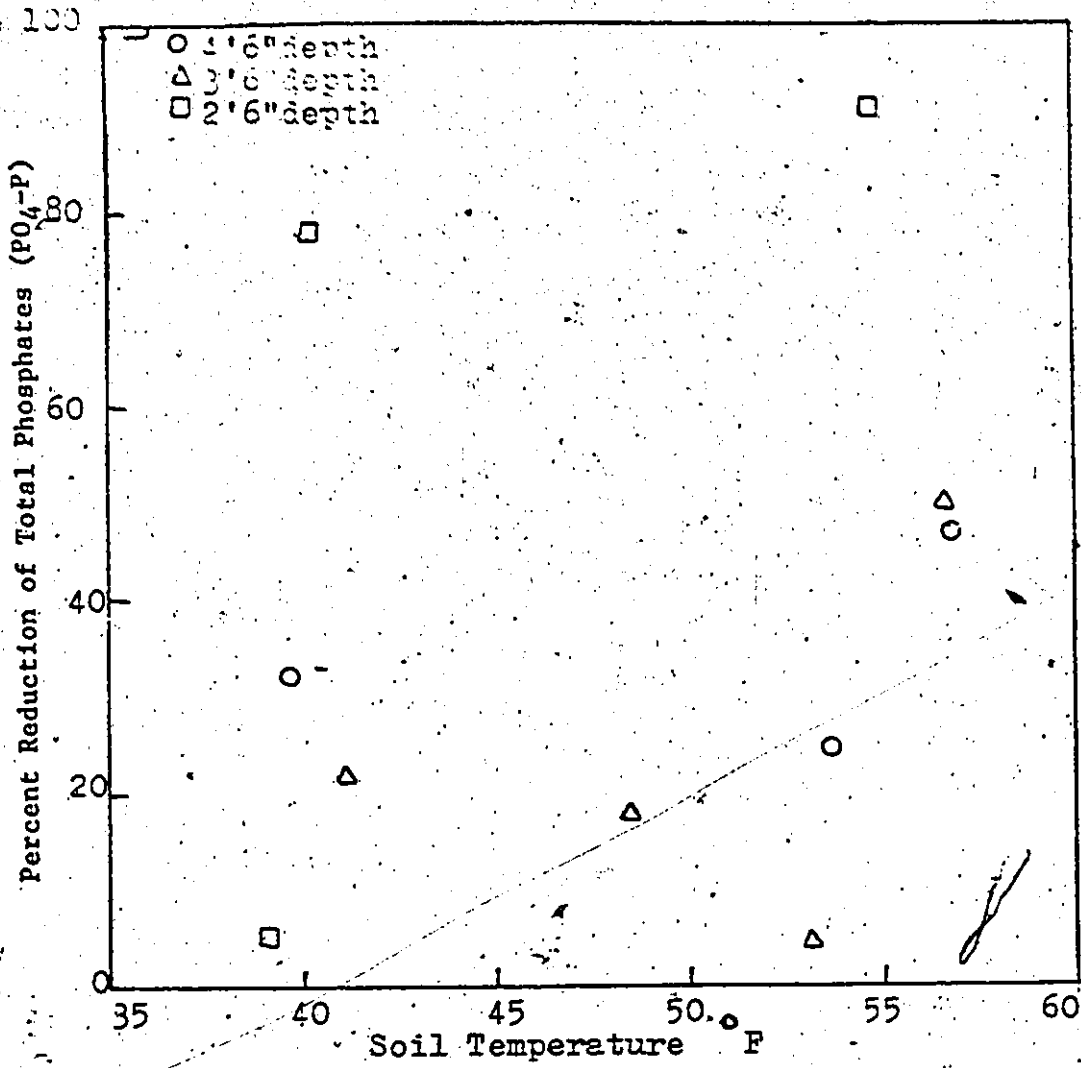


Fig.30. Effect of Soil Temperature on Total Phosphates Reduction

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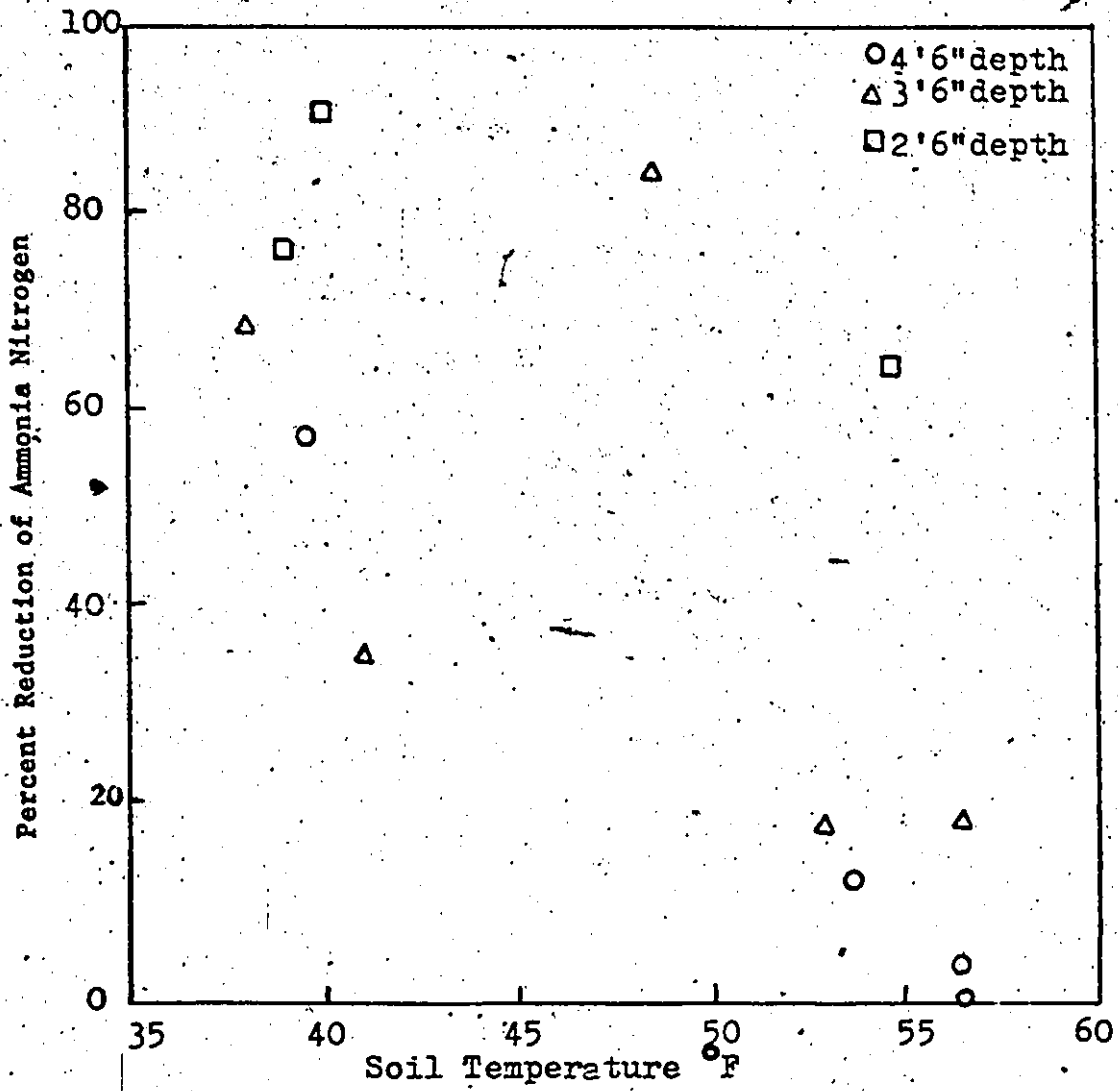


Fig. 31. Effect of Soil Temperature on Ammonia Nitrogen Reduction

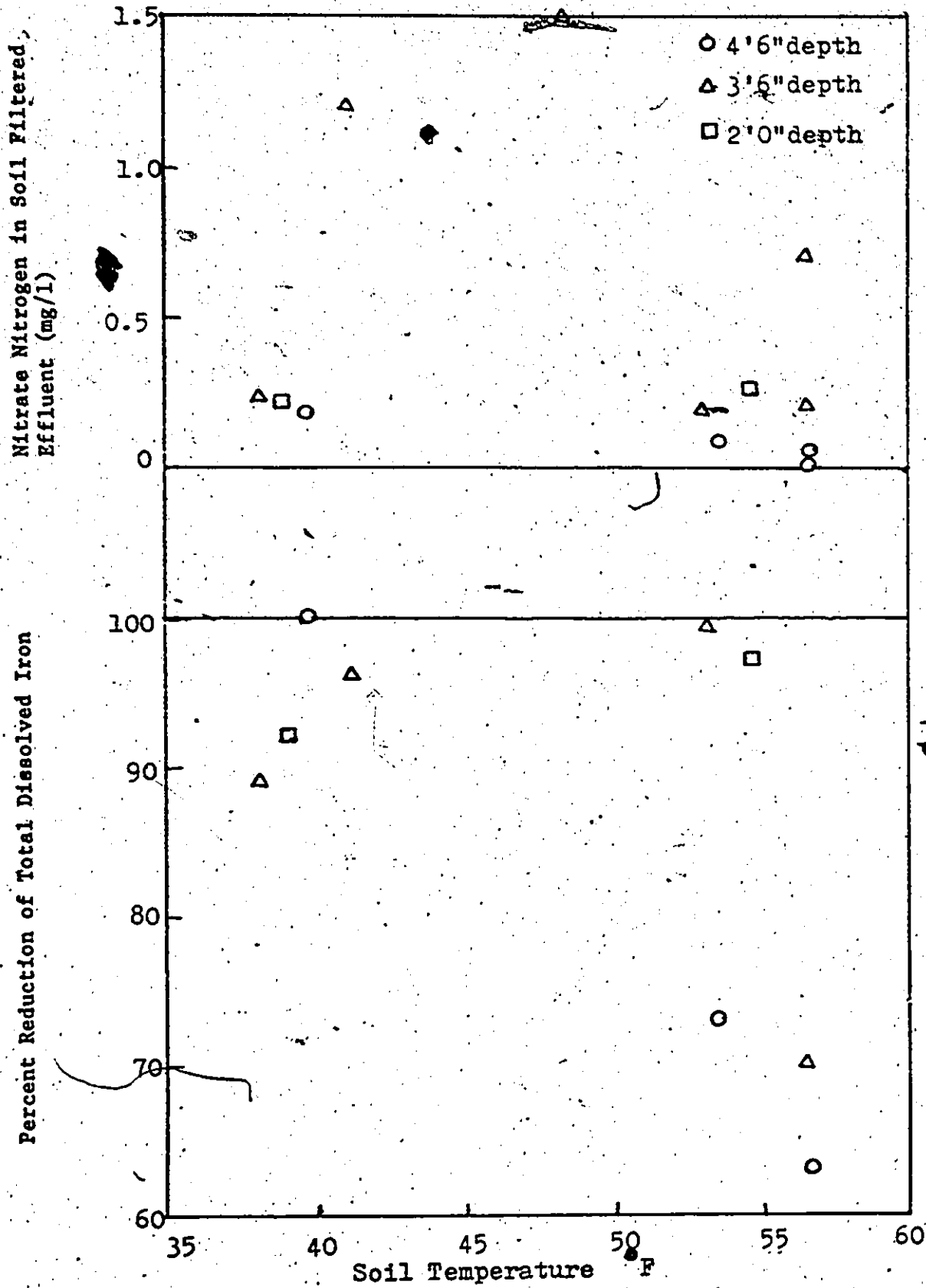


Fig. 32. Effect of Soil Temperature on Iron Reduction and on Nitrification

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duration of loading and other effects due to variation in soil depth and the depth to groundwater level. Reference to Figs. 27 to 32 shows that there is a wide scatter to decipher any trend. Physical adsorption increases with decrease in temperature (16,126) and this was observed especially in the case of phosphates by Mack (72). It is however observed that normal temperature variations generally have only minor effects on adsorption process in water and wastewater treatment (126). It is also necessary to keep in mind that this analysis had ignored the effects of duration of loading, unsaturated depth of soil and other effects of depth like oxygen penetration. The aspect of pollutant removal by plant uptake was also ignored in the analysis. However, when soil temperatures at various depths were independently taken into account for each depth along with air temperatures (Fig. 33), it can be concluded that during the period between July to October when the soil and air temperatures were relatively higher, the efficiencies showed an increasing trend for most of the parameters.

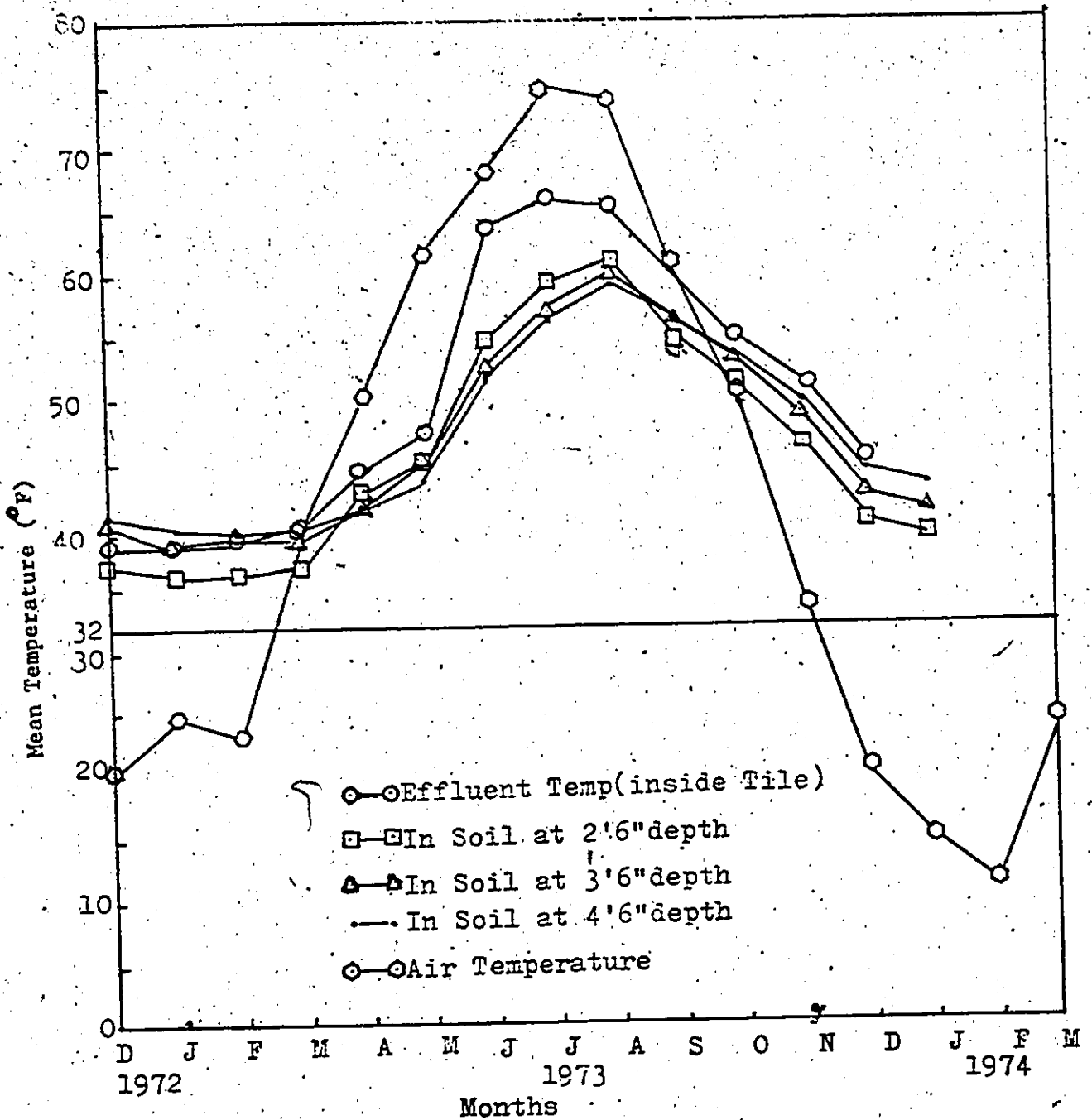


Fig. 33. Mean Monthly Air, Soil and Effluent Temperatures

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4.1.2 Results of Groundwater Quality Investigations

The variations in chemical characteristics of the groundwater adjoining the test tile with time for the entire period of 65.5 weeks covering the investigation are given in Table 31 and Figs. 34 and 35. Mean monthly chemical characteristics of the adjoining groundwater are shown in Table 32 and Figs. 36 to 38. Samples were not taken for four months of August, September, October and November of 1973 as the groundwater receded from the bottom of the observation trench, from which samples were collected. Variations in bacteriological characteristics of the adjoining groundwater with time for the period February to July 1973 are shown in Table 33 and Figs. 39 and 40.

Temporal Variations of Adjacent Groundwater Quality

An analysis of the variations with time of the various parameters for the groundwater adjacent to the test tile revealed the following features. Though the groundwater tended to move to the alkaline range in the early weeks of loading, it subsequently moved back to slightly acidic levels just below pH 7.0 for most of the period except for occasional values equal to or slightly higher than pH 7.0. It would appear that the influence of the septic tile on the adjacent groundwater pH was not perceptible. TSS, BOD, COD and TOC generally exhibited a rising trend, except for the period when loadings were discontinued, i.e., from 12th to 16th week

Table 31. Chemical Characteristics of Adjoining Groundwater

Date of sample	Time in weeks from start of loading	pH	TSS mg/l	VSS mg/l	SS mg/l	Fixed	BOD mg/l	COD mg/l	TOC mg/l	PO ₄ -P mg/l	NH ₃ -N mg/l	NO ₃ -N mg/l	Total Soluble Fe mg/l	Chlorides mg/l
15-12-72	0	6.82	56	40	16		41	0.0	9.0	6.2	1.40	0.20	0.0	3.0
27-12-72	1.5	7.70	20	-	-		13.3	29.8	10.0	-	-	0.08	0.0	-
04-01-73	2.5	7.10	12	-	-		16.0	33.4	8.0	-	-	0.12	0.0	-
11-01-73	3.5	7.0	116	8	108		59.0	82.0	21.0	-	48.0	0.18	0.0	-
18-01-73	4.5	7.22	100	24	76		59.0	257.0	38.0	10.0	49.2	-	0.0	-
29-01-73	6.0	6.90	128	100	28		55.0	183.5	27.0	21.6	400.0	-	0.5	-
05-02-73	7.0	6.80	60	32	28		94.0	152.0	36.0	27.0	250.0	0.04	0.5	-
12-02-73	8.0	6.90	44	16	28		100.0	179.0	29.0	10.2	50.0	0.04	0.5	-
26-02-73	10.0	6.74	92	49	43		155	243	16	12.6	100.0	0.04	1.0	-
05-03-73	11.0	7.00	86	48	38		146	288	15	6.5	70.0	0.06	0.0	-
12-03-73	12.0	6.90	84	40	44		64	147	22	6.2	22.7	0.00	1.7	-
26-03-73	14.0	6.72	68	20	48		26	65.5	51	12.6	10.0	0.10	0.5	14
02-04-73	15.0	6.80	64	28	36		60	21.0	16	1.4	11.3	0.12	1.5	15
16-04-73	17.0	7.0	11	7.5	3.5		68	47.6	10	0.5	8.6	0.02	2.0	74
23-04-73	18.0	6.72	16	12	4		43	65.4	13	1.5	12.1	0.00	0.5	21
04-05-73	19.5	6.7	20	12	8		29	53.6	12	3.7	8.6	0.27	0.5	20
14-05-73	21.0	6.6	24	6	18		73	63.6	8	2.4	22.7	0.00	2.8	29
28-05-73	23.0	6.58	38	24	14		83	138	25	3.0	49.3	0.04	8.0	36
01-06-73	23.5	6.72	134	46	88		76	140	41	3.9	60.7	0.02	0.0	36
11-06-73	25.0	6.76	62	44	18		257	138	34.5	1.25	87.0	0.01	1.5	36
18-06-73	26.0	6.70	44	26	18		67	287	43	9.2	76.6	0.04	1.0	36
25-06-73	27.0	6.72	50	48	2		107	290	49	10.0	76.6	0.06	0.5	38
13-07-73	29.5	6.62	50	38	12		93	155	45	11.0	93.3	0.08	1.76	36
23-07-73	31.0	6.60	88	66	22		145	203	57	5.0	84.7	0.04	2.04	50
18-12-73	52.0	6.60	34	30	4		139	197	24	27.0	12.75	0.04	-	64
30-01-74	58.0	6.80	44	34	10		46	81	20	10.0	38.0	2.0	0.5	49
21-02-74	61.0	6.80	36	30	6		42	52	25	16.0	54.7	0.32	0.3	47
25-03-74	65.5	7.15	10	6	4		32	54	5	10.0	38.0	0.30	0.3	40

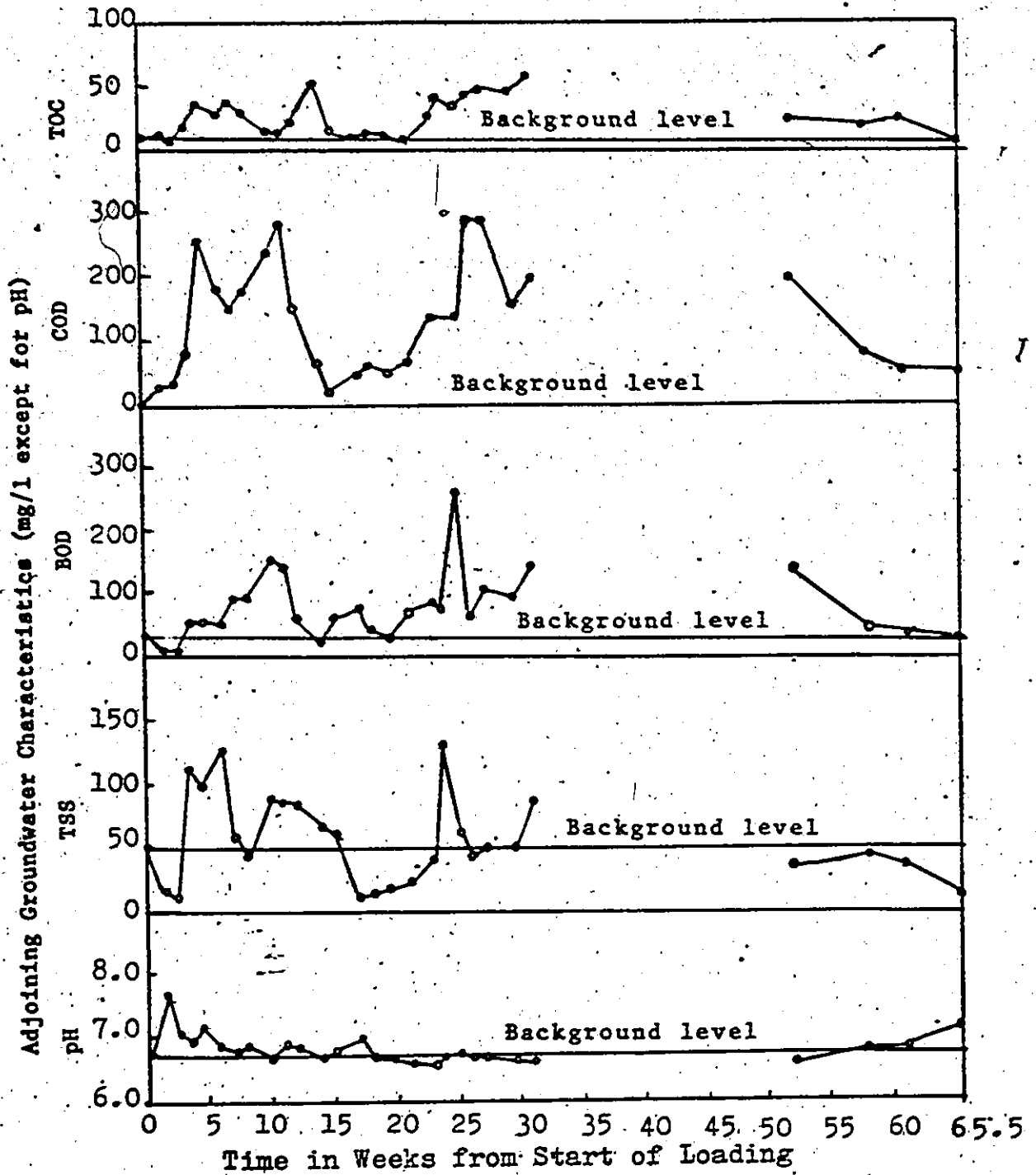


Fig. 34. Variations in Adjoining Groundwater Quality (pH, TSS, BOD, COD and TOC) with Duration of Loading

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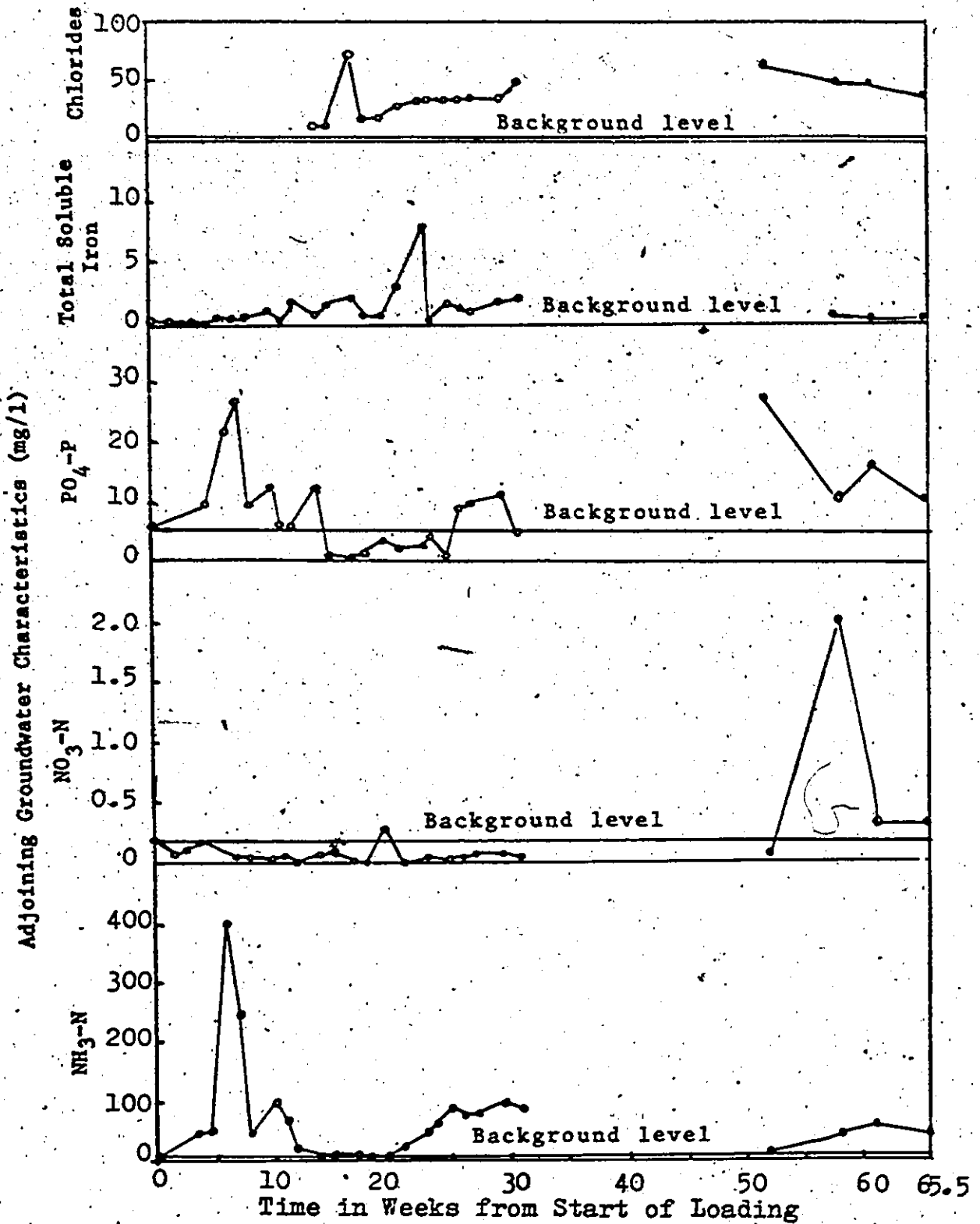


Fig.35. Variations in Adjoining Groundwater Quality (NH₃-N, NO₃-N, PO₄-P, Total Soluble Fe and Chlorides) with Duration of Loading.

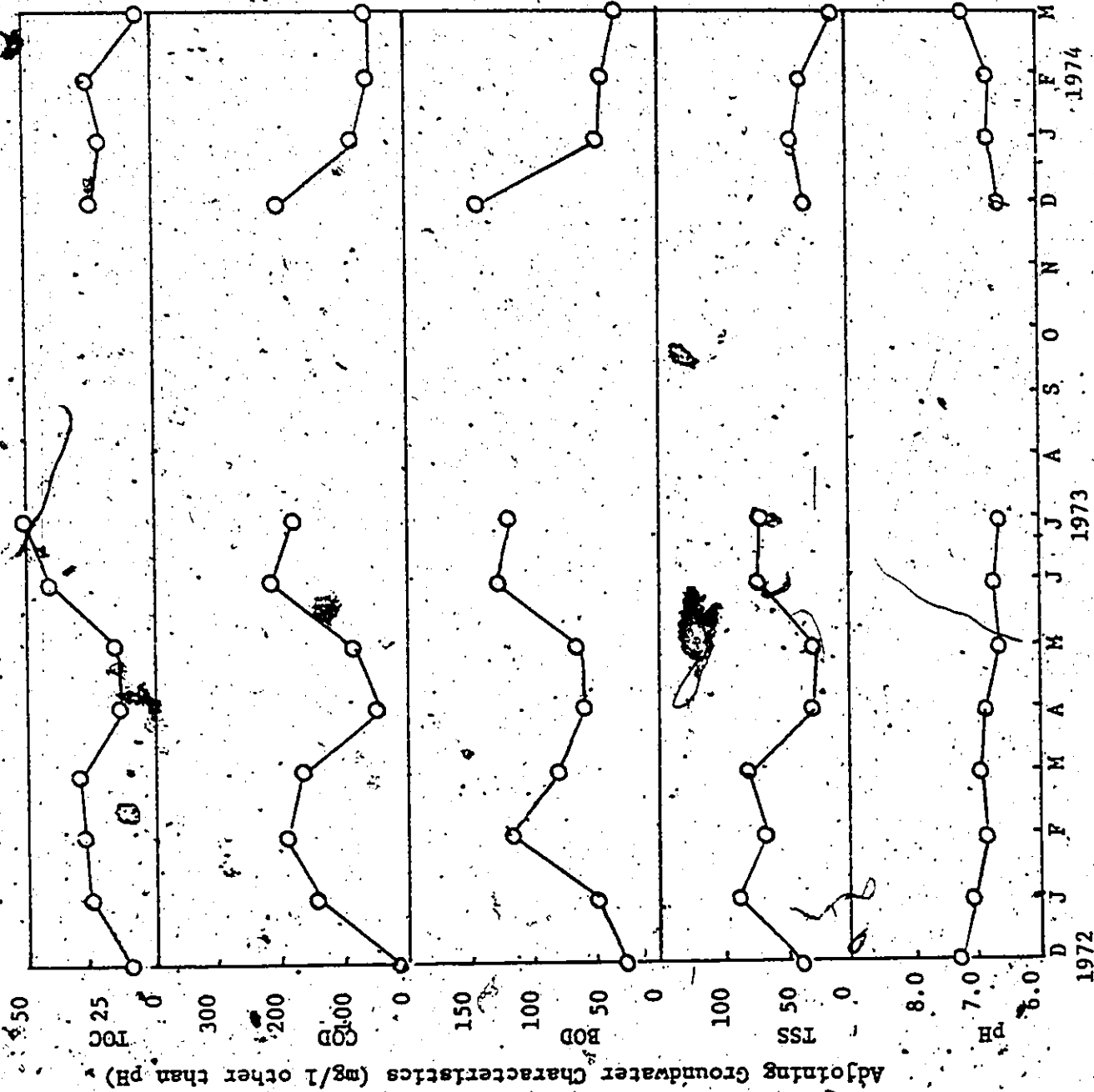
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Table 32. Mean Monthly Chemical Characteristics of Adjoining Groundwater

Month	pH	TSS	BOD	COD	TOC	PO ₄ -P	NH ₃ -N	NO ₃ -N	Total Soluble Iron	Chlorides
December 1972	7.26	38	27	15	9.5	6.2*	1*	0.14	0.0	3*
January 1973	7.06	89	48	139	23.5	15.8	166	0.15	0.1	-
February 1973	6.81	65	116	191	27.0	16.6	133	0.04	0.7	-
March 1973	6.87	79	79	167	29.3	8.4	34	0.05	0.7	14
April 1973	6.84	30	57	45	13.0	1.1	11	0.05	1.3	37
May 1973	6.63	27	62	85	15.0	3.0	27	0.10	3.8	28
June 1973	6.75	73	125	214	41.9	6.1	75	0.03	0.8	37
July 1973	6.61	69	119	179	51.0	8.0	90	0.06	1.9	43
December 1973*	6.60	34	139	197	24.0	27.0	13	0.04	-	64
January 1974*	6.80	44	46	81	20.0	10.0	38.0	2.0	0.5	49
February 1974*	6.80	36	42	52	25.0	16.0	54.7	0.32	0.3	47
March 1974*	7.15	10	32	54	5.0	10.0	38.0	0.30	0.3	40

* Single value only

Note: All figures are in mg/l except for pH



Time in Months
1972 1973 1974
Fig. 36. Mean Monthly Variations in Adjoining Groundwater Characteristics (pH, TSS, BOD, COD, and TOC)

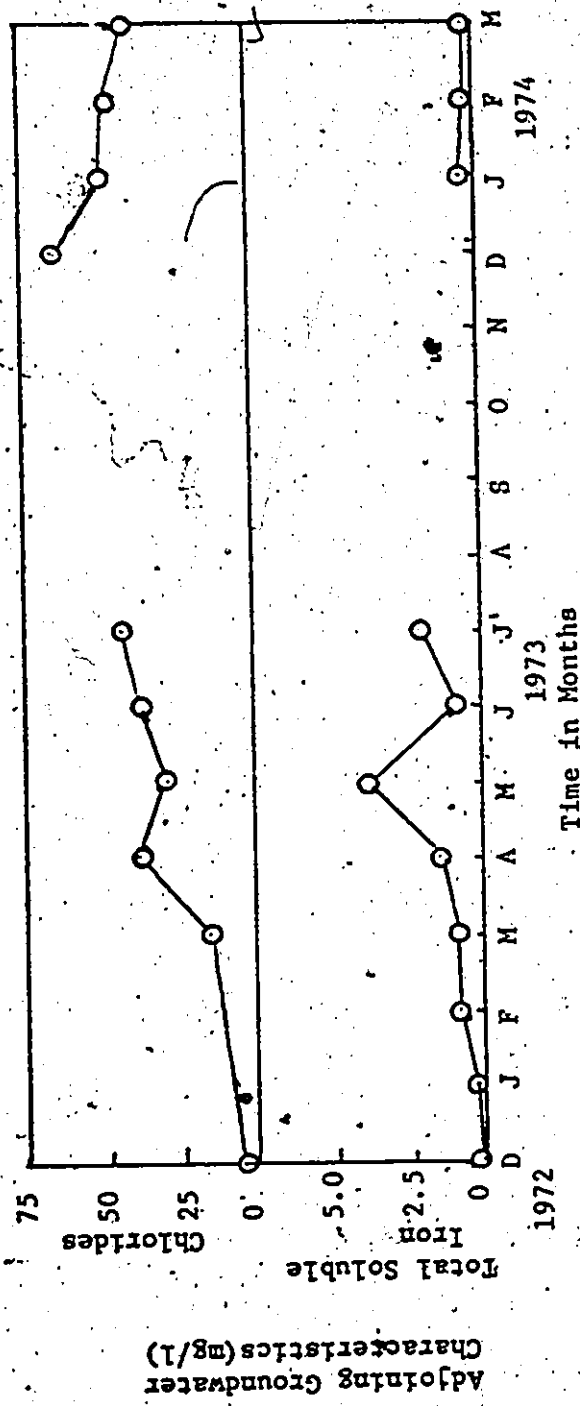


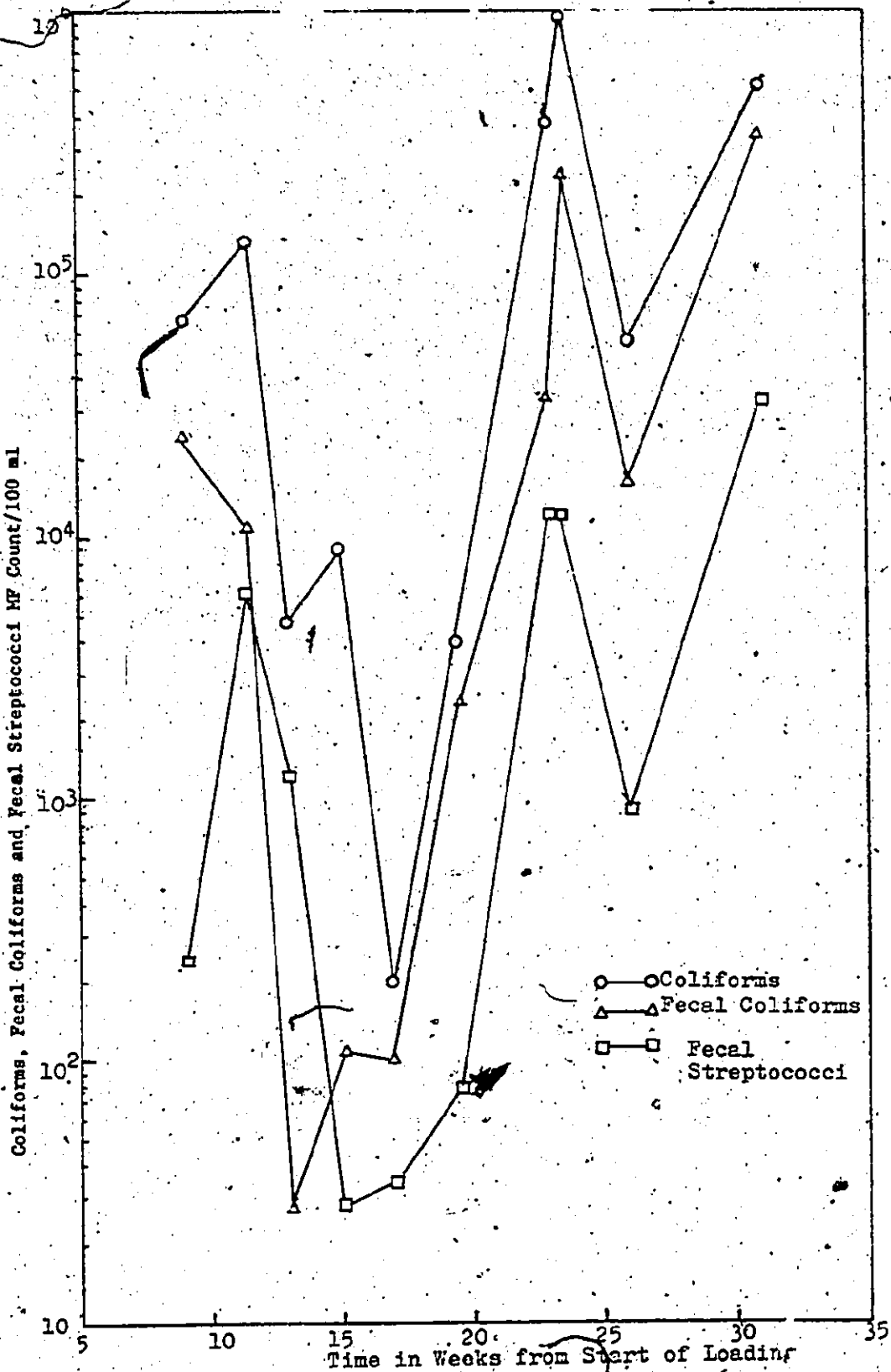
Fig. 38. Mean Monthly Variations in Adjoining Groundwater Characteristics (Iron and Chlorides)

