PB84-196229

Characterization of Soil Disposal System Leachates

Rice Univ., Houston, TX

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

May 84

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS®

EPA-600/2-84-101
May 1984

CHARACTERIZATION OF SOIL DISPOSAL SYSTEM LEACHATES

by
Mason Tomson
Carol Curran
J.M. King
Helen Wang
Joe Dauchy
Virginia Gordy
B.H. Ward
Department of Environmental Science and Engineering
Rice University
Houston, Texas 77251

Cooperative Agreement No. CR-806931

Project Officers

Ronald F. Lewis
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

Marion R. Scalf
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

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

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-84-101	2.	3. RECIPIENT'S ACCESSION NO. PB84 196229
4. TITLE AND SUBTITLE CHARACTERIZATION OF SOIL DISPOSAL SYSTEM LEACHATES		5. REPORT DATE May 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Mason Tomson, Carol Curran, J. M. King, Helen Wang, Joe Dauchy, Virginia Gordy, C. H. Ward		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dept. of Environmental Science & Engineering, Rice University, P.O. Box 1892, Houston, Texas 77251		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. CR-806931
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory - Cin., OH, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio		13. TYPE OF REPORT AND PERIOD COVERED Final, 1980-1983
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Ronald F. Lewis, (513) 684-7644 and Marion R. Scalf (913)743-2303

16. ABSTRACT

In the present study, ground water from a total of ten septic tank systems around the country has been sampled and analyzed for inorganic ions, bacteria, viruses, and chromatographable trace level organics (C-TLOs). Generally, the distribution box at each site was sampled and taken to be input to the soil adsorption field. The primary emphasis of the work has been C-TLOs. From preliminary studies, twenty-two C-TLOs were targeted for quantitation. These 22 compounds included: chloroform, trichloroethylene, toluene, dichlorobenzenes, naphthalene, skatole, p(1,1,3,3-tetramethylbutyl)phenol, benzophenone, and bis(2-ethylhexyl)phthalate, several of which are priority pollutants. Concentration of the 22 target compounds varied from a high of ~300 μg l^{-1} in the distribution boxes to a high of ~15 μg l^{-1} in the ground water wells. Typical concentrations in the distribution boxes and ground water samples were <1 μg l^{-1} and <0.1 μg l^{-1} respectively, indicating generally >90% removal of C-TLOs within a few tens of feet.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Septic tanks Ground water Contamination Organics	Septic tanks Municipal waste water	

18. DISTRIBUTION STATEMENT Release to public.	19. SECURITY CLASS (This Report) unclassified	21. NO. OF PAGES 87
	20. SECURITY CLASS (This page) unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

Although the information described in this article has been funded wholly or in part by the United State Environmental Protection Agency through the cooperative agreement number CR 806931 to the National Center for Ground Water Research and by subcontract to the Department of Environmental Science and Engineering of Rice University, it has not been subjected to the Agency's required peer and administrative review and therefore does not necessarily reflect the views of the Agency and no offical endorsement should be inferred. Neither does mention of trade names or commercial products constitute endorsement or recommendation for use.

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. The complexity of the 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.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

About 30% of Americans use septic tanks to treat their domestic waste. As the trend to move back to less populated areas continues, the percentage of septic tank users is likely to increase. Previously, little attention has been given to the impact of septic tanks on ground water. Almost no attention has been directed to the extent of ground water contamination by chromatographtable trace level organics (C-TLOs), such as pesticides, plasticizers, organic solvents, and neutral chlorinated hydrocarbons.

In the present study, ground water from a total of ten septic tank systems around the country has been sampled and analyzed for inorganic ions, bacteria, viruses, and C-TLOs. Generally, the distribution box at each site was sampled and taken to be input to the soil adsorption field. The primary emphasis of the work has been C-TLOs. From preliminary studies, twenty-two C-TLOs were targeted for quantitation. These 22 compounds included: chloroform, trichloroethylene, toluene, dichlorobenzenes, naphthalene, skatole, (p(1,1,3,3-tetramethyl-butyl)phenol, benzophenone, and bis(2-ethylhexyl)phthalate, severl of which are priority pollutants. The most thorough analysis was performed on samples from a site at Speonk, New York, where about one hundred people in three apartment buildings discharge waste water into a common sandy soil adsorption system.

Concentration of the 22 target compounds varied from a high of ~300 $\mu g\ l^{-1}$ in the distribution boxes to a high of ~15 $\mu g\ l^{-1}$ in the ground water wells. Typical concentrations in the distribution boxes and ground water samples were <1 $\mu g\ l^{-1}$ and <0.1 $\mu g\ l^{-1}$, respectively, indicating generally >90% removal of C-TLOs within a few tens of feet. This potential for chemical pollution, as well as nuisance factors (taste and smell) due to C-TLO ground water contamination from septic tanks, has been demonstrated. The concern should be greatest in areas with sandy soil where poor C-TLO retardation and adsorption are expected.

CONTENTS

Foreword iii

Abstract iv

Figures vi

Tables vii

Acknowledgment viii

1. Introduction 1

2. Conclusions 6

3. Recommendations 7

4. Methods 9

5. Septic Tank Systems Studied 12

a. Site #1, Speonk, New York 13
b. Site #2, Cisco Grove, California 24
c. Site #3, Sun Valley, Nevada 32
d. Site #4, Stinson Beach, California 41
e. Site #5, Penwaugh, Texas 47
f. Site #6, Aldine KOA Campground, Houston, Texas. . 54
g. Site #7, Pearland, Texas, Mobile Home Park . . . 58
h. Site #8, Lawrence, Kansas, Single Family Dwelling Septic Tank System 61
i. Site #9, Southern Bible College, Houston, Texas . 65
j. Site #10, Stellacoom, Washington 66

6. Discussion and Summary of C-TLOs Found in Septic Tank Systems 67

References 75

FIGURES

Number		Page
1	Schematic of an on-site septic tank system.	2
2	Distribution of on-site septic systems, by state (Otis *et al.*, 1977), along with locations where samples were obtained for C-TLOs analysis in this study	5
3	Pictorial summary of laboratory procedures used to sample and analyze C-TLOs associated with septic tank systems	10
4	Schematic of Speonk, New York, site	14
5	GC traces from samples obtained from Speonk, New York.	16
6	Diagram of leach field at Cisco Grove, California.	25
7	GC traces from samples obtained from Cisco Grove, California	27
8a	Map showing location of monitoring wells and example of septic tank system in Sun Valley, Nevada.	33
8b	Diagram of static water levels in Sun Valley, Nevada.	34
9	GC traces from samples obtained from Sun Valley, Nevada.	37
10	Map of Stinson Beach, California, showing monitoring well sites	42
11	GC traces from samples obtained from Stinson Beach, California	45
12	Schematic of Penwaugh, Texas, site.	48
13	GC traces from samples obtained from Penwaugh, Texas	51
14	Diagram of Aldine, Texas, site.	55
15	GC traces from samples obtained from Aldine, Texas	56

FIGURES (Cont.)

Number		Page
16	Diagram of Pearland, Texas, site	59
17	GC traces from samples obtained from Pearland, Texas.	60
18	Diagrams of Lawrence, Kansas, site	62
19	GC traces from samples obtained from Lawrence, Kansas	63
20	Plot of the logarithm of C-TLO concentrations (ng ℓ^{-1}) and conductance (μmhos cm^{-1}) vs the logarithm of distance for selected compounds found in the ground water at Speonk, New York. . .	69

TABLES

Number		Page
1	Water Characteristics, Speonk, New York, July 7-11, 1981	15
2	Speonk, New York, Trace Organics (μg/l)	23
3	Characteristics of Water at Cisco Grove, California (June 1-2, 1981)	26
4	Cisco Grove, California, Trace Organics (μg/l)	30
5	Characteristics of Water at Sun Valley, Nevada	35
6	Sun Valley, Nevada, Trace Organics (μg/l)	36
7	Characteristics of Water at Stinson Beach, California	43
8	Stinson Beach, California, Trace Organics (μg/l)	44
9	Characteristics of Water at Penwaugh, Texas, January 22, 1981	49
10	Summary of C-TLOs Found at Penwaugh, Texas, Site; Sampling: January 23, 1981	50
11	Onsite Chemical Analyses of Water and Waste Water from Home Septic Tank System, Lawrence, Kansas, May 8, 1981	64
12	Major Uses of C-TLOs Targeted for Study	68
13	Summary of C-TLO concentrations (μg/l) found at four primary septic tank system sites	70
14	Compounds Identified by Reverse Ion Search in Water Samples from Speonk, New York, Site	72

ACKNOWLEDGMENT

This is to acknowledge the continuous support and encouragement given by the personnel at Municipal Environmental Research Laboratory, Cincinnati, Ohio, and by W. J. Dunlap, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma. Portions of this work were supported by EPA Grant No. CR-806931, National Center for Ground Water Research Subcontract No. 6931-6, and EPA Grant No. R-805292. Additionally, the continuous support by C. P. Gerba for the virology analysis is acknowledged. The manuscript was prepared by Suzette Pruit, and that is gratefully appreciated.

