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TREATMENT AND DISPOSAL OF WASTES PUMPED FROM SEPTIC TANKS

by

John J. Kolega
Arthur W. Dewey
Benjamin J. Cosenza
Robert L. Leonard
Storrs Agricultural Experiment Station
University of Connecticut
Storrs, Connecticut 06268

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Project Officer

G. K. Dotson
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report presents results of a study that was conducted to identify alternative methods of treating and disposing of wastes from septic tanks. About a third of the country's population live in homes that are not served by sewers. Increased population density and stricter standards of environmental protection have made old disposal methods unsatisfactory and caused the search for more acceptable alternatives.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

A multidisciplinary team was organized to identify feasible methods for treating and disposing wastes pumped from septic tanks (septage). Biological, chemical, and physical properties of septage were determined. Statistical data and design curves were developed for use in the design of septage treatment processes and facilities.

Two approaches were developed, tested in both laboratory and pilot plant studies, and found feasible for treating and disposing of septage: (1) soil injection, and (2) anaerobic-aerobic series processes. These series processes can sustain shock loadings and reduce the concentrations of BOD_5, COD, and total Kjeldahl nitrogen by at least 93 percent. Most of the nitrogen is converted to nitrate. Consideration was given to combined treatment of septage and sewage in a conventional biological treatment plant. A figure of 70 gallons (265 liters) per person per year was estimated as the volume of septage to be treated and disposed. Criteria were developed for the design of septage-receiving facilities.

As a rule of thumb, the total cost of treating 1000 gallons (3,785 liters) of septage is approximately 18 times the cost for treating the same amount of raw wastewater in a secondary treatment facility. Operating costs for treating septage in 10 mgd plants are estimated to be about half the treatment costs in 1 mgd plants or at 1972 prices, $1.80/1,000 gallons ($0.48/1000 liters) as compared with $3.24/1,000 gallons ($0.86/1000 liters).

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ABBREVIATIONS

APHA	American Public Health Association
AWWA	American Water Works Association, Inc.
BBL	Baltimore Biological Laboratories
BCP	Brom creosol purple
BOD	Biochemical oxygen demand
BOD_5	Five day BOD
BPL	Beta-propiolactone
COD	Chemical oxygen demand
Cl	Chloride
CTA	Cystine trypticase agar
D.O.	Dissolved oxygen
EPA	Environmental Protection Agency
EtO	Ethylene oxide
FC	Fecal coliform
FID	Flame ionization detector
fsl	Fine sandy loam
g	Gram
gpm	Gallons per minute
GA	Glucose-asparagine
HE	Hektoen Enteric agar
l	Liter
LAS	Linear alkylate sulfonate
lb	Pound
L_tD	Salmonella typhimurium
m	Meter
mg/l	Milligrams per liter
ml	Milliliter
mm	Millimeter
MGD	Million gallons per day
MLD	Million liters per day
MLSS	Mixed liquor suspended solids
min	Minute
MPN	Most probable number

ABBREVIATIONS (continued)

N	Normal
N_2	Nitrogen
NH_3	Ammonia nitrogen
NO_3	Nitrate
OF	Oxidative fermentative
PCA	Plate count agar
P-F-C	Plow furrow cover
PFU	Plaque forming units
pH	Hydrogen ion
ppm	Parts per million
PTA	Phosphotungstic acid
SCS	Soil Conservation Service
SIM	Sulfide indol motility agar
SPC	Standard plate count (Total viable count)
spp	Species
S-S-I	Sub-soil-injection
TC	Thermal conductivity detector
TGYE	Tryptone glucose extract agar
TS	Total solids
TSA	Trypticase soy agar
TSB	Trypticase soy broth
TSI	Triple sugar iron
TSS	Total suspended solids
TVA	Total volatile acids
M	Millimicron
VS	Volatile solids
VSS	Volatile suspended solids
WMF	White Memorial Foundation, Inc.
WPCF	Water pollution control facility or facilities

ACKNOWLEDGMENTS

This multidisciplinary study was funded, in part, by the U. S. Environmental Protection Agency (EPA) under Grant No. 17070 DKA, "Treatment Processes--Wastes Pumped from Septic Tanks." Mr. G. K. Dotson, of the EPA Ultimate Disposal Section, Wastewater Research Division, Municipal Environmental Research Laboratory in Cincinnati, served as project officer.

Individuals who contributed to sections of the final written report were Dr. Joseph F. Calabro, former Ph.D. candidate in microbiology; Dr. Frank S. Chuang (anaerobic-aerobic treatment processes), post-doctoral fellow in agricultural engineering; and Dr. A.F. Halim (gas chromatography studies), post-doctoral fellow in agricultural engineering.

Research technicians, Mr. Ralph C. Gold and Mr. Randall C. May, carried on the field operation phase of the septage land disposal study. Mr. George F. Sweeney, District Conservationist, USDA Soil Conservation Service, Litchfield, Ct. played an important role in the selection of the WMF site and worked cooperatively with the University during the course of the study. Similarly involved was Mr. Robert Shropshire, Superintendent at the WMF. Other assistance and cooperation during the course of the study came from Mr. Richard Gillett of the Connecticut Sewage Disposal Association, and Mr. Theodore W. Roberg, Litchfield, Ct. Consultations were had with the Torrington area health district in the course of the investigation. Lastly, it was the White Memorial Foundation, Litchfield, Ct. that made the excellent site available. The search for information about our natural environment through organized scientific observation and experimentation and the public dissemination of this knowledge has been one of the White Memorial Foundation's guiding principles.

In the preliminary septage land disposal studies, Mr. Bryon L. Tart, M.S. candidate in microbiology, assisted in the microorganisms soil distribution study. Mr. Gerald Wolfson was the research assistant and Mr. Theodore Roberg of Litchfield the cooperator.

The data presented on biological, chemical, and the physical properties of septage would not have been possible without the assistance of Dr. Ashwani; Joseph F. Calabro, doctoral candidate in microbiology; and research assistants Jaihind S. Dhodhi, Mrs. Mahusen Halim, Tripat S. Basur, Lawrence V. Cammarato, and Randall C. May. Mr. Ning Wang assisted with the computer analyses of data.

Mr. Raymond Lavery and personnel of the E. Hartford, Ct. Metropolitan District WPCF provided the necessary assistance for septage sample collection and refrigeration. This group also obtained the information source data.

Dr. Charles S. Shu, doctoral candidate in civil engineering, assisted with the receiving station and combined sewage-septage treatment studies. Cooperation in the latter investigation was received from Mr. Gregory Satzuk and personnel at the University of Connecticut WPCF. Cooperating from the Connecticut Sewage Disposal Association was Mr. William McKinney.

The study involved interstate cooperation between Rutgers University, New Brunswick, New Jersey, and the University of Connecticut, Storrs Agricultural Experiment Station. Prof. Charles H. Reed of the Agricultural Engineering Department of Rutgers University was the institituonal cooperator and participant. Collaborators from the Connecticut State Department of Health, Environmental Health Services Division were Mr. Joseph Kosman, Chief, Municipal Wastewater Control Section, and Mr. Ronald E. Topazio, Senior Sanitary Engineer. Dr. Rain Laak and Prof. William C. Wheeler, respectively, of the Univesity of Connecticut Civil and Agricultural Engineering Departments were other collaborators.

Mr. George Lebetkin, formerly of the E. Hartford Metropolitan District Commission WPCF assisted in the early years of the study. During the last year, Mr. Wilbur L. Widmer, Professor of the University Civil Engineering Department, provided assistance in terms of consultations and suggestions. Prof. Ralph P. Prince, Acting Head of the University Agricultural Engineering Department, provided assistance in critical areas when needed and made suggestions on manuscript copy material prepared. The cooperation from Dr. R. W. Wengel of the University Plant Science Department as it relates to the use of the Technicon autoanalyzer and Kjeldahl nitrogen apparatus is appreciated.

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Mr. Raymond Blanchette of University publications prepared most of the drawings and figures with some assistance from Mr. Ranjit Roy.

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Special recognition should be given to agricultural publications staff members, David W. Bechenholdt and David Kimball, for coming up with the word, "septage", to replace the phrase "septic tank pumpings". This word has been received and is being used on a national and international level.

SECTION I

INTRODUCTION

This report presents the findings of a multidisciplinary team investigation for the disposal of septic tank pumpings; such pumpings are referred to as septage. Septage is defined as the mixed liquid and solid contents pumped from septic tanks and dry wells receiving domestic type sewage. Septage may also include the pumpings of similar biodegradable materials obtained from the septic tanks of schools, motels, restaurants, and similar establishments.

The primary participants in this investigation were the Storrs Agricultural Experiment Station and the University of Connecticut Departments of Agricultural Engineering, Agricultural Economics, and the Microbiology Section of the Biological Sciences Group. Financing in part was from the U.S. Environmental Protection Agency. Active cooperators at various stages of the study were the Metropolitan District Commission, Bureau of Public Works, East Hartford Water Pollution Control Facility; the White Memorial Foundation, Inc., Litchfield; representatives of the Connecticut Sewage Disposal Association; and the Rutgers University (New Jersey) Agricultural Engineering Department. Serving as collaborators in the study were the Connecticut State Department of Health, Environmental Health Services Division; the USDA Soil Conservation Service, Litchfield Work Unit; and the University of Connecticut Civil Engineering Department. In addition to the University of Connecticut Agricultural Engineering Department laboratory and pilot plant facilities, use was made as needed of the Plant Science Department's Technicon autoanalyzer and nitrogen apparatus, and the University of Connecticut Computer Center Facilities.

The Manual of Septic Tank Practice (U.S. Department of Health, Rev. 1967) states that septic tanks should be inspected at least once a year and cleaned when necessary. The necessity for pumping the septic tank depends upon the amount of sludge and scum that has accumulated. A general recommendation for homeowners is to pump the septic tank at intervals of three to five years (Rockey, 1963). If the practice of inspecting a septic tank is not followed, then pumping at more frequent intervals is recommended.

Another reason for more frequent septic tank pumping is poor site selection. Poor soil acceptance capability or a seasonal high ground water table may result in backup or overflow of household sewage. The condition can be temporarily alleviated by emergency pumping. Frequent pumpings may be required when septic systems have been improperly designed or installed. To minimize septic system failures, the state and some municipalities or the health districts of which they are members hire trained sanitarians to insure better compliance with the Connecticut Public Health Code Regulations.

Few homeowners and municipal officials are knowledgeable about local septage disposal practices. Yet, in unsewered communities, there is an almost continuous demand for septage disposal facilities. Since this study began, the need for developing and improving facilities for receiving and processing septage has begun to receive more public attention.

Lack of knowledge concerning the properties of septage has hampered both designers and operators of sewage treatment facilities. Plant operators, unfamiliar with septage, often assume that it has different properties than it really has. Where septage is received, plant operators are often concerned with establishing working ratios for mixing septage with incoming sewage. Thus, septage as a trucked liquid waste needs design and operational criteria for physical handling and treatment.

When a wastewater treatment facility is not available, septage is commonly disposed of in unacceptable ways. One such practice in Connecticut is the use of earth excavated pits. In these pits, the septage depth varies depending on the ground water level, the amount of land available, and the volume of septage being handled. These pits tend to become hazardous when they are filled and abandoned.

The research undertaken in Connecticut and reported in this study was designed to develop information to the following questions:

1. What is the nature of septage?

2. Is septage compatible with sewage for treatment in water pollution control facilities?

3. What special treatment methods are appropriate for handling septage?

4. What economic and governmental factors determine the design, regulation, and operation of septage disposal systems?

SECTION 2

CONCLUSIONS

1. Experimental findings have provided data for use in the design of treatment and disposal processes for septage (the wastes pumped from septic tanks).

   This information as it relates to BOD_5, COD, total solids, volatile solids, total suspended solids, volatile suspended solids, organic nitrogen, and ammonia-nitrogen has been presented statistically and in the form of design curves. Related data of interest in characterizing septage include pH, color, odor, gas utilization and production, total volatiles, settleable solids, and detergents. For estimating the volume of septage to be disposed of, a figure of 70 gallons (265 liters) per capita per year was established.

2. In selecting a system for septage disposal, attention should be given to the following types of treatment and disposal methods that can be used singly or in combination:

   (a) Treating with wastewater in a wastewater treatment facility.

   (b) Land disposal.

   (c) Specialized treatment process in preparation for disposal.

3. The biological, chemical, and physical properties of septage, although different from that of incoming raw sewage, indicate that this material can be treated in wastewater treatment facilities.

   In planning to accept septage at a wastewater treatment facility, the following factors should be considered:

   (a) The need for a septage holding or storage tank.

   (b) The timing and control of septage flow into the treatment process.

   (c) The volume of septage relative to the available plant capacity.

   (d) Pretreatment through a bar screen followed by a grit chamber and comminuter to remove grit before the septage enters the main wastewater treatment processes.

4. Soil injection of septage was demonstrated as a feasible method of disposal without contaminating ground waters. Depending upon geographic location, soil injection may not be a year round disposal method. Under this circumstance, a combination of septage disposal methods will be required, e.g., disposal in a wastewater treatment facility during the colder seasons and soil injection during the warmer seasons.

5. The anaerobic-aerobic series processes can be used for treating septage. Laboratory and pilot plant studies showed that these processes can withstand shock loadings and reduce the concentrations of BOD_5, COD, and total Kjeldahl nitrogen by at least 93 percent. Most of the nitrogen is converted to nitrate.

6. Operating costs for treating septage in a 10 mgd (37.9 mld) wastewater treatment facility is estimated at approximately $1.80/1,000 gallons ($0.48/1,000 liters). Operating costs for treating septage in a 1 mgd (3.8 mld) facility is estimated at approximately $3.24/1,000 gallons ($0.86/1,000 liters) at 1972 prices.

7. Disposal charges, methods of collecting charges, regulations governing acceptance of septage, and enforcement of regulations are major factors that affect the relative volumes of septage received at adjacent disposal outlets.

   Septage volumes received at already established outlets could change substantially if receiving stations were established beyond a 15-mile radius of existing wastewater treatment facilities and if the septage were then trucked from the stations to treatment facilities.

8. Intervention by state and intrastate (regional) agencies may be a necessary step for modifying existing policies whenever the authority and responsibility for septage disposal rests solely with municipalities. Without intervention

   (a) there may be a shirking of legislatively assigned responsibilities;

   (b) working agreements among adjacent municipalities may be difficult to establish and maintain;

   (c) incentives will be minimal for upgrading septage disposal practices and facilities or for requiring their use when low cost dumping pits are available; and

   (d) many receiving facilities for septage at many treatment plants will continue to be inadequate and unsanitary.

9. A comparison of microorganisms recovered from septage and those reported for sewage showed slight variation in distribution.

The gram negative, non-lactose fermenters were the predominant types present in septage. A total of 474 bacterial isolates were obtained and grouped as to genus.

10. Bacteriophage isolated from septage and septic tank sewage can lyze cells of Citrobacter freundii and Shigella flexneri.

    Host specificities range studies indicated that rough forms of certain gram negative bacteria are sensitive to phage. This may account for the rapid disappearance of Escherichia coli and related forms in septage.

11. Health hazards to pumpers (presence of enteric pathogens) were investigated by introducing a biological marker, Salmonella typhimurium, into a septic tank system and observing its survival time. Results indicate that this pathogen is unable to compete with other less fastidious microorganisms in the system. This observation, coupled with the inability to isolate Salmonellae from this niche previously, substantiates the view that enteric pathogens die within a relatively short time.

12. A plexiglas multichambered tank specifically designed and constructed to assess the interactions of predominant bacterial types present in septage, either singly or in combination, is functional as in other areas of biology and medicine.

    For example, the original prototype tank was modified and used at the University of Connecticut Health Center to study the interaction of microorganisms found in the oral cavity. It has also been adapted to ecological studies and is commonly referred to as an eco-chamber.

SECTION 3

RECOMMENDATIONS

1. Septage should be examined for the presence of heavy metals, total organic carbon and animal viruses.

2. Policies for the disposal of septage should be developed at municipal, intermunicipal, state and national levels.

   This information should be presented in a manner useful to individual states in the preparation of their respective policies regarding the disposal of septage.

3. An interagency technical advisory committee on septage should be established to:

   (a) Coordinate the overall approaches being taken towards solution of the septage disposal problems:

   (b) Determine priorities for future research if needed.

4. Because septage disposal is a problem throughout the United States, the EPA or some other designated Federal agency should develop and sponsor a national meeting or a series of regional meetings to discuss means for disposing of septage.

5. Application of findings from the soil injection pilot study for septage disposal should be demonstrated.

   The purpose of this demonstration would be to:

   (a) Demonstrate the adaptability of the EPA WQO project to Grant No. 17070 DKA research findings to the public management of septage disposal.

   (b) Enchance the development of public plans and programs for the disposal of septage.

   (c) Evaluate the long-term effects of continued septage disposal by soil injection on the ground water quality and soil permeability.

   (d) Determine the effects of microbial activities on crops grown.

6. A study is needed on the feasibility of modifying pumping schedules to conform with seasonal opportunities for soil injection. In order to minimize the number of emergency pumpings during periods when soil injection is not feasible, scheduled pumping would have to be accompanied by a program of inspection and enforced correction of defective septic tank and drainage systems.

7. Continued research is needed to develop a better understanding of the soil as a mechanism for use in the degradation of septage.

8. Design and construction criteria should be developed for shallow basins or lagoons in series for the disposal of septage in areas where odor will not be a nuisance.

9. At septage disposal sites, studies should be initiated to determine the extent of aerosol formation and disposal.

SECTION 4

MATERIALS AND METHODS

SAMPLING (For examination of biological, chemical and physical properties of septage.)

Septage samples were collected primarily from vehicles carrying septage to the Metropolitan District Commission, E. Hartford Connecticut Water Pollution Control Facility (WPCF). A 3-inch tee, with a shut-off valve, was used in conjunction with a 10-foot section of discharge hose to collect the sample. The collection assembly was attached to the tank discharge pipe. The sample was collected as a side stream while the septage was being discharged into a sewer. Sample collection was at the beginning, the mid-point, and near the end of the unloading period.

A limited number of septage samples were collected from North Haven, Ellington, and Mansfield, Connecticut. The North Haven location is a water pollution control facility, whereas Ellington and Mansfield are pumper-owned or leased dumping sites.

The septage samples were refrigerated until analyzed. The size of sample was either about 500 ml or about 2000 ml depending upon the number and type of tests to be performed. Later in the study a few 5-gallon samples were collected. These samples were not refrigerated.

Most of the sampled septage loads (180) were from household residences. Other sources were schools, a convalescent home, restaurants, motels, apartment units, a food chain store, and light industry. For each sample collected, information was obtained as to:

(1) Date

(2) Load source (name, address, and telephone number of the household residence or commercial establishment).

(3) Estimated size of the septage load.

(4) Name of the septic tank pumper.

(5) pH of septage at the receiving station and upon arrival of the sample at the laboratory.

Deviations in sample collection procedure from the above, e.g., specialized studies, are explained as appropriate in the sections which follow.

In addition to the septage samples, raw sewage and primary digester sludge samples were collected from the sewage treatment plants at the University of Connecticut, City of Willimantic, and East Hartford. These samples were used to compare the gases produced and their quantities.

CHEMICAL AND PHYSICAL

Analytical (STANDARD METHODS)

The laboratory methods followed the procedures in 1965 and 1971 editions of the (APHA, AWWA and WPCF) STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. The analyses were: biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), pH, settleable solids, total solids, volatile solids, suspended solids, ammonia nitrogen and organic nitrogen. The number of replications and simultaneous tests conducted per sample varied according to the personnel available, day of the week, and the limitation of laboratory facilities. Physical and visual observations were used for recording odor and color. A limited number of samples were examined for the presence of detergents and chlorine demand. Total volatile acids (TVA) concentration was measured by a chromatographic technique.

Instrumentation

When a large number of samples were involved a Technicon Autoanalyzer (Technicon Corporation, Tarrytown, N.Y.) was used for measuring COD, chloride and nitrate-nitrogen concentrations. Nitrate-nitrogen concentrations also were measured with a: (1) Hach DR Colorimeter (Hach Chemical Co., Ames, Iowa); (2) specific ion electrode (Orion Research Inc., Cambridge, Mass.); and (3) Delta Model No. 260 photometric analyser (Delta Scientific Corp., Lindenhurst, N.Y.). The Hach DR Colorimeter also was used for measuring phosphate concentrations. Some chloride measurements were made with a specific ion electrode. A Model 51 oxygen meter (Yellow Springs Instrument Co., Yellow Springs, Ohio) was used to measure dissolved oxygen (D.O.). This instrument was checked periodically by a chemical technique using the STANDARD METHODS procedure.

Early in the study, known standards were not used in the colorimetric analyses for measuring nitrate-nitrogen concentrations. However, the nitrate-nitrogen concentrations on a select number of samples were compared with measurements also made on the Technicon Autoanalyzer.

Gas Products and Reactants

For analyses of gases and reactants a Model 1860 Varian Aerograph (Walnut Creek, California) gas chromatograph equipped with dual-flame ionization detectors (FID) and a thermal conductivity detector (TC) was used. Quantitative measurements were made by means of a Varian Aerograph Model 480 electronic digital integrator.

For the analyses of gases, a Porapak Q, 80-100 mesh, 12 feet by 1/8 inch (3.7 meters by 0.3 cm) o.d., stainless steel column was used for the separation of air (oxygen and nitrogen), methane and carbon dioxide (Bell, 1968). A molecular sieve 13X, 30-60 mesh, 13 feet by 1/8 inch (4 meters by 0.3 cm) o.d., stainless steel column was used to separate the oxygen from nitrogen. The gas chromatographic analyses conditions using either column were as follows: (1) temperatures for the injector, TX and column were 150°C, 150°C and 52°C respectively; (2) helium flow rate was 35ml/min; and (3) bridge current 100 mA.

A total of 21 different septage, raw sewage, and primary digester sludge samples were collected. From each sample, one and one-half liters were transferred to a 2-1/2 liter screw-cap flask. The screw-cap had a circular hole (1/2 cm diam.) and was fitted with a rubber septum on the inside. The samples were kept at ambient temperature without exposure to any activation procedure. A 0.2 ml portion of the head space gas of each sample was withdrawn for injection into the chromatographic column using a 1 ml capacity gas-tight Hamilton syringe.

Total Volatiles, Including Mercaptans and Sulfides

The total volatiles including the mercaptan and sulfides were analyzed on a Porapak Q, 50-80 mesh, 4 feet by 1/4 inch (1.2 meters by 0.6 cm) o.d., stainless steel column. A 1-1/2 foot (0.5 meter) section of this column was bent into a U-shape for use as a precolumn trap. Temperature of the injector and dual-flame ionization detectors (FID) was 250°C. The column temperature was initially held at 135°C for 4 min., programming 135°C - 175°C, 10°C/min.; held at 175°C for 4 min., programming 175°C - 225°C, 10°C/min.; and then held at 225°C until the completion of analysis. The flow rates for helium, hydrogen and air were 25, 25, and 250 ml/min., respectively.

The total volatiles including the mercaptan and organic sulfides found in the different liquid wastes were initially trapped in the U-shaped portion of the Porapak column. The assembly and sampling procedures were prepared according to Burnett, 1969. For the description of the odor character of each fraction emerging from the column, a stream-splitter was used whereby part of the fraction was vented to the sniffing port of the gas chromatograph. Some of the organic sulfur compounds could be tentatively identified by their characteristic odors as well as retention time data.

Prolonged Holding of Septage

Two samples were examined for determining the biochemical characteristics and the changes taking place when septage was stored under quiescent conditions for a prolonged period of time. One sample was obtained from a trucked septage load received at the East Hartford WPCF and the second sample came from the White Memorial Foundation, Inc. land disposal experimental site located in Litchfield. The sample size was approximately four liters. Each sample was collected in plastic containers and refrigerated until the start of the experiment.

Two different laboratory assemblies were designed. One assembly was used for the cumulative collection and periodic analysis of the gas mixture (Figure 1). A one-liter bottle was filled with septage up to its 4/5 mark. The bottle was connected to a 500 ml graduated buret and the latter, in turn, was attached to a one-liter aspirator bottle. The buret and the aspirator were filled with acidified NaCl-saturated aqueous solution. The aspirator functioned as a regulator for the internal pressure of the system in reference to atmospheric pressure. Two gas-sampling ports were inserted; one at the top of the sample bottle and the other at the top of the buret. At the beginning of the experiment, the water level in the graduated buret was adjusted to the zero graduation mark under atmospheric pressure by means of the aspirator. The initial volume of the gas (100% air) trapped in the system measured approximately 270 ml for each sample assembly. To minimize air entry into the system, the pressure of the trapped gas was kept slightly above atmospheric pressure. Before recording the volume of the gas evolved, the gas components were homogeneously mixed together by rapidly moving the water level in the buret up and down. The efficiency of mixing was further improved by frequent withdrawing and pumping the gas through each gas-sampling port using a 10 ml gas-tight Hamilton syringe. The system was then returned to atmospheric pressure and the amount of gas evolved daily was recorded. The same mixing procedure was repeated before withdrawing sample for gas chromatographic analysis. The assemblies were placed in an uncontrolled temperature room. However, before any gas measurement or sampling, the room temperature was adjusted to $70° \pm 2°$ F. The gas chromatographic column and conditions were the same as previously described under the gaseous products and reactants section. For quantitative measurement, volume/volume of each individual component in the gas, a calibration chart was developed by plotting the digital integrator counts against the volume of the gas injected. Care was taken so that all samples and reference gases (carbon dioxide, methane, and air) were analyzed under the same chromatographic conditions.

The other assembly was designed to determine changes in pH, chemical oxygen demand (COD), total volatile fatty acid (TVA) content and the relative percentage of the individual volatile fatty acids. Eleven bottles (125 ml capacity) were each filled with about 100 ml of the septage sample. Each bottle was tightly closed with a rubber stopper fitted with a 15-inch (38.1 centimeters) glass tube. The tube was shaped so that the opposite end could be conveniently dipped into a beaker filled with water. Excess gases were expelled through the water without allowing atmospheric air into the sample head space. Ten sample bottles were analyzed daily within the first 35 days, after which one sample was used for analysis every third or fourth day. The last sample bottle was stored for an additional 2-1/2 months. This sample was then analyzed for pH, COD and TVA.

The relative percentage of individual fatty acids was measured on 50 milliliters of the liquid waste. The analytical procedure was to

(1) centrifuge at 3200 rpm for 30 minutes.

(2) transfer the supernatant to an evaporating dish.

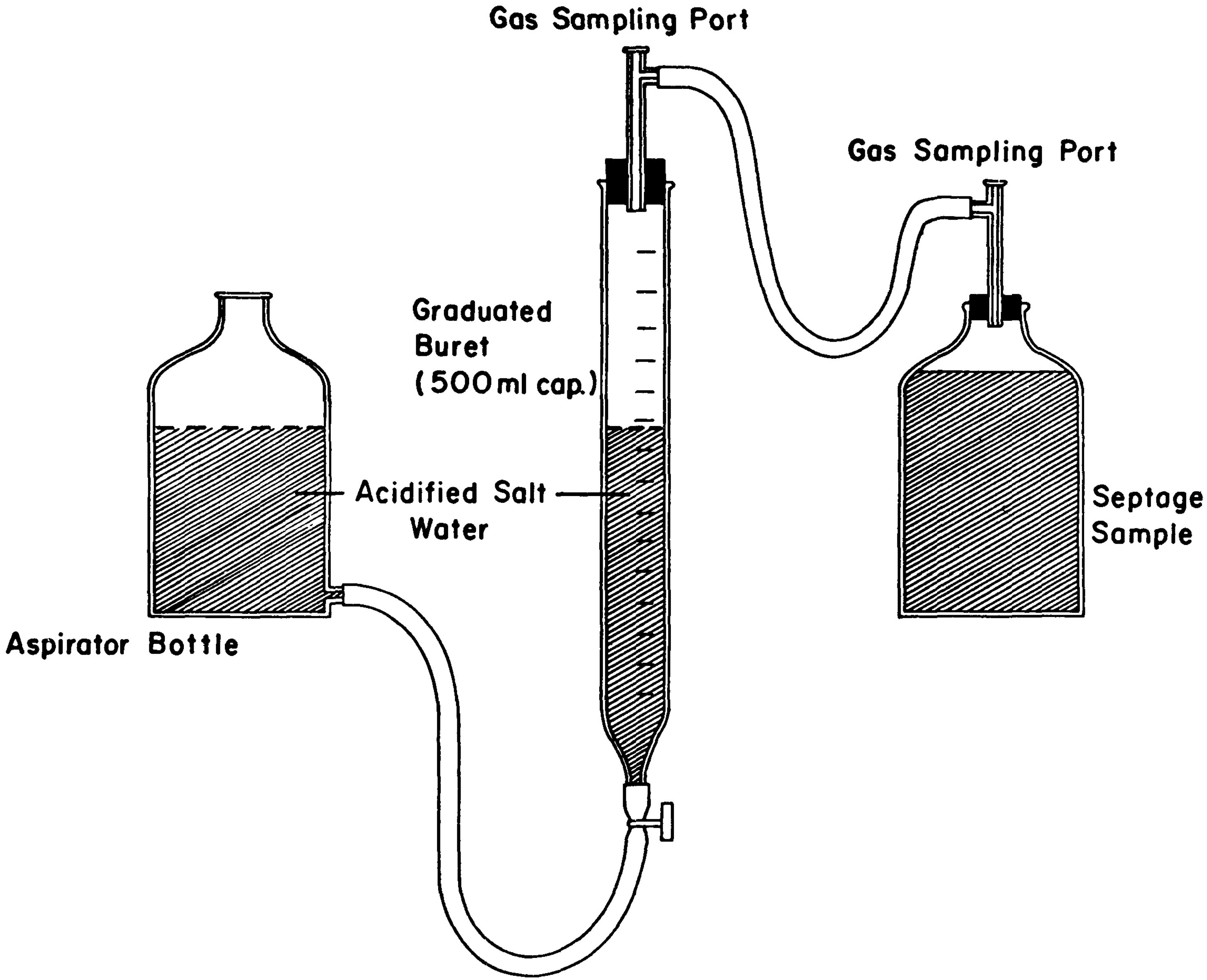


Figure 1. Schematic diagram of gas collection and sampling.

(3) adjust pH of the supernatant to between 9 and 10 with a few drops of 1N NaOH.

(4) concentrate the supernatant to about 3 milliliters on a boiling water bath.

(5) adjust pH of the supernatant concentrate to 2 with 1N H_2SO_4.

(6) transfer the supernatant concentrate to a test tube. The residue on the evaporating dish was washed into the test tube with about 1 milliliter of distilled water.

(7) The supernatant concentrate was then saturated with anhydrous Na_2SO_4 (2 g) and thoroughly shaken with freshly distilled ether (10 ml).

(8) The ethereal layer was separated and the remainder of the solvent was removed by bubbling a slow stream of pure nitrogen gas through the water phase.

(9) Two microliters of the ethereal extract of fatty acids were injected into the gas chromatograph. A 5-foot (1.58 meters) by 1/8 inch (0.32 cm.) o.d. stainless steel column packed with a neopentylglycol succinate (20%) plus phosphoric acid (2%) on fire brick 60-70 mesh was used.

The gas chromatographic conditions were:

(1) temperature of the injector, FID and column were 265°C, 250°C and 150°C, respectively.

(2) flow rates of helium, hydrogen and air were 30, 30 and 300 ml/min., respectively.

Identification of the individual acids was made by the retention time comparison with reference samples.

BIOLOGICAL

Media Preparation

All media, glassware, and equipment were sterilized by autoclaving at 15 psi and 121°C unless otherwise stated.

The initial pH reading of all media and solutions was adjusted to 7.2 ± 0.1.

Sample dilutions were made in bottles containing 90 ml of sterile phosphate buffer (STANDARD METHODS FOR EXAMINATION OF WATER AND WASTEWATER, 1965).

Maintenance of Cultures

All isolates were maintained on trypticase soy agar (TSA) (Baltimore Biological Laboratories, Baltimore, Md.) slants and transferred every three months. Strict anaerobes were held in cystine trypticase agar (CTA, BBL).

Special Equipment

Liquid wastes from a septic tank were collected with a special sampling device. The unit consisted of a cylindrical tube which could be opened or closed at one end by a spring-action mechanism to permit sampling at various depths.

Brewer anaerobic jars containing H_2-CO_2 disposable gas packs (BBL) were employed for establishing anaerobic conditions. Methylene blue served as the oxidation/reduction indicator.

Plastic and/or glass Millipore filter holders (Millipore Corporation, Bedford, Mass.) were used for filtration. Prefilters and membranes were 47 mm in diameter and presterilized.

Electron micrographs of bacteriophage isolated for septage were taken with a Philips, Model 75 electron microscope.

Sample Collection

In addition to trucked septage, samples were also obtained at a depth of two and four feet from the inlet end of a household septic tank. Each sample was thoroughly mixed and a representative portion placed under anaerobic conditions. Also, samples were collected from a household septic tank for the *Salmonella typhimurium* survival time study and the methylene blue reduction time test. Sample collection was made at a depth of 18 inches using a hand operated diaphragm pump.

Isolation and Enumeration Procedures

Two methods for isolation and enumeration of microorganisms were followed. In one procedure, samples in duplicate were serially diluted in phosphate buffer, and aliquot portions were overlayed with plate count agar (PCA) (Difco Laboratories, Detroit, Mich.). The standard plate count (SPC)/ml was determined after 48 hours incubation under aerobic and anaerobic conditions at 24°C ± 1. Predominating types were selected and transferred to TSA for further characterization. Strict anaerobes were inoculated into thioglycollate (Difco) broth.

In the other procedure, 20 ml of each sample was pre-filtered to remove gross organic matter. The prefilter pad was washed twice with sterile phosphate buffer and the filtrate was passed through a Millipore membrane (0.45 uM). Microorganisms were dislodged from the Millipore filter by a 15-minute agitation in a phosphate buffer with a magnetic stirrer. This agitation step was repeated twice using fresh buffer. The washings from the membrane were combined and serially diluted. Membrane filters from anaerobically treated samples were washed under nitrogen. Spread plates were made on plate count agar from the dilutents, and counted after 48 hours incubation, aerobically and anaerobically, at 24°C.

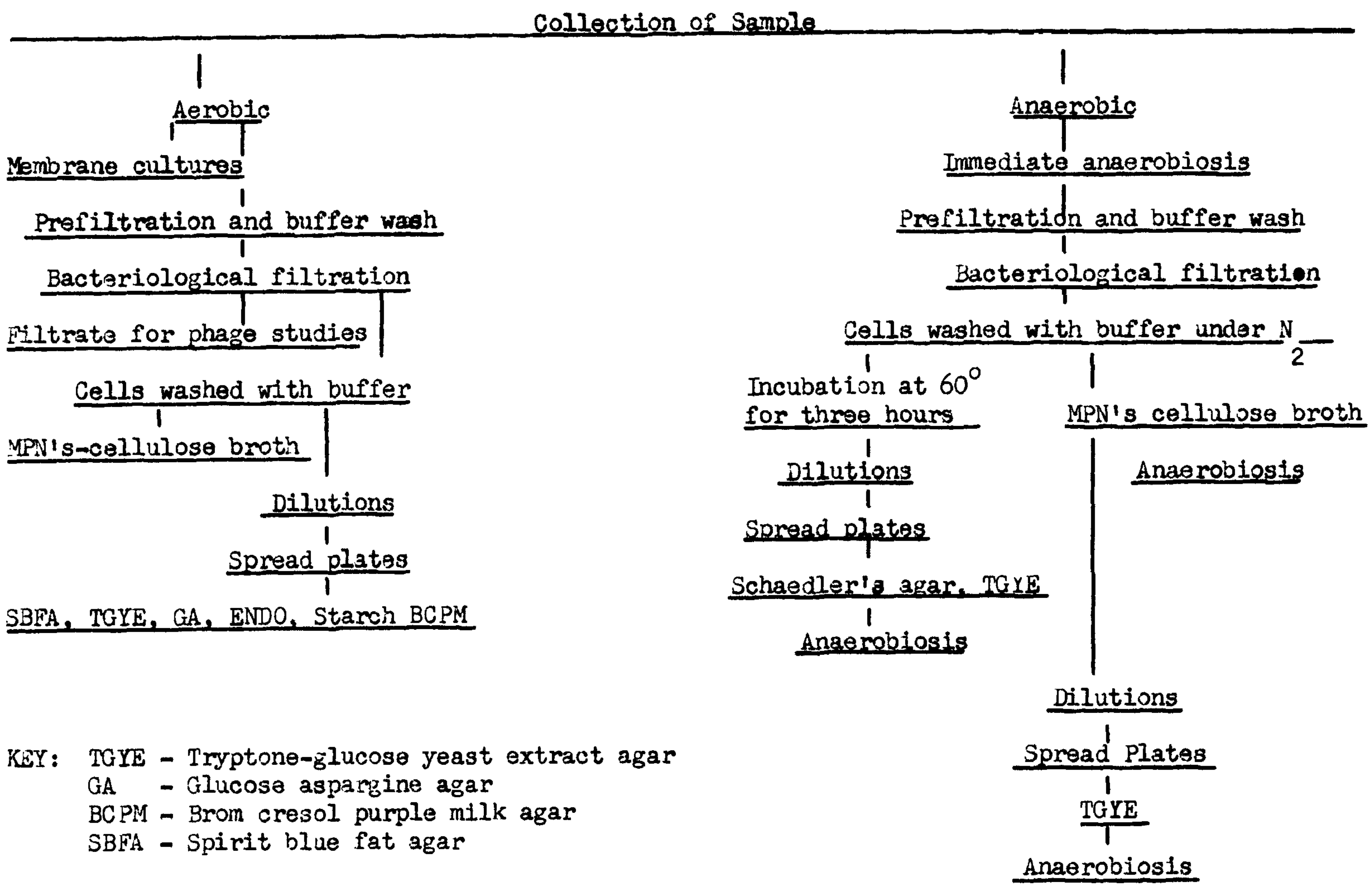
Enzymic activities of microorganisms were observed when cultured on specific differential media. Enumeration of bacteria with simple nutritional requirements was obtained on glucose-asparagine (GA) agar. The most probable number (MPN) method was used to detect cellulolytic bacteria in modified medium of Kadota (1956).

To isolate and enumerate clostridial types, washed samples were incubated at 60°C for three hours to kill vegetative forms. Spread plates were made on Schaedler's anaerobic agar (Schaedler, Dubos, and Costello, 1965) and TGYE. The plates were incubated anaerobically at 24°C for 48 hours.

A summary of the protocol for biological assay is shown in Figure 2.

To detect bacteriophage, septage samples were centrifuged at 5,000 rpm for 30 minutes. The supernatants were passed through a 0.22 uM membrane filter. The filtrates were assayed for phage activity using bacterial hosts recovered from septage. Hosts included Escherichia coli, Citrobacter freundii, Alcaligenes sp., Pseudomonas sp., Streptococcus fecalis, and Mima-Herellea-Achromobacter spp. In addition, laboratory strains of Salmonella typhimurium and Shigella flexneri were also tested. Aeration of cultures produced log phase cells in approximately three hours at 30°C in KC broth (Hutchison and Sinsheiner, 1966). To enchance the growth of Streptococcus fecalis and Citrobacter fruendii, 0.5 percent phytone was added to 3 ml of KC broth. Then, 0.1 ml of each host cell was transferred and the tubes were aerated for three to four hours to insure infection and lysis of the particular host. The intact cells were removed by centrifugation and the supernatants were drawn through 0.22 uM membrane filter. Concentrates were tested for bacteriophage using the spot plate method. Petri plates, containing KC bottom agar (Hutchison and Sinsheiner, 1966) were divided into twelve sectors. Then, 0.2 ml of each host was added to 4.8 ml of KC top agar (Hutchison and Sinsheiner, 1966). Overlays were made on KC agar plates to ensure an even bacterial lawn. After the surface agar had solidified, 0.02 ml of each enriched filtrate was added. The spots were permitted to dry and the plates were incubated at 30°C for 48 hours. The presence of clear zones indicate phage infection and lysis of host cells.

Morphological features of each bacteriophage were obtained with the electron microscope. To increase the titer of phage present in the original filtrate, 2 ml of host cells (1×10^6 cells/ml) and 3 ml of each filtrate were transferred to flasks containing 50 ml of KC broth. The cultures were aerated for three hours and the remaining bacteria removed by centrifugation and filtration. Then the phage titer was estimated from the filtrates using the double layer plaque counting method. The filtrates were concentrated by dialyzing overnight against ammonium carbonate (ionic strength, 0.006), after which they were centrifuged (Spinco, model L) at 93,000 G for six hours. The precipitate was reconstituted in 0.2 ml of dialyzate, placed on 200 mesh copper grids, and negatively stained with two percent phosphotungstic acid (PTA).



KEY: TGYE - Tryptone-glucose yeast extract agar
GA - Glucose aspargine agar
BCPM - Brom cresol purple milk agar
SBFA - Spirit blue fat agar

Figure 2. Protocol for biological sample assay.

Characterization of Isolates

Bacteria isolated from septage as previously described were subjected to various morphological and physiological tests as described in the Manual of Microbiological Methods (1957). The Gram reaction was performed on cells from an 18-hour TSA slant. Flagella stains were prepared according to Leifson's method (1960). Morpnological observations were made using bright field and phase contrast microscopy. Colonial and cultural characteristics were examined in Trypticase Soy Broth (TSB) and TSA. Beef Heart Infusion (Difco) slants served to enhance pigment production. Gram negative bacteria were initially characterized on Triple Sugar Iron (TSI) (Difco) slants. Hydrogen sulfide production was observed in Sulfide Indol Motility Agar (SIM) (Difco) stabs. The formation of nitrite from nitrate was visualized in nitrate broth by adding alpha-napthol amine and sulfanilic acid. Urease activity was detected in urea broth (Stuart, von Stratum and Rustigan, 1945). Cytochrome oxidase and phenyalanine deaminase were observed from the methods of Ewing and Johnson (1960). The method of Moeller (1955) was used to assay for lysine decarboxylation. Specific reagents were added to the media to detect indole production, pH changes, and production of acetyl methyl carbinol. Growth in Koser's citrate resulted from the utilization of citrate as a sole carbon source. Metabolic patterns were observed in OF basal medium (Difco) supplemented with 1.0 percent glucose (Hugh and Leifson, 1953). All cultures were incubated at 24°C $\pm$ 1, and examined after 24, 48, and 72 hours.

E. coli was enumerated and characterized using the Millipore method and elevated temperature (Geldreich, Clark, Huff, and Bert, 1965). Samples from septage and/or septic tank sewage were filtered through a 0.22 uM membrane. The membrane was then transferred to disposable petri dishes containing pads saturated with m-FC (Difco) broth. The dishes were covered, placed in plastic bags, and incubated in a water bath at 44.5°C $\pm$ 0.1.

The Millipore method was also used to enumerate and characterize fecal streptococci. Membranes were placed on m-Enterococcus agar (Difco) and incubated at 37° for 48 hours.

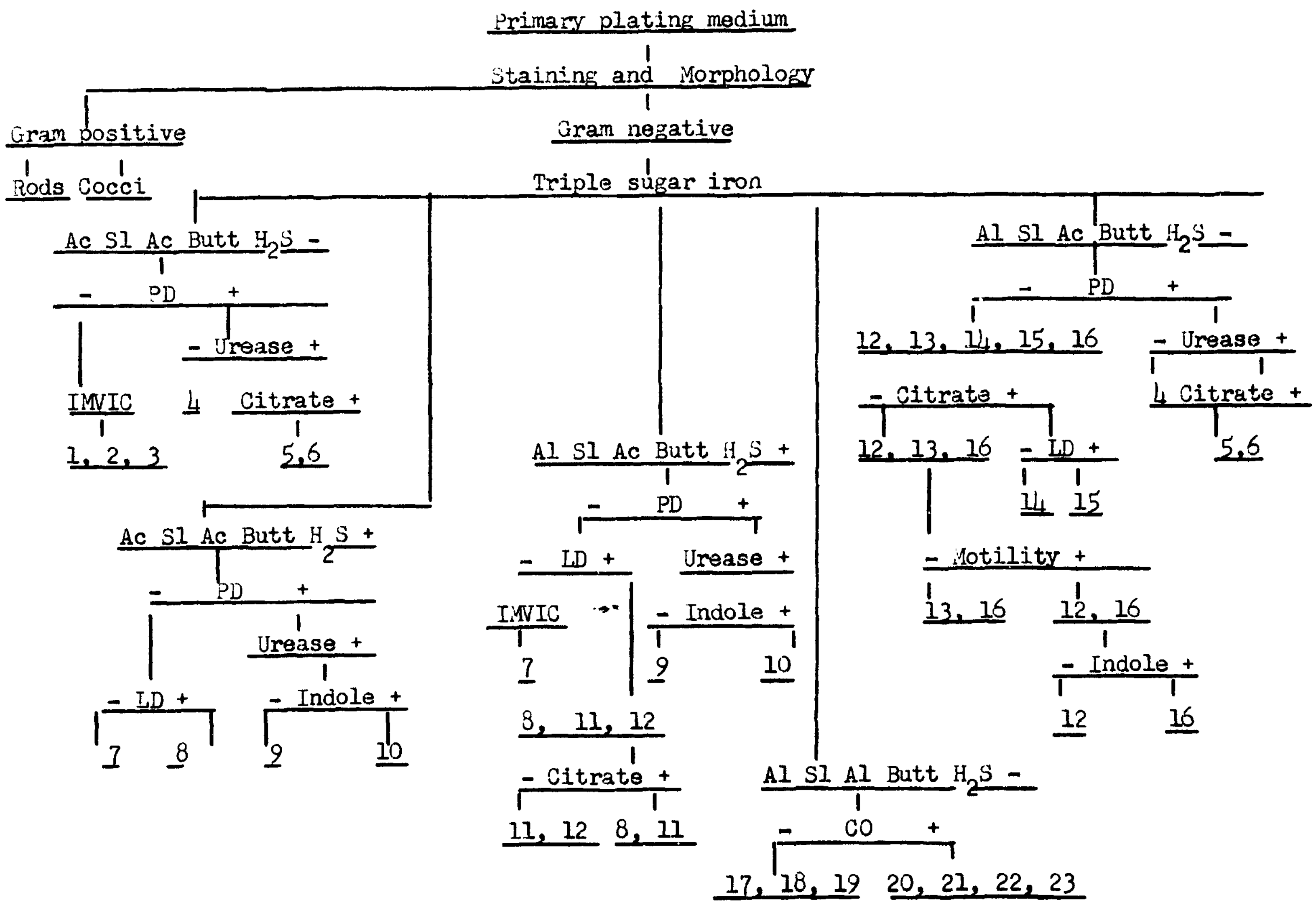
A scheme for characterizing bacterial isolates is shown in Figure 3.