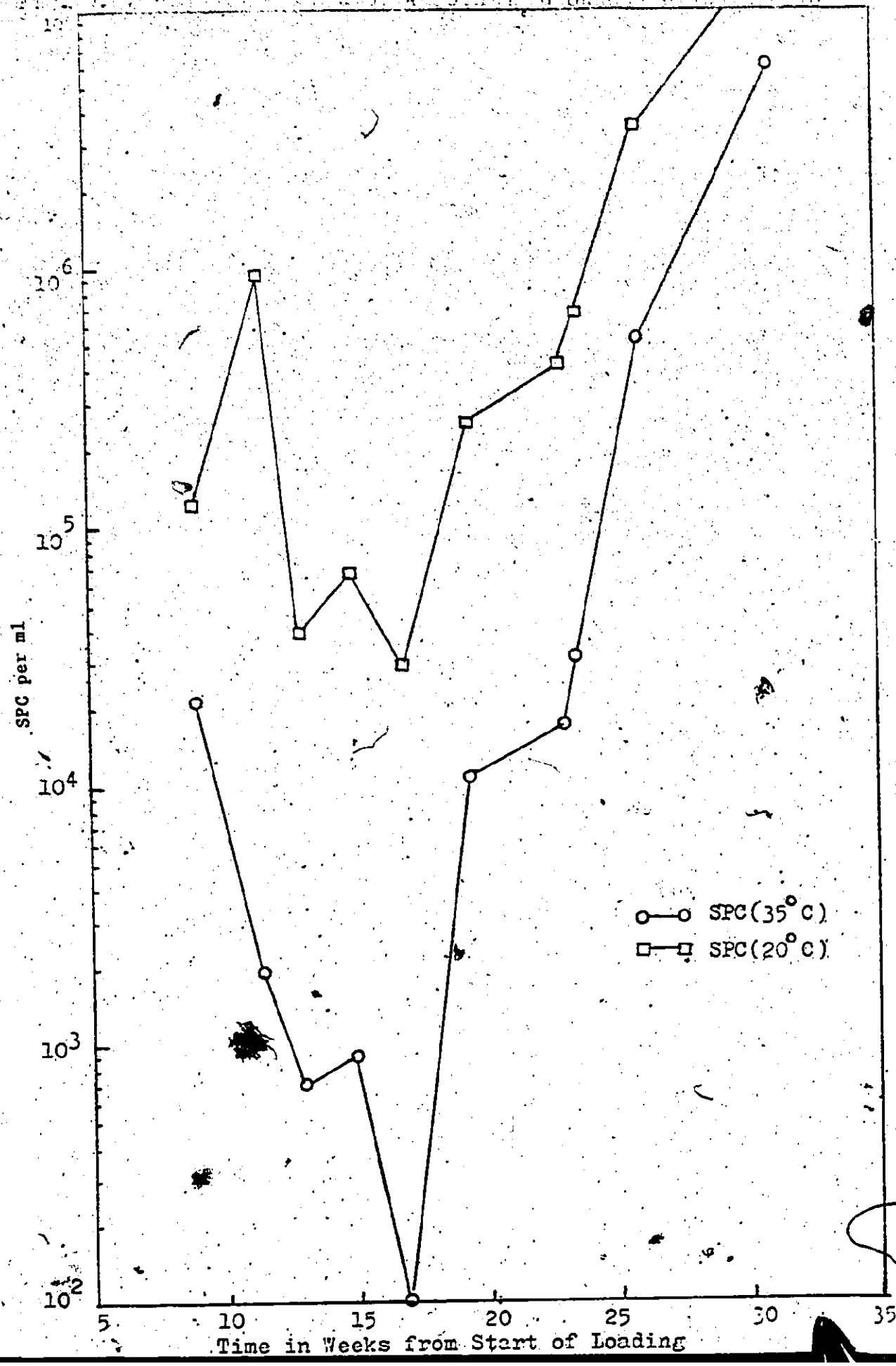
Table 33. Variations in Bacteriological Characteristics of Adjoining Groundwater with Time

Date	Time in Weeks from Start of Loading	SPC per ml			Pseudomonas aeruginosa MPN/100 ml
		Coliform MF count/100 ml	Fecal Coliform MF count/100 ml	Fecal Streptococci MF count/100 ml	
19-02-73	9.0	67,000	24,000	240	7
09-03-73	11.5	130,000	11,000	6,000	4
19-03-73	13.0	4,900	27	1,200	11
02-04-73	15.0	9,000	110	28	17
16-04-73	17.0	200	100	34	8
04-05-73	19.5	4,000	2,400	78	<2
28-05-73	23.0	380,000	34,000	12,000	2
01-06-73	23.5	990,000	240,000	12,000	<0.2
18-06-73	26.0	57,000	16,000	900	2
23-07-73	31.0	530,000	340,000	32,000	15

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Fig. 30. Variations in Coliform, Fecal Coliform and Fecal Streptococci Counts in Adjoining Groundwater with Time





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from the start and from 63rd to 65.5th week when the study ended. Though TSS and TOC values were smaller at the 52nd week than they were at the 31st week, BOD and COD values were nearly the same. It would however be reasonable to assume that these parameters would have declined in summer and early fall and then increased in values when the water level rose back to the bottom of the trench. In the case of ammonia nitrogen, there was an unusual peak at the end of the 6th week, but it levelled off to a more gradual declining trend till the 21st week, rising again beyond this. $\text{NH}_3\text{-N}$ values were much lower in the later period of the study. Nitrates generally dropped in the earlier periods of operation, showing a significant increase during the period when there was no loading and for a couple of weeks thereafter. Phosphates increased with time till the 14th week, but thereafter declined in value till the 25th week, mostly due to absence of loading from 12th to 16th week. Phosphate level was significantly very high at 52nd week, when sampling was resumed, indicating the possibility that the adsorbed phosphate might have been brought back into solution by the rising groundwater. Iron exhibited though not a distinctly rising trend including some very low values during the early weeks. Chlorides have remained rather steady apart for an unusual peak on the 17th week after loading.

In the case of bacteriological characteristics, it may be observed from Figs. 39 and 40, p.157-58, that the

total microorganisms as exhibited by SPC, coliform, fecal coliforms and fecal streptococci counts significantly dropped when loading was discontinued and these values started to rise, increasing significantly as time passed by. However, no such trend was noticeable in the Pseudomonas aeruginosa levels. On a general analysis it may be concluded that both the important chemical and bacteriological parameters increased with time when loading was continued, indicating that the removal efficiencies may tend to decline with duration of loading. It may be however necessary to examine many of these results, keeping in view the environmental factors that influenced the performance of the system.

During December 1972 and early January 1973, when soil depth available for pollutant travel varied between 15" and 9", the pollutant increase with time was not so high in the early 3 to 4 weeks. In February and afterwards, the unsaturated soil available for travel to groundwater became negligible, making dilution the only factor that would reduce the pollutant concentration in groundwater. Dilution was maximum at the time of snowmelt and during the months of March and April, coupled with the fact there was discontinuance of loading, the groundwater showed a trend to return to its earlier levels prior to loading. It may be realistic to assume that the pollutant concentrations would have declined in summer and early fall, when greater soil depth was available for pollutant travel. It may be observed that phosphate

concentration was quite high compared to the earlier period, when the groundwater was sampled on its rising trend, indicating the possibility of adsorbed phosphates in the soil being brought back to solution by rising groundwater. Thus it may be concluded that the level of the water table was an important factor for stabilization of the effluent and also for minimizing groundwater pollution.

Groundwater Quality below the Existing Tile Field.

An examination of the chemical and bacteriological characteristics of the groundwater below the existing system (Tables 34 and 35), in comparison with background levels of the groundwater in the area showed that though the pollutant concentrations in the groundwater were much lower than that in the septic tank effluent (either due to passage through soil or dilution or both), the concentrations were quite high compared to background levels, especially COD, TOC, phosphates ammonia and chlorides in some cases. Phosphate levels as high as 21.6 mg/l were observed; $\text{NH}_4\text{-N}$ levels in the 50-75 mg/l range were observed under one lateral; chlorides have registered an increase of 20-30 mg/l from background levels under two laterals. The system had been in operation for 3 years when the sampling was carried out. These results showed that though soil removed a good proportion of pollutants from the septic tank effluent, the concentrations in the groundwater observed under the three laterals, significantly varied,

Table 34. Chemical Characteristics of Groundwater below Existing Septic Tile System

Date of Sample	pH	TSS mg/l	VSS mg/l	SS mg/l	Fixed				TOC mg/l	PO ₄ -P mg/l	NH ₃ -N mg/l	NO ₃ -N mg/l	Total Soluble Fe mg/l	Chlorides mg/l
					BOD mg/l	COD mg/l	BOD mg/l	COD mg/l						
<u>Location "A" under Lateral 2</u>														
11-06-73	7.12	12	8	4	183	42	5	1.20	0.33	0.01	5.8	4		
18-06-73	6.7	18	12	6	48	193	6	0.10	0.67	0.02	0.0	4		
25-06-73	6.7	4	-	-	19	n11	5	20.0	-	0.04	0.0	3		
13-07-73	6.5	42	28	14	21	47	12	0.8	6.7	0.02	0.2	5		
<u>Location "B" under Lateral 2</u>														
11-06-73	7.11	12	6	6	176	77	7	1.20	2.53	0.04	5.0	3		
18-06-73	6.7	12	8	4	40	187	8	0.25	2.33	0.02	0.0	3		
25-06-73	6.6	16	-	-	29	45	9	21.6	2.40	0.02	0.0	4		
13-07-73	6.6	34	28	6	33	101	23	2.0	13.3	0.08	4.04	8		
23-07-73	6.6	94	40	54	78	192	41	1.5	10.0	0.04	3.80	10		
10-08-73	6.94	120	102	18	105	156	7	15.6	31.3	0.00	1.0	10		
<u>Location "C" under Lateral 3</u>														
11-06-73	7.25	30	18	12	186	138	49.5	1.20	75.0	0.0	1.5	23		
18-06-73	7.00	12	8	4	61	187	41	1.50	58.0	0.20	0.2	23		
25-06-73	6.50	-	-	-	52	157	54	14.2	63.3	0.02	0.5	23		
13-07-73	6.50	-	-	-	28	140	25	1.0	36.7	0.32	0.94	29		
<u>Location "D" under Lateral 5</u>														
11-06-73	7.04	8	4	4	560	218	15	1.20	6.30	0.12	3.0	22		
18-06-73	6.64	16	12	4	42	0	21	-	-	0.22	0.4	22		
25-06-73	6.55	14	12	2	26	49	22	1.5	9.2	0.14	1.8	25		
13-07-73	6.46	76	56	20	38	97	25	1.5	14.7	0.02	0.18	33		
<u>Groundwater Sample Away From System</u>														
02-04-73	7.0	40	24	16	35	35	7	4.4	1.3	0.00	0.80	2		

Table 35. Bacteriological Characteristics of Groundwater below Existing Septic Tile System

Location	Date of Sample	Coliform		Fecal Coliform		Fecal Streptococci		SPC per ml		Pseudomonas aeruginosa MPN/100 ml
		MF count/ 100 ml	MF count/ 100 ml	MF count/ 100 ml	MF count/ 100 ml	35°C	20°C			
'B' under Lateral 2	23-07-73	540,000	660	130,000	22x10 ⁴	28x10 ⁴	2			

because of the variations in the depth to groundwater table (Table 36) and also probably due to non-uniform loadings dictated by the hydraulics of the system in place.

Horizontal Travel of Pollutants

BOD, COD, TOC, $\text{NH}_3\text{-N}$ and chloride levels in groundwater downstream from the end of the test tile shown in Table 37 and Figs. 41 and 42, exhibited a declining trend. Nitrates, however, showed an increase in the first ten feet, declining thereafter. During this first ten feet, ammonia nitrogen dropped down from an average value of about 40 mg/l to 1.0 mg/l, while the average nitrate nitrogen value registered an increase from 0.01 mg/l to 0.45 mg/l. Apparently, the ammonia nitrogen was quickly oxidized in the aerobic soil zone and converted to nitrate nitrogen. Since ammonia is readily adsorbed by the soil, the phenomena of adsorption and biological oxidation by nitrifying bacteria are interrelated. This was also observed by Preul (93), who found that biological oxidation was the dominant mechanism occurring in the soil to reduce ammonia concentration and that the oxidation occurred near the tile field. Similar trends in the decline of concentration of nitrates and chlorides, in the groundwater away from the tile field are reported by Polkowski and Boyle (88) (Fig. 5, page 16). No significant trend was however noticeable in the downstream concentrations of phosphates or total soluble iron. In the case of indicator organisms,

Table 36. Groundwater Level Below the Existing Septic Tile System

Date	Location	Lateral No.	Groundwater level from ground in inches
11-06-73	A	2	33
18-06-73	A	2	20
25-06-73	A	2	31
13-07-73	A	2	22
11-06-73	B	2	32
18-06-73	B	2	19
25-06-73	B	2	20
13-07-73	B	2	20
23-07-73	B	2	36
10-08-73	B	2	36
11-06-73	C	3	23
18-06-73	C	3	14
25-06-73	C	3	17
13-07-73	C	3	16
11-06-73	D	5	40
18-06-73	D	5	25
25-06-73	D	5	30
17-07-73	D	5	29

Table 37. Groundwater Chemical Characteristics from End of Septic Tile

S.No.	Characteristics of Groundwater	Date of Collection	Distance in feet from end of tile					
			0	10	20	30	40	50
1	pH	14-05-73	6.60	6.60	6.60	6.50	6.70	6.60
		01-06-73	6.72	6.84	6.76	6.67	6.72	6.67
	Mean		6.66	6.72	6.68	6.58	6.71	6.64
2	BOD ₅ 20° (mg/l)	14-05-73	73	38	42	45	38	48
		01-06-73	76	24	14	18	18	14
	Mean		75	31	28	32	28	31
3	COD (mg/l)	14-05-73	64	8	36	8	12	0.0
		01-06-73	140	68	72	53	61	49.0
	Mean		102	38	54	31	37	25.0
4	TOC (mg/l)	14-05-73	8	0.0	2.0	7.0	3.0	1.0
		01-06-73	41	1.5	1.0	0.5	1.0	3.0
	Mean		24.5	0.75	1.5	3.75	2.0	2.0
5	PO ₄ -P (mg/l)	14-05-73	2.40	2.75	2.0	0.50	12.3	12.3
		01-06-73	3.90	5.40	3.5	5.0	5.4	3.9
	Mean		3.15	4.10	2.75	2.75	8.9	8.1
6	NH ₃ -N (mg/l)	14-05-73	22.7	1.70	1.67	0.67	0.33	0.16
		01-06-73	60.7	0.33	0.33	0.46	0.60	0.60
	Mean		41.7	1.00	1.00	0.57	0.47	0.38
7	NO ₃ -N (mg/l)	14-05-73	0.00	0.26	0.12	0.08	0.00	0.00
		01-06-73	0.02	0.64	0.36	0.18	0.13	0.02
	Mean		0.01	0.45	0.24	0.13	0.07	0.01
8	Total Soluble Fe (mg/l)	14-05-73	2.8	1.3	3.0	0.5	0.5	0.5
		01-06-73	0.0	3.0	1.8	0.9	8.8	3.8
	Mean		1.4	2.15	0.7	4.7	2.15	
9	Chloride (mg/l)	14-05-73	29	5	11	5	5	4
		01-06-73	36	5	4	5	6	4
	Mean		33	5	7.5	5	5.5	4

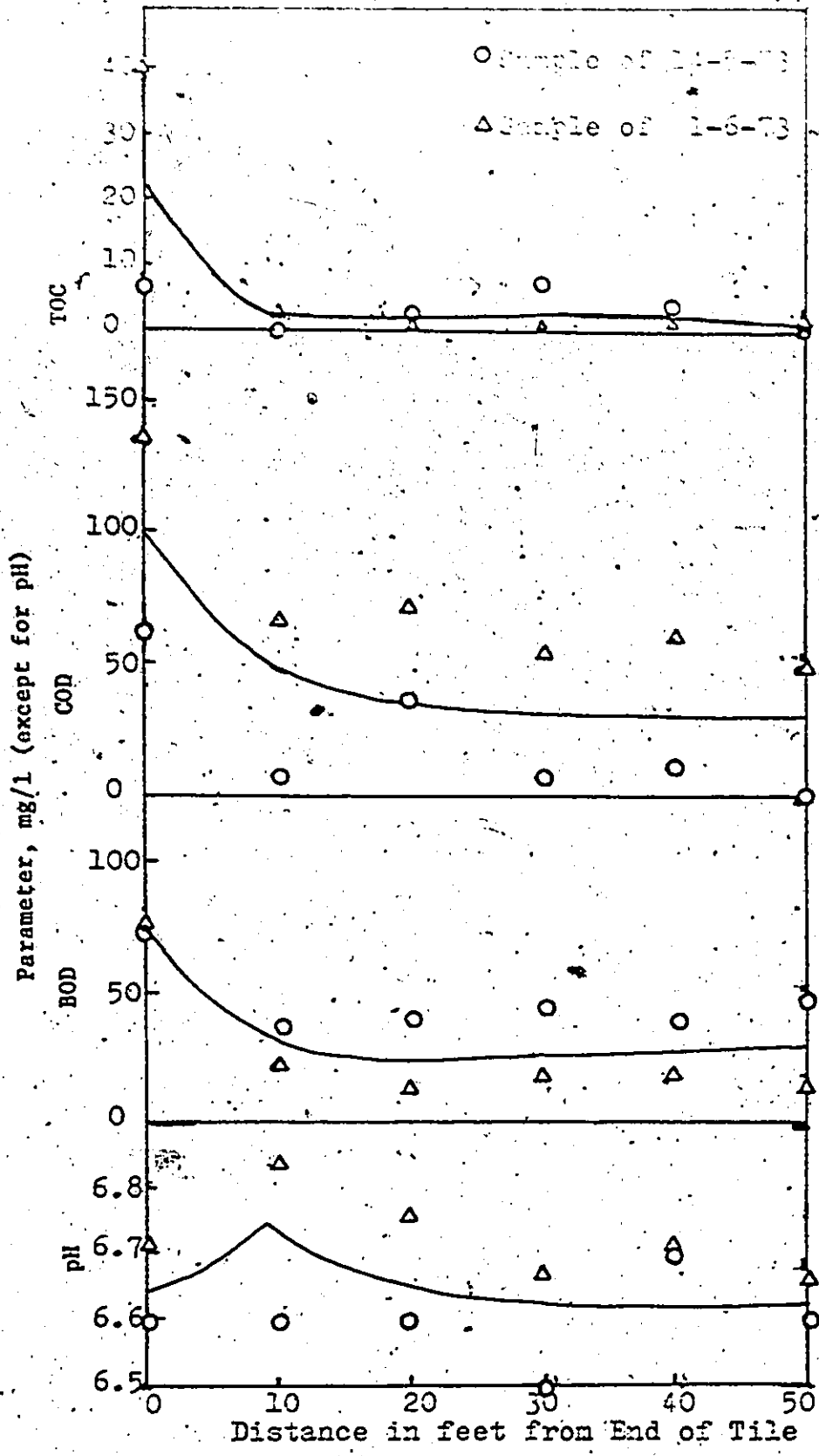


Fig. 41. pH, BOD, COD and TOC in Groundwater Downslope from End of Septic Tile.

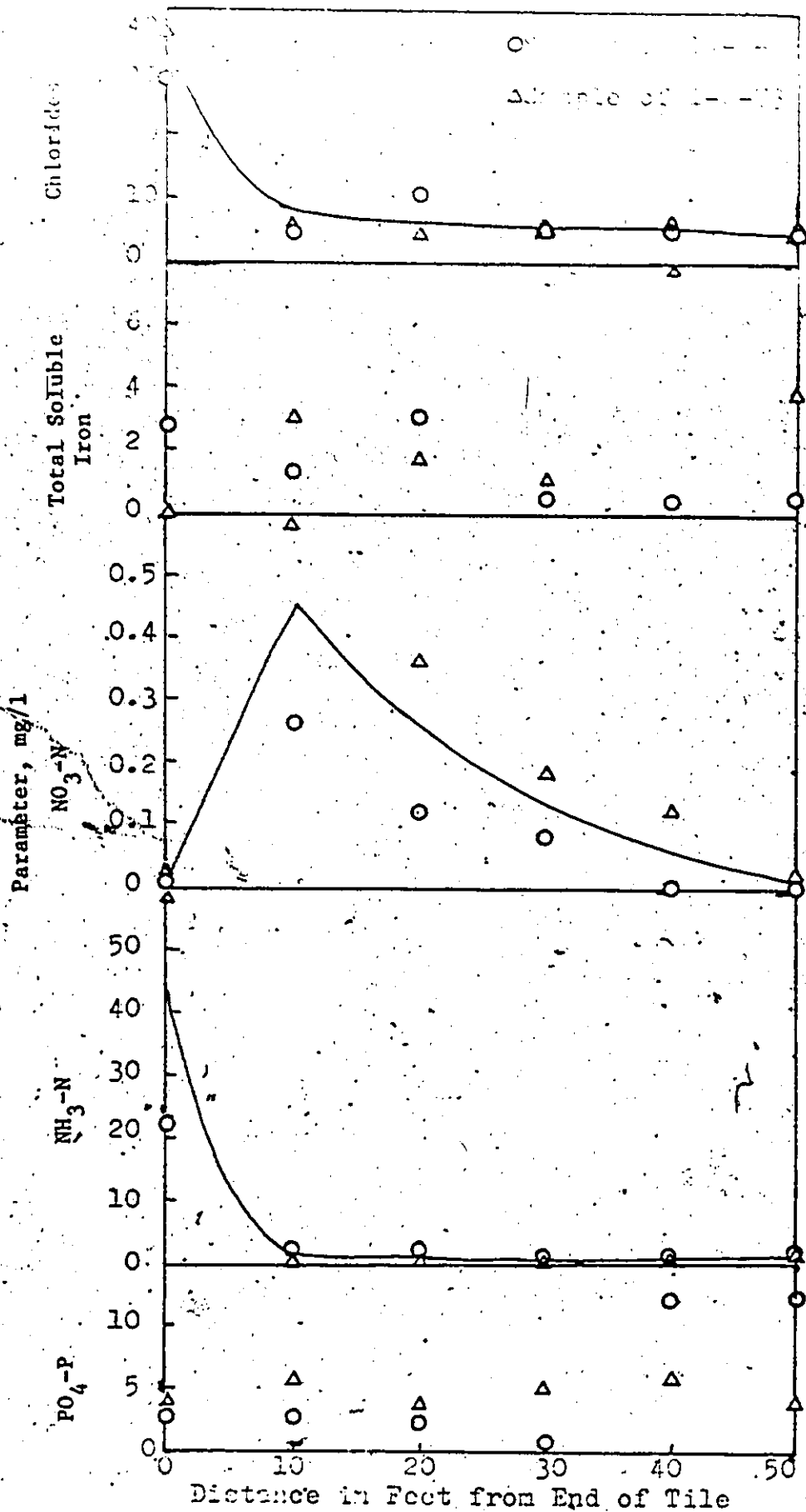


Fig. 42. Total Phosphate, Ammonia Nitrogen, Nitrate Nitrogen, Iron and Chloride in Groundwater Downslope from End of Septic Tile

coliforms, fecal coliforms and fecal streptococci exhibited a declining trend with distance away from the septic tile (Table 38 and Figs. 43 to 46). The groundwater samples were taken after about 6 months of operation of the septic tile. The presence of fecal coliforms and fecal streptococci at considerable levels at the point 50' away was strong evidence that the pollutants from the septic tank effluent had moved this distance. Thus it was observed that the concentration of pollutants was highest near the tile and reduced significantly with samples taken farther down slope from the end of the tile. However, in the case of nitrate nitrogen, there was a sharp increase in the initial ten feet presumably due to aerobic oxidation of ammonia present and beyond this, dilution reduced the levels at distances farther downstream from the end of the septic tile.

Phosphates, Nitrates and Chlorides in Soil Samples

A reference to Table 39 indicates that the soil samples taken at various depths 0 to 4'0" near the tile, had slightly greater amounts of PO_4-P , NO_3-N and chlorides compared to samples taken away from the tile. The study also indicated that phosphate levels in the sample near the tile increased at 2'6" depth and later decreased at 3'6" and 4'0" depths, due to contribution of phosphates from the effluent and later adsorption by the soil respectively. Similar trend was noticed in the nitrate levels, the increase being due to

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Table 38. Groundwater Bacteriological Characteristics Downslope from End of Septic Tile

Characteristics of Groundwater	Date of Collection	Distance from end of tile in feet					
		0	10	20	30	40	50
Coliforms MF Count/100 ml	01-06-73	980,000	7,100	5,000	800	900	1,700
	18-06-73	57,000	90,000	150,000	10,000	120,000	20,000
Fecal Coliforms MF Count/100 ml	01-06-73	240,000	1,800	<10	<10	<100	<100
	18-06-73	16,000	700	1,100	<100	<100	<100
Fecal Streptococci MF Count/100 ml	01-06-73	12,000	1,600	20	40	400	600
	18-06-73	900	4,800	5,100	10,000	700	100
SPC per ml (35°C)	01-06-73	32,000	3,100	2,100	820	5,200	3,700
	18-06-73	540,000	120,000	210,000	150,000	40,000	21,000
SPC per ml (20°C)	01-06-73	690,000	3,000	46,000	13,000	43,000	19,000
	18-06-73	3,500,000	510,000	1,200,000	3,600,000	440,000	290,000
Pseudomonas aeruginosa MPN/100 ml	01-06-73	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	18-06-73	2	42	7	2	<2	<2

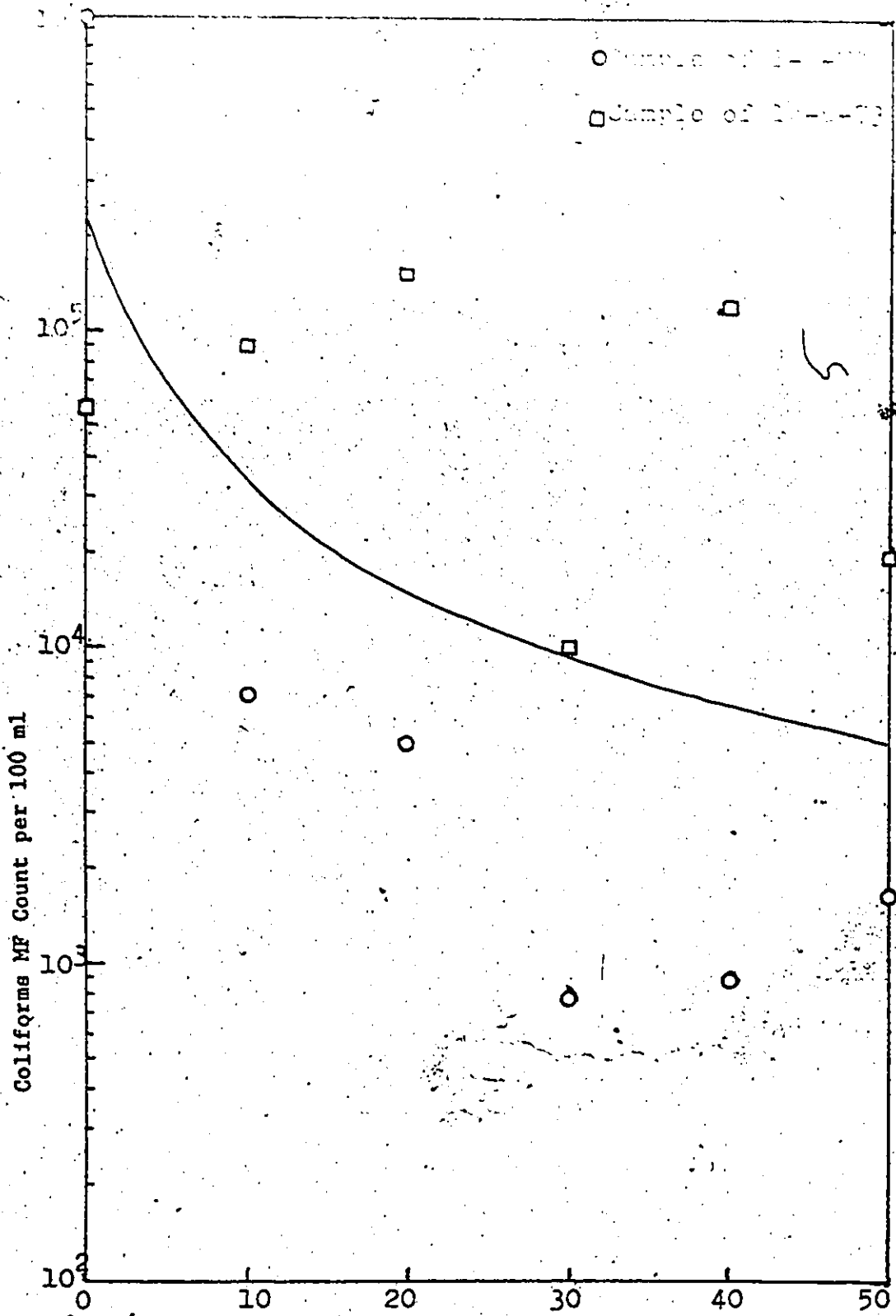


Fig. 43. Coliforms in Groundwater Downslope from End of Septic Tile

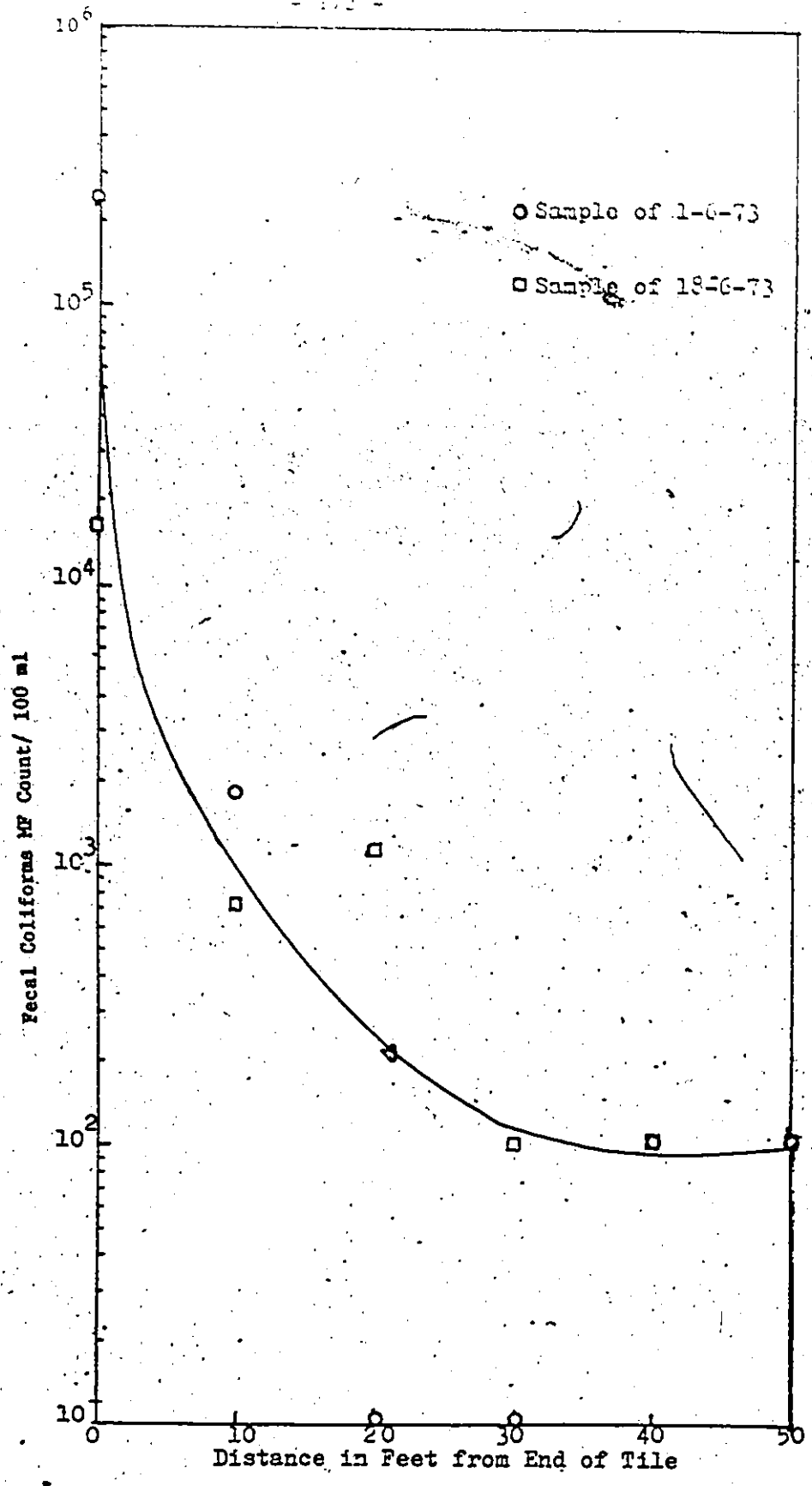


Fig. 44. Fecal Coliforms in Groundwater Downslope from End of Septic Tile

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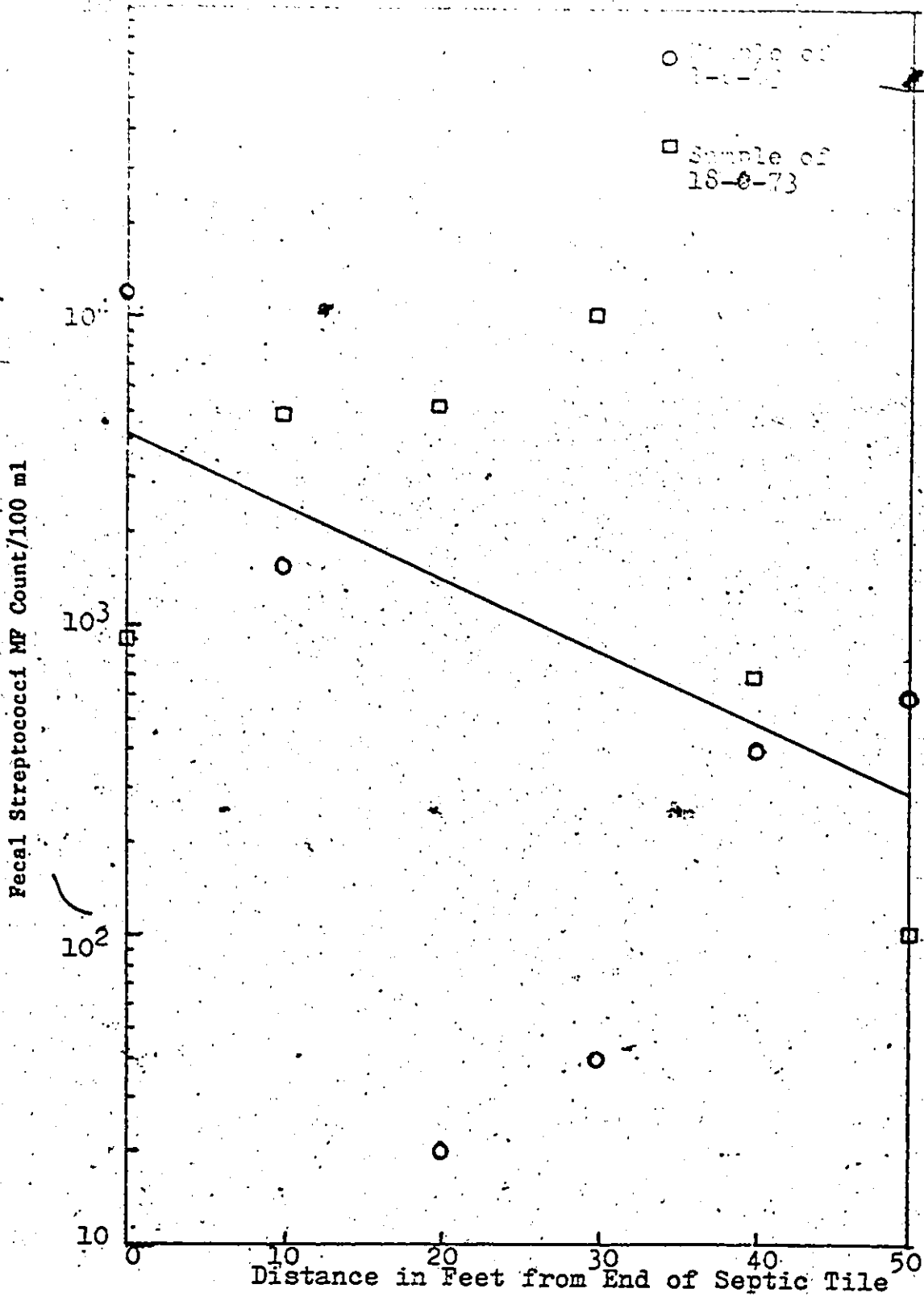


Fig. 45. Fecal Streptococci in Groundwater Downslope from End of Septic Tile

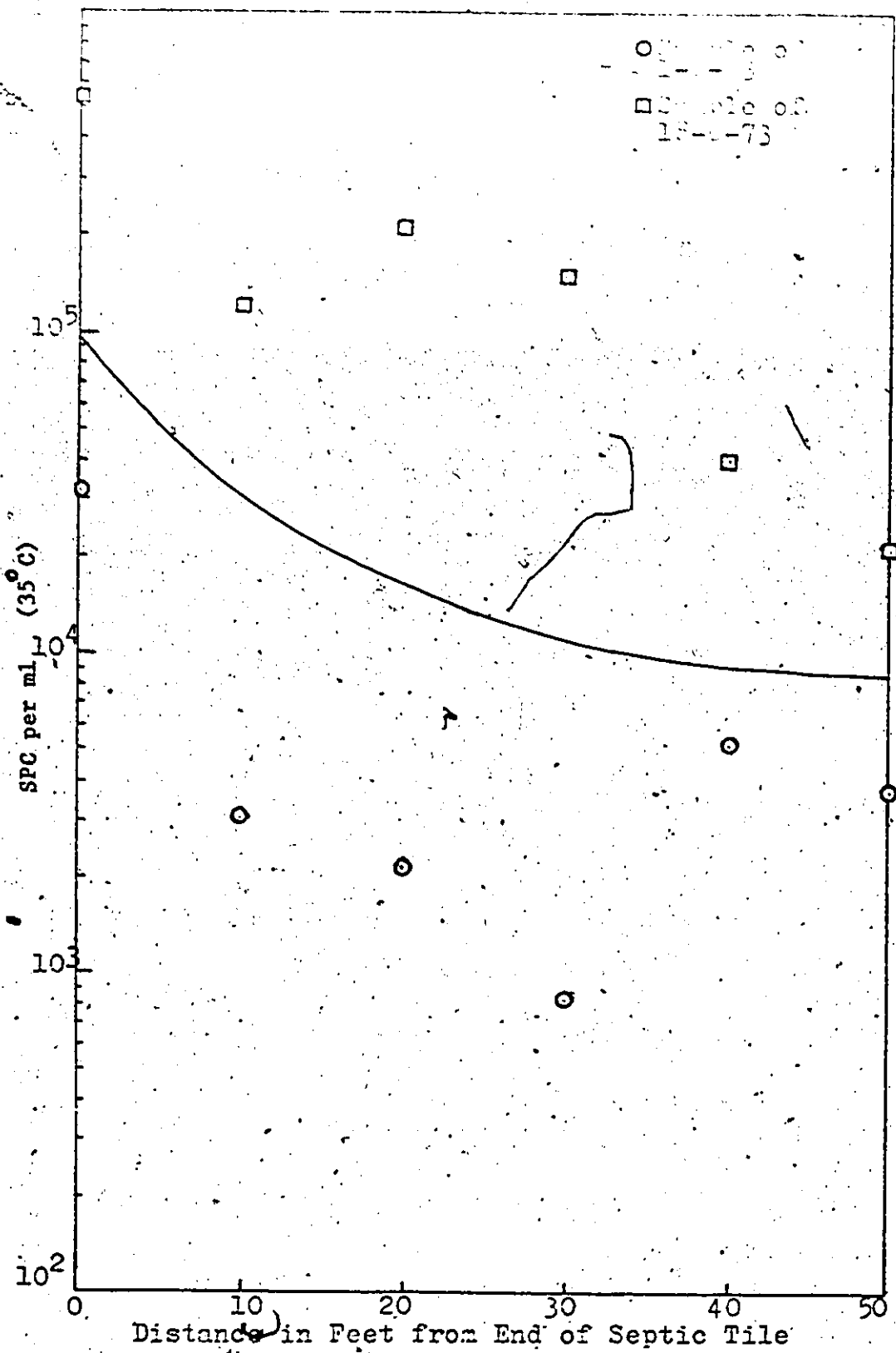


Fig. 46. SPC of Groundwater Downslope from End of Septic Tile

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Table 39. Chemical Analysis of Soil Samples

Particulars	Sample Depth	PO ₄ -P µg/gm of dry soil	NO ₃ -N µg/gm of dry soil	Chlorides µg/gm of dry soil
Sample away from tile	0	1.0	5.0	1.0
	2'6"	2.5	4.0	1.5
	3'6"	4.0	3.0	2.0
	4'0"	3.0	3.0	2.0
Sample 12" from the edge of tile trench	0	2.0	6.0	2.0
	2'6"	10.0	12.0	8.0
	3'6"	5.0	7.0	12.0
	4'0"	4.0	5.0	11.0

oxidation of ammonia in the effluent and the decrease presumably due to denitrification in an anaerobic environment. The chlorides registered an increase at 2'6" depth and remained slightly higher than at 2'6", at the other two depths. This soil analysis indicated that while chlorides and nitrates were more mobile, a good proportion of phosphates could be lost through adsorption while the effluent seeped through the soil.