SECTION 1

INTRODUCTION

GENERAL STATEMENT

About 30% of Americans use septic tanks to treat their residential waste water (Dunlap, 1977). Salvato (1982, p. 379) lists the following six criteria that an excreta, sewage, or wastewater disposal system should meet:

1. Prevention of pollution of water supplies and contamination of shellfish intended for human consumption.
2. Prevention of pollution of bathing and recreational areas.
3. Prevention of nuisance, unsightliness, and unpleasant odors.
4. Prevention of human wastes coming into contact with man, animals, and foods or being exposed on the ground surface accessible to children and pets.
5. Prevention of fly and mosquito breeding; exclusion of rodents and other animals.
6. Strict adherence to standards for ground water and surface waters; compliance with local regulations governing wastewater disposal and water pollution control.

A typical septic tank and soil absorption lateral field is shown in Figure 1. The actual septic tank itself is generally sized to hold one to two days of liquid waste and one to several years of solid waste. Most solids are removed in the septic tank, but little BOD removal takes place. The leach field acts to absorb and remove BOD, pathogens, and inorganic minerals. If solids pass into the leach field, they tend to plug the soil. For a thorough discussion of various overall septic tank designs, details of designs, and background on their operation and failure, the following references should be consulted: Salvato, 1982; Otis et al., 1977; Scalf, Dunlap, and Kreissl, 1977; Chanlett, 1979; and Imhoff and Fair, 1940.

The following criteria are generally considered when permitting a septic tank system design:

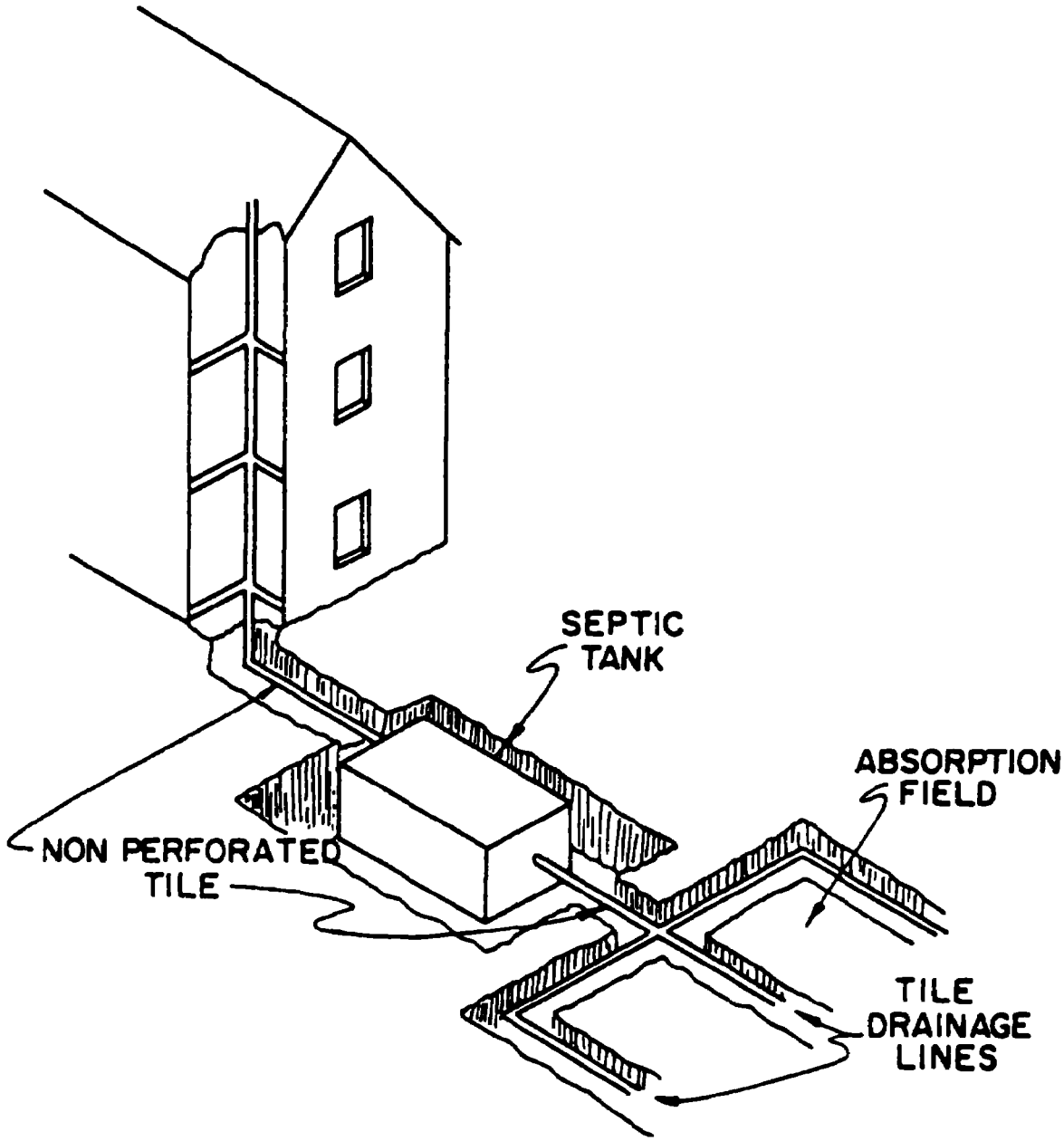


Figure 1. Schematic of an on-site septic tank system (Scalf *et al.*, 1977). (For further details and drawings, see Salvato, 1980, pp. 399 and 421.)

1. A percolation test is run which determines the allowable infiltration rate (gal/ft^2/day) for sizing the lateral field.
2. Some estimate of the expected daily flow is made. For residential waste often this is based upon the number of bedrooms in the house(s) or 150 gal/day/bedroom (USPHS, 1976). For commercial facilities, generally some formula based upon experience is used.
3. The horizontal distance to the nearest drinking water well from any point in the leach field is generally required to be 100 ft or greater.
4. Finally, most states have some requirement on the distance from the bottom of the lateral trench to the top of the ground water table or to the top of a clay or rock strata. Generally, this vertical distance is from 18 to 48 in or greater.

Despite these considerations, it is estimated that only half of the septic tank systems perform satisfactorily for their fifteen to twenty year design life (Scalf, Dunlap, Kreissl, 1977). The most common manifestation of septic tank system failure is the appearance of moisture at the soil surface associated with the leach field. This is generally caused either, first, by crusting or clogging of the soil surface inside the leach field trenches or, second, by a seasonally high water table. As a consequence, as long as a septic tank system receives water and allows it to percolate downward, the system is generally assumed to be working.

Ground water contamination is rarely assessed as a problem with septic tank systems. The primary focus of this research has been on ground water pollution by septic tank effluents. In 1977 USEPA in a report to Congress classified subsurface soil absorption systems (septic systems) as Category I ground water pollution sources because they discharge directly into the ground water (USEPA, 1977). Salvato (1982, pp. 175-181) has reviewed the literature on microorganism and chemical pollution movement in ground water. In one study of a sandy soil shallow aquifer (Stiles et al., 1927) coliform bacteria were shown to travel 232 ft and chemical pollution (uranin dye) moved 450 ft in about 2-1/2 years; furthermore, the pollution did not disperse in the aquifer, but remained concentrated at the surface near the water table. In that same study chromate was found to travel 1000 ft in only three years, and wells 2000 ft away from a garbage dump were contaminated. Additionally, if a well is pumping in the area, ground water flow will generally tend to be in the direction of the well. This "cone of influence" often extends out 400 to 1000 ft from a well and causes accelerated ground water and pollution movement toward the well. Bacteria die off with depth in unsaturated soil, but increase in number once the water table is approached. From these observations it is clear that septic

tank systems are potentially a major source of ground water pollution and that current design practice, such as the 100 ft separation distance to a water well, may be inadequate.