Conventional anaerobic techniques were employed to establish anaerobic populations in septage and septic tank sewage. Attempts were made to isolate non-spore-forming as well as spore-forming types.

Methylene Blue Reduction Time

Selected redox indicators were used to estimate the biological activity in liquid waste. Methylene blue, resazurin, and indigo carmine were added to liquid wastes in concentrations sufficient to color the suspensions.

The following liquid wastes were tested: a) Septage from a recently pumped tank; b) Septic tank sewage from a normal operating tank; and c) Raw domestic sewage from a local treatment plant. After the indicators were



See Appendix F for identity key.

Figure 3. Characterization of bacteria isolated from septage and/or septic tank sewage.

added, the samples were shaken thoroughly and incubated at 25°C. Visual observations of color were made at 30-minute intervals.

Survival Time of *Salmonella typhimurium*

A study of the survival time of *Salmonella typhimurium* (Lt_2) in septage was made using Hektoen Enteric (HE) agar (King and Metzger, 1968) to select for *Salmonella*. In the preparation of the inoculum, the bacterium was cultured in a liter of TSB for 18 hours at 30°C. Approximately 7.0 x 10^8 cells/ml were suspended in 100 ml of phosphate buffer. These were introduced into an individual septic tank system via the household commode and mixed. Then, using a diaphragm pump, a sample was taken at zero and designated time intervals. Measured amounts of the diluted samples were filtered through 0.22 uM membrane filters. The filters were placed on HE agar plates and counted after 48 hours.

Microbiological Growth Chamber

An octagonal, plexiglass growth chamber, Figures 4 and 5, was constructed for the purpose of studying the microbial interactions of bacterial types recovered from septage and/or septic tank sewage. The experimental growth chamber, fitted with a cover containing sampling ports, consisted of eight compartments surrounded by a center well. The sides adjacent to the well were slotted and contained removable membrane filters to allow exchange of substrates and/or end products between the compartments.

Ethylene oxide was used as the sterilant. Preliminary experiments were performed to determine the time, temperature, and concentration necessary for sterilization. The apparatus was placed in a plastic bag containing 200 ml of liquid ethylene oxide (10 percent), and a swab saturated with *Bacillus cereus* spores served as a sterility check. The bag was gas-tight and placed in a 45°C incubator for six hours. Then it was aerated at room temperature for 18 hours, to remove the residual vapors.

LAND DISPOSAL

Preliminary Site

The first land disposal experiment was conducted on a 100 feet by 208 feet (30.5 meters by 63.4 meters) field site located in Litchfield County. The soil is a Paxton fine sandy loam type, as classified by a USDA Soil Conservation Service Soil and Capability Map. This field site was subdivided into two plots: 20 feet by 208 feet (6.1 meters by 63.4 meters) and 50 feet by 208 feet (15.8 meters by 63.4 meters), Figures 6 and 7. The 20 feet by 208 feet plot was used to follow the lateral distribution of microorganisms along the fracture line and the survival time of septage isolates. The 50 feet by 208 feet plot was used to evaluate the subsoil injection method and the effects on crop growth and soil water. Also on the 50 feet by 208 feet plot two tile drain lines were installed, 4-inch (10.2 centimeter) diameter and 50 feet (15.8 meters) long, with collection well pits.

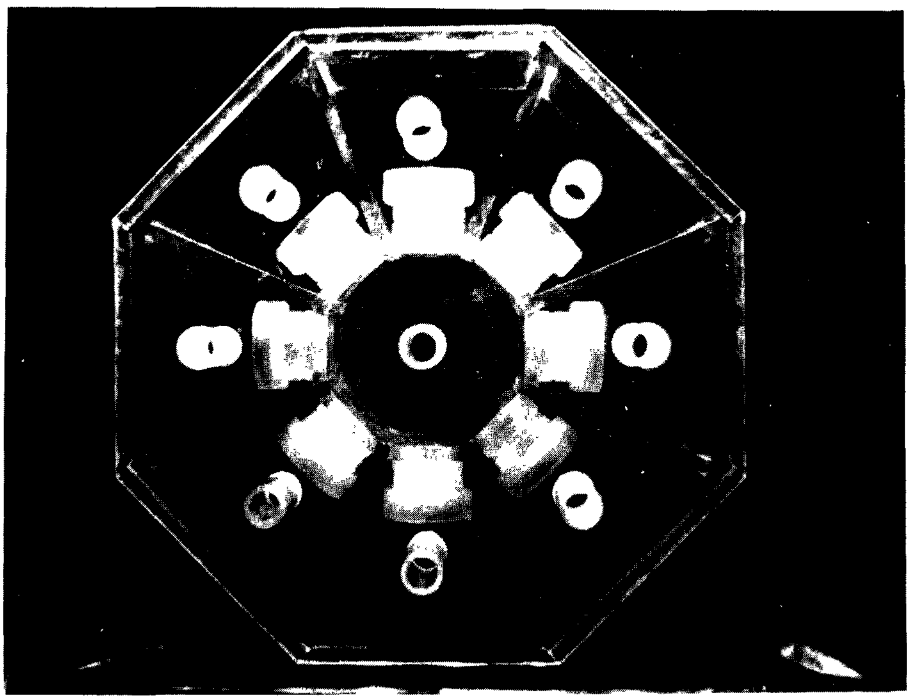


Figure 4. Growth chamber for study of microbial interactions: Top view.

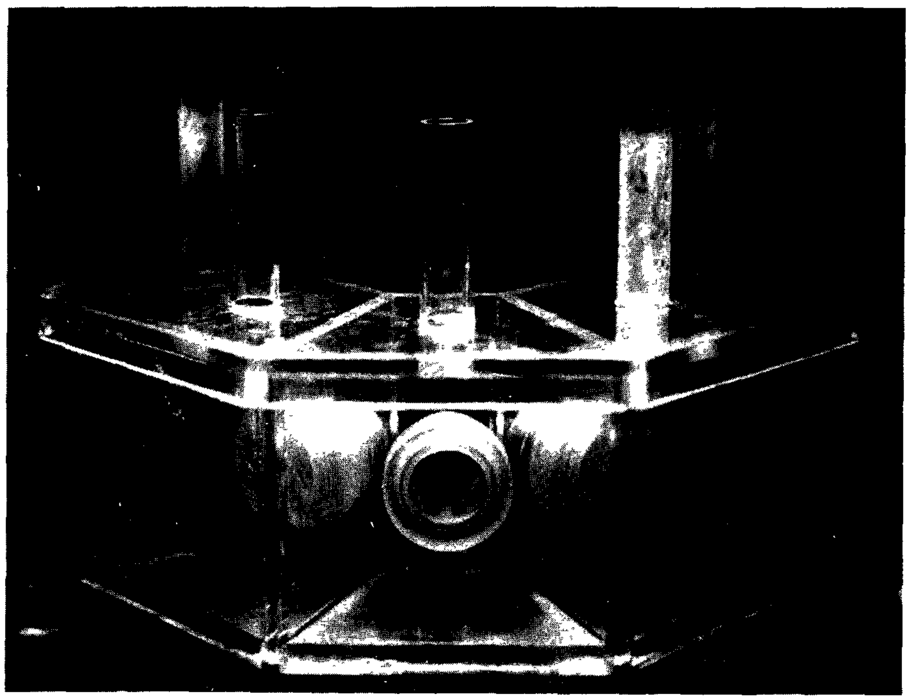
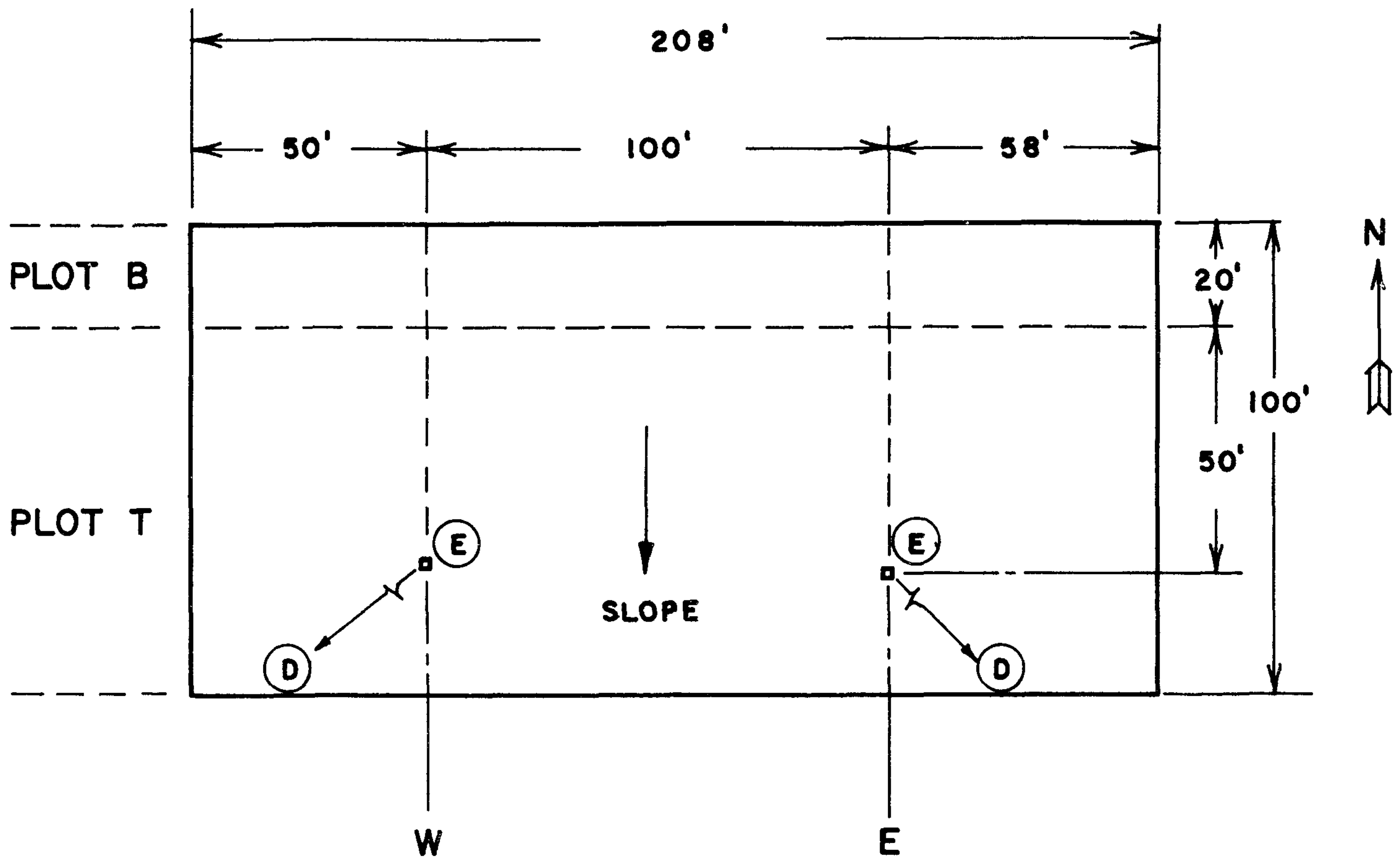


Figure 5. Growth chamber for study of microbial interactions: Side view.



Plot B - Microbiological Studies
Plot T - Terreator Studies
Point E - Sample Collection Well

----- W Tile drainage lines
----- E

Point D - Collection well excess water discharge to surface elevation; approximate distances: 125 ft (E-D) for Line W and 111 ft (E-D) for Line E

For meters, multiply feet by 0.305.

Figure 6. Land disposal field plot preliminary studies.

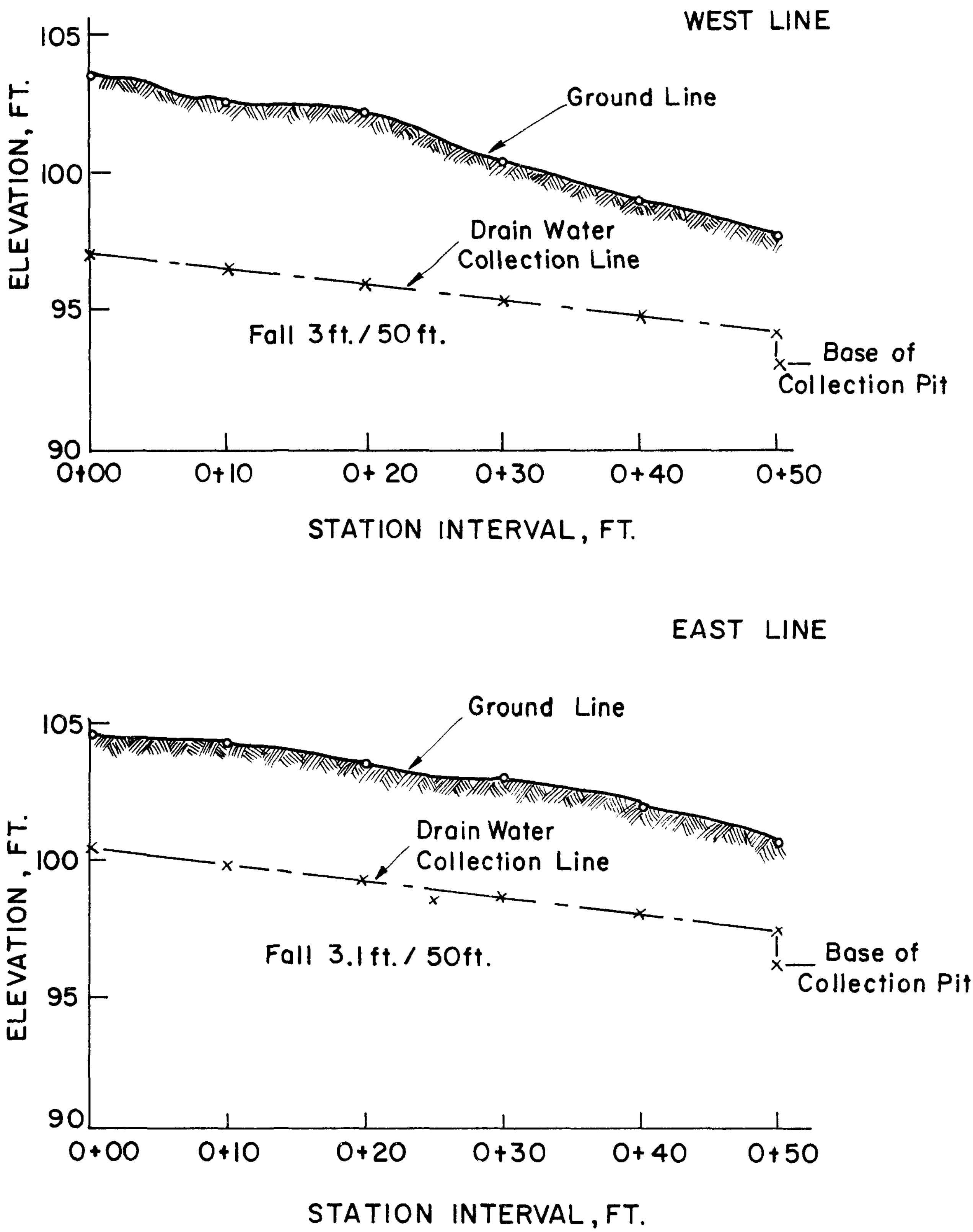


Figure 7. Profile of tile drain line and collection pit.

For septage application, a tank truck was driven alongside the tractor, and Terreator. The septage was discharged by gravity from the tank truck through a 3-inch (7.6 centimeter) diameter hose connected to a 4-1/4 inch (10.8 centimeter) diameter curved tube attached to the Terreator. The Terreator is described on pages 31 and 32.

Before septage application, representative soil samples were examined for microbiological types and contents.

After deposition of septage into the trench line, samples were collected by coring after 24, 48, 72, and 144 hours. Figure 8 shows the collection points. Soil samples collected were placed in sterile glass stoppered bottles. One gram of soil sample was placed in 99 ml of sterile water and subsequent dilutions were plated on TGYE. The plates were incubated at 28°C and counted after 24 hours.

Selective media, previously described, were employed to determine numbers of Escherichia coli and Streptococcus fecalis in treated soil and to follow the survival of coliforms and enterococci in the soil. In addition, microbial profiles indicated the time involved to restore the soil to normal conditions.

Experimental Site

The pilot study experimental site, Figure 9, was a 5-acre (2 hectares) parcel of land owned by the White Memorial Foundation, Inc. (WMF) in Litchfield, Connecticut. This site was an abandoned field that had been used by farmers for cutting hay. It was a cleared area surrounded by woods located approximately one-third of a mile from a normally travelled road.

The soil where septage was injected is classified by the USDA Soil Conservation Service (SCS) as a Woodbridge fine sandy loam. This soil is described in the SOIL SURVEY (Gonick et al., 1970) as being moderately well-drained, underlain by a compact layer, or pan, at a depth of about 24 inches. Soil samples also were taken at various depths during the drilling of the observation wells. The soil profile was determined down to bedrock.

The experimental site had two separate areas. These areas will be referred to as the receiving or unloading area and the disposal site (the field where septage was injected). The disposal site, Figure 9, was divided into three areas. One area was used for the plow-furrow cover disposal method. Another area was used to study the subsoil injection disposal technique. A third area was reserved for special applications, such as demonstrations for interested individuals or groups.

Receiving Area

The receiving area was approximately two acres (0.8 hectares) in size. On the site was a storage (receiving) tank for septage; a turn-around area for the pumper trucks; a loading area for the tractor-septage trailer unit; a miscellaneous area for general vehicle parking, tank storage and equipment;

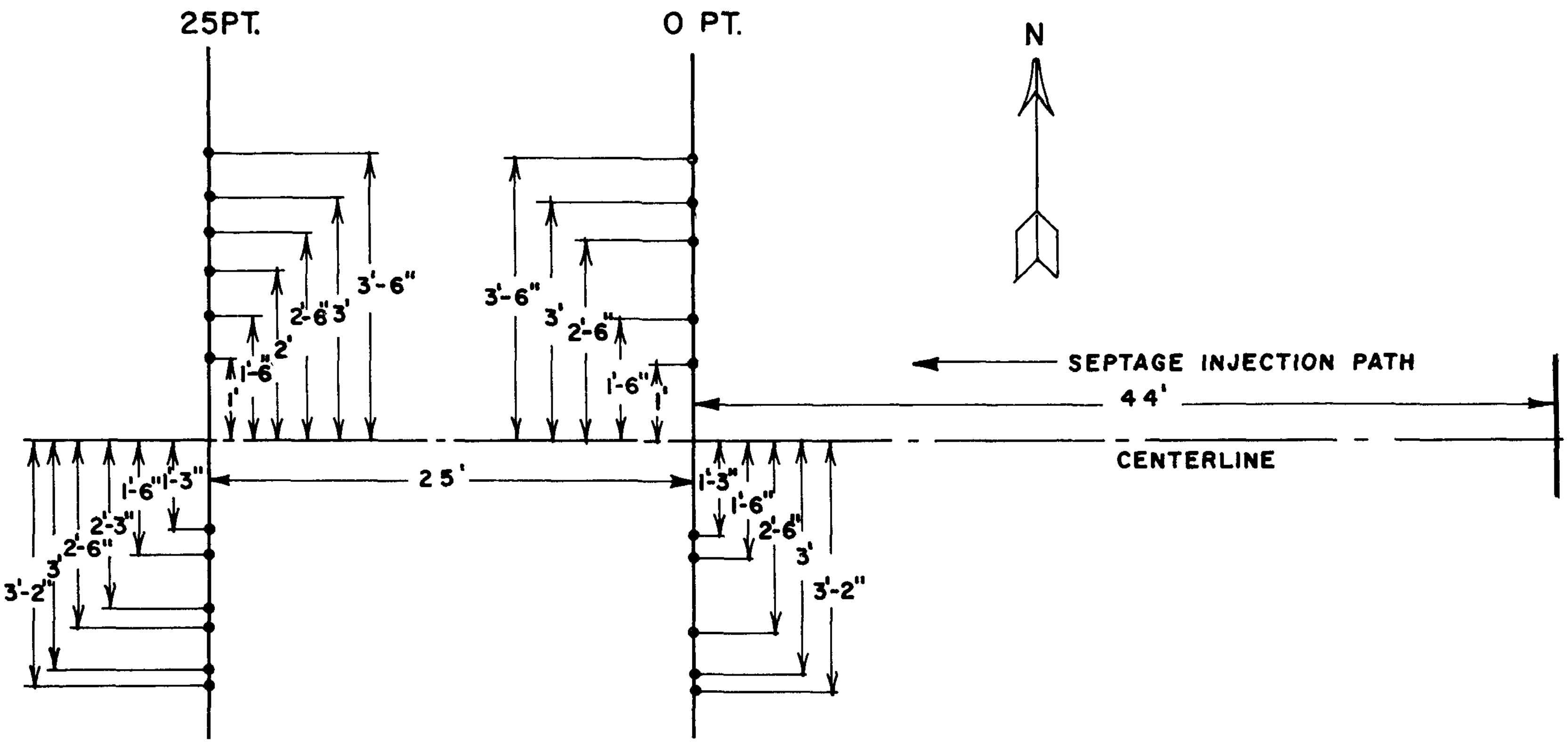


Figure 8. Plan view of sampling area for septage microorganism study.

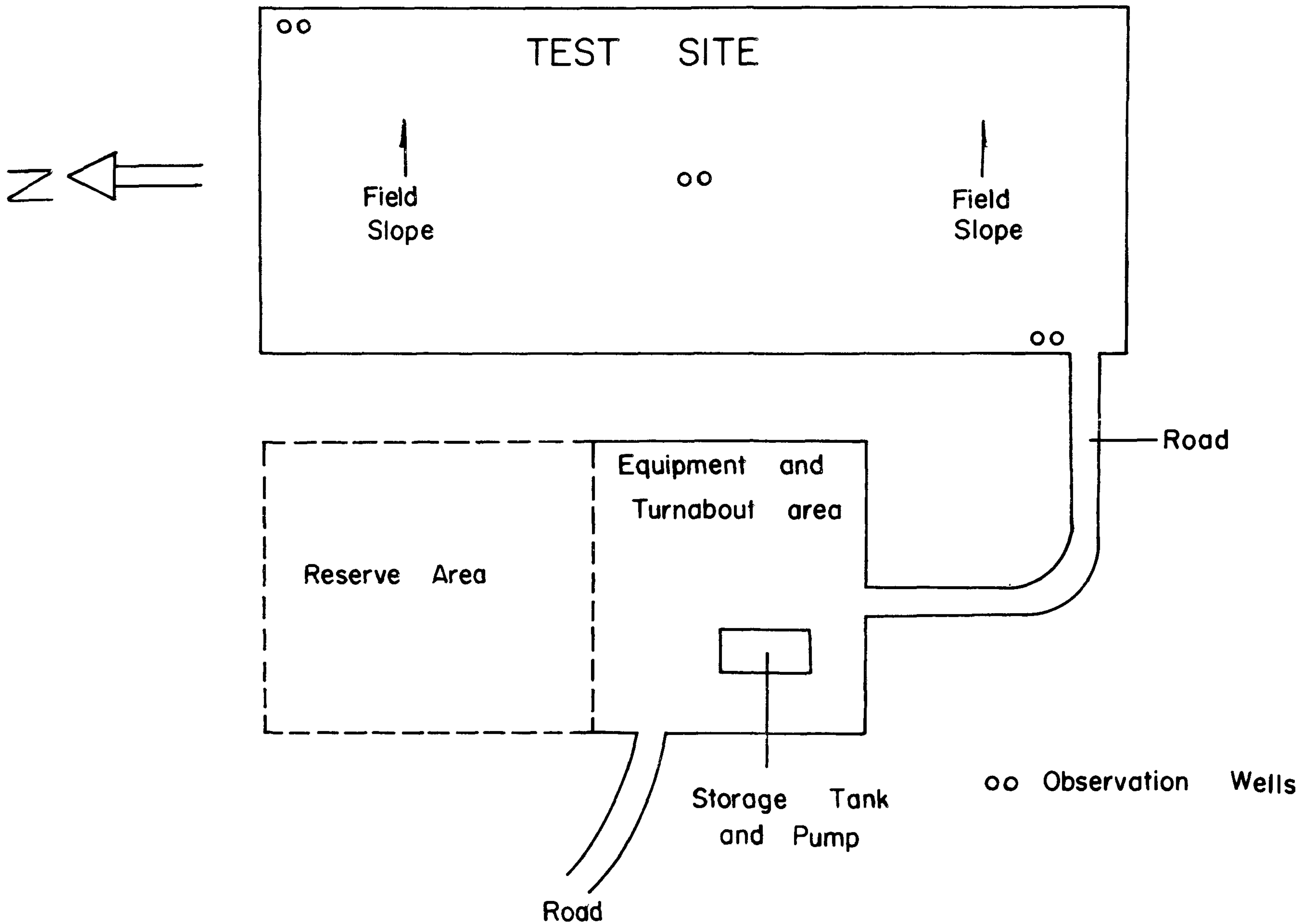


Figure 9. Experimental site layout for study of sub-soil disposal of septage.

and septage subsoil injection machinery. Fuel supplies, tools, and miscellaneous items needed for daily operation were stored nearby in a plywood box.

A 10,000 gallon (37,850 liters), steel reinforced, precast concrete tank (A. Rotondo and Sons, Inc., Avon, Connecticut) 8' (2.4m) by 8' (2.4m) by 34' (10.4m) was used to receive and hold septage, Figure 10. The liquid depth in the tank was 7 feet (2.1 meters). The tank was set on a 6-inch (15 centimeter) compacted gravel bed and projected approximately two feet above the ground. The tank was made watertight after it was installed to insure against ground water contamination.

Septage discharge into the storage tank was by gravity. Water for clean-up was available from a 1,000 gallon (3,785 liter) storage tank mounted on a 4-wheel trailer. A record of septage loads brought to the site was maintained.

A tractor power take-off driven liquid manure pump (International Harvester No. 1150) was used to mix the septage prior to loading the septage hauling tank-trailer. A small stationary tractor was used to drive the pump. The liquid manure pump manufacturer's discharge rating was 500-700 gpm (35-40 liters/sec).

<u>Septage Field Application Area</u>

The maximum amount of septage to be applied by the subsoil disposal method was determined by the septage nitrogen content. A maximum of 300 pounds of nitrogen per acre in one year was selected as the limiting factor. This nitrogen loading limit was based upon:

(1) Agricultural field practices presently used.

(2) Research studies (Wengel and Kolega, 1970) on the effects of high poultry manure application rates on soil water.

(3) A preliminary investigation of subsurface application of septage to a 50 feet by 208 feet (15.8 meters by 63.4 meters) experimental site having a subsurface drainage system. Analysis of a limited number of drain water samples showed no noticeable effect on the soil water after approximately 10,000 gallons (37,850 liters) was injected.

Appendix D illustrates a sample calculation for estimating the size of a land plot needed for septage disposal based on an estimated nitrogen content. The nitrogen concentrations assumed for the septage were 92 mg/l for ammonia-nitrogen and 37 mg/l for organic nitrogen. In this study only 25% of the septage samples analyzed exceeded these assumed nitrogen levels. Thus, this theoretical calculation approach estimates that up to 279,000 gallons (1,053,000 liters) of septage could be applied per acre in one year under conventional cropping practices and without detrimental effect on ground water quality.

Figure 10. Receiving station for land disposal of septage.

Three pairs of six-inch (15.2 centimeter) diameter observation wells were installed on the diagonal of the rectangular field. These wells were used to monitor the effects on ground water quality after septage applications. One of each pair of wells went into bedrock at a depth of about 10 feet (3 meters). The other well was left in the soil water or aeration zone. The wells were capped. Water samples were collected by means of a hand-operated diaphragm pump (Dart Union Co., Providence, Rhode Island). Water samples were analyzed for chloride, COD, nitrate, pH, phosphate, and for the presence of fecal coliforms.

Land Disposal Equipment

Septage was transferred to an 800 gallon capacity tank-trailer pulled by a Ford 4000 tractor. The material was then transported to the field site and injected into the soil. The tank-trailer design was based upon the earlier studies of Reed (1969). The tank-trailer was a multi-purpose unit designed so that septage, dairy or poultry manure, or sewage sludge could be handled in field application. The design of the equipment involved interstate cooperation with Rutgers University (The State University of New Jersey), and assistance from Waymark, Inc. (Cortland, New York), the manufacturer of the prototype tank-trailer. This concept centered around the fabrication of a basic tank unit which could be adapted to the final intended use, i.e., a septage trailer unit would not necessarily require an auger type agitator. The tank-trailer unit is shown in Figure 11.

Tank-Trailer

The tank hauler was rectangular with straight sides that tapered into a U-shaped bottom. Overall tank dimensions were 10' (3m) long by 5' (1.5m) wide by 3-1/2' (1.1m) deep. Corten steel was used in the tank fabrication, with No. 12 gage steel used for the sides and No. 10 gage steel for the bottom. For filling purposes there was a 30" (76cm) by 30" (76cm) hinged manhole cap in the tank cover.

The tank was mounted on a two-wheel trailer chassis having 17" (43 cm) by 20" (51cm) flotation tires. The trailer chassis was adjustable to permit changing trailer wheels to an offset position. The gooseneck tongue was an integral part of the tank-trailer and provided ease of tractor maneuverability when it was used with subsoil injection equipment. A trailer braking system was included.

Slurry agitation and heavy slurry unloading were aided by a nine-inch (23 cm) diameter auger in the U-shaped trough. The auger was driven by a hydraulic motor at a speed not to exceed 250 rpm. A hydraulic motor, 10 brake horsepower in size, was mounted on the front end of the tractor and it was also used to operate a 12-inch (30.5cm) stainless steel knife gate valve for septage discharge control. The position of the gate valve could be regulated by a hydraulic piston to control the flow rate of the septage discharge. An additional hydraulic oil reservoir tank (Gresen Mfg. Co., Minneapolis, Minnesota) was mounted near the seat of the tractor operator. Hydraulic pump hoses, necessary fittings, and a flow control valve, mounted on the gooseneck frame of the trailer, completed the hydraulic system.

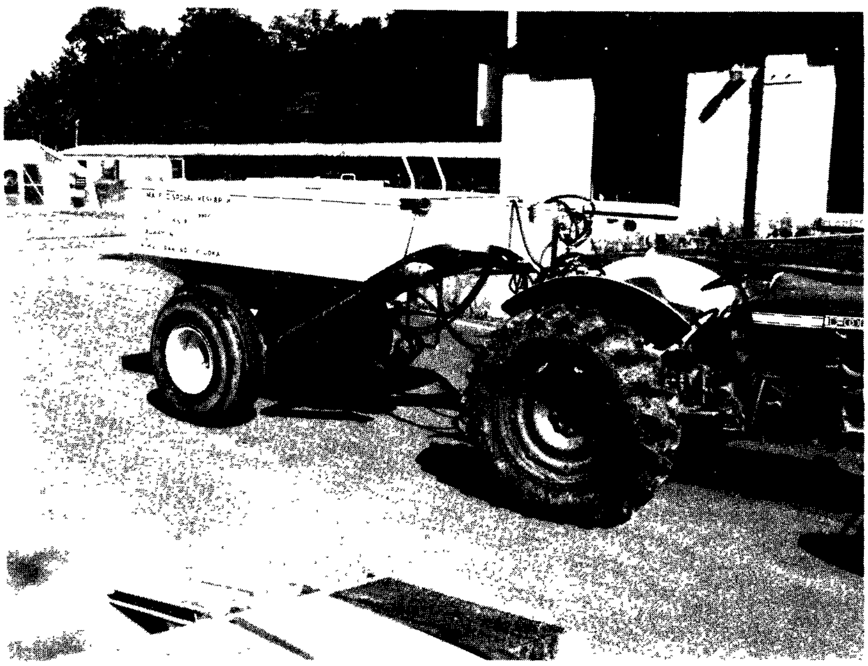


Figure 11. Experimental tank-trailer.

Septage Application Equipment

Two basic septage application methods were tested: (1) Plow-Furrow Cover (P-F-C), and (2) Subsoil Injector (S-S-I). Two subsoil injection units were used: (1) subsoil and (2) Terreator. All subsoil injection units had a standard three point hitch for attachment to a tractor. The P-F-C and S-S-I techniques were those developed for liquid manure disposal (Reed, 1970).

The Terreator (U.S. Patent No. 2,694,354), Figure 12, was a subsoil injection device developed by Mr. T. Roberg of Litchfield, Connecticut. This unit could be either hydraulically or power-take-off driven from the tractor. A 3-3/4 inch (9.5 centimeters) diameter mole-type hole was made by an oscillating chisel point device. Attached to the Terreator was a 4-1/2 inch (11.4 centimeters) diameter curved tube attachment for receiving the septage and its injection into the soil. Injection with the Terreator was to a depth of twenty inches (50.8 centimeters) at a discharge rate of about two gallons per linear foot (24.8 liters/linear meter) of travel. Terreator application passes were spaced 5 feet (1.5 meters) apart to give an overall application rate of 17,424 gallons per acre (163,000 liters/hectare) during the study.

The P-F-C technique involved the use of a 16-inch (40.6 centimeters) single bottom moldboard plow, a furrow wheel, and a 16-inch coulter (40.6 centimeters). Septage was applied in a six to eight inch (15.2 to 20.3 cm) deep plowed furrow and immediately covered with soil, and at the same time opening another furrow for the next septage application. The septage application rate was approximately one gallon per linear foot (12.4 liters/linear meter) of travel. For one acre, the equivalent volume of septage applied was 32,700 gallons (306,000 liters/hectare).

The subsoil method, Figure 13, consisted of two plows assembled together to provide a 24-inch (61 centimeters) wide opening for injection of septage six to eight inches (15.2 to 20.3 centimeters) beneath the sod surface. It had a Category II three-point hitch (American Society of Agricultural Engineers Yearbook, 1971). The septage application rate was approximately two gallons per linear foot (24.8 liters/linear meter) of travel. For one acre, the equivalent volume of septage applied was 43,560 gallons (407,500 liters/hectare).

The tank-trailer was designed so that septage discharge was either from the side of the tank for P-F-C soil injection, or from the bottom front center of the tank when used with the S-S-I or Terreator techniques. The size of the tank discharge opening was six inches (15.2 centimeters). An adapter was provided for reducing the discharge opening to four inches (10.2 centimeters). The septage flowed by gravity into a 4 or 6 inch (10.2 or 15.2 cm) flexible hose and then into the furrow or subsoil injection apparatus. A quick coupling attachment (Andrews Industries, Inc., Dayton, New Jersey) was used to connect the flexible hose at the trailer discharge point. The hose material used was corrugated plastic pipe for the four-inch (10.2 centimeters) application, and a corrugated neoprene hose with reinforcing coil for the six-inch (15.2 cm) application.

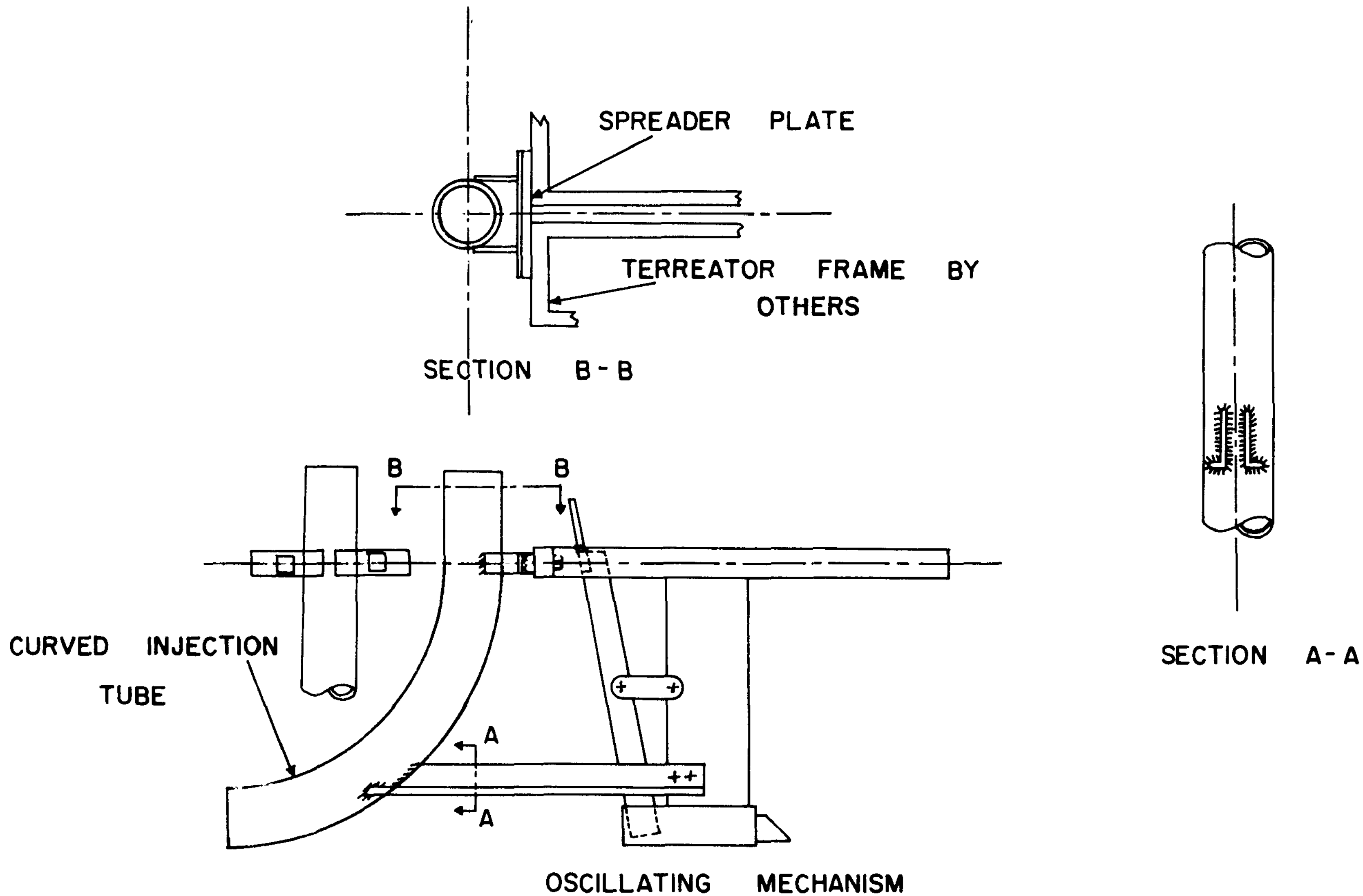


Figure 12. Terreator (U.S. Patent No. 2,694,354) for sub-soil injection.

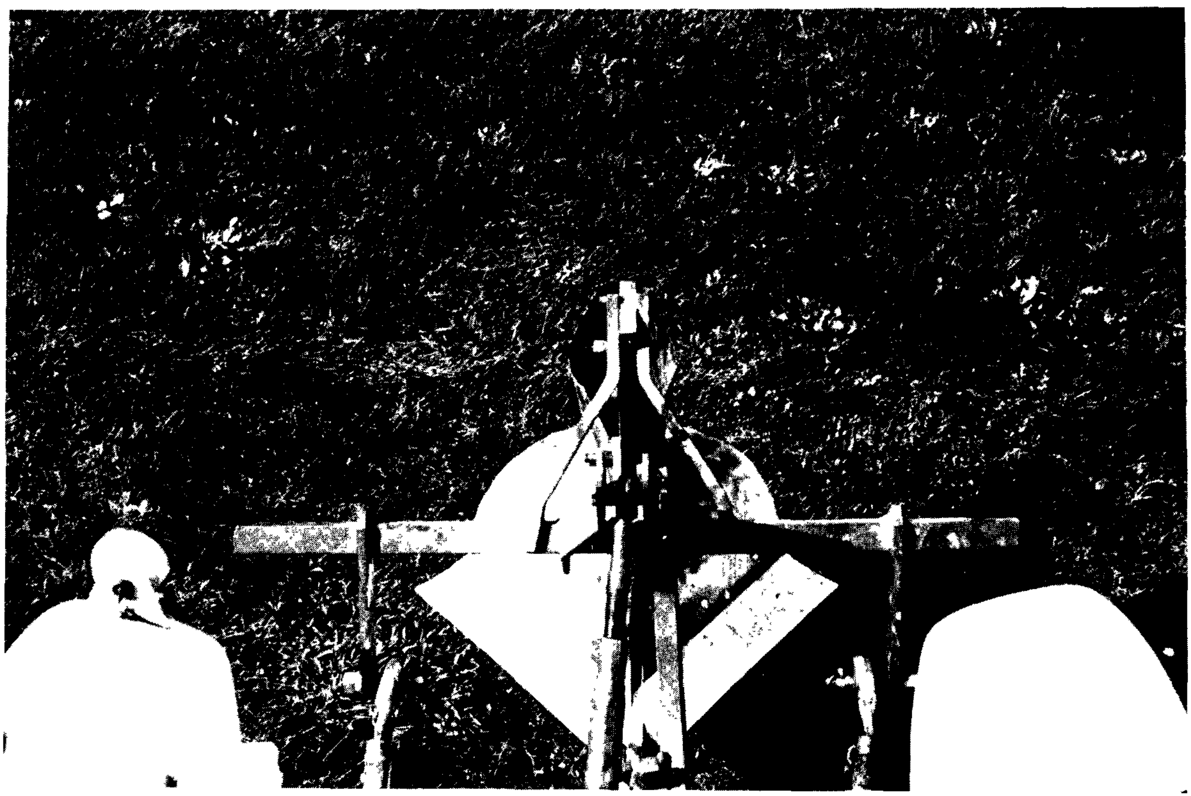


Figure 13. Top view of sub-sod injector (Rutgers University).

SPECIALIZED TREATMENT PROCESSES: ANAEROBIC-AEROBIC

The anaerobic-aerobic series processes were selected for study to treat septage. Factors influencing this selection were the

(1) wide variability possible among septage loads.

(2) frequency at which trucked septage loads are received.

(3) quantities of septage being pumped in different areas.

(4) process controls required for system operation and maintenance.

(5) costs relative to alternate treatment processes.

It was hypothesized that solids degradation could be achieved in the anaerobic stage followed by the degradation of soluble organics in the aerobic stage. Sand filtration was added as a final treatment step to insure acceptable effluent for discharge into a stream. Another purpose for the anaerobic stage was to improve process control for the aerobic treatment step by reducing the effects of both shock loading and variability of the septage properties.

High rate digestion was used for anaerobic treatment. A retention time of 15 days was selected for the laboratory bench scale study. A retention time of 10 days (Rich, L.G., 1963) was selected for the pilot plant study. Digestion temperature was maintained at the mesophilic optimum of 90°F to 100°F (32.2°C to 37.8°C). In contrast to the usual practice, the digester contents were not agitated.

The design of the aerobic stage was based upon the BOD_5 to be removed which is expressed by the following steady state material balance equation: (Influent BOD_5, lbs/day) - (Effluent BOD_5, lbs/day) = BOD_5 removed, lbs/day when evaporation and leakage are negligible, equation may be written as:

$$C_iQ - C_eQ = K_1V \qquad (1)$$

Where: C_i = Influent BOD_5 concentration, mg/l

C_e = Effluent BOD_5 concentration, mg/l

Q = Septage flow rate per day, gallons/day

V = Aeration tank volume, gallons

K_1 = BOD_5 removal rate, mg/l (day)

BOD_5 removal is considered to be a first order reaction. The BOD_5 removal rate (K_1) is proportional to the effluent BOD concentration. Assuming complete mixing, the concentration of BOD_5 throughout the aerated tank is equal to the effluent concentration, C:

$$\frac{dC}{dt} = K_e C \qquad (2)$$

Where: $\frac{dC}{dt}$ = the time rate of change in BOD concentration at any time, t

K_e = BOD_5 removal rate constant, day^{-1}

When the system comes to equilibrium, the BOD_5 removal rate, K_1 is equal to $K_e C_e$. Substituting equation $K_e C_e$ in (1) and letting t = V/Q, the equation becomes:

$$\frac{C_i - C_2}{C_2} = K_e t \qquad (3)$$

$$\frac{C_2}{C_i} = \frac{1}{1 + K_e t} \qquad (4)$$

Where: $\frac{C_2}{C_i}$ is the fraction of BOD_5 remaining

The percent BOD_5 removed is

$$R = 100 - \frac{100}{1 + K_e t} \qquad (5)$$

The detention time t, in days, can also be expressed as:

$$t = \frac{R}{(100 - R)\, K_e} \qquad (6)$$

By knowing the percent BOD_5 removal required, the value of K_e which can be measured experimentally, fixes the detention time. In this study, a K_e value of 0.5 was chosen for the anaerobic digester supernatant. Using 95 percent BOD_5 removal as criteria, the aerobic theoretical detention is 38 days.

The anaerobic-aerobic effluent was sand filtered prior to discharge.

The septage treatment evaluation consisted of

(1) a five-month laboratory bench scale study.

(2) a six-month pilot plant study.