4.1.3 Investigation on the Clogging of the Experimental Tile

On exposing the tile trench, after about 15 months of operation, it was found that the gravel had a slimy coating and the slimy layer extended about 4 to 5 inches below the trench bottom. The permeability of this material at the interface was found to be 3.35×10^{-8} cm/sec, the average of two values 2.0×10^{-8} cm/sec and 4.7×10^{-8} cm/sec, about three orders less than the original permeability of the soil, indicating that the long term infiltration rate would be much smaller than the initial infiltration rate. Initial infiltration rates at the tile trench at 2'0" depth and at the unclogged soil nearby were found to be 0.042 gpm and 0.050 gpm respectively over the initial thirty minutes; the difference was not considered appreciable enough to come to any conclusion on the clogging of the trench. The relatively higher value obtained in the trench was probably due to increased

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flow through the gravel portion of the sides compared to soil sides in the pit dug for comparison.

The microscopic examination of the slimy layer of soil showed large number of bacterial organisms. Evidently there was an abundance of microbial activity. Standard Plate Counts (20°C for 48 hours) made on this sample and on another soil sample at 2'0" depth away from the tile were found to be 1×10^8 and 4×10^7 per gram weight of dry soil respectively. These results did not show any significant difference in total number of organisms. This may be due to the fact that the bacterial populations at both the sites may be different, reacting differently to the same nutrient medium.

The difference in ferrous sulphide in the soil beneath the tile and in the soil close by (Table 40) was also not significant. Probably the system had not reached such an anaerobic environment for an excessive ferrous sulphide build-up leading to clogging of the trench. The slimy soil sample however answered the qualitative test for polysaccharides, indicating the greater possibility of microbial clogging.

In the present study, the groundwater table rose above the trench bottom during the snowmelt period and declined thereafter. Laboratory experiments by Laak (58) have shown that there could be partial recovery in respect of permeability by backwashing operations. It is not certain how far the rising groundwater could disturb the mat and improve the permeability at the interface.

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Table 40. Amount of Ferrous Sulphide Present in Soil

Location	Depth from ground	Amount of FeS present mg/gm dry wt		
		Sample 1	Sample 2	Average
Away from tile	2'0"	1.5	1.8	1.65
Below tile	2'0"	2.3	3.0	2.65

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4.2 Analysis of Environmental Factors

The important environmental factors considered were temperature, unsaturated depth of soil (depth to groundwater) and snow cover.

4.2.1 Temperature and Snow Cover

Air temperature around 10:00 a.m. everyday for the period December, 1972, to March, 1974, are shown in Table D1 in Appendix D (page 276). Mean monthly air temperatures for the above period are shown in Table 41 and in Fig. 33 (page 156). Soil temperatures taken around 10:00 a.m. on various days during the investigation at soil depths of 2'6", 3'6" and 4'6", inside the septic tank, in the soil by the side of the septic tank and inside the tile are furnished in Table D2 in Appendix D (page 277). Mean monthly temperatures are shown in Table 41 and Fig. 33 (page 156). The daily depth of snow on the ground for the period December, 1972, to April, 1973, and from November, 1973, to March, 1974, are furnished in Table D3, Appendix D, (page 280). There was no snow on the ground from May, 1973 to October, 1973. Mean monthly snow on the ground for the various months during the period of investigation are shown in Table 42 and Fig. 26 (page 119). Measurements taken for the depth to groundwater level from ground on various days during the investigation are shown in Table D4, Appendix D, page 281. The mean monthly values may be found in Table 42 and in Fig. 26 (page 119). An analysis

Table 41. Mean Monthly Air, Soil and Effluent Temperatures Around 10:00 a.m.

Month	Mean Temperature °F							Air temperature
	Inside Tile	In soil at 2'6" depth	In soil at 3'6" depth	In soil at 4'6" depth	Inside septic tank	Soil just outside septic tank at 2'6" depth	Soil just outside septic tank at 2'6" depth	
December 1972	38.0	37.0	39.6	41.0	60.4	49.6	20.2	
January 1973	38.2	36.0	38.1	39.7	61.2	49.6	24.4	
February 1973	38.5	36.0	39.1	39.0	60.8	49.3	22.9	
March 1973	39.4	36.9	38.7	39.7	62.3	49.5	39.0	
April 1973	44.0	42.7	41.5	41.4	62.4	53.3	50.2	
May 1973 ¹	47.0	45.0	45.0	43.5	64.0	59.0	61.6	
June 1973	63.4	55.0	52.9	51.8	68.6	66.5	68.1	
July 1973	65.7	59.5	57.6	56.9	70.7	68.6	74.7	
August 1973	64.9	61.1	60.4	59.0	69.0	68.3	73.7	
September 1973 ¹	-	54.8	56.6	56.8	65.2	63.0	60.2	
October 1973	54.6	51.0	53.1	53.6	64.5	60.8	50.8	
November 1973	51.1	46.4	48.5	49.7	61.1	57.6	33.4	
December 1973	45.0	40.3	42.2	44.5	63.3	57.6	19.9	
January 1974	-	39.1	41.1	43.1	62.8	57.1	14.9	
February 1974							11.0	
March 1974							24.3	

¹Temperatures other than air temperature are for one day only.

Table 42. Environmental Factors
(Snow cover and Unsaturated Depth of Soil)

Month	Depth of Snow on ground in inches ¹			Depth of groundwater level from ground level in inches		
	Mean	Min	Max	Mean	Min	Max
December 1972	9.6	2	20	36	30	39
January 1973	9.7	4	13	24	20	30
February 1973	7.7	5	10	22	20	24
March 1973	4.9	0	16	15	12	20
April 1973	0.2	0	3	20	5	34
May 1973	0	0	0	22	16	26
June 1973	0	0	0	31	30	34
July 1973	0	0	0	40	37	43
August 1973	0	0	0	>65	>65	-
September 1973	0	0	0	>65	>65	-
October 1973	0	0	0	>65	>65	-
November 1973	0.3	0	2	>65	>65	-
December 1973	7.4	0	20	34 ²		
January 1974	15.4	10	19	44 ²		
February 1974	12.0	9	16	42 ²		
March 1974	6.8	0	14	15		

¹At Ottawa (from Summary Record issued by the Weather Office, Ottawa).

²Single values only.

of these environmental factors reveals several interesting facts.

The average temperature of the septic tank contents during the period of investigation was 64.0°F, while the average soil temperature at 2'6" depth quite close to the outside wall of the septic tank was 57.9°F, with an average differential of 6.1°F and a range of 0.7°F-12.8°F. Even during colder months, when air temperatures were below freezing point, the septic tank liquid temperatures were around 60°F, while the soil temperatures in the area at a depth of 2'6" were around 37°F, during these colder months. The household has a pressure water system and domestic hot water. There is no doubt that large amounts of relatively warm water contributed to the septic tank contents being kept at temperatures well above that of the surrounding ground.

The mean air temperatures taken around 10:00 a.m. during December, 1972, January, February and December, 1973, and the first three months of 1974 remained below freezing point. Even during these months, the temperature of the sewage inside the tile was significantly higher, close to 38°F, due to the use of hot water discharged from the household.

The soil temperatures showed an increasing trend with depth for the last month of 1972 and the first three months of 1973 - the winter period - when there was a mean snow cover varying from 9.6 to 4.9 inches, which acted as

an insulator. The soil temperatures during April to August, 1973 showed an increased value at the higher level of soil than at the bottom, reflecting the fact that the top soils got heated first and it took time for the heat energy to travel down. This pattern was reversed for the months of September, 1973 to January, 1974, with higher temperatures at the lower depths, as the air temperatures began to drop down in the fall and winter months. The average soil temperature at 2'6" depth, where the effluent was usually discharged from the septic tile, was found to be 45.8°F for the period of investigation; these soil temperatures were around 37°F during the winter period when the air temperatures were below freezing point. This would indicate that winter operation did not pose any special problem, as soil temperatures close to the tile and below were much higher than that of prevailing air temperatures, in view of the soil mass and the insulating snow cover on the ground. In addition, the temperature of the effluent in the tile was quite above the freezing point, due to the hot water discharged to the system.

4.2.2 Depth to Groundwater

The most important environmental factor that affected the groundwater quality was the depth to groundwater or the unsaturated depth of soil. In fact, this limited the depth of soil mantle available for the pollutant discharged by the tile before it met the water table. The chances of

greater percentage of the pollutants being absorbed or adsorbed by the soil would depend on the depth available for their travel. The tile at the southern end, where the groundwater level measurements were made, was at a depth of 21 inches from ground level. From Table 42, page 181, it may be seen that the depths of soil available for pollutant travel in December 1972 and early January varied between 15 inches and 9 inches; there was 3 inches available by late January. During March, the groundwater level was nearly at the same level as the tile, while during March, April and some part of May, the groundwater was above the tile level. The groundwater reached as close as 5" below ground during snowmelt period in April. During the latter part of June and thereafter till February, 1974, the groundwater level was below the tile; however, the average depth available for pollutant travel increased to 10" in June, and to 19" by July, while during August to November, the depth was greater than 44 inches. The depth available for pollutant travel before reaching groundwater varied between 13" and 23" in the last month of 1973 and in the first two months of January, 1974.

4.2.3 Effect of Environmental Factors on the Efficiency of the Septic Tile

It may be observed from the discussion of the results presented in the earlier part of this chapter (pages

137 and 146) that the efficiency of the septic tile in respect of reduction of various parameters showed an increasing trend when soil and air temperatures were relatively higher and that efficiency was higher during the summer and early fall when unsaturated depth was also greater.

4.3 Water Use Pattern, Raw Sewage and Septic Tank Effluent Characteristics and Efficiency of the Septic Tank

4.3.1 Water Use Pattern

The residence concerned is located in an extensive valley area in Cantley, Gatineau County, Québec and had been in occupation since June 28, 1970. A single family of 12 members - 2 adults and 10 children formed the household. There are 6 bedrooms, 3 bathrooms, 3 toilets, 2 tubs and 2 showers (one in use). The family uses a food grinder, washer, dryer (not connected to waste system) and a dishwasher. The household obtains its drinking water from a tube well sunk to a depth of 90 feet. The domestic wastewaters are treated in a septic tank system. The septic tank is of 1,250 imperial gallons capacity, with two compartments, with an overall length of 9'8" and a width of 4'8", walls 2-1/2" thick. The compartments are of sizes 5'8" x 4'3" x 6'2" (liquid depth) and 3'4" x 4'3" x 3'9" (liquid depth) respectively. The capacities of the compartments are 148 cft and 52 cft respectively. The effluent from the septic tank is disposed of

through a tile field system, consisting of 10 laterals, each 56 feet long, as mentioned in Chapter 3. The widths of tile trenches are 2'0" and gravel of 1" to 3" size has been used for a depth of 11 inches, with 2" above the tile and 6" below the tile. The tile pipe is of 3" diameter. The chemical and bacteriological characteristics of the well water supply, tested on two occasions are shown in Table 43. It meets drinking water quality criteria, the iron and chlorides are very low.

The daily intake of water and the water used for flushing, expressed as a percentage, for the period December 11, 1972 to April 1, 1973 and for the period November 29, 1973 to January 6, 1974, for a total period of 141 days, are shown in Table E1 of Appendix E (page 283). However a complete record of daily total water use and water used for flushing for every day of the week was available only for ten weeks. The data for these ten weeks alone were used in the analysis. The total daily water use for each day of the week for ten weeks is shown in Table 44. The mean daily intake varied between 192 and 342 imp. gallons, on a weekly basis and the mean daily water use by day varied between 257 and 307 imp. gallons. The overall mean was 271.9 imp. gallons per day, working out to 22.7 gpcd. The daily flow from a single family dwelling adopted in the design of septic tanks in various provinces of Canada varies between 35 and 75 imp. gallons per day (Table 1, page 11), with a figure in the

Table 43. Characteristics of Well Water Supply

No.	Characteristics	Sample date	
		11-04-72	12-03-73
1	pH	8.0	7.65
2	Total solids (mg/l)	108.0	190.0
3	Total suspended solids (mg/l)	-	32.0
4	Volatile suspended solids (mg/l)	-	12.0
5	Fixed suspended solids (mg/l)	-	20.0
6	BOD ₅ 20°C (mg/l)	-	-
7	COD (mg/l)	-	-
8	TOC (mg/l)	-	10.0
9	Total phosphates as P (mg/l)	1.0	0.1
10	NH ₃ -N (mg/l)	0.027	1.33
11	Nitrate-N (mg/l)	1.25	0.12
12	Total soluble Iron (mg/l)	-	0.20
13	Hardness as CaCO ₃ (mg/l)	148.0	140.0
14	Chlorides (mg/l)	1.0	4.0
15	Coliform MF Count per 100 ml	<2	-
16	Fecal coliform MF Count per 100 ml	<2	-
17	Fecal streptococci MF Count per 100 ml	<2	-
18	<i>Pseudomonas aeruginosa</i> MPN/100 ml	<2	-

Table 44. Total Daily Water Use

Days	Weekly							Mean by day			
	1	2	3	4	5	6	7				
Monday	149	294	397	255	281	234	193	192	261	312	257
Tuesday	204	179	263	243	374	354	210	181	220	484	271
Wednesday	223	182	244	365	188	414	266	246	238	309	268
Thursday	150	226	373	236	185	253	381	228	227	334	259
Friday	205	306	298	284	284	222	330	301	324	327	288
Saturday	246	355	389	362	317	173	217	389	336	306	309
Sunday	170	191	296	260	296	288	281	187	349	322	264
Mean by week	192	247	323	301	246	277	268	246	279	342	

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range of 40 imp. gpcd being common. A recent Ontario study (25) revealed average figures (over 10 months) varying from 19.8 to 41.9 imp. gpcd from 7 households. On the basis of the entire community, the water usage was 31.4 imp. gpcd. It would appear that the value of 22.7 imp. gpcd for water usage from this household is comparatively a low value, considering the fact that the household uses a food grinder, a washer and a dishwasher. It is necessary to examine the composition of the household, to interpret this low figure of per capita daily water consumption. The residence had 12 members, consisting of 2 adults and 10 children, quite atypical compared to an average Canadian household with 3 to 4 members. Considering the large number of children, a low average per capita figure would not appear to be inconsistent.

The mean daily water use by day varied between 257 imp. gallons on Mondays and 309 imp. gallons on Saturdays. The difference between these extreme means was found to be not statistically significant (Probability (P) = 0.10). This would, in effect, lead to the conclusion that there was no particular washing day in a week, which normally accounted for the increased water use. A check with the household confirmed this observation.

For the ten-week period studied, water used daily for toilet flushing as a percentage of the total daily water use, is furnished for each day in Table 45. For this period, the mean use of water for toilet flushing was found to be

Table 45. Water Used for Toilet Flushing

Days	Percentage of Total Daily Water Use										Mean by Day
	1	2	3	4	5	6	7	8	9	10	
Monday	73.5	17.8	17.6	24.7	18.7	30.0	30.8	25.6	21.6	20.2	28.1
Tuesday	25.7	32.2	18.6	15.8	12.2	12.9	23.4	29.0	21.3	15.2	20.6
Wednesday	26.7	36.5	15.8	14.4	31.2	9.3	27.6	17.0	19.5	22.7	22.1
Thursday	44.5	26.4	14.1	25.2	39.8	25.0	15.7	21.4	18.5	18.8	24.9
Friday	27.3	13.7	21.0	19.7	12.3	28.4	19.1	12.8	16.3	23.6	19.4
Saturday	24.2	16.7	14.4	19.3	18.7	24.3	24.2	17.1	19.8	23.0	20.2
Sunday	37.0	27.5	24.8	29.6	16.5	19.5	20.0	31.8	20.0	19.6	24.6
Mean by week	37.0	24.4	18.0	21.2	21.3	21.3	23.0	22.1	19.6	20.4	

22.6% of the total daily intake. The highest mean value (28.1%) was observed on Mondays and the lowest (19.4%) on Fridays. The difference between these means was not statistically significant ($P > 0.1$). The mean weekly values varied between 18.0% and 37.0%. The difference in weekly means was however found to be significant ($P = 0.02$). An examination of the data indicates that the maximum values by day and by week were very much influenced by a single high value of 73.5% on one particular day and that the first week showed relatively higher percentages on most days of the week. An average figure of 22.6% for water use for toilet flushing would appear to be smaller than the usual figures in the 40-45% range reported in the literature (61). Again, this could be due to the rather different composition of this particular household.

An examination of the diurnal fluctuations in water use observed on three days (Table 46 and Fig. 47) indicates that there is an afternoon or a late afternoon peak, sometimes two peaks. The peak hourly values were 160-180% of the average values; higher peak values than those observed are however not uncommon in rural individual water supply systems.

4.3.2 Characteristics of the Raw Sewage

Composite samples were collected on two occasions and grab samples were collected on eleven occasions for chemical analysis. Seven grab samples were collected for

Table 46. Typical Diurnal Fluctuations in Water Use

December 16, 1972		December 17, 1972		December 9, 1973	
Period	Water use gallons Imp.	Period	Water use gallons Imp.	Period	Water use gallons Imp.
0-7.00	0	0-6.30	0	0-6.30	0
7.00-9.00	36	6.30-7.30	7.3	7.00-9.30	78.6
9.00-11.00	27	7.30-8.40	13.0	9.30-14.30	92.3
11.00-14.15	46	8.40-9.30	12.3	14.30-19.00	113.9
14.15-17.50	29	9.30-10.30	15.0	19.00-21.50	54.6
17.50-19.50	26	10.30-11.30	20.0		
19.50-21.50	27	11.30-16.00	73.8		
21.50-23.45	14	16.00-17.00	15.5		
		17.00-18.45	3.9		
		18.45-20.00	56.8		
		20.00-21.00	15.5		
		21.00-22.15	12.7		

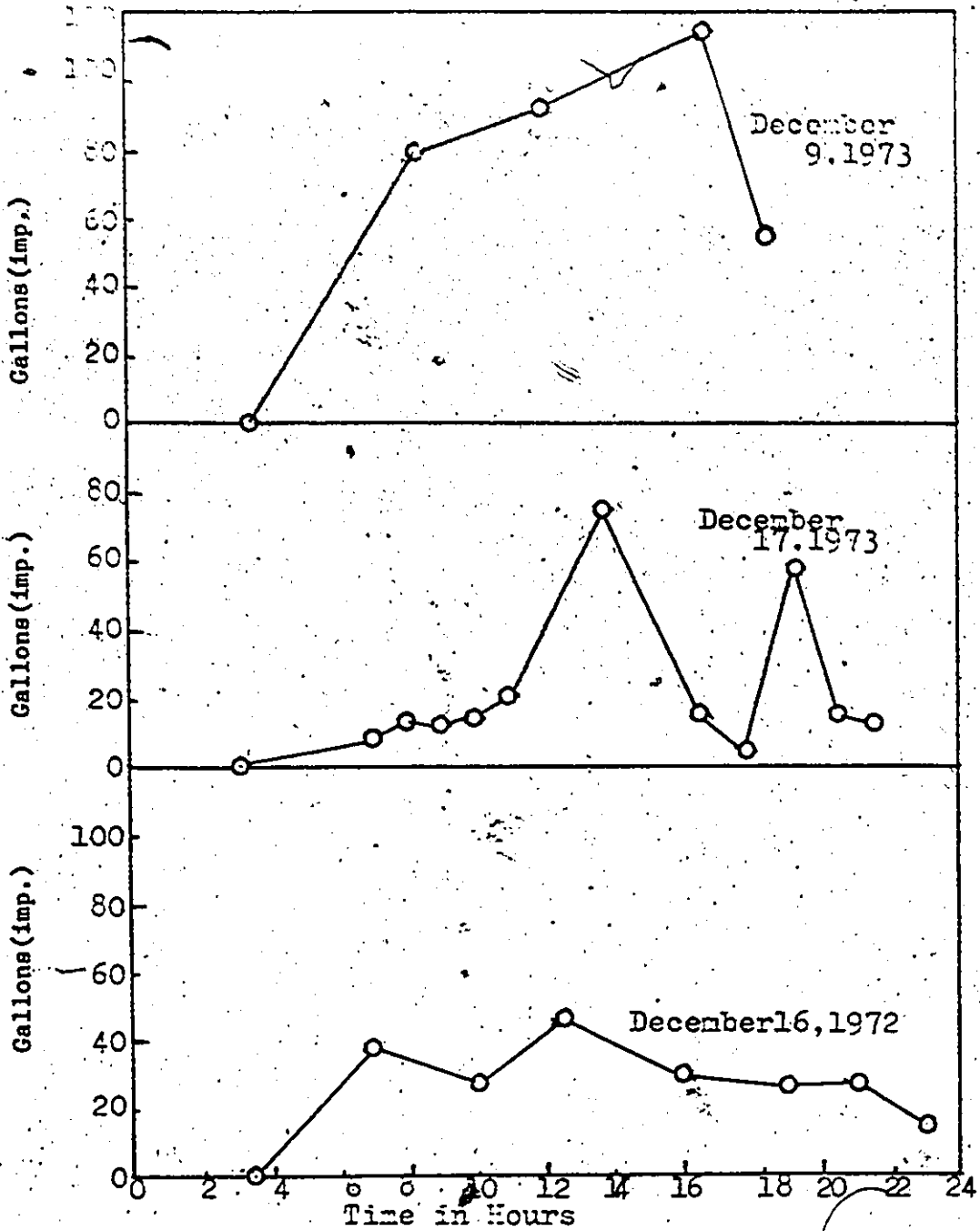


Fig.47. Diurnal Fluctuations in Water Use

bacteriological analysis. The chemical characteristics of the raw sewage for the various samples along with the mean values for grab and composite samples are shown in Table 47. The bacteriological characteristics of the raw sewage are shown in Table 48.

The characteristics of the raw sewage and the septic tank effluent vary with time. Many of the chemical characteristics of the raw sewage and the septic tank effluent either approximate or can be transformed to approximate a "normal" distribution. These can be displayed as a straight line on arithmetic probability paper (121). Certain types of data such as bacterial density are logarithmically normal. Such a distribution will plot as a straight line on log-probability paper (122). The procedure adopted to plot observed or experimental data on probability paper was as follows:

- 1) The data was arranged in order of ascending magnitude.
- 2) A serial number 'm' was assigned to each of the n values 1, 2, 3, n.
- 3) The plotting position of each serial value, giving the probability equal to or less than each value, was computed by the ratio $\frac{m}{n+1}$ expressed as a percentage.
- 4) The points were then plotted on a probability paper (either arithmetic or logarithmic). A straight line plot indicates that the data have a normal or a log-normal

Table A7. Chemical Characteristics of Raw Sewage

Date of Sample	pH	TSS mg/l	VSS mg/l	BOD mg/l	COD mg/l	TOC mg/l	PO ₄ -P mg/l	NH ₃ -N mg/l	NO ₃ -N mg/l	Total Soluble Pe mg/l	Chlorides mg/l
21-01-73 ¹	6.60	100	32	407	945	142	3.4	52	-	0.3	-
12-03-73	8.29	136	44	484	846	470	35.0	200	0.08	3.7	-
19-03-73	7.35	372	344	397	805	120	2.5	6	0.02	0.3	-
26-03-73	7.85	192	132	442	2880	144	35.0	23	-	9.0	21.0
02-04-73	7.27	192	156	465	350	140	9.0	10	0.11	0.6	22.0
16-04-73	9.10	120	100	-	2600	1040	7.5	23	0.08	2.0	200.0
23-04-73	6.73	100	84	580	892	344	20.0	55	0.60	0.0	296.0
04-05-73	6.90	116	96	514	648	436	45.0	45	0.00	0.0	190.0
14-05-73	8.54	60	34	582	528	184	12.5	227	0.00	1.5	247.0
13-07-73	8.22	38	32	244	310	100	11.30	40	0.18	1.6	67.0
23-07-73	6.50	748	726	1312	2492	174	2.5	3	0.04	0.5	42.0
10-08-73	6.35	312	296	585	1108	90	9.0	38	0.08	0.3	34.0
09-12-73 ¹	6.9	381	367	423	1366	148	5.6	24	0.014	1.05	90.0
Mean (grab)	7.55	217	186	561	1224	295	15.7	61	0.12	1.80	124.3
Mean (composite)	6.75	241	200	415	1156	145	4.5	38	-	0.70	-

¹ Composite samples; the rest are grab samples taken around 10:00 a.m.

Table 48. Bacteriological Characteristics of Raw Sewage

Date	Fecal coliform MF count/100 ml		Fecal streptococci MF count/100 ml	SPC. per ml		Pseudomonas aeruginosa MPN/100 ml
	Coliform MF count/100 ml	Fecal coliform MF count/100 ml		35°C	20°C	
19-02-73	1,100	600	1,200	280,000	430,000	92,000
09-03-73	1,300,000	110,000	44,000	160,000	140,000	50
19-03-73	11,000,000	15,000	11,000	1,700,000	3,800,000	280
02-04-73	22,000,000	6,000,000	91,000	620,000	840,000	14
16-04-73	3,100,000	160,000	600,000	1,700,000	4,300,000	330
04-05-73	230,000	2,800	360	120,000	120,000	230
23-07-73	12,000,000	23,000	230,000	2,000,000	3,000,000	<2
Mean (geometric)	1,168,000	34,750	22,160	568,700	841,000	160

distribution depending on the type of probability paper on which the data are plotted.

In the case of the chemical characteristics of the raw sewage, only the data obtained from grab samples were treated in the above manner, as the number of composite samples was not sufficient for such an analysis. The available bacteriological data were treated in the above manner, using log-probability paper. The data as arranged for probability charts are shown in Tables F1 to F3 in Appendix F (p.290-292). The probability plots are shown in Figs. F1 to F10, Appendix F (p.293-302). The mean values 50% and the 15% and 85% of the time values for each parameter were taken from the graph and furnished in Table 49. Diurnal fluctuations in the chemical characteristics of the raw sewage on December 9, 1973 are furnished in Table 50 and shown in Figs. 48 and 49.

It may be seen from Table 47, page 195, that the mean values of grab samples and of composite samples did not differ very much in respect of TSS, VSS, BOD, and COD, while the values in respect of $\text{NH}_3\text{-N}$, $\text{PO}_4\text{-P}$ and total soluble iron differed in a large way. Since the major contributions of nitrogen and phosphates are from urine and clothes washer respectively (61) and since these contributions occur not uniformly through a day, higher values for grab samples in respect of these parameters are possible.

Table 49. Statistical Analyses of Raw Sewage Characteristics
(based on grab samples)

Characteristics	Percent of time equal to or less than			Standard Deviation
	15	50 values	85	
pH	6.45	7.60	8.7	1.1
TSS, mg/l	80	200	320	120
BOD, mg/l	362	520	670	150
COD, mg/l	350	1000	1650	600
TOC, mg/l	70	280	470	200
PO ₄ -P, m/l	0.0	14.0	32.0	15
NH ₃ -N, mg/l	17.0	47.0	75.0	30
NO ₃ -N, mg/l	0.0	0.10	0.19	0.1
Total soluble iron, mg/l	0.0	1.50	3.0	1.5
Chlorides, mg/l	0.0	130.0	260	120
Total coliform/100 ml	2.2x10 ⁵	2x10 ⁶	1.6x10 ⁷	
Fecal coliform/100 ml	1.5x10 ³	3x10 ⁴	6.6x10 ⁵	
Fecal streptococci/100 ml	1.5x10 ³	3x10 ⁴	5.6x10 ⁵	
SPC/ml (35°C)	1.3x10 ⁵	5.6x10 ⁵	2.5x10 ⁶	
SPC/ml (20°C)	1.4x10 ⁵	8x10 ⁵	4.7x10 ⁶	
Pseudomonas aeruginosa/ 100 ml	-	150	4x10 ³	

Table 50. Diurnal Fluctuations in Chemical Characteristics of Raw Sewage

(December 9, 1973)

No	Chemical Characteristics	Samples			
		1	2	3	4
1	pH	7.1	6.6	7.3	6.5
2	TSS (mg/l)	362	202	114	1324
3	VSS (mg/l)	350	194	98	1296
4	Fixed SS (mg/l)	12	8	16	28
5	BOD ₅ at 20°C (mg/l)	330	274	544	555
6	COD (mg/l)	948	508	2040	2100
7	TOC (mg/l)	85	75	223	220
8	Total Phosphate (PO ₄ -P) mg/l	10.0	6.0	17.6	6.0
9	NH ₃ -N (mg/l)	47.0	3.3	32.0	10.0
10	NO ₃ -N (mg/l)	0.00	0.02	0.00	0.06
11	Total soluble iron (mg/l)	1.20	1.22	1.00	0.60
12	Chlorides (mg/l)	120	34	137	38

Note: Sample 1 Collected between 7.00 to 9.30
 2 Collected between 9.30 to 14.30
 3 Collected between 14.30 to 19.00
 4 Collected between 19.00 to 21.50

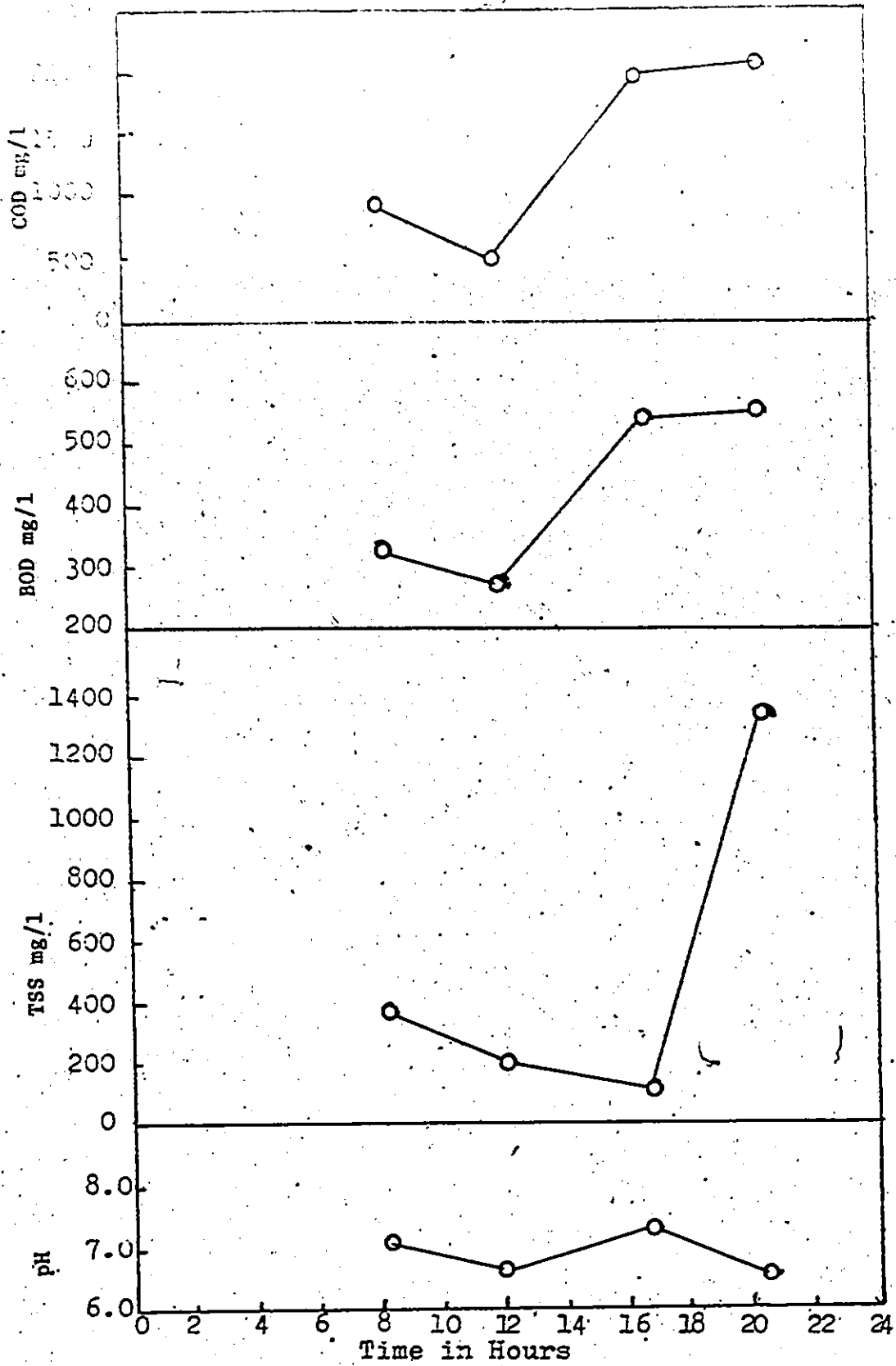


Fig.48. Diurnal Fluctuations in Chemical Characteristics (pH, TSS, BOD and COD) of Raw Sewage on Dec 9, 1973

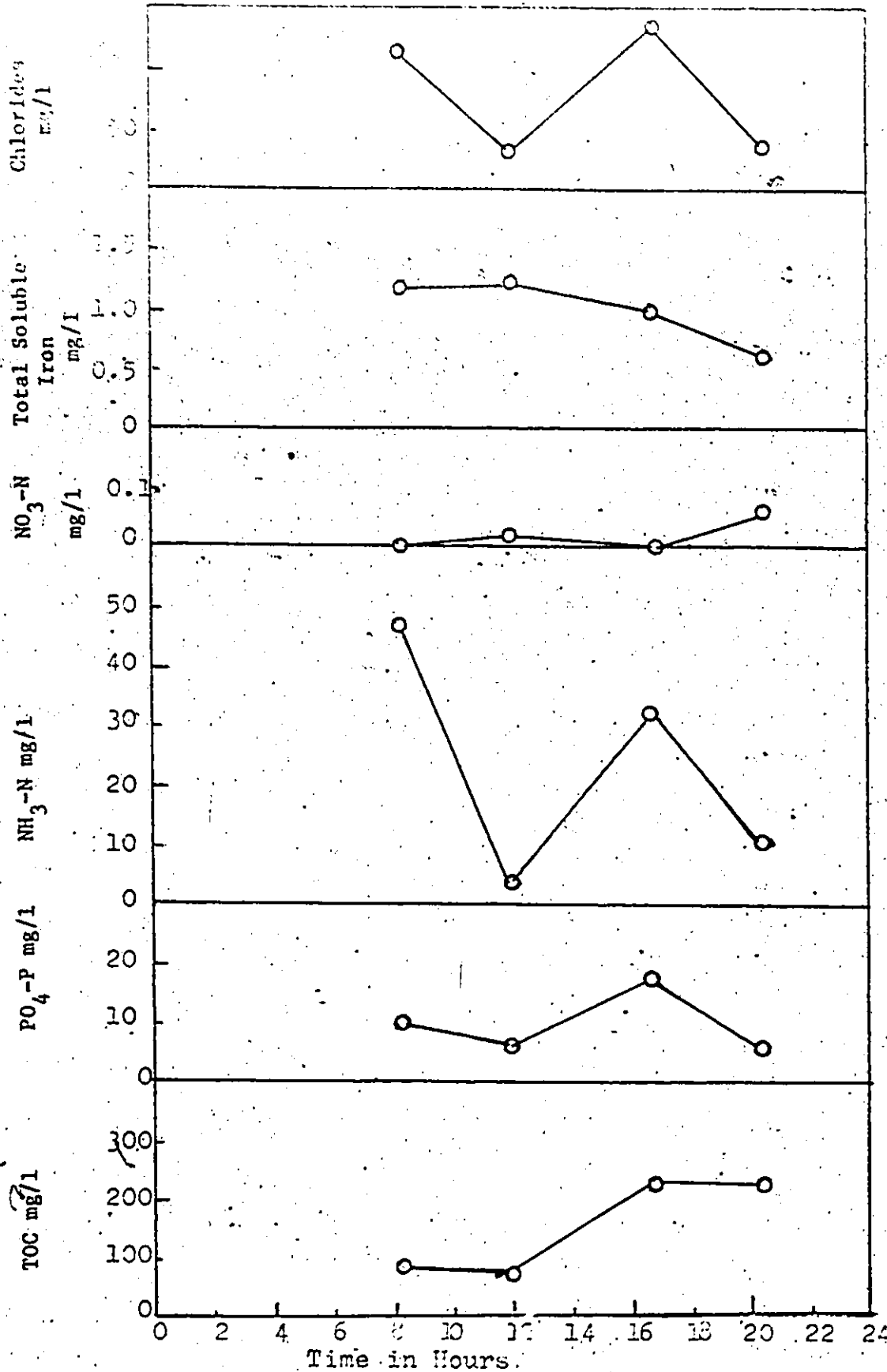


Fig. 49. Diurnal Fluctuations in Chemical Characteristics (TOC, PO₄-P, NH₃-N, Fe and Chlorides) of Raw Sewage on Dec 9, 1973

pH

The pH of the raw sewage (grab samples) varied between 6.35 and 9.10, with a mean of 7.55, while the mean pH of composite samples was 6.75. The pH of the raw sewage varied during the day as seen from Fig. 48; higher values were probably due to washing and cleaning operations.