As noted by Salvato (1982, p. 181) and Scalf et al. (1977, p. 25), very little is known about the fate of chromatographable trace level organics (C-TLOs) such as chlorinated hydrocarbons, aromatics, or phthalate esters in ground water below septic tank systems. Many of these compounds are either solvents or synthesized organics. Often these compounds, such as phthalate plasticizers, are chosen by industry personnel for their stability and resistance to degradation.

The overall objective of this research has been to determine if potentially harmful C-TLOs are being systematically added to ground water by septic tank systems, and if so, which compounds or compound classes are present at what concentration levels and to what extent they might migrate in the subsurface. Domestic septic tank systems were our primary focus and when possible, we studied larger systems used by several homes. Finding larger septic tank systems which we could obtain permission to sample and which had appropriate monitoring wells was rather tedious. In total, ten systems, some single family, were sampled; the locations of these ten systems are indicated on the map in Figure 2. Two of the ten, Speonk, New York, and Cisco Grove, California, were particularly well suited for study and produced the most definitive information of the potential migration of C-TLOs in ground water beneath septic tanks. Data related to C-TLOs from each of these ten systems will be presented, but emphasis will be placed on the two mentioned above.

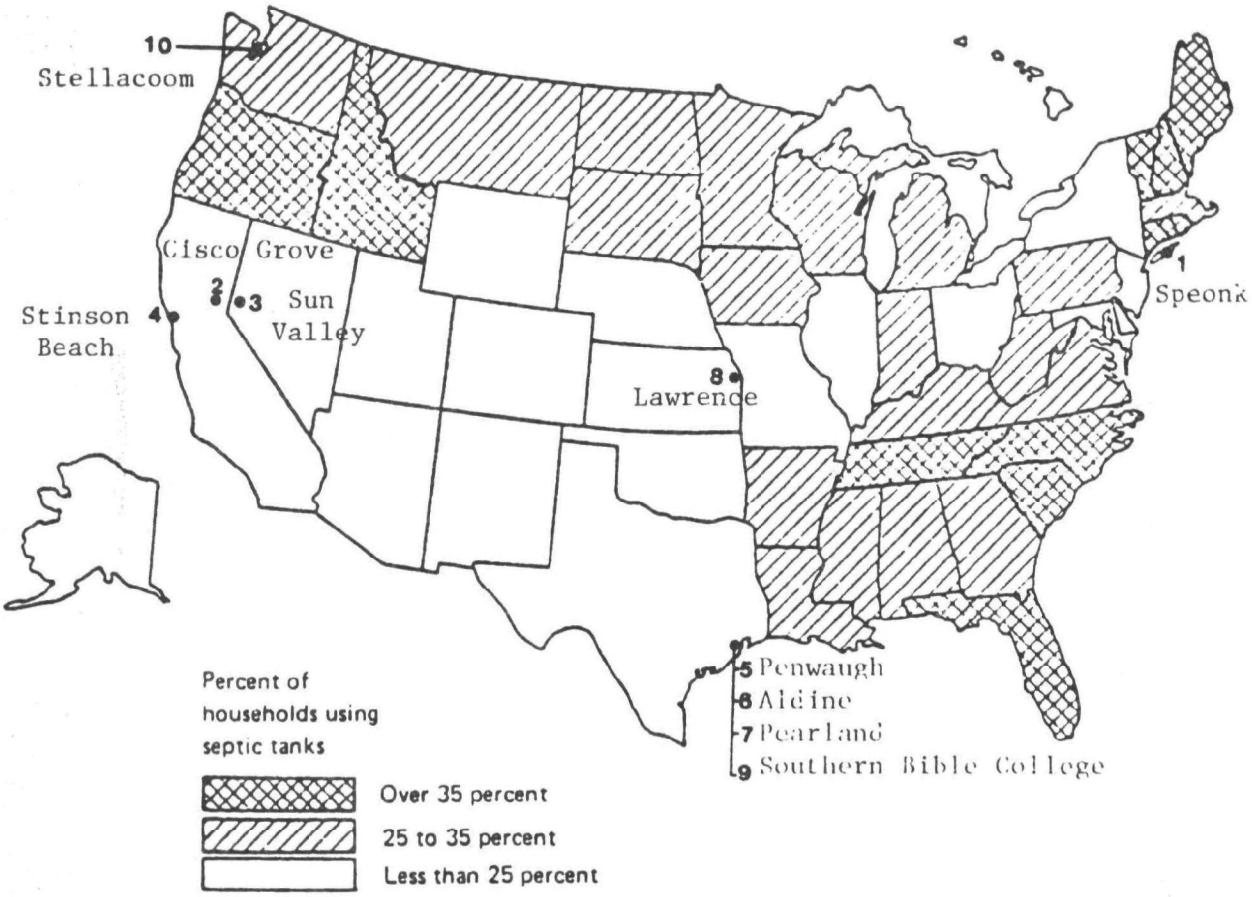


Figure 2. Distribution of on-site septic systems, by state (Otis et al., 1977), along with locations where samples were obtained for C-TLOs analysis in this study.

SECTION 2

CONCLUSIONS

1. Many domestic septic tank effluents contain more than a hundred chromatographable trace level organics in the $\mu g\ l^{-1}$ range with potential impact upon the ground water. Many of these C-TLOs can be accounted for by products in a normal household.

2. In sandy soils significant C-TLO compounds may be detected up to 200 ft away from the leach field, although at greater than 90% removal. A few tens of feet (~50 ft) is probably not sufficient for significant C-TLO removal.

3. C-TLOs may only travel a few feet in heavy clay soils.

4. Several classes of C-TLOs can be identified which together account for most C-TLOs which persist in ground water:

   a. chlorinated hydrocarbons
   b. plasticizers
   c. antioxidants
   d. aromatic solvents
   e. bicyclo compounds such as borneol

5. Both viruses and coliforms are generally removed in a few tens of feet in sandy soils and more quickly in clays.

SECTION 3

RECOMMENDATIONS

A. Possible Actions

1. Consider C-TLOs in septic tank siting studies and permitting. If there is a significant industrial input to the septic tank system, consideration of C-TLOs may be even more important.

2. Consider soil type when siting septic tank systems. Sandy soils with low clay and organic content may allow C-TLOs to travel long distances virtually unattenuated. Furthermore, if drinking water wells are located downdip from septic tank systems, problems of taste and odor may present a nuisance at levels far below analytical detection limits.

3. Consider variations in annual rainfall which may cause a rapid ground water movement. This will be a particular problem in sandy soils.

4. Consider the use of indicator C-TLOs which could be followed by capillary GC alone. This could make routine monitoring for C-TLOs much more feasible.

5. Consider using a rapid laboratory test to assess the potential for C-TLO and microbial migration in the ground water beneath septic tank leach fields. Soil from each site or group of sites to be permitted could potentially be screened in this manner. This could be an extension of or a replacement for the present percolation test. Promising research along this line of study is being conducted at Rice University.

B. Possible Studies

1. Study a few systems more thoroughly in both space and time. This might be done for a clay, loam, and sandy soil. It would be useful to map where the leach field plume goes once it interacts with the top of the saturated aquifer: does it stay on top, disperse, form a mound, sink, etc.? C-TLOs probably persist

for longer times and distances than microbes, but both should be examined.

2. Enough data on the specific fate of C-TLOs should be collected to perform a reasonable (± 20%) mass balance. It is generally assumed that if some C-TLO decreases in concentration that the decrease is due to either microbial degradation or to adsorption, but this has not been verified.

3. The strategy of combining the waste water from several houses into one septic tank system vs separate systems should be examined as to how the alternative strategies affect ground water.

4. The fate of trace metals such as Cd^{2+}, Hg^{2+}, Fe^{2+}, Zn^{2+}, and Pb^{2+} should be followed in sandy soils, where exchange interactions are probably minimal.

5. Finally, most septic tanks are used to treat domestic effluents. It is likely that if certain household products were found to be the major source of C-TLOs, alternative products could be used, thus reducing the C-TLO levels in ground water.