Laboratory Bench Scale Unit

A schematic of the laboratory bench scale unit is shown in Figure 14. The anaerobic digestion tank was located in a controlled environment room. Temperature was maintained at 90°F (32.2°C) using thermostatically controlled

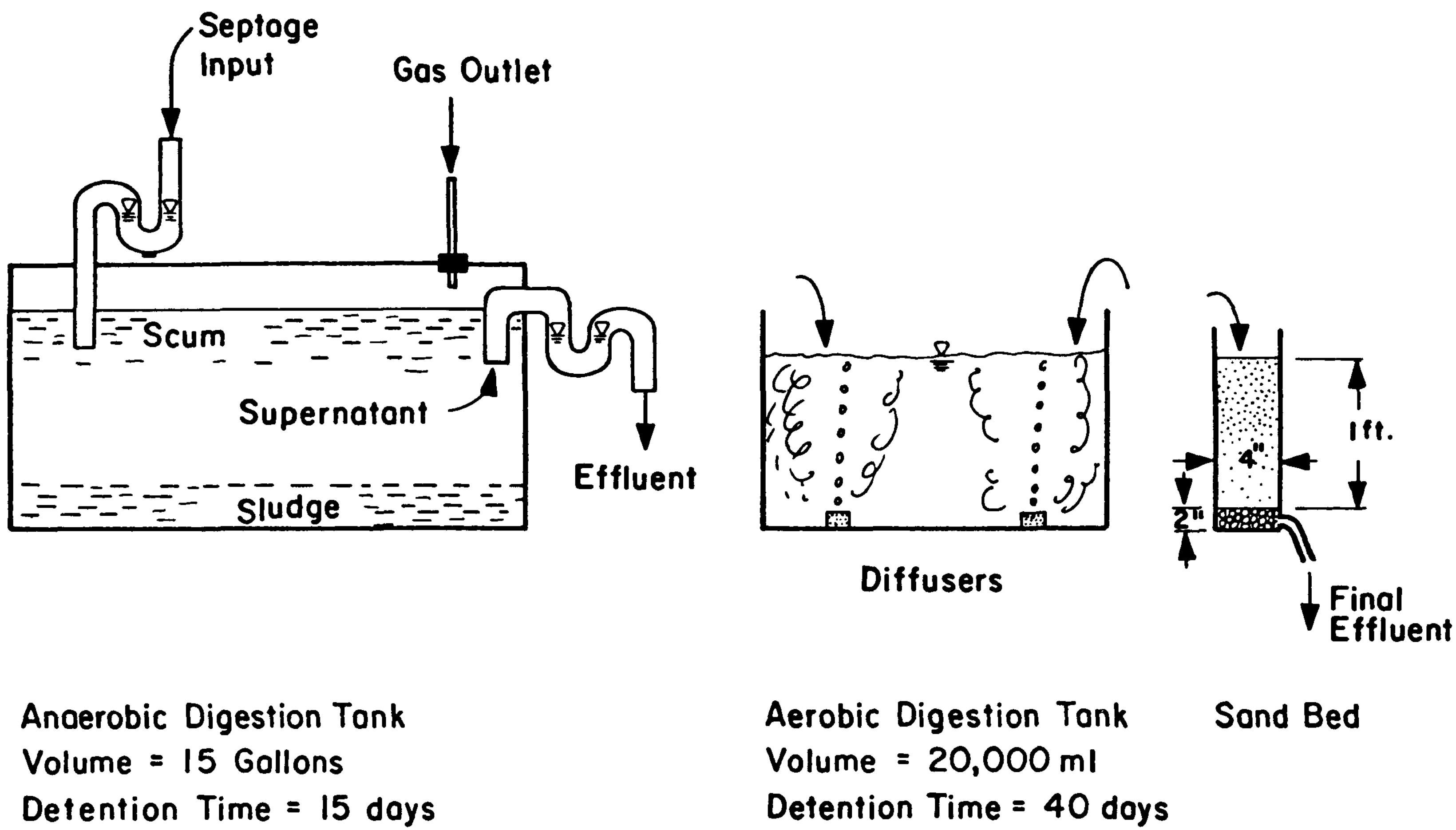


Figure 14. Bench scale anaerobic-aerobic unit for treatment of septage.

electric space heaters. The aerobic treatment tank was operated at ambient laboratory room temperature. Air was supplied to the aerobic digestion tank through two stone diffusers for aeration and mixing. Septage loads were obtained from the East Hartford, Connecticut Water Pollution Control Facility.

Samples, 500 ml each, were taken weekly to evaluate the effectiveness of the anaerobic-aerobic-sand filtration series processes for treating septage. The sample points were: (1) anaerobic digester supernatant (feed to the aerobic tank), (2) aeration tank mixed liquor two hours after the addition of the anaerobic digester supernatant and (3) sand filter effluent. On the first day of each operational week a 900 ml sample was removed from the aeration tank. Five hundred milliliters was used for laboratory analysis. The remaining 400 ml was passed through the sand filter. For the period Tuesday through Friday, 500 ml of anaerobic digester supernatant was added daily to the aeration tank and 400 ml was removed to make up the Monday aeration tank volume loss. Aluminum foil was placed over the aeration chamber to minimize evaporation losses.

The sand filter was checked periodically for clogging. If signs of clogging were evident, the upper one-inch layer was stirred.

The excess anaerobic effluent, one gallon (3.785 liters) collected versus 500 ml added to the aeration tank was discarded.

The following analyses were conducted on the samples collected: total solids, volatile solids, COD, BOD_5, nitrate-nitrogen, ammonia-nitrogen, organic nitrogen, fecal coliform, total phosphate, total suspended solids, pH, and D.O. Tests for nitrogen components, COD and BOD_5 were begun after collection of the samples. Other physical and chemical tests were completed as soon as possible. Samples were refrigerated when tests could not be completed the day samples were taken.

PILOT PLANT

The anaerobic-aerobic process components were housed in a 20-foot (6.1 meters) metal frame building. The pilot plant components were

(1) two 1,000 gallon (3,785 liters) holding tanks.

(2) for the anaerobic digester, a steel circular tank housed in a controlled environment room.

(3) an above ground plywood (American Plywood Association, 1970) oxidation ditch for aerobic biological treatment.

(4) a 4-foot (1.2 meters) by 3-1/2 foot (1.1 meters) sand filter to polish the effluent from the aerobic ditch.

For receiving and storage of septage, two buried tanks were located outside the metal frame building. One tank used was a conventional concrete septic tank. The other tank was made of steel. Both tanks had special openings for admitting septage. The normal inlet and outlet openings were plugged to prevent loss of septage or entry of ground water. Septage used in the pilot study came from the Manchester, Connecticut region.

A manually operated diaphragm pump (Dart Union Company, Providence, Rhode Island) was used to pump septage in 100 gallon (378 liters) quantities from the storage tank into the heated anaerobic digestion tank. This circular digestion tank had base supports to prevent its movement. Approximate tank dimensions were: diameter - 5 feet (1.5 meters) and length - 8 feet (2.4 meters). On top of the tank and at each end were two 18-inch (45.7 centimeters) access openings with gasket bolted plywood cover plates. Room temperature was maintained at 95-100°F (35 to 37.8°C) using thermostatically controlled electric space heaters. A 2-inch (5 centimeters) diameter flexible plastic tubing was used on the suction and discharge side of the diaphragm pump. Effluent discharge from the heated digester was by gravity through a 4-inch (10.2 centimeters) diameter clear plastic pipe into the oxidation ditch. Semi-circular steel baffles were located on both the inlet and outlet ends of the heated digester.

The oxidation ditch dimensions were: length - 23 feet (7 meters); overall width - 6 feet 6 inches (2 meters); depth - 3 feet 10 inches (1.2 meters). Sizing of the oxidation ditch was based on an installation used for a poultry waste treatment study (Loehr, R.C., et al., 1971) and the size of plywood sheets available. Having two ditches, one from the referenced study and the other from this study, similar in size, enabled comparisons to be made of oxidation ditch performance for treating two types of biodegradable wastes - poultry and septage. The inside of the ditch was lined with fiberglass. In the fabrication of the plywood ditch, a silastic type adhesive was used in conjunction with conventional wood fasteners. A liquid depth of 27-1/2 inches (69.9 centimeters) was maintained in the ditch during system operation.

A horizontally mounted paddle type surface aerator (Thrive Centers, Inc., Monmouth, Illinois) was used to oxygenate the liquid in the oxidation ditch. The paddle aerator rotor diameter was 27-1/2 inches (69.9 centimeters) and its length was 34-1/2 inches (87.6 centimeters). A single phase, 2 hp motor drove the rotor aerator at a speed of 100 rpm through a speed gear reducer and belt driven pulleys. The rotor aerator paddle blades were rectangular in shape measuring 2-1/2 inches (6.4 centimeters) by 6 inches (15.2 centimeters). The paddle blade was immersed to a depth of 3-1/7 inches (7.9 centimeters).

Prior to starting the experiment, the anaerobic-aerobic process system components were tested using water. After satisfactory system performance was demonstrated, septage was introduced into the system at a rate of 100 gallons (378 liters) per day. The data presented in this study started with the time period after all of the calculated water volume in the system had been displaced with an equivalent volume of one septage throughout.

Septage was fed into the system, each afternoon, daily Monday through Friday. This subjected the anaerobic-aerobic process to shock loading.

Each morning, Monday through Friday, a general inspection was made of the anaerobic-aerobic process system components. Measurements were made of the dissolved oxygen, pH and temperature of the mixed liquor in the oxidation ditch. Each Thursday approximately 1000 ml of a mixed liquor sample was taken from the oxidation ditch for suspended solids analyses. The remainder of the sample, 400 ml, was sand filtered with the same unit used in the laboratory bench scale study. Also on a weekly basis, the solids volume index (SVI) of the mixed liquor was measured using a 1,000 ml graduated cylinder. Thereafter, the rotor aerator was shut down for one hour to settle the mixed liquor. The liquid portion was pumped (T-6 Series Sigmamotor pump manufactured by the Sigmamotor Pump, Inc., Middleport, New York) into the University sewer line or sand filtered (pilot unit). The sand filter effluent was discharged into a subsurface drainage system. Provisions were also made for chlorination of the effluent. The factor which determined the amount pumped from the oxidation ditch was the liquid depth. The liquid depth was maintained at 27-1/2 inches (69.9 centimeters).

While the rotor aerator was shut down, the temperature in the digestion tank room was measured. Also, routine equipment maintenance was performed.

Samples were collected weekly on Wednesdays from four locations in the pilot plant:

(1) feed to the anaerobic digester.

(2) influent (anaerobic digester supernatant to the oxidation ditch).

(3) grab sample from the oxidation ditch at the corner where liquid movement was toward the rotor aerator.

(4) sand filter effluent.

The septage feed to the digester and the supernatant from the digester were taken in the afternoon and at the beginning of the pumping sequence. The oxidation ditch grab sample was taken in the morning after restarting the aeration process. The wastewater analyses were the same as those described under the bench scale unit test procedure.

SECTION 5

EXPERIMENTAL DATA AND RESULTS

CHEMICAL AND PHYSICAL OBSERVATIONS

The septage pH ranged from 4.8 to 10.5, though most pH measurements are below 7.0. The septage color varied from greyish-green, greyish-black, greenish-black, brown-black to black. Its odor was at least equivalent to sewage. Occasionally, the septage odor was nauseating.

Analyses of the liquid fractions (supernatant, after one hour settling in a Imhoff cone) and the entire septage samples are shown in Table 1. Before conducting analyses, the septage samples were mixed in a Waring blender. The volatile total solids, volatile fixed and volatile suspended solids analyses were made by igniting the samples at 600°C for 30 minutes in an electric muffle furnace.

In Table 1 the weighted mean is shown because of the varying number of sample replications of the 180 septage samples (Appendix C). A coefficient of variation greater than 25 percent indicates a highly varying material. For the population, the interval of a true weighted mean for a student distribution (Steel, R.C.D. and J.H. Torrie, 1969) 95 percent confidence level is shown in the last column of Table 1.

For the designer of septage waste treatment facilities, data which provides flexibility in the selection of septage parameter numbers has merit. Figures 15 through 25 show the accumulated percentages of samples analyzed versus the physical or chemical parameter of interest. The cumulative frequency distribution represents successive addition of the number of observations falling within a given percentage starting with the lowest value. The approximate vertical ordinate increment was 10 percent.

For examples of the use of Figures 15 through 25, a designer may consider concentrations of a specific parameter that will include 75 percent of the observations. Thus for BOD_5 a 75 percent design value is 6350 mg/l or less (Figure 15). A 50 percent BOD_5 design value would include all values approximately 2900 mg/l or less. Comparatively, the 75 percent value for BOD_5 seems to be more than twice as large as the 50 percent value. If design evaluations are needed for septage total solids, then Figure 16 shows that the 75 and 50 cumulative percentages would include all samples with 3 percent or less or all samples with 1 percent or less total solids, respectively. The decision whether to use a statistic or design curve is left up to the user.

Table 1. SEPTAGE DATA STATISTICAL SUMMARY

Name of Test	Arithmetic Mean	Weighted Mean, X	Median	Standard Deviation	Coef. of Variation	Range of X[a]
BOD_5 Septage mg/l	4,794	3,840	2,912	4,410	115.0	± 510
BOD_5 Supernatant, mg/l	1,948	1,860	1,528	1,240	66.5	± 171.5
COD Septage mg/l	26,162	25,600	16,803	26,900	104.9	± 3,220
COD Supernatant, mg/l	6,343	6,690	5,280	7,280	108.6	± 1,100
Total Solids Septage, %	2.24	2.37	1.45	2.69	113.4	± 0.43
Volatile Solids Septage, %	67.8	67.5	70.5	15.4	22.8	± 2.46
Fixed Solids, Septage, %	32.2	32.4	29.2	15.4	47.6	± 2.46
Total Suspended Solids Supernatant, mg/l	2,350	2,530	2,302	1,410	55.7	± 321
Volatile Suspended Solids Supernatant, mg/l	1,819	1,880	1,343	1,390	73.8	± 323
Organic N Septage mg/l	26	32.7	12	45.7	139.5	± 10.45
Ammonia N Septage mg/l	72	71.7	62	41.7	58.2	± 8.55

[a] 95% confidence limits

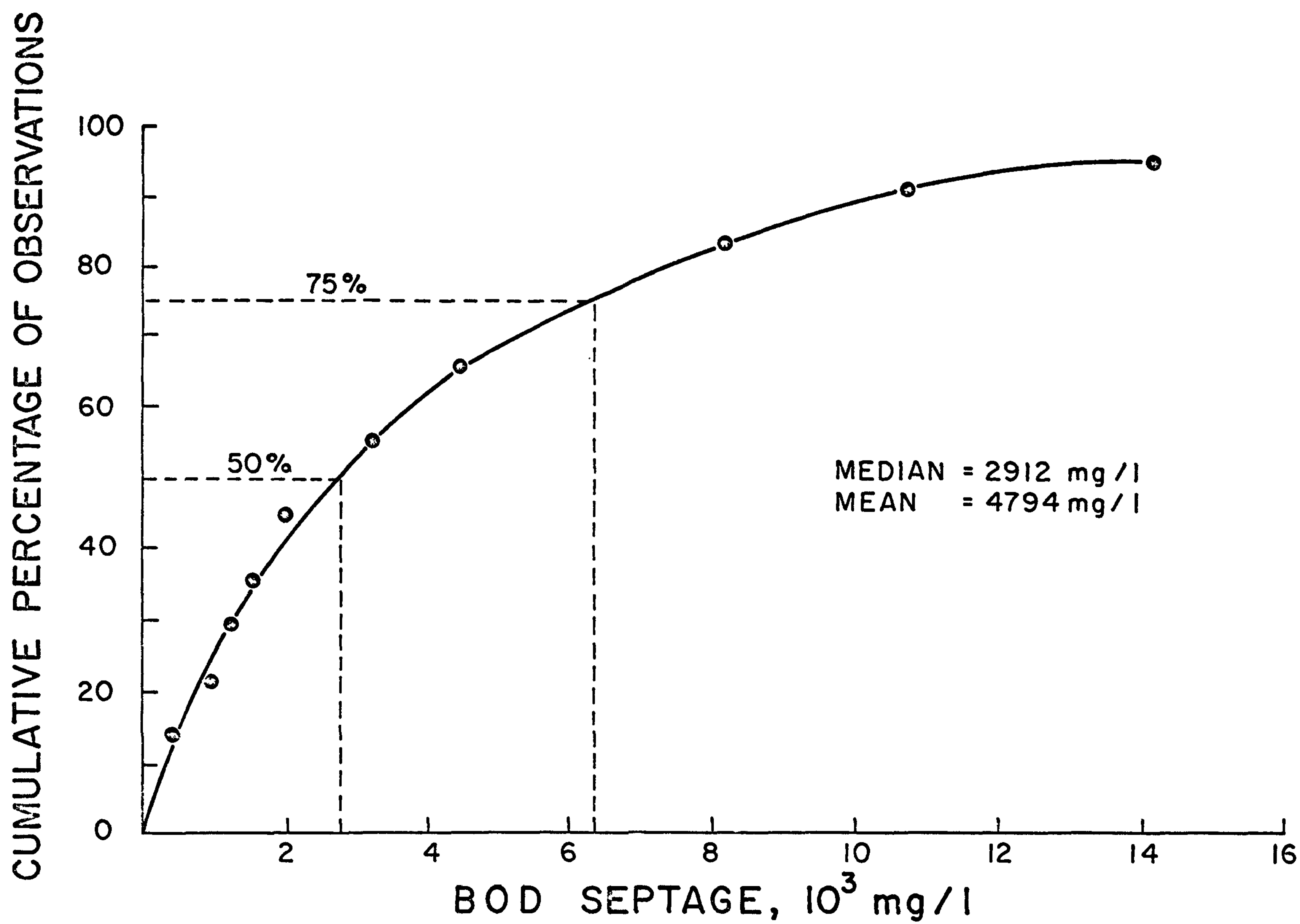


Figure 15. BOD_5 septage design curve.

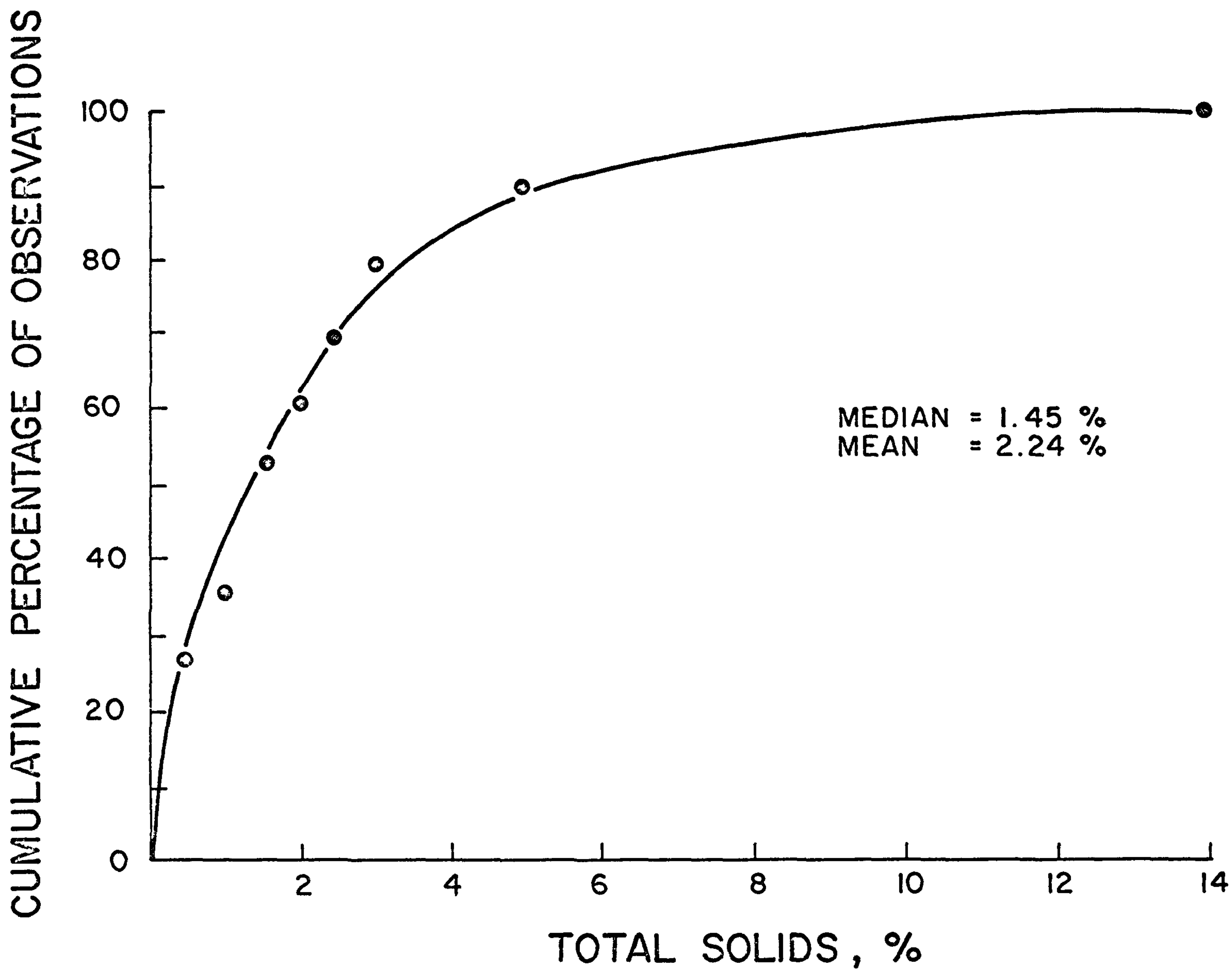


Figure 16. Total solids design curve.

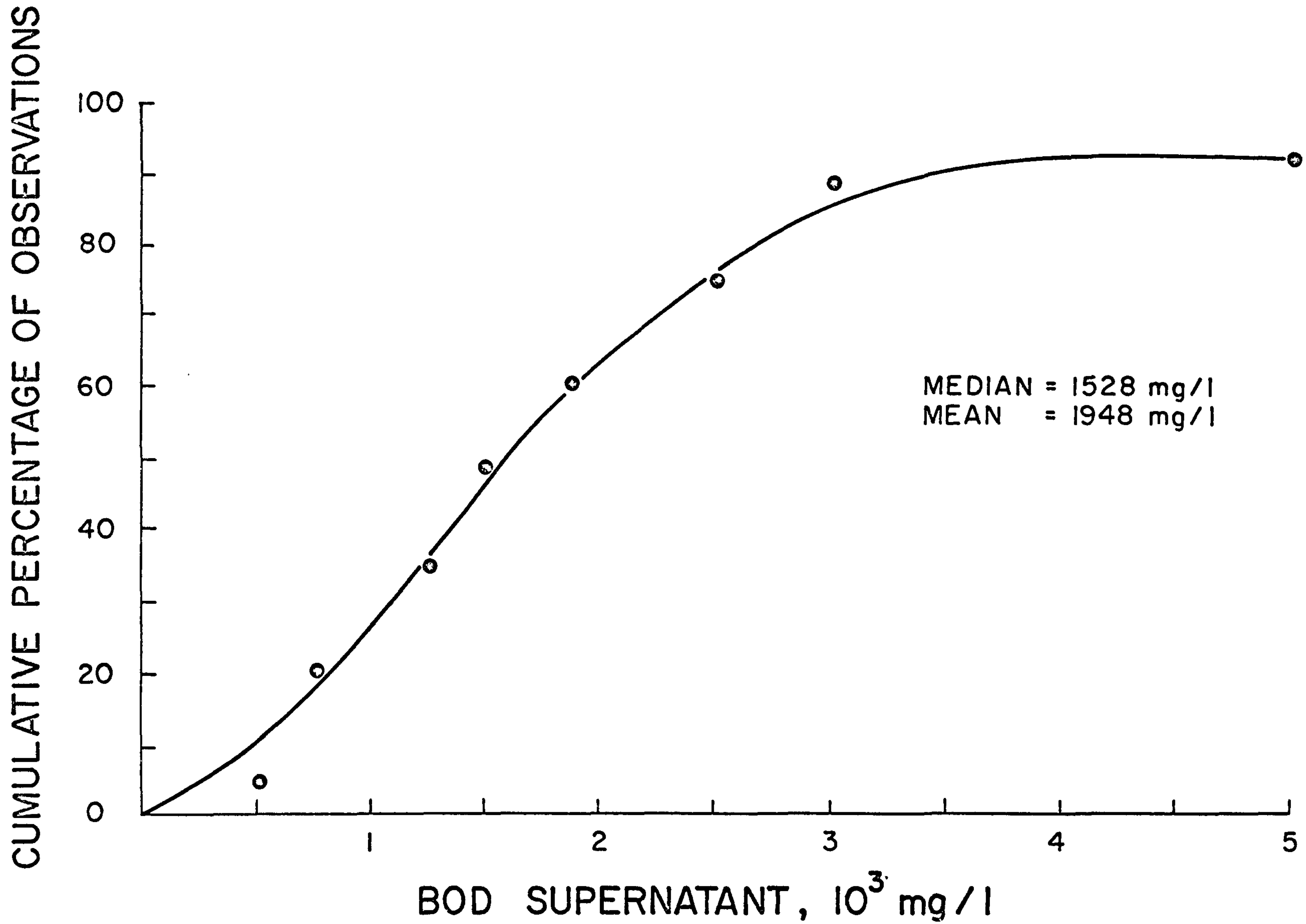


Figure 17. BOD_5 septage supernatant design curve.

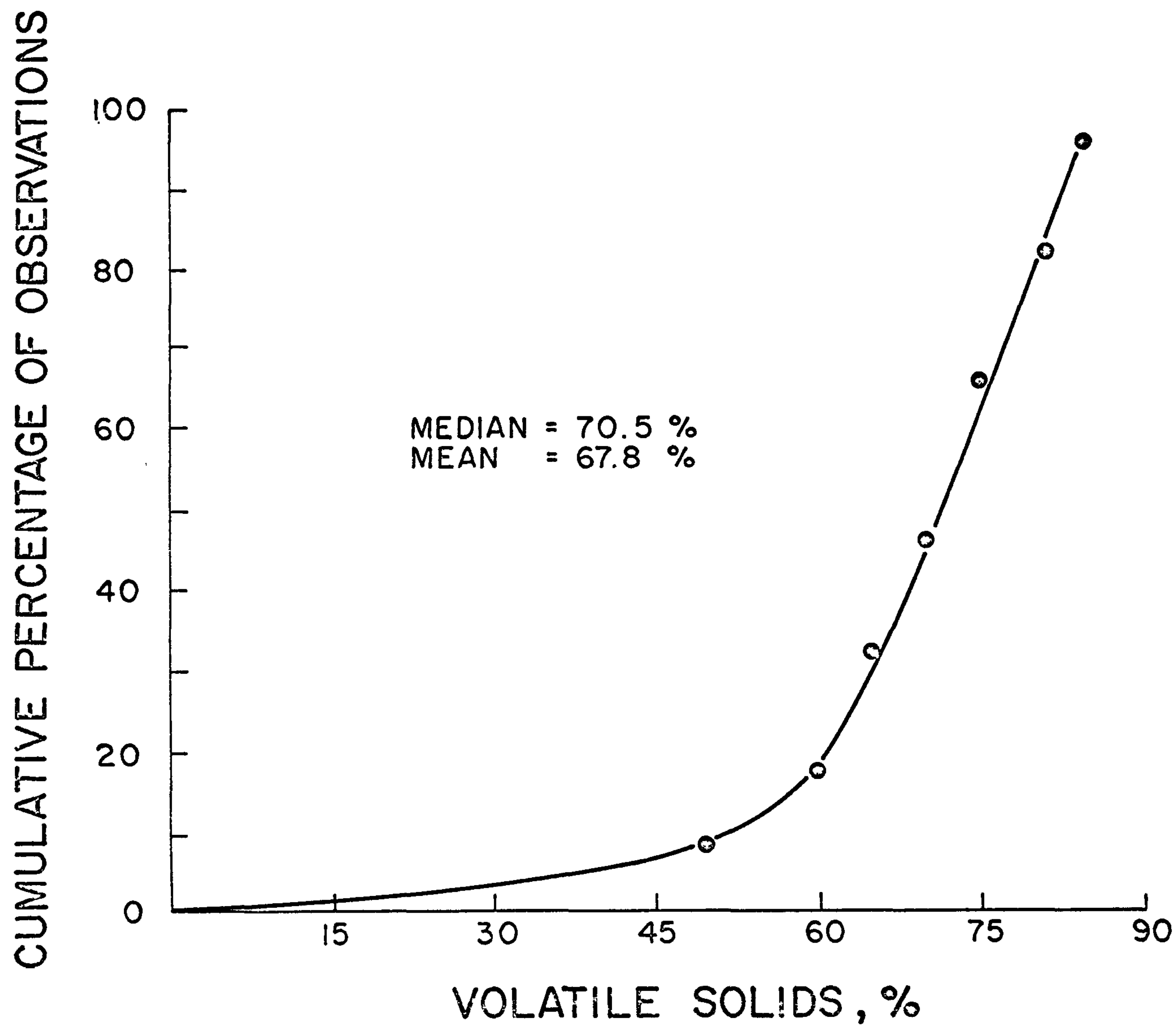


Figure 18. Volatile total solids septage design curve.

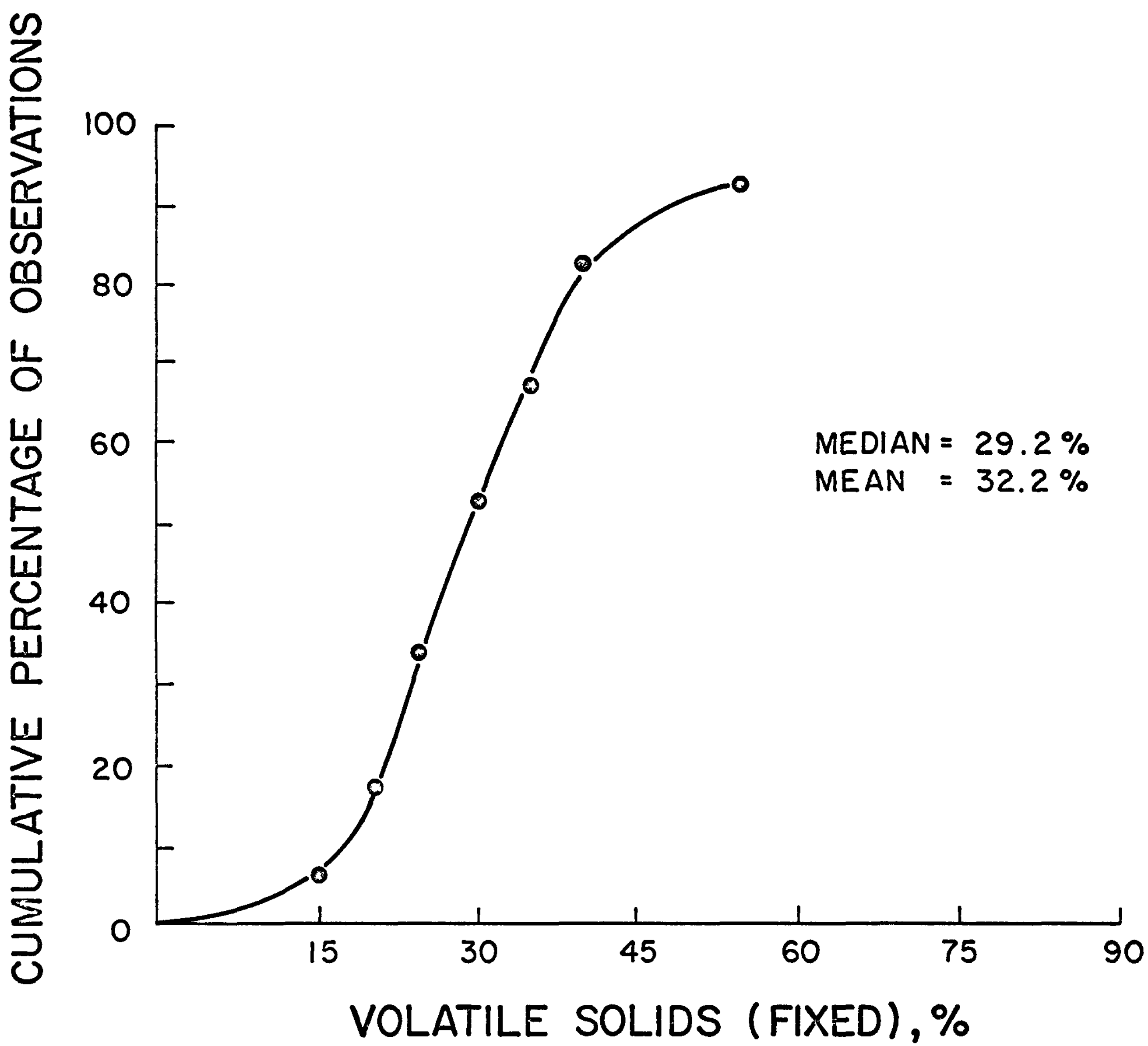


Figure 19. Fixed volatile total solids septage design curve.

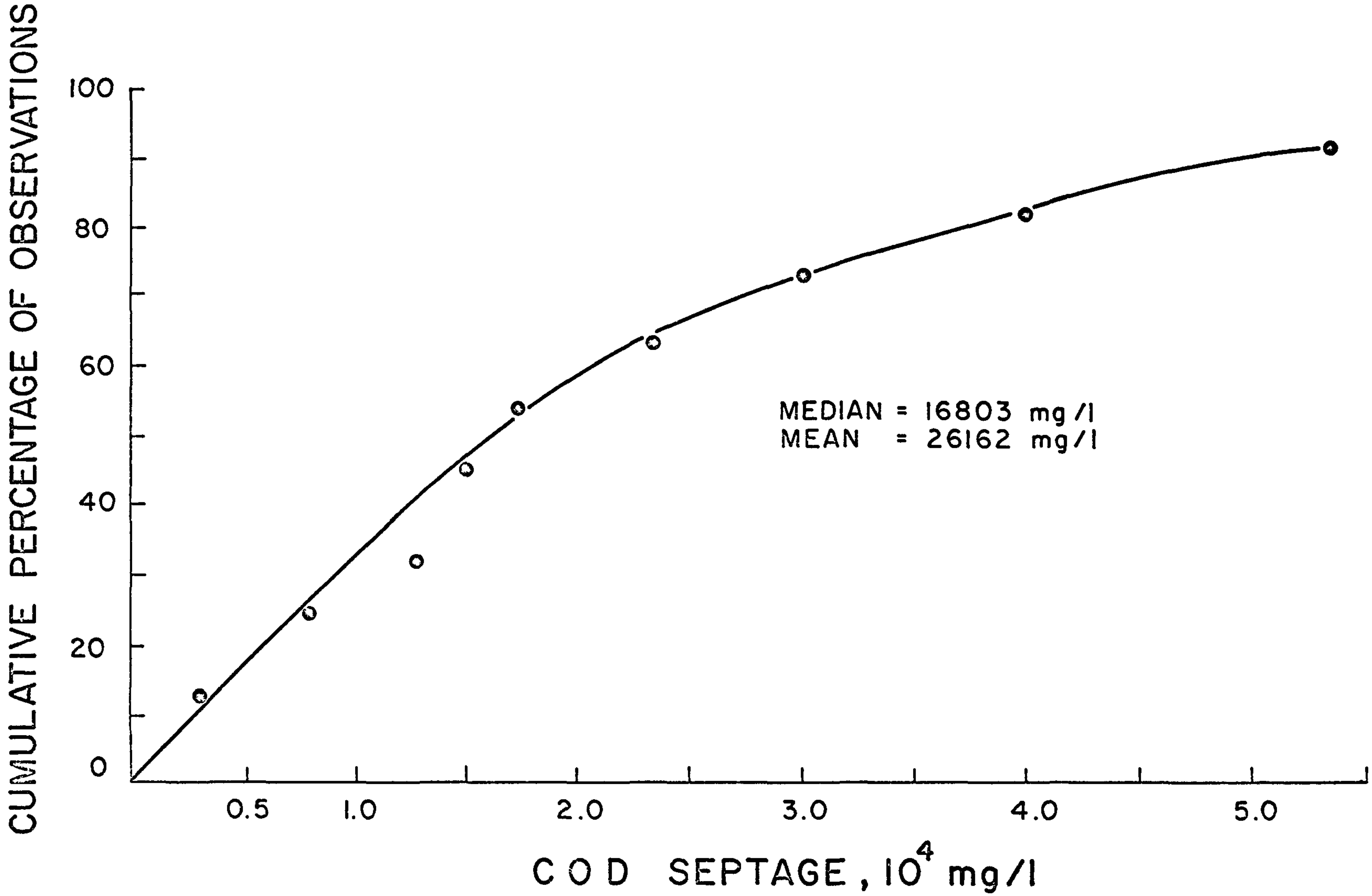


Figure 20. COD septage design curve.

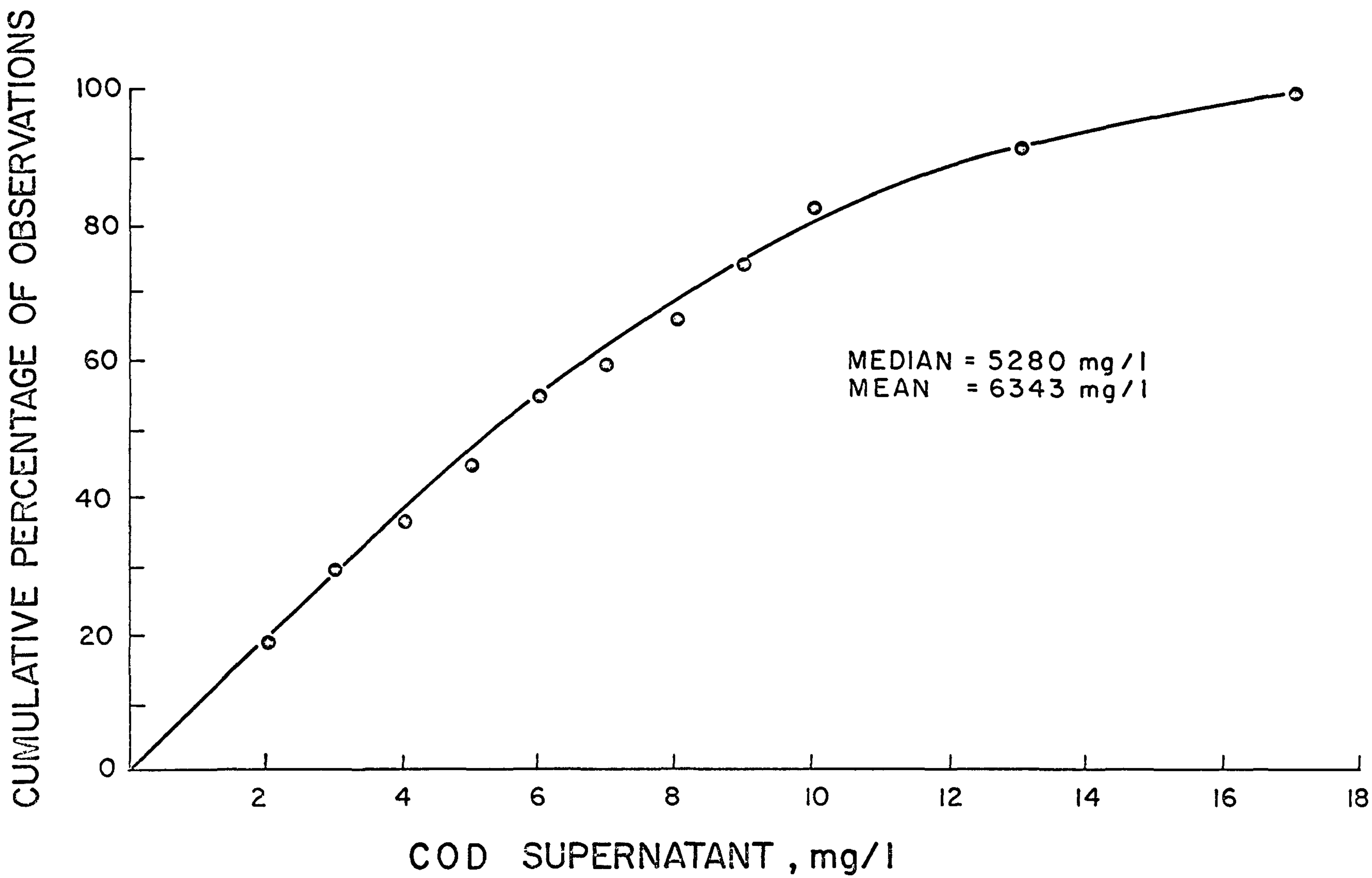


Figure 21. COD septage supernatant design curve.

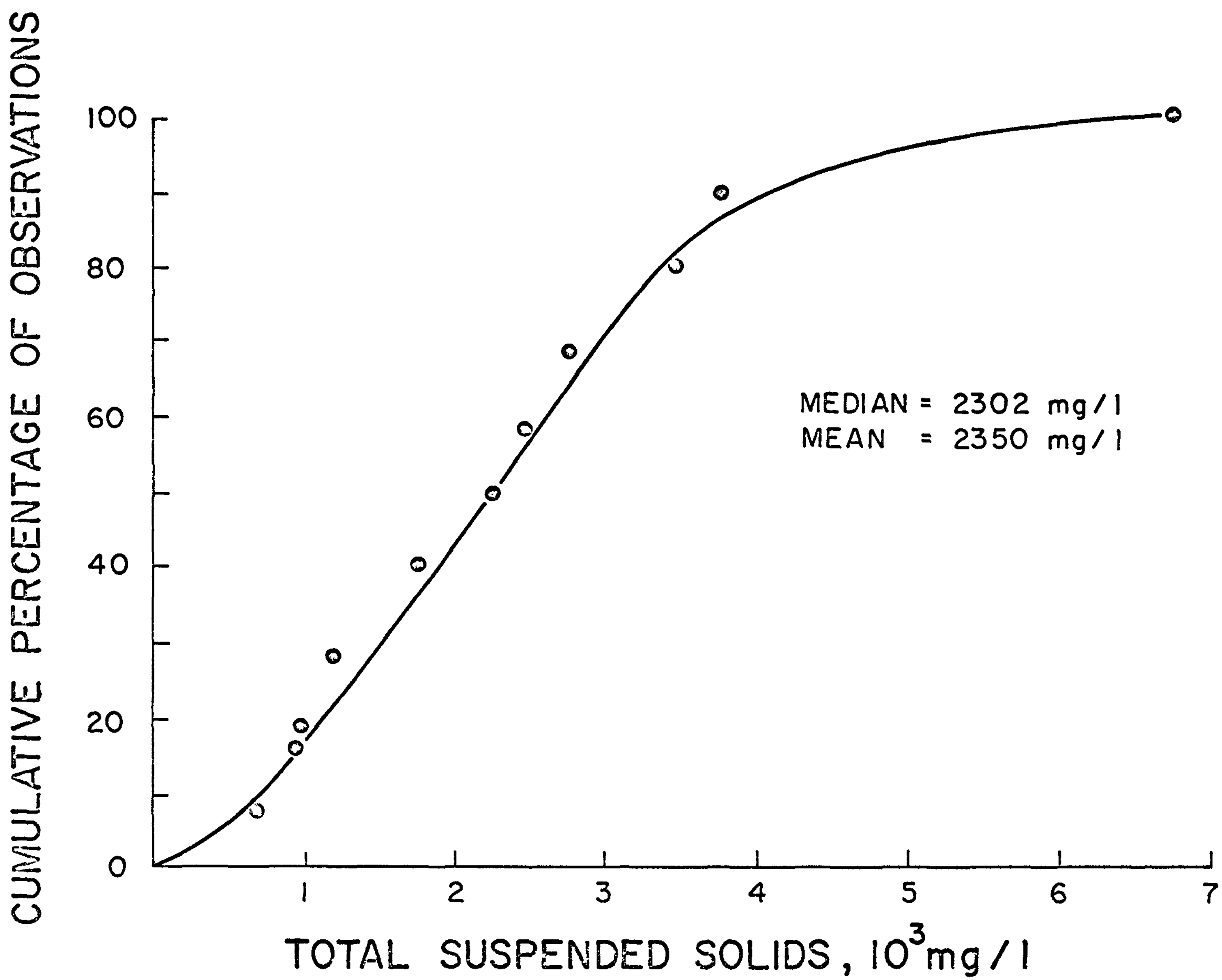


Figure 22. Total suspended solids design curve.

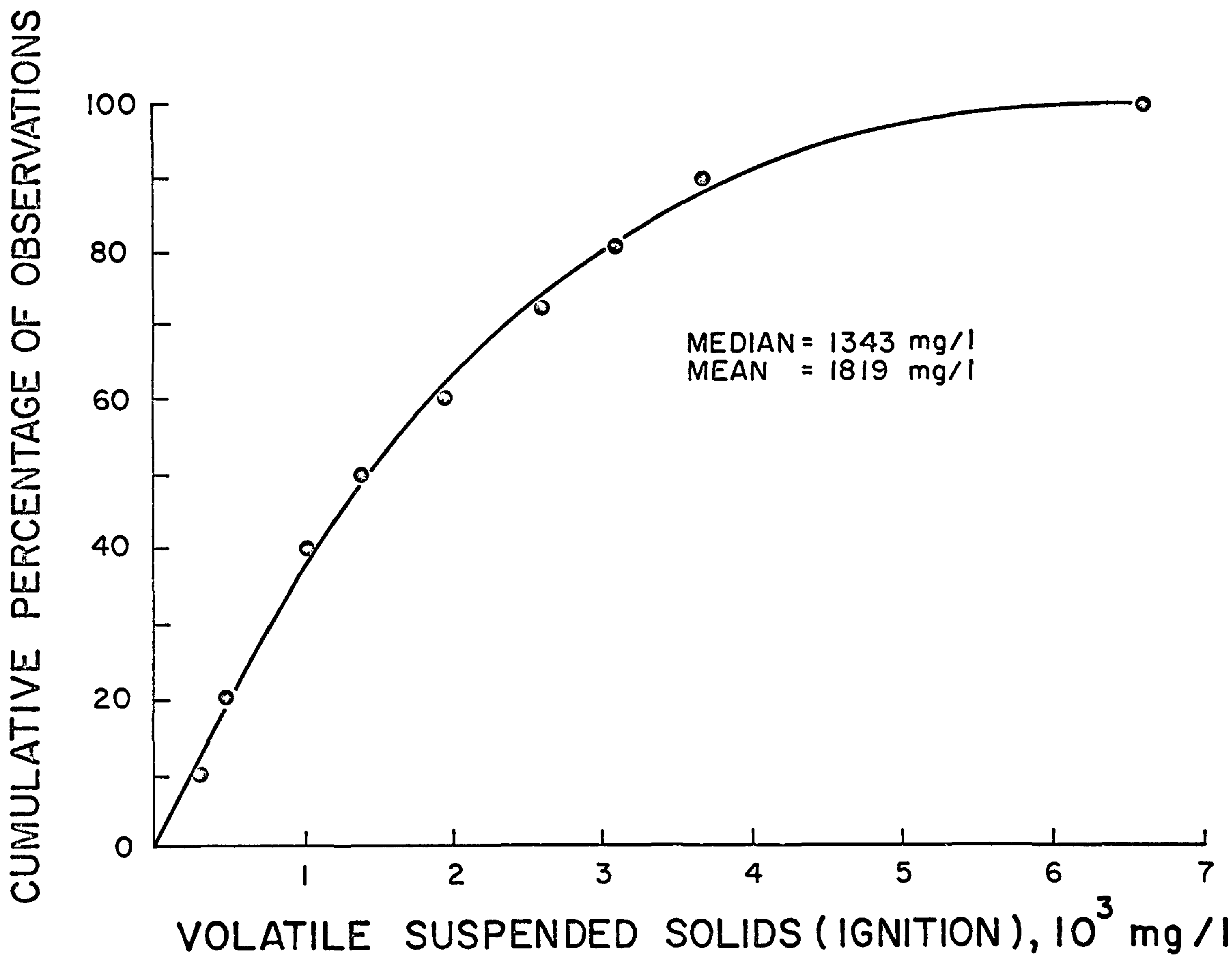


Figure 23. Volatile suspended solids design curve.