TSS, VSS and Fixed SS

The TSS in the raw sewage (grab samples) varied between a very low value of 38 mg/l and a high value of 748 mg/l, with a mean value of 217 mg/l, while the mean TSS value of composite samples was 241 mg/l. Cleaning and washing operations during sampling would have contributed to the rather high TSS values observed on some occasions. The TSS values observed are consistent with those reported in the literature. The VSS in raw sewage averaged 186 mg/l based on grab samples and 200 mg/l on composite samples. The mean VSS values were respectively 86.5% and 83% of the TSS values. These observations are in line with the results of the earlier investigations that a large fraction of suspended solids (75-85%) in raw sewage is volatile.

BOD, COD and TOC

The BOD of the raw sewage based on grab samples varied between 244 mg/l and 1312 mg/l, with a mean of 561 mg/l, while the mean value of the composite samples was 415

mg/l. The COD of the raw sewage based on grab samples fluctuated between 310 mg/l and 2880 mg/l, with a mean value of 1224 mg/l, whereas the mean value of the composite samples was 1156 mg/l. The TOC of the raw sewage based on grab samples was found to be in the 90-1040 mg/l, with a mean value of 295 mg/l, while the average TOC value based on composite samples was only 145 mg/l. In the case of the above three parameters, only in the case of TOC, there appeared to be a significant difference in the mean values derived from grab and composite samples. It is also necessary to bear in mind that the samples for BOD and COD analyses were direct samples, while filtered samples were used for TOC analysis.

The BOD and COD of the raw sewage can be correlated with TOC; however, it may be necessary to appreciate these limitations (31):

i) A portion of the COD may be due to the dichromate oxidation of ferrous iron, nitrogen, sulphites, sulphides and other oxygen consuming inorganics while the TOC analysis does not include oxidation of these compounds.

ii) The BOD and COD tests do not include many organic compounds which are partially or totally resistant to biochemical or dichromate oxidation. However, all of the organic carbon in these compounds is recovered in the TOC analysis, and

iii) The BOD test is susceptible to variables which include seed acclimation, dilution, temperature, pH

and toxic substances. The COD and TOC tests are generally independent of these variables. Theoretically, the stoichiometric COD/TOC ratio would approximate the molecular ratio of oxygen to carbon ($32/12=$) 2.66. The calculated relationship between BOD and TOC is:

$$\frac{\text{BOD}_5}{\text{TOC}} = \frac{\text{O}_2}{\text{C}} = \left(\frac{32}{12}\right)(0.9)(0.77) = 1.85$$

where 1) the ultimate BOD will exert approximately 90% of the theoretical oxygen demand, and 2) the BOD_5 is 77% of the ultimate BOD of the domestic waste.

In the present study, the COD/TOC ratio was found to be 4.15 and BOD/TOC ratio was found to be 1.90, in the case of grab samples. In the case of composite samples, the COD/TOC and BOD/TOC ratios were 8.0 and 2.85 respectively. The fact that filtered samples were used in TOC analysis would influence these ratios significantly, as quite a substantial percentage of organic matter (above 40%) may be removed as suspended matter. This obviously accounted for the low values of TOC and the quite high values for the COD/TOC ratio. It may be of interest to note that the average per capita daily BOD contribution from the household in this study was 0.09 lbs, compared to 0.17 lbs usually adopted in the design of community systems.

Total Phosphates

The total phosphates ($\text{PO}_4\text{-P}$) in the raw sewage varied between 2.5 mg/l and 45.0 mg/l, with a mean value of 15.7 mg/l, in respect of grab samples; in the case of composite samples, the mean was 4.5 mg/l. The higher values observed for grab samples may be due to sampling done at the time of clothes washing operations.

Ammonia Nitrogen and Nitrate Nitrogen

The ammonia nitrogen in raw sewage was found to vary between 3.3 mg/l and 226.6 mg/l with an average value of 61.0 mg/l for the grab samples; the mean value for composite samples was 38.4 mg/l. The higher mean value for the grab samples was probably due to sampling at the time of use of the washroom. The mean concentration of nitrate nitrogen in raw sewage samples was found to be 0.12 mg/l based on grab samples. Since the sewage collected for analysis was fresh, nitrates may be present in raw sewage, at concentrations reported.

Total Soluble Iron

The average concentration of total soluble iron in the raw sewage was found to be 1.80 mg/l based on grab samples and 0.68 mg/l based on composite samples. Though iron was present in the water supply, the concentration of total soluble iron was low (0.20 mg/l). Most of the iron found in raw sewage was contributed from the household.

Chlorides

The mean contribution of chlorides in the raw sewage was found to be 124.3 mg/l, based on grab samples. The chlorides in the water supply were below 5 mg/l. The chloride pick up was essentially from the household.

Total Coliforms, Fecal Coliforms and Fecal Streptococci

The total coliforms in raw sewage varied between 1100 and 22×10^6 per 100 ml; with a geometric mean of 1,168,000 per 100 ml. Fecal coliforms ranged between 600 and 6×10^6 per 100 ml, with a geometric mean of 34,750 per 100 ml. Fecal streptococci were in the range of 360 to 600,000 per 100 ml, with a geometric mean of 22,160 per 100 ml. It was found by Geldreich and his associates (38, 39) that the ratio of fecal coliforms to fecal streptococci was greater than 4 in human feces and domestic wastes, whereas the ratio was less than 0.7 in the feces of farm animals, cats and dogs or wastewaters polluted with the same. In the present study, mean fecal coliform counts were found to be about 3% of the mean total coliforms. It was also observed that the ratio of mean values of fecal coliforms to mean values of fecal streptococci was 1.56, much less than the value reported by Geldreich for domestic wastes, but higher than the ones for farm animal feces and wastes. The ratios reported by Geldreich for domestic wastes however related to domestic sewage from community systems rather than from

individual households. The smaller ratio observed in this study could be due to greater grab samplings at times when flow contained lesser fecal matter compared to other household waste matter.

Pseudomonas aeruginosa

Other than an extreme value of 92,000 per 100 ml (MPN), the rest were below 400 per 100 ml. The mean (geometric) was 160 per 100 ml. The values would appear to be quite small compared to values reported in the literature for domestic wastes (41).

4.3.3 Characteristics of the Septic Tank Effluent

The chemical and bacteriological characteristics of the samples of the septic tank effluent analyzed on various occasions during the period of the investigation are furnished in Tables 19 and 20, pages 112-113. The data analysis for probability charts was carried out in the same manner as for raw sewage. The data as arranged for probability charts are shown in Tables F4 to F7, Appendix F, p.303-306. The probability plots are shown in Figures F11 to F19, Appendix F, p.307-315. The mean values (50%), 15% and 85% of the time values for each parameter as taken from the graphs are furnished in Table 51.

An analysis of the characteristics of the septic tank effluent as found in the Tables mentioned earlier, reveals the following salient features.

Table 51. Statistical Analyses of Septic Tank Effluent Characteristics

Characteristics	Percent of time equal to or less than			Standard Deviation
	15	50 values	85	
pH	6.65	6.90	7.15	0.3
TSS, mg/l	80	165	250	80
BOD, mg/l	170	280	350	85
COD, mg/l	300	550	800	245
TOC, mg/l	35	70	105	35
PO ₄ -P, mg/l	6.5	10.5	14.0	3.5
NH ₃ -N, mg/l	80	92	105	12
NO ₃ -N, mg/l	0.0	0.02	0.04	0.02
Total soluble iron, mg/l	0.0	2.25	4.75	2.2
Chlorides, mg/l	35	50	67	15
Total coliforms/100 ml	3.7x10 ⁵	2.3x10 ⁶	1.45x10 ⁷	
Fecal coliforms/100 ml	1x10 ⁴	1.6x10 ⁵	2.6x10 ⁶	
Fecal streptococci/100 ml	2.2x10 ⁴	1.1x10 ⁵	5.1x10 ⁵	
SPC/ml (35°C)	5x10 ⁴	3x10 ⁵	1.7x10 ⁶	
SPC/ml (20°C)	4.2x10 ⁵	8.2x10 ⁵	1.6x10 ⁶	
<i>Pseudomonas aeruginosa</i> /100 ml	<2	28	520	

pH

The pH of the septic tank effluent was between 6.53 and 7.45, with an average of 6.90. It was observed that 64% of the time, the pH was equal to or less than 7.0, compared to 30% of the time for raw sewage samples. The effluent samples were in the alkaline range for lesser number of times. The effluent samples also varied over a smaller range of pH than the raw sewage samples. The detention available in the septic tank and anaerobic digestion occurring in the tank had evidently brought the mean pH nearer 7.0.

TSS, VSS and Fixed SS

The TSS in the septic tank effluent varied between 68 mg/l and 624 mg/l, with a mean value of 176 mg/l. The VSS varied between 44 mg/l and 540 mg/l, with a mean value of 137 mg/l. The mean VSS was 77% of the TSS, less than the percentage observed in the case of raw sewage. On some occasions, it was observed that the TSS of the effluent was higher than that of the raw sewage; this may be due to hydraulic scouring and/or sludge gasification forcing re-entrainment of appreciable quantities of sedimented material in the effluent stream (60).

BOD, COD and TOC

The BOD of the septic tank effluent varied between

140 mg/l and 666 mg/l, with a mean of 280 mg/l. The COD varied between 240 mg/l and 2026 mg/l, with a mean value of 568 mg/l. The TOC of the effluent was found to be in the 24-190 mg/l, with a mean value of 73 mg/l. The ratio of BOD to COD was found to be 0.49; the COD/TOC and BOD/TOC ratios were 7.8 and 3.8 respectively. The use of filtered samples in the TOC analysis was reflected in the higher ratios observed for COD/TOC and BOD/TOC.

Total Phosphates (PO₄-P)

The total phosphates in the effluent were in the 6.25-30.0 mg/l range, with a mean value of 11.6 mg/l. The mean effluent phosphate level was found to be lower than that of raw sewage, though on some occasions, the effluent concentration was found to be higher.

Ammonia Nitrogen and Nitrate Nitrogen

The ammonia nitrogen in the effluent was found to vary between 76.6 mg/l and 110.0 mg/l, with a mean value of 96.9 mg/l. The mean concentration of nitrate nitrogen in the effluent was found to be 0.026 mg/l. There was an increase in ammonia nitrogen and a decrease in nitrate nitrogen, compared to raw sewage, due to anaerobic reactions taking place in the septic tank.

Total Soluble Iron

The average concentration of total soluble iron in the septic tank effluent was found to be 2.63 mg/l, higher than the amount found in the raw sewage. The reason for this is not clear.

Chlorides

The mean concentration of the chlorides in the septic tank effluent was found to be 53 mg/l. The effluent chloride level was less than that of raw sewage.

Total Coliforms, Fecal Coliforms and Fecal Streptococci

The total coliforms in the septic tank effluent varied between 240,000 and 24×10^6 per 100 ml; with a geometric mean of 2,278,000 per 100 ml. Fecal coliforms ranged between 4100 and 5.2×10^6 per 100 ml, with a geometric mean of 176,400 per 100 ml. Fecal streptococci levels were in the range of 14,000 to 740,000 per 100 ml, with a geometric mean of 110,800 per 100 ml. In the present study, the mean fecal coliforms counts were found to be about 8% of the mean total coliforms. It was also observed that the ratio of mean values of fecal coliforms to mean values of fecal streptococci was 1.59, close to the value observed in the case of raw sewage.

Pseudomonas aeruginosa

The values ranged over a wide margin from less than 0.2 MPN/100 ml to 16,000 MPN/100 ml, with a geometric mean of 30 per 100 ml. The effluent Pseudomonas aeruginosa level was found to be less than that of raw sewage.

4.3.4 Efficiency of the Septic Tank

For an assessment of the overall efficiency of the septic tank system, it was necessary to determine the efficiency of the septic tank. The efficiency of the septic tank process was evaluated with respect to the following parameters: Removal of TSS, removal of BOD, COD, and TOC and removal (if any) of microorganisms like coliforms, fecal coliforms and fecal streptococci. Data obtained from chemical and bacteriological analyses of the raw sewage and of the septic tank effluent were used to determine the removal efficiencies. Efficiencies of removal using 15%, 50% (mean) and 85% probabilities of occurrence were determined and are presented in Table 52.

It may be seen from the Table, that TSS were removed to an extent of about 20%, whereas BOD and COD removal were in the 50% range. TOC removal was found to be fairly high. There was a wide margin of difference between mean values of composite and grab samples of raw sewage in respect of TOC; the efficiency of removal will be about 50% if the mean value of composite samples were taken for calculation.

Table 52. Efficiency of Septic Tank

Percent of time equal to or less than	Efficiency of Removal (percentage)					
	TSS	BOD	COD	TOC	SPC 35°C	<i>Pseudomonas aeruginosa</i>
15	Nil	53	14	50	62	-
50 (mean value)	18	46	45	75	46	81
85	22	48	52	78	32	87

The efficiencies observed were in agreement with reported values, except for TSS, in which case, the efficiency obtained in the present study was found to be much smaller than reported values (35-60%). Results showed a removal of about 46% in the total number of organisms on a gross estimate based on Standard Plate Count at 35°C. However such a definite trend was not noticeable when the results of Standard Plate Count at 20°C were analyzed. In respect of coliforms, fecal coliforms and fecal streptococci, the effluent values were more often greater than the raw sewage values, leading to the conclusion that there was hardly any removal of indicator microorganisms through the septic tank process. Fairly high removals (greater than 80%) of Pseudomonas aeruginosa were observed through treatment in the septic tank.

4.3.5 Sludge and Scum Accumulations in the Septic Tank

The measurements taken to obtain the depth of sludge and scum in both the compartments of the septic tank, on three occasions are furnished in Table G1, Appendix G, page 317. The total sludge and scum accumulations in the septic tank on the three occasions are presented in Table 53. The total sludge and scum accumulations were 70.5 cft, 104.2 cft and 115.5 cft at the end of 2 years 4 months, 2 years 11 months and 3 years 3 months respectively from the starting of the septic tank. The accumulation observed at the end of

Table 53. Sludge and Scum Accumulations in the Septic Tank

Date of observation	Time since installation	Total sludge accumulation cft	Total scum accumulation cft	Total sludge and scum cft
30-10-72	2 years 4 months	43.4	27.1	70.5
01-06-73	2 years 11 months	70.1	34.1	104.2
18-09-73	3 years 3 months	74.4	41.1	115.5

2 years 4 months was close to the value obtained by the USPHS formula (Equation 2.1, page 15), but the values for the other periods were found to be quite on the high side. The reason for a rather high sludge accumulation, an increase of about 80% during the 7 month period, is not clear. The scum accumulations had also registered considerably high increases through the period.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary and Conclusions

A field investigation was carried out with the primary objective of determining the efficiency of a septic tile system receiving domestic wastes from a rural household under seasonally varying environmental conditions. A test tile 26 feet long was installed and a portion of the septic tank effluent entering the regular system was diverted to the test tile. Zero-tension lysimeters were installed at 2'0", 3'6" and 4'6" depths to collect percolates. Chemical and bacteriological quality of the percolates and the groundwater adjoining the test tile were analyzed, along with the composition of raw sewage and septic tank effluent. This investigation covered a period of 15 months from December, 1972 to March, 1974. An investigation was conducted to monitor horizontal travel of pollutants from the end of the septic tile. Chemical and bacteriological quality of the groundwater below the existing tile field system was also studied during the summer of 1973. Environmental parameters considered in the study were air and soil temperatures, snow cover and unsaturated depth of the soil.

The following conclusions can be drawn from this study involving the use of one septic tile system.

1. a) The soil had the ability to reduce high percentage (75-90%) of TSS, BOD, COD and TOC present in the septic tank effluent.

b) Reduction of phosphates obtained in the present study were usually in the 25-50% range, much lower than those reported in the literature. This has special significance to lake shores where travel distances may be short and substantial amounts of phosphorous may be added to the lake.

c) High ammonia reductions (80-90%) are observed; with increase in ammonia reduction, corresponding increase in nitrification had been observed, both in the percolate and in the adjoining groundwater. This may lead to nitrate build-up in the groundwater and lakes nearby causing possible health hazards and accelerating eutrophication.

d) There was significant removal of indicator organisms - coliforms, fecal coliforms and fecal streptococci through the soil system compared to numbers present in the septic tank effluent.

2. The efficiency of the septic tile was affected by the duration of the loading. The efficiency of the septic tile showed a decline till the end of 40 weeks from start of loading in respect of reduction of various parameters TSS, BOD, COD, TOC, PO_4 -P, NH_3 -N and total soluble iron, though it showed improvement thereafter, due to other factors.

3. The efficiency of the septic tile was influenced

by seasonal variations. There were greater efficiencies (80-90%) for various parameters during the summer and early fall extending from August to November, when the unsaturated depth of soil was greater. These efficiencies tended to decrease to about 70-75% in respect of BOD and TSS, to a greater extent (20-35%) in the case of $\text{NH}_3\text{-N}$ during the winter period when the water levels started to rise. Nitrate nitrogen levels also showed a declining trend during the winter months.

4. Generally, periods of higher air and soil temperatures witnessed in summer, showed better efficiencies in the 75-85% range for most of the parameters.

5. The concentrations of pollutants in the groundwater indicated by BOD, COD, TOC, $\text{NH}_3\text{-N}$ and chlorides were higher near the tile and reduced significantly farther down-slope from the tile end.

6. In the case of nitrate nitrogen, there was a sharp increase in the initial ten feet from the tile end, presumably due to biological oxidation of ammonia present, and beyond this point, dilution reduced the levels at distances farther downstream from the end of the septic tile.

7. Winter operation did not pose any special problems in the case of the septic tile system, as soil temperatures close to the tile and below were much higher than that of prevailing air temperatures in view of the insulating snow cover on the ground. In addition, the temperature of the

effluent in the tile was quite above the freezing point due to hot water discharged to the system.

8. There was a reduction in permeability of the soil just below the trench, made up of slimy mat layer. Microbial organisms were abundant in this layer. From the study done, it would appear that ferrous sulphide clogging was not indicated, though microbial clogging indicated by the presence of polysaccharides, may occur. It was however not possible to conclude on the extent of any clogging for the period of time of the study.

9. a) The average water consumption in the household was 22.7 imp. gpcd; the mean use of water for toilet flushing was found to be 22.6% of the total daily intake. These low values may be due to the large number of children in the household.

b) The average per capita daily BOD contribution from the household was 0.09 lbs, compared to 0.17 lbs usually adopted in the design of community systems.

c) The septic tank removed about 20% of TSS and about 50% of BOD and COD. There was hardly any removal of indicator organisms like coliforms, fecal coliforms and fecal streptococci, through the septic tank. However, fairly high removals (greater than 80%) of Pseudomonas aeruginosa were observed through treatment in the septic tank.

5.2 Suggestions for Further Research

It would be necessary to direct further research on the use of "mound" type (14) of septic tile system for a situation encountered in this study, of a fluctuating water table close to the tile and sometimes rising above the tile. Though failure of the system as such did not occur in the present case, the efficiency of removal, especially of micro-organisms would be significantly poor, necessitating the use of modified systems when the depth of soil available below the tile up to the water table is less than 4 feet.

It would be necessary also to study more extensively about phosphate adsorption and possible release when water table fluctuates. Further research is indicated in the area of clogging of the tile bed keeping in view the need to develop designs based on a long term acceptance rates because of the reduced permeability of the clogging mat at the interface. Research on the travel of viruses and other pathogenic bacteria through the soil-system would be desirable, as many isolated hospitals in many parts of the world use septic tank systems for their waste disposal. Further research would be necessary to develop soil systems wherein denitrification could be induced, to avoid excessive nitrate buildup in groundwaters.

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APPENDIX A

SITE PARTICULARS

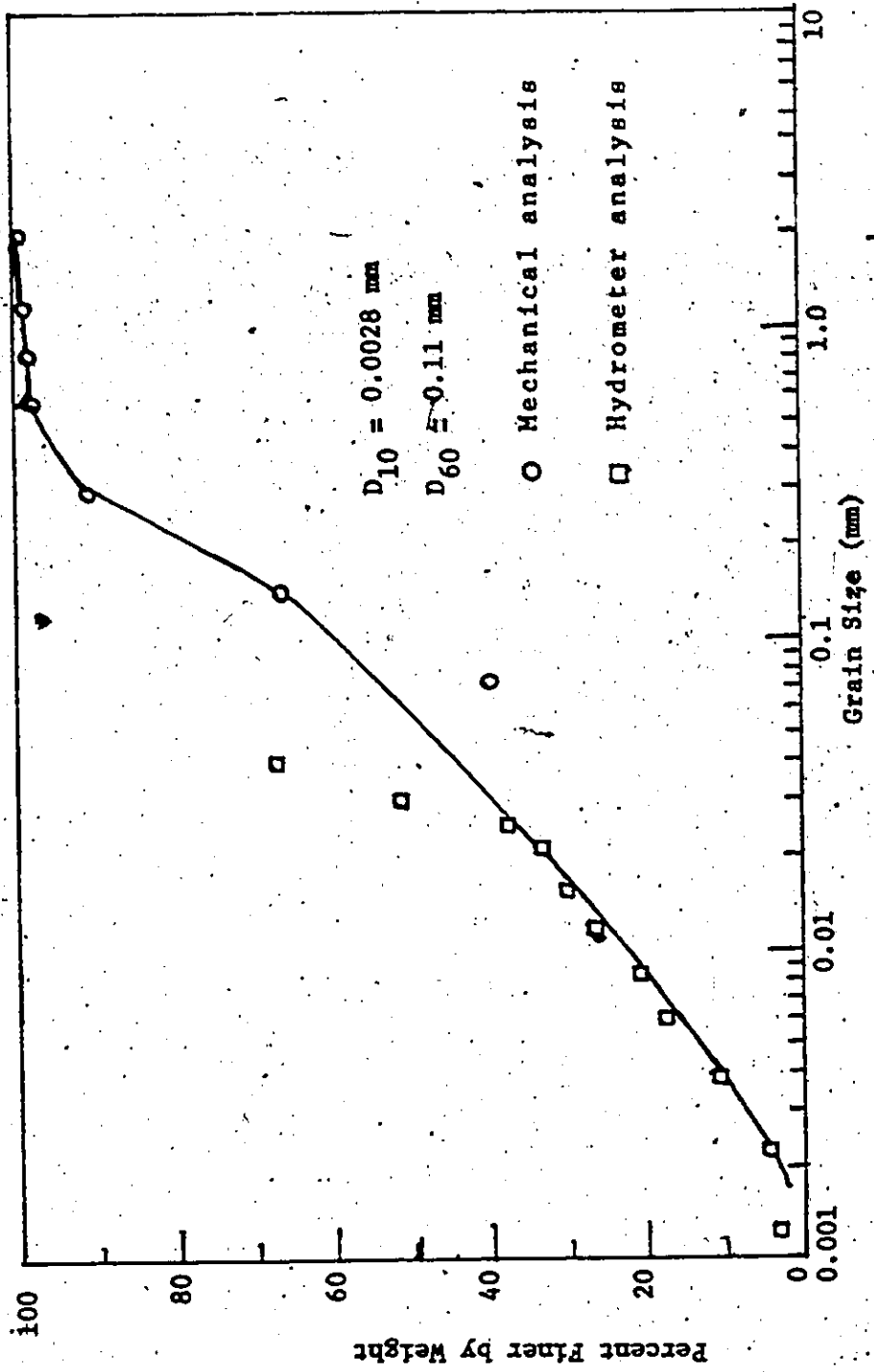


Fig. A 1. Grain Size Distribution Curve for Soil at 0 to 1 depth from Ground

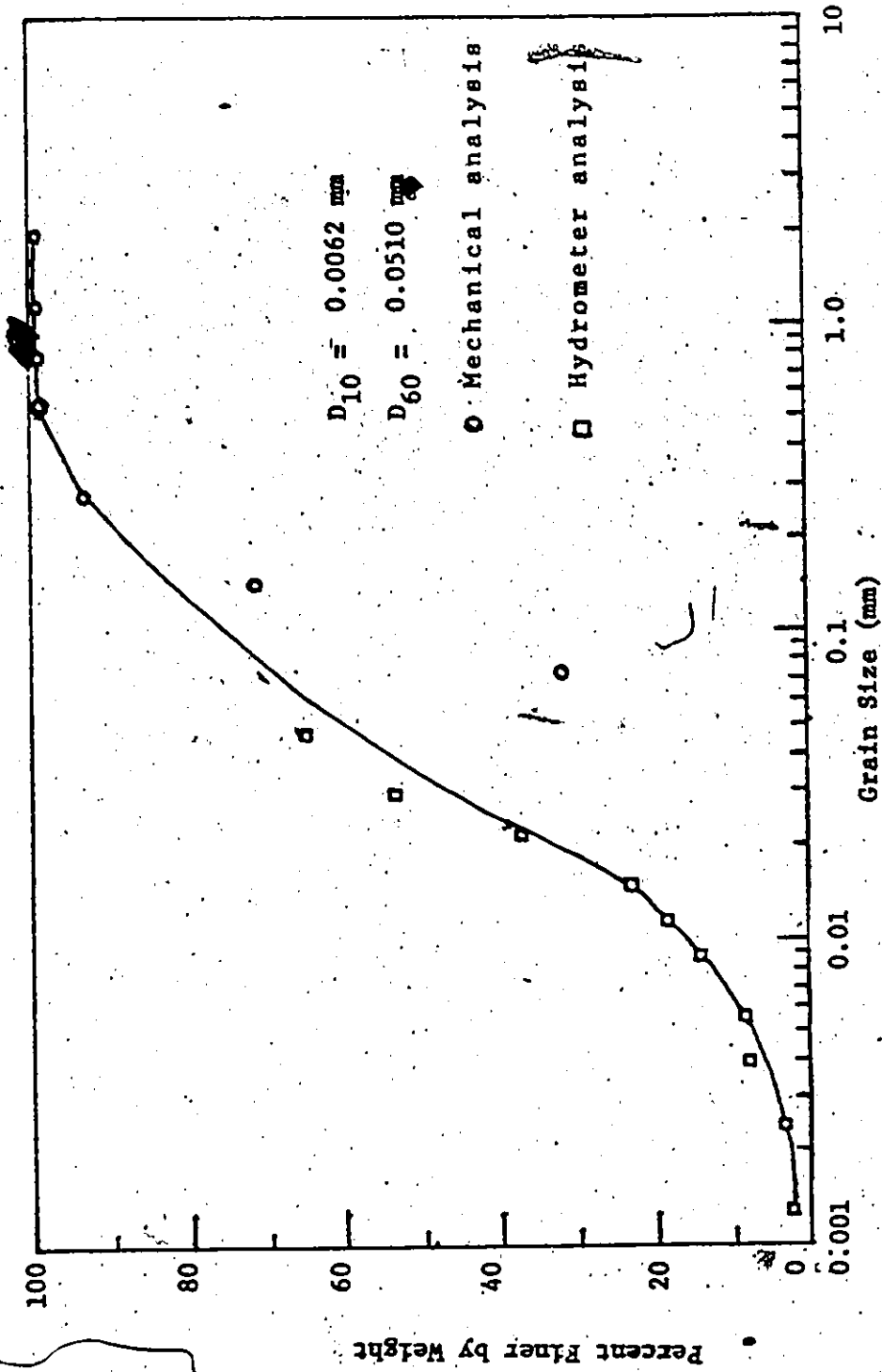


Fig. A 2. Grain Size Distribution Curve for Soil at 1 to 2' Depth from Ground

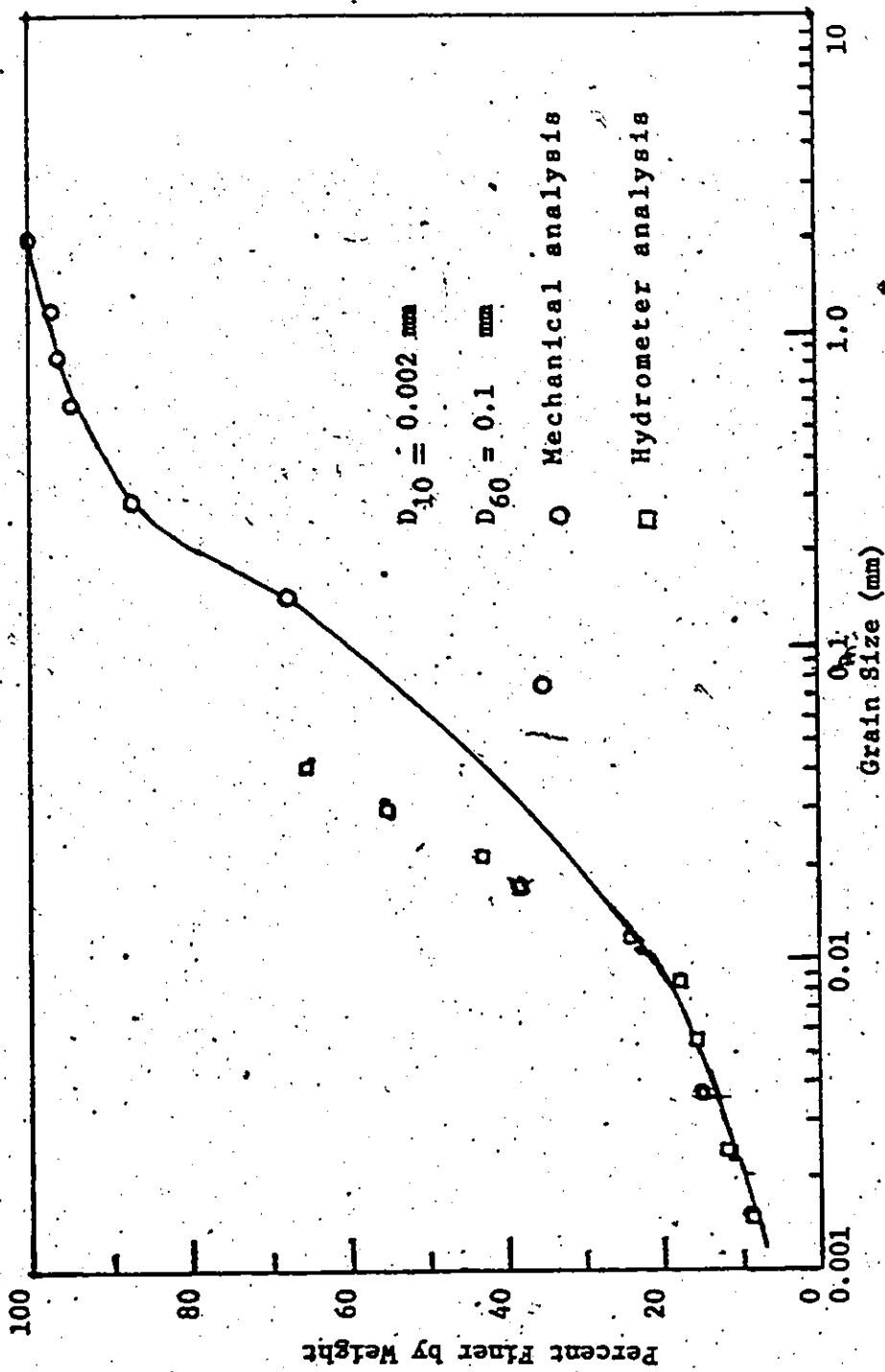


Fig. A 3. Grain Size Distribution Curve for Soil at 2' to 3' Depth from Ground

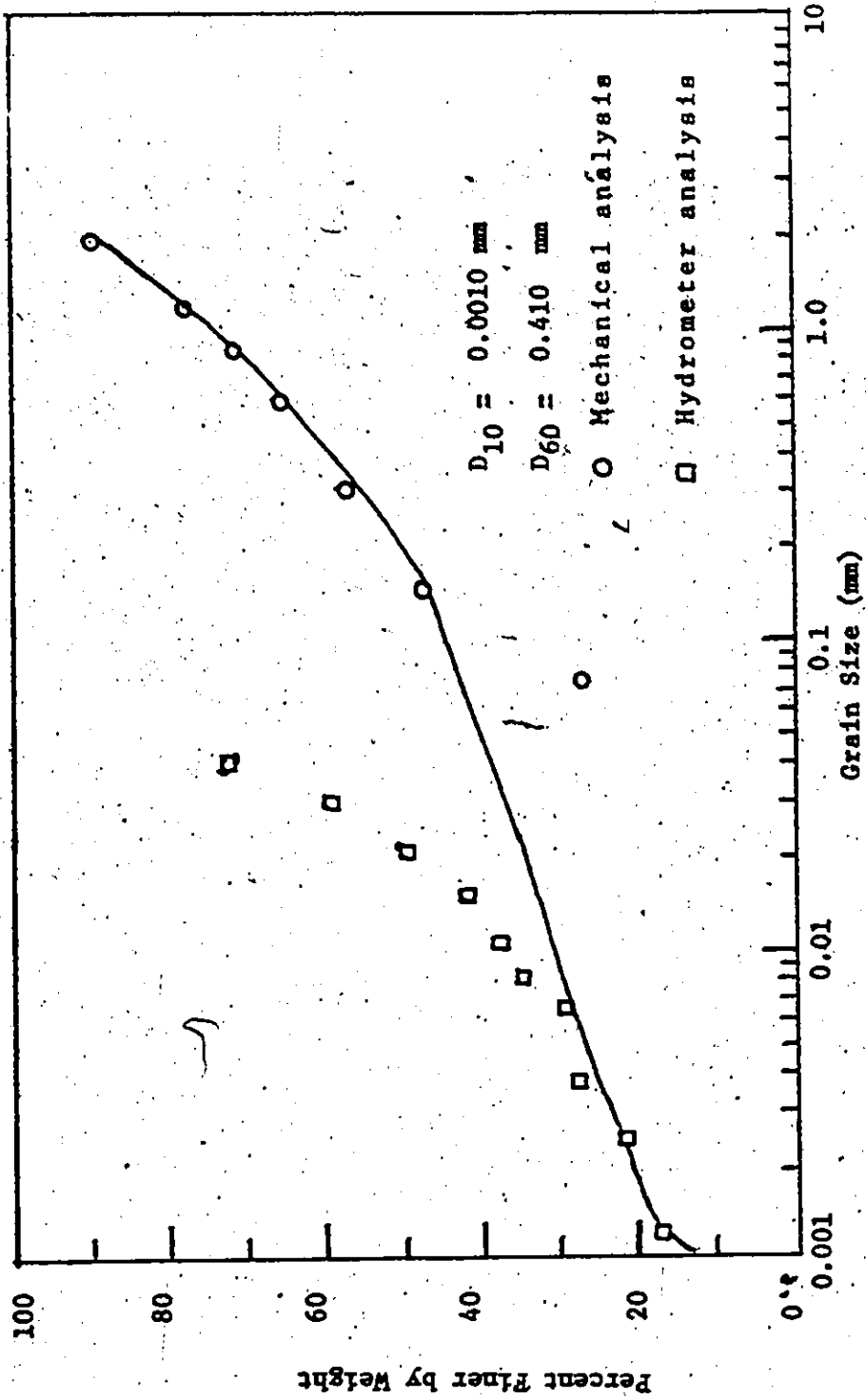


Fig. A 4. Grain Size Distribution Curve for Soil at 3' to 4' Depth from Ground

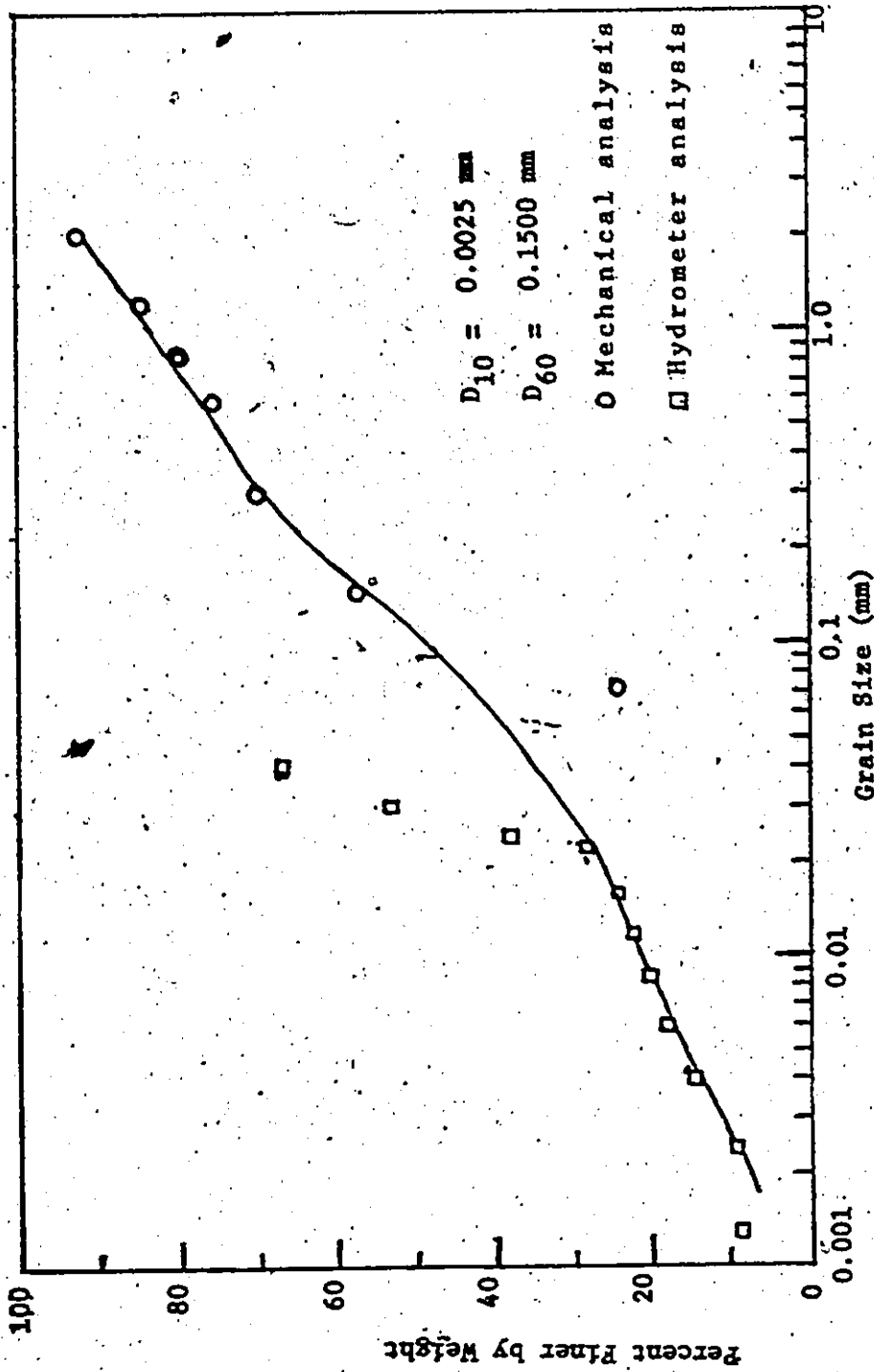


FIG. A 5. Grain Size Distribution for Soil at 4' to 5' Depth from Ground

Table A1. Percolation Test Details

Date of Test: September 28, 1971

Test Hole No. 1		Test Hole No. 2	
Time Lapse min	Drop in Level inches	Time Lapse min	Drop in Level inches
30	3	31	9/16
29	2-5/8	29	3/8
28	2-1/2	30	5/8
29	2-1/2	28	1/2
31	2-1/2		
Stopped		Stopped	