SECTION 4

METHODS

COD, TOC, AND INORGANICS ANALYSES

The following analyses were generally performed on each water sample in the field except as noted: total and free Cl_2; conductivity, chloride, fluoride, iron, sulfate, sulfide, hardness, alkalinity, pH, NH_4^+, NO_3^-, NO_2^-, inorganic and organic phosphate; COD; TOC; and DO. Most of the parameters were measured using a portable Hach kit, DR/EL-4. COD was measured in the field using a portable heating block and premixed ampules (Hach 21258). TOC was measured in the laboratory using a OI 600 TOC Analyzer. DO was measured with a YSI (51B meter) probe. TOC samples were stored on ice in low head-space screw-cap vials until analysis. Due to instrumental problems, many of the TOC analyses were discarded.

MICROBIOLOGICAL ANALYSES

Analysis for viruses was performed by C. P. Gerba, Baylor College of Medicine, Houston, Texas. For virus analysis generally 5 gal., for sewage, or 100 gal, for ground water, of water was passed through either a positively charged 1-MDS filter or a negatively charged Filterite filter in the field. Work up was done according to the procedures of Gerba et al. (1980). Total coliforms, fecal coliforms, and fecal streptococci were determined either by local personnel at each site or by the Houston Public Health Service according to Standard Methods (1980).

SOIL ANALYSIS

All soil analyses were performed by Harris Labs, Lincoln, Nebraska.

CHROMATOGRAPHABLE-TRACE LEVEL ORGANICS (C-TLOs)

C-TLOs were analyzed using well documented procedures of separation, concentration, and chromatography (Tomson et al., 1981; Dunlap, 1977; and Junk, 1974). A pictorial summary of the collection and analysis procedure is presented in Figure 3. Generally, 5 to 20 l of water was slowly (~30 ml/min) pumped

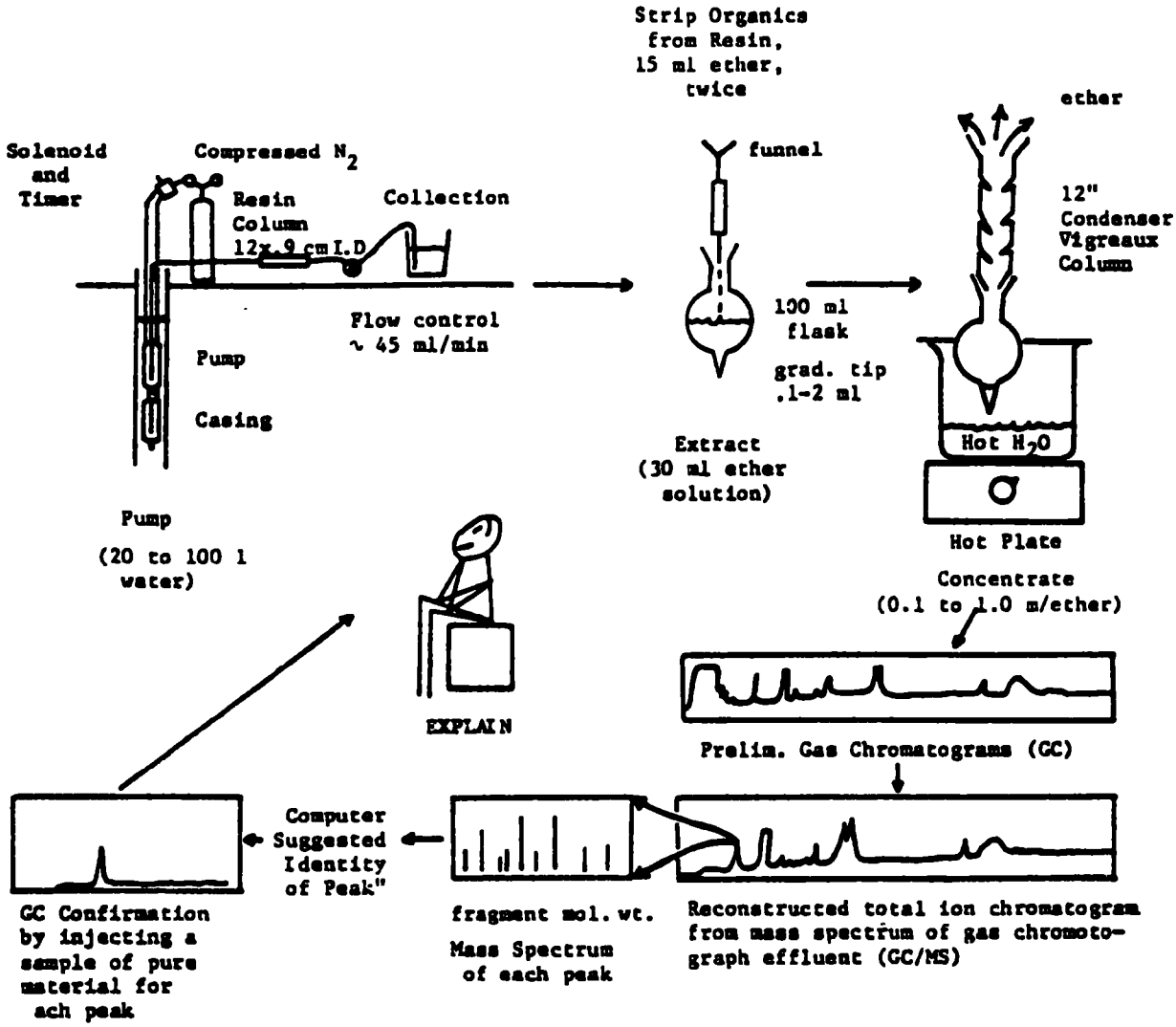


Figure 3. Pictorial summary of laboratory procedures used to sample and analyze C-TLOs associated with septic tank systems.

(MasterFlex pump) through a Teflon resin column containing 8 ml of XAD-2 (Rohm and Haas) amberlite macroreticular resin. The resin columns were then capped and stored on ice in a bag containing activated charcoal for shipment to the laboratory at Rice University for workup. The C-TLOs were stripped from the resin column with about 40 ml of methylene chloride. The methylene chloride solution was then concentrated to either 1 or 0.1 ml by evaporation. Generally, the same day the sample was concentrated, a gas chromatographic trace was obtained using a Tracor 560 GC, FID, and either a 6 ft 2 mm ID OV-17 packed column or a 50 m SP 2100 capillary column. GC spectra were recorded on a Spectra Physics 4100 integrating computer. Several portions (~10 μl ea) of each sample were then put into surface deactivated melting point tubes and the ends melted closed. These small samples were either stored at -40°C for future examination or used for GC-MS analysis (Finnigan 4000). One set of samples had to be stored several months before GC-MS analysis, but spot GC trace checks confirmed little alteration of the stored samples. To illustrate by visual comparison, the GC traces for the Speonk, New York, tap water sample run at the time of collection and two years later are reproduced and are virtually identical (see Speonk, New York, section). By preliminary research and previous experience, a suite of 22 compounds was chosen for quantitation on the GC/MS by reverse-ion search against a prepared standard containing each at 20 ppm. An internal spike of D_8-naphthalene was added to each sample. For visual comparison, a "scaling factor" defined as

$$\text{Scaling Factor} \equiv \frac{(\text{GC-attenuation})(\text{ml in final concentrate})}{(\text{GC-injection volume})(\text{volume pumped in field})}$$

was calculated for each field sample and normalized to the smallest value for that site (set equal to one). This relative scaling factor is included on each field sample GC-trace and the peaks should be multiplied by that factor for visual comparison.

FIELD SAMPLING

Resin column blanks were taken on each field trip and treated the same as the sample resin column, except no water was passed through them. These resin columns were then returned to the laboratory and treated as the other samples. Both GC and GC/MS analyses were performed on these extracts. If a target compound appeared in the blank at any detectable concentration, it has been noted in the reported data and less importance given that compound in all subsequent interpretation. A large ethylacetate contamination peak appears at about 4 min in each chromatogram and is a systematic consequence of the laboratory procedure.