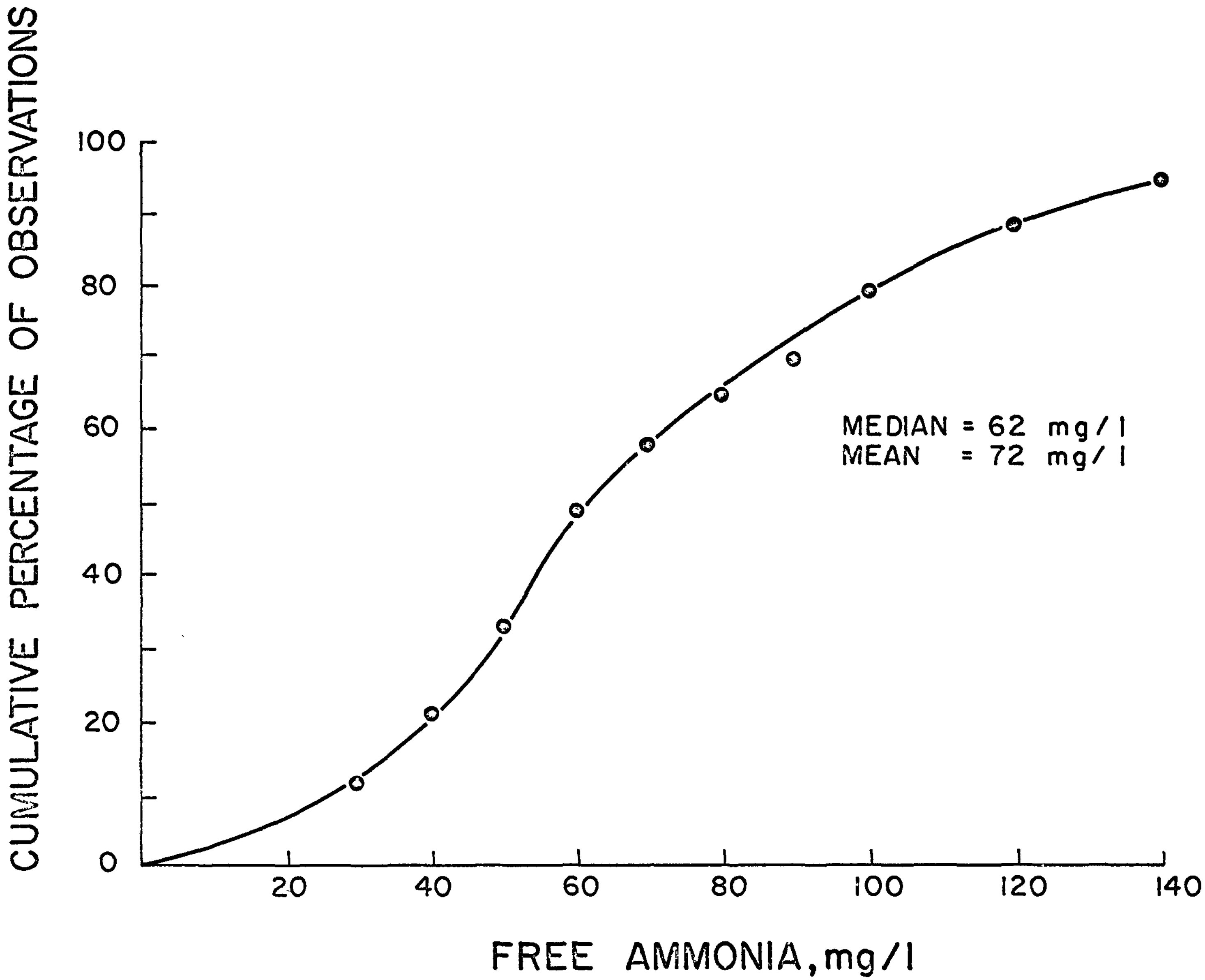


Figure 24. Free ammonia septage design curve.

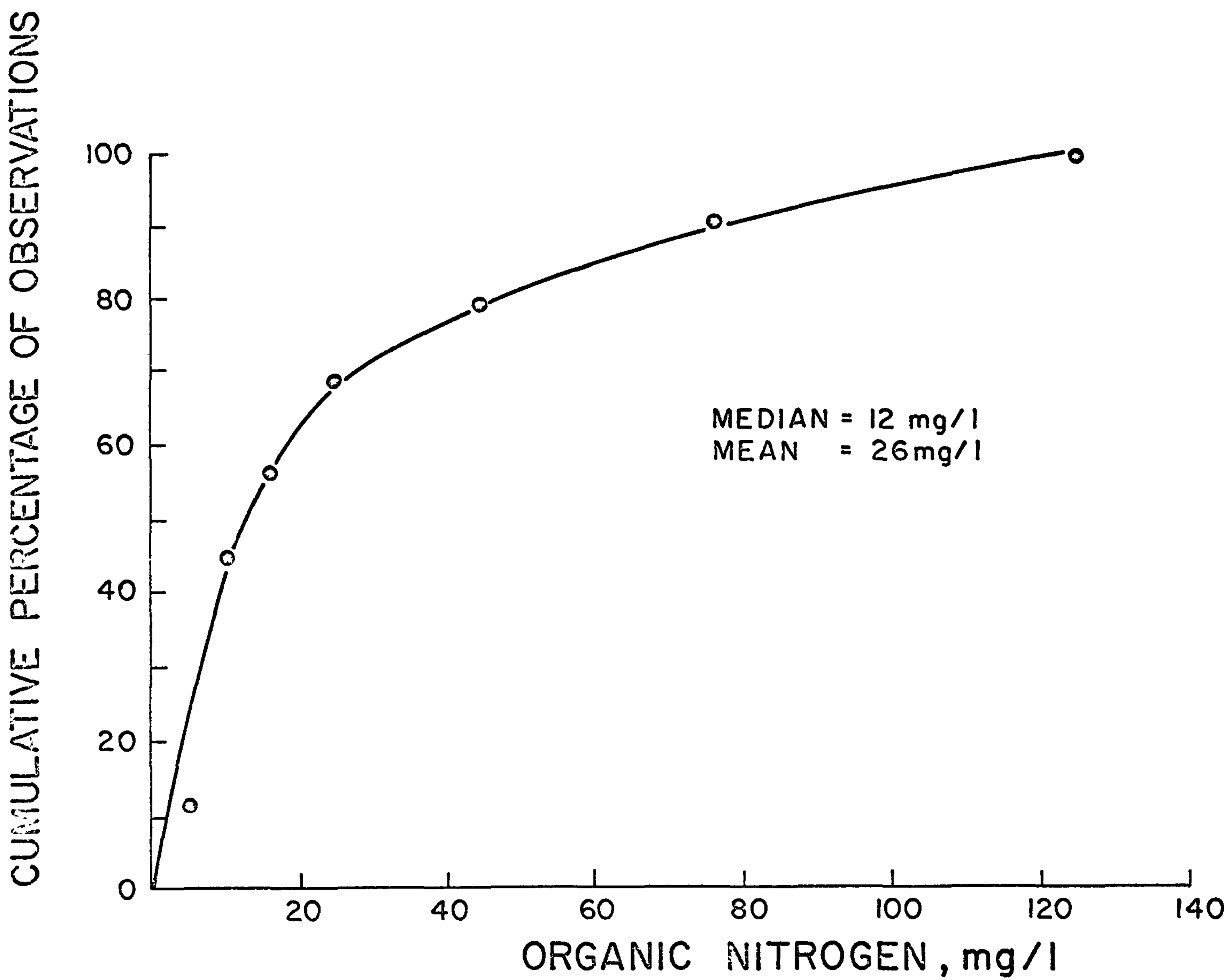


Figure 25. Organic nitrogen septage design curve.

With nitrogen analyses, foaming was experienced. Therefore, 30 septage samples were analyzed for surfactants. All 30 samples contained detergents. The linear alklyate sulfonate (LAS) concentrations ranged from 3 mg/l to 61 mg/l; average concentration was 23.6 mg/l. These analyses imply that the household septic treatment does not completely decompose LAS.

GAS UTILIZATION AND PRODUCTION

Several septage samples, raw wastewater and digester sludge were taken from different sources for head space gas composition analyses. Table 2 shows the percentage of oxygen, nitrogen, methane and carbon dioxide gases in the head space of each sample. These samples were collected periodically and immediately transferred to stoppered bottles. The bottles were kept tight to prevent any immediate equilibration of trapped gases with the outside atmosphere. Any substantial increase of internal pressure from the production of methane and/or carbon dioxide was followed by releasing a limited portion of the head space gas from the bottles; e.g. samples 4 and 6, Table 2. After gas production virtually ceased (e.g. all raw wastewater samples after the third week) equilibration with the outside atmosphere proceeded at a relatively slow rate.

The raw wastewater and digester sludge samples showed similar gas composition patterns. However, the septage samples showed wide variation (Table 2). Several factors may influence the chemical, physical and biological characteristics of the septage:

(1) inputs to the septic tank

(2) frequency of pumping

(3) efficiency of individual household sewage system

The production of methane was slow for most septage samples, whereas the digester sludge produced significant amounts of the gas within 24 hours. The raw wastewater samples did not show any detectable amount of methane at the highest sensitivity setting of the TC detector; even with a simultaneous injection of as much as 2 ml of the head space gas. The utilization of oxygen and the production of carbon dioxide proceeded at a significant but variable rate in all samples, increasing in following order: sewage, septage, and digester sludge.

Total Volatiles, Including Mercaptans and Sulfides

The septage material also was examined by gas chromatography for its volatile contents; organic sulfur and other compounds. The results were compared with those of sewage and digester sludge samples. In a preliminary examination, the volatiles in the septage material (400 ml) were swept by nitrogen gas through a lead acetate tube to remove the hydrogen sulfide and then through an aqueous solution of mercuric chloride (4% w/v) (Gumbmann and Burr, 1964) to precipitate any volatile organic sulfur present. After passing nitrogen gas for one hour, no white precipitate or turbidity could be detected in the mercuric chloride solution indicating that only traces of these

Table 2. PERCENTAGE COMPOSITION OF THE GAS MIXTURE IN THE HEAD SPACE OVER SEPTAGE, SEWAGE, AND DIGESTER SLUDGE

Sample Identity	Time Period, Days	O_2	N_2	CH_4	CO_2
Septage #1	2	16.70	79.62	0.09	3.47
Septage #2	2	19.97	79.29	0.06	0.66
Septage #3	1	18.89	77.14	0.27	3.69
Septage #4	35	1.10	73.00	3.87	22.02
	42	1.32	68.20	5.09	25.37
	55	0.77	65.12	7.35	26.75
	84	0.76	56.13	15.90	27.10
Septage #5	12	1.11	77.04	1.45	20.38
	19	0.09	71.93	1.96	25.20
	32	0.87	70.95	2.23	25.94
	61	1.01	74.19	1.77	23.00
Septage #6	12	1.08	71.47	5.73	21.71
	19	0.59	52.36	20.32	26.72
	32	0.58	38.93	30.61	30.00
	61	0.54	36.46	29.82	33.10
Septage #7	9	1.38	77.66	0.16	20.79
	16	1.62	75.43	0.13	22.82
	29	3.95	74.70	0.09	20.83
	58	3.90	87.60	tr.	8.50
Septage #8	9	2.36	82.54	0.12	14.97
	16	2.57	75.53	0.29	21.60
	29	1.12	73.79	1.17	23.89
	58	2.40	78.50	0.28	17.80
Sewage (Univ. of Conn.)	8	9.82	83.06	--	7.11
	15	7.22	84.57	--	8.21
	28	8.17	84.30	--	7.53
	57	20.28	78.22	--	1.48
Sewage	1	17.67	80.04	--	2.28
	8	6.62	83.04	--	10.33
	21	7.30	83.49	--	9.19
	50	18.01	77.03	--	4.96

Table 2. (continued).

Sample Identity	Time Period, Days	O_2	N_2	CH_4	CO_2
Sewage (E. Hartford)	0.25	20.63	79.37	--	--
	7	9.11	83.38	--	7.36
	20	9.78	83.18	--	7.02
	49	18.60	77.89	--	3.51
Primary Digester Sludge (Willimantic)	1	8.06	38.39	28.08	25.45
	2	0.30	13.44	43.17	43.09
	8	0.16	7.51	46.16	46.16
	21	0.37	15.29	40.92	43.40
	50	0.97	40.81	23.20	35.02
Primary Digester	0.25	20.00	76.96	0.49	2.55
	1	0.89	31.07	33.46	34.58
	7	0.55	12.46	45.21	41.77
	10	0.66	20.70	38.17	40.45
	49	0.90	60.45	10.86	27.78

volatile sulfur compounds were present. Consequently, the pre-column trapping technique (Burnett, 1969) was followed for concentrating volatiles.

While several peaks were obtained with all three classes of liquid wastes, the dissimilarities between the classes were apparent. Raw wastewater samples did not show any traces of mercaptans or sulfides. Digester sludge samples showed evidence of mercaptans and sulfides with comparatively small peaks of other nonsulfur compounds. All of the septage samples showed several sizable peaks for both organic sulfur and nonsulfur compounds. The following mercaptans and sulfides were tentatively identified; methylthiol, ethylthiol, n-propylthiol, n-butylthiol, and methyl sulfide. Other unidentified sulfur compounds could be easily located on the chromatogram by their characteristic odors.

PROLONGED HOLDING OF SEPTAGE

East Hartford Septage Sample

The East Hartford septage odor was not offensive, nor did it turn offensive during the study. The liquid portion even after two weeks settling, remained turbid. Table 3 shows the effect of storage on the pH, COD, TVA and the relative percentage of individual volatile acids. Figure 26 shows the rate of gas production and changes in the gas components, in addition to changes in COD and TVA.

The total COD concentration (Table 3) stayed fairly constant over five weeks. However, the supernatant COD concentration continually decreased, and after three weeks reached a minimum level of approximately 900 mg/l, or an average reduction of 84 percent. Thereafter, the COD concentration stayed relatively constant for two more months.

Initially, the volume of trapped air (Figure 26) was 270 ml of which 56 ml was oxygen. Oxygen was rapidly consumed and after one week the D.O. concentration was reduced to and maintained a relatively constant level of 7 mg/l.

From the beginning of the experiment, the total volatile fatty acids (see Table 3, Figure 26) decreased steadily while CO_2 showed a parallel increase up to the 10th day after which CO_2 production slowed down. Thereafter, the fatty acids concentration showed a marked increase from 60 mg/l on the 12th day to 252 mg/l on the 15th day, after which the concentrations decreased steadily but without any significant increase in CO_2 production.

The wide variation in the relative percentage of each individual fatty acid (Table 3) was indicative of an active metabolism in the sample. However, the data did not follow a characteristic pattern that would permit elucidation of the metabolic pathways of the acids.

The production of methane was very slow at the beginning of the experiment mainly because of the presence of molecular oxygen which inhibits the activity of the methane-forming bacteria. When the oxygen content became

Table 3. CHANGES IN THE COD, FATTY ACIDS CONTENTS, AND pH OF THE EAST HARTFORD SEPTAGE SAMPLE.

Date of Analysis for Each Sample	pH	COD Total mg/l	COD Super-natant mg/l	TVA as Acetic mg/l	Percentage Composition of Fatty Acids					
					Acetic	Propionic	Isobutyric	Butyric	Isovaleric	Valeric
10/21/71	7.50	15,346	5,714	108	53.43	5.49	11.33	4.41	21.45	3.85
10/25/71	7.40	15,841	5,142	84	44.13	31.30	5.98	4.56	12.17	1.83
10/28/71	7.40	14,850	2,066	72	47.54	37.37	5.04	2.47	5.16	2.38
11/01/71	7.20	15,200	2,000	60	72.82	6.88	7.10	3.02	9.81	0.65
11/04/71[a]	6.95	13,877	2,040	252	Sample mixed before analysis; data omitted					
11/08/71	6.95	15,587	1,214	240	49.53	41.43	5.17	1.27	2.40	0.17
11/11/71	7.00	15,289	868	216	38.40	49.09	5.70	2.81	3.62	0.35
11/15/71	7.05	15,164	901	192	52.38	35.58	6.72	0.54	4.57	0.19
11/18/71	7.20	15,120	877	96	73.20	17.95	6.38	0.84	1.46	0.37
11/22/71[a]		15,239	916	84	Sample mixed before analysis; data omitted					
1/07/72	7.05		940	zero						
3/25/72		11,128	443							

[a] Limited data

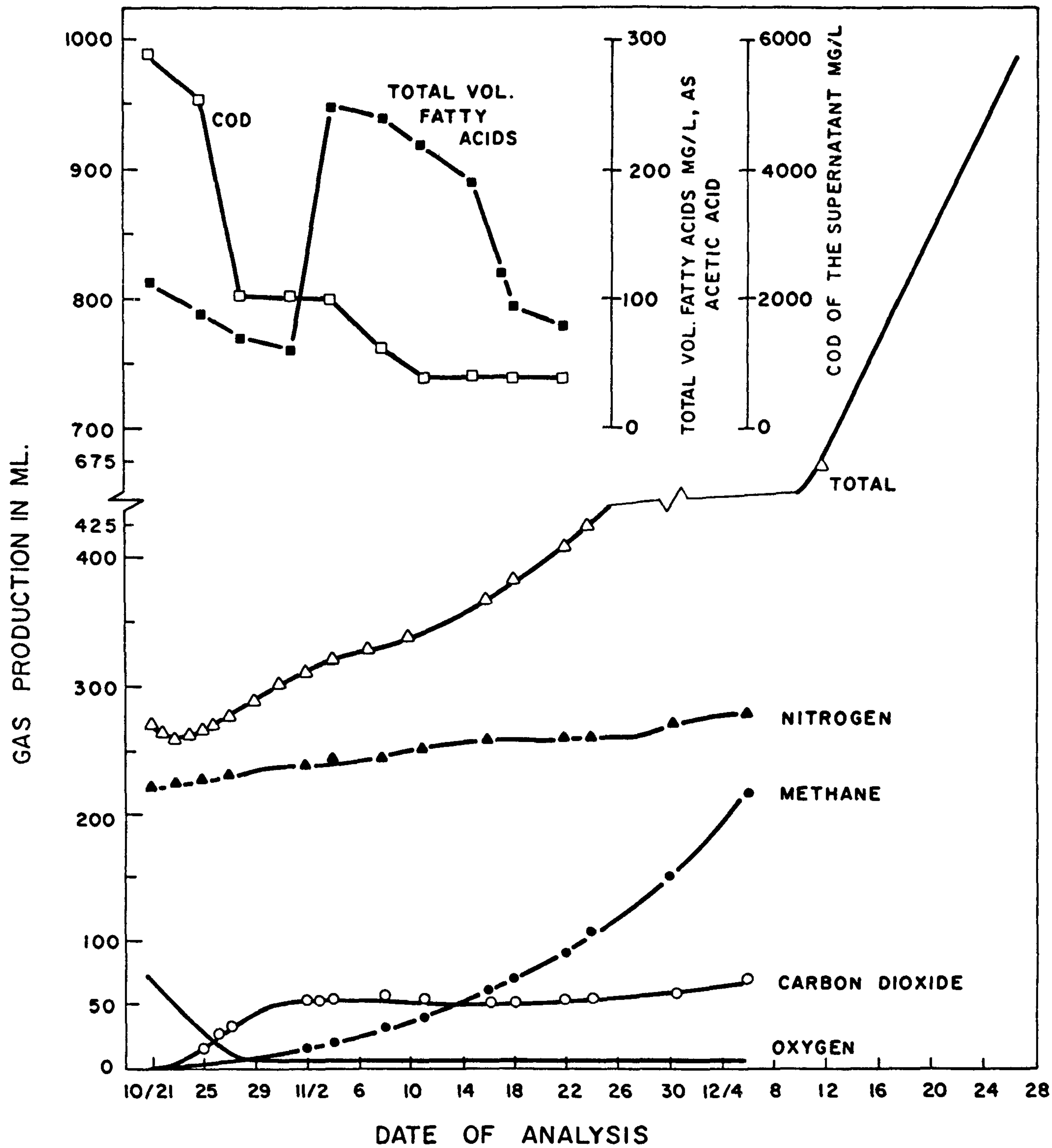


Figure 26. Changes in the gas production, COD, and total volatile fatty acids contents of septage during prolonged storage at ambient temperature.

minimal, methane production increased rapidly and the CH_4/CO_2 ratio increased progressively (Figure 26).

The total gas production rate was recorded almost daily (Figure 26). A slow but continuous increase in the nitrogen content of the gas from the very beginning of the experiment was observed. After seven weeks, the daily increase in total gas production volume averaged around 20 ml. After the eleventh week, the rate of gas production slowed to only 2-3 ml/day. Consequently, the last septage sample (No. 11) was analyzed for its COD and TVA contents. Although supernatant COD remained unchanged (940 mg/l), the sample was virtually free of any acid content. On the 14th week and thereafter, it became evident that the biological activity in the sample almost ceased because no additional gas was produced. The gas assembly was dismantled after 22 weeks. The supernatant COD to concentration had decreased 443 mg/l. The total COD was 11.128 mg/l.

Litchfield Septage Sample

During the experiment, the odor of the Litchfield septage sample remained offensive and penetrating. In addition, the supernatant stayed turbid. Table 4 shows the effect of storage on the pH, COD, TVA and the relative percentage of the individual fatty acids. The total COD remained unchanged over a period of five weeks. The reduction in the supernatant COD over the same period was irregular.

The gas production continually increased in the first week of the experiment. The net increase amounted to 70 ml, which comprised 4 ml methane, 50 ml carbon dioxide. After the first week, the increase in gas production either slowed down considerably, stopped completely, or showed some decrease. No significant changes occurred in the relative quantities of the gas components over the next nine weeks.

During the first week the pH remained in the optimum range for active biological reactions (Table 4, sample No. 1 and 2). However, from the second to the fifth week, the pH dropped significantly below that range. The TVA content (Table 4) was originally high (greater than 500 mg/l) and it increased steadily to a maximum of 972 mg/l. This TVA increase may be due to the inhibition of the methane-forming bacteria by the low pH, by contact with molecular oxygen or insufficient nutrients, or breakdown of organics to volatile acids via bacterial action and possible air leakage. Meanwhile, the acid-forming bacteria managed to grow under these conditions producing more acids with relatively slow changes in the percentage composition of the different fatty acids.

Without any apparent reason the Litchfield sample after ten weeks started to increase in gas production. Consequently, the last sample bottle (No. 11) was examined for its pH, TVA, and COD. Its pH was within the optimum range, 6.85; its TVA was significantly reduced to 372 mg/l; and its supernatant COD showed some reduction (Table 4). After almost 24 weeks of increased gas production, the volume of the gas exceeded 500 ml. The percentage composition of the gas components were then determined: O_2, 2.6;

Table 4. CHANGES IN COD, FATTY ACID CONTENTS, AND pH OF THE LITCHFIELD SEPTAGE SAMPLE.

Sample No.	Date of Analysis	pH	COD Total mg/l	COD Supernatant mg/l	TVA as Acetic mg/l	Percentage Composition of Fatty Acids: Acetic	Propionic	Isobutyric	Butyric	Isovaleric	Valeric
1	10/21/71	7.20	16,831	8,700	504	23.80	63.70	3.60	2.40	6.25	0.25
2	10/25/71	7.10	16,831	8,720	756	36.20	45.83	3.06	5.70	5.70	3.44
3	10/28/71	6.40	16,867	4,956	864	26.80	47.44	3.90	6.50	8.27	4.64
4	11/01/71	6.10	16,400	5,080	912	40.50	52.15	1.80	2.75	1.90	6.84
5	11/04/71	6.00	16,122	3,673	924	29.00	51.32	4.32	4.94	7.38	3.00
6	11/08/71	6.00	16,801	3,724	924	28.21	48.97	4.24	5.52	9.24	3.79
7	11/11/71	6.00	16,528	4,297	972	31.12	49.58	3.84	4.12	8.64	2.68
8	11/15/71	5.90	16,080	4,385	972	33.98	50.72	3.37	3.42	6.30	2.18
9	11/18/71	6.20	16,028	3,266	876	43.35	51.06	1.75	0.28	3.37	0.16
10	11/22/71	6.05	16,832	3,187	804	40.94	50.12	2.62	1.42	4.36	0.51
11	1/07/72	6.85		2,170	372						
12	4/08/72		11,600	1,568							

N_2, 36.4; CH_4, 50; CO_2, 11. The supernatant COD was reduced to 1568 mg/l and the total COD was found to be 11,600 mg/l.

The Litchfield sample reactivated itself. This could be due to air leakage into the bottle after which the presence of O_2 plus bacteria acclimation resulted in gas production increase once past the lag phase. The type of trend discussed is also observed in sewer lines carrying raw wastewater in which there is an increase in biological activity after the raw wastewater is in the sewer line for a given time period.

BIOLOGICAL

During the summer of 1969, 374 bacterial isolates were obtained from 38 septage samples using conventional laboratory techniques. Throughout the fall and winter of 1969-70, an additional 100 isolates were recovered from septage and septic tank sewage samples using modified techniques as shown in the protocol for sample analysis (see Figure 2).

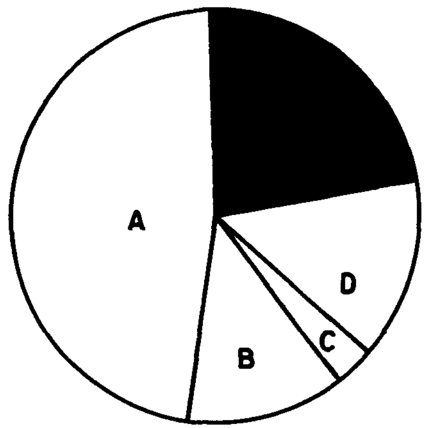
The distribution of bacteria from the summer and fall-winter isolates, Figure 27, shows the gram negative non-lactose fermenting bacilli were predominate. These include Alcaligenes, Pseudomonas, Mima-Achromobacter-Herellea, and others which are considered aerobic. Percentages found were as follows: Alcaligenes, 62; Pseudomonas, 16; Mima-Achromobacter-Herellea, 6; Providence, 2; and others, 14. Their recovery suggests the presence of oxygen in septage.

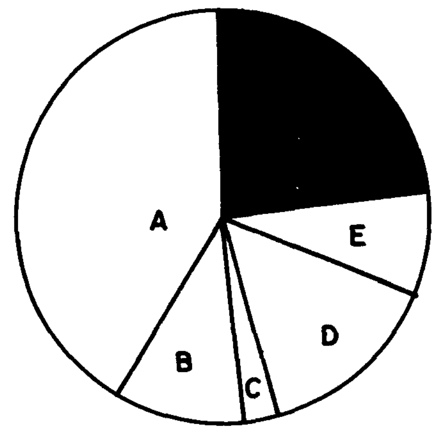
Of the 35 anaerobic spore-formers recovered from treated septage and samples taken from septic tanks, 24 were obligate anaerobic. Their characteristics are shown in Table 5. Clostridium lituseburence and Cl. perfringens were most frequently encountered. The fastidious nature of many of the microorganisms that constitute the seven remaining families may account for their inability to compete with the resident flora in septage.

The host specificity range of bacteriophages isolated from septage is shown in Table 6. E. coli and S. typhimurium mutants were sensitive to phage specific for Citrobacter freundii. The wild type of S. typhimurium (Lt_2) and 20 strains of E. Coli isolated from septage were smooth and insensitive to phage infection. It seems likely that rough variants lack a portion of the antigenic determinants which results in a loss of type specificity.

Electron micrographs of phage morphology revealed two morphological types: short-tailed phages similar to T_3 and T_7 and a long-tailed phage similar to T even phages. One type was present in the filtrate active against C. freundii, whereas, the other types were found in filtrates active against S. flexneri.

The results of the enumeration studies of aerobic and anaerobic (facultative) bacteria present in septage and in a single septic tank system are presented in Figure 28. Salmonellae and Shigellae were not encountered, and fecal streptococci counts were less than 1×10^2 per ml. Cellulolytic bacteria were detected in cellulose broth and appeared in association with other bacterial types.





	PER CENT Summer	PER CENT Fall-Winter
☐ Gram negative	78.6	77.0
■ Gram positive	21.4	23.0
Gram Negative Distribution		
A. Non-lactose fermenters	47.5	41.9
B. *Aerobacter aerogenes*	10.9	10.4
C. *Escherichia coli*	1.5	2.6
D. Coliform intermediates	18.7	15.6
E. Others	-	6.5

Figure 27. Distribution of microorganisms in composite septage.

Table 5. CHARACTERIZATION OF CLOSTRIDIAL SPECIES ISOLATED FROM SEPTIC TANK SEWAGE.

Species	Number of isolates	Motility	Spore location	Gelatin liquification	Indole production	Milk	Glucose	Lactose	Mannitol	Maltose	Salicin	Nitrate reduction	H_2S production
						Reactions in:							
Clostridium lituseburence	9	-	ST	+	-	P	a	-	-	-	-	-	+
Cl. perfringens	7	-	C	+	-	ag	ag	ag	-	a	-	+	+
Cl. butyricum	2	-	ST	-	-	ag	ag	ag	-	ag	ag	-	-
Cl. saprogenes	1	+	T	±	-	RC	a	a	-	a	-	-	-
Cl. amylolyticum	1	+	ST	-	+	AC	a	-	a	a	-	+	-
Cl. lactoacetophilum	1	+	ST	-	-	a	a	a	a	a	a	-	+
Gl. perenne	1	+	T	±	-	RC	a	a	-	a	-	-	-
Cl. filforme	1	-	ST	-	-	AC	ag	ag	ag	-	-	-	-
Cl. multifermentans	1	-	ST	-	-	AC	a	a	-	a	a	-	-

KEY:
T = terminal
ST = sub terminal
C = central

a = acid
g = gas
P = proteolysis (peptonization)

RC = rennet curd
AC = acid curd

Table 6. HOST SPECIFICITY RANGE OF BACTERIOPHAGES ISOLATED FROM SEPTAGE.

Bacteria	Active filtrates[a] 1	2	3	Variant[b]
Escherichia coli isolated from septage (20 strains)	-	-	-	S
E. coli B	+	-	-	R
E. coli K_{12}	+	-	-	R
E. coli 200P	+	-	-	R
E. coli 3300	+	-	-	R
E. coli C	+	-	+	R
Salmonella typhimurium Lt_2	-	-	-	S
S. typhimurium R_a	+	-	-	R
S. typhimurium R_b	+	-	-	R
S. typhimurium R_c	+	-	-	R
S. typhimurium R_d	-	-	-	R
S. typhimurium R_2	+	-	-	R
Erwinia carotovora	-	-	-	S
Alcaligenes viscolactis	-	-	-	S
Pseudomonas aeruginosa	-	-	-	S
P. fluorescens	-	-	-	S
Proteus vulgaris	-	-	-	S
P. Myxofaciens	-	-	-	S
Serratia marcescens	-	-	-	S
Flavobacterium sp.	-	-	-	S
Klebsiella penumoniae	-	-	-	S
Aerobacter (Enterobacter) aerogenes	-	-	-	S

[a]Filtrates:

1 Active against Citrobacter freundii
2,3 Active against Shigella flexneri

[b]R = Rough
S = Smooth

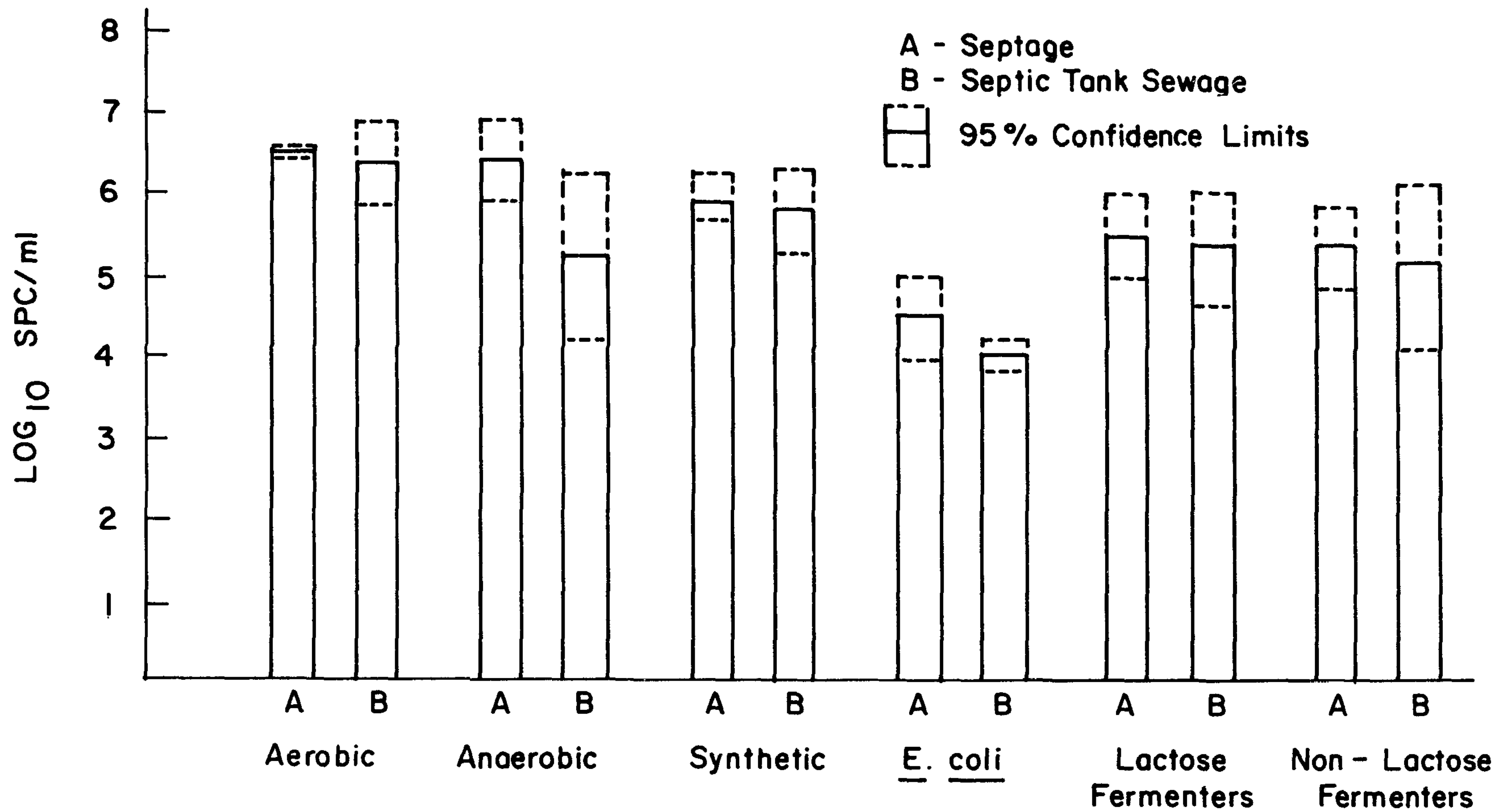


Figure 28. Comparative enumeration of specific types of microorganisms with 95 percent confidence limits.

Biochemical activities of microorganisms as observed aerobically on specific media are shown in Figure 29. The results indicate that the predominant microorganisms present in the system are able to hydrolyze a variety of nutrients present in the tanks.

Biological characteristics of septage are not significantly different from the characteristics of the contents of an operating septic tank except for protease and amylase activities and for nitrogen levels, Table 7 and Figure 30. The quantity of reducing sugar in both systems was low and not significantly different in septage as compared with septic tank contents.

Four methods were used in the determination of nitrate levels in septic tank sewage. The amount of nitrate present, as measured with the brucine method, was higher and suggestive of the presence of organics in the samples which frequently interfered with the color reaction. The data are presented in Table 8.

Methylene blue, resazurin and indigo carmine were tested to measure biological activity in septage and sewage samples, Table 9. Methylene blue was the most satisfactory while rasazurin and indigo carmine were not reduced after two weeks in at least one type of liquid waste. Perhaps with modification, the methylene blue reduction test can be developed into a rapid precise method for estimating the strength of septic tank sewage and the corresponding relationship to the need for septic tank pumping. An active septic tank should have a short reduction time. To supplement the methylene blue reduction time study, additional data on ammonia, organic nitrogen, pH, and SPC/ml values were sought and are presented in Table 10.

The enumeration of specific types of microorganisms in septage and septic tank sewage show little variation as indicated by the range given in Figure 31. The distribution of specific types of microorganisms and selected physiological activities is shown in Figure 32.

A comparison of septage with available literature values for untreated sewage indicated slight differences in E. coli counts, aerobic types, B-glactosidase, and proteolytic activities. The streptococci counts in septage were always lower than those reported for sewage (Gaub, 1924), and the ratio of coliforms to enterococci was approximately 20:1 in septage. The low numbers of enterococci are probably the result of their inability to multiply when substrates are limiting. When sterile septage was seeded with S. fecalis, there was no increase in the cell number after 48 hours.

An experiment was designed to determine the survival time of S. typhimurium in a septic tank system. Approximately 7.0 x 10^8 cells/ml were introduced into a septic tank via the household commode. A sample was taken at zero and designated time intervals. An examination of the growth curve (A) in Figure 33 indicates that the survival time is approximately two weeks. Similar results were obtained when the experiment selected was repeated (B). S. typhimurium colonies possess a distinct morphology and exhibit a black pigment on HE agar. Suspicious colonies were selected, cultured on TSI, and urea broth verified by a slide agglutination with somatic (Type O) antisera.

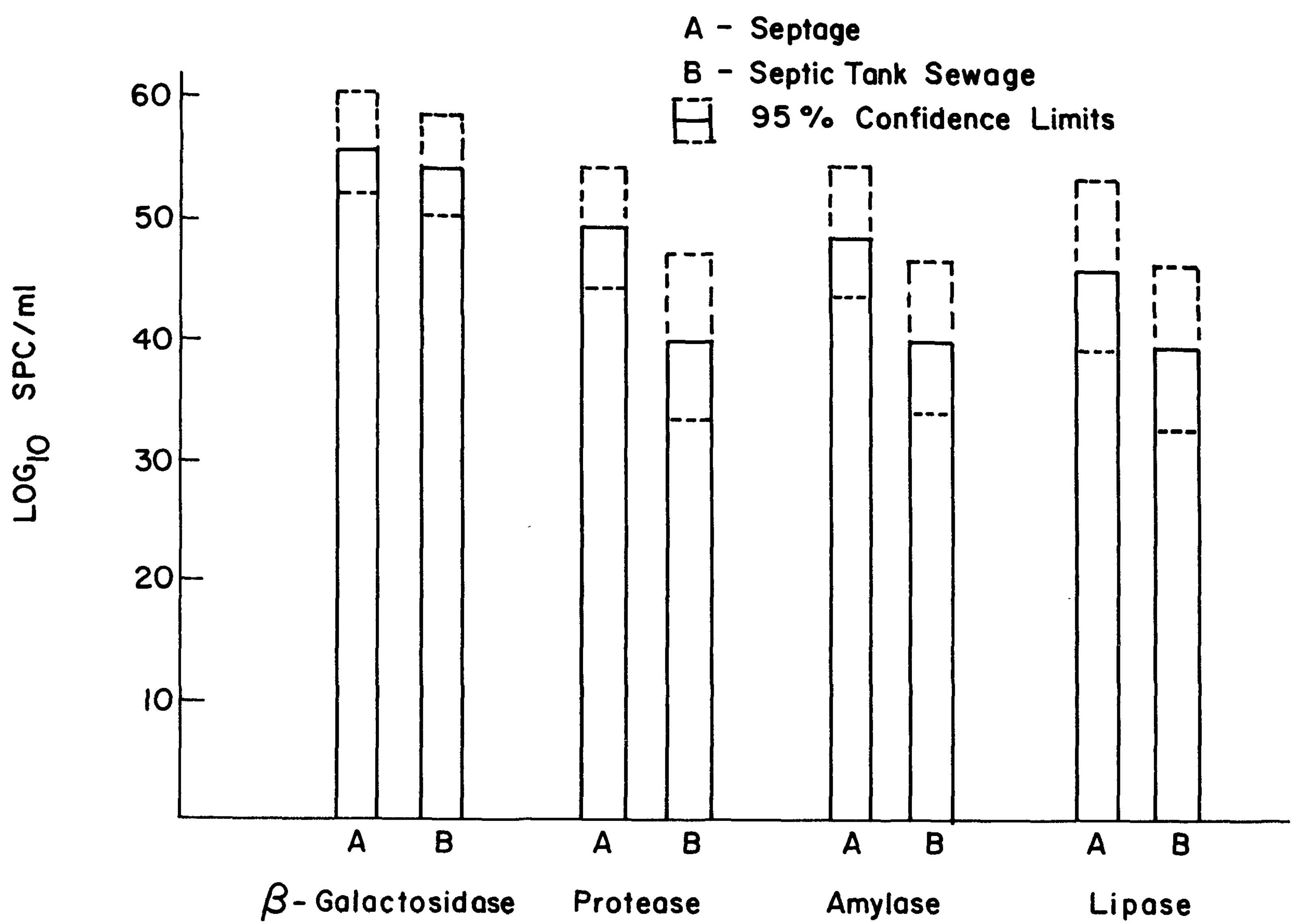


Figure 29. Comparative enumeration with selected physiological activities with 95 percent confidence limits.

Table 7. SIGNIFICANCE TESTS (t)[a] COMPARING SEPTAGE AND SEPTIC TANK SEWAGE USING 12 PAIRED OBSERVATIONS.

	Value of t statistic	Significance at 0.95
Aerobic	0.72	-
Anaerobic	2.05	-
Synthetic	0.22	-
Escherichia coli	2.00	-
Lactose fermenters	0.49	-
Non-lactose fermenters	1.50	-
Protease	2.45	+
Amylase	2.97	+
Lipase	2.01	-
Ammonia level	4.40	+
Organic N_2 level	2.96	+
Reducing sugar level	1.49	-
Nitrate level	1.20	-

[a]Significance level for t values = 2.20.

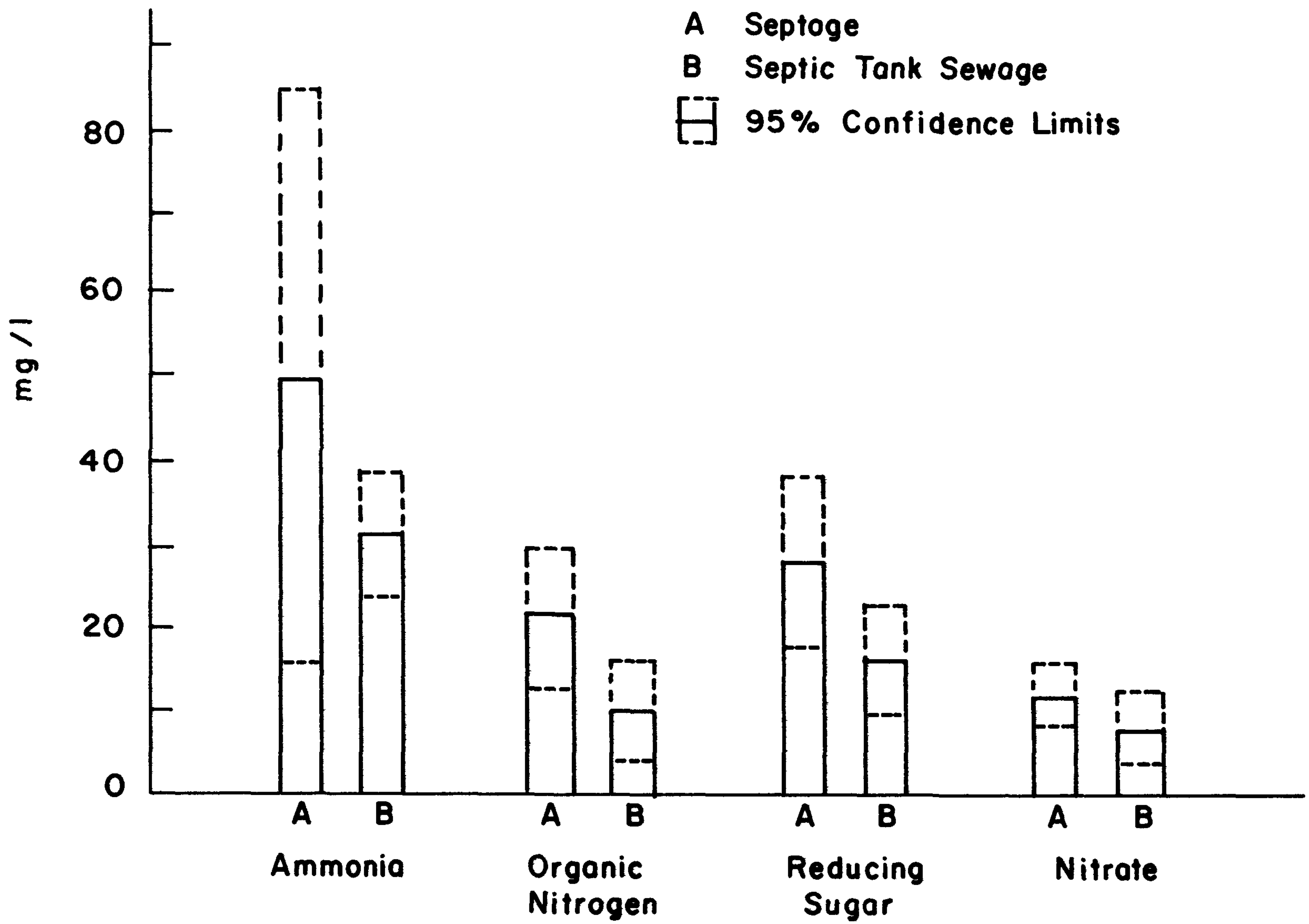


Figure 30. Comparative distribution of substrate levels with 95 percent confidence limits.

Table 8. NITRATE CONCENTRATION IN SEPTIC TANK SEWAGE.

	Methods Employed			
Sample	Reductive Hydrazine mg/l	Direct UV mg/l	Brucine Sulfanilic Acid mg/l	Nitrate Specific Ion Electrode mg/l
1	1.3	6.0	11.1	3.5
2	4.4	6.6	10.2	4.3
3	2.2	2.2	3.0	2.8
4	4.9	15.2	13.2	4.2
5	1.8	3.2	3.1	3.1

Table 9. REDUCTION TIME IN HOURS OF SEPTAGE AND SEWAGE.