Test Hole No. 3		Test Hole No. 4	
Time Lapse min	Drop in Level inches	Time Lapse min	Drop in Level inches
34	2-3/8	31	2-7/8
29	2-1/16	29	2-9/16
30	1-15/16	31	2-5/8
27	1-7/8	28	2-5/16
34	2-3/16	30	2-7/16
30	2-1/16	31	2-1/2
33	2-1/4	30	2-9/16
30	2	29	2-9/16

Table A2. Calculations for Percolation Rate

Test Hole No. 1

ΔD inches	ΔT min	$R = \frac{\Delta T}{\Delta D}$	T min	T/R
3	30	10.0	15	1.50
2-5/8	29	11.0	44	4.00
2-1/2	28	11.2	72	6.42
2-1/2	29	11.6	101	8.70
2-1/2	31	12.4	132	10.65

Test Hole No. 2

9/16	31	55.1	15.5	0.28
3/8	29	77.3	44.5	0.58
5/8	30	48.0	74.5	1.55
1/2	28	56.0	102.5	1.83

Test Hole No. 3

2-3/8	34	14.3	17	1.18
2-1/16	29	14.1	46	3.20
1-15/16	30	15.5	76	4.90
1-7/8	27	14.4	103	7.15
2-3/16	34	15.5	137	8.83
2-1/16	30	14.5	167	11.51
2-1/4	33	14.7	200	13.60
2	30	15.0	230	15.32

Test Hole No. 4

2-7/8	31	10.8	15.5	1.44
2-9/16	29	11.3	44.5	3.94
2-5/8	31	11.8	75.5	6.40
2-5/16	28	12.1	103.5	8.55
2-7/16	30	12.3	133.5	10.85
2-1/2	31	12.4	164.5	13.25
2-9/16	30	11.9	194.5	16.30
2-9/16	29	11.3	223.5	20.00

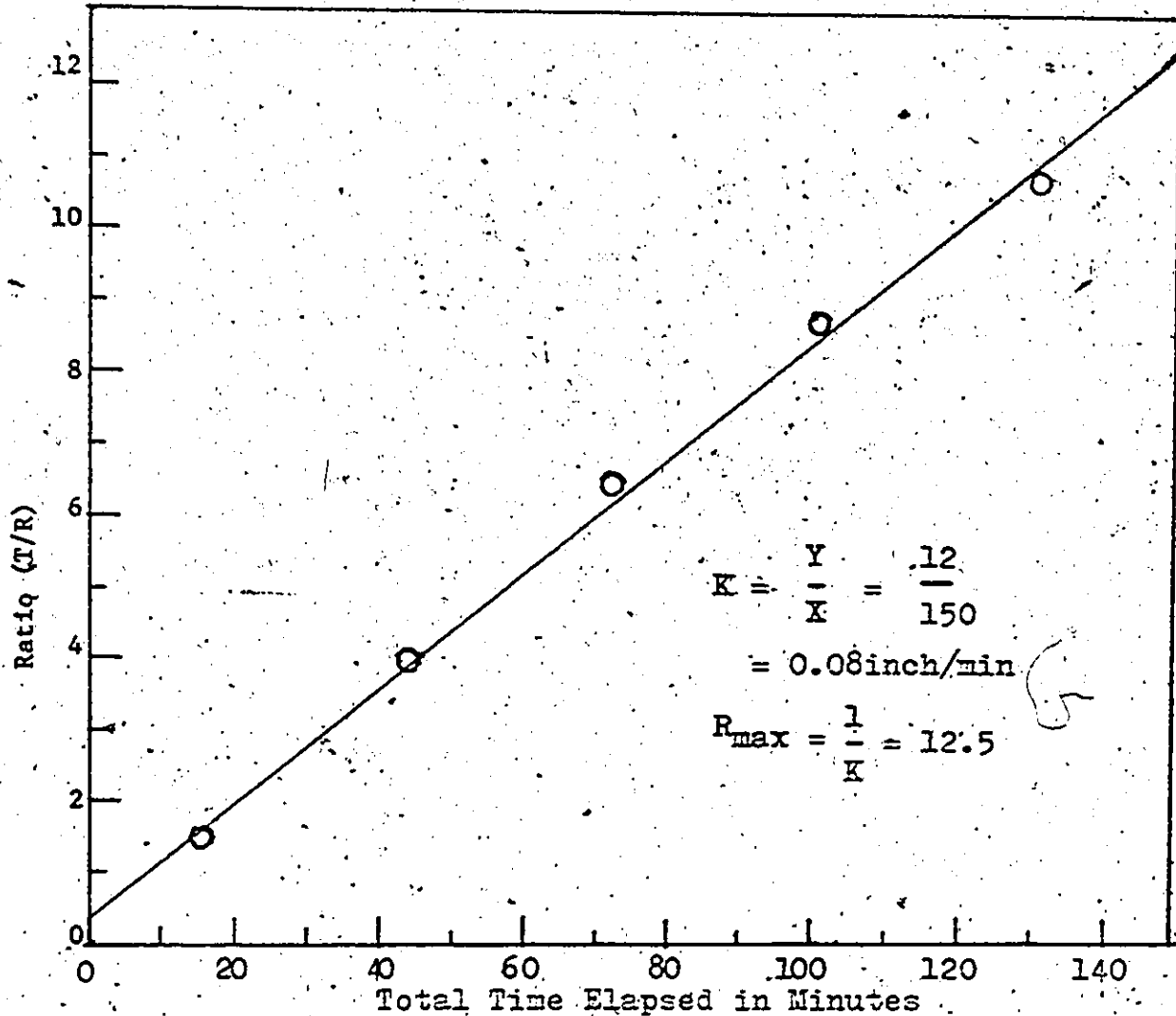


Fig.A6. Plot of Percolation Test Data for Test Hole No.1.

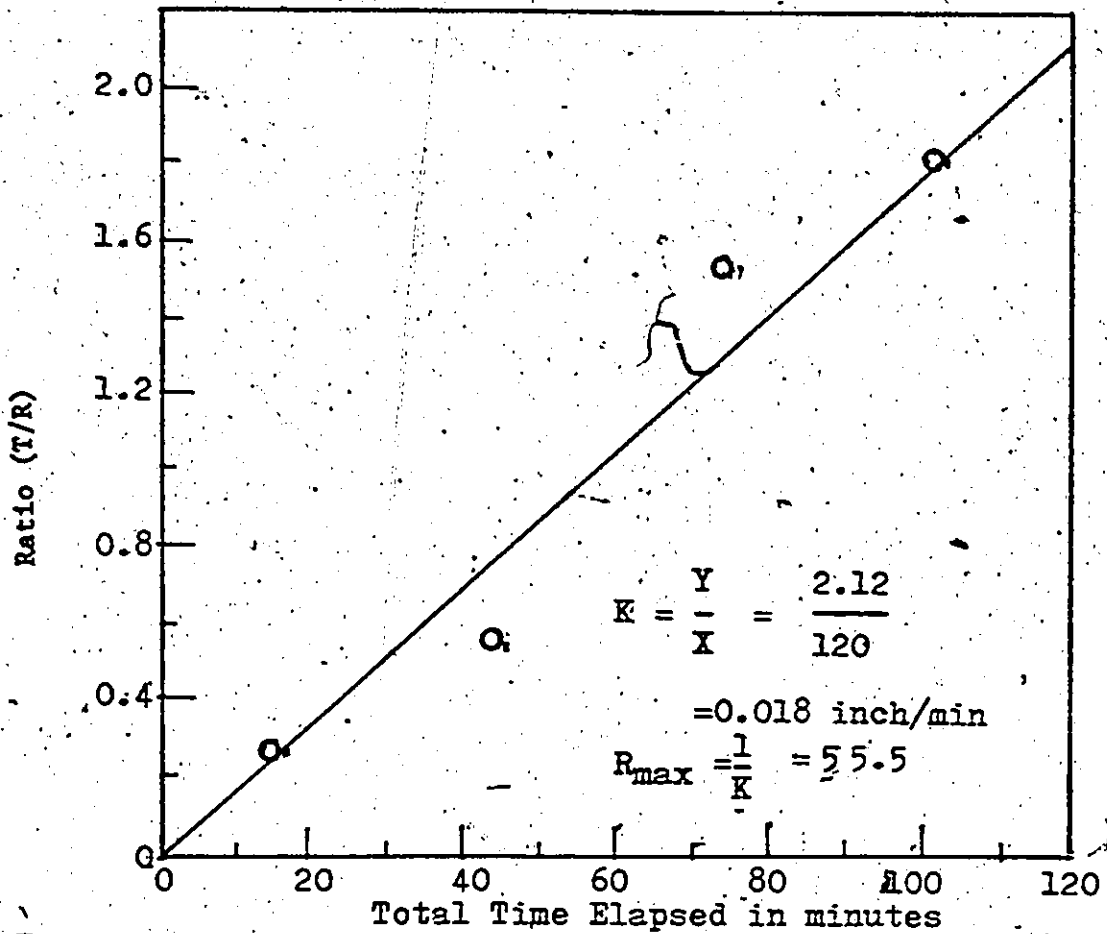


Fig. A7. Plot of Percolation Test Data for Test Hole No.2

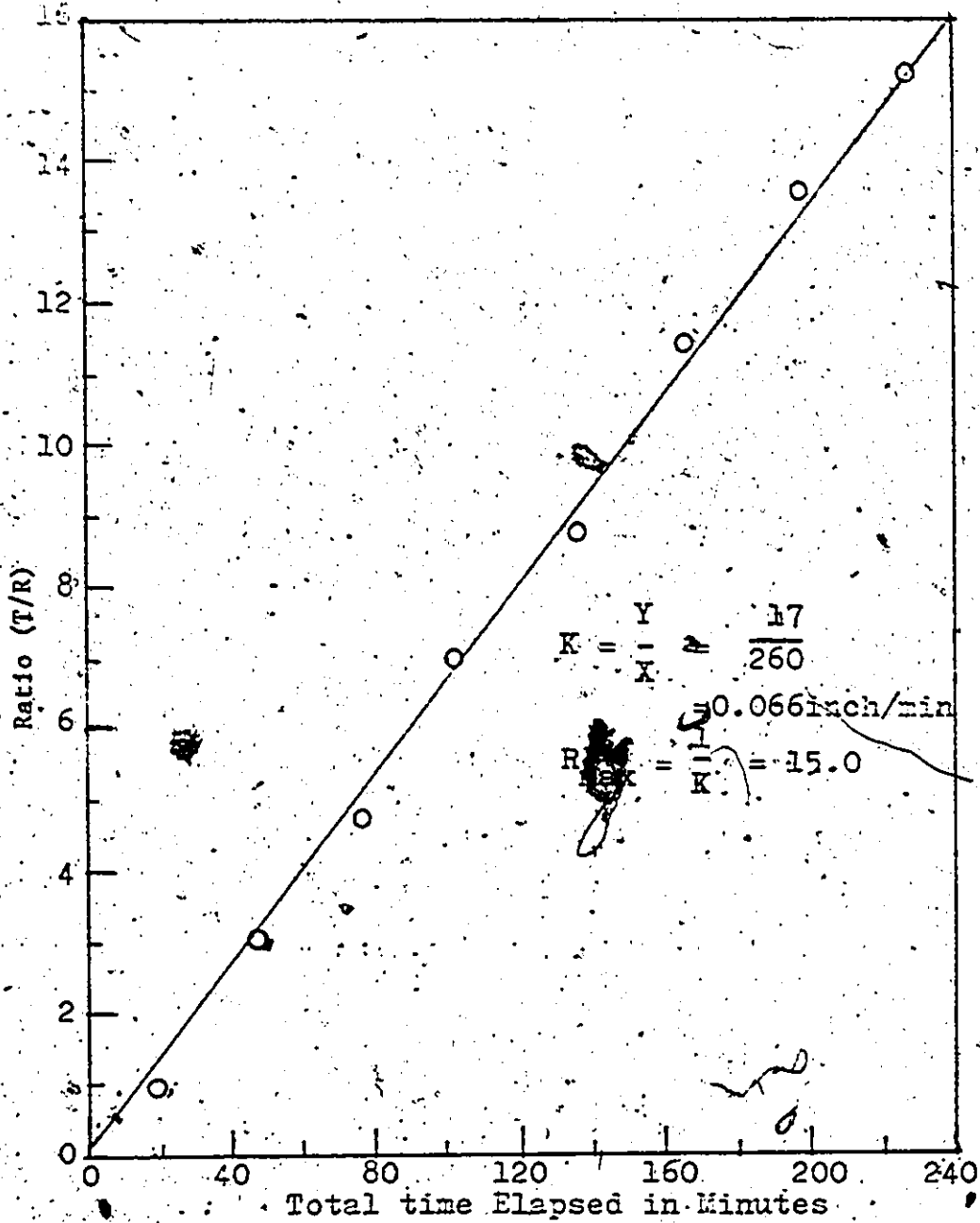


Fig. A8. Plot of Percolation Test Data for Test Hole No. 3

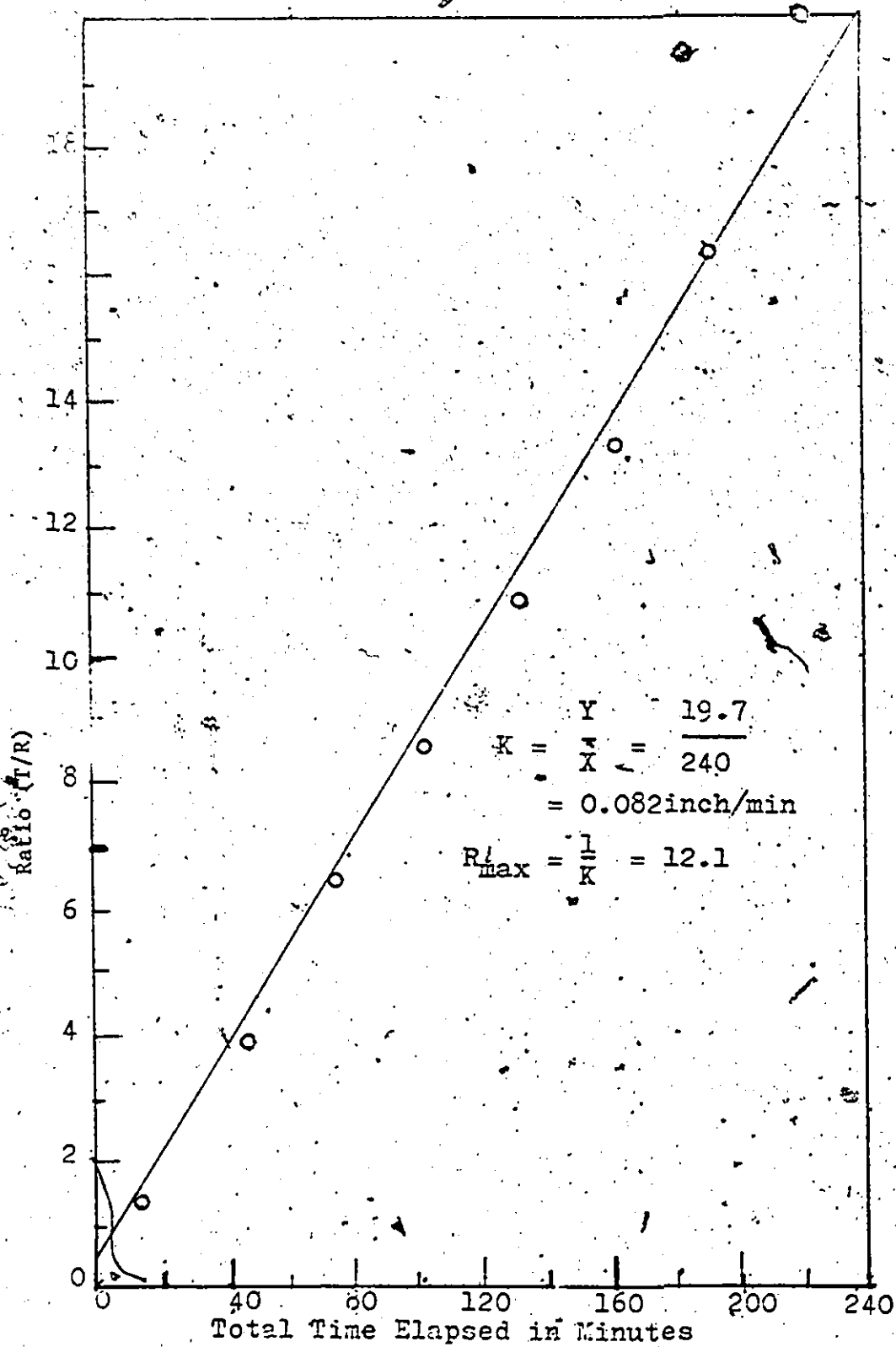
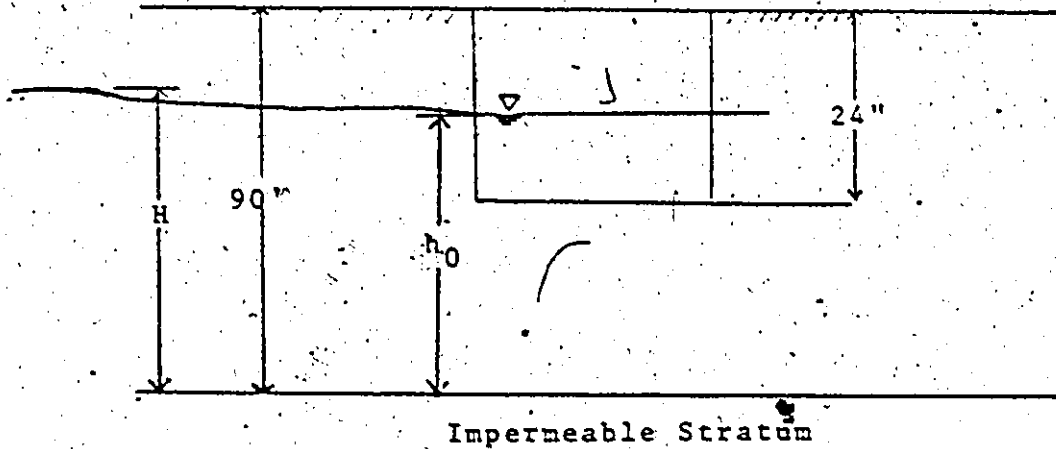


Fig. A9. Plot of Percolation Test Data for Test Hole No 4.



$$K = \frac{\Delta h}{\Delta t} \frac{A}{1.37 (H^2 - h_0^2)}$$

where K = Permeability in ft/minute

Δh = Difference in water level after bailing = 0.4'

Δt = Elapsed time for water level to return to original level = 632 minutes

A = Area of the pit

H = Distance to impermeable stratum from original water level = 88.52'

h_0 = Distance to impermeable stratum from depressed water level = 88.12

Substituting the values

$$K = 2.61 \times 10^{-5} \text{ ft/minute}$$

Fig. A10. Bailing Test Calculations

APPENDIX B

RECORD OF LOADING OPERATIONS

Table B1. Record of Loading Operation

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
17-12-72	9.13	54.0	
18-12-72	7.25	43.0	
19-12-72	14.00	83.5	
20-12-72	16.00	95.0	
21-12-72	9.13	54.0	
22-12-72	9.62	57.0	
23-12-72	12.62	75.0	
24-12-72	7.00	41.5	
25-12-72	5.25	31.0	
26-12-72	9.75	57.5	
27-12-72	11.75	69.5	
28-12-72	5.87	34.8	
29-12-72	9.50	56.0	
30-12-72	8.75	51.7	
31-12-72	10.75	63.5	
01-01-73	8.38	49.5	
02-01-73	7.75	45.7	
03-01-73	9.25	54.7	
04-01-73	8.75	51.7	
05-01-73	14.25	84.0	
06-01-73	-	-	No loading
07-01-73	12.50	74.0	
08-01-73	4.00	23.7	
09-01-73	6.63	39.2	
10-01-73	7.50	44.5	
11-01-73	6.25	37.0	
12-01-73	8.25	49.0	
13-01-73	10.0	59.2	
14-01-73	12.25	72.5	
15-01-73	11.25	66.7	Continuous loading till 16-10
16-01-73	-	-	
17-01-73	8.25	49.0	
18-01-73	14.00	83.5	
19-01-73	11.25	66.7	
20-01-73	12.25	72.5	Continuous till 15-15
21-01-73	-	-	
22-01-73	13.00	77.0	
23-01-73	10.00	59.2	
24-01-73	-	-	No loading
25-01-73	9.75	57.5	

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
26-01-73	12.63	75.0	
27-01-73	10.50	62.2	
28-01-73	10.62	63.0	
29-01-73	-	-	No loading
30-01-73	26.63	157.0	
31-01-73	-	-	No loading
01-02-73	12.38	73.5	
02-02-73	15.00	89.0	
03-02-73	8.75	51.7	
04-02-73	12.75	75.5	
05-02-73	6.00	35.4	
06-02-73	11.75	69.5	
07-02-73	12.00	71.0	
08-02-73	20.50	121.0	
09-02-73	9.50	56.0	
10-02-73	-	-	No loading
11-02-73	10.25	60.5	
12-02-73	10.50	62.2	
13-02-73	11.25	66.7	
14-02-73	15.25	90.5	
15-02-73	7.00	41.5	
16-02-73	10.87	64.2	
17-02-73	9.50	56.0	
18-02-73	15.50	92.0	
19-02-73	-	-	No loading
20-02-73	13.50	80.0	
21-02-73	12.00	71.0	
22-02-73	6.13	36.3	
23-02-73	11.25	66.7	
24-02-73	7.50	44.5	
25-02-73	10.50	62.2	
26-02-73	16.38	97.0	
27-02-73	8.25	49.0	
28-02-73	10.75	63.5	
01-03-73	13.00	77.0	
02-03-73	13.25	78.5	
03-03-73	-	-	Loading continuous
04-03-73	-	-	Loading continuous till 19-30
05-03-73	6.25	37.0	
06-03-73	20.25	120.0	

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
07-03-73	17.50	103.5	
08-03-73	10.25	60.5	
09-03-73	7.00	41.5	
10-03-73	-	-	No loading
11-03-73	14.50	86.0	
12-03-73	-	-	No loading from 12-3-73 to
12-04-73	12.50	74.0	11-4-73
13-04-73	18.25	108.5	
14-04-73	22.50	133.0	
15-04-73	18.75	110.5	
16-04-73	12.63	75.0	
17-04-73	11.87	70.5	
18-04-73	-	-	No loading
19-04-73	37.12	220.0	
20-04-73	15.00	89.0	
21-04-73	8.50	50.2	
22-04-73	10.25	60.5	
23-04-73	22.50	133.0	
24-04-73	13.38	79.5	
25-04-73	12.25	72.5	
26-04-73	-	-	No loading
27-04-73	14.00	83.5	
28-04-73	8.25	49.0	
29-04-73	17.38	103.0	
30-04-73	-	-	No loading
01-05-73	24.00	142.0	
02-05-73	13.75	81.5	
03-05-73	-	-	No loading
04-05-73	15.25	90.5	
05-05-73	12.13	72.0	
06-05-73	16.00	95.0	
07-05-73	17.75	105.0	
08-05-73	-	-	No loading
09-05-73	3.50	20.6	
10-05-73	9.62	57.0	
11-05-73	27.00	160.0	
12-05-73	10.38	61.5	
13-05-73	14.50	86.0	
14-05-73			No loading from 14-5-73 to 24-5-73

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
25-05-73	28.75	170.0	
26-05-73	-	-	No loading
27-05-73	15.75	93.0	
28-05-73	-	-	No loading
29-05-73	26.00	153.5	
30-05-73	-	-	No loading
31-05-73	28.50	168.5	
01-06-73	14.00	83.5	
02-06-73	-	-	No loading
03-06-73	29.50	175.0	
04-06-73	21.00	124.0	
05-06-73	13.50	80.0	
06-06-73	-	-	No loading
07-06-73	29.00	171.5	
08-06-73	17.75	105.0	
10-06-73	13.50	80.0	
11-06-73	-	-	No loading
12-06-73	30.00	178.0	
13-06-73	29.75	175.5	
14-06-73	23.00	136.0	
15-06-73	29.00	171.5	
16-06-73	-	-	No loading
17-06-73	30.00	178.0	
18-06-73	17.00	100.5	
19-06-73	29.00	171.5	
20-06-73	30.00	178.0	
21-06-73	16.00	95.0	
22-06-73	-	-	No loading
23-06-73	26.00	153.5	
24-06-73	-	-	No loading
25-06-73	30.00	178.0	
26-06-73	-	-	No loading
27-06-73	-	-	No loading
28-06-73	29.50	175.0	
29-06-73	-	-	No loading
30-06-73	-	-	No loading
01-07-73	30.00	178.0	
02-07-73	-	-	No loading
03-07-73	-	-	No loading
04-07-73	30.00	178.0	

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
05-07-73	-	-	No loading
06-07-73	-	-	No loading
07-07-73	30.00	178.0	No loading
08-07-73	-	-	No loading
09-07-73	-	-	No loading
10-07-73	30.00	178.0	No loading
11-07-73	-	-	No loading
12-07-73	-	-	No loading
13-07-73	30.00	178.0	No loading
14-07-73	-	-	No loading
15-07-73	-	-	No loading
16-07-73	30.00	178.0	No loading
17-07-73	-	-	No loading
18-07-73	-	-	No loading
19-07-73	30.00	178.0	No loading
20-07-73	-	-	No loading
21-07-73	-	-	No loading
22-07-73	30.00	178.0	No loading
23-07-73	-	-	No loading
24-07-73	-	-	No loading
25-07-73	30.00	178.0	No loading
26-07-73	-	-	No loading
27-07-73	-	-	No loading
28-07-73	30.00	178.0	No loading
29-07-73	-	-	No loading
30-07-73	-	-	No loading
31-07-73	30.00	178.0	No loading
01-08-73	-	-	No loading
02-08-73	-	-	No loading
03-08-73	30.00	178.0	No loading
04-08-73	-	-	No loading
05-08-73	-	-	No loading
06-08-73	30.00	178.0	No loading
07-08-73	-	-	No loading
08-08-73	-	-	No loading
09-08-73	30.00	178.0	No loading
10-08-73	-	-	No loading
11-08-73	-	-	No loading
12-08-73	30.00	178.0	No loading
13-08-73	-	-	No loading

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
14-08-73	-	-	No loading
15-08-73	30.00	178.0	
16-08-73	-	-	No loading from 16-8-73 to
24-08-73	30.00	178.0	23-8-73
25-08-73	-	-	No loading
26-08-73	-	-	No loading
27-08-73	30.00	178.0	
28-08-73	-	-	No loading
29-08-73	-	-	No loading
30-08-73	30.00	178.0	
31-08-73	-	-	No loading
01-09-73	29.25	173.0	
02-09-73	-	-	No loading
03-09-73	29.25	173.0	
04-09-73	-	-	No loading
05-09-73	29.25	173.0	
06-09-73	-	-	No loading
07-09-73	29.25	173.0	
08-09-73	-	-	No loading
09-09-73	29.25	173.0	
10-09-73	-	-	No loading, flap door broken
20-09-73	21.00	124.0	till 19-9-73
21-09-73	22.00	130.0	
22-09-73	25.50	151.0	
23-09-73	29.25	173.0	
24-09-73	-	-	No loading till 27-9-73
28-09-73	15.25	90.5	
29-09-73	15.75	93.5	
30-09-73	18.75	111.0	
01-10-73	20.50	121.0	
02-10-73	-	-	No loading
03-10-73	-	-	No loading
04-10-73	20.25	120.0	
05-10-73	-	-	No loading
06-10-73	20.25	120.0	
07-10-73	-	-	No loading
08-10-73	18.25	108.0	
09-10-73	-	-	No loading
10-10-73	10.75	64.0	
11-10-73	11.25	67.0	

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
12-10-73	-	-	No loading
13-10-73	18.75	111.0	
14-10-73	24.00	142.0	
15-10-73	12.25	72.8	
16-10-73	-	-	No loading
17-10-73	13.50	80.0	
18-10-73	-	-	
19-10-73	17.25	102.0	
20-10-73	11.25	66.7	
21-10-73	12.25	72.8	
22-10-73	10.25	60.7	
23-10-73	17.25	102.0	
24-10-73	-	-	No loading
25-10-73	-	-	No loading
26-10-73	19.25	114.0	
27-10-73	12.00	71.0	
28-10-73	14.50	86.0	
29-10-73	15.50	92.0	
30-10-73	-	-	No loading
31-10-73	15.00	89.0	
01-11-73	-	-	No loading
02-11-73	-	-	No loading
03-11-73	10.25	60.5	
04-11-73	24.75	147.0	
05-11-73	-	-	No loading
06-11-73	18.50	109.5	
07-11-73	-	-	No loading
08-11-73	21.25	126.0	
09-11-73	-	-	No loading
10-11-73	23.50	139.0	
11-11-73	-	-	No loading
12-11-73	25.00	148.0	
13-11-73	-	-	No loading
14-11-73	15.50	92.0	
15-11-73	12.00	71.0	
16-11-73	10.50	62.2	
17-11-73	-	-	No loading
18-11-73	22.50	133.5	
19-11-73	-	-	No loading
20-11-73	-	-	No loading

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. Gallons per day	Remarks
21-11-73	24.00	142.0	
22-11-73	-	-	No loading
23-11-73	28.75	170.0	
24-11-73	-	-	No loading
25-11-73	9.25	54.7	
26-11-73	-	-	No loading
27-11-73	18.50	109.5	
28-11-73	10.25	60.5	
29-11-73	10.50	62.2	
30-11-73	9.25	54.7	
01-12-73	11.00	65.5	
02-12-73	10.25	60.5	
03-12-73	-	-	No loading
04-12-73	17.75	105.0	
05-12-73	-	-	No loading
06-12-73	21.25	126.0	
07-12-73	-	-	No loading
08-12-73	10.50	62.2	
09-12-73	11.75	69.5	
10-12-73	15.25	90.5	
11-12-73	-	-	No loading
12-12-73	22.0	130.0	
13-12-73	-	-	No loading
14-12-73	21.0	124.0	
15-12-73	12.0	71.0	
16-12-73	11.0	65.5	
17-12-73	-	-	No loading
18-12-73	28.0	165.0	
19-12-73	-	-	No loading
20-12-73	26.0	154.0	
21-12-73	-	-	No loading
22-12-73	12.0	71.0	
23-12-73	10.0	59.2	
24-12-73	9.0	53.2	
25-12-73	-	-	No loading
26-12-73	18.0	106.5	
27-12-73	17.0	100.5	
28-12-73	-	-	No loading
29-12-73	11.0	65.5	
30-12-73	12.0	71.0	

Table B1 - continued

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
31-12-73	15.0	89.0	
01-01-74	10.0	59.2	
02-01-74	12.0	71.0	
03-01-74	-	-	No loading
04-01-74	11.0	65.5	
05-01-74	13.0	77.0	
06-01-74	-	-	No loading
07-01-74	-	-	No loading
08-01-74	-	-	No loading
09-01-74	-	-	No loading
10-01-74	-	-	No loading
11-01-74	18.0	106.5	
12-01-74	-	-	No loading
13-01-74	16.50	97.5	
14-01-74	10.25	60.5	
15-01-74	-	-	No loading
16-01-74	-	-	No loading
17-01-74	10.0	59.2	
18-01-74	-	-	No loading
19-01-74	8.0	47.2	
20-01-74	10.0	59.2	
21-01-74	-	-	No loading
22-01-74	-	-	No loading
23-01-74	12.0	71.0	
24-01-74	9.6	57.0	
25-01-74	10.9	64.2	
26-01-74	12.6	75.0	
27-01-74	22.9	135.5	
28-01-74	14.4	86.0	
29-01-74	-	-	No loading
30-01-74	25.8	153.0	
31-01-74	-	-	No loading
01-02-74	14.4	86.0	
02-02-74	-	-	No loading
03-02-74	10.8	64.0	
04-02-74	26.4	155.0	
05-02-74	30.0	178.0	
06-02-74	-	-	No loading
07-02-74	30.0	178.0	
08-02-74	-	-	No loading

Table B1 - concluded

Date	Drop in Effluent Level in Collecting Tank in inches	Loading Imp. gallons per day	Remarks
09-02-74	30.0	178.0	
10-02-74	-	-	No loading
11-02-74	30.0	178.0	
12-02-74	-	-	No loading
13-02-74	30.0	178.0	
14-02-74	-	-	No loading
15-02-74	30.0	178.0	
16-02-74	-	-	No loading
17-02-74	30.0	178.0	
18-02-74	-	-	No loading
19-02-74	30.0	178.0	
20-02-74	-	-	No loading
21-02-74	30.0	178.0	
22-02-74	-	-	No loading
23-02-74	30.0	178.0	
24-02-74	-	-	No loading
25-02-74	-	-	No loading
26-02-74	14.4	86.0	
27-02-74	-	-	No loading
28-02-74	9.6	57.0	
01-03-74	8.4	49.5	
02-03-74	15.6	92.0	
03-03-74	24.0	142.0	
04-03-74	-	-	No loading
05-03-74	19.2	114.0	
06-03-74	-	-	Loading stopped because of high groundwater level

APPENDIX C

CHEMICAL ANALYSIS CALIBRATIONS

Table C1. Calibration for Phosphate

ml of phosphate standard solution in 50 ml	$\mu\text{g PO}_4$	Absorbance at 690 m μ
0.0	0	0.028
0.5	25	0.435
1.0	50	0.770
1.5	75	1.200
2.0	100	1.450
3.0	150	2.000

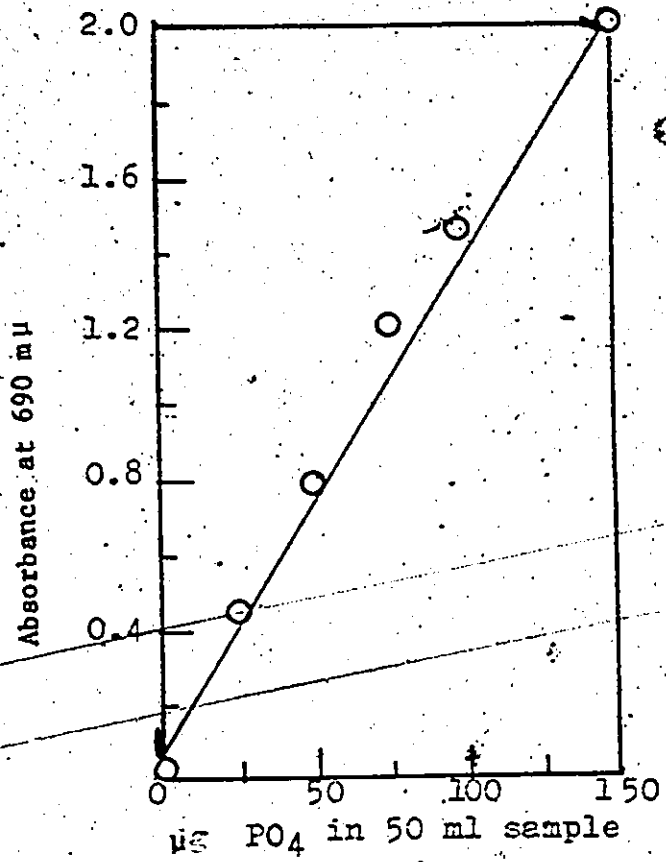


Fig. C1. Calibration Curve for Phosphates

Table C2. Calibration for $\text{NH}_3\text{-N}$

ml in 50 ml	conc. ($\mu\text{g-N}$)	Absorbance at 450 m μ
0	0	0.015
0.5	5	0.032
1.0	10	0.040
1.5	15	0.052
2.0	20	0.065
3.0	30	0.088
5.0	50	0.140
7.5	75	0.212
10.0	100	0.270
20.0	200	0.550
30.0	300	0.750