SECTION 5

SEPTIC TANK SYSTEMS STUDIED

OVERVIEW

In general ten septic tank systems were examined in varying degrees of thoroughness. For most of the systems, data on microbes, inorganics, and C-TLOs were obtained. Most of the bacteria and virus data were obtained either from Dr. C. P. Gerba (University of Arizona, Tucson, Arizona) or by local personnel and are so noted on each system. Inorganic data for waste water characterization was generally determined by Rice University personnel on site at the time of sample collection. The primary objective of this work was to characterize the C-TLOs from septic tank systems which might impact upon ground water. Basically, three types of C-TLO data were obtained:

1. The chromatographic trace of the extracted ground water.
2. Reverse ion search and quantification for 22 target C-TLOs commonly encountered in ground waters.
3. A computer library search of the remaining peaks in the GC/MS reconstructed total ion chromatogram.

When available for a site, results of the first two types are presented in this section; a brief and edited summary of the general library search will be presented in the next section of this report. The presentation order of sites is essentially from those with most to those with least information. In all cases, more thorough documentation of each site is referenced and all supporting GC/MS data is stored both on paper and on computer disk for future reference.

SITE #1, SPEONK, NEW YORK

Background

Speonk, New York, is located near Brookhaven National Labs on the southeastern shore of Long Island. Top soil in the area is a sandy loam. The water table is generally about 25 ft in sandy gravel material producing high permeability for ground water movement. Vaughn (1980, 1981) at Brookhaven National Labs was responsible for having most of the monitoring wells installed and has done extensive study of the migration of bacteria and viruses in the ground water beneath the site. The area hydraulic gradient is estimated at 7.3 ft per mile. The site was designed in 1967 for a six apartment building complex with 80 units; to date, only three building and 40 units are built (see Figure 4). The septic tank system consists of a 15,000 gal septic tank, three distribution pools (150 ft^3 ea) and 40 leach pools (175 ft^3 ea). Each leach pool is 7 ft high with a base at 9-10 ft below grade. A 12 ft unsaturated zone was thought to exist below each leach pool. The overall direction of ground water movement is S 40° W (Figure 4), but due to slight mounding and the small water table slope, well #1--intended as a control well--has also been contaminated. Monitoring wells generally consisted of a 2 in ID steel pipe with a 3 ft screen at 5 to 6 ft below the water table. The drinking water well for the apartment complex is about 220 ft south of the septic tank and is screened at 63 ft below grade.

Results and Discussion

Water quality measurements for sample wells, distribution box, and tap water are presented in Table 1. The virus and coliform analyses indicate normally excellent removal of microorganisms. Vaughn (1980, 1981) reported generally similar removals of microbes but sporadically high coliform and viral counts in some of the monitoring wells. For example, only once did he observe any viruses in the 50 ft well (9.06 PFU/gal on 4/7/80) and only once on 5/17/80 he measured 0.01 PFU/gal in the tap water. No FCs were found in either the tap water, 198 ft, 150 ft, 100 ft, 50 ft, or 10 ft wells.

Most of the inorganic analyses were performed in the field and may be subject to larger error than otherwise, but similar overall results were reported by Vaughn (1980, 1981) for the conductivity and nitrate. The unexpectedly high DO values probably reflect a well aerated sandy soil with little microbial activity and are consistent with the generally increasing NO_3^- and NO_2^- levels with distance.

A chromatographic summary of the presence of C-TLOs is presented in Figure 5 and the concentrations of the 22 tar-

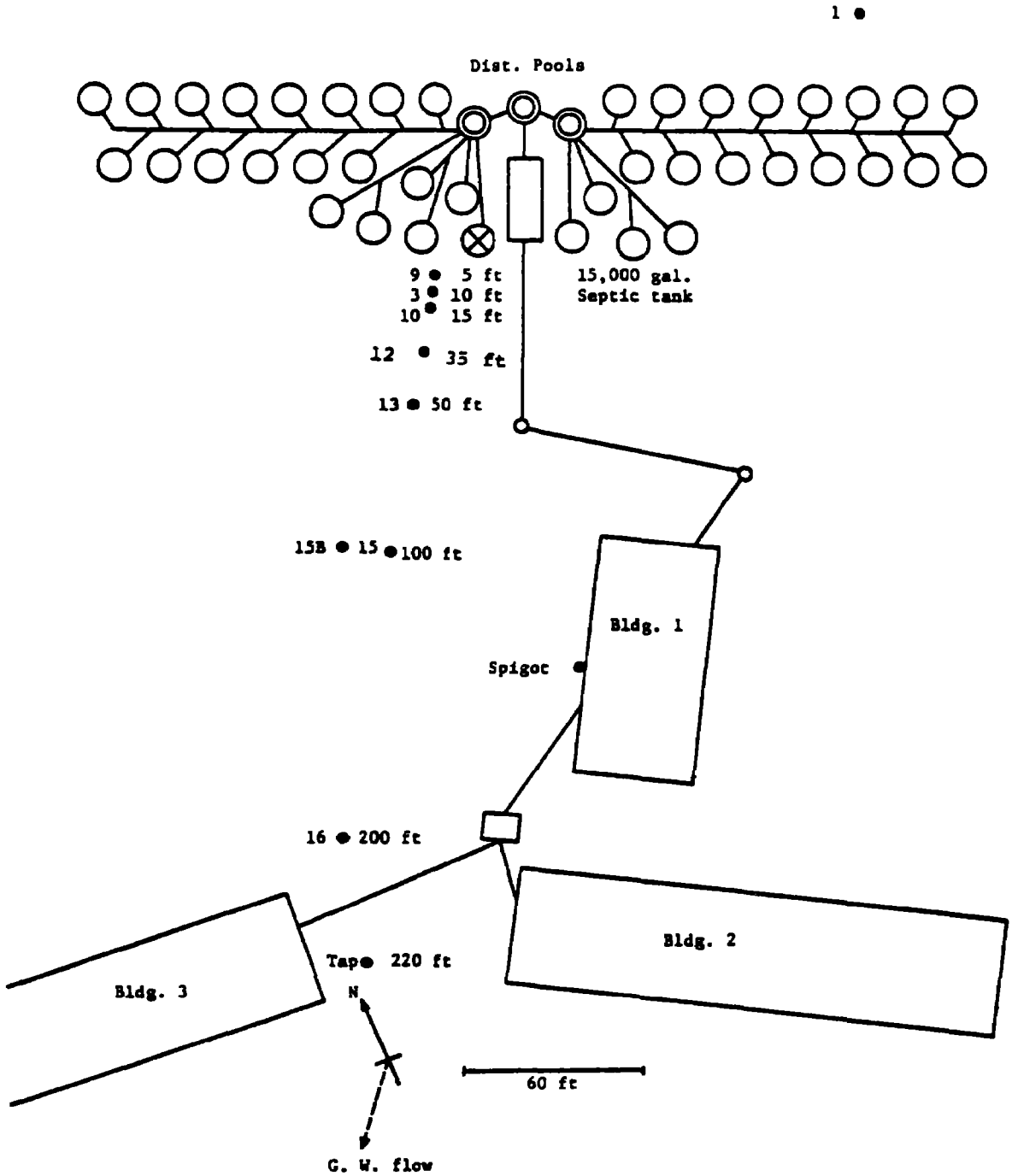


Figure 4. Schematic of Speonk, New York, site.

TABLE 1. WATER CHARACTERISTICS, SPEONK, N. Y., JULY 7-11, 1981*

Parameter	Dist. Box (0)	Well Number (Distance from Dist. Box in ft) #1 (?)	#3 (10)	#9 (5)	#12 (35)	#13 (50)	#15 (100)	#15B (100)	#16 (198)	Tap Water (220)
Well Depth (ft)			29	34	30	32	24	32	32	40
Water depth (ft)			4	8	6	8	3	8	9	
Sample volume (l)	6.5	20	15	16	16.5	20	17.5	20	20	- -
Total Chlorine	0	0.25	0.26	0.20	0.40	0	0	0.025	0.060	- -
Free Chlorine	0.02	0.03	0.06	0	0.07	0	0.02	0	0.04	- -
Conductivity (μmhos/cm)	750	140	1550	1550	1250	950	400	40	200	200
Hardness	29	29	69	101	56	63	66	14	57	- -
Alkalinity	168	2	326	325	260	125	53	8	56	38
pH	6.51	5.42	6.24	6.31	6.25	5.81	5.79	6.60	6.08	- -
NH_4	30.5	0	44	48	40	10.7	1.03	0	0.45	- -
NO_3	0	3.0	0	0.6	0	3.0	7.8	1.0	5.5	- -
NO_2	0.003	0.24	0.002	0	0.008	0.510	0.480	0.015	0.250	- -
PO_4	1.25	0.017	0.53	1.12	0	1.98	0.06	0.37	0	- -
Organic P	0.59	0.20	0	0.13	0.07	0	0.58	0.24	0.10	- -
COD	175	22	45	117	85	55	15	29	0	- -
DO	3.5	4.5	7	7	6.4	5	5	6	6	6.6
Temp. (°C)	25	17	17	18	17	16	17	16	15.5	25
Virus Plaques in BGM cells			0	1**		0	0		0	
Total Coliforms per 100 ml			3	240		<3	<3		<3	
Fecal Coliforms per 100 ml			<3	24.5		<3	<3		<3	