	Redox Indicator					
	Resazurin		Methylene Blue		Indigo Carmine	
Sample	March	April	March	April	March	April
Septage	4	5	5	5	5	5
Septic Tank Sewage	--[a]	--	6	21	14	21
Raw Domestic Sewage	--	--	21	17	--	21

[a]-- indicates no reduction after two weeks.

Table 10. METHYLENE BLUE REDUCTION TIME AND SELECTED ACTIVITIES OF SEPTIC TANK SEWAGE.

Daily samples	Reduction time (hours)	SPC/ml	NH_3 mg/l	Organic-N mg/l	pH
1	18	$1.8x10^5$	29.4	3.8	7.0
2	17	$1.8x10^6$	28.0	3.5	6.7
3	16	$6.9x10^5$	28.2	14.7	6.8
4	17	$5.9x10^5$	40.7	8.9	6.6
5	16	$2.5x10^6$	35.0	7.0	6.7
6	14	$1.1x10^5$	28.6	12.2	7.0
7	15	$7.7x10^5$	-	11.0	6.8

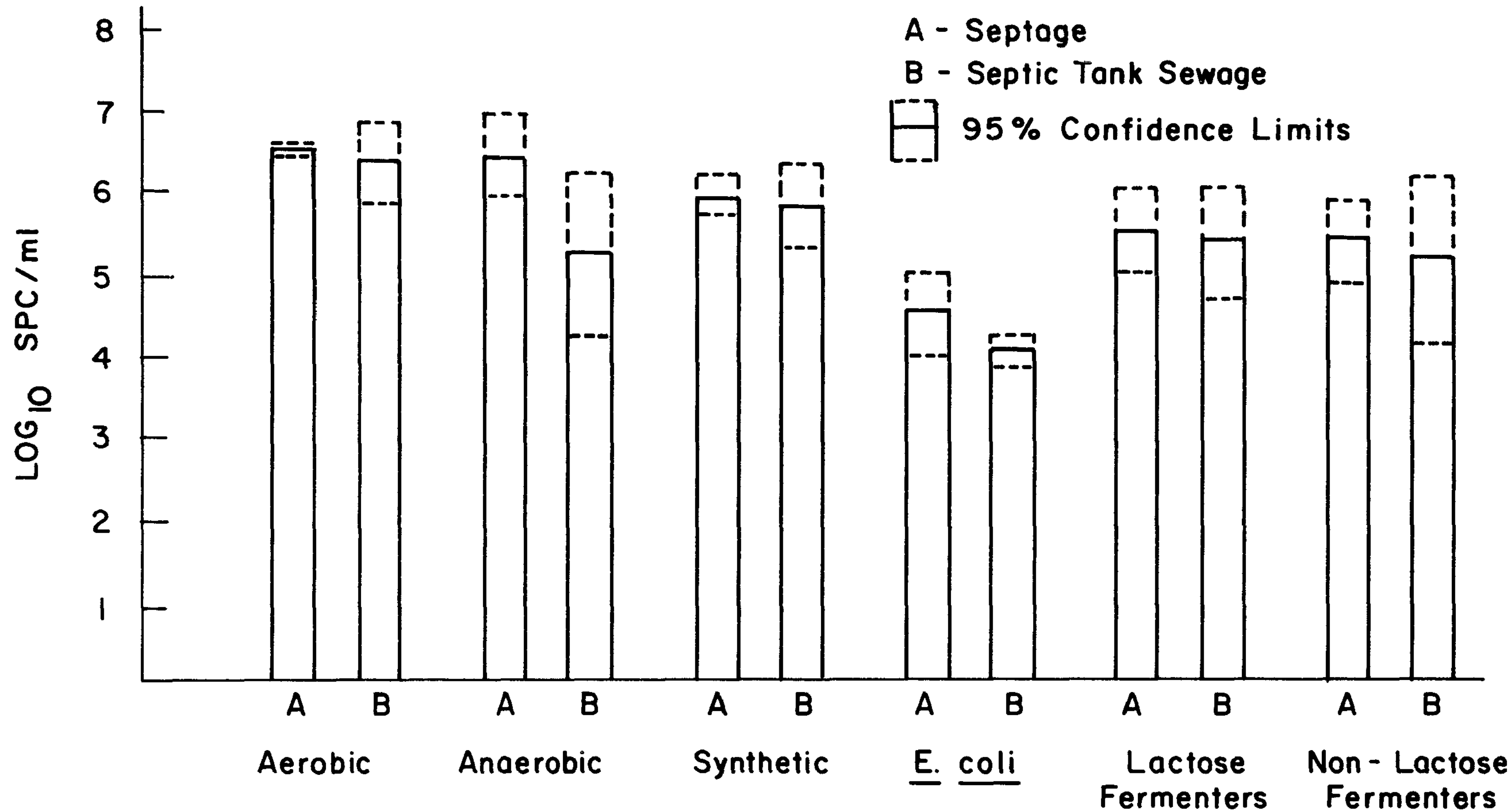


Figure 31. Comparative enumeration of selected physiological activities with 95 percent confidence limits.

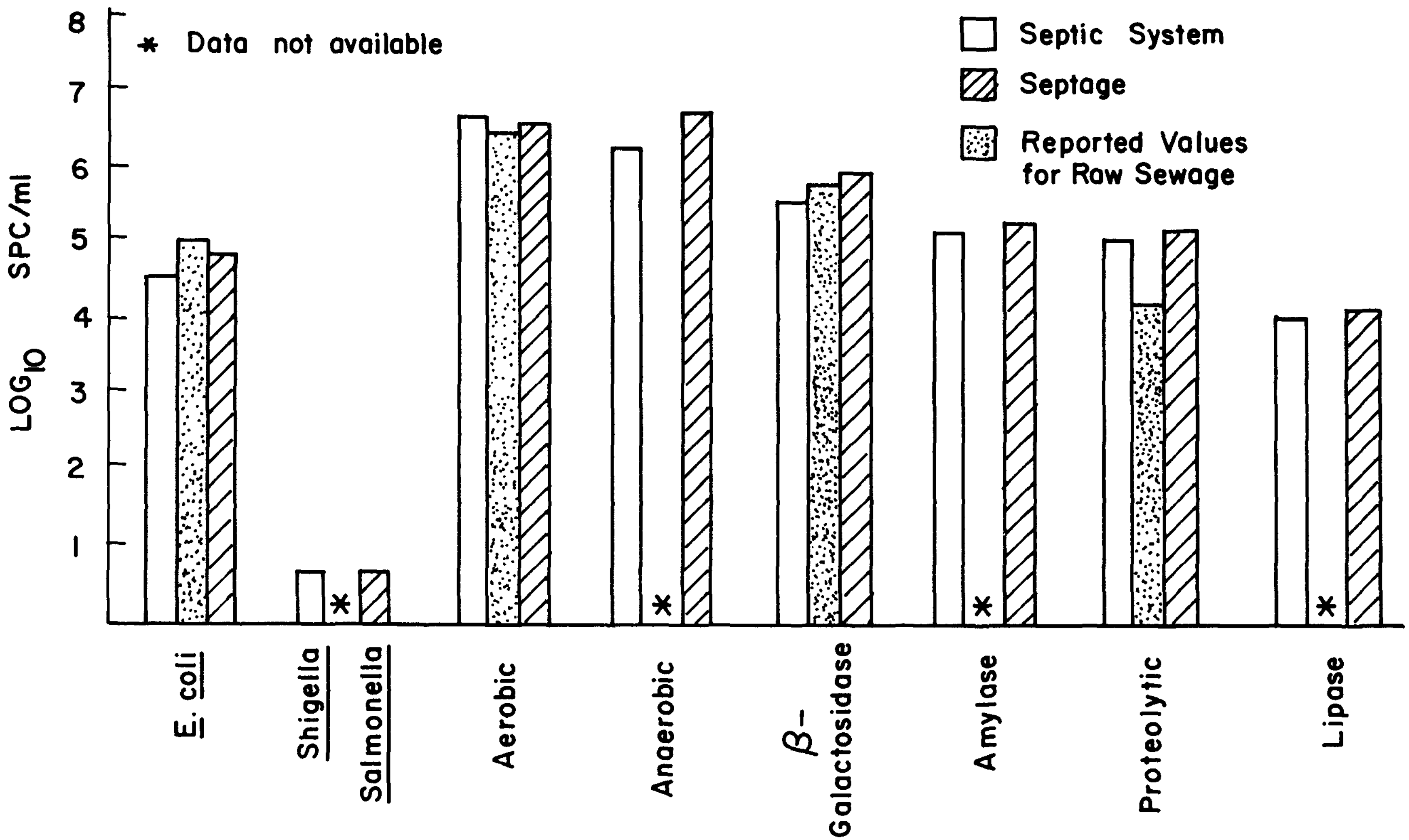


Figure 32. Comparative distribution of specific types of microorganisms and their physiological activities.

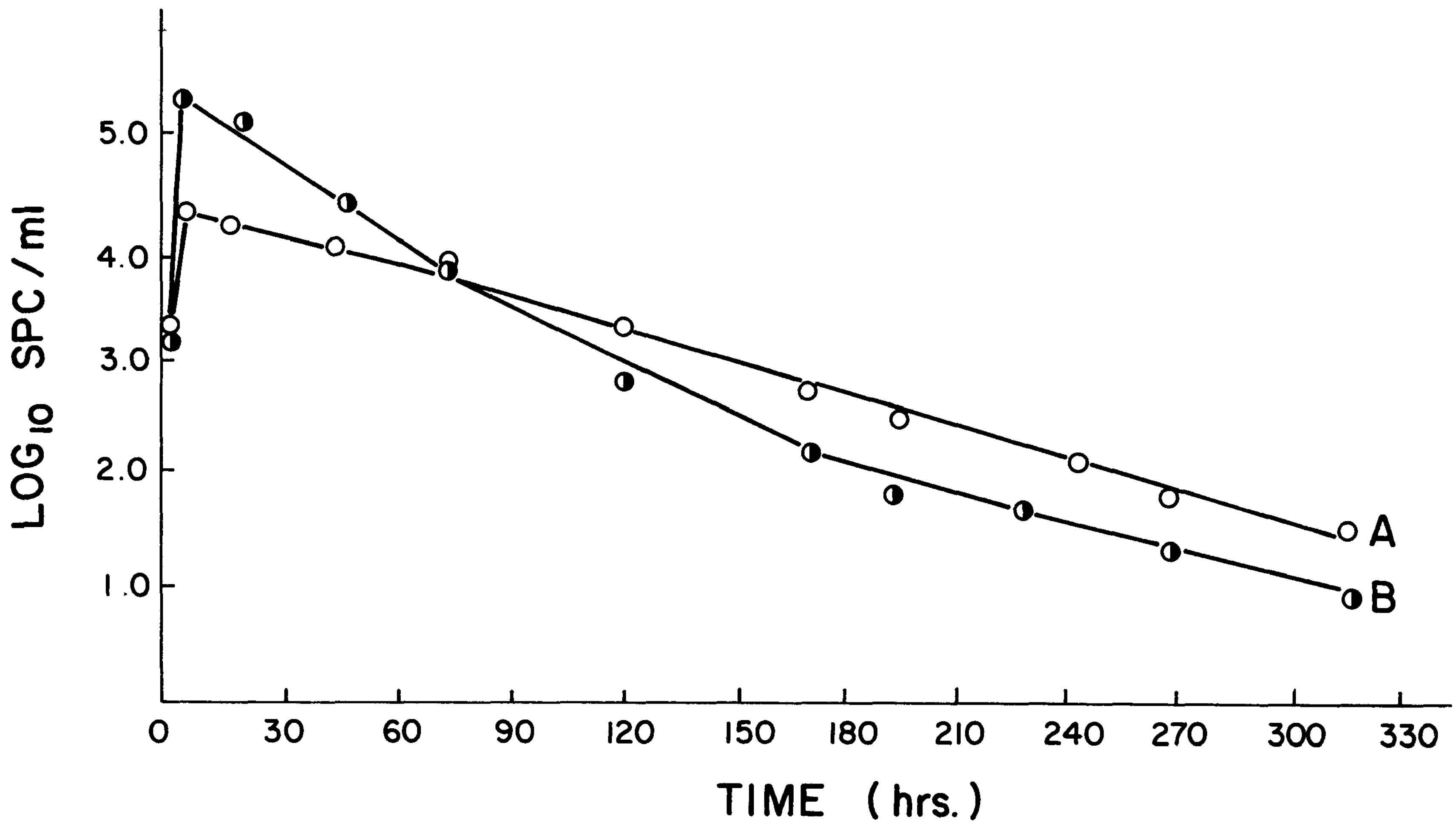


Figure 33. Survival curves of Salmonella Typhimurium in septic tank sewage.

Although investigators (Gaub, 1924 and Maki, 1953) have recovered cellulolytic bacteria from various stages of sewage treatment, especially primary digesters, these microorganisms were not isolated from septage and/or septic tank sewage under aerobic or anaerobic conditions.

Dissolved oxygen level of the incoming wastewater when combined with mixing at the inlet may provide conditions for growth of aerobic type bacteria. Another possibility exists in that the septic tank may act as a chemostat. The displacement of effluent by influent may provide a constant number of aerobic types. In this situation, a resident flora would exist. Oxidative bacteria especially Pseudomonads and related forms are capable of degrading detergents and lipids, a desirable feature of the system.

Growth chamber studies dealt with one aspect of microbiology frequently bypassed--the study of mixed cultures. These studies were limited to the determination of acceptable membrane filter pore sizes for bacteriological use. Membrane filters with pore sizes of 0.22 u and 0.45 u were found to be acceptable. The technique developed is one which may contribute to the progress of research in this area.

LAND DISPOSAL

Preliminary Studies

In a preliminary study to determine biological effects of injecting septage into the soil, two standard microbiological methods were selected for rapid assessment of the land site, (1) total viable counts on TGYE and (2) enumeration of fecal indicators. Counts were established for the control area. Total counts (SPC/g) at the 3, 6, 12, and 20 inch (7.6, 15.2, 30.5, and 50.8 centimeters) depths were as follows: 850,000, 330,000, 240,000, 240,000, and fecal counts were less than 20 per gram of soil.

After introducing septage, samples were collected and counts were made at 24, 48, 72, and 144 hours. The data are presented in Tables 11 and 12. Examination of the data show lateral and vertical movement of bacterial population in the soil. (This was of particular interest since the advantage of this method of injection were the fracture lines as avenues of liquid movement and may also provide more efficient filtration of wastewater.) The northern points exhibit greater lateral movement of septage than the southern. Bacterial counts at the center indicate vertical seepage as well as lateral movements. The counts obtained from samples collected at points 0 and 25 differ. The differences suggest that the loading procedure was ineffective in delivering the septage into the soil uniformly.

Approximately two weeks later, samples were drawn at 6 and 9 inch depths at weekly intervals. The plot was monitored by viable count and by fecal coliform enumeration. The counts presented in Table 13 demonstrated that the fecal coliform survival time in soil was short and both viable counts and fecal counts decreased at lower depths and laterally. The decrease may be attributed to the competition with normal flora, inhibitors present in the soil, lack of essential nutrients for growth, or its filtering capacity.

Table 11. COMPARISON OF VIABLE COUNTS (SPC/g) FROM SEPTAGE SAMPLES INTRODUCED IN SOIL AT POINT 0 ON AUGUST 11, 1970.

Location		24 hrs.	48 hrs.	72 hrs.	144 hrs.
Center	3"	1,000,000	---	---	---
	6"	370,000	---	---	---
1'3" South	3"	370,000	---	---	---
	6"	170,000	---	---	---
1'6" South	3"	---	540,000	---	---
	6"	---	420,000	---	---
2'6" South	3"	---	40,000,000	---	---
	6"	---	28,000,000	---	---
3' South	3"	---	---	450,000	---
	6"	---	---	6,000,000	---
3'2" South	3"	---	---	---	230,000
	6"	---	---	---	270,000
1' North	3"	370,000	---	---	---
	6"	160,000	---	---	---
1'6" North	3"	---	22,000,000	---	---
	6"	---	3,200,000	---	---
2'6" North	3"	---	7,300,000	---	---
	6"	---	580,000	---	---
3' North	3"	---	---	330,000	---
	6"	---	---	570,000	---
3'6" North	3"	---	---	---	660,000
	6"	---	---	---	540,000

Table 12. COMPARISON OF VIABLE COUNTS (SPC/g) FROM SEPTAGE SAMPLES INTRODUCED IN SOIL AT POINT 25 ON AUGUST 11, 1970.

Location		24 hrs.	48 hrs.	72 hrs.	144 hrs.
Center	6"	9,400,000	LA(1)	21,000,000	180,000,000
	9"	74,000,000	250,000,000	240,000,000	120,000,000
1'3" South	6"	3,200,000	---	---	---
	9"	510,000	---	---	---
1'6" South	3"	---	900,000	---	---
	6"	---	50,000	---	---
2'3" South	3"	---	---	950,000	---
	6"	---	---	520,000	---
3' South	3"	---	---	---	---
	6"	---	---	---	6,100,000
1' North	6"	720,000	---	---	---
	9"	3,700,000	---	---	---
2' North	6"	360,000	---	---	---
	9"	440,000	---	---	---
1'6" North	3"	---	640,000	---	---
	6"	---	1,300,000	---	---
2'6" North	3"	---	850,000	---	---
	6"	---	18,000,000	---	---
3' North	3"	---	---	320,000	---
	6"	---	---	9,000,000	---
3'6" North	3"	---	---	---	11,000,000
	6"	---	---	---	5,700,000

(1) Laboratory accident

Table 13. COUNT DISTRIBUTION AFTER INITIAL SEPTAGE SUBSOIL INJECTION.

Location Point 0

Sample Location		8/27/70	9/2/70 SPC/g of Soil	9/10/70
Center	6"	77,000,000 (230,000)	20,000,000 (43,000)	12,000,000 (10)
	9"	190,000,000	12,000,000 (58,000)	70,000,000 (9,000)
1[1] South	6"	32,000,000	---	4,300,000
2[1] South	3"	---	11,000,000	---
	6"	27,000,000	---	---
1[1] North	6"	180,000,000	---	7,300,000
	9"	---	---	10,000,000
2[1] North	3"	---	1,900,000	---
	6"	6,500,000	2,000,000	---

Control Area		Viable Count/Gram of Soil
	3"	21,000,000
	6"	77,000,000
	9"	10,500,000

Location Point 25

Sample Location		8/27/70	9/2/70	9/10/70
Center	6"	6,500,000 (160,000,000)	260,000,000 (33,000,000)	11,100,000 (10)
	9"	144,000,000	110,000,000 (10,000,000)	56,000,000 (10)
1[1] South	6"	3,500,000	28,000,000	6,500,000
	9"	3,900,000	---	30,000,000
2[1] South	6"	9,700,000	40,000,000	---
	9"	5,000,000	24,000,000	---
1[1] North	6"	30,000,000	50,000,000	4,500,000
		86,000,000	89,000,000	25,000,000
2[1] North	6"	4,500,000	15,000,000	---
	9"	8,000,000	67,000,000	---

[1] Center refers to the center of the septage deposition line. The North and South points are measured from the center of the deposition line.

Table 14. COUNT DISTRIBUTION (SPC/g OF SOIL) ON TGYE AND ENUMERATION OF FECAL COLIFORMS AFTER SECOND APPLICATION OF SEPTAGE.

Collection Date	Sample Location: O C 9"	O S 9"	O N 9"	O C 18"	O S 18"	O N 18"
10/10/70	1.5×10^9 (3000)	8.0×10^8	1.7×10^9	1.2×10^9 (10)	6.7×10^9	1.3×10^9
10/15/70	1.2×10^9 (10)	4.5×10^{10}	8.8×10^9	7.0×10^{10} (10)	1.2×10^{10}	9.7×10^{10}
10/21/70	6.5×10^7 (10)	4.2×10^6	2.6×10^6	1.8×10^7 (10)	4.1×10^6	LA
10/29/70	2.3×10^7 (10)	1.9×10^7	1.6×10^8	8.5×10^7 (10)	1.2×10^8	3.5×10^7
11/6/70	1.6×10^7 (10)	4.7×10^5	6.6×10^5	5.7×10^6 (10)	3.7×10^6	6.2×10^5
11/11/70	1.5×10^7 (100)	4.7×10^5	2.5×10^5	1.4×10^5 (10)	3.0×10^4	1.5×10^4
11/19/70	1.8×10^7 (10)	3.1×10^5	3.8×10^5	7.7×10^4 (10)	4.0×10^6	9.9×10^4

LA - Laboratory accident

Table 14 (continued). COUNT DISTRIBUTION (SPC/g OF SOIL) ON TGYE AND ENUMERATION OF FECAL COLIFORMS AFTER SECOND APPLICATION OF SEPTAGE.

Collection Date	Sample Location: 25' C 9"	25' S 9"	25' N 9"	25' C 18"	25' S 18"	25' N 18"
10/10/70	1.8×10^{9} (70)	1.9×10^{9}	1.5×10^{9}	8.2×10^{7} (20)	5.0×10^{9}	1.0×10^{10}
10/15/70	6.3×10^{7} (10)	2.1×10^{6}	5.0×10^{5}	2.0×10^{7} (10)	1.6×10^{6}	1.8×10^{6}
10/21/70	7.0×10^{6} (10)	2.8×10^{6}	3.0×10^{6}	8.7×10^{5} (10)	1.5×10^{6}	4.8×10^{6}
10/29/70	8.0×10^{7} (20)	3.8×10^{5}	1.2×10^{6}	1.5×10^{5} (10)	1.6×10^{5}	1.6×10^{5}
11/6/70	7.9×10^{6} (10)	6.7×10^{5}	6.0×10^{5}	7.9×10^{5} (10)	2.6×10^{5}	4.9×10^{5}
11/11/70	1.3×10^{7} (10)	9.6×10^{5}	1.0×10^{6}	7.6×10^{5} (10)	8.5×10^{4}	4.0×10^{5}
11/19/70	9.3×10^{6} (10)	7.3×10^{5}	7.4×10^{5}	1.9×10^{7} (10)	6.3×10^{4}	6.1×10^{4}

Table 15. OBSERVATION WELL DATA FOR THE WHITE MEMORIAL FOUNDATION, LITCHFIELD SEPTAGE SOIL INJECTION EXPERIMENTAL SITE.

Observation Period	Observation Wells	Chloride ppm	COD mg/l	pH	Nitrate-N ppm	Phosphate ppm
Weeks preceding application						
6	U	---	---	---	---	---
	C	5.6	10.0	7.1	1.5	0.4
	L	24.6	6.0	7.3	0.4	1.0
4	U	---	---	---	---	---
	C	7.0	19.2	8.7	1.3	1.2
	L	24.8	14.2	8.2	1.3	2.9
2	U	---	---	---	---	---
	C	6.0	19.2	8.0	0.3	2.1
	L	6.0	15.8	8.2	0.3	2.3
Weeks after initial septage application						
0	U	4.7	8.4	7.1	0.3	1.1
	C	6.0	12.6	7.7	0.1	1.0
	L	20.8	16.8	7.6	0.1	0.2
2	U	4.5	19.2	6.7	0.5	1.1
	C	6.4	18.6	7.0	0.3	0.7
	L	3.2	15.2	6.9	1.0	2.4
3	U	---	---	---	---	---
	C	5.1	22.7	7.0	1.5	0.2
	L	22.4	19.2	6.9	0.1	0.3
6	U	7.5	12.0	7.1	0.7	1.0
	C	8.0	16.0	7.6	0.3	0.9
	L	4.0	8.0	7.7	0.0	0.4
7	U	5.5	21.0	8.3	0.1	2.5
	C	8.5	25.0	7.7	0.1	0.2
	L	27.0	12.0	7.8	0.7	0.9
8	U	6.5	14.0	7.4	0.0	0.6
	C	6.5	8.0	7.8	0.0	0.6
	L	23.0	10.0	7.8	0.9	0.4

Table 15 (continued). OBSERVATION WELL DATA FOR THE WHITE MEMORIAL FOUNDATION, LITCHFIELD SEPTAGE SOIL INJECTION EXPERIMENTAL SITE.

Weeks after initial septage application	Observation Wells	Chloride ppm	COD mg/l	pH	Nitrate-N ppm	Phosphate ppm
9	U	6.0	15.0	7.2	0.3	2.6
	C	6.0	8.0	7.7	0.0	0.6
	L	---	---	---	---	---
10	U	3.0	14.7	7.8	0.4	0.5
	C	5.0	7.3	8.5	0.2	0.4
	L	11.0	9.8	8.6	0.1	0.1
11	U	3.9	21.0	7.6	0.0	0.8
	C	7.3	16.0	8.4	0.1	0.7
	L	12.0	21.0	7.9	0.1	0.3
12	U	3.3	12.2	7.7	0.1	0.5
	C	6.4	19.6	8.5	0.1	0.7
	L	10.3	25.4	8.2	0.1	0.3
	Septage Applications Ceased					
13	U	3.4	18.5	7.8	0.1	0.5
	C	6.4	18.5	8.2	0.2	0.2
	L	12.3	14.2	7.9	0.1	0.3
14	U	4.7	17.3	7.6	0.1	0.4
	C	7.5	18.5	8.2	0.1	0.6
	L	14.1	24.0	7.7	0.1	0.3
15	U	5.1	12.0	7.3	0.1	0.2
	C	9.2	12.7	8.0	0.2	0.1
	L	13.6	14.0	7.6	0.2	0.1
16	U	5.3	7.6	7.4	0.1	0.5
	C	7.2	8.1	8.1	0.1	0.3
	L	12.7	7.9	7.6	0.1	0.2
20	U	8.6	7.6	7.5	0.0	0.1
	C	8.2	7.7	8.1	0.0	0.1
	L	11.9	7.8	7.8	0.0	0.1

Key:
U - Upper wells
C - Center wells
L - Lower wells

Generally, trends in lateral distribution were not well defined, but a slight reduction in numbers of viable cells was observed.

An additional injection of septage at the same location rendered essentially the same trends over one-month period. This is shown in Table 14.

Experimental Site

During the twelve-week application period, approximately 120,000 gallons of septage were received and injected. The nitrogen equivalent of the total septage volume that was applied was about 43 lbs/acre. The results shown below are in agreement with the predicted or forecasted result that there would not be any detrimental effect on the ground water. The field equipment proved to be serviceable and no serious equipment problems were encountered.

Observations, Table 15, made during the summer and fall on the concentrations of chloride, COD, nitrate-N, phosphate and hydrogen ion (pH) in the soil water show no significant effects of the septage applications. Concentration levels fluctuated but no trends that could be related to septage applications were observed.

Weekly checks were made for fecal coliforms on the ground water samples during this period. Except for one sample, there were no fecal coliforms found in the water samples analyzed throughout the entire reporting period. This single incidence of contamination was from one of the two upper observation wells. The positive observation occurred during the second week of septage application and may have been due to contamination picked up during sampling.

Averages of observations for the period preceding septage application, for the twelve weeks of application, and for the eight weeks after application that ended in the late fall are shown in Table 16.

TABLE 16. TEST WELL OBSERVATION DATA SUMMARY

Parameter	Unit of Measure	6 Weeks Preceding Application	12 Weeks During Application	8 Weeks Subsequent to Application
Chloride	ppm	11.7	8.5	8.7
COD	mg/1	13.6	15.6	13.1
Nitrate-N	ppm	0.6	0.3	0.1
Phosphate	ppm	1.4	0.8	0.3

Averages for observations made during the following spring--chloride, 5 ppm; COD, 21.4 mg/l; nitrate-N, 0; and phosphate, .7 ppm--showed no significant differences that could be attributed to the earlier septage applications.

Thus, the pilot study demonstrated that soil injection of septage can be a feasible disposal method. Further investigations are required both in terms of an increase in the rate of septage application and to discover any long-term effects on ground water quality from continued application of septage to a given plot of land. Additional information should also be obtained on the effects on crop responses on land on which septage has been applied. The findings in the present study provide evidence that if the septage application rate is controlled, this recycling scheme can be used as a means for disposing of septage or other comparable biodegradable materials.

Land Disposal Equipment Appraisal

The equipment performance was satisfactory for experimental purposes and demonstrated the feasibility of soil injection as an acceptable method for septage disposal. The study was conducted under research controls and objectives which are different from those that may be encountered under publicly managed operating conditions.

The plow-furrow-cover (P-F-C) method is preferred to either of the subsoil-injection (S-S-I) methods. With the subsod injection method, a sod cover is required and the frequency of equipment access to the field site is less because of field techniques used. More corrective work on the Terreator would be required before its performance could be evaluated. There is uncertainty as to whether the vibrating action from the Terreator had a beneficial effect in the septage soil injection operation. However, the flexibility for depth control of septage application may be an advantage of the Terreator. It also appeared that this unit might be capable of performing under more rugged soil terrain than the P-F-C and the subsod units. The heavier weight of the Terreator, 570 lbs (259 Kg), may be a disadvantage.

Instead of a research-oriented, multipurpose tank-trailer, a tank-trailer unit should be designed specifically for the injection of septage. Suggested modifications are as follows:

(1) A larger tank-trailer would be advantageous. An increased transport tank size will decrease the number of trips necessary from the septage receiving tank area to the land disposal area and in turn will result in a more efficient operation. The minimum suggested tank size is 1500-2000 gallons (5678-7570 liters) as compared to the 800 gallon (3028 liters) unit used.

(2) Flotation tires should be used on the tank-trailer to minimize compaction of the soil.

(3) Suggested changes in the experimental tank-trailer.

    (a) The control levers on the tank-trailer unit should be relocated on the tractor where they can be more readily accessible to the operator. Refinements can also be made in the overall hydraulic system.

(b) With the P-F-C method, there was an occasional splashing of septage on the plowed ground. This can be overcome by improving the septage hose delivery system from the tank-trailer to the furrow.

(c) The S-S-I units could be located on the gooseneck tongue. This would simplify the delivery of slurry from the tank-trailer to an S-S-I unit.

(d) It was necessary to remove the initial jack provided with the tank-trailer. A jack to permit easier connection between the tank-trailer and hauling tractor is desirable. It is also, perhaps, a needed safety factor in equipment design.

(e) If both the P-F-C and S-S-I units are to be used interchangeably, a mast having a three-point hitch to permit mounting these units would contribute to a saving in equipment changeover time.

(f) The surge braking system did not operate satisfactorily when the tank-trailer was carrying a load. Reconstruction of the braking system is suggested.

(g) Although one position of the trailer-axle was used for most of the field studies conducted, the adjustment for changing the angle of the trailer could be improved.

ANAEROBIC-AEROBIC: BENCH SCALE STUDY

The sample points were: (1) septage feed; (2) heated anaerobic digester supernatant (feed to the aeration tank); (3) mixed liquor in the aeration tank, and (4) sand filter effluent. Figures 34 through 43 show measurements versus time for parameters that define the efficiency of this treatment system.

The BOD_5 and COD concentrations in the septage feeds varied considerably. However, the BOD_5 and COD concentrations in the digester effluents (anaerobic supernatant) aerations tanks were relatively constant. Thus, this septage treatment system can apparently withstand shock loading effects. Both the BOD_5 and COD concentrations were reduced more than 95 percent. The BOD_5 and COD concentrations in the sand filter effluents (percolate sample) were approximately 40 mg/l and 100 mg/l, respectively. Both BOD_5 and COD concentrations in the septage feed were greater than 3,000 mg/l.

The changes in ammonia-nitrogen and total Kjeldahl-nitrogen concentrations after each stage of treatment are shown in Figures 36 and 37. Both ammonia-nitrogen and Kjeldahl-nitrogen concentrations decreased progressively after each treatment stage. The total ammonia-nitrogen removal was approximately 92 percent, for total Kjeldahl-nitrogen approximately 93 percent.

The total solids content in septage ranged from 0.3 percent to 8 percent, Figure 38. The total solids removed by the heated anaerobic digester

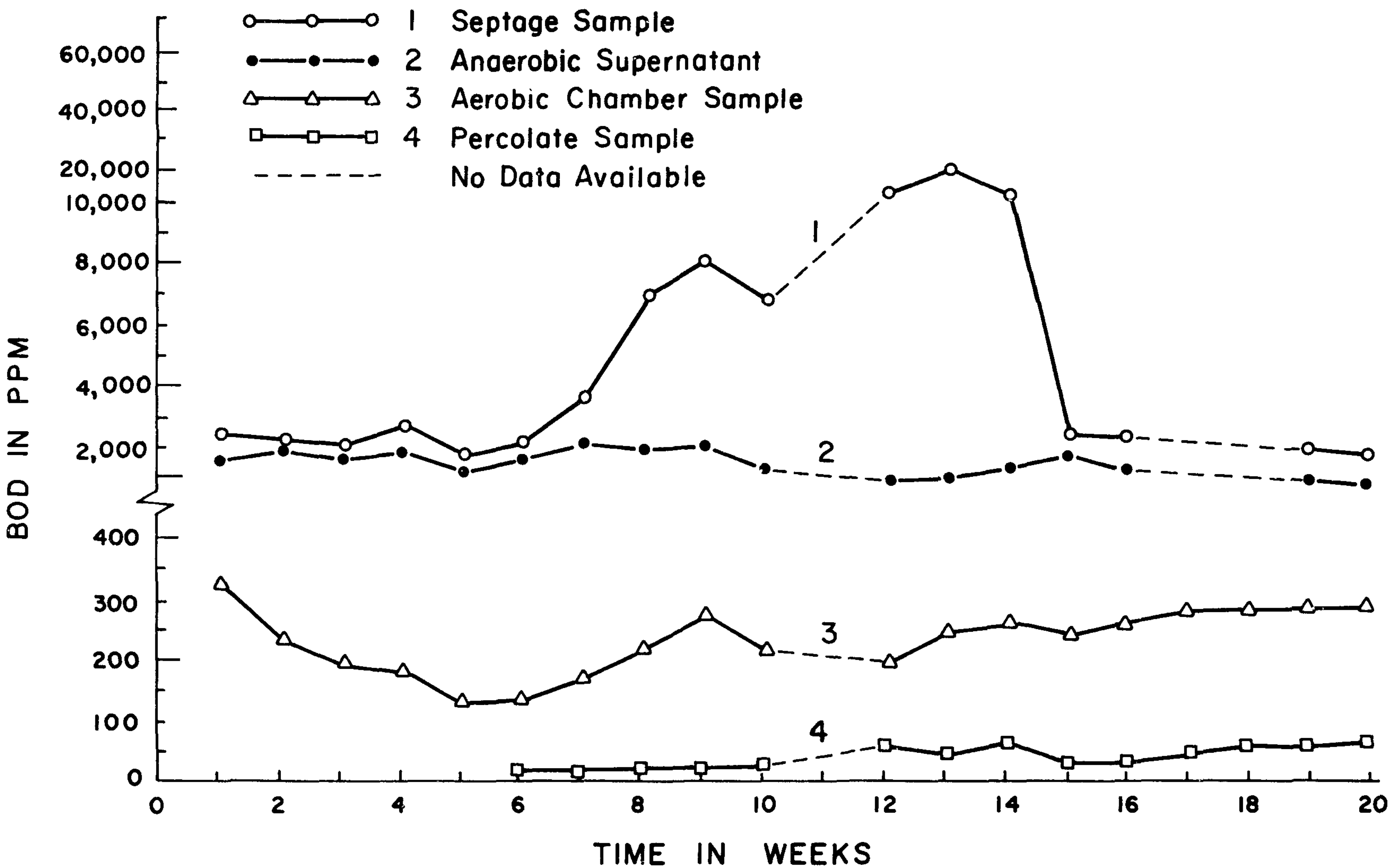


FIG. 2 Biochemical Oxygen Demand Of System

Figure 34. Bench scale: Biochemical oxygen demand reduction by system.

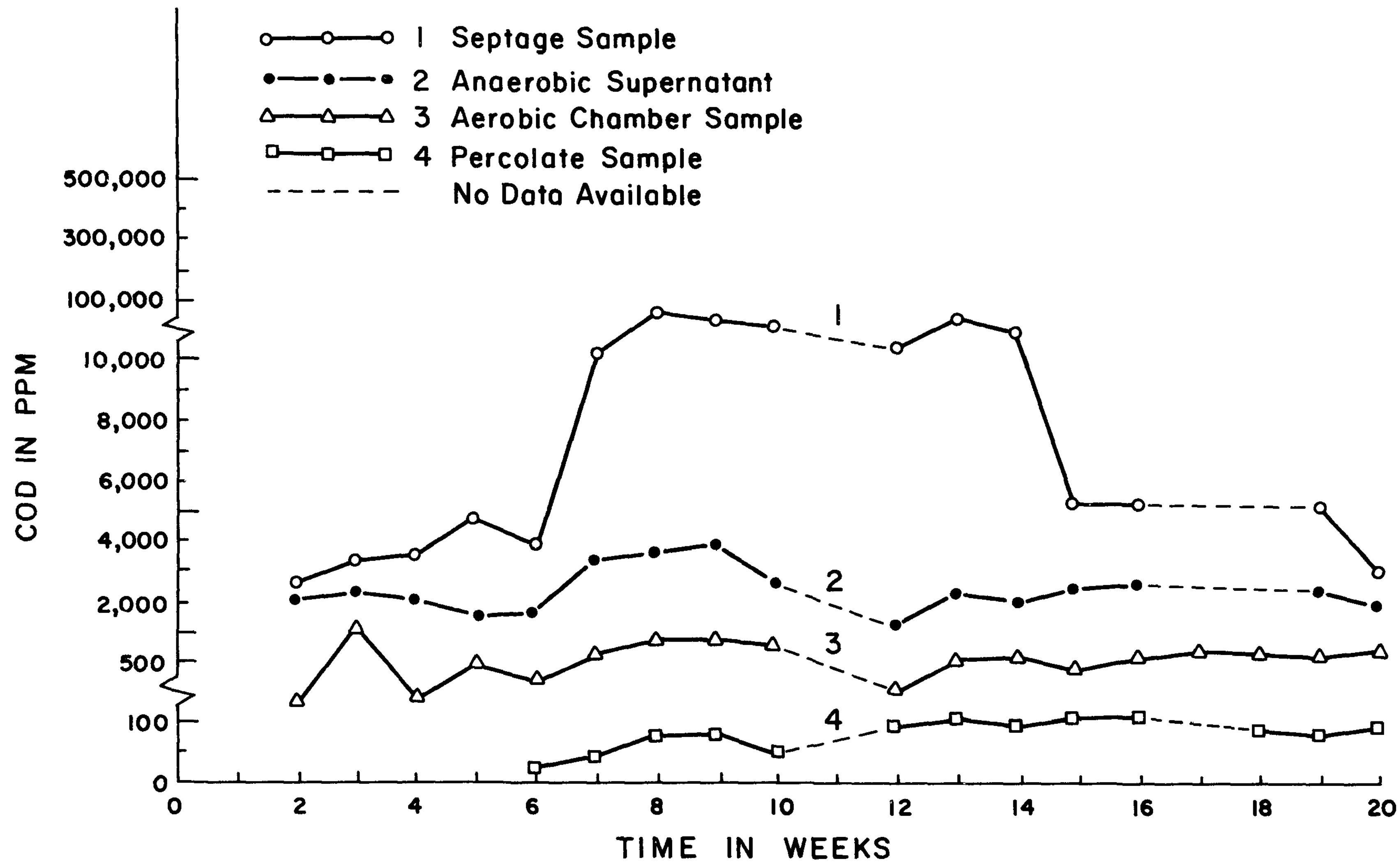


FIG. 3 Chemical Oxygen Demand Of System

Figure 35. Bench scale: Chemical oxygen demand reduction by system.

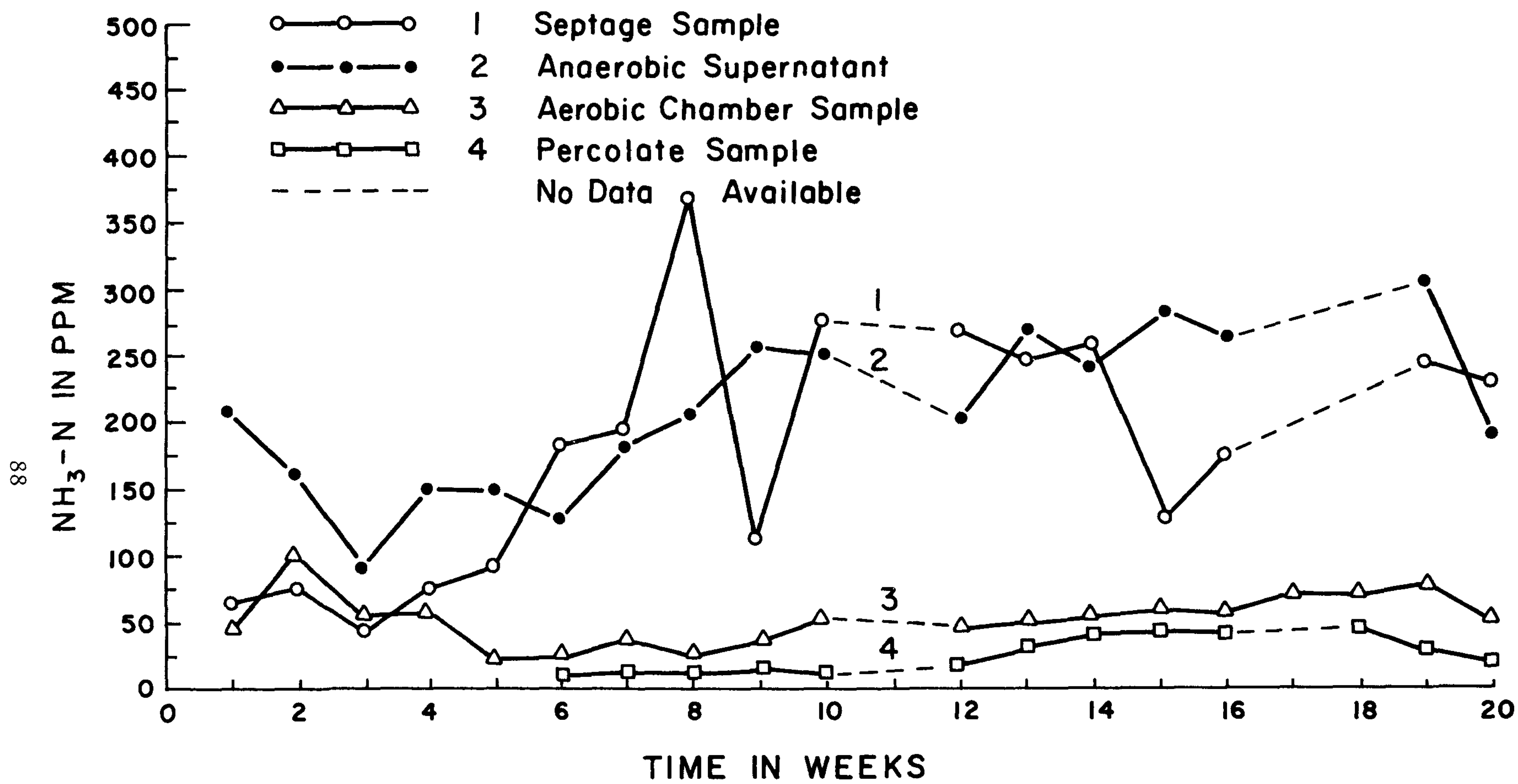


Figure 36. Bench scale: Ammonia nitrogen of system.

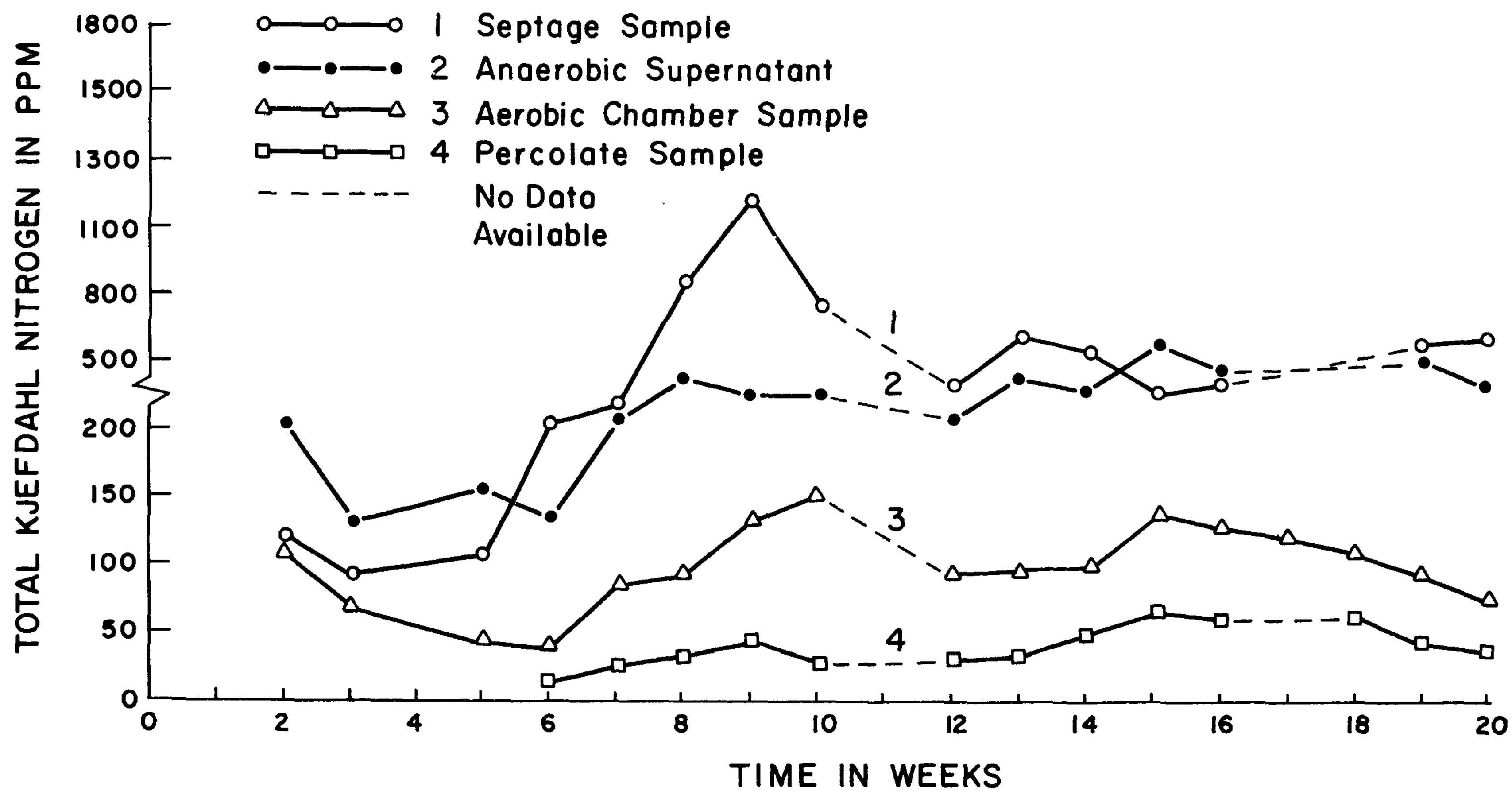


Figure 37. Bench scale: Total Kjeldahl nitrogen of system.