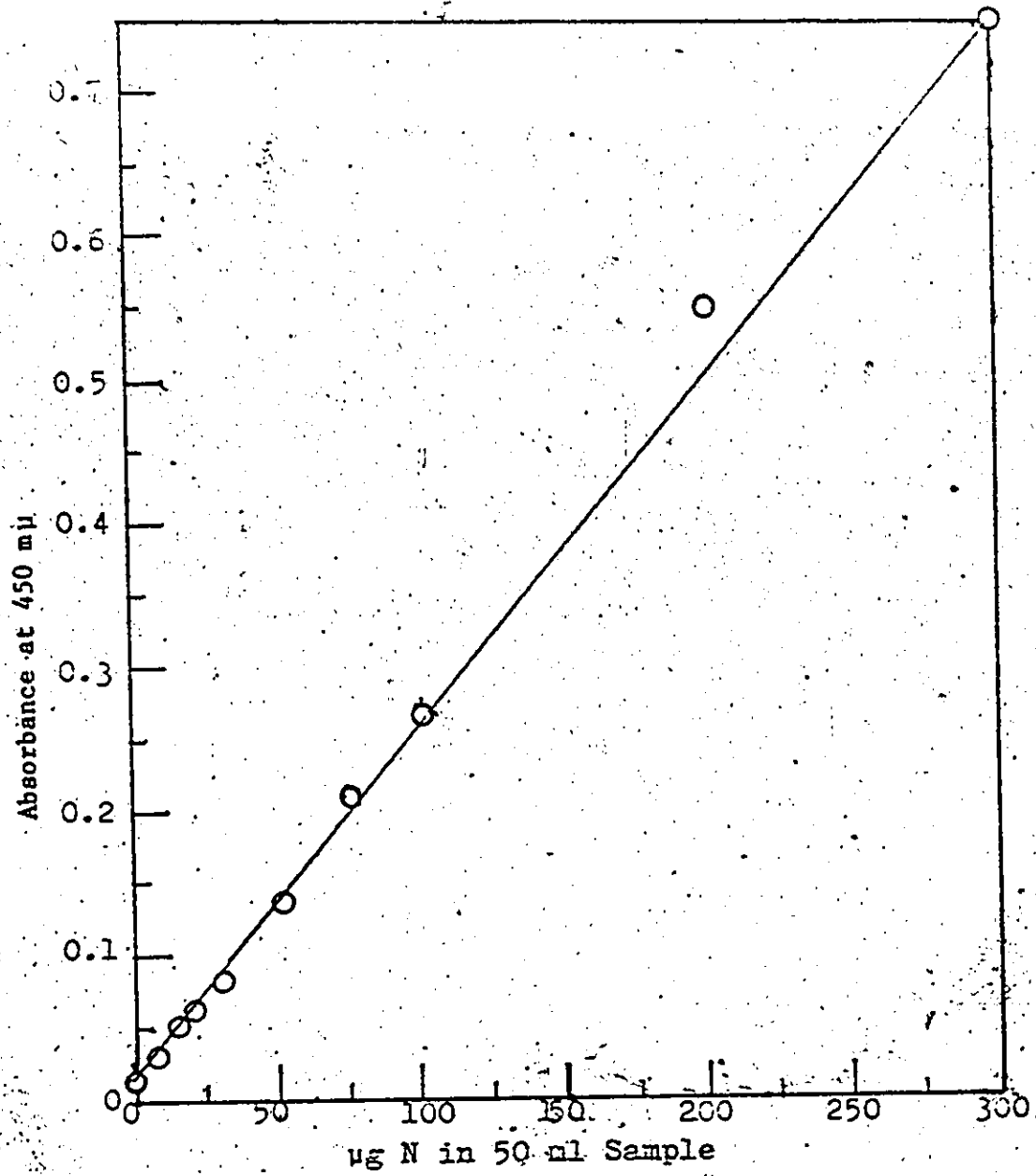


Fig. C2. Calibration Curve for Ammonia,

Table C3. Calibration for Nitrate Nitrogen

Amount of Nitrogen in 50 ml Sample ($\mu\text{g N}$)	Absorbance at 520 m μ
0	0.020
5	0.045
10	0.065
20	0.125
50	0.260
100	0.510

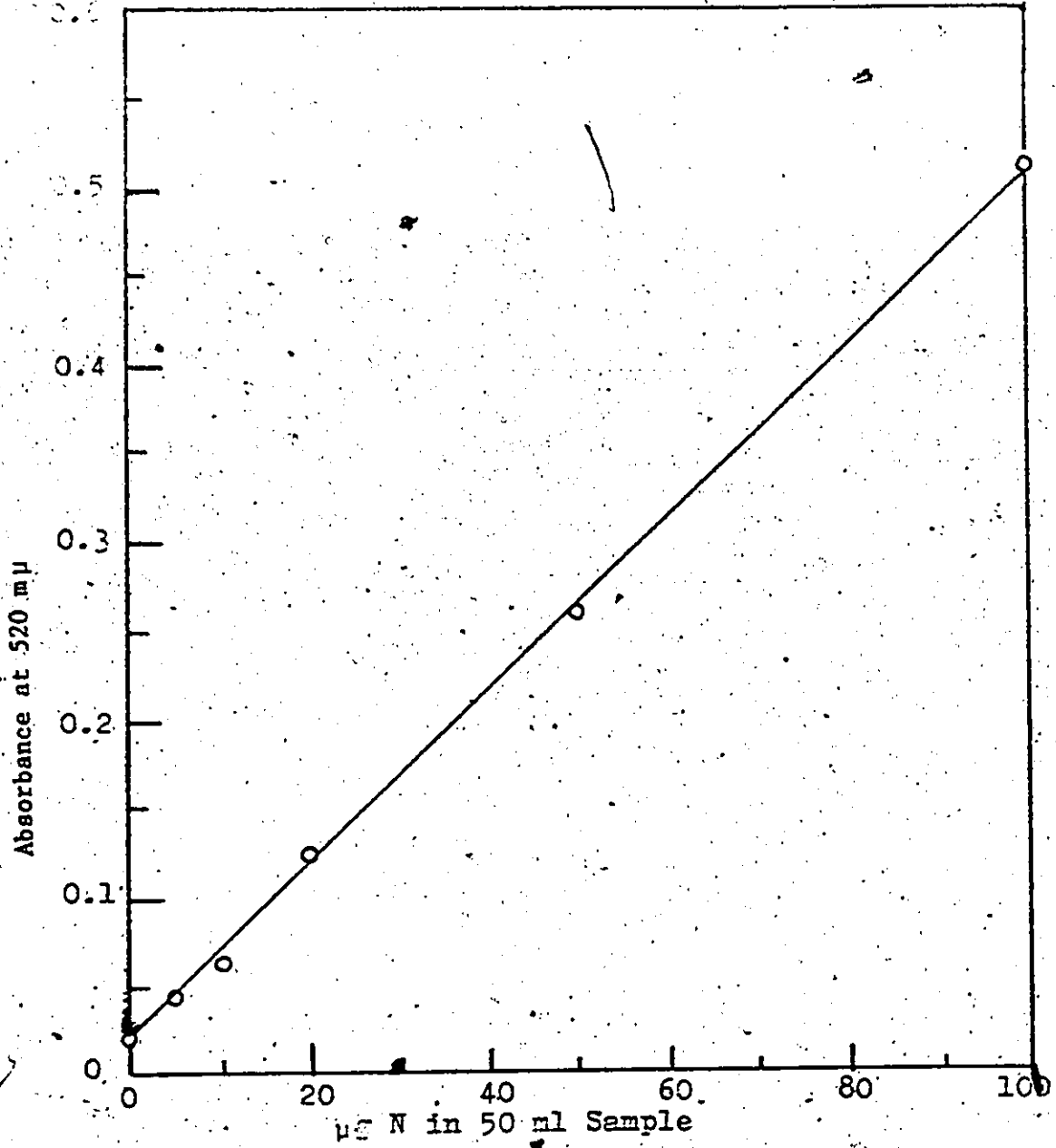


Fig. C3. Calibration Curve for Nitrate Nitrogen.

Table C4. Calibration for Iron using Atomic Absorption Spectrophotometer

Conc. of Iron mg/l	Absorbance
0.5	0.005
1.0	0.010
2.0	0.021
3.0	0.030
4.0	0.040
5.0	0.050
6.0	0.060

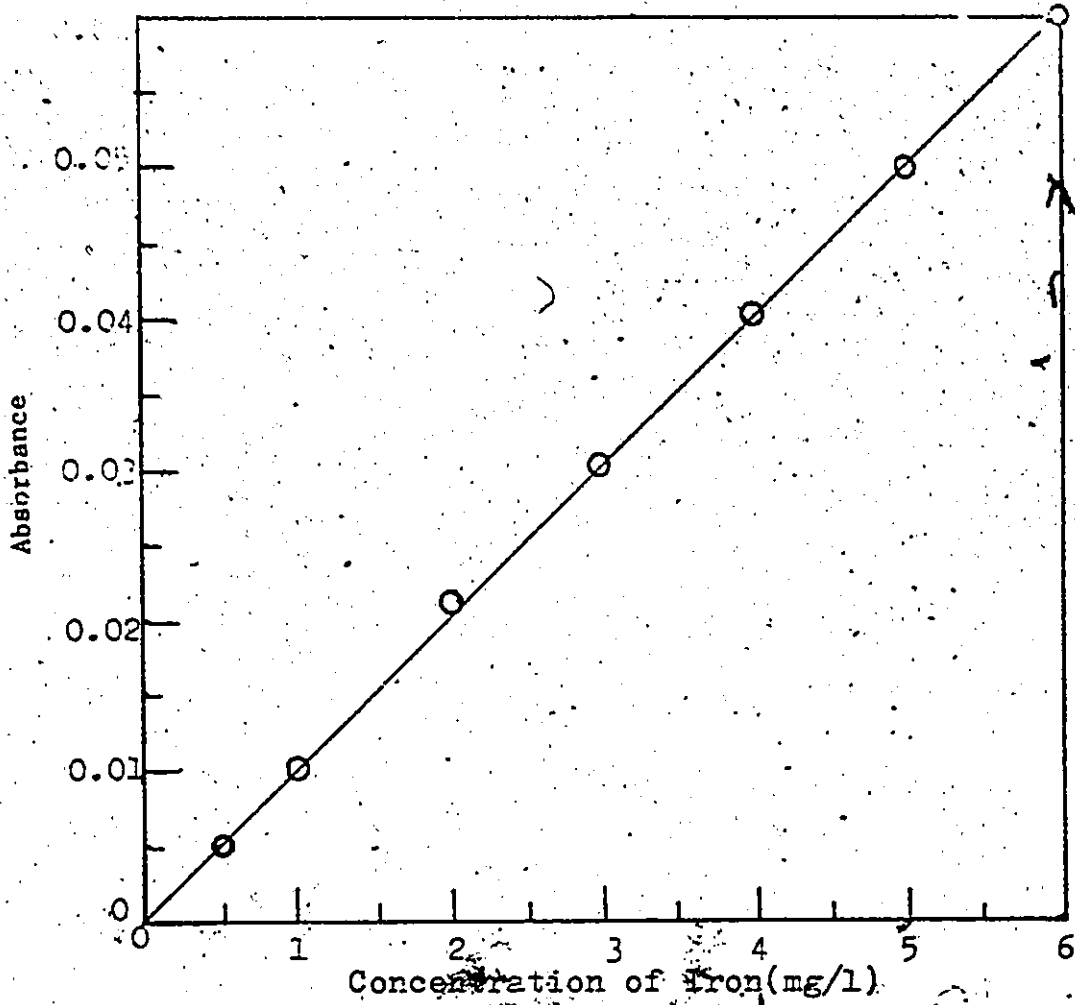


Fig. C4. Calibration Curve for Iron Using Atomic Absorption Spectrophotometer

Table C5. Calibration for Iron using Spectronic 20

Stock Soln \equiv 200 $\mu\text{g Fe/ml}$

Ml of Iron Soln in 50 ml	Amount of Iron in 50 ml ($\mu\text{g Fe}$)	Absorbance at 510 m μ
0	0	0.04
0.2	40	0.22
0.4	80	0.405
0.6	120	0.60
0.8	160	0.76
1.0	200	0.85
1.5	300	1.25

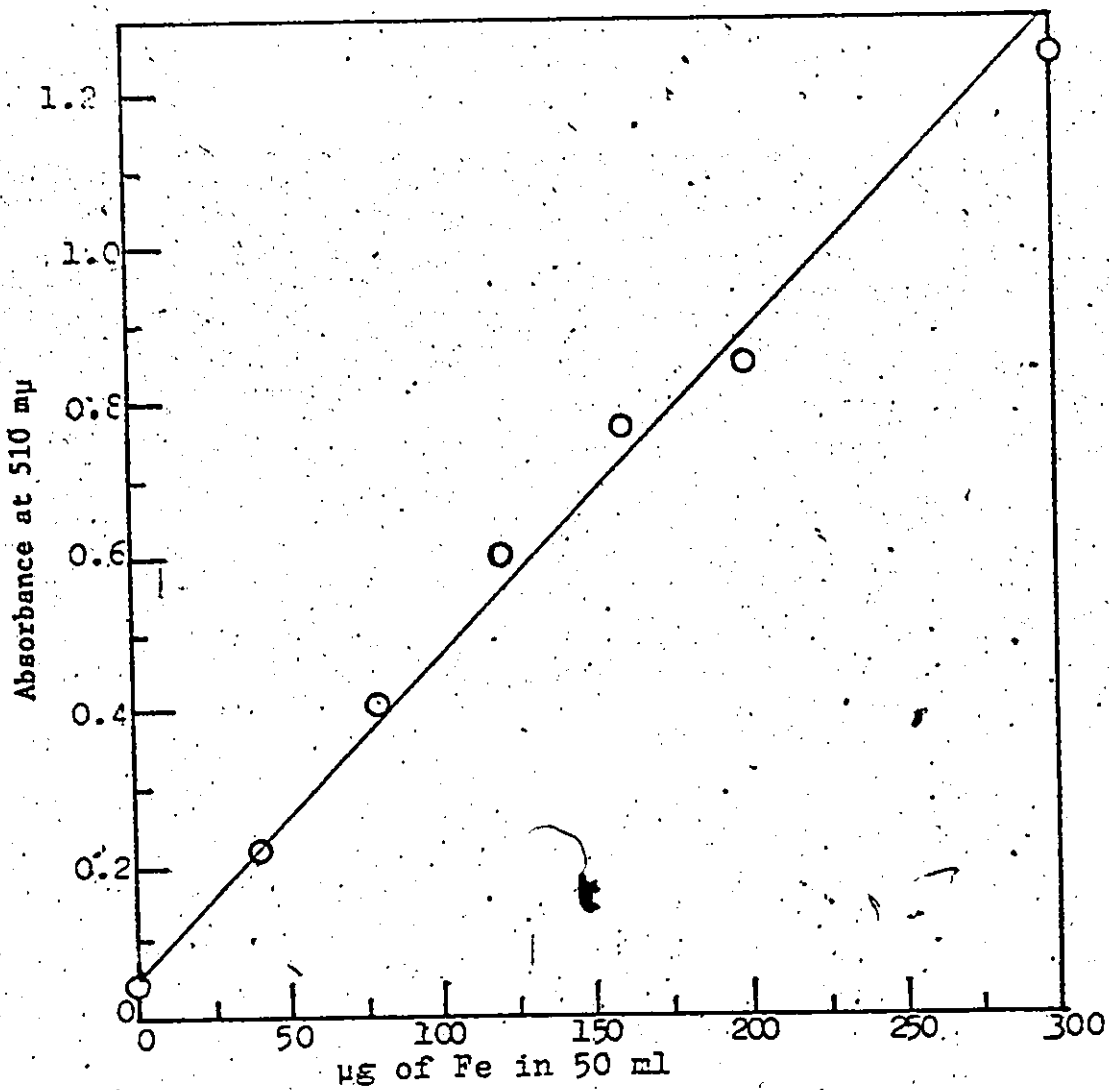


Fig. C5. Calibration Curve for Iron Using Spectronic 20



APPENDIX D

ENVIRONMENTAL CONDITIONS

Table D1. Air Temperatures around 10:00 a.m.

Date	Air Temperatures °F															
	Dec. 1972	Jan. 1973	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 1974	Feb.	Mar.
1	28	28	-	22	48	56	64	70	70	79	59	47	28	20	1	29
2	24	22	34	27	41	68	52	78	72	82	55	27	24	3	-8	22
3	20	26	30	34	38	59	63	75	72	82	59	39	32	13	-4	18
4	5	24	34	40	38	66	57	79	71	78	58	34	45	14	-4	41
5	10	29	26	42	40	65	67	74	75	82	58	31	38	15	-3	37
6	28	6	20	35	45	65	75	74	73	70	54	28	37	17	3	41
7	14	0	24	42	40	-	71	81	76	59	54	30	24	16	8	46
8	12	0	23	47	40	64	72	84	78	55	57	38	24	-6	6	22
9	20	-	20	38	40	66	74	81	80	54	61	26	25	-2	7	20
10	20	-	22	32	32	62	70	72	79	57	51	27	31	1	4	25
11	15	-	10	37	33	52	76	58	79	65	44	26	30	13	17	26
12	-	-	4	40	40	52	74	64	72	58	53	39	11	2	12	15
13	-	-	20	46	34	52	73	70	73	58	64	45	23	-2	26	12
14	-	18	20	34	50	63	80	74	76	61	54	48	16	17	-5	20
15	-	24	30	37	52	70	53	71	69	61	52	36	4	11	-3	23
16	-	34	5	41	66	64	49	72	75	51	43	28	7	1	9	27
17	-	36	14	36	64	60	59	75	79	52	42	30	7	-8	21	25
18	-	33	26	35	66	70	58	76	76	47	44	30	-2	-9	9	19
19	-	38	32	40	67	62	62	76	73	59	46	27	-8	3	21	34
20	-	22	36	31	58	66	75	69	73	43	43	29	10	1	30	12
21	8	18	26	38	63	60	78	74	74	49	44	27	17	26	27	18
22	20	24	30	33	-	66	72	74	57	43	49	36	-2	23	30	24
23	26	38	27	40	66	60	66	76	67	59	57	37	12	22	8	41
24	25	27	34	43	56	62	72	79	62	53	52	29	-6	21	4	18
25	16	20	20	50	62	59	69	82	71	56	47	37	5	27	10	9
26	20	34	22	52	59	52	75	77	68	61	60	36	38	30	13	30
27	25	36	6	42	60	61	77	80	70	67	42	31	34	44	24	17
28	20	24	22	42	54	62	78	80	80	54	37	37	35	36	35	11
29	10	16	22	40	45	61	69	70	83	59	41	38	35	33	14	14
30	12	12	44	44	62	62	72	73	84	52	49	35	25	37	25	25
31	26	-	43	43	60	60	78	79	79	47	47	18	18	43	33	33
Mean	20.2	24.4	22.9	39.0	50.2	61.6	68.1	74.7	73.7	60.2	50.8	33.4	19.9	14.9	11.0	24.3

Note: Temperatures from December 1972 to May 1973 recorded at the site. Temperatures from June 1973 onwards taken from the Weather Office, Ottawa.

Table D2. Temperature Record
(taken around 10:00 a.m.)

Date	Thermistor (Probes) Readings °F							
	0	1	2	3	4	5	6	7
16-12-72	39.0	38.0	40.0	42.0	61.0	49.0	-	
18-12-72	38.0	37.7	39.2	41.0	60.5	-	53.5	
22-12-72	39.0	38.0	41.0	42.0	61.0	50.0	52.0	
25-12-72	36.8	36.0	38.5	40.0	60.0	49.0	48.5	
26-12-72	37.5	37.5	41.0	42.0	62.0	50.5	49.0	
27-12-72	37.2	36.2	38.5	40.0	60.5	49.8	51.0	
28-12-72	38.8	36.0	38.5	40.0	60.5	49.8	51.0	
29-12-72	38.0	36.2	39.1	40.6	60.2	49.8	50.1	
30-12-72	37.8	35.8	38.7	40.0	59.5	48.3	50.1	
31-12-72	38.0	39.0	41.0	42.0	59.0	50.0	54.0	
01-01-73	38.0	36.0	38.5	40.7	59.5	48.0	47.2	
02-01-73	37.4	36.2	38.0	40.2	59.5	48.2	48.5	
03-01-73	36.8	35.8	38.2	39.8	60.8	48.8	49.3	
04-01-73	37.2	37.5	38.5	41.8	60.8	49.2	48.5	
05-01-73	39.0	36.0	38.2	40.0	60.2	49.0	48.2	
06-01-73	37.0	35.8	38.2	39.8	60.2	49.0	48.8	
07-01-73	37.0	35.8	38.2	39.8	60.8	49.8	50.6	
08-01-73	37.2	36.0	38.2	39.8	61.5	49.8	51.5	
09-01-73	39.0	36.0	38.2	39.8	61.0	49.5	47.8	
11-01-73	37.2	36.2	38.6	39.8	60.0	49.3	47.2	
13-01-73	37.0	36.2	38.2	39.8	61.2	49.5	47.2	
14-01-73	38.0	35.8	38.0	39.8	60.8	49.8	49.2	
17-01-73	49.2	35.8	38.0	39.8	61.8	50.0	57.0	
18-01-73	37.5	36.0	38.0	39.5	61.8	50.0	50.5	
19-01-73	37.8	35.5	37.8	39.0	63.0	50.7	52.5	
20-01-73	38.0	36.0	38.0	40.0	62.8	50.2	48.2	
21-01-73	42.2	35.8	38.2	39.4	65.2	50.2	57.0	
22-01-73	38.0	36.0	38.2	39.4	64.0	50.4	48.8	
23-01-73	38.0	37.0	39.0	40.5	63.2	51.5	45.8	
25-01-73	38.0	35.8	38.2	39.0	61.2	49.8	48.0	

1. Inside tile.
2. In soil at 2'6" depth.
3. In soil at 3'6" depth.
4. In soil at 4'6" depth.
5. Inside septic tank
6. In soil at 2'6" depth outside septic tank.
7. Inside collecting chamber.

Table D2 - continued

Date	Thermistor (Probes) Readings °F						
	1	2	3	4	5	6	7
26-01-73	38.0	35.8	38.0	39.2	61.4	49.6	50.2
27-01-73	38.0	36.0	38.0	39.2	60.4	49.5	50.0
29-01-73	38.0	36.0	38.2	39.2	59.2	49.0	48.6
30-01-73	37.0	35.8	38.0	39.0	59.8	49.2	45.0
31-01-73	40.2	35.8	38.0	39.0	60.2	49.4	46.8
01-02-73	37.2	36.0	38.0	38.0	60.2	49.2	43.0
02-02-73	37.8	-	-	-	60.8	49.8	44.2
04-02-73	39.0	35.8	38.2	39.0	61.0	49.0	46.8
05-02-73	39.2	36.0	38.0	39.2	61.8	49.8	46.8
08-02-73	39.0	36.0	38.0	39.5	61.0	50.0	48.4
12-02-73	38.2	36.0	38.0	39.0	61.5	49.6	45.0
17-02-73	39.5	36.0	38.2	39.0	61.0	49.2	50.2
26-02-73	38.0	36.0	38.0	39.0	58.8	48.2	50.0
05-03-73	41.4	35.4	37.8	39.0	62.2	49.0	53.8
12-03-73	39.0	36.0	38.0	39.0	63.2	49.5	50.3
19-03-73	36.2	36.2	37.0	38.0	62.0	49.2	46.0
26-03-73	41.0	40.0	41.8	42.7	61.8	50.2	44.2
02-04-73	41.8	41.0	41.0	41.0	63.0	52.0	43.0
06-04-73	41.0	43.0	43.0	43.0	59.3	49.5	-
09-04-73	41.8	43.8	43.5	44.0	62.0	51.0	46.2
19-04-73	48.5	40.8	39.0	38.8	63.5	57.0	53.2
23-04-73	47.0	45.0	41.0	40.0	64.2	60.2	54.8
04-05-73	47.0	45.0	45.0	43.5	64.0	59.0	56.2
05-06-73	63.0	53.4	50.2	48.0	66.6	63.3	66.2
15-06-73	64.0	55.2	53.9	53.1	69.5	68.4	65.2
28-06-73	63.2	56.4	54.8	54.3	69.7	67.9	63.7
12-07-73	65.1	59.3	57.0	56.6	70.2	68.3	62.4
30-07-73	66.2	59.7	58.2	57.3	71.2	68.9	68.0
10-08-73	65.0	60.3	59.7	58.4	69.8	67.5	68.7
25-08-73	64.8	61.8	61.0	59.6	68.2	69.2	65.0
27-09-73	-	54.8	56.6	56.8	65.2	63.0	61.8
08-10-73	57.8	54.4	55.8	55.8	65.0	63.2	57.2
18-10-73	55.0	52.3	54.2	54.5	64.8	61.8	56.6
27-10-73	53.8	50.2	52.2	53.0	64.2	61.0	53.2
28-10-73	53.6	50.0	52.0	52.8	64.0	60.2	52.0

Table D2 - concluded

Date	Thermistor (Probes) Readings °F						
	1	2	3	4	5	6	7
29-10-73	54.8	49.4	52.0	52.8	64.0	59.0	52.0
30-10-73	52.6	49.8	52.2	52.8	65.2	59.8	53.7
06-11-73	55.6	48.4	50.8	51.8	63.4	57.0	48.8
14-11-73	53.2	47.4	49.8	50.6	64.0	58.4	47.2
20-11-73	48.6	46.2	47.8	49.0	63.8	57.6	44.4
30-11-73	47.0	43.6	45.4	47.2	63.2	57.2	46.2
11-12-73	45.0	41.6	43.2	45.4	63.8	57.8	44.6
23-12-73	-	39.0	41.2	43.5	62.8	57.4	42.2
02-01-74	-	39.2	41.2	43.2	62.0	56.2	41.0
13-01-74	-	39.0	41.0	43.0	63.5	58.0	-

Table D3. Depth of Snow on Ground¹

Date	Depth of Snow on Ground in inches									
	Dec 1972	Jan 1973	Feb 1973	Mar 1973	Apr 1973	Nov 1973	Dec 1973	Jan 1974	Feb 1974	Mar 1974
1	4	9	9	7	0	0	0	13	9	8
2	4	9	10	16	0	0	0	14	9	9
3	12	9	5	15	tr	0	0	14	9	9
4	8	10	5	13	0	0	0	14	9	8
5	6	10	5	10	1	0	0	14	9	3
6	6	12	5	10	0	tr	0	13	9	3
7	3	12	5	10	0	0	tr	13	9	2
8	2	12	6	9	0	tr	tr	14	9	2
9	5	12	7	11	0	tr	tr	14	10	2
10	4	12	7	11	tr	tr	4	14	10	2
11	6	12	7	11	3	0	3	15	12	1
12	6	12	7	9	1	1	3	16	13	1
13	8	12	7	7	1	0	3	16	14	1
14	7	12	7	6	tr	0	6	15	14	1
15	7	13	9	5	tr	0	6	14	13	1
16	12	13	10	2	0	2	6	17	13	tr
17	13	12	9	2	0	2	5	18	14	7
18	13	12	9	2	0	1	10	17	14	12
19	13	11	9	2	0	1	8	18	16	12
20	13	9	9	1	0	1	10	18	16	10
21	13	9	9	1	0	1	16	18	15	10
22	13	9	9	1	0	tr	18	17	15	14
23	13	9	9	1	0	tr	20	19	12	14
24	10	5	9	tr	0	tr	20	19	13	10
25	10	5	9	tr	0	tr	19	19	13	10
26	10	5	8	tr	0	tr	18	19	13	10
27	13	5	8	tr	0	0	14	17	13	11
28	14	4	8	0	0	0	11	13	12	11
29	15	8		0	0	0	10	13		10
30	15	9		0	0	tr	10	13		9
31	20	9		0	0		10	10		7
Mean	9.6	9.7	7.7	4.9	0.2	0.3	7.4	15.4	12.0	6.8

¹At Ottawa (from Summary Record issued by the Weather Office, Ottawa).

²No snow on ground from May 1973 to October 1973.

Table D4. Depth to Groundwater Level from Ground in Inches

Day	Depth to groundwater level from ground in inches																
	Dec. 1972	Jan. 1973	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec. 1974	Jan. 1974	Feb.	Mar.	
1	39						30										
2	39				5												
3																	
4		30				16											
5	38		24	20													20
6																	
7																	
8																	
9					23												
10																	
11		24					34										
12			22	20													
13																	
14						24											
15	37																
16																	
17																	
18			22				30										
19																	
20																	
21																	
22			22	12													42
23																	
24						34											
25	33																
26			20	15													15
27	30																15
28																	
29			20														
30																	
31																	
Mean	36	24	22	15	20	22	31	40	>65	>65	>65	>65	34	44	42	42	15

APPENDIX E

WATER USE RECORD

7



Table E1. Water Use Record

Year	Month	Date	Day	Water Meter Reading Imp. gallon	Water used Imp. gallons	No. of flushes per day	Quantity of Water used for Toilet flushing Imp. gallons	% of Total Daily Water use		
1972	December	11	Mon	156	149	31	109.5	73.5		
		12	Tues	1,305	204	15	52.5	25.7		
		13	Wed	1,509	223	17	59.5	26.7		
		14	Thurs	1,732	150	19	66.5	44.5		
		15	Fri	1,882	205	16	56.0	27.3		
		16	Sat	2,087	246	17	59.5	24.2		
		17	Sun	2,333	170	18	63.0	37.0		
		18	Mon	2,503	222	22	77.0	34.7		
		19	Tues	2,725	192	15	52.5	27.4		
		20	Wed	2,917	405	13	45.5	11.2		
		21	Thurs	3,322	206	16	56.0	27.2		
		22	Fri	3,528	186	11	38.5	20.7		
		23	Sat	3,714	267	12	42.0	15.7		
		24	Sun	3,981	-	-	-	-		
		25	Mon	-	-	-	56.0	35.4		
		26	Tues	4,512	178	18	63.0	19.6		
		27	Wed	4,690	161	9	31.5	22.4		
		28	Thurs	4,851	188	12	42.0	18.1		
		29	Fri	5,039	193	10	35.0	22.7		
		30	Sat	5,232	216	14	49.0	23.0		
		31	Sun	5,448	243	16	56.0	17.8		
		1973	January	1	Mon	5,691	294	15	52.5	32.2
				2	Tues	5,985	179	17	59.5	36.5
				3	Wed	6,164	182	19	66.5	26.4
				4	Thurs	6,346	226	17	59.5	13.7
				5	Fri	6,572	306	12	42.0	16.7
				6	Sat	6,878	355	17	59.5	

Table E1 - continued

Year	Month	Date	Day	Water Meter Reading Imp. gallon	Water used Imp. gallons	No. of flushes per day	Quantity of Water used for Toilet flushing Imp. gallons	% of Total Daily Water use		
1973	January	7	Sun	7,233	191	15	52.5	27.5		
		8	Mon	7,424	-	15	52.5	-		
		9	Tues	-	-	-	-	-		
		10	Wed	7,823	244	12	42.0	17.3		
		11	Thurs	8,067	302	14	49.0	16.3		
		12	Fri	8,369	232	8	28.0	12.1		
		13	Sat	8,601	368	12	42.0	11.4		
		14	Sun	8,969	268	21	73.5	27.4		
		15	Mon	9,237	185	12	42.0	22.7		
		16	Tues	9,422	255	19	45.5	17.8		
		17	Wed	9,677	-	18	63.0	-		
		18	Thurs	-	-	-	-	-	-	
		19	Fri	10,227	421	12	42.0	10.0		
		20	Sat	10,648	326	14	49.0	15.0		
		21	Sun	10,974	200	18	63.0	31.5		
		22	Mon	11,174	226	14	49.0	21.6		
		23	Tues	11,400	-	20	70.0	-		
		24	Wed	-	-	-	-	-	-	
		25	Thurs	11,900	190	13	45.5	24.0		
		26	Fri	12,090	348	14	49.0	14.1		
		27	Sat	12,438	227	23	80.5	35.5		
		28	Sun	12,665	250	14	49.0	19.6		
		29	Mon	12,915	397	20	70.0	17.6		
		30	Tues	13,312	263	14	49.0	18.6		
		31	Wed	13,575	244	11	38.5	15.8		
		1973	February	1	Thurs	13,819	373	15	52.5	14.1
				2	Fri	14,192	298	18	63.0	21.0
				3	Sat	14,490	389	16	56.0	14.4
				4	Sun	14,879	296	21	73.5	24.8

Table E1 - continued

Year	Month	Date	Day	Water Meter Reading Imp. gallon	Water used Imp.gallons	No. of flushes per day	Quantity of		% of Total Daily Water use	
							Water used for Toilet flushing Imp. gallons	Water used for Toilet flushing Imp. gallons		
1973	February	5	Mon	15,175	255	18	63.0	24.7		
		6	Tues	15,430	243	11	38.5	15.8		
		7	Wed	15,673	365	15	52.5	14.4		
		8	Thurs	16,038	236	17	59.5	25.2		
		9	Fri	16,274	284	16	56.0	19.7		
		10	Sat	16,558	362	20	70.0	19.3		
		11	Sun	16,920	260	22	77.0	29.6		
		12	Mon	17,180	281	15	52.5	18.7		
		13	Tues	17,461	374	13	45.5	12.2		
		14	Wed	17,835	188	17	59.5	31.2		
		15	Thurs	18,023	185	21	73.5	39.8		
		16	Fri	18,208	284	10	35.0	12.3		
		17	Sat	18,492	317	17	59.5	18.7		
		18	Sun	18,809	296	14	49.0	16.5		
		19	Mon	19,105	234	20	70.0	30.0		
		20	Tues	19,339	354	13	45.5	12.9		
		21	Wed	19,693	414	11	38.5	9.3		
		22	Thurs	20,107	253	18	63.0	25.0		
		23	Fri	20,360	222	18	63.0	28.4		
		24	Sat	20,582	173	12	42.0	24.3		
		25	Sun	20,755	288	16	56.0	19.5		
		26	Mon	21,043	193	17	59.5	30.8		
		27	Tues	21,236	210	14	49.0	23.4		
		28	Wed	21,446	266	21	73.5	27.6		
		1973	March	1	Thurs	21,712	381	17	59.5	15.7
				2	Fri	22,093	330	18	63.0	19.1
				3	Sat	22,423	217	15	52.5	24.2
				4	Sun	22,640	281	16	56.0	20.0
5	Mon			22,921	-	13	45.5	-		
6	Tues			-	-	-	-	-		
7	Wed			23,423	227	13	45.5	20.0		
8	Thurs			23,650	212	17	59.5	28.0		

Table E1 - continued

Year	Month	Date	Day	Water Meter Reading Imp. gallons	Water used Imp. gallons	No. of flushes per day	Quantity of Water used for Toilet flushing Imp. gallons	% of Total Daily Water use
1973	March	9	Fri	23,862	-	14	49.0	-
		10	Sat	-	-	-	-	-
		11	Sun	24,477	-	15	52.5	-
		12	Mon	-	-	-	-	-
		13	Tues	25,024	253	13	45.5	18.0
		14	Wed	25,277	293	21	73.5	25.0
		15	Thurs	25,570	-	14	49.0	-
		16	Fri	-	-	-	-	-
		17	Sat	26,243	297	14	49.0	16.5
		18	Sun	26,540	225	21	73.5	32.8
		19	Mon	26,765	190	13	45.5	24.0
		20	Tues	26,955	-	15	52.5	-
		21	Wed	-	-	-	-	-
		22	Thurs	27,417	-	14	49.0	-
		23	Fri	-	-	-	-	-
		24	Sat	28,045	369	18	63.0	17.1
		25	Sun	28,414	286	20	70.0	24.4
		26	Mon	28,700	311	12	42.0	13.5
		27	Tues	29,011	254	13	45.5	17.9
		28	Wed	29,265	325	12	42.0	12.9
		29	Thurs	29,590	203	15	52.5	25.8
30	Fri	29,793	305	13	45.5	14.9		
31	Sat	30,098	492	12	42.0	8.5		
1973	April	1	Sun	30,590	-	15	52.5	-
1973	November	29	Thurs	103,612	199	12	42.0	21.0
		30	Fri	103,811	363	13	45.5	12.5
1973	December	1	Sat	104,174	338	18	63.0	18.6

Table E1 - continued

Year	Month	Date	Day	Water Meter Reading Imp. gallon	Water used Imp.gallons	No. of flushes per day	Quantity of Water used for Toilet flushing Imp. gallons	% of Total Daily Water use
1973	December	2	Sun	104,512	221	21	73.5	33.2
		3	Mon	104,733	284	15	52.5	18.5
		4	Tues	105,017	269	16	56.0	20.8
		5	Wed	105,286	228	13	45.5	20.0
		6	Thurs	105,514	229	12	42.0	18.4
		7	Fri	105,743	311	-	-	-
		8	Sat	106,054	330	17	59.5	18.0
		9	Sun	106,384	247	19	66.5	27.0
		10	Mon	106,621	192	14	49.0	25.6
		11	Tues	106,813	181	15	52.5	29.0
		12	Wed	106,994	246	12	42.0	17.0
		13	Thurs	107,240	228	14	49.0	21.4
		14	Fri	107,468	301	11	38.5	12.8
		15	Sat	107,769	389	19	66.5	17.1
		16	Sun	108,158	187	17	59.5	31.8
		17	Mon	108,345	261	16	56.0	21.6
		18	Tues	108,606	220	14	49.0	21.3
		19	Wed	108,826	238	13	45.5	19.5
		20	Thurs	109,064	227	12	42.0	18.5
		21	Fri	109,291	324	15	52.5	16.3
		22	Sat	109,615	336	19	66.5	19.8
		23	Sun	109,951	349	20	70.0	20.0
		24	Mon	110,300	312	18	63.0	20.2
		25	Tues	110,612	484	21	73.5	15.2
		26	Wed	111,096	309	20	70.0	22.7
		27	Thurs	111,405	334	18	63.0	18.8
		28	Fri	111,739	327	22	77.0	23.6
		29	Sat	112,066	306	20	70.0	23.0
		30	Sun	112,372	322	18	63.0	19.6
		31	Mon	112,694	311	17	59.5	19.1

Table E1 - concluded

Year	Month	Date	Day	Water Meter Reading Imp. gallon	Water used Imp. gallons	No. of flushes per day	Quantity of Water used for Toilet flushing Imp. gallons	% of Total Daily Water use
1974	January	1	Tues	113,005	308	19	66.5	21.6
		2	Wed	113,313	376	21	73.5	19.5
		3	Thurs	113,689	314	15	52.5	16.7
		4	Fri	114,003	498	16	56.0	28.3
		5	Sat	114,201	365	20	70.0	19.2
		6	Sun	114,566	-	19	-	-

APPENDIX F

PROBABILITY PLOTS FOR RAW SEWAGE
AND SEPTIC TANK EFFLUENT CHARACTERISTICS

Table Fl. Chemical Characteristics of Raw Sewage
(arranged for probability plot)

pH	TSS mg/l	VSS mg/l	COD mg/l	TOC mg/l	PO ₄ -P mg/l	NH ₃ -N mg/l	Total Soluble Fe mg/l	Ranking of sample (m)	% Equal to or less than $\frac{m}{n+1} \times 100$
6.35	38	32	310	90	2.5	3.3	0.0	1	8.3
6.50	60	34	350	100	2.5	6.3	0.0	2	16.6
6.73	100	44	528	120	7.5	10.25	0.3	3	25.0
6.90	116	84	648	140	9.0	22.6	0.3	4	33.3
7.27	120	96	805	144	9.0	23.0	0.5	5	41.7
7.35	136	100	846	174	11.25	38.0	0.6	6	50.0
7.85	192	132	892	184	12.5	40.0	1.5	7	58.3
8.22	192	156	1108	344	20.0	45.3	1.6	8	66.6
8.29	312	296	2492	436	35.0	55.3	2.0	9	75.0
8.54	372	344	2600	470	35.0	200.0	3.7	10	83.3
9.10	748	726	2880	1040	45.0	226.6	9.0	11	91.7

Table F2. Raw Sewage Characteristics
(Arranged for Probability Plot)

NO ₃ -N	BOD	Rank of Sample	% Equal to or less than
mg/l	mg/l	(m)	$\left(\frac{m}{n+1}\right) \times 100$
0.00	244	1	9.1
0.00	397	2	18.1
0.02	442	3	27.3
0.04	465	4	36.4
0.08	484	5	45.5
0.08	514	6	54.5
0.08	580	7	63.6
0.11	582	8	72.7
0.18	585	9	81.6
0.60	1312	10	90.0

Chlorides	Rank of Sample	% Equal to or less than
mg/l	(m)	$\left(\frac{m}{n+1}\right) \times 100$
21	1	10
22	2	20
34	3	30
42	4	40
67	5	50
190	6	60
200	7	70
247	8	80
296	9	90

Table F3. Bacteriological Characteristics for Raw Sewage
(for probability chart)