* Unless otherwise specified, concentrations are in mg/l

** Identified as Coxsackie B3. 55 gal samples were passed through a positively charged 1-MDS filter.

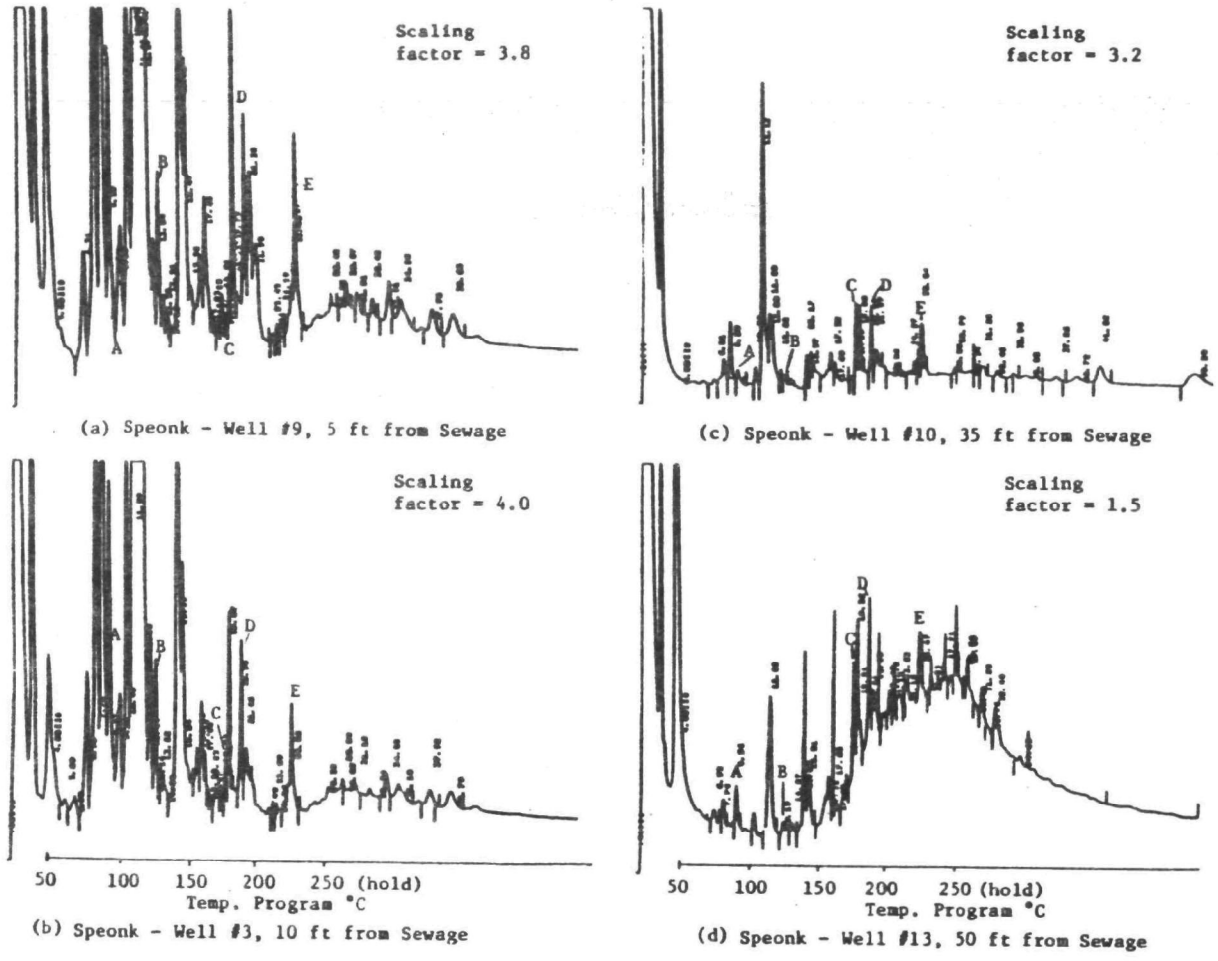
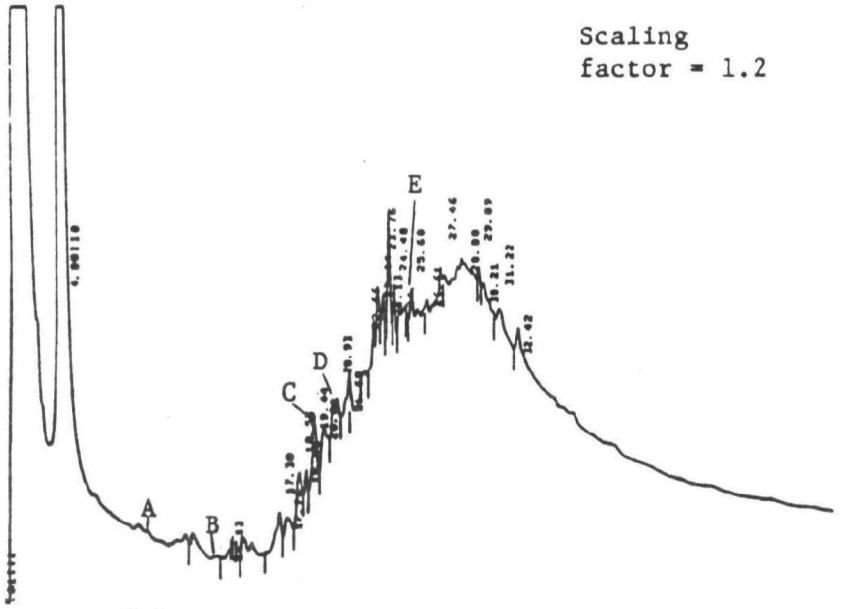
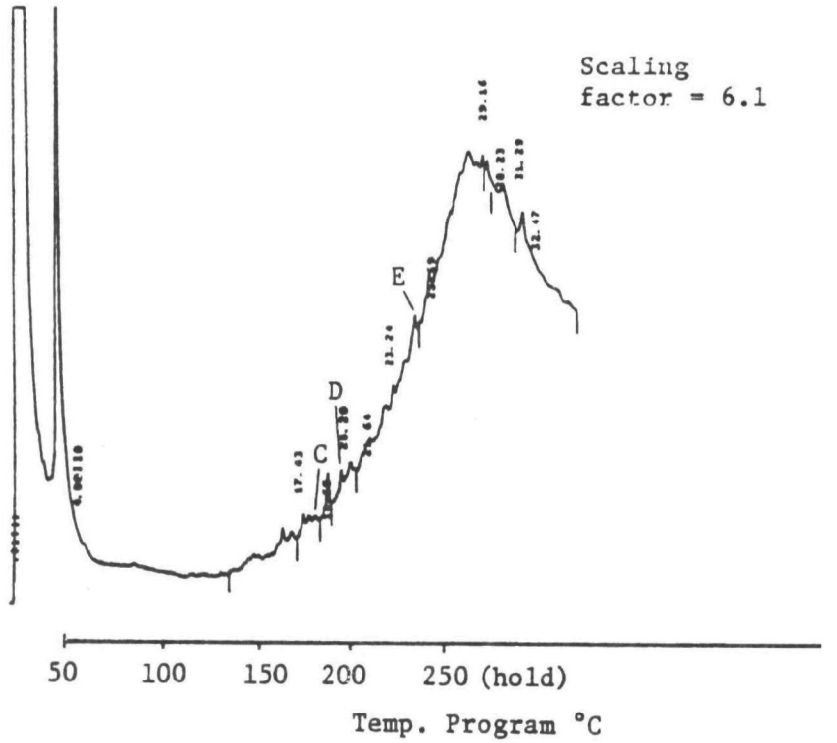


Figure 5. GC traces from samples obtained from Speonk, New York.