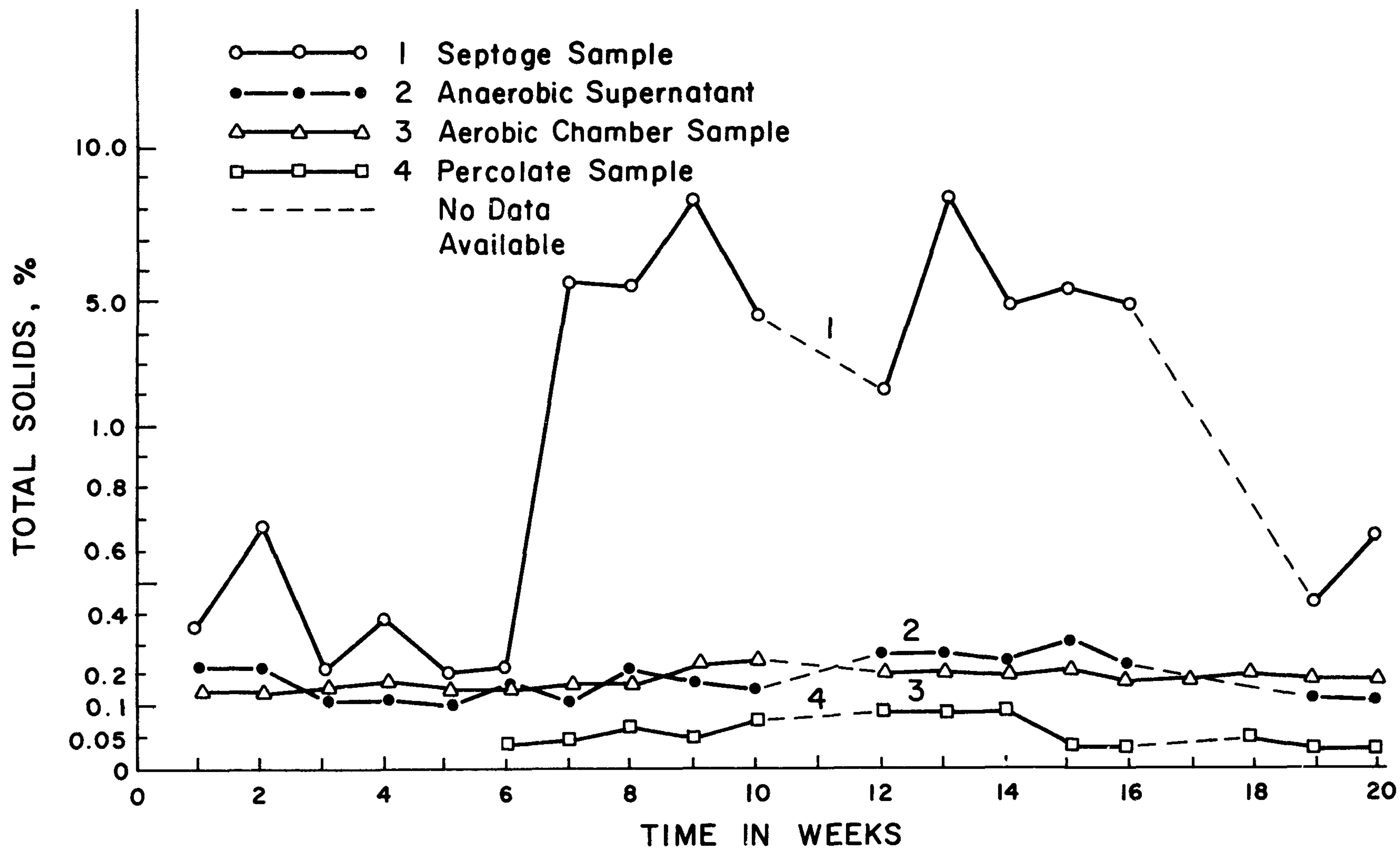


FIG. 6. Total Solids Of Systems

Figure 38. Bench scale: Total solids reduction by system.

was greater than 93 percent. The total solids content was reduced slightly after aerobic treatment. However, sand filtration resulted in a further decrease in total solid content to approximately 0.05 percent in the effluent. Volatile solids were also removed in each treatment stage. The overall reduction was approximately 36 percent, Figure 39.

The total phosphate removed was low until the aerobic effluent was filtered through a one-foot (30 centimeter) tall, 4-inch diameter (10 centimeter) sand bed column. The total phosphate concentration was reduced 92 percent, Figure 40.

The nitrate-nitrogen concentration in septage and the digester effluent were approximately 1 mg/l, Figure 41. The nitrate-nitrogen concentrations after aerobic treatment and in the sand filter effluent increased to over 100 mg/l after four weeks of operations. Simultaneously, after several weeks of operations the D.O. concentration in the aerobic treatment increased to and leveled off between 6 and 7 mg/l, Figure 42. Figure 43 shows that the pH was decreased and corresponding increase in nitrate-nitrogen concentration is due to oxidation (nitrification) of ammonia-nitrogen. One procedure for controlling nitrate-nitrogen production would be to reduce the D.O. concentration in the aerobic tank to less than 2 mg/l. This procedure would leave a relatively high concentration of ammonia-nitrogen in the final effluent. Another approach would be to add methanol to the sand filter influent to promote biological denitrification in the sand filter. The latter procedure may be preferable where the sand filter effluent is either discharged to a stream, or percolated; and the buildup of nitrate-nitrogen or a D.O. sag in a receiving stream would be undesirable.

The fecal coliform MPN in septage varied considerably. However, these organisms were not detected in the final effluents. It also was observed that a limited number of aerobic microorganisms were present in septage. Apparently some of these microorganisms are carried over into the aerobic treatment. To follow the movement of aerobic microorganisms, an examination of the aerobic system was conducted. Weekly samples were taken from the aerobic tank. Viable counts were recorded on Tryptone Glucose Yeast Extract Agar (TGYE). During a 6-week period, the MPN ranged from 1-9 million bacteria/ml. Heterotrophic types were selected, checked for purity and identified using conventional microbiological techniques. The generic distribution of 88 isolates were as follows: *Alcaligenes*, 52.3; *Flavobacterium*, 4.8; *Bacillus*, 11.3; *Enterobacter*, 4.5; *Pseudomonas*, 2.2; *Micrococci*, 15.9; *Corynebacterium*, *Rhodotorula*, 2.3; and unidentified isolates 4.5. The majority of the microorganisms selected exhibited proteolytic activities. The presence of nutritional microorganisms indicate probable utilization of organics, more specifically proteins, thus paving the way for oxidation of NH_3 to NO_2 and ultimately to NO_3 by autotrophic microorganisms. Coliforms were absent in 0.1 ml of sample examined from the aerobic tank.

ANAEROBIC-AEROBIC: PILOT PLANT

Comparable data observations for BOD_5, COD, total solids, volatile solids, pH, nitrate nitrogen, ammonia nitrogen, total Kjedahl nitrogen, and

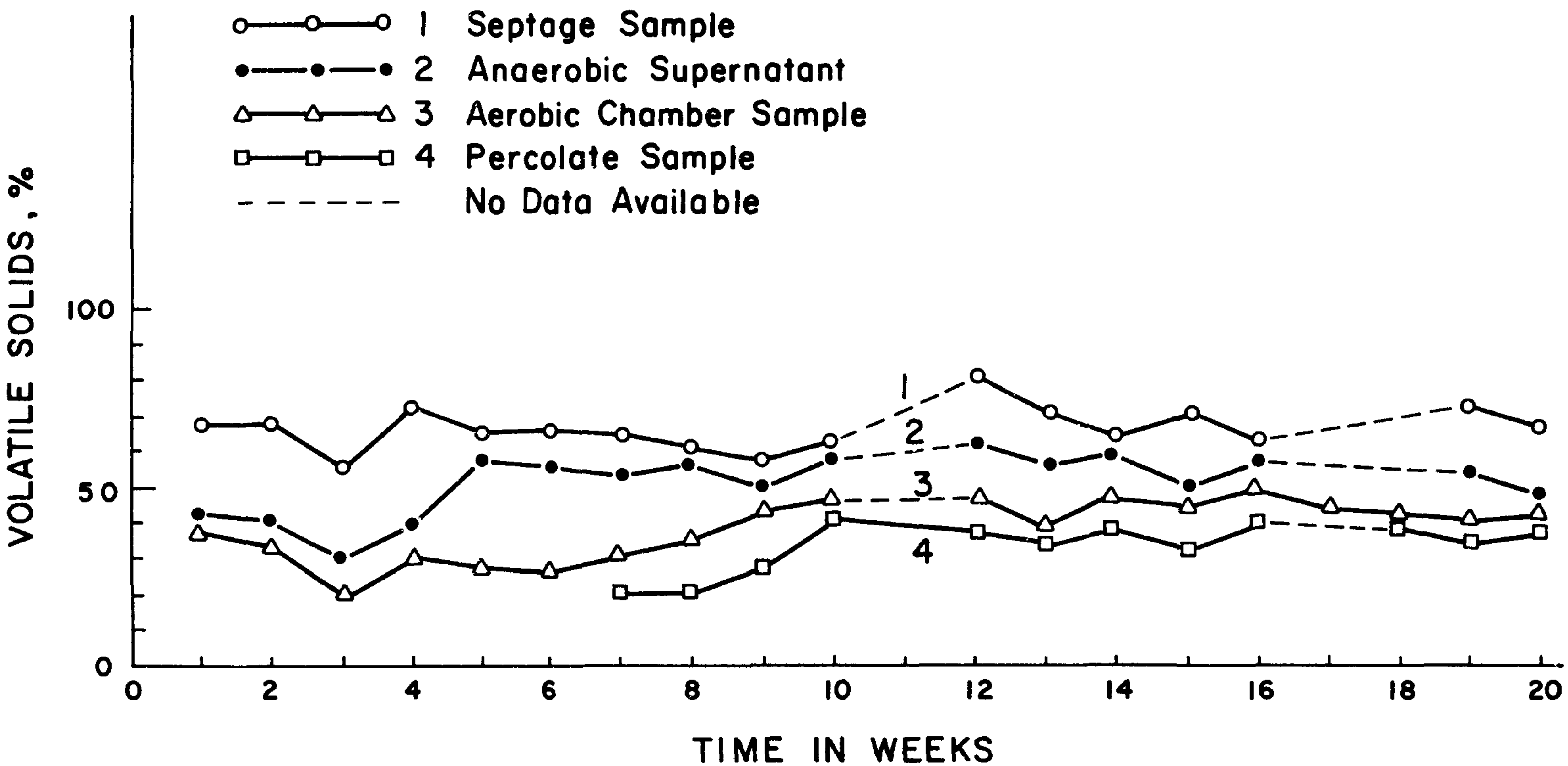


Figure 39. Bench scale: Volatile solids of system.

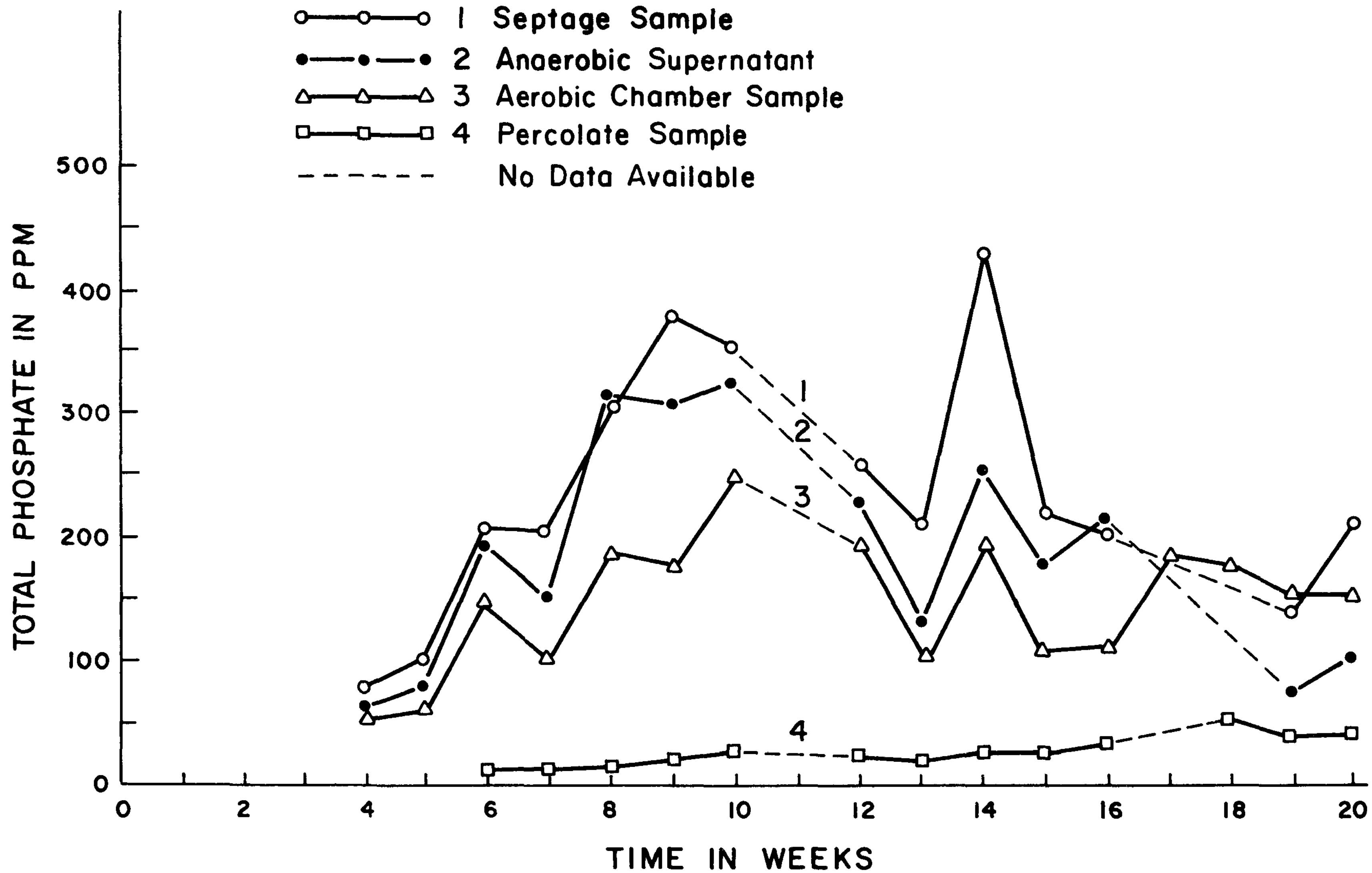


Figure 40. Bench scale: Total phosphate of system.

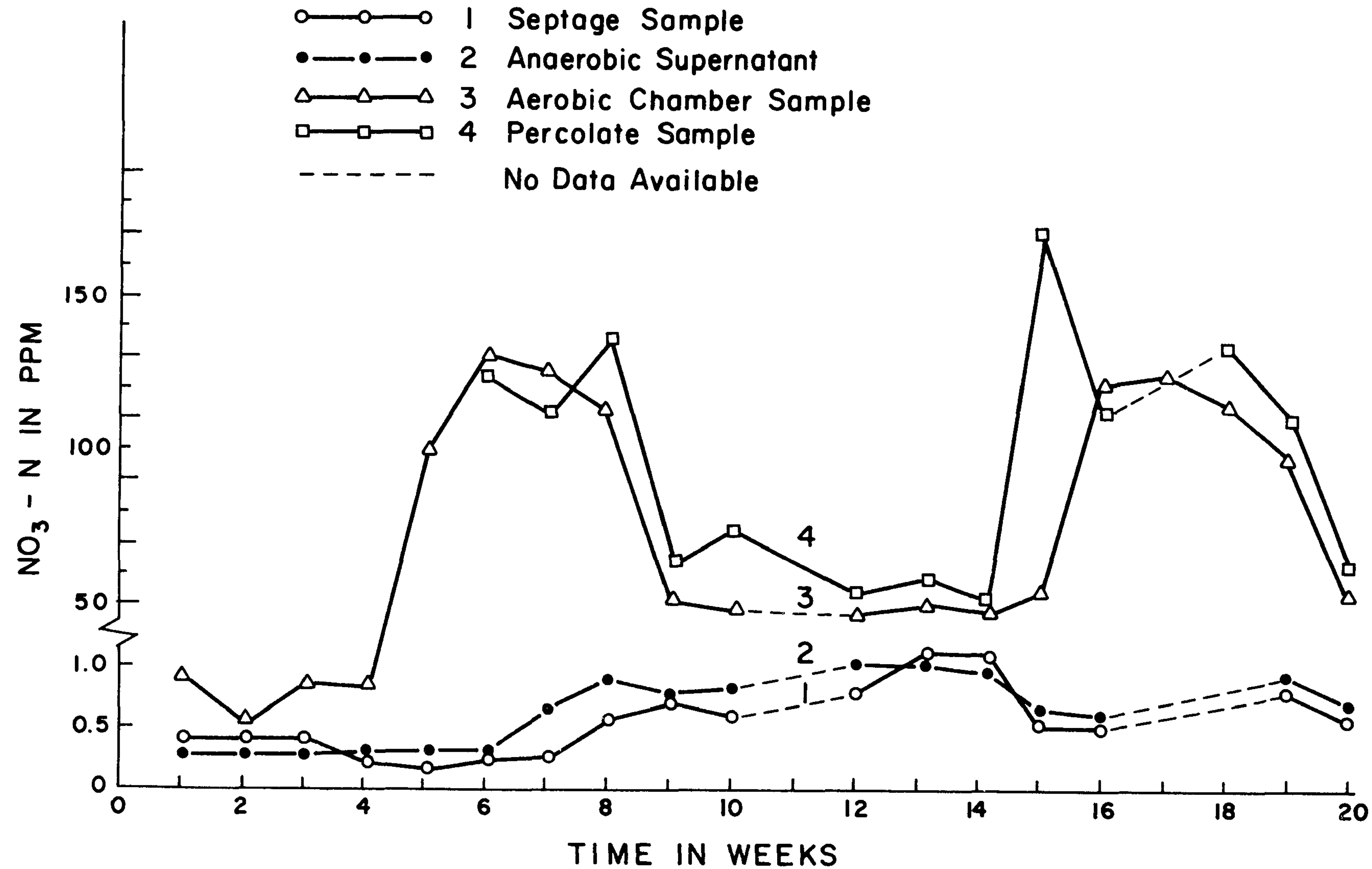


Figure 41. Bench scale: Nitrate nitrogen of system.

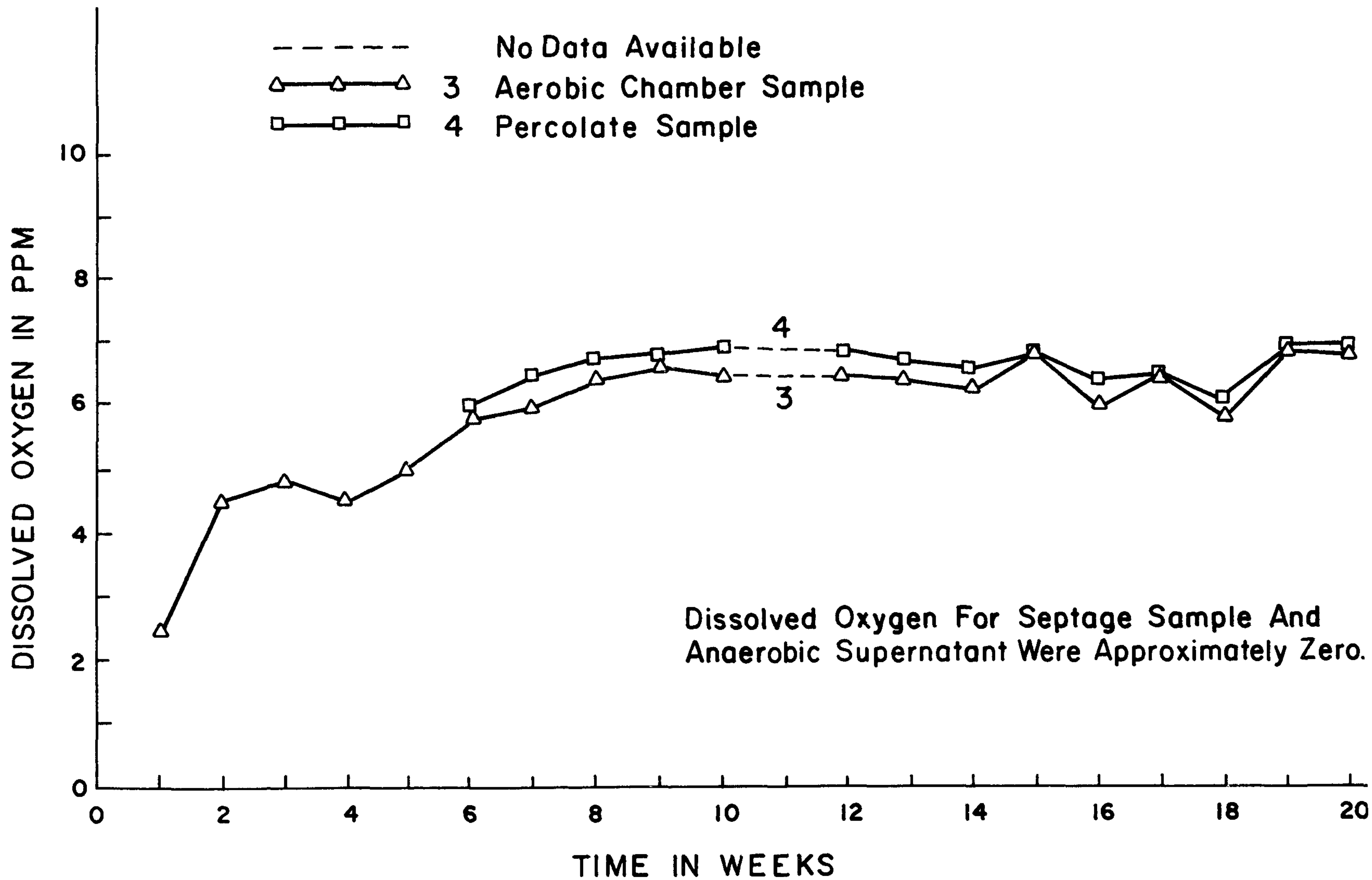


Figure 42. Bench scale: Dissolved oxygen of system.

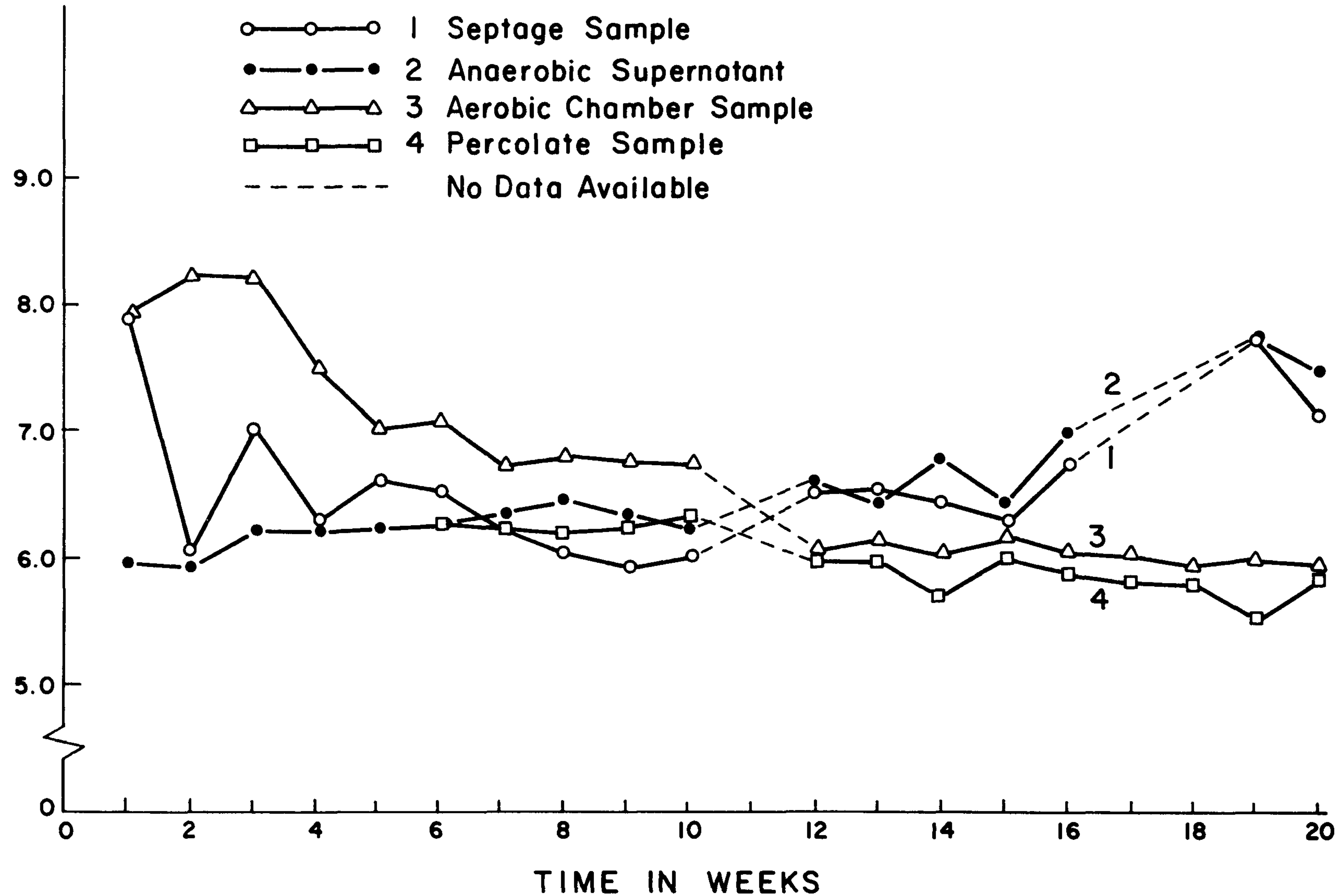


Figure 43. Bench scale: pH of system.

total phosphate for the anaerobic-aerobic pilot plant study over the six-month test period are shown in Figures 44 through 52.

The concentration of BOD_5 which averaged 1042 mg/l in the septage (Figure 44) was reduced by over 96 percent to an average aerobic ditch effluent concentration of 35 mg/l. The BOD_5 aerobic ditch effluent concentration ranged from 5 to 86 mg/l, with the higher concentrations measured in the early part of the study. The sand filter effluent (oxidation ditch supernatant filtered through the laboratory sand column) BOD_5 concentration averaged 4 mg/l, with the highest concentration measured at 7 mg/l. This represents over 99 percent BOD_5 removal. COD removal by the pilot treatment system, including sand filtration, was 92 percent, Figure 45.

Ammonia-nitrogen and total Kjeldahl-nitrogen concentrations were reduced 99 and 96 percent, respectively (Figures 46 and 47). The heated anaerobic digester effluent ammonia-nitrogen concentration averaged 80 mg/l, whereas the ammonia-nitrogen concentration in the septage feed to the digester was 59 mg/l. This ammonia-nitrogen increase reflects the bacterial conversion of unassimilated protein matter.

As also observed in the laboratory bench scale study, there was a high amount of nitrification after the aerobic ditch and sand filtration treatment steps. The nitrate-nitrogen concentration, Figure 48, in the oxidation ditch and sand filter samples averaged 72 mg/l and 70 mg/l, respectively. These nitrate-nitrogen levels exceed the U.S.P.H.S. drinking water standard of 10 mg/l. Though not tested, the nitrate-nitrogen concentration could be reduced by adding methanol to the sand filter influent and biologically denitrifying on the filter.

The total solids concentrations of the septage feeds averaged 0.6 percent and ranged from 0.1 to 7.2 percent, Figure 49. The septages in the storage tank were not agitated before pumping. Therefore, the pilot plant septage feed solid levels varied according to the liquid height and the amount of solids that settled in the tank. The total solids concentrations after pilot plant treatment (after the aerobic treatment step) averaged 0.16 percent. Samples of this effluent were polished by the laboratory sand filter. The filter effluent solids concentrations showed a further reduction to 0.1 percent. The volatile solids removal, Figure 50, in the final sand filter effluent averaged only 29 percent as compared to an average removal of 65 percent in the laboratory bench scale study. This lower percent removal could be due to volatile solids settling in the storage tanks and would not show up as being removed by the basic treatment system.

Total phosphate removal was 78 percent after pilot plant treatment and 88 percent after sand filter polishing, Figure 51. Phosphate removal was also less than observed in the laboratory bench scale study.

The oxidation ditch dissolved oxygen concentration averaged 5.6 mg/l. The D.O. concentrations ranged from 4.2 mg/l to 6.6 mg/l. Figure 52 shows the pH measurements for the septage feeds, digester supernatant and pilot plant and sand filter effluents.

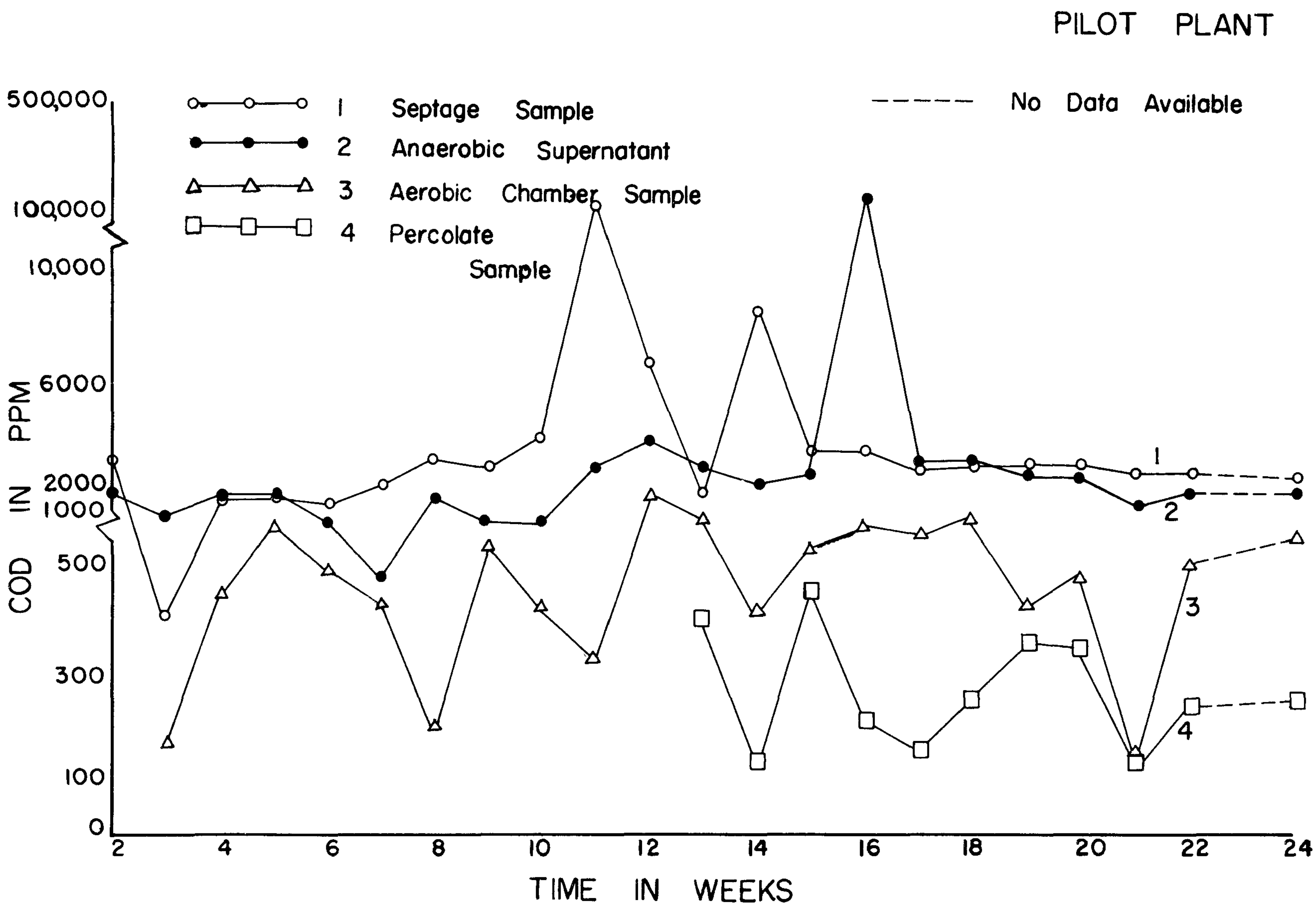


Figure 44. Pilot plant: Biochemical oxygen demand.

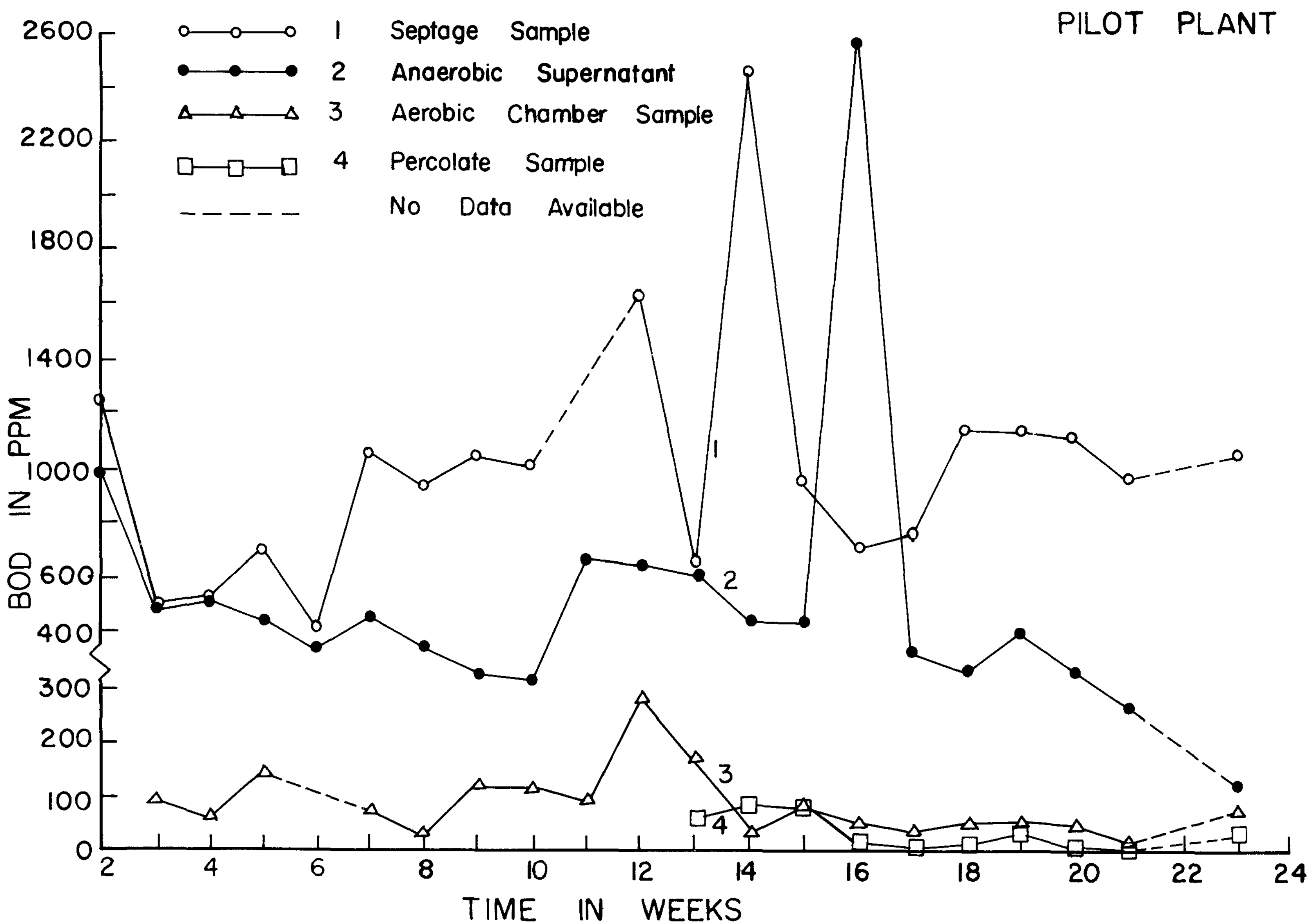


Figure 45. Pilot plant: Chemical oxygen demand reduction by system.

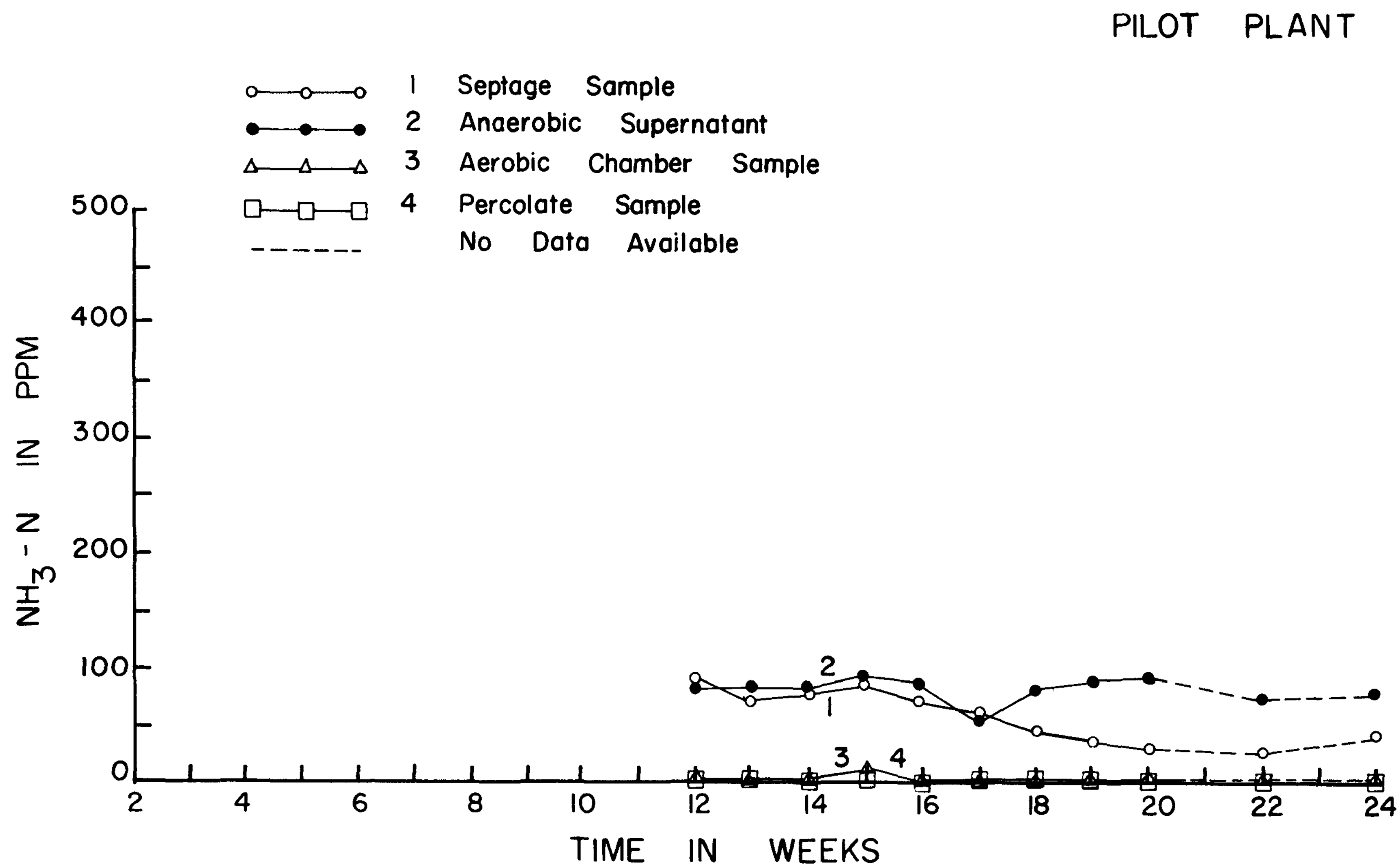


Figure 46. Pilot plant: Ammonia nitrogen of system.

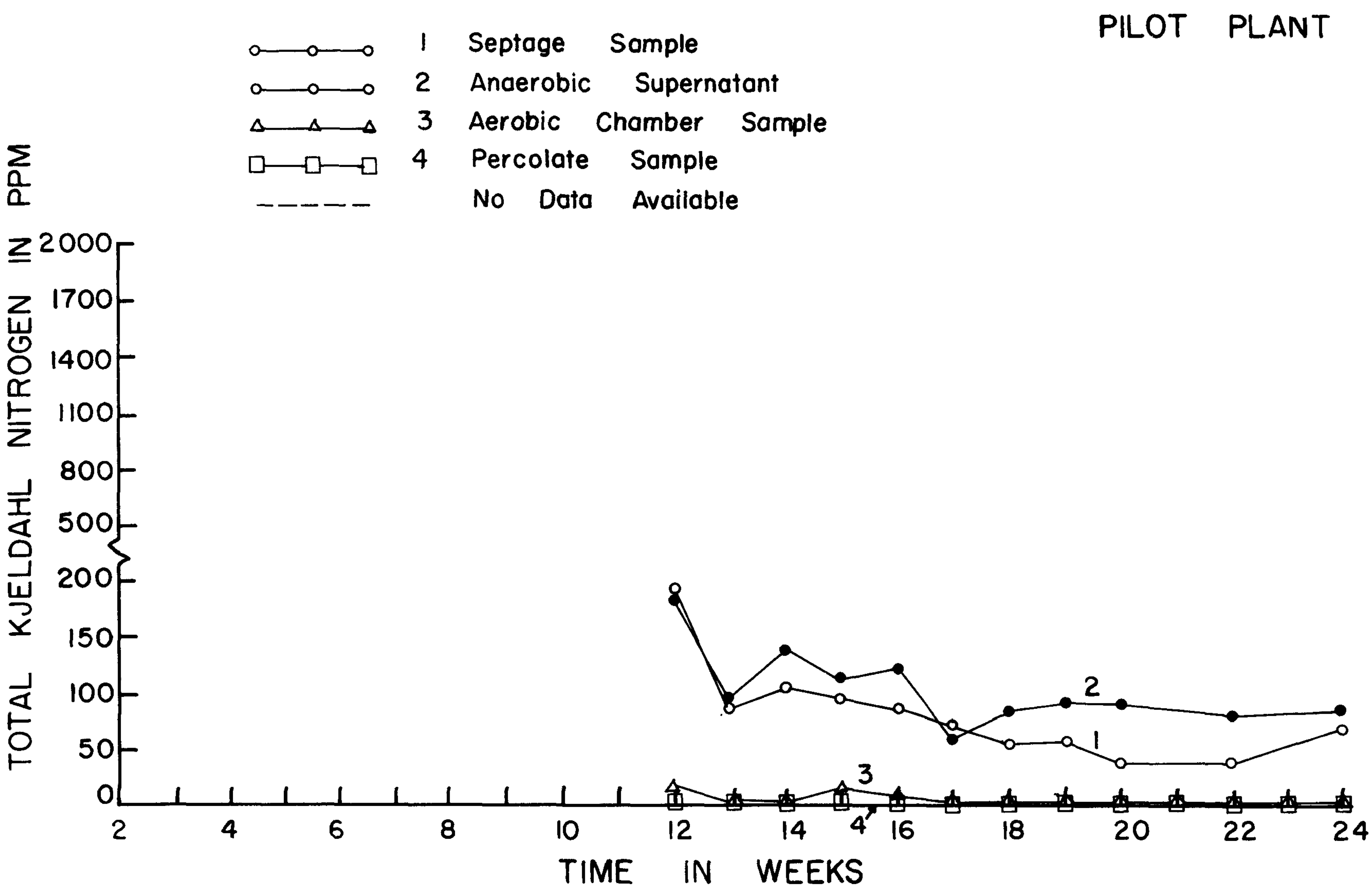


Figure 47. Pilot plant: Total Kjeldahl nitrogen of system.