Coliform MF count/ 100 ml	Fecal Coliform MF count/ 100 ml		Fecal Streptococci MF count/ 100 ml		SPC per ml		Pseudomonas aeruginosa MPN/100 ml	Ranking of Samples (m)	% Equal to or less than $(\frac{m}{n+1}) \times 100$
	35°C	20°C	35°C	20°C	35°C	20°C			
1,100	600	360	120,000	120,000	<2		1	12.5	
230,000	2,800	1,200	160,000	140,000	14		2	25.0	
1,300,000	15,000	11,000	280,000	430,000	50		3	37.5	
3,100,000	23,000	44,000	620,000	840,000	230		4	50.0	
11,000,000	110,000	91,000	1,700,000	3,000,000	280		5	62.5	
12,000,000	160,000	230,000	1,700,000	3,800,000	330		6	75.0	
22,000,000	6,000,000	600,000	2,000,000	4,300,000	92,000		7	87.5	

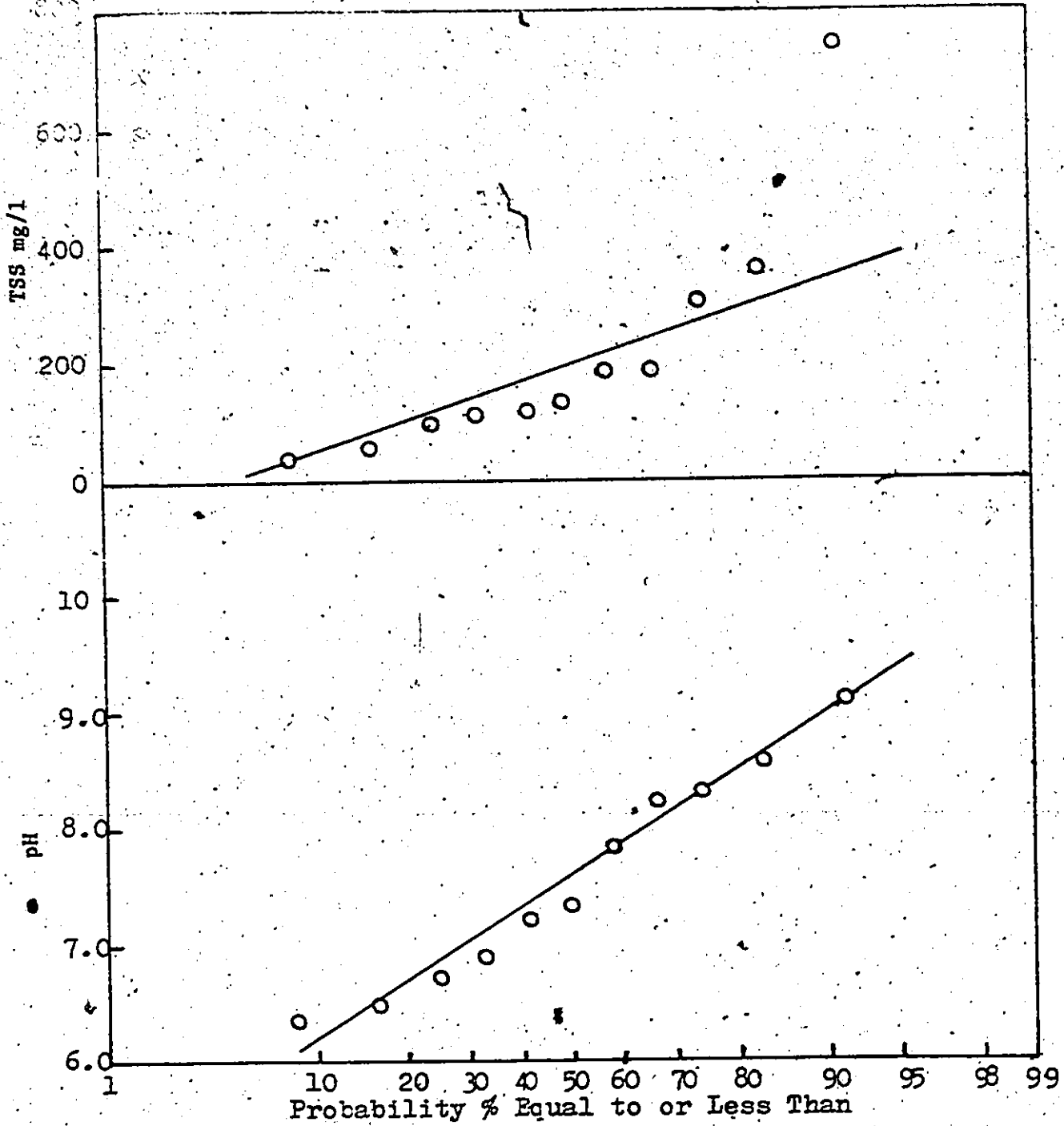


Fig.F1. Raw Sewage Characteristics

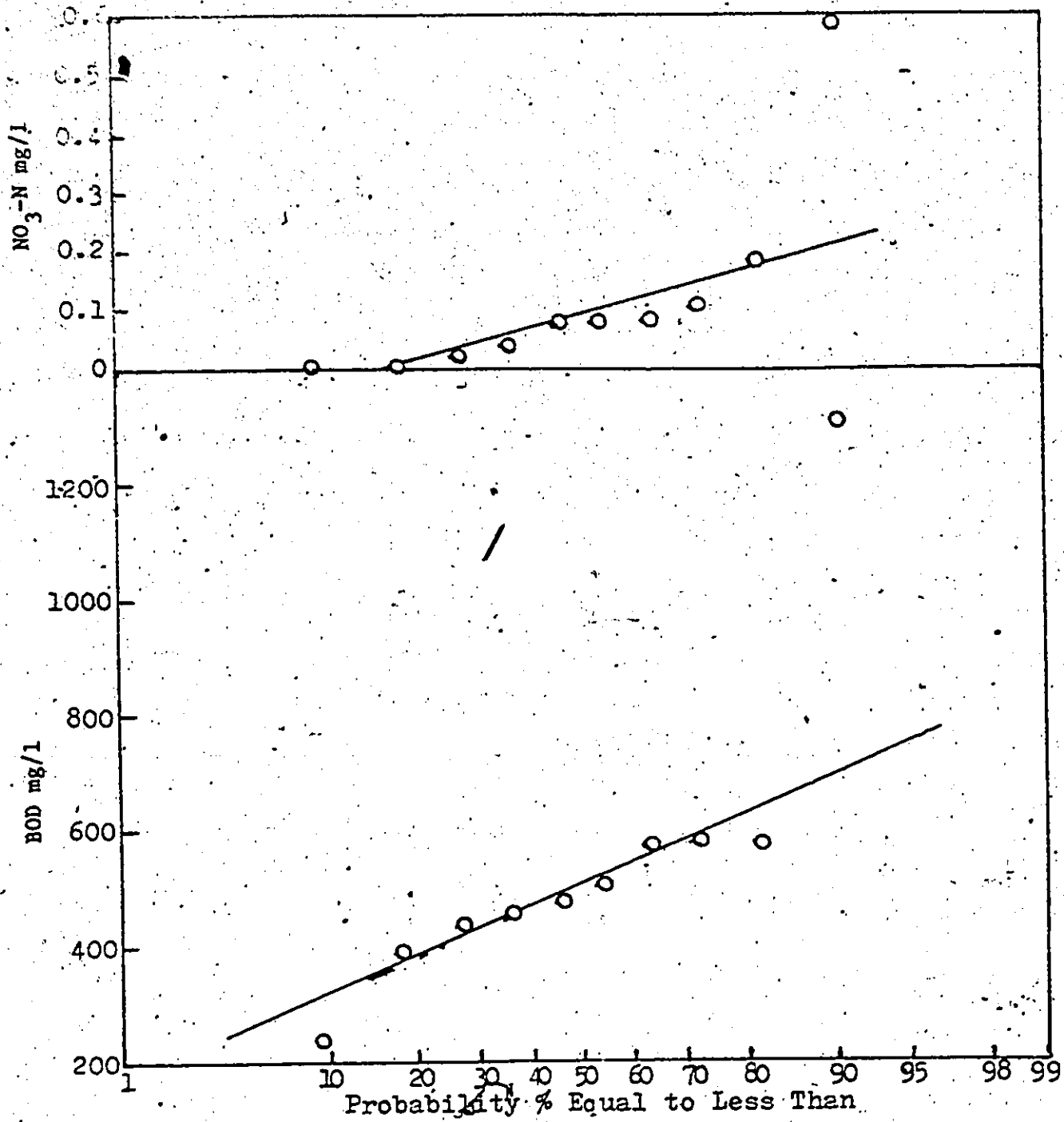


Fig. F2. Raw Sewage Characteristics

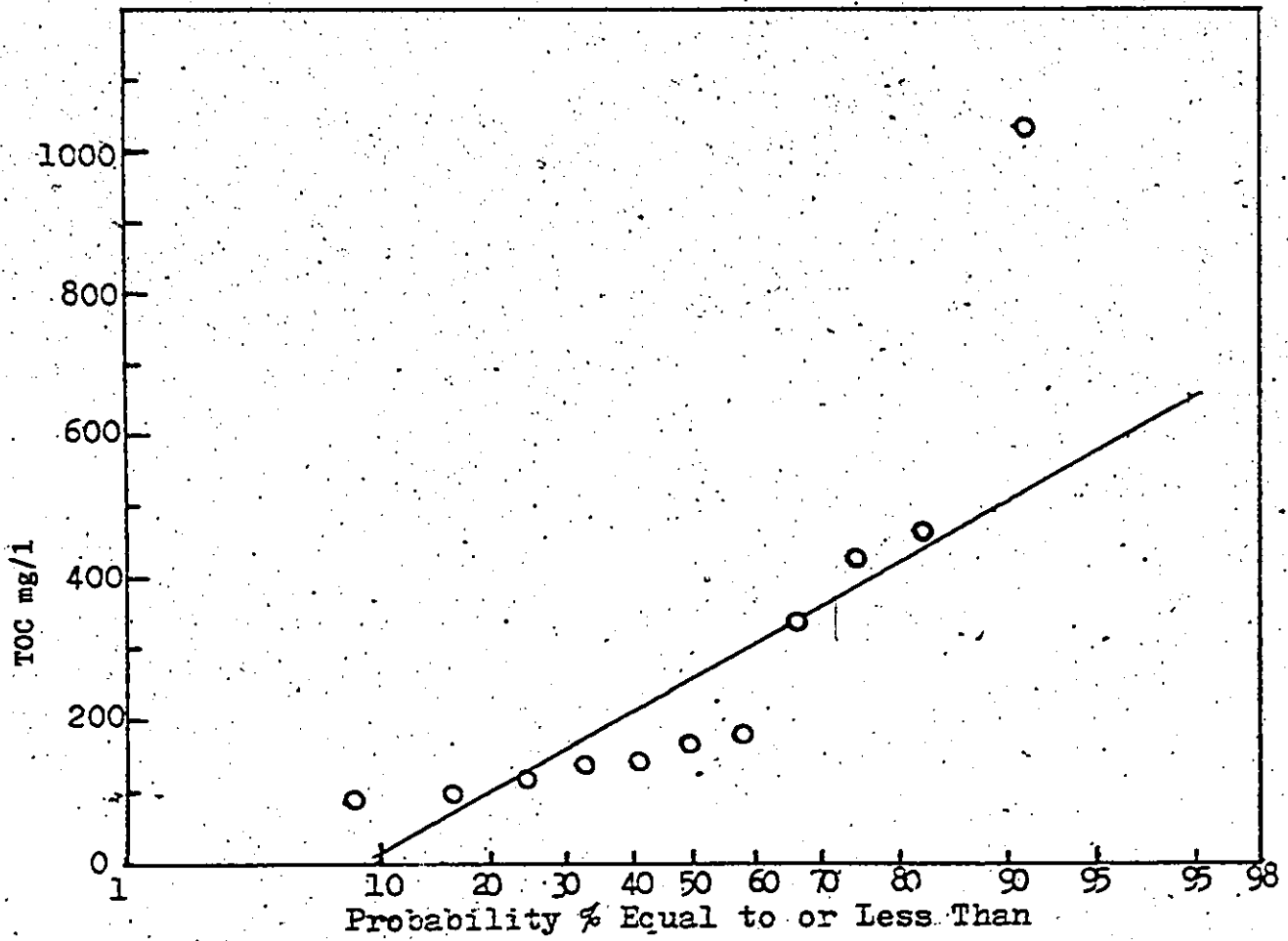


Fig. F3. Characteristics of Raw Sewage

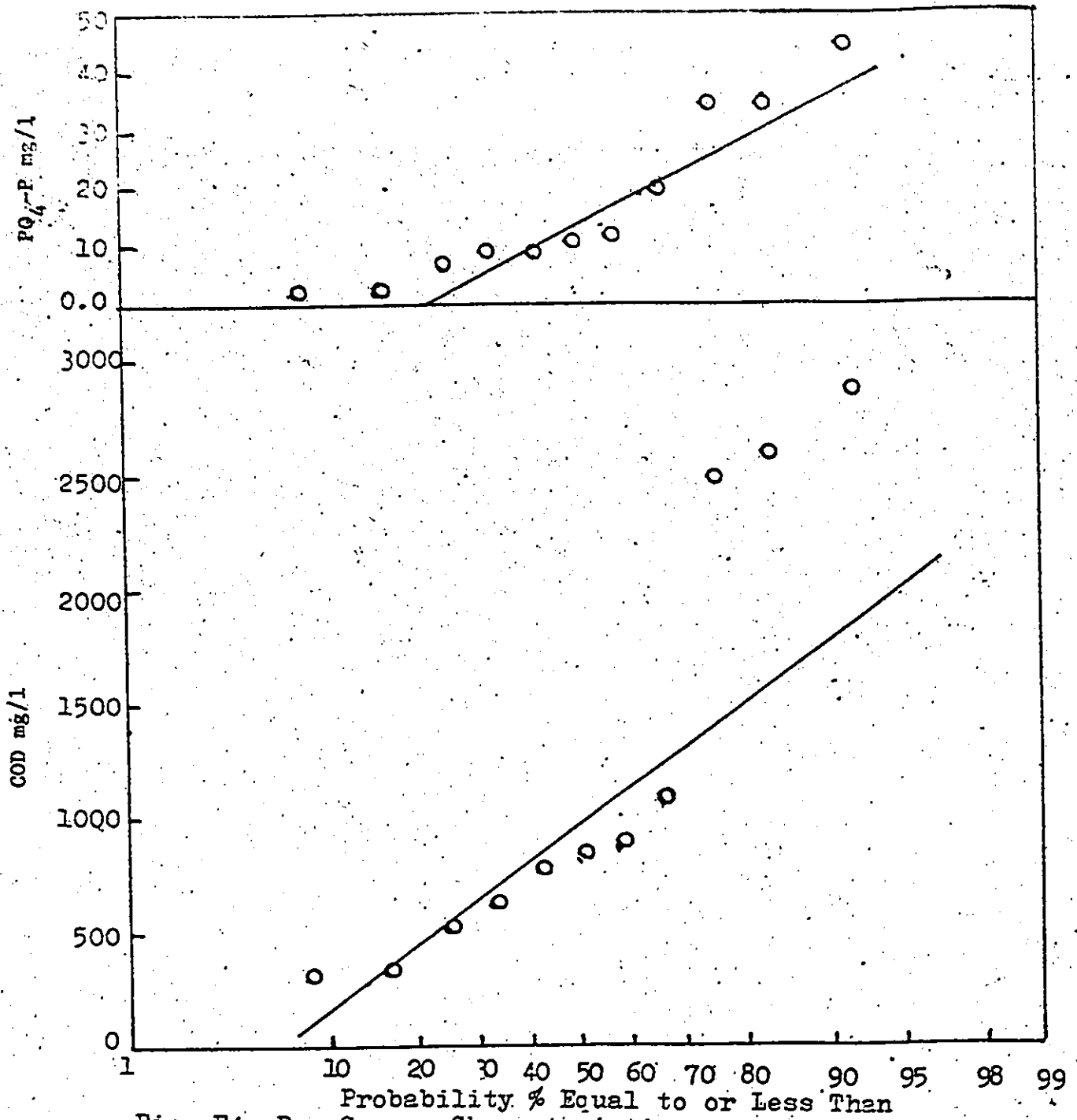


Fig. F4. Raw Sewage Characteristics

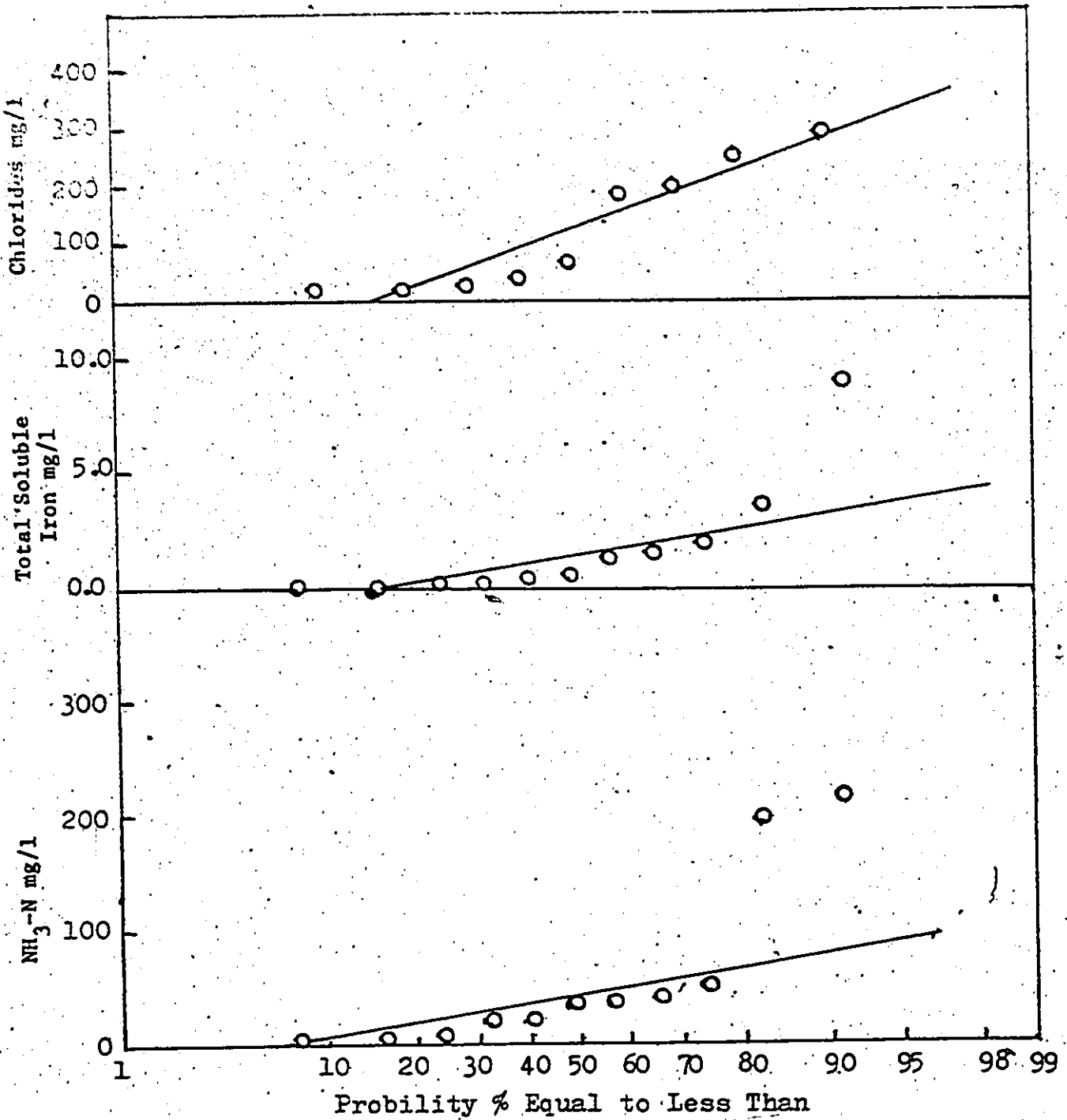


Fig. F5. Raw Sewage Characteristics

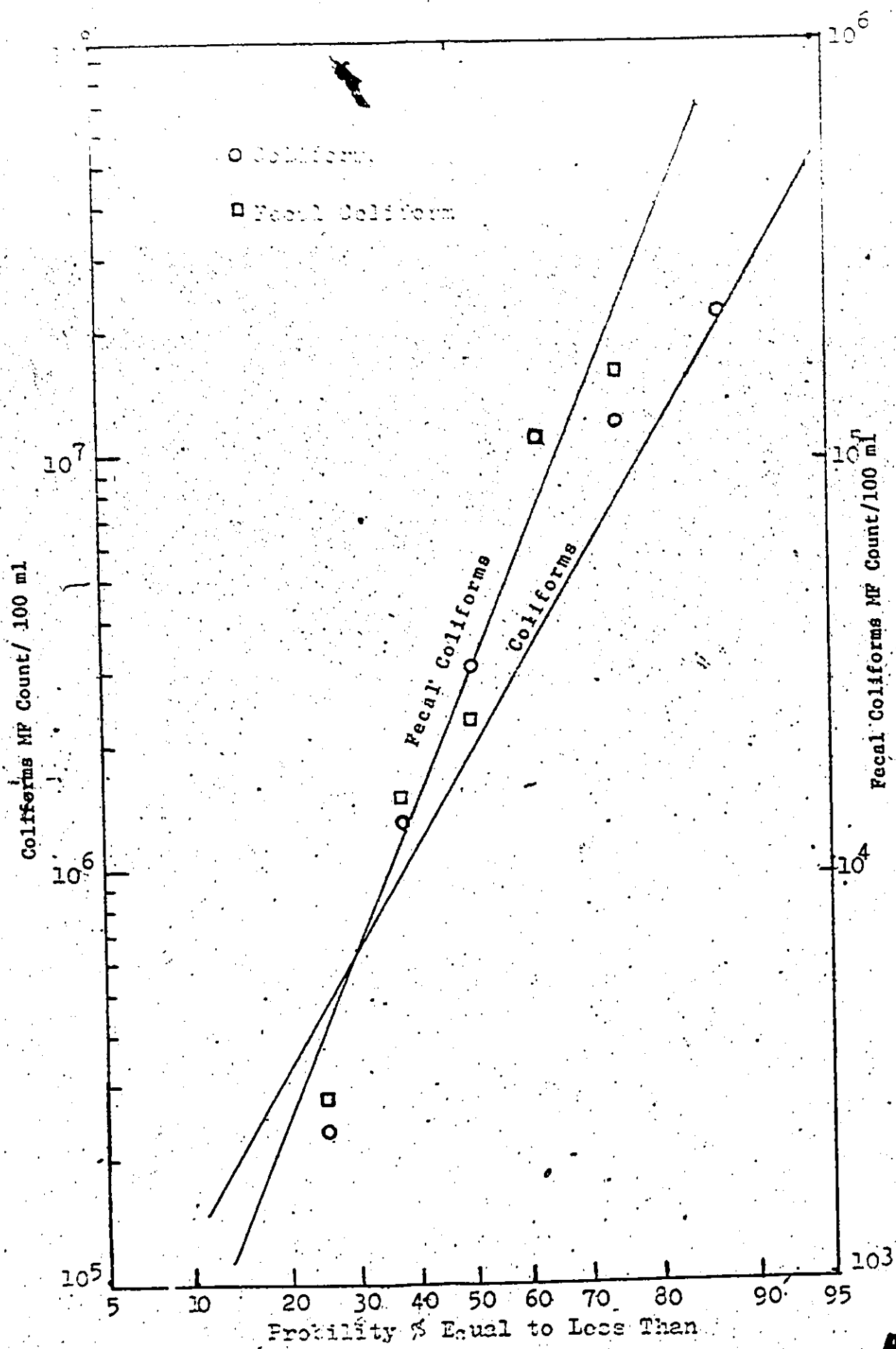


Fig. F6. Characteristics of Raw Sewage

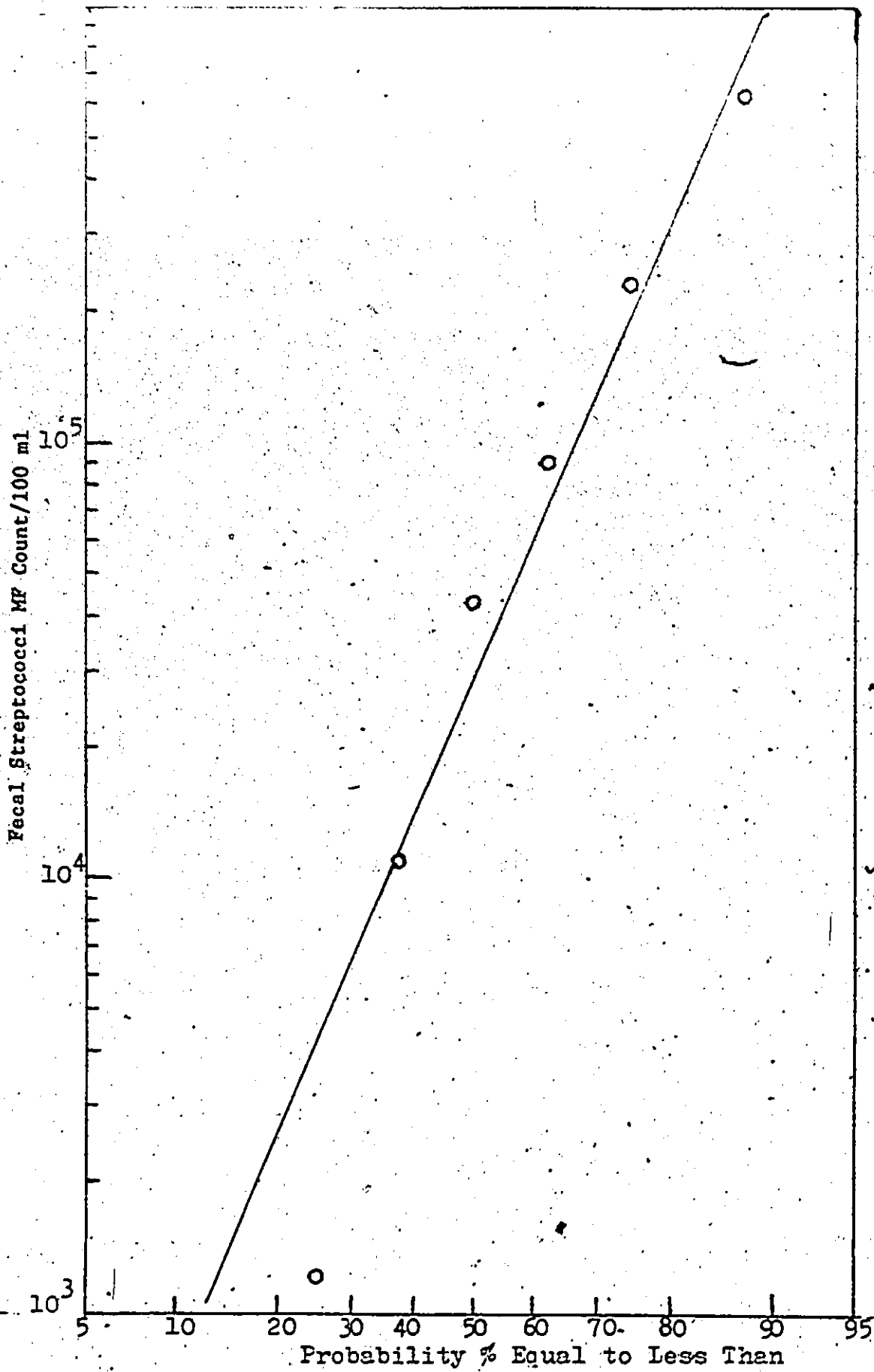


Fig. F7. Characteristics of Raw Sewage

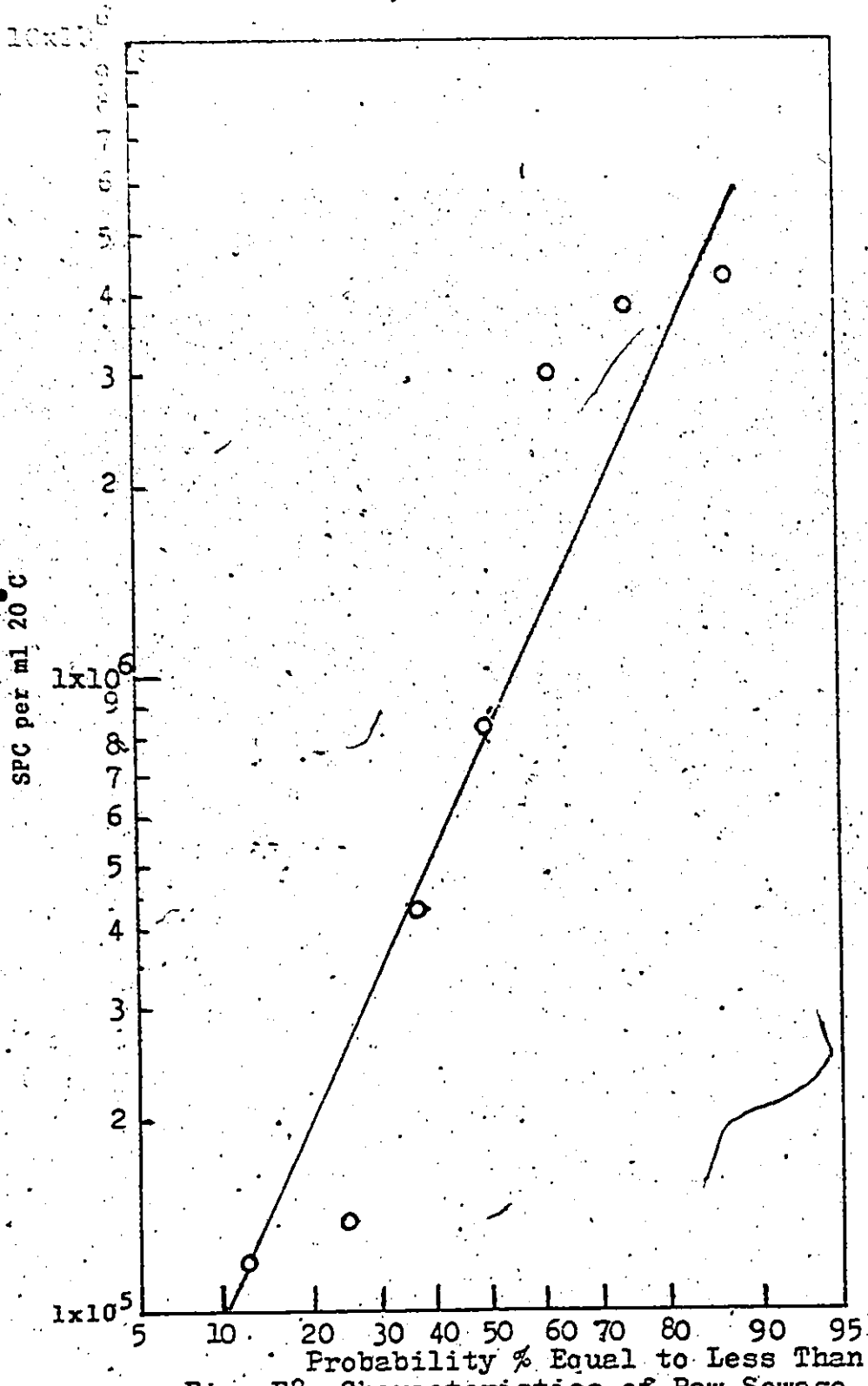


Fig. F8. Characteristics of Raw Sewage.

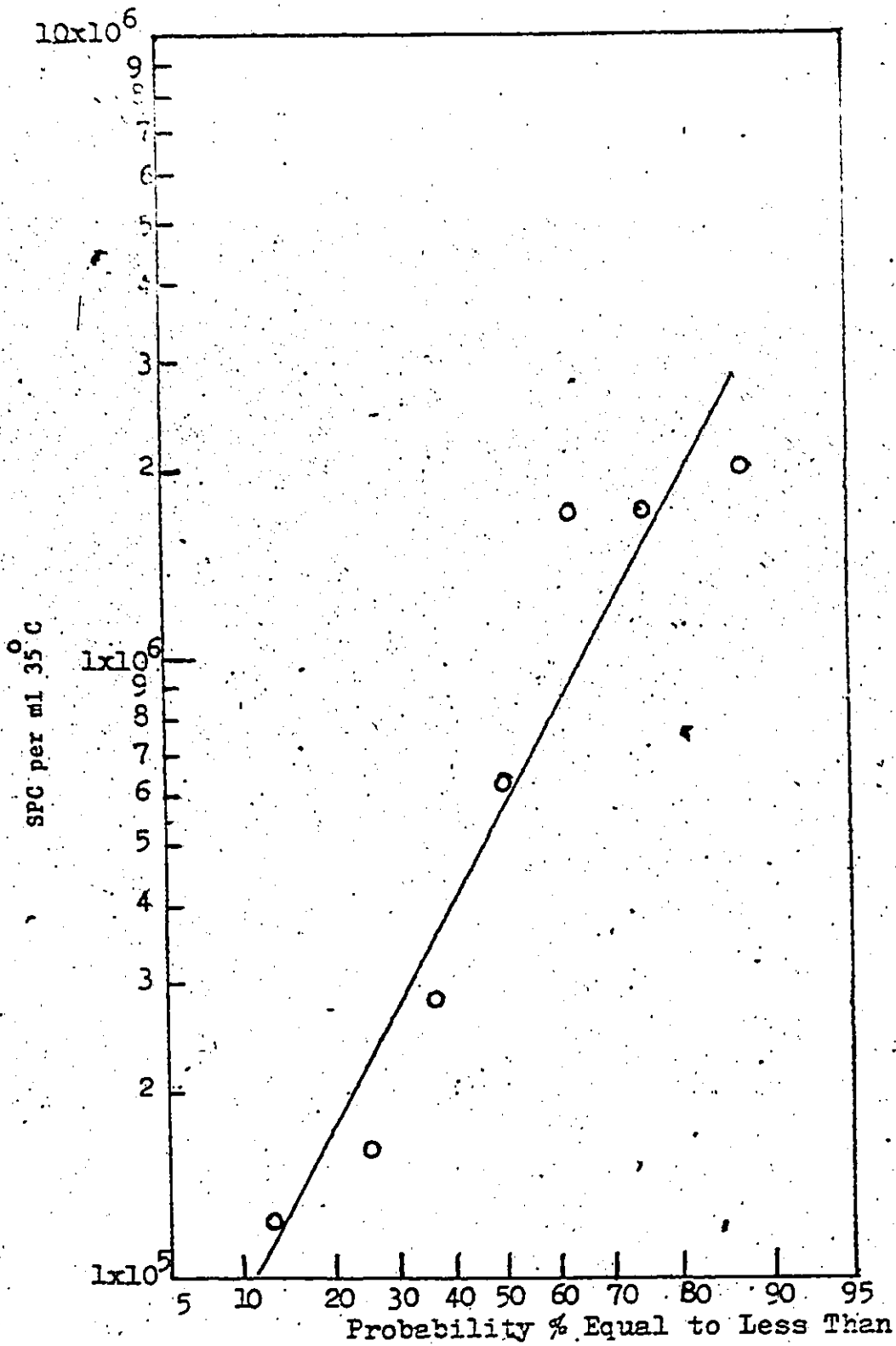


Fig. F9. Characteristics of Raw Sewage

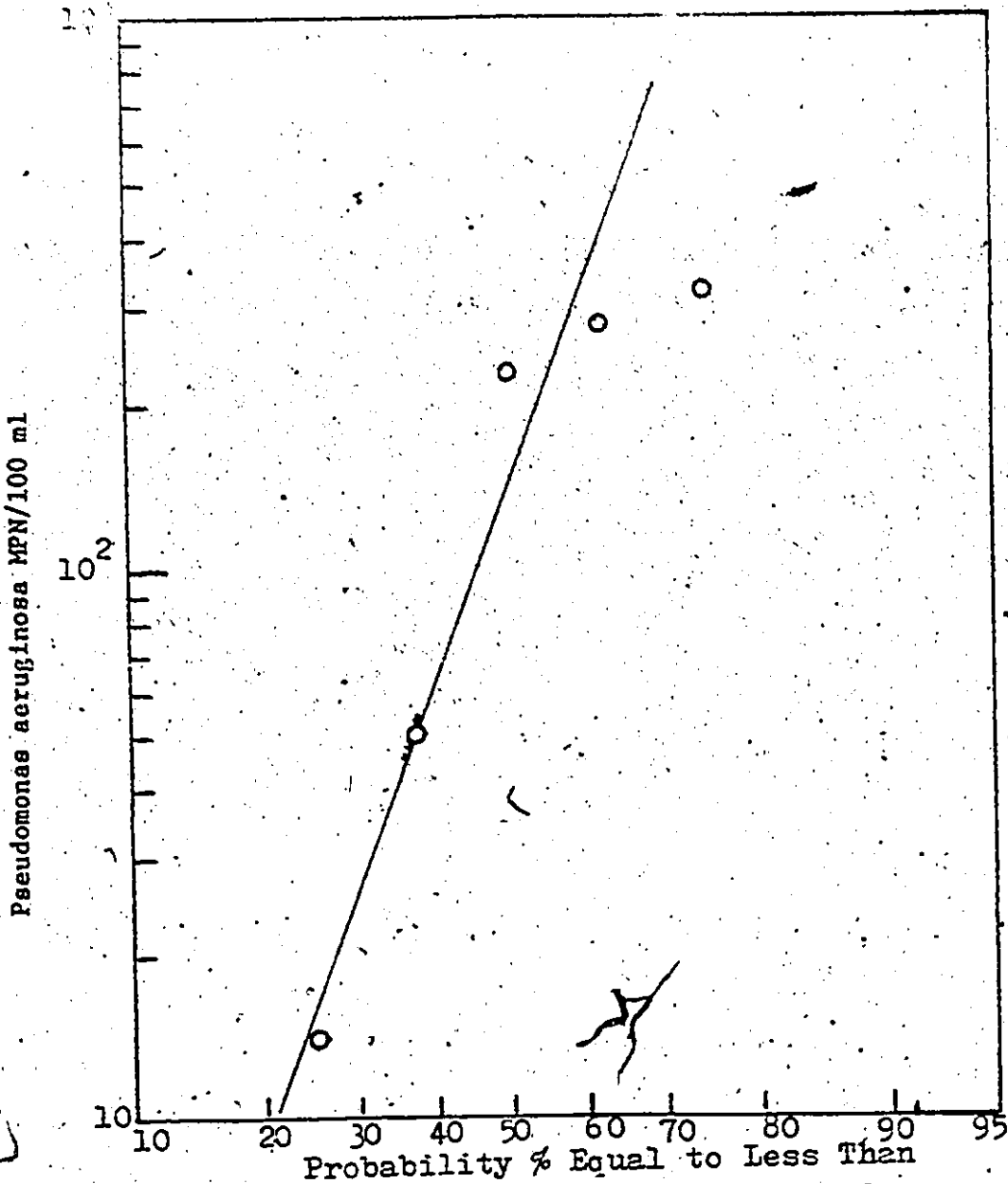


Fig. F 10. Characteristics of Raw Sewage

Table F4. Chemical Characteristics of Septic Tank Effluent. (For probability chart)

pH	TSS mg/l	BOD mg/l	COD mg/l	TOC mg/l	PO ₄ -P mg/l	NH ₃ -N mg/l	Total soluble iron mg/l	Ranking of sample (m)	% Equal to or less than
6.53	68	140	240	24	6.25	76.6	0.00	1	4.8
6.70	80	160	254	32	6.50	80.0	0.00	2	9.5
6.70	88	166	290	42	7.50	83.3	0.00	3	14.3
6.76	90	167	303	44	7.50	83.3	0.20	4	19.0
6.80	92	180	336	48	7.50	92.0	0.30	5	23.8
6.80	96	200	346	50	8.00	93.0	0.46	6	28.6
6.82	102	200	354	58	8.20	95.3	0.50	7	33.3
6.85	116	205	368	60	9.00	97.0	0.50	8	38.1
6.86	116	208	372	60	9.00	100.0	0.50	9	42.8
6.89	120	247	380	64	10.00	100.0	0.56	10	47.6
6.90	124	268	440	64	11.00	100.0	0.70	11	52.4
6.91	126	270	520	64	11.00	100.0	0.76	12	57.1
6.95	142	288	525	64	11.20	100.0	0.94	13	61.9
6.96	162	296	536	68	11.25	100.0	1.10	14	66.6
6.97	204	304	660	76	12.20	104.6	3.00	15	71.4
7.00	204	318	668	80	13.50	104.6	3.50	16	76.2
7.00	294	380	676	90	14.25	104.7	5.00	17	81.0
7.04	296	448	734	114	15.00	105.3	5.00	18	85.7
7.14	376	478	1331	160	23.00	108.0	9.50	19	90.5
7.45	624	666	2026	190	30.00	110.0	20.00	20	95.2