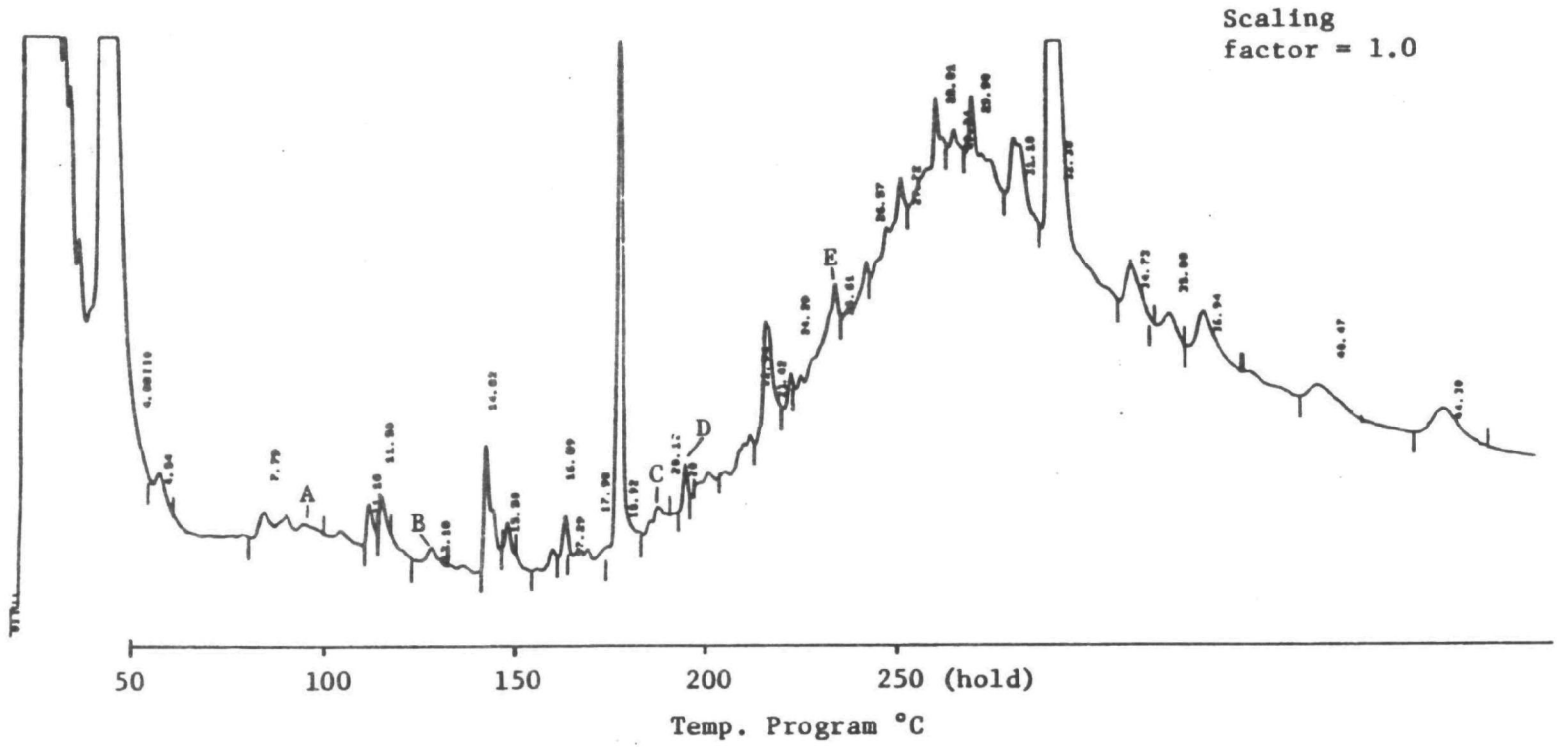


(e) Speonk - Well #15A, 100 ft from Sewage



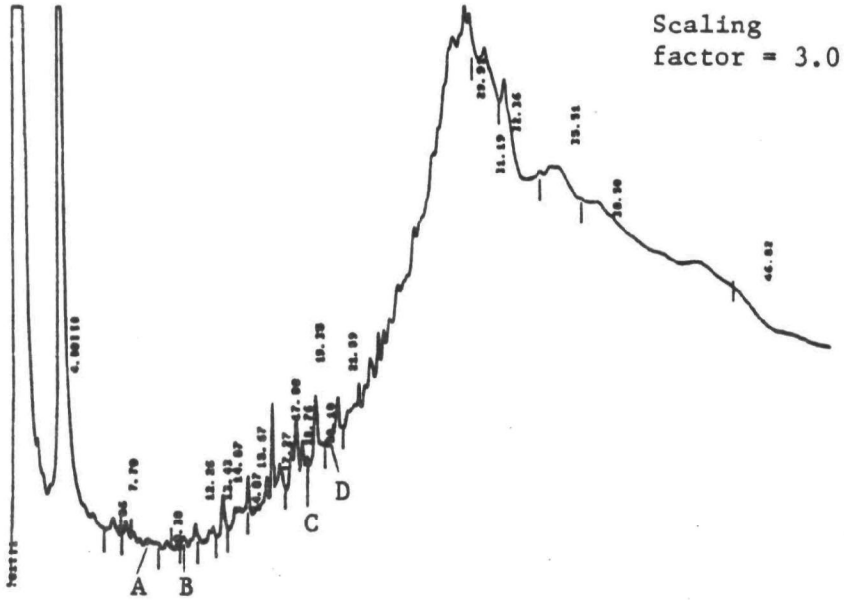
(f) Speonk - Well #15B, 100 ft lateral from Sewage

Figure 5. (continued)

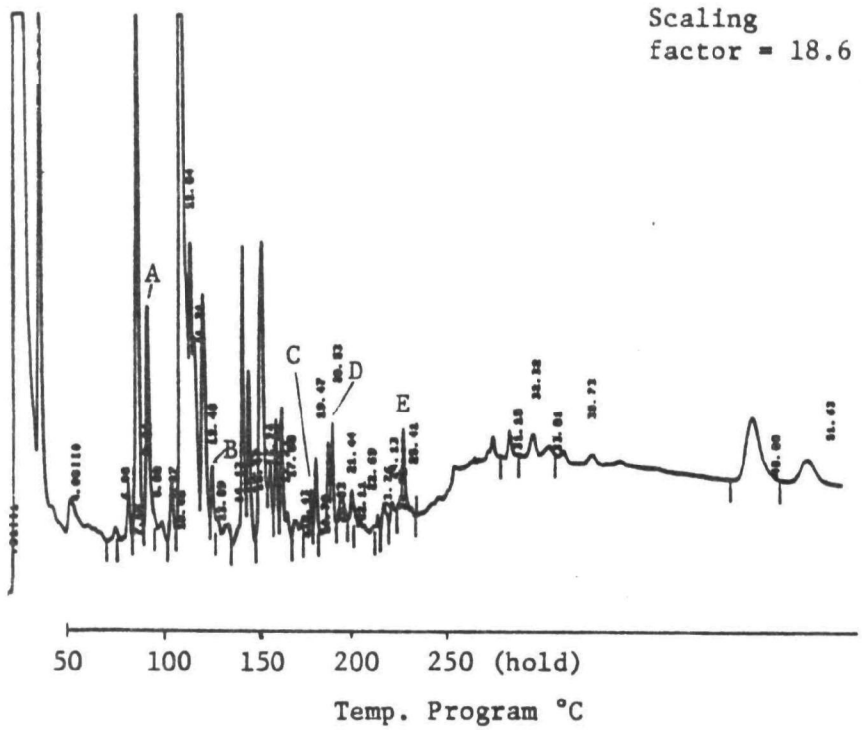


(g) Speonk - Well #16, 198 ft from Sewage

Figure 5. (continued)