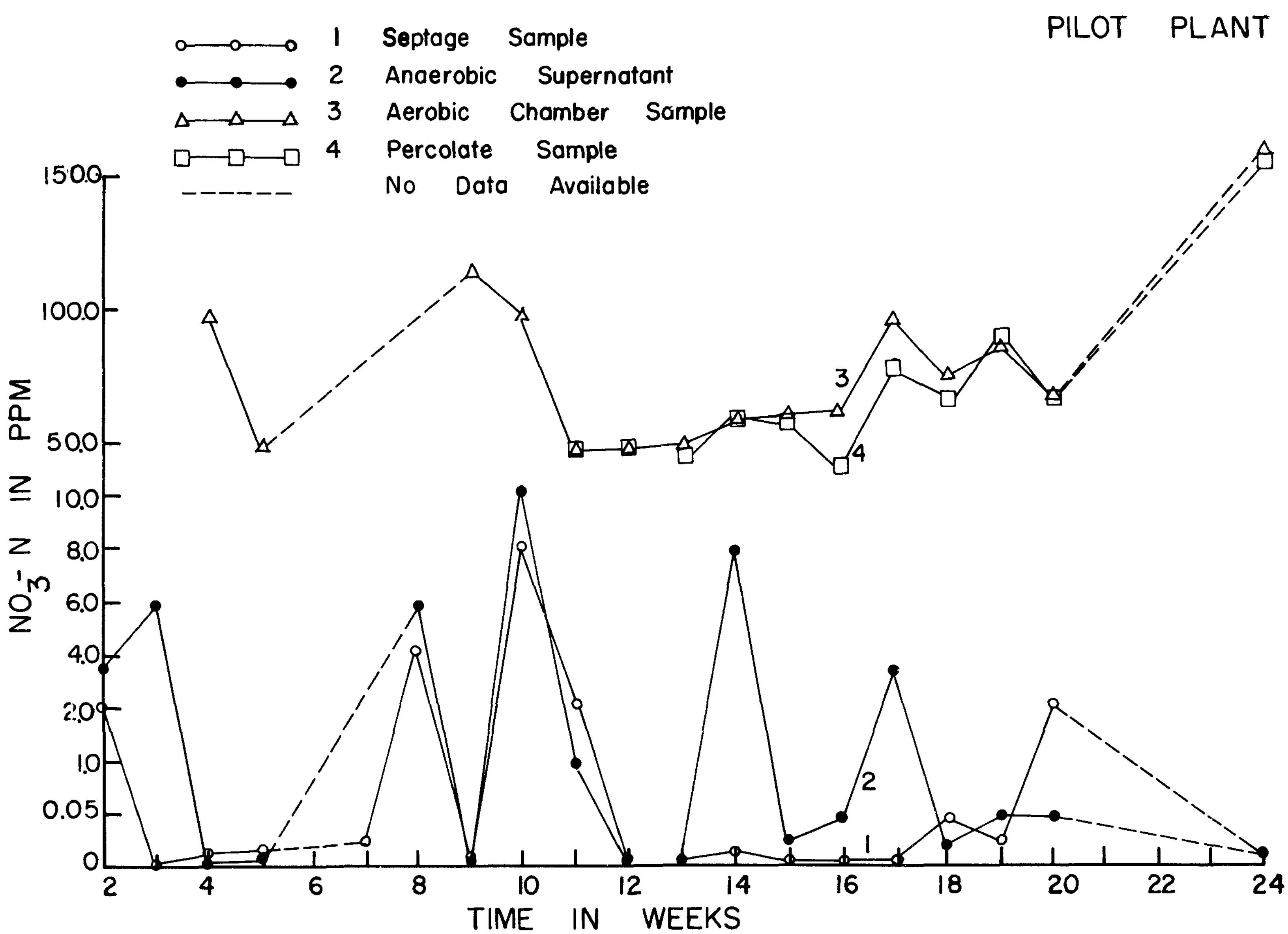


Figure 48. Pilot plant: Nitrate nitrogen of system.

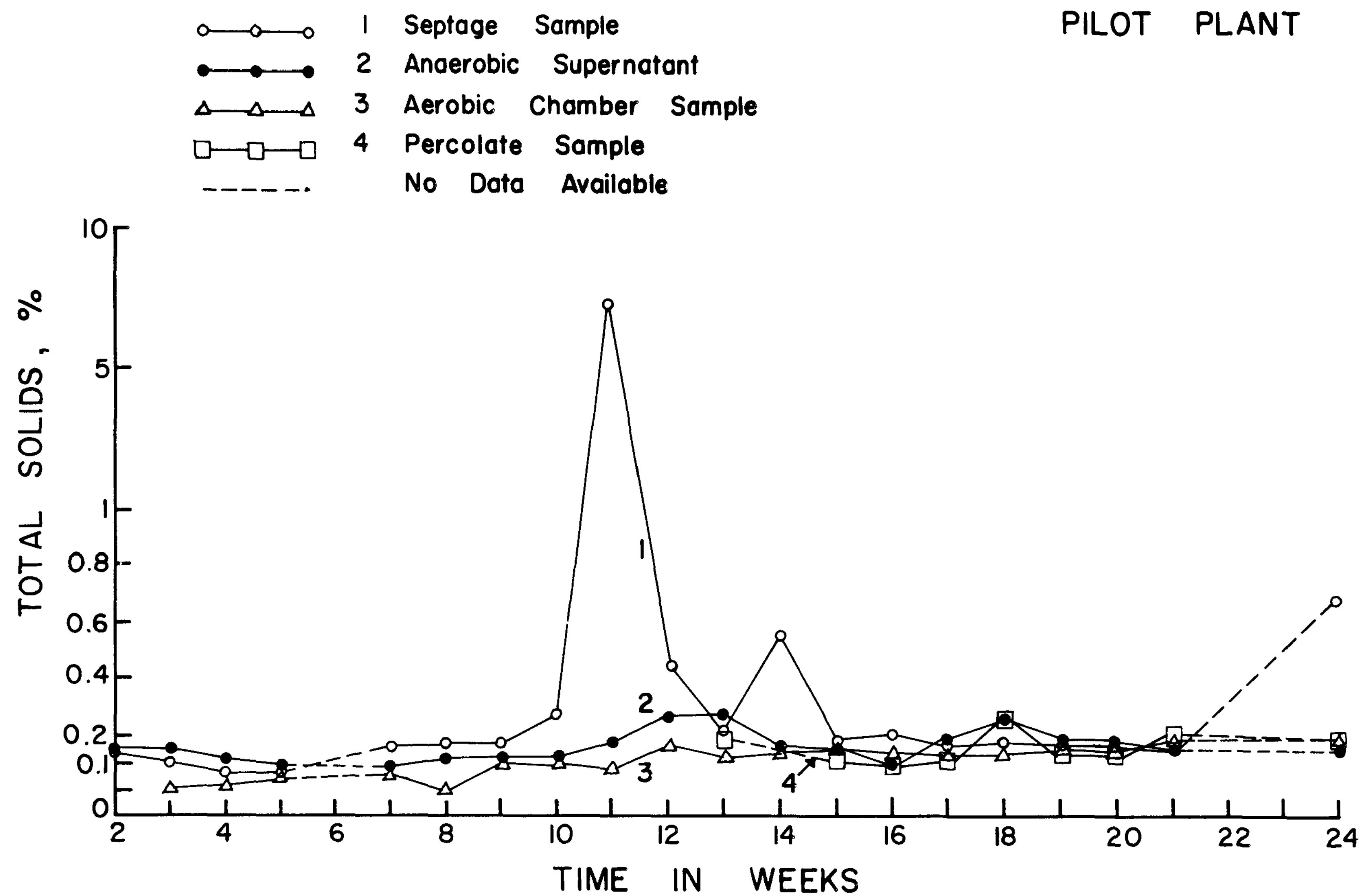


Figure 49. Pilot plant: Total solids reduction by system.

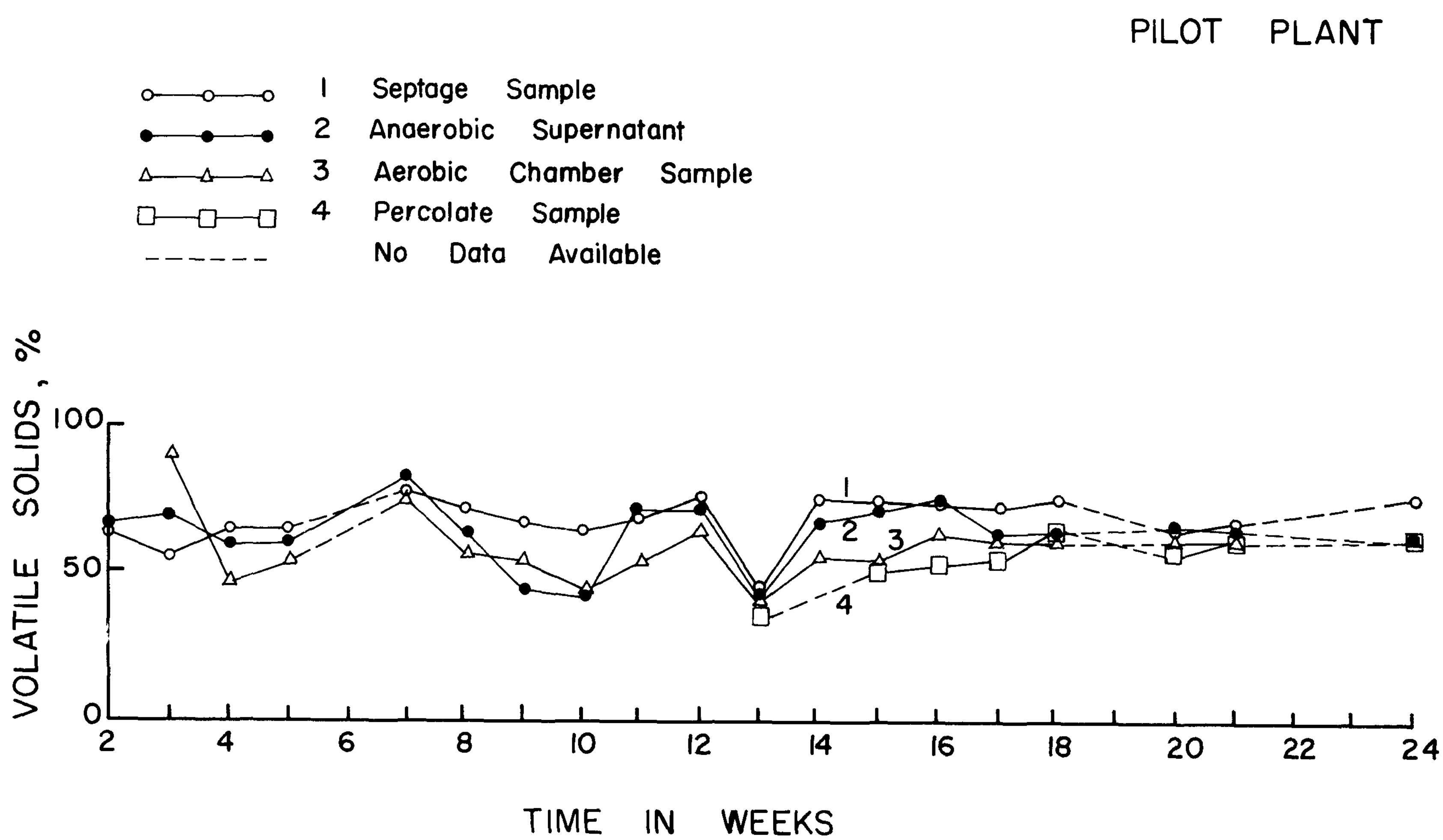


Figure 50. Pilot plant: Volatile solids of system.

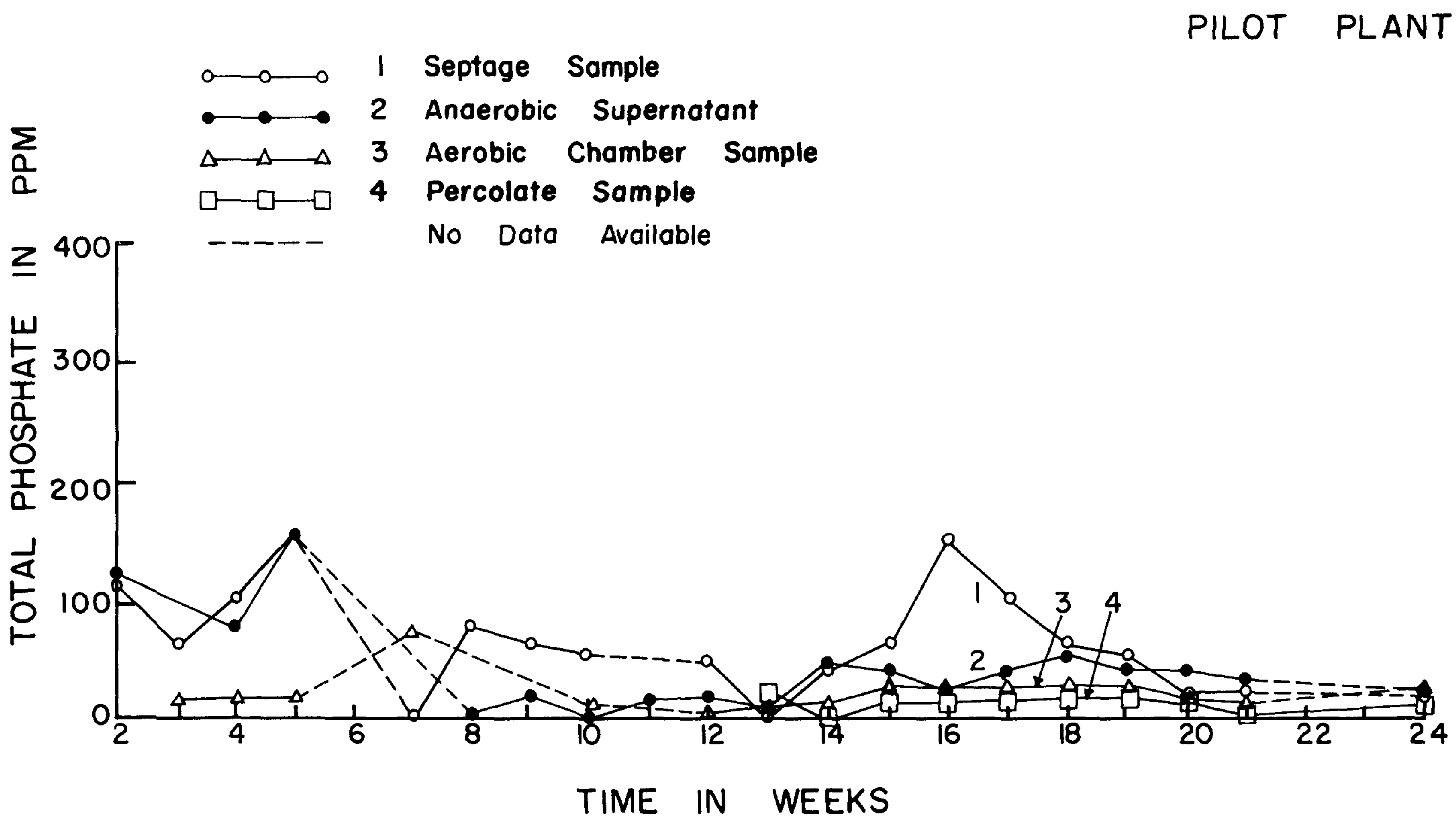


Figure 51. Pilot plant: Total phosphate of system.

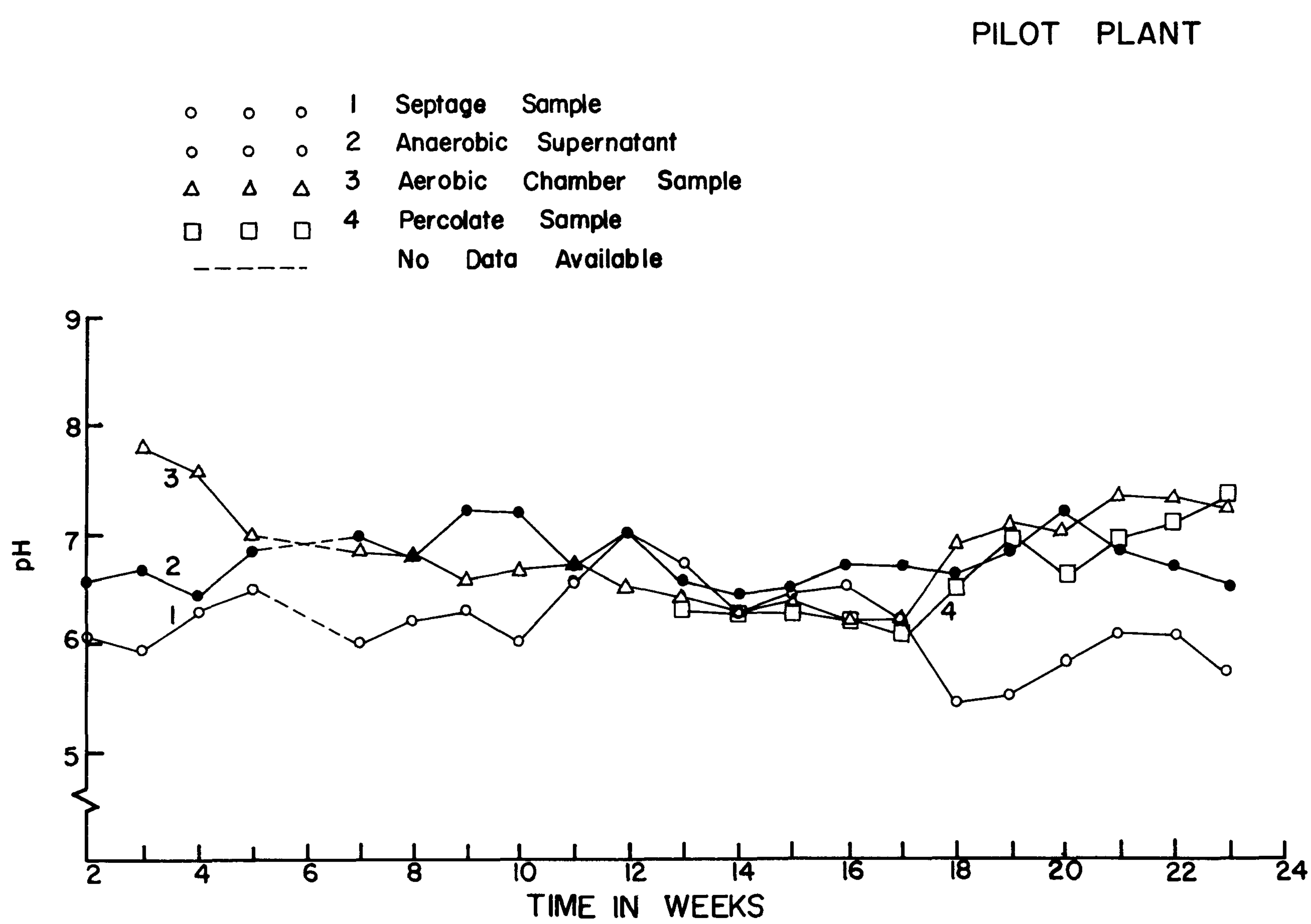


Figure 52. Pilot plant: pH of system.

As in the laboratory bench scale study, fecal coliforms were not detected in the final effluent.

At the end of the pilot study, inspection of the heated anaerobic digester showed little damage. A rather rigid scum mat, approximately one inch thick, developed on top of the liquid. Some mold growth was observed on top of the scum mat. In the bottom of the tank the settleable solids accumulation buildup was two to three inches. Hair was present in the digester tank slurry.

OTHER ASPECTS OF SPECIALIZED TREATMENT OF SEPTAGE

There are treatment methods other than the anaerobic-aerobic process which would be considered for septage treatment. In several instances, the investigators offered to evaluate commercially available methods, but the offers were not accepted. For various specialized treatment units that were evaluated in a somewhat cursory manner, the processes did not appear to lend themselves to treatment of septage. However, by not having available specialized treatment processes for careful test evaluation does not imply their unacceptability for septage treatment.

The specialized treatment processes tested are used in the treatment of domestic type sewage. They also have been used with wastes that are more difficult to treat than septage, e.g., certain agricultural or food processing wastes. To choose a treatment system, an assumption would need to be made concerning the maximum daily volume of septage to be treated. Some of the criteria for evaluation of specialized treatment processes include (a) potential for effective septage treatment; (b) costs in relation to estimated volume of septage to be handled; (c) field performance reports and site observation; (d) simplicity of operation and maintenance; and (e) personnel required. For a large volume of septage, full-time personnel working eight hours per day with plant emergency control devices for the nonworking hours might be required.

A comparison of the treatment needs for septage and municipal sewage in terms of detention time, the amount of oxygen required, aeration volume and surface area needs, power requirements, and estimated costs for the conventional activated sludge process and the extended aeration sludge process are presented in Table 1 of Appendix G. Also included is a summarization of BOD_5 loading range and expected percent BOD removal efficiency for selected aeration processes, Table 2 of Appendix G.

SEPTAGE TREATMENT AT A WATER POLLUTION CONTROL FACILITY

One approach is to combine septage with raw sewage for treatment in a conventional water pollution control facility (WPCF). Septage can be introduced into the raw wastewater from a tank truck, or pumped from a septage storage tank, under controlled conditions. When using a septage storage tank, the WPCF installation should include a grit chamber and communitor ahead of the storage tank. Possibly, septage can be added directly to the plant sludge digestion treatment provided that grit removal is first available.

In a preliminary survey, Kolega, J.J., in 1967, discussed combined septage-sewage treatment in Connecticut water pollution control facilities. The survey reported on what appears to be unwarranted objections from treatment plant operators:

(1) septage is harmful to digester operations and, therefore, this material is not acceptable for combined treatment.

(2) septage is of little value to a WPCF because of the added cost of treating septage with no resulting benefit.

(3) as a policy, a new septage treatment plant would exclude septage based on the advice received from other WPCF superintendents.

However, septage is a biodegradable waste even though its biological, chemical and physical characteristics are different from raw sewage. Thus, an adequately designed WPCF should be able to treat septage.

Calculations were made of the probable effects of adding septage to a conventional WPCF. These calculations are for various combinations of hydraulic and BOD_5 loadings with the raw sewage for selected time periods. Table 17 shows the results of these calculations.

The increase in the amount of solids to be handled should not adversely affect plant operation unless the sewage treatment plant is already overloaded.

Tests on the effect of septage addition to sewage were made at the University of Connecticut WPCF. The first test was conducted in late summer, two weeks prior to the start of the fall term. The second test was conducted during the two-week winter recess. These time periods were chosen because the University's WPCF was exceeding its design capacity during the school academic year.

A 1,000-gallon (3,785 liters) tank was placed above ground level for storing septage. This tank was coated with Thoroseal to insure against leakage. A diaphragm submersible pump was installed in the tank. A plastic pipe line was installed from the pump discharge into a manhole at the sewage influent line just outside the University's WPCF. A wood stirrer was used for mixing the septage prior to and during pumping.

In the first test, septage was fed into the manhole in slugs of 250 gallons (946 liters) over a 4-hour period. In the second test, the septage was fed directly from the tank truck into the raw sewage line. The estimated raw sewage flow during both tests was approximately 0.5 mgd (1.9 mld). Samples were taken hourly for analyses over a 16-hour period, at the four sampling locations shown in Figure 53. These analyses were compared to the analyses of samples taken at the same locations during plant operations without septage addition.

The septage added to the raw wastewater had no significant effect on the concentration levels of chloride, COD, nitrate-nitrogen and pH. Digester performance was not affected. However, at the bar screen and grit chamber

Table 17. BOD_5, IN mg/1, OF COMBINED WASTES (SEWAGE & SEPTAGE) FROM DIRECT DISCHARGE INTO RAW SEWAGE INFLOW.

WPCF Flow in MGD	2000 gal. septage discharged in 15 min.				2000 gal. septage discharged in 10 min.			
	(1) 3000 mg/1		1700 mg/1		3000 mg/1		1700 mg/1	
	(2) 200 mg/1	300 mg/1	200 mg/1	300 mg/1	200 mg/1	300 mg/1	200 mg/1	300 mg/1
0.5	970	1,050	620	690	1,220	1,290	750	810
1.0	650	735	445	570	825	905	535	615
1.5	515	615	370	460	650	735	440	525
2.0	440	540	330	420	550	640	390	475
3.0	365	465	290	385	445	540	330	425
4.0	325	425	270	365	390	480	300	395
5.0	300	400	255	350	350	450	280	375
10.0	260	350	230	325	280	375	240	340

NOTE: (1) 3,000 mg/1 is for septage at approximately 50% BOD_5 on design curve; 1700 mg/1 is for septage supernatant between 55 to 60% BOD_5 on design curve.

(2) 200 mg/1 and 300 mg/1 are average and maximum BOD_5 of raw sewage (Babbitt, H. E. and Baumann, E. R., 1958).

EXAMPLE: If a 2,000 gallon capacity tank truck discharges 2,000 gallons of septage in 15 min. to a 1 MGD plant at a high BOD_5 stage, 300 mg/1, the combined strength of the waste when the septage BOD_5 is 3,000 mg/1 will be 735 mg/1.

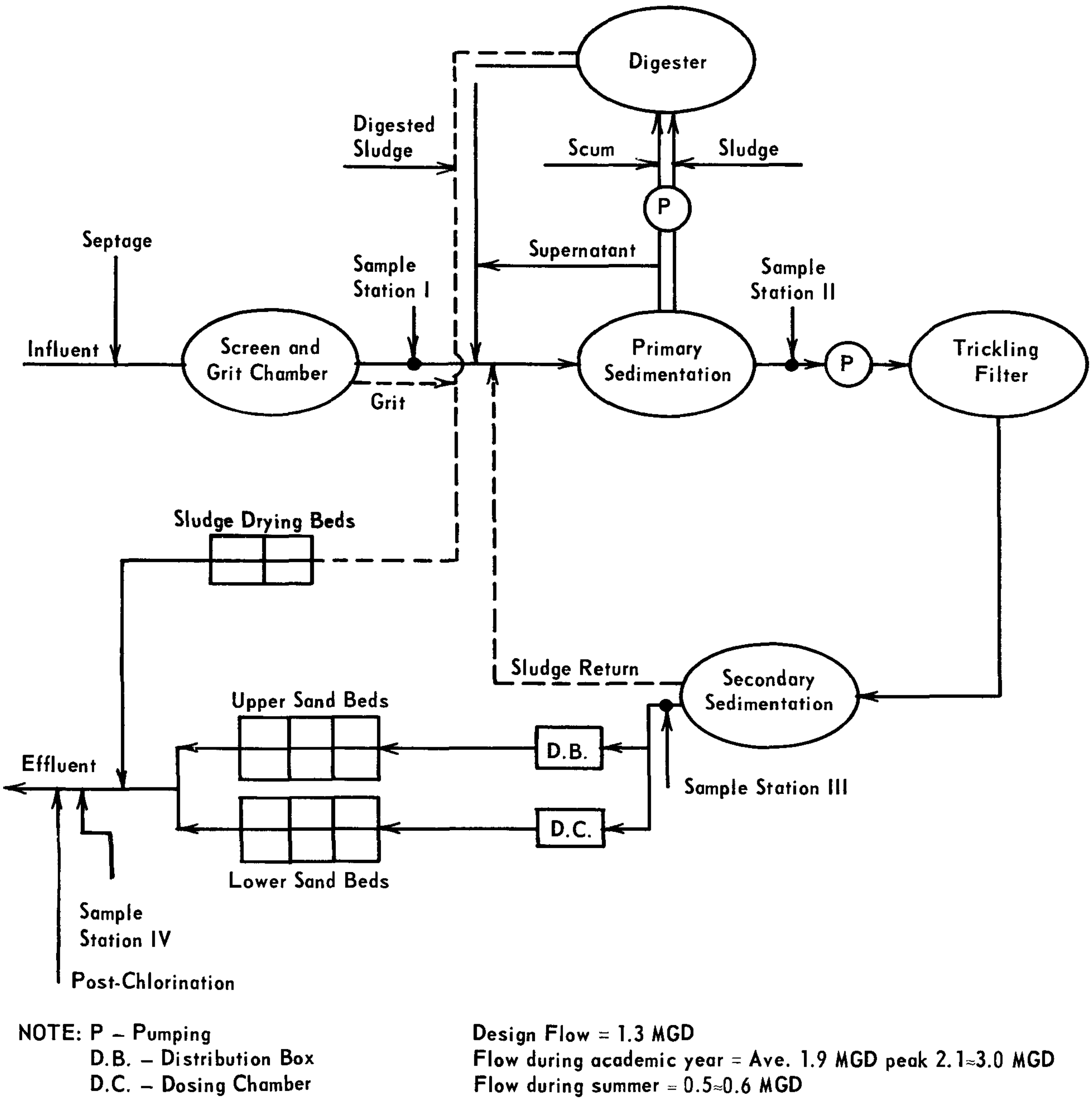


Figure 53. Sampling locations for combined waste treatment study.

locations, the labor time needed did increase slightly. Additional tests are needed to better evaluate the effects of septage-sewage ratios on WPCF operations.

SECTION 6

SEPTAGE VOLUME PUMPING ESTIMATES

HOMEOWNER SURVEY

A survey was made of homeowners with septic tank systems to estimate the volume of septage pumped. Four areas in Connecticut were selected, representing a mixture of soil types and population densities. The towns chosen were:

(1) Harwinton

(2) Old Saybrook

(3) Tolland

(4) East Hartford (most of the unsewered parts)

In each town, one sixteenth of the single family homes (a total of approximately 565 homeowners) were randomly chosen from the city directories. Of the 188 questionnaires returned, four were for summer residences and were discarded. The number of times a septic tank was emptied during the three preceding years indicated the pumping frequency. The estimated tank capacity was reported in gallons. Also the number of people in the dwelling was requested.

Of the 184 septic tanks reported on, 103, or 57 percent, were pumped one or more times in the preceding three years. In total, there were 186 pumpings over the three year period. Thus, the average was 0.34 pumping per tank, per year. The tank volume, reported by 120 of the 184 respondents, averaged 763 gallons (2,885 liters).

An estimate was made of the volume of septage pumped, per person, per year from the pumping frequencies, tank volumes and the number of people using the septic tank systems. The volume pumped was assumed equal to the septic tank size. Multiplying the average septic tank size, 763 gallons (2,885 liters) times the average number of pumpings per year per tank, 0.34 gives an estimate of the volume of septage pumped, 259 gallons (980 liters) per year, per residence. The average annual volume pumped per tank, 259 gallons (980 liters) divided by the average number of persons per household, 3.9, gave an estimate of the annual per capita volume of septage pumped, or 66 gallons (250 liters) per person per year. Where small sewered areas are scattered through a generally unsewered region, commercial and public buildings would probably utilize the sewered areas. In generally unsewered regions, allowances for nonresidential buildings and summer residences would require that the 66 gallon per person per year estimate be modified.

The homeowner survey also provided some insight into reasons for load to load variations in septage characteristics. Pumpings at frequent intervals are often associated with seasonally high ground water. Volumes pumped may be considerably larger than those indicated by tank sizes alone because of reverse water flow from the flooded drainfields. Some tanks were pumped only after many years of service, and this septage would presumably contain a rather high concentration of solids.

Forty-four percent of the septic tank systems showed some form of failure. Problems were so severe for three systems in East Hartford that they had to be pumped a total of 34 times in three years.

STATEWIDE SEPTAGE PUMPING VOLUME ESTIMATES

Information from a statewide survey of septic tank pumpers provided primary data for estimating the septage volume pumped in Connecticut. A questionnaire was sent to each of the 213 septic tank pumpers listed in the yellow pages of the telephone directories. The 44 or 20 percent of the pumpers who replied to this initial survey reported on the number of tanks they pumped annually and the disposal facilities they used. These pumpers were classified, first, by type of disposal outlet they used and, then, into one of three size groups according to the number of septic tanks pumped; namely, more than 700 tanks per year; 300 to 700 tanks per year; and fewer than 300 tanks per year. The average number of tanks pumped by each group was calculated, Table 18.

A follow-up survey was made to determine the size class of non-respondent pumpers. This survey was accomplished by supplying the names of the nonrespondent pumpers to nearby respondent pumpers and asking them to classify each non-respondent by size group. This second survey plus some follow up checking provided a nonduplicative pumper population in Connecticut, Table 19.

The total number of tanks pumped annually was determined for each classification by multiplying the number of pumpers by the average number of tanks pumped. The volume of septage pumped annually was estimated by multiplying the number of tanks pumped by the average septic tank size. The average septic tank size was 847 gallons (3,206 liters). This figure was based on delivery slips turned in by pumpers who delivered septage to the East Hartford WPCF, Table 20.

About 1.3 million persons, or 43 percent of Connecticut's total 1970 population of 3 million, are dependent on septic tank systems for the disposal of household wastes. This estimate of the state's unsewered population was based, in part, on an updating of the population served by sewers in each municipality made in 1966 by the Connecticut State Health Department. The differences between the estimated sewered population and the total population for each municipality provided the unsewered population estimate.

Table 18. SEPTIC TANK PUMPINGS REPORTED BY 44 PUMPERS CLASSIFIED BY SIZE OF PUMPER OPERATION AND DISPOSAL OUTLET.

	Disposal Outlet				Total
	Treatment Facilities		Other than Treatment Facilities[a]		
Size of Pumping Operation (Tanks Pumped per year)	Pumpers	Average No. tanks pumped	Pumpers	Average No. tanks pumped	Average No. tanks pumped
More than 700 tanks	8	1,350	8	1,230	1,290
300 to 700 tanks	6	422	11	471	454
Fewer than 300	4	136	7	153	147

[a] Includes six pumpers who disposed of part of the septage at treatment facilities.

Table 19. SEPTIC TANK PUMPINGS IN CONNECTICUT CLASSIFIED BY DISPOSAL OUTLETS.

	Disposal Outlet				Total	
	WPCF		Other than WPCF			
Size of Pumping Operation (Tanks pumped per year)	Pumpers	Tanks Pumped	Pumpers	Tanks pumped	Pumpers	Tanks pumped
More than 700 tanks	26	35,100	18	22,140	44	57,240
300 to 700 tanks	60	25,320	36	16,959	96	42,279
Under 300 tanks	36	4,896	18	2,754	54	7,650
TOTAL	122	65,316	72	41,853	194	107,169

Table 20. SEPTAGE DELIVERIES BY SIZE OF TANK PUMPED, E. HARTFORD WPCF FOR FOUR SELECTED MONTHS.

Size of Septic Tank (gallons)	Class mode (gallons)	Deliveries (number)	Deliveries (gallons)
Under 350	250	2	500
350 to 650	500	86	43,000
651 to 850	750	197	147,750
851 to 950	900	181	162,900
951 to 1050	1,000	84	84,000
1051 to 1350	1,200	3	3,600
1351 to 1650	1,500	6	9,000
1651 to 1999	1,800	8	14,400
2000	2,000	6	12,000
2500	2,500	1	2,500
3500	3,500	1	3,500
5000	5,000	1	5,000
TOTAL		576	488,150

Average = 847 gallons (3,206 liters), For other liter equivalents, multiply by 3.785.

With an estimated annual volume of septage pumped of 91 million gallons (344 x 10^6 liters), and an unsewered population of 1.3 million, the annual volume of septage pumped per person, per year is estimated to be 70 gallons (265 liters). This 70 gallons per capita estimate provides a useful first approximation for the amount of septage that may be expected from an area where the unsewered population is known. Also, this per capita estimate is slightly higher than that reported in the homeowner survey. The difference could be due to the additional septage pumped from commercial, industrial, and public sources.

TABLE 21. SEPTAGE VOLUMES RELATED TO POPULATION CLASSIFIED BY AREAS ACCORDING TO DISPOSAL METHOD, CONNECTICUT

Area Classification	Total Septage Pumped (mil. gal.)	Connecticut Unsewered Population (thousands)	Septage Pumped Per Capita (gallons)	(liters)
WPCF disposal	55	806	68	257
Other disposal outlet	36	501	72	272
	91	1,307	70	265

In Table 21, municipalities and their respective unsewered populations were classified according to whether or not their probable septage disposal outlet was a WPCF. Information for this classification came partly from the initial pumper survey in which the survey respondents also indicated the names of those municipalities in which they pumped. The classification of municipalities by disposal outlet was also based in part on information from an earlier survey of municipal policies regarding septage receipts. The classification also took into account data on actual septage receipts that were reported by the WPCF to the State Department of Health. Based upon this, central and southwestern shoreline parts of Connecticut were presumed to go to a WPCF, Figure 54. This is an area of high population density. Of the approximately 1.3 million persons who must rely on septic tank systems, approximately 60 percent live in this designated area. In the remaining parts of the state, where the other 40 percent of the state's unsewered population reside, septage is usually disposed of in excavated pits.

Since the research study of septage disposal was started in 1969, seven WPCF's with septage receiving and processing facilities have been built in areas where disposal in excavated pits has prevailed. To date, septage disposal at these recently completed plants have been meager. This failure to change disposal outlets can be attributed to two major reasons: (1) septage dumping fee at the WPCF is higher than the cost to pumpers who have access to excavation pits, and (2) the lack of enforcement regulations leading to establishing or upgrading of septage disposal outlets.

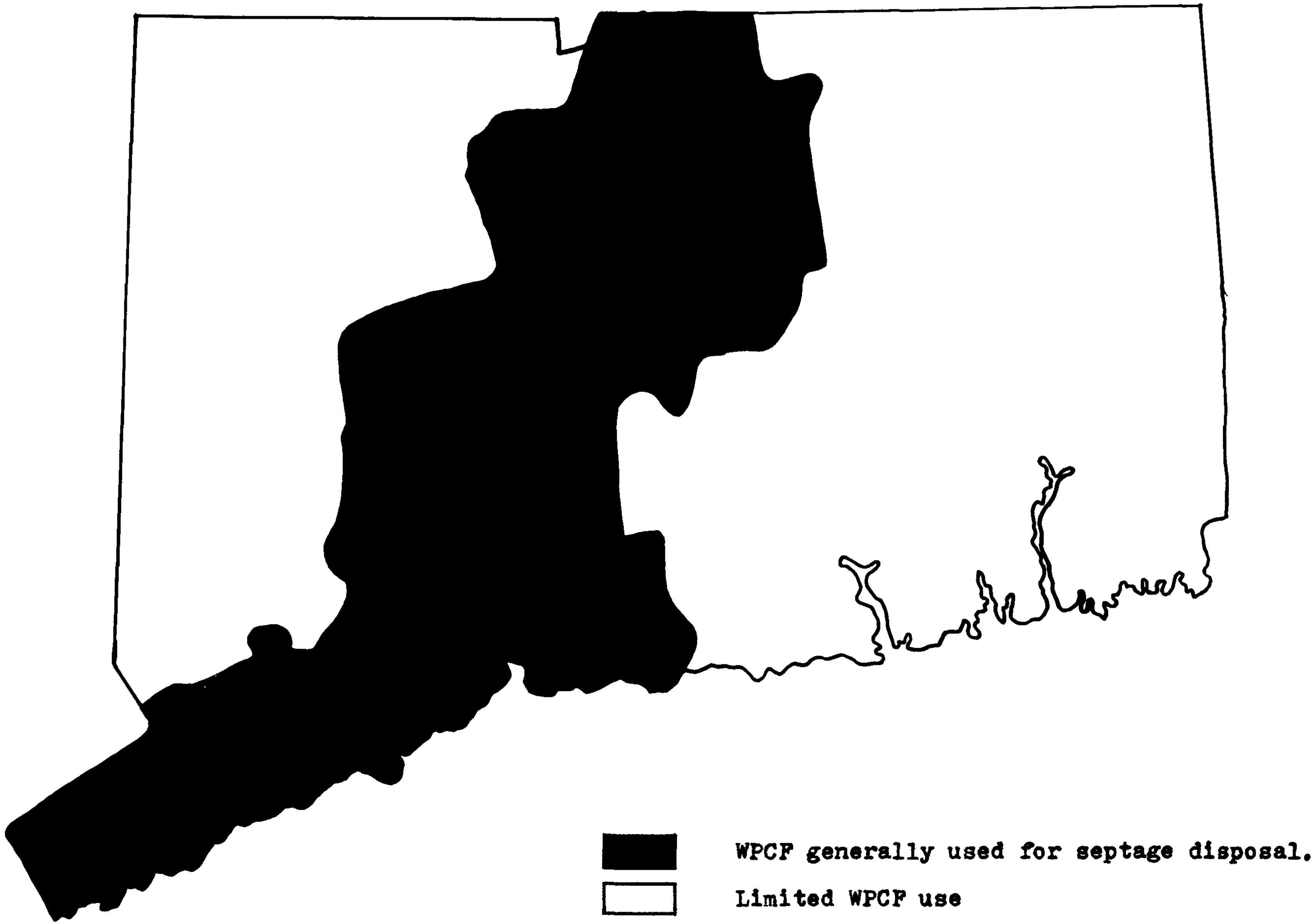


Figure 54. Septage disposal in Connecticut.

SECTION 7

MODEL LAND DISPOSAL SYSTEM

SOIL INJECTION COSTS AND LAND REQUIREMENTS

Soil injection is one of several feasible methods that are being developed for septage disposal. Soil injection lends itself to recycling a biodegradable liquid waste with a minimum of ground water pollution.

The feasibility of septage disposal by soil injection depends upon the availability of an adequate site or sites that are acceptable to municipalities, regulatory agencies, septage pumpers, and the nearby neighborhood. The costs of soil injection must compare favorably with other available means for treatment of septage, e.g., water pollution control facilities, other methods of land disposal, and specialized treatment processes. In developing the soil injection land disposal method in the study, environmental acceptability as well as costs was considered.

In considering the soil injection approach to the treatment and disposal of septage, the factor of heavy metals should be considered. This factor was not investigated.

In general, land disposal of septage by soil injection is not intended for year-round application. Instead, soil injection could be combined with other waste treatment processes that together would constitute a year-round septage disposal program for a designated area. If land disposal is used for septage that would otherwise go to a WPCF, this would contribute to a reduction in the hydraulic and organic loadings placed upon the WPCF, particularly during the warm weather period when a final effluent discharge into a stream is being chlorinated. In winter months biodegradable rates are slowed down because of lower temperatures. This may work against septage addition to a WPCF.

Land requirements for the six months (Connecticut) when soil injection can be carried out are necessarily based on the expected septage volumes. It may be assumed that 5/7 of the total septage in the area being served will be pumped during the six-month injection period. Thus, if the septage volume for an area to be served is estimated to be 70 gallons (265 liters) of septage per capita, the volume for injection would be estimated at 50 gallons (189 liters) per capita.

An adequate site for soil injection is one with a receiving area which is adjacent to a moderately drained soil area suitable for field cropping.

The useable field area should allow for a two-year rotation, i.e., used for injection one year and cropped the second year. Crops selected for the rotation should be those which would enhance the removal of nitrates from the soil.

With the plow-cover method of injection, septage can be applied at the rate of one gallon (3.785 liters) per linear foot (305 cm) using a 16-inch (41 cm) plow. Once over, this amounts to approximately 33,000 gallons/acre (308,727 liters/hectare). With eight septage injections in the same area over a six-month period, a total of 284,000 gallons (1,075,000 liters) would be disposed of per acre (0.4 hectare). This rate of application is equivalent to a nitrogen application of slightly over 300 pounds (136 kilograms).

As an illustration for estimating land requirements, a population of 10,000 that generated 700,000 gallons (2,650,000 liters) of septage annually would need enough field area for injecting 500,000 gallons (1,893,000 liters) of septage. At an injection rate of 284,000 gallons per acre (2,680,000 liters/hectare), this would require about 1.8 acres (0.7 hectare) of useable field area per year or a minimum 3.6 acres (1.4 hectares) for a two-year rotation. Land for roadways and headlands would bring the field requirement up to at least five acres (2 hectares). In addition to the field injection area, approximately one acre (0.4 hectare) of land is required for a septage receiving area to provide space for temporary equipment storage, a tank truck washing area, a turnabout for transport vehicles, and a tank for temporary septage storage. Thus, six acres (24 hectares) of land might be the adequate requirement for a population of 10,000.

Given a 1,000 gallon (3,785 liters) trailer tank, an injection rate of 4,000 gallons (15,140 liters) per hour is possible. Injection at this rate for six hours of a working day would amount to 24,000 gallons (80,800 liters). Under minimally favorable conditions whereby injection could be three days per week, over 70,000 gallons (265,000 liters) could be injected weekly. If the temporary storage tank proved to be inadequate during an extremely wet period, arrangements for disposal elsewhere would be necessary.

The requirements and a representative budget for soil injection, Table 22, were developed from the pilot study discussed in the section on materials and methods. The dollar cost figures shown in Table 22 were prepared for a grant to carry out a demonstration project on the site of the pilot project. Those capital costs that may be spread over a period of years are amortized at 6 percent interest. The septage storage tank, site improvement and maintenance costs are amortized over ten years; and machinery capital costs, over five years. Included among the listed requirements are some that are not absolutely essential to the operation but which are considered to be highly desirable.

This representative injection system is considered to be adequate for handling 1.5 million gallons (5,678,000 liters) during a season, one that could serve a population of 30,000. More likely, systems would be designed to serve smaller populations and handle smaller volumes of septage. Cost adjustments would then be required for most budgeted items.

Table 22. REQUIREMENTS AND COSTS (1972) FOR SEPTAGE INJECTION AT A 10 ACRE SITE IN LITCHFIELD, CONNECTICUT, TO SERVE A SURROUNDING POPULATION OF 22,000 PERSONS.

Item	Costs to be Amortized at 6 Percent	Annual Cost
1. Land rent		$ 1,000
2. Site improvement and maintenance	(Amortized over 10 yrs.)	
Well and water pump (300 feet @ $8/ft. + $300)	$2,700	367
(Observation wells)	1,000	136
Drainage (if needed)	750	102
Electric Power Line (1,000 ft.)	1,200	162
Establish roadway	1,000	136
Maintain roadway		200
Grade site	500	68
Planting materials		150
		$ 1,321
3. Storage tank		
30,000 gallon tank	$3,000	408
Excavate for tank	500	68
		$ 476
4. Machinery capital costs	(Amortized over 5 yrs.)	
Tractor	$8,000	1,900
Plow	375	90
Tank trailer (Experimental model $5,000)	3,000	710
Septage pump w/electric motor	2,076	492
		$ 3,192
5. Machinery operating costs		
Hardware and replacement parts		500
Lubricants, fuel, electricity		300
		$ 800
6. Labor		
1 man @ $4 per hour, 26 weeks		4,160
Fringe benefits		400
Insurance		200
		$ 4,760
	GRAND TOTAL	$11,549

Whether the septage disposal site is leased or owned is a factor in land costs. If the land were owned by a municipality, the ownership costs might take into account the resale value of the land as well as its cost or book value. Soil injection is unlikely to adversely affect the land and it can enhance soil enrichment. In developing the representative budget for soil injection, land rental costs of $1,000 per year were assumed.

Necessary facilities, in addition to the common ones, may well include two that would be unique to septage disposal. One facility is a water supply for hosing down any spillage and for washing the trucks. A second item would be observation wells from which ground water samples could be drawn.

The capital cost for constructing large, poured in place, concrete, underground storage tanks was estimated at $100 per 1,000 gallons ($26.42 per 1,000 liters) of capacity (Casler, G.H., 1969). Contract price in Connecticut for an equivalent size precast concrete tank, dropped in place would be much higher.

The largest budgeted item in machinery capital costs was for the field tractor. The tractor used in the pilot study pulled the septage field tank-trailer as well as supplying hydraulic power. The tractor might be used solely for septage injection work or it might be used for other work during six months of the year.

Labor is a major operating cost. The proper amount of wages to attribute to field injection depends on the circumstances. Because of weather conditions and limited volumes of septage a person might not be needed full time at the site. On the other hand, dangers associated with the operation of machinery might mandate a two-person crew. The representative budget provided for one person full time for six months. This presumes that a one-person equivalent during a six-month period could inject 1.5 million gallons (5,678,000 liters) of septage, maintain the equipment, manage the site, and keep records.