Table F5. Nitrate Nitrogen in Septic Tank Effluent
(for probability chart)

NO_3N	Ranking of Sample (m)	% Equal to or less than $(\frac{m}{n+1}) \times 100$
0.00	1	5
0.00	2	10
0.00	3	15
0.00	4	20
0.00	5	25
0.00	6	30
0.00	7	35
0.01	8	40
0.02	9	45
0.02	10	50
0.02	11	55
0.02	12	60
0.04	13	65
0.04	14	70
0.04	15	75
0.04	16	80
0.06	17	85
0.08	18	90
0.10	19	95

Table F6. Chlorides in Septic Tank Effluent
(for probability chart)

Chlorides	Ranking of Sample (m)	% Equal to or less than $\left(\frac{m}{n+1}\right) \times 100$
37	1	5.6
37	2	11.1
38	3	16.7
40	4	22.2
40	5	27.8
42	6	33.3
42	7	38.9
45	8	44.4
52	9	50.0
52	10	55.6
53	11	61.1
53	12	66.7
56	13	72.2
56	14	77.8
67	15	83.3
85	16	88.9
101	17	94.4

Table F7. Bacteriological Characteristics of Septic Tank Effluent
(for probability chart)

Coliform MF count/ 100 ml	Fecal coliform MF count/ 100 ml	Fecal Streptococci MF count/ 100 ml	SPC per ml		Pseudomonas aeruginosa MPN/100 ml	Ranking of Sample (m)	% Equal to or less than $(\frac{m}{n+1}) \times 100$
			35°C	20°C			
240,000	4,100	14,000	84,000	270,000	<0.2	1	9.1
920,000	14,000	26,000	90,000	370,000	<2	2	18.1
1,200,000	14,000	44,000	100,000	620,000	2	3	27.3
1,300,000	200,000	79,000	170,000	680,000	4	4	36.4
1,300,000	380,000	80,000	200,000	850,000	17	5	45.5
2,700,000	380,000	120,000	310,000	850,000	39	6	54.5
3,300,000	480,000	210,000	450,000	930,000	79	7	63.6
4,200,000	500,000	250,000	650,000	940,000	110	8	72.7
11,000,000	1,200,000	590,000	1,400,000	1,400,000	2,200	9	81.6
24,000,000	5,200,000	740,000	2,200,000	3,900,000	16,000	10	90.0

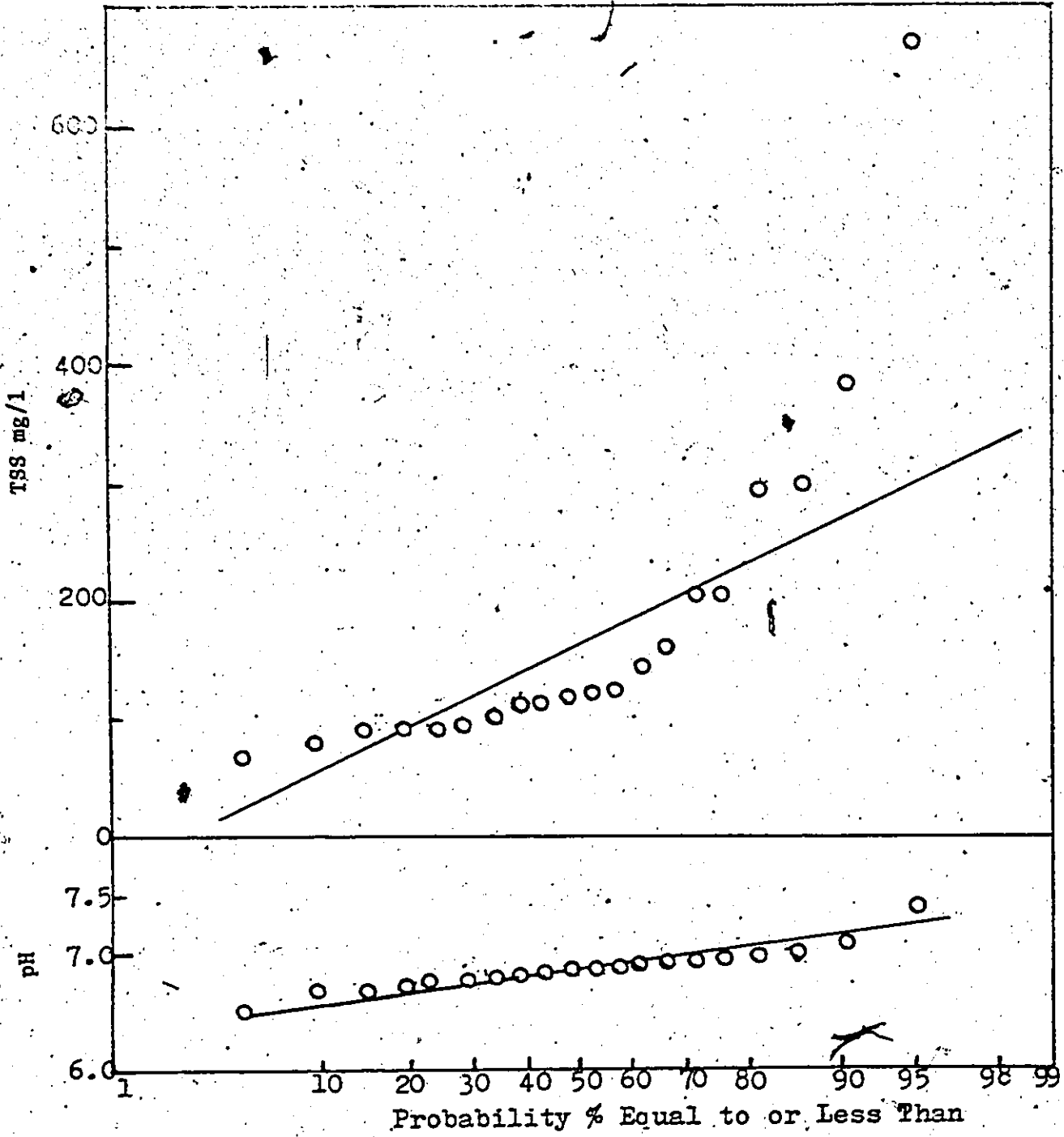


Fig. P 11. Characteristics of Septic Tank Effluent

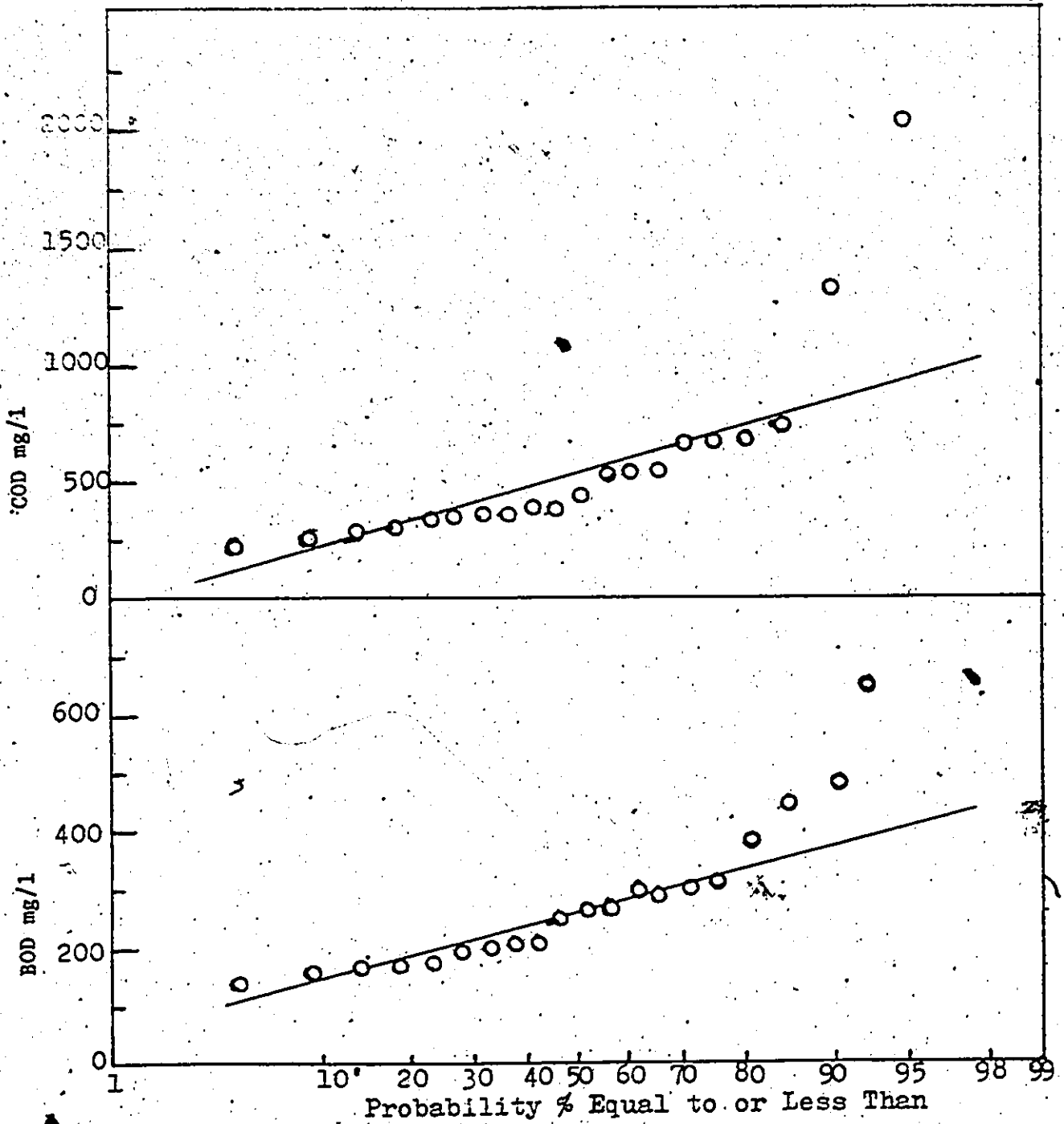


Fig. F 12. Characteristics of Septic Tank Effluent

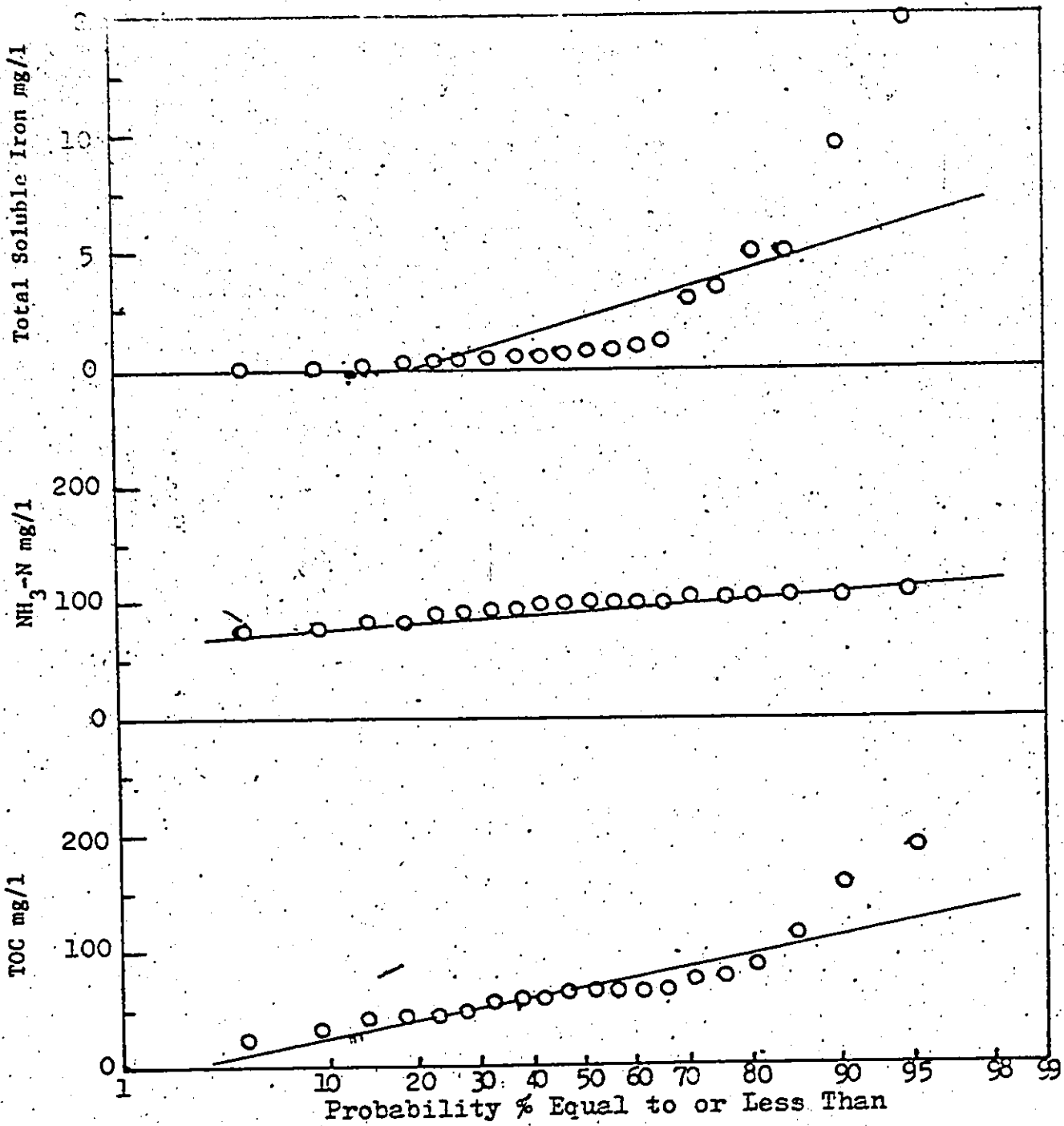


Fig. F 13. Characteristics of Septic Tank Effluent

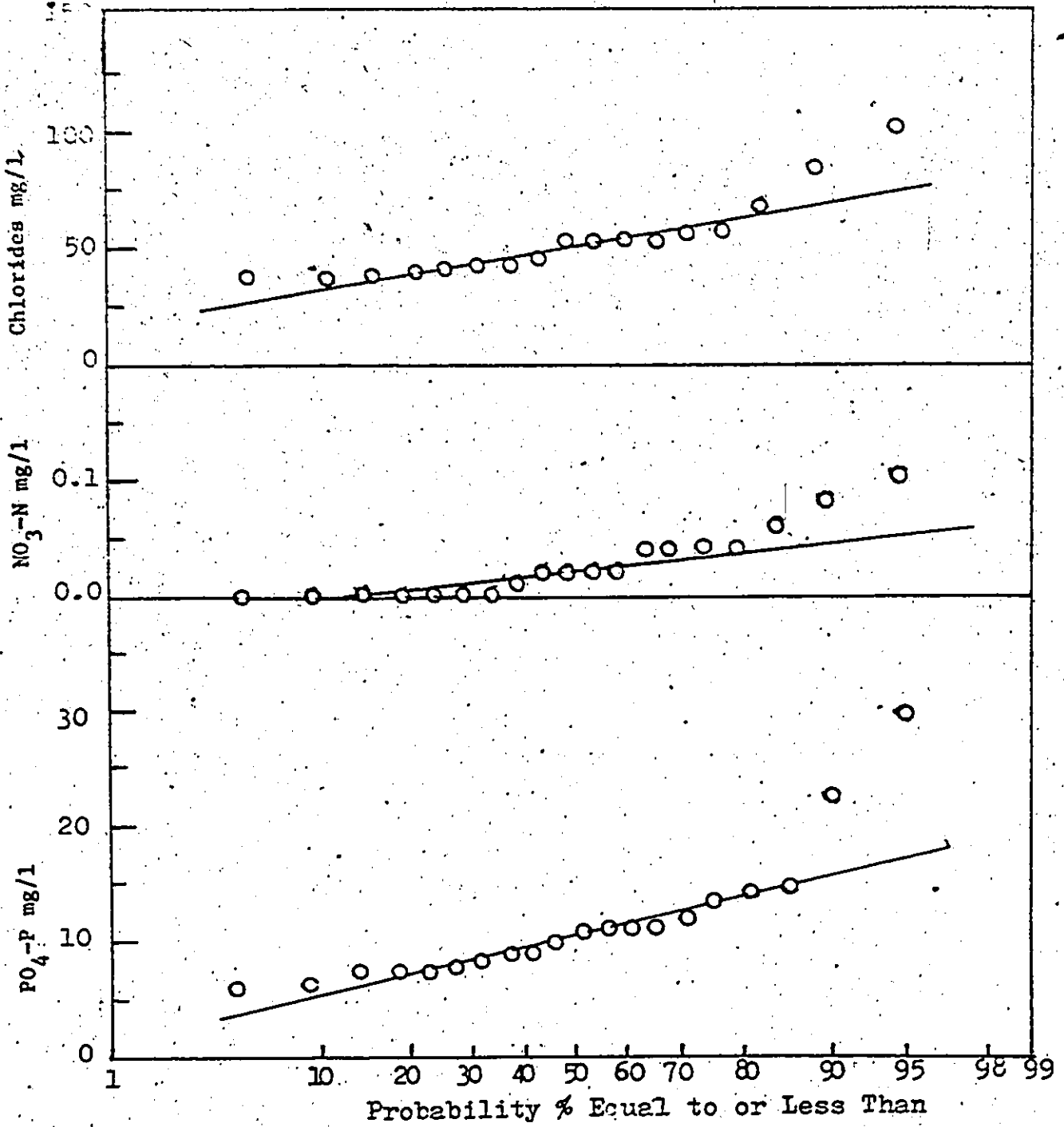


Fig. F 14. Characteristics of Septic Tank Effluent

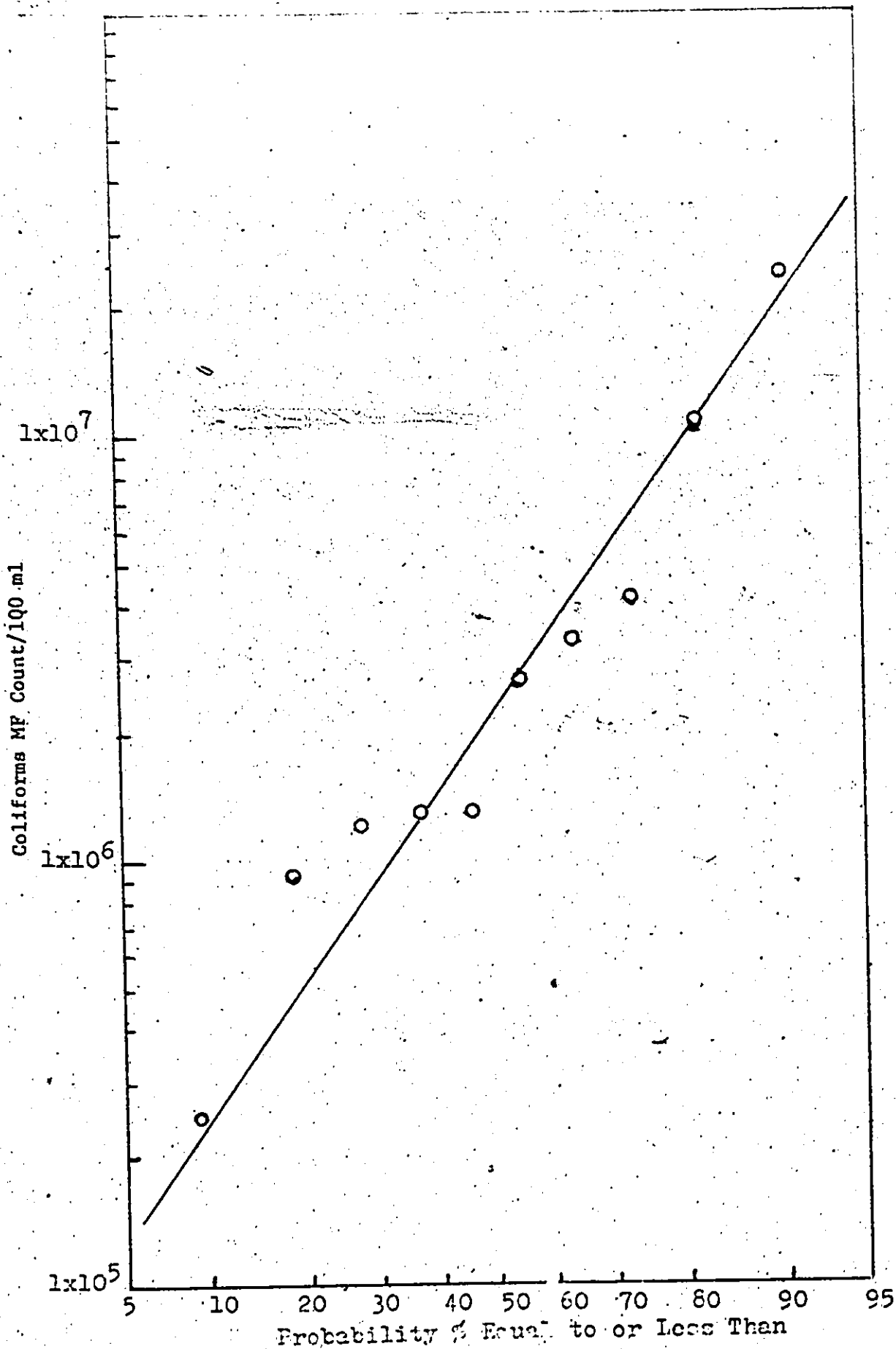


Fig. F 15. Characteristics of Septic Tank Effluent

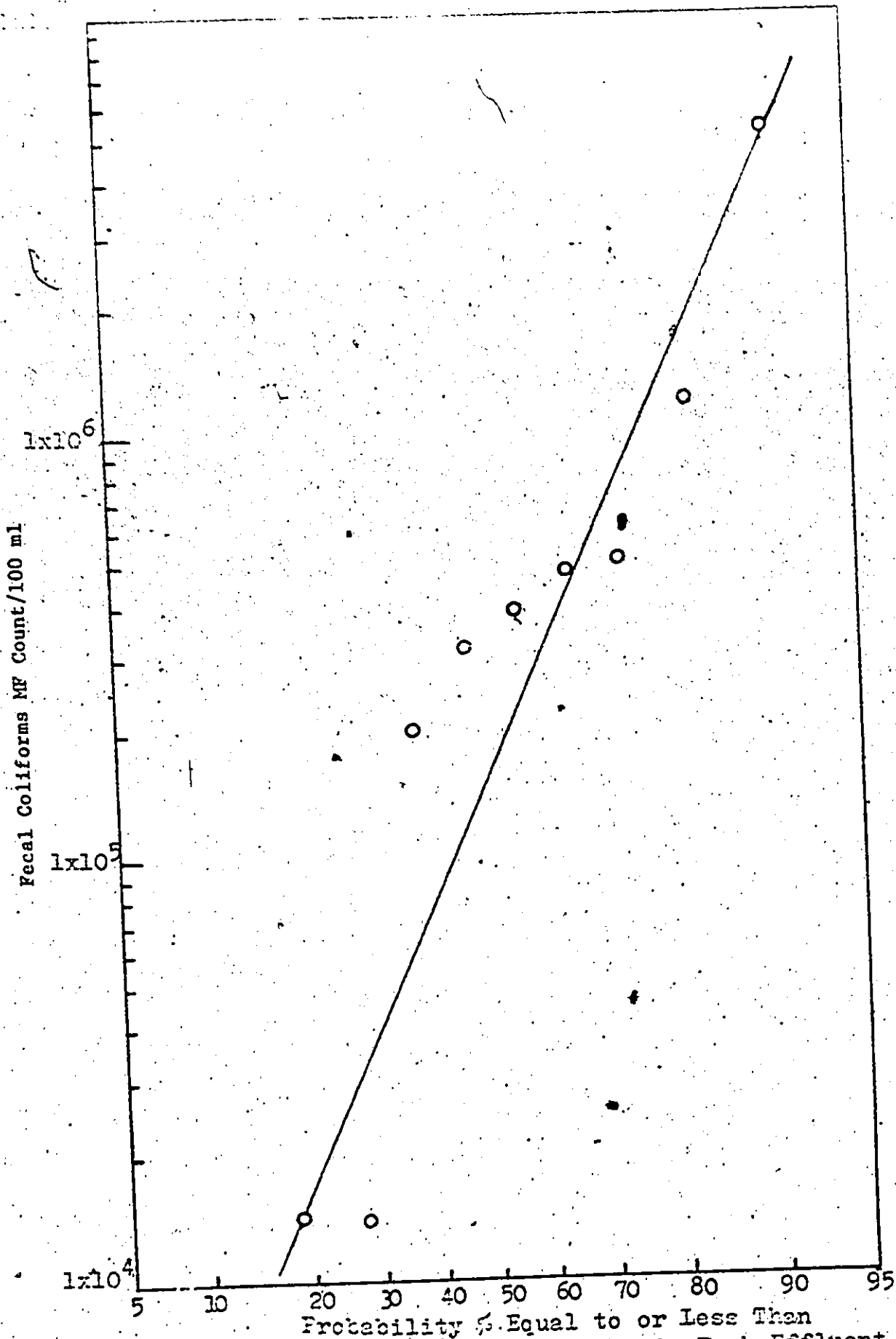


Fig. F 16. Characteristics of Septic Tank Effluent.

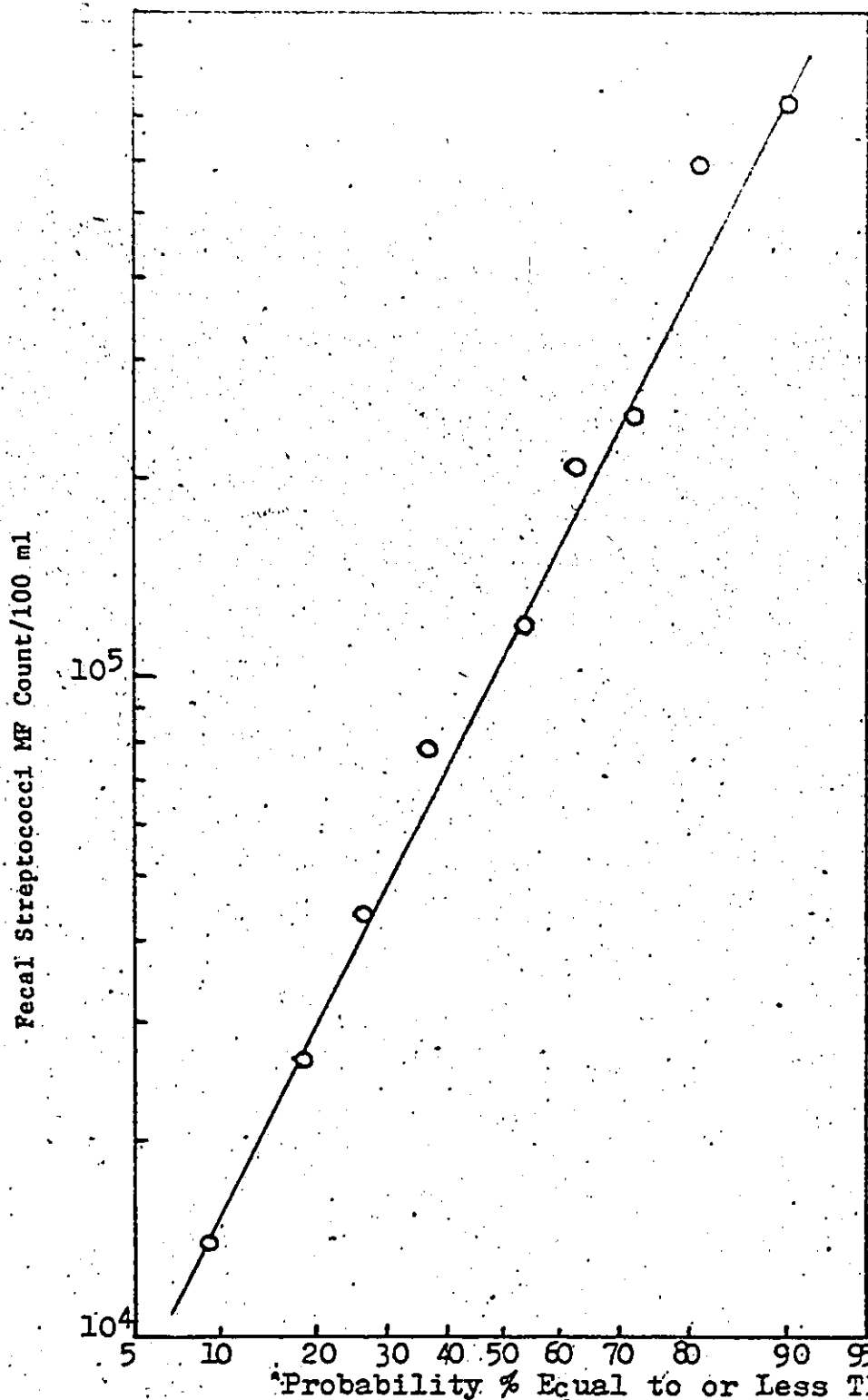


Fig. F 17. Characteristics of Septic Tank Effluent

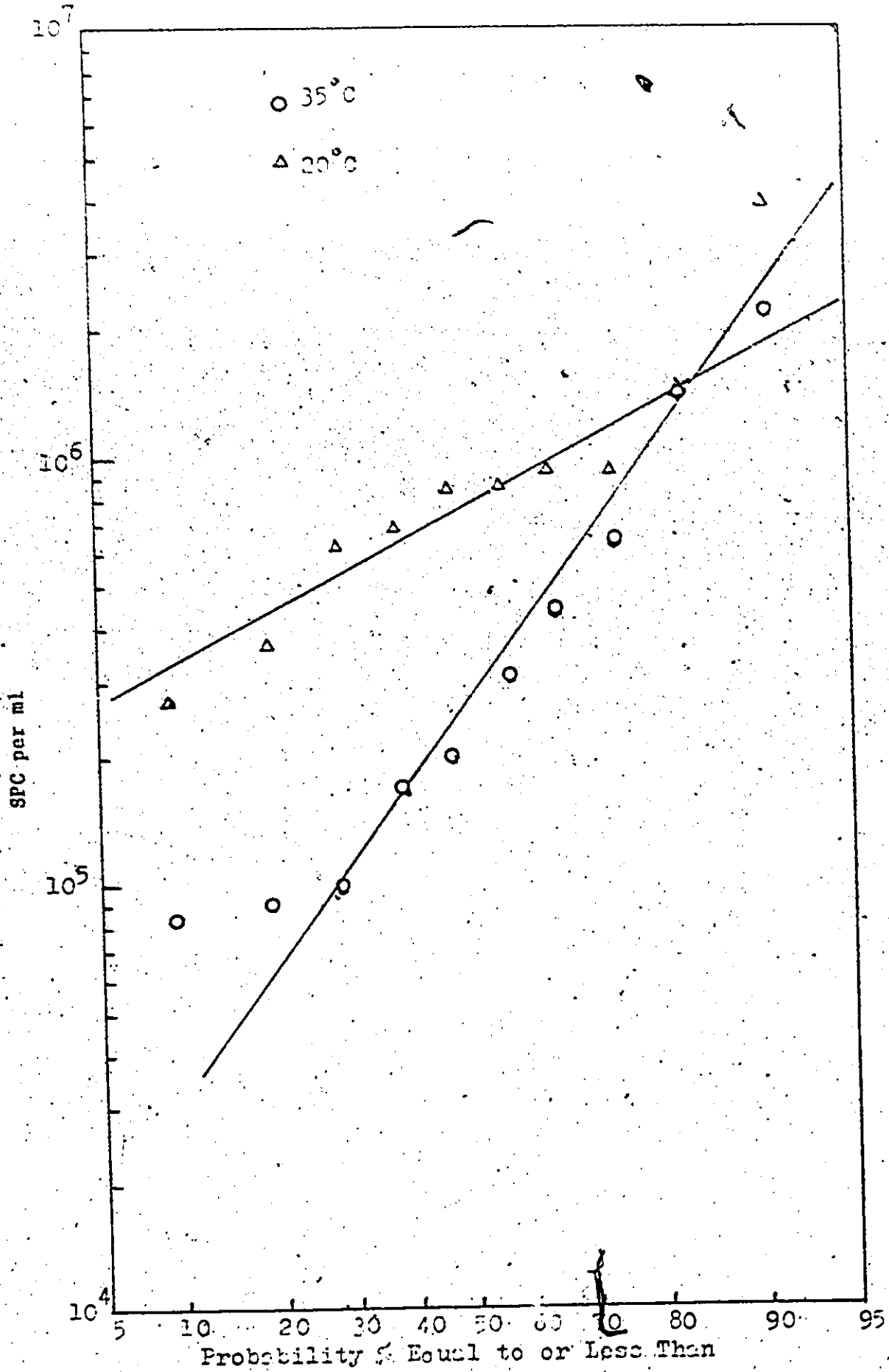


Fig. F 18. Characteristics of Septic Tank Effluent.

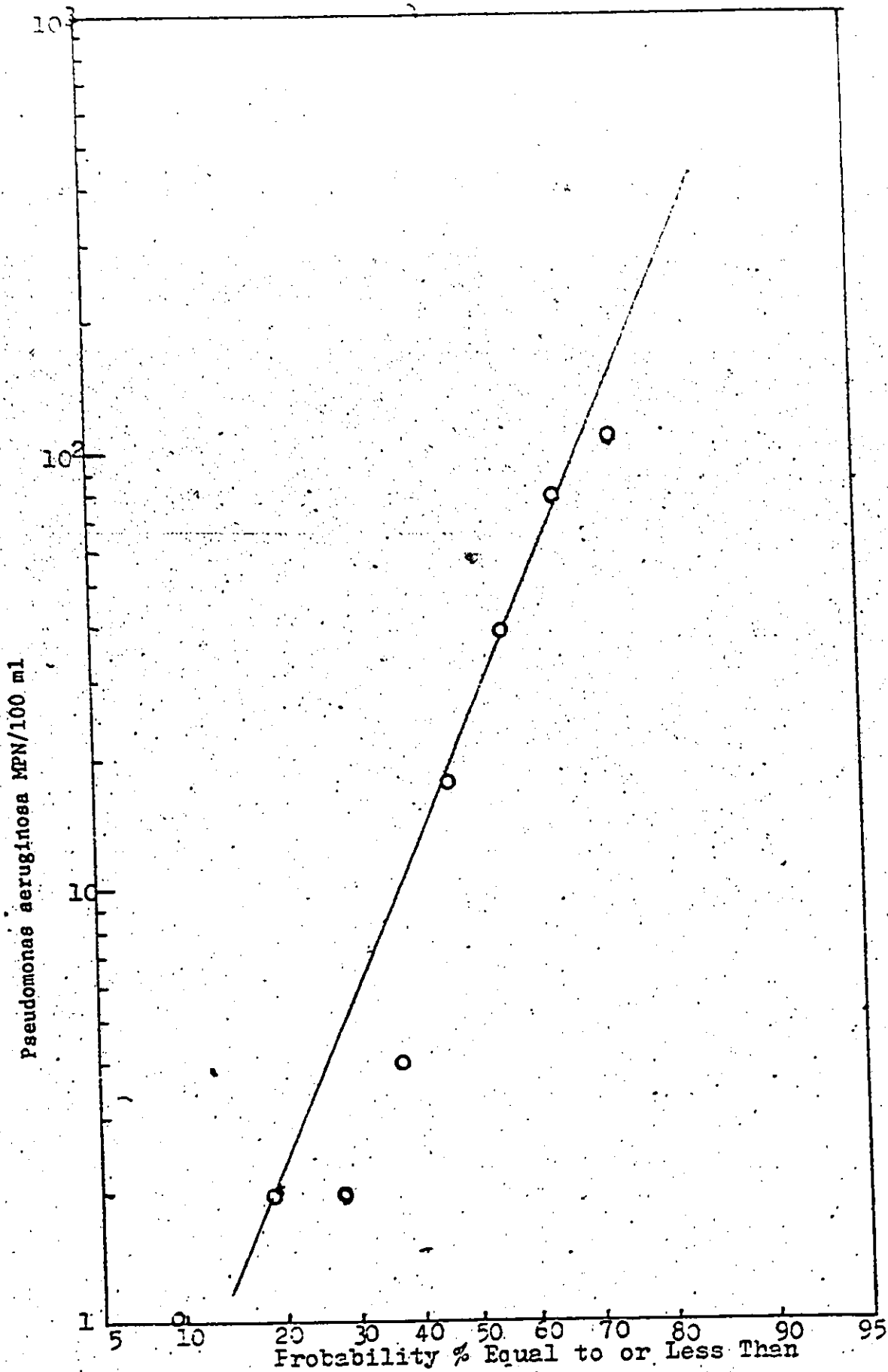


Fig. F 19. Characteristics of Septic Tank Effluent

APPENDIX G

SLUDGE AND SCUM MEASUREMENTS

Table G1. Scum and Sludge Measurements
(Distance from top of tank wall in inches)

Date	Compartment Number	Scum				Sludge				
		Top	Bottom	Fluid Floating	Submerged	Total Top	Bottom Depth			
30-1072	1	3-1/2	15-1/2	9	5-1/2	6-1/2	12	66	83	17
	2	6-1/2	9	7-1/2	1	1-1/2	2-1/2	45	53	8
01-06-73	1	3	17	6	3	11	14	53-1/2	83	29-1/2
	2	7	12	7-1/2	1/2	4-1/2	5	44	53	9
18-09-73	1	3-1/2	20-1/2	6-1/2	3	14	17	53	83	30
	2	6	12	6-1/2	1/2	5-1/2	6	41	53	12