Estimated total annual costs of $11,549 are divided between capital costs of $5,989 including $1,000 for land costs, and operating costs, of $5,560. The operating budgeted costs for 1.5 million gallons (5.7 million liters) of septage gives an average of $3.77 per 1,000 gallons ($1.00 per 1,000 liters). Other budgets for differing septage volumes and different operating procedures would, of course, give different budgeted cost figures.

The significance of these findings lies, first, in the listing of somewhat compatibly sized components required for the injection system that was based on the experiences of a pilot operation. Secondly, cost of soil injection as opposed to lower cost disposal in excavated pits may be justified because the septage is better degraded. The degradation resulting from soil injection compares favorably to what can be achieved in a WPCF having tertiary treatment.

OFF SEASON HANDLING OF SEPTAGE

A dual system of septage disposal might be established that would provide for trucking septage from the storage tank on the disposal site to a municipal WPCF during periods when injection is not feasible. The cost of conveyance in large trailer trucks of 4,000 gallon (15,140 liters) capacity would probably be similar to that for liquid petroleum. Rates, current in 1971, set by the Connecticut Public Utilities Commission for trucking liquid petroleum are as follows:

One-Way Distance In Miles	Trucking Rates Per 1000 Gallons	Trucking Rates Per 1000 Liters
15	$5.40	$1.43
20	6.30	1.66
25	7.10	1.88
30	8.10	2.14
35	9.10	2.40
40	9.70	2.56

Charges levied by the facility that accepted the septage, which might be in the range of $3 to $5 per 1,000 gallons ($0.79 to $1.32 per 1,000 liters) of septage, would have to be added to the trucking charge and the costs associated with operating the storage facility.

If all the septage pumped in an area were to be disposed of by soil injection, additional storage would have to be built. For each 10,000 population an additional tank of 190,000 gallons (719,000 liters) would be required for cold weather storage. If these storage costs were to be amortized at 5 percent on a ten-year basis, this would require an additional annual capital expenditure of $5,030.

For soil injection to be a solution by itself, implementation of new concepts in scheduling pumping of septage could be invoked. For example, a community might require the compulsory pumping of septic tanks on a predetermined calendar schedule. Off season pumping, then might be restricted to emergency needs. Such a regulated program of pumping might be combined with a program of inspection and enforced correction of septic tank systems not meeting present-day health standards. The enforcement of these regulations would partially affect the limitations of season (temperature) and the weather elements. Regulated pumping, however, could disadvantage commercial pumpers whose businesses would become even more seasonal than at present.

SECTION 8

COSTS FOR TREATING SEPTAGE IN CONVENTIONAL WATER POLLUTION CONTROL FACILITIES

Both experimental results and field experience demonstrate that septage can be successfully treated in conventional water pollution control facilities. The maximum quantity of septage treatable at a plant and the associated costs depend on plant size, design characteristics, and sewage flow in relation to design capacity. While this section of the report is focused on treatment operating costs, consideration must also be given to maximum volume determinants for any given plant.

Available plant capacity, and the ratio of septage to sewage, must be considered in determining the volume of septage treatable at a particular facility. Some problems associated with septage treatment can be reduced through use of a storage tank and pump system for introducing septage at a controlled rate into the treatment plant. Plants receiving a small volume of sewage, those with less than 1.0 mgd, may need a storage tank-pump system for septage to avoid shock resulting from the rapid discharge of loads of septage.

There is no direct way of measuring the incremental operating costs of treating septage at water pollution control plants. Because septage relative to sewage generally comprises such a small volume, usually less than 0.5 percent of total influent, changes in septage flow do not show in operation costs. For instance, seasonal and day-to-day variations in septage receipts do not result in identifiable variations in operating costs. Likewise, differences in plant design, sewage characteristics and operating practices preclude the comparative analysis approach.

No attempt has been made to assign capital costs for treating septage. Much of the capital costs for municipal water pollution control facilities are now covered by federal and state grants. However, when costs are borne locally, they should be of concern in determining charges for septage treatment.

One approach to estimating septage treatment operating costs is to begin with the average cost of treating sewage and then adjust for the relative composition of septage and sewage. A second approach is to examine and apply surcharges of the type used for strong industrial wastewater.

SEPTAGE/SEWAGE OPERATING TREATMENT COST RATIO

The component parameters measured for septage are not in the same proportions as are those found in sewage. However, treatment costs can be estimated for the parameters which are similar for both sewage and septage. Total solids of the septage and BOD_5 of the supernatant from primary settling appear to be directly related to the economically important processes in a plant with activated sludge, anaerobic sludge digestion and vacuum filtration.

The objective of the cost ratio analysis is to relate the costs of treating septage to the costs of treating sewage through adjustments that account for the relative concentrations of major waste components. The adjustment process involves two steps:

(1) An identification of the percentage of operating costs associated with particular waste components, and

(2) A combination of cost distribution percentages with concentration ratios.

Taken together, these provide an estimate of the cost relationships between sewage treatment and septage treatment.

The addition of water alone to a system appears to increase operating costs by only 40 percent as much as the addition of the same volume of sewage. This estimate was derived through a simulation model (Smith, R.E., et al., 1968; and Leonard, current research). Thus, if 40 percent of the operating costs can be attributed to volume, the remaining 60 percent can be attributed to content, Table 23.

TABLE 23. DISTRIBUTION OF OPERATING COSTS FOR SEWAGE TREATMENT

Primary phase			
Volume		20%	
Total Solids		30%	
	Subtotal		50%
Secondary phase			
Volume		20%	
Supernatant BOD		30%	
	Subtotal		50%
	TOTAL		100%

The costs associated with inflow content can be further subdivided between primary and secondary treatment phases through the following assumptions: (1) that costs associated with content for the primary phase (including preliminary treatment, sludge digestion, and solids disposal) are in proportion to the amount of total solids in the influent wastewater; and (2) that costs associated with content for the secondary phase (including chlorination) are in proportion to the BOD_5 of the influent to the secondary treatment phase. Available data indicate that the primary and secondary treatment phases account for approximately equal shares of the total operating costs (Smith, R.E., et al., 1968).

TABLE 24. CONCENTRATION RATIOS FOR SOLIDS AND BOD_5 IN SEPTAGE AND SEWAGE

Total solids in septage		23,700 mg/l
Total solids in sewage		553 mg/l
Concentration ratio	42.3 to 1	
Supernatant BOD_5 for septage		1,860 mg/l
Supernatant BOD_5 for sewage		120 mg/l
Concentration ratio	15.5 to 1	

The septage characteristics shown in Table 24 are the weighted mean values for the Connecticut samples analyzed. Data for sewage are mean values for wastewater treated during 1969 at the Metropolitan District Commission Water Pollution Control Plant in Hartford, Connecticut.

These concentration ratios in combination with the estimated distribution of costs provide a basis for estimating the cost of treating septage in relation to the cost of sewage treatment. For any given plant, let "C" represent the operating and maintenance costs per thousand gallons of sewage treated. The cost per thousand gallons for treating septage can then be estimated by components as follows:

Water, 0.20C + 0.20C =	.40C
Total solids, 0.30 (42.3)C=	12.69C
Supernatant BOD_5, 0.30 (15.5)C =	4.65C
TOTAL	17.74C

Thus, the rule of thumb suggested by the analysis is that for a given plant with sufficient capacity for handling septage, the cost of treating 1,000 gallons (3,785 liters) of septage is approximately 18 times the costs of treating 1,000 gallons (3,785 liters) of sewage in that plant.

Sewage treatment costs data for the period 1965-1968 are available from federal audits of facilities receiving federal construction grants. From these audits, average operating and maintenance costs for activated sludge plants were estimated at $.05/1,000 gallons ($0.01/1,000 liters) of sewage for plants treating 10.0 mgd (37.9 mld) and $.09/1,000 gallons ($0.02/1,000 liters) for plants treating 1.0 mgd (3.8 mld) (Michel, 1970). Limited available data indicate corresponding current costs in Connecticut might be about twice these amounts. These adjustments would place the estimated cost of septage treatment at $1.80/1,000 gallons ($0.48/1,000 liters) in plants treating 10.0 mgd (37.9 mld) of sewage and $3.24/1,000 gallons ($0.86/1,000 liters) in plants treating 1.0 mgd (3.8 mld) of sewage.

SURCHARGES AND TOTAL CHARGES

An increasing number of municipalities levy additional charges on industrial firms discharging large quantities of heavily polluted wastewater into the municipal WPCF. The usual approach is to combine a basic sewer service charge with a surcharge for wastes exceeding limits defined for "normal sewage." Surcharges are usually levied on one or more of the following waste constituents: BOD, suspended solids (SS), pH, and chlorine demand. Surcharges for BOD and SS that are discussed below may have a direct bearing on estimating costs and setting charges for treating septage in water pollution control facilities.

In Connecticut, municipal experience with surcharges has been limited to a few cases of extra charges levied on an individual basis. On a national basis surcharge levels vary widely. Averaging surcharge rates for several municipalities would be misleading. There are variations in the combination of factors and in the definition of normal sewage. Some rates are clearly lower than treatment costs. In some cases, the basic sewer service rates and surcharge rates are set to cover a portion of capital costs as well as operating and maintenance costs. A perspective on charges for septage treatment in relation to surcharges for industrial wastewater can be gained from two examples where the basis of the surcharge is known.

In Charlotte, North Carolina, surcharges are levied to include a proportionate share of capital cost as well as operating cost. The surcharge is $56.43 per thousand pounds ($0.124/kg) of BOD_5 in excess of 250 mg/l (Franklin, 1969). Of this rate $23.34 is to cover capital costs, while the remaining $33.09 per thousand pounds of BOD_5 is based on current operating costs. Application of the $56.43 rate to septage with a BOD_5 of 3840 mg/l (the weighted mean of the Connecticut samples tested) would result in a surcharge of $1.69 per thousand gallons ($0.45/1,000 liters) of septage. Major steps in the conversion are:

$$(\$.05643/\text{lb } BOD_5) \times (3.840 - .250) \text{ lb } BOD_5/1{,}000 \text{ lb septage} \times (8345 \text{ lb}/1{,}000 \text{ gal. septage}) = \$1.69/1{,}000 \text{ gal.}$$

If only the $33.09 associated with operating cost is used in setting a surcharge for septage, the surcharge would be $0.99 per thousand gallons ($0.26/1,000 liters) of septage.

Greensboro, North Carolina, levies a surcharge of $15 per thousand pounds ($0.033/kg) of suspended solids in excess of 300 mg/l and $22 per thousand pounds ($0.048/k) of BOD_5 in excess of 300 mg/l (Shaw, 1969). From the explanation of water and sewer pricing, it would appear that a small but unidentifiable share of capital costs is included in the surcharge. Application of the Greensboro surcharge to a septage with a BOD_5 of 3840 mg/l and a supernatant SS of 2530 mg/l (the weighted mean of Connecticut samples tested) would result in a surcharge of $0.93 per thousand gallons ($0.25/1,000 liters) of septage. Inasmuch as the total solids in septage, 23,700 mg/l, is very high in relation to total SS in sewage, application of the Greensboro surcharge with total solids instead of supernatant SS appears to be more realistic than the use of SS alone. Using total solids and BOD_5 for septage in the Greensboro surcharge formula would result in a surcharge of $3.58 per thousand gallons ($0.95/1,000 liters) of septage.

In both Charlotte and Greensboro, the basic sewer service charge to which the surcharge is added is on a declining block pricing system. For instance, the first block rates began at $.40 per thousand gallons ($0.11/1,000 liters) in Charlotte and $.44 per thousand gallons ($0.12/1,000 liters) in Greensboro. These basic rates cover both the operating costs and a portion of the capital costs for the sewer collection and treatment system. The Charlotte basic sewer service charge <u>plus</u> the surcharge applied to septage would result in a total charge of $2.09 per thousand gallons ($0.55/1,000 liters) of septage. The Greensboro basic service charge <u>plus</u> the surcharge would be equivalent to a charge for septage of $4.02 per thousand gallons ($1.06/1,000 liters).

SECTION 9

ECONOMIC AND GOVERNMENTAL ASPECTS OF SEPTAGE DISPOSAL

The septic tank pumping industry is a competitive one in Connecticut. There are about 200 privately owned firms that provide pumping services, and almost all parts of the state are served by more than one pumper. Pumping may be a specialized business activity or associated with septic tank-soil absorption system installation and repair. There are no franchises for pumping and usually no municipal licenses are required. Pumpers pay dumping fees for deliveries made to the municipal disposal facilities. These dumping charges are passed on to the septic tank owners in their septic tank pumping charges.

In some parts of the state, pumpers may own or lease their disposal sites which are usually excavated pits or trenches. These areas may or may not be fenced. Costs associated with this method of disposal are usually minimal. In addition to land costs, other costs include occasional bulldozer work for excavations and roadway maintenance.

MUNICIPAL PROVISION FOR SEPTAGE DISPOSAL

Municipalities vary widely in the provisions they make for septage disposal. Many municipalities that operate WPCF provide for septage disposal at such facilities. However, most pumpers feel that improvements can be made at the septage receiving station locations.

Approximately 120 of the 169 general municipalities in Connecticut either have no WPCF or have a facility of insufficient size or capacity for processing septage. About 15 percent of those municipalities that are without available WPCF for septage disposal provide public disposal land sites, usually excavation pits, or have septage disposal agreements with adjacent municipalities. A few municipalities have installed lagoons in series.

Each municipality that allows septage disposal in its WPCF establishes the dumping charges or fees that pumpers pay and regulates the receiving of septage. Dumping fees in 1972 for septage coming from within municipalities and delivered to their respective WPCF varied from no charge to seldom more than $5.00 per 1,000 gallons ($1.32 per 1,000 liters). Usual dumping charges are not inconsistent with cost estimates for processing septage which were discussed in the section on surcharges and total charges. Some municipalities have regulations to exclude septage pumped outside the municipality. Others may set higher dumping fees for septage brought in from adjacent municipalities than fees for within-town septage.

Usually, septage disposal policies are made unilaterally by each municipality; these policies can be changed at municipal discretion. A recent example of unilateral action was that of a city with a large WPCF which for years had accepted at no charge the septage from adjacent municipalities. These were suburban municipalities without WPCF's. The city without consultation with these municipalities announced its unwillingness to accept such septage in the absence of intermunicipal agreements, but later, in response to protests, established instead unusually high fees for receiving out-of-city septage. Another example is that of a municipality with a new WPCF that set sufficiently high fees for outside septage so as to exclude it. However, setting dumping fees at exclusionary levels or to limit septage receipts are exceptions and do not reflect representative practices for Connecticut.

There are, of course, exceptions to unilateral municipal regulation of septage disposal. In a few instances municipalities that have a joint sewer system make joint provision for septage disposal. Inasmuch as almost all municipal WPCF's are under separate municipal control, however, there are few built-in incentives for more joint actions. In areas where excavation pits are the disposal method, there is a growing interest in joint municipal actions.

Positive municipal action to provide septage disposal facilities would appear to have been mandated in a 1971 Connecticut Statute, Chapter 361a, Solid Waste Management, Section 19-524n, which reads, in part, "Each municipal authority shall make provisions for the safe and sanitary disposal of all solid wastes which are generated within its boundaries, <u>including septic tank pumpings</u> ..." (emphasis added). Municipal responses were often not what was expected. In some municipalities where no provision was made for septage disposal, municipal executives interpreted the law to mean that if pumpers were able to find or provide their own disposal sites, as they were obviously already doing, then no municipal action was required. On the other hand, the amendment has suggested to pumpers in a few localities that job action or the threat of job action may be a legitimate means to force municipalities to do what would appear to be what the legislature had in mind.

STATE POLICY CONSIDERATIONS

Developing a state policy for septage disposal in a state even as small as Connecticut is complicated by differing physical and economic situations such as watershed areas for public water supplies, availability of disposal sites, distances to approved disposal sites, and extent of residential and recreation development. Furthermore, in New England general municipal governmental powers rest with towns of relatively small size (townships) which in Connecticut are seldom more than 50 square miles. Municipal-based systems might often display limitations imposed by small size, but they would reflect the differences in the disposal problem to be solved. Intermunicipal disposal systems that recognize municipal differences might more than counterbalance inefficiencies associated with size and lack of uniformity. Therefore, if varied solutions are an acceptable end product, then the planning process could be one that took local situations into account and reacted positively to those differing situations.

A state-municipal interactive process for septage disposal is implied in the 1971 Act on Solid Waste Management. This Act, referred to above, requires the Department of Environmental Protection to prepare a solid waste management plan for each solid waste planning region in the state. Because solid waste includes septage, planning for septage disposal is being given attention. To the maximum extent feasible, the state's regional planning agencies are to be allowed to prepare solid waste management plans. Municipalities are indirectly made a part of the planning process through their representatives on the boards of directors of the planning agencies. When completed, each municipality is to adopt the regional solid waste management plan and its own municipal plan. Each local plan will require the approval of the State Commissioner and the regional planning agency.

The 1972 Session of the Connecticut Legislature appropriated funds for the preparation of a state-wide plan for solid waste disposal. The General Electric Company, to whom a contract to this end was awarded, has taken under advisement how septage disposal might be made a part of solid waste disposal activities.

Legislation alone will not insure the provision of adequate septage disposal practices or facilities. Such measures must be accompanied by programs which encourage public responsibility for action. However, legislative intent formulated as state policy can help guide septage disposal programming. In so doing, the problems of municipal indifference and laggardness may be overcome, and incidents such as unnecessary confrontations leading to pumper strikes can be avoided.

FEDERAL POLICY CONSIDERATIONS

Septage is clearly a "pollutant" as the term is defined in Sec. 502(6) of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). Likewise, facilities for receiving and treating of septage are within the definition of "treatment works" as the term is defined in Sec. 212(2)(A) of the same Act. This latter definition qualifies septage receiving and treatment facilities for Federal grants for the construction of publicly owned treatment works. Moreover, the definition of "treatment works" includes "... site acquisition of the land that will be an integral part of the treatment process or is used for ultimate disposal of residues resulting from such treatment."

SECTION 10

SEPTAGE RECEIVING STATIONS

Where septage is handled for treatment at Connecticut water pollution control facilities, the facilities provided have generally been considered to be inadequate in terms of sanitation, aesthetics, and efficiency of septage discharge. To effectively overcome the objections in the areas indicated, the design and layout of a septage receiving station should be approached from both the septage hauler and water pollution control facility point of view. This approach was taken and a basic plan layout, Figure 55, was developed for a septage receiving station. Suggested modifications of the basic layout are given in Figures 56 and 57. This information can be related as necessary to water pollution control facility sites by the designer or engineer. In addition, a final design or layout should meet the following criteria:

(1) From the septage hauler point of view.

(a) An easily accessible discharge point is desirable with simple transport vehicle movement. A straight through traffic pattern is preferred as shown in Figure 55. A turn-around drive loop is a less desirable alternative.

(b) The point for septage discharge from the truck should be one that little or no spillage may occur.

(c) Provision should be made for septage discharge by gravity.

(d) Water should be available for cleaning the septage transport vehicle and any septage spillage resulting from discharge. For cleaning purposes, a high pressure water system is preferred. The sepage hauler should be able to personally clean up before leaving the septage receiving station.

(f) The area should be well lighted.

(g) A telephone booth at the receiving station site is a desirable convenience item.

(2) From the water pollution control facility point of view.

(a) The locations for receiving septage should be at points where treatment plant operators can know about and control dumpings.

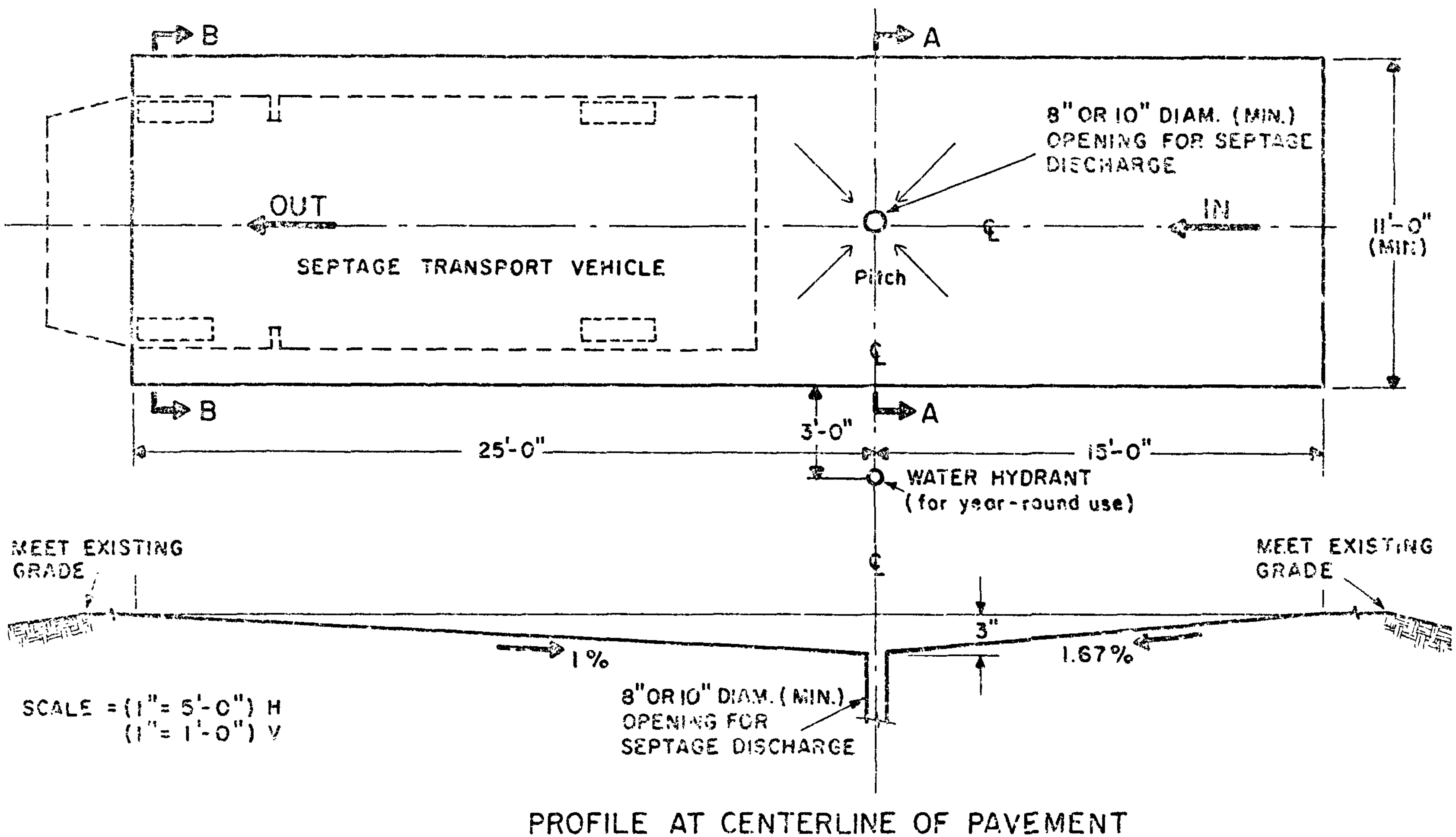


Figure 55. Septage receiving station basic layout.

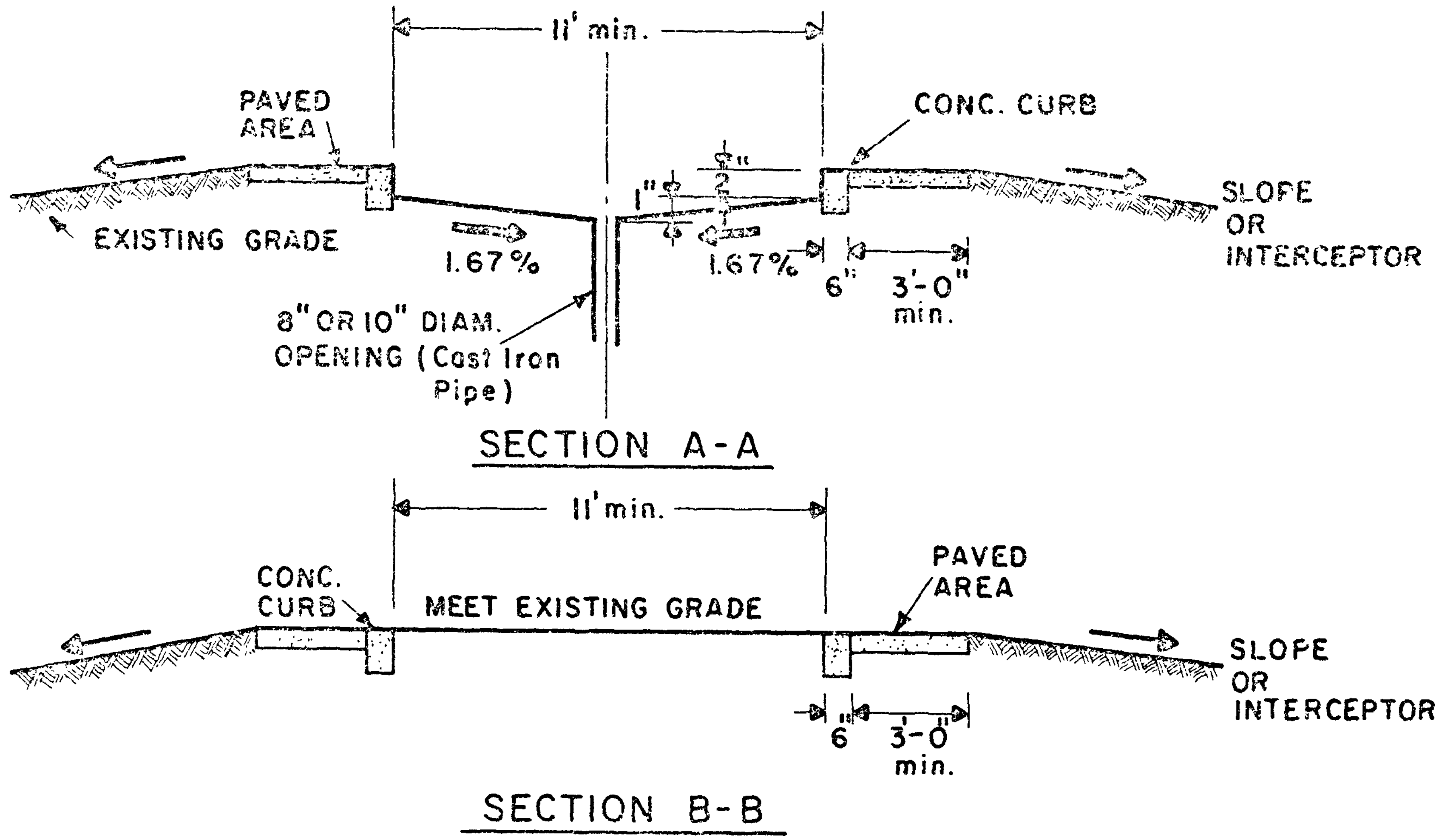


Figure 56. Septage receiving station: Scheme 1.

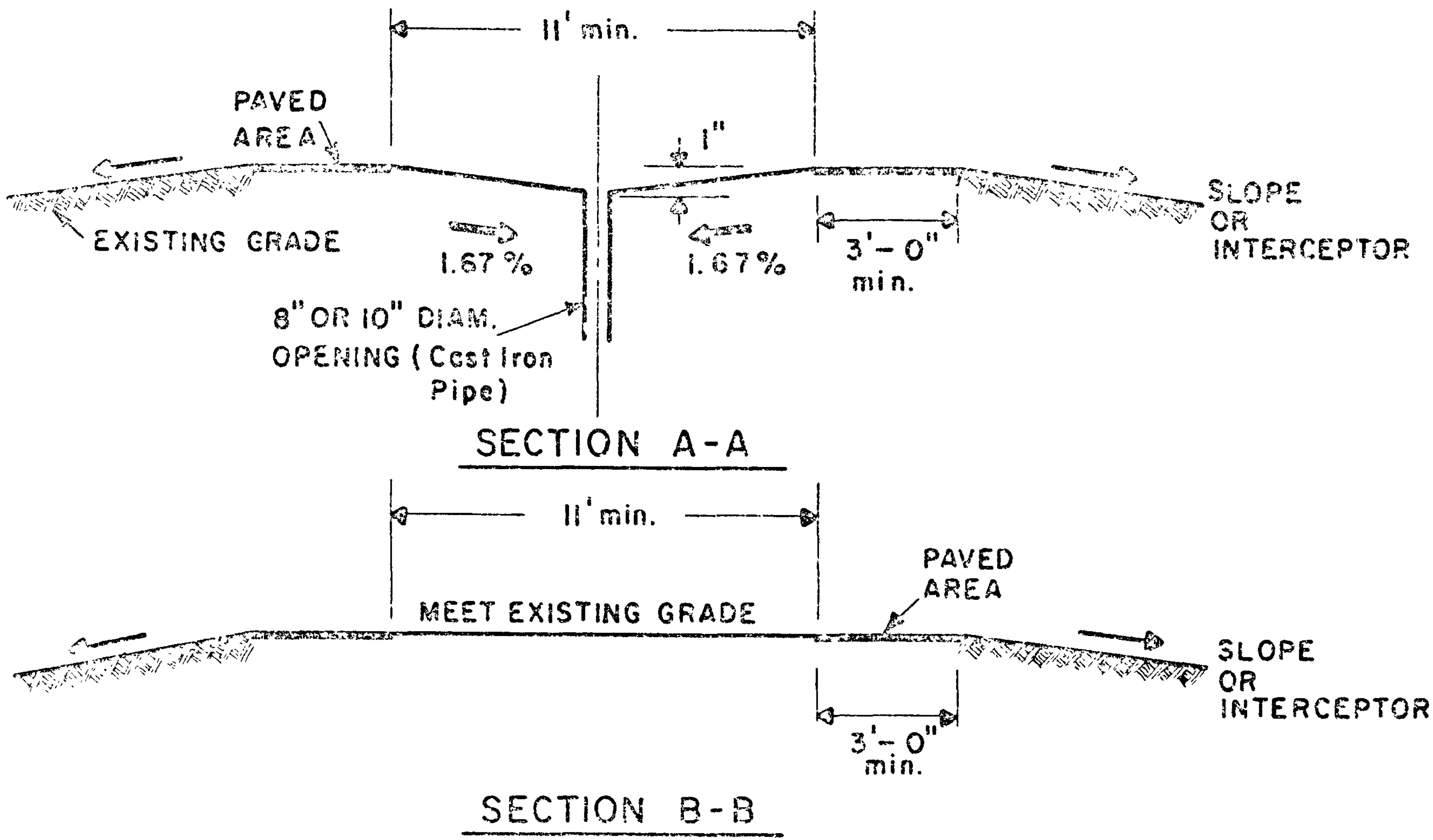


Figure 57. Septage receiving station: Scheme 2.

(b) Aesthetic consideration with regard to dumping site is important. For example, septage discharge in front of a water pollution control facility greatly detracts from a good public image.

(c) The septage receiving station area should be one which easily promotes cleanliness.

(d) Septage may be either discharged directly into the incoming sewage or into storage tanks. If stored, septage is then pumped into the waste treatment process in controlled quantities in order to have the least effect on the treatment processes.

(e) Adequate inflow pipe size, no smaller than eight inches in diameter, is suggested for handling septage discharges from trucks.

(f) Attractive fencing enclosures may be necessary.

Keeping the above points in mind should result in the design of septage receiving facilities in accordance with today's needs. It should be remembered that septage can at times be unpleasantly odoriferous. The odors can permeate the atmosphere to an area beyond the water pollution control facility itself as well as penetrating within the treatment plant itself. Proper septage receiving station design as suggested can contribute to containing such odors.

Although the above criteria were developed for septage receiving stations, a similar approach is applicable for septage discharged at land disposal sites.

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APPENDIX A

QUESTIONNAIRE MAILED TO HOMEOWNERS

UNIVERSITY OF CONNECTICUT
Storrs, Connecticut
August 5, 1969

Dear

Your assistance will be helpful in planning for the proper disposal of wastes pumped from septic tanks. Data from individual households in selected areas will be used in estimating the current and future volume of pumped wastes. A reply envelope and a summary of the major aspects of the research project are enclosed.

Questions you may have regarding the use and management of home sewage disposal systems will be answered to the extent that information is available. If you have no questions and wish to remain anonymous, tear off the name and address.

Thank you,

John J. Kolega, Associate Professor
Department of Agricultural
Engineering

When was the septic tank and drainage system installed? ____________

When was the septic tank last cleaned? ____________
(a) Just prior to the last cleaning:
Was water rising to the ground surface? _______
Were drains from the house slow or inoperative _______
(b) If the system was functioning properly why did you decide to have the tank cleaned?

How many times has the tank been cleaned in the last three years? _____

What is the size of the septic tank? ______ gallons. (Known ________, unknown _________, estimated ________).

How many persons use the system?
No. of adults ______. No. of children ages 12 to 18 _____. No. under 12

Is laundry water discharged into the septic tank? ________
Is kitchen water discharged into the septic tank? ________

Do you have a garbage disposal? _______

Have you had any problems with the septic tank or drainage system not covered by the above questions?
How long have you lived at your current address? _______
Your Comments or Questions (continue on back if additional space is needed).

APPENDIX B

QUESTIONNAIRE MAILED TO SEPTIC TANK PUMPERS

UNIVERSITY OF CONNECTICUT
Storrs Agricultural Experiment Station
Storrs, Conn. 06268
November 14, 1969

Dear

As a part of our research study for finding better ways for disposal of septage, Art Dewey and Bob Leonard of the Department of Agricultural Economics, need information on the pumping of household septic tanks. Two summary reports are enclosed on what this research study is about. In order for us to do an adequate job, your cooperation is needed.

If you pump septic tanks, please fill out the questionnaire below as best you can and return it in the postage-paid self-addressed envelope. If you wish to remain anonymous please tear off your name.

Very truly yours,

J. Kolega
Department of Agricultural Engineering

1. What is the capacity of each truck you use for hauling septage?

   ______gallons ______ gallons ______ gallons ______ gallons

2. How many household septic tanks did you pump last year? ______

3. How much of the household septage you pumped was handled at sewage treatment plants? (Check one).

   None _____, 1/3 _____, 1/2 _____, 3/4 _____, all _____.

4. What is a reasonable maximum one-way distance for hauling septage?

   ________ miles

5. What problems result from dumping in fields, trenches or lagoons?

6. Do you feel that all disposal sites should be public and operated by town governments?

7. What should a good septage dumping facility include?

APPENDIX C

LABORATORY ANALYSES SUMMARY[a]

Parameter	Number of Samples	Total Number of Test Replications
BOD_5 Septage	85	287
BOD_5 Supernatant	47	204
COD Septage	107	271
COD Supernatant	61	185
Total Solids	104	153
Volatile Total Solids	104	153
Fixed Total Solids	104	153
Total Suspended Solids	51	77
Volatile Suspended Solids	51	74
Organic Nitrogen	63	77
Free Ammonia	75	94

[a]The total number of different septage samples analyzed were 180.

APPENDIX D

NITROGEN APPLICATION CALCULATIONS

Sample Calculations for Rate of Nitrogen-N, Application for Land Disposal of Septage.

Free Ammonia,	75% design value:	92 mg/l
Organic Nitrogen,	" " "	37 mg/l
Assumption of above summation as being equal to total Nitrogen		129 mg/l

Free ammonia and ammonia-nitrogen are the same in meaning.

1 ppm is equal to approximately 1 mg/l which is equal to approximately 8.34 lbs/1,000,000 gallons

$$\text{lbs of Nitrogen/1,000,000 gals} = 129 \times \frac{8.34 \text{ lbs}}{(1{,}000{,}000 \text{ gals})}$$

$$= 1075 \text{ lbs N/1,000,000 gallons septage (75\% design)}$$

Selecting a maximum Nitrogen application rate of 300 lbs/acre

$$\text{Gallons Septage to be Applied per acre} = \frac{300 \text{ lbs N/acre}}{1075 \text{ lbs N/1,000,000 gals}}$$

$$= 279{,}000 \text{ gallons septage/acre}$$

OR

Acreage required/1,000,000 gallons of septage =

$$\frac{1075 \text{ lbs N/1,000,000 gals}}{300 \text{ lbs N/acre}}$$

= 3.58 acres needed for 1,000,000 gallons of septage

APPENDIX E

SEPTAGE LAND APPLICATION DATA

Location: White Memorial Foundation, Inc., Litchfield, Ct.
Time Period: July 20, 1971 through October 14, 1971

Date	Method of Injection	No. of Passes of 400 ft.	Trailer Loads, 800 Gallons per Load	Estimated Septage Volume, (gals.)	Cumulative Volume Injected, (gals.)
July 20	Plow-Furrow-Cover	17	10	8,000	8,000
21	Plow-Furrow-Cover	22	11	8,800	16,800
27	Plow-Furrow-Cover	17	6	4,800	21,600
27	Sub-Sod Injector	5	5	4,000	25,600
28	Sub-Sod Injector	8	8	6,400	32,000
29	Sub-Sod Injector	5	5	4,000	36,000
Aug. 5	Sub-Sod Injector	1	1	800	36,800
5	Plow-Furrow-Cover	1	1	800	37,600

Problem: Tractor-trailer stuck. The tractor wheel had gone over an area where septage had been injected previously (at an earlier date).

Observation: Difficulty was probably due to wet field conditions. There was a fair amount of rainfall that week.

Action taken: Delayed field application of septage (August 6, Friday, and weekend until Monday, August 9).

Date	Method of Injection	No. of Passes of 400 ft.	Trailer Loads, 800 Gallons per Load	Estimated Septage Volume, (gals.)	Cumulative Volume Injected, (gals.)
9	Plow-Furrow-Cover[a]	25	13	10,400	48,000
10	Plow-Furrow-Cover	14	7	5,600	53,600
11	Plow-Furrow-Cover	6	3	2,400	56,000

Problem: Field conditions wet; operation stopped because of rain.

Date	Method of Injection	No. of Passes of 400 ft.	Trailer Loads, 800 Gallons per Load	Estimated Septage Volume, (gals.)	Cumulative Volume Injected, (gals.)
12	Sub-Sod Injector	3	3	2,400	58,400

Problem: Field conditions wet. Septage application still possible.

Date	Method of Injection	No. of Passes of 400 ft.	Trailer Loads, 800 Gallons per Load	Estimated Septage Volume, (gals.)	Cumulative Volume Injected, (gals.)
13	Terreator	1	1	800	59,200

Problem: Hydraulic oscillating mechanism did not perform satisfactorily.

---

[a] Second septage application coverage for this area.

Date	Method of Injection	No. of Passes of 400 ft.	Trailer Loads, 800 Gallons per Load	Estimated Septage Volume, (gals.)	Cumulative Volume Injected, (gals.)
Aug. 16	Terreator	11	10	7,000	66,200
22	Sub-Sod Injector	1	1	800	67,000
22	Plow-Furrow-Cover	1	1	800	67,800
24	Sub-Sod Injector	Applications made; data not entered			
31	Sub-Sod Injector	5	5	4,000	71,800
31	Plow-Furrow-Cover[b]	16	8	6,400	78,200
	Problem: Plow tripped three times during P-F-C series. Wet field conditions was the reason for changeover from S-S-I to P-F-C method. (Tropical storm in area on Friday and Saturday.)				
Sept. 3	Plow-Furrow-Cover	22	11	8,800	87,000
	Problem: Plow tripped 11 times.				
8	Plow-Furrow-Cover	20	10	8,000	97,000
	Problem: Plow tripped 10 times.				
10	Scheduled field application, but septage not available.				
16	Sub-Sod Injector	2	1	800	97,800
	Reclaimed pasture area used.				
	Problem: Rain on weekend and during week; wet field conditions which prevented septage application.				
30	Sub-Sod Injector	10	10	8,000	105,800
Oct. 4	Sub-Sod Injector	3	3	2,400	108,200
	Problem: Insufficient quantity of septage.				
5	Plow-Furrow-Cover	5	2.5	2,000	110,200
13	Plow-Furrow-Cover	6	3	2,400	112,600
14	Plow-Furrow-Cover	9	5	4,000	116,600

[b] Third septage application coverage for this area.

APPENDIX F

IDENTIFICATION KEY TO CHARACTERIZATION OF BACTERIA ISOLATED FROM SEPTAGE AND/OR SEPTIC TANK SEWAGE.

PD - Phenylalanine deaminase

LD - Lysine decarboxylase

CO - Cytochrome oxidase

1. Klebsiella-Enterobacter
2. Aerobacter-Serratia
3. Escherichia coli

4. Providenis sp.
5. Proteus rettgeri
6. P. morganii

7. Citrobacter sp.
8. Arizona sp.
9. P. mirabilis

10. P. vulgaris
11. Salmonella sp.
12. S. typhi

13. Shigella sp.
14. S. paratyphi A
15. S. cholerae-suis

16. Escherichia
17. Mima
18. Herellea

19. Achromobacter
20. Pseudomonas
21. Aeromonas

22. Alcaligenes
23. Mima polymorpha var. oxidans

APPENDIX G

AERATION PROCESSES

Table 1. AERATION PROCESS REQUIREMENTS FOR TREATMENT OF SEPTAGE AS COMPARED TO SEWAGE TREATMENT PRACTICE

Parameter	Septage	Sewage
Detention time	(1) 3.9 days (2) 7.8 days	(1) 0.39 days (2) 0.78 days
Oxygen required	(1) 38.6 lb. o.c./day (2) 38.6 lb. o.c./day	(1) 3.9 lb. o.c./day (2) 3.9 lb. o.c./day
Area required	(1) 521 ft^3 9' -0" x 19' -4" x 3' (2) 1042.5 ft^3 11' -0" x 23' -8" x 4' -0"	(1) 52 ft^3 (2) 104 ft^3
Costs	$ 10(123 x 47)3/4 = 6.70/1000 gal	$ 10(12.3 x 47)3/4 = 1.20/1000 gal
Power required	300 hp/mgd	50 hp/mgd

(1) Conventional activated sludge process
(2) Extended aeration activated sludge process

o.c. = oxygenation capacity

Table 2. FEATURES OF AERATION PROCESSES (GLOYNA, E.F. ET AL, 1968).

Process	Population Range	Loading Range lbs. BOD/day/1000 ft^3 Aeration Volume	Degree of Removal (%)
Conventional Activated Sludge	Unlimited	25 - 50	90 - 95
Extended Aeration	500 - 5000	10 - 15	85 - 90
Contact Stabilization	1500 to Unlimited	25 - 75	85 - 90
High Rate Activated Sludge	10,000 to Unlimited	100 - 150	50 - 75

APPENDIX H

FREQUENCY OF PUMPING IN RELATION TO SIZE OF SEPTIC TANK

Number of tanks

Number of times pumped within a three-year period	Unknown	200-399	400-599	600-799	800-999	1000-1199	1200-1399	1400+
15					1			
14								
13								
12								
11		1						
10					1			
9	1							
8								
7								
6			1					
5	1							
4			1			1		
3	4		2	1		1		
2	7		2	2	1	5	1	
1	26	4	16	11	3	11	1	
0	27	5	11	8	9	17		2

Tank size (gallons)

APPENDIX I

SEPTAGE* SEMINAR

University of Connecticut
College of Agriculture & Natural Resources Auditorium
Storrs, Connecticut

PROGRAM SPONSORSHIP

Storrs Agricultural Experiment Station
Cooperative Extension Service
Institute of Water Resources
Conn. State Dept. of Health Environmental Health Services Division
Connecticut Sewage Disposal Association

January 28, 1971

9:30 - 10:00 A.M. Registration

Program Moderator for Morning Session:

G. Kenneth Dotson, Advanced Waste Treatment Research Laboratory, U.S. Dept. of Interior, Federal Water Quality Administration, Cincinnati, Ohio.

10:00 - 10:30 A.M. Biological Parameters of Septage

Micro-organisms found in septage and their distribution; a comparative evaluation in terms of similarities or differences to known microorganisms of conventional water pollution control facilities; are pathogens present?

10:30 - 11:00 A.M. Physical and Chemical Parameters of Septage

The presentation of design curves and their use based upon analyses of septage for BOD, COD, total solids, volatile solids, suspended solids, free ammonia, and organic nitrogen; data on odor, settling rates, color, and observed pH levels.

11:00 - 11:15 A.M. Break

11:15 - 11:45 A.M. Volumes and Implications for Disposed Septage

Estimated total and per capita septage volumes have been developed for the state and for thirteen subregions. These estimates together with information on pumper disposal requirements and on municipal dumping regulations will be used to define economic aspects of septage disposal problems. The methodology for making volume estimates will be briefly discussed.

11:45 - 12:15 P.M. Costs Associated with Septage Treatment

Data on the content of septage will be related to the operating and maintenance costs of particular sewage treatment processes.

12:15 - 12:45 P.M. Pilot Studies: Progress Report

Septage injection in soil; interstate activities; discharging septage at water pollution control facilities.

1:00 - 2:00 P.M. LUNCH

Program Moderator for Afternoon Session:

Joseph Kosman, Municipal Wastewater Control Section, Environmental Health Services Division of the Connecticut State Department of Health, Hartford, Connecticut.

2:15 - 3:00 P.M. W. Widmer, Civil Engineering Department, "A Sanitary Engineer in Pakistan."

3:00 - 3:45 P.M. An Economic Engineering Analysis of Septage Disposal Systems.

Types of septage disposal systems; criteria for their evaluation and systems evaluation.

3:45 - 4:14 P.M. Open Discussion

*Septage, or septic tank pumpings, is defined as the mixed liquid and solid contents pumped from septic tanks and dry wells used for receiving domestic type sewage.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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EPA-600/2-77-198		

4. TITLE AND SUBTITLE	5. REPORT DATE
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7. AUTHOR(S) John J. Kolega, Arthur W. Dewey, Benjamin J. Cosenza, Robert L. Leonard	8. PERFORMING ORGANIZATION REPORT NO.
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15. SUPPLEMENTARY NOTES

Project Officer: G. Kenneth Dotson (513) 684-7661

16. ABSTRACT

The study identified methods of treating and disposing of septic tank sludge (septage). Biological, chemical, and physical properties of septage were determined and curves were developed for designing septage treatment facilities.

Two processes were tested for treating and disposing of septage. Injecting septage in the soil appears to be practical, but is limited to periods when the ground is not frozen. A bench and pilot process that reduced BOD_5, COD, and Kjeldahl nitrogen by 93 percent or more consisted of anaerobic digestion-aeration-sand filtration.

Consideration was given to treating septage in publicly owned wastewater treatment plants with municipal wastewater. Criteria for desirable receiving facilities were developed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste treatment Digestion Sludge disposal Septic tanks	Septage treatment Soil injection Septage disposal Aerobic treatment Anaerobic digestion Soil treatment	13B

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