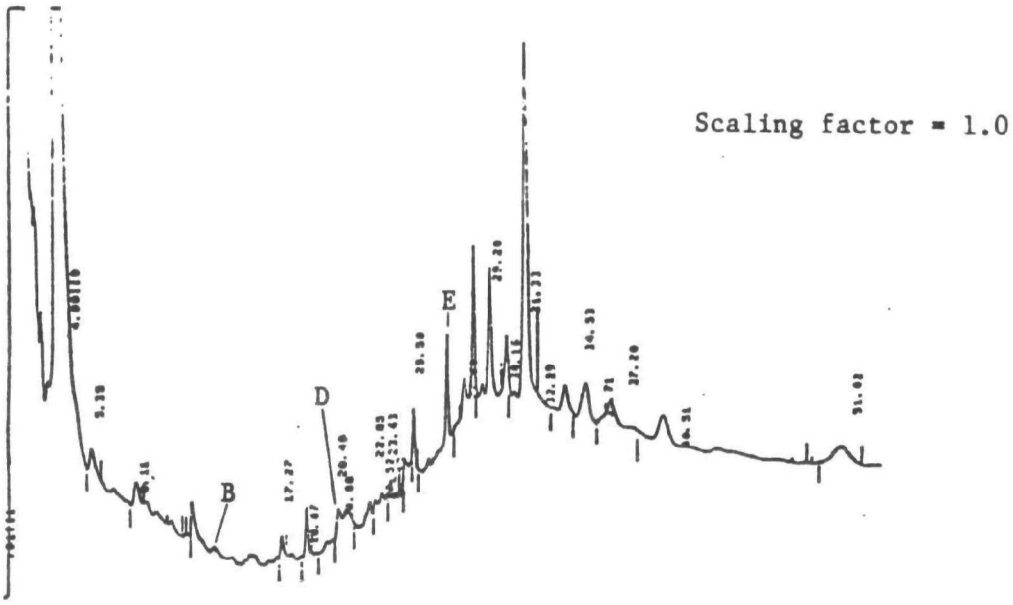


(h) Speonk - Control Well #1

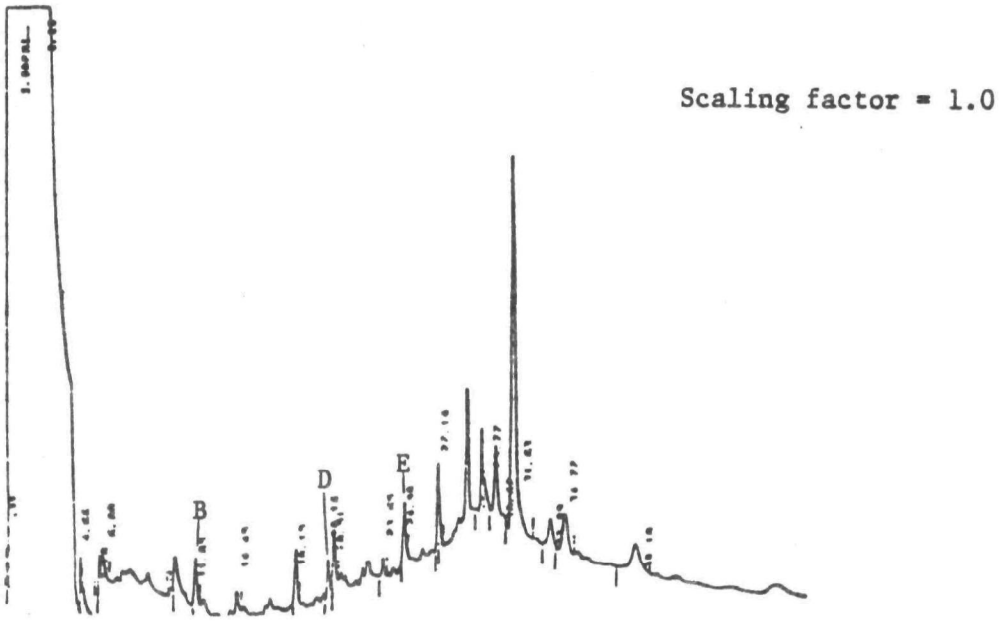


(i) Speonk - Distribution Box Sewage

Figure 5. (continued)

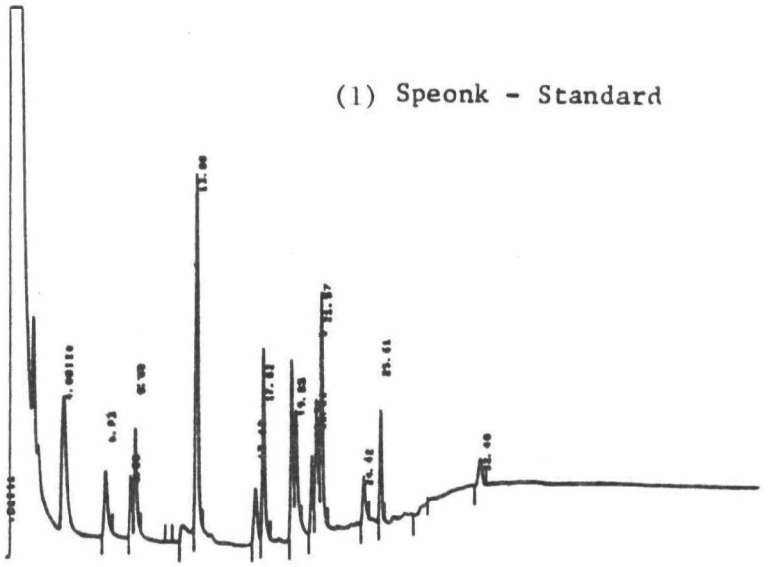


(j) Speonk - Tap Water



(k) Speonk - Tap Water
(run approx. 2 yrs later using stored sample)

Figure 5. (continued)



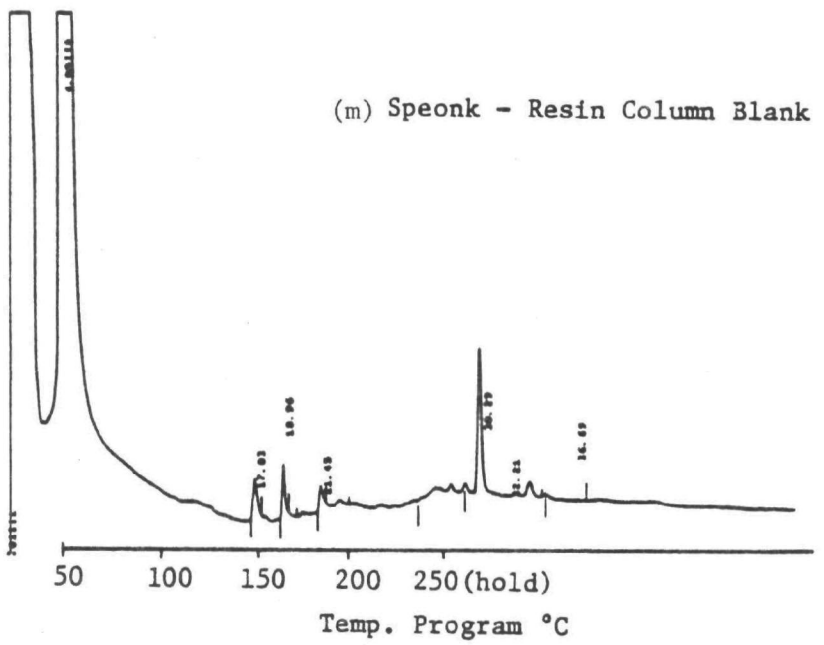


Figure 5. (continued)

get compounds from GC/MS reverse ion search quantitation are presented in Table 2. For the Resin Column Blank in addition to the large ethylacetate peak at 4 min, there are four additional sizeable peaks at 17.03, 18.96, 21.45, and 30.29 min. These impurities do not systematically appear in subsequent spectra nor do they occur in the GC/MS reconstructed total ion chromatograms and hence may have been an impurity on that particular column at that time; another resin blank GC trace did not show these impurities.

From the GC-traces and the data in Table 2, three observations can be made:

1. There is a large number of C-TLOs in the sewage at the 0.1 to several $\mu g l^{-1}$ level which could potentially impact on ground water quality.
2. Within a few tens of feet most of the compounds present in the sewage have disappeared to below detection limits.
3. The drinking water well at 220 ft from the distribution box has been impacted by the C-TLOs from the sewage leach field. It is interesting to note that conversations with several of the apartment residents revealed that most of the occupants used bottled water for drinking because of the objectionable taste of the well water.

TABLE 2. SPEONK, NEW YORK, TRACE ORGANICS (μg/l)

Compound*	Dist. Box (0)	Well Number (Distance from Dist. Box in ft) #1 (?)	#9 (5)	#10 (15)	#13 (50)	#15 (100)	#16 (200)	Tap Water** (220)
Chloroform	0.52	0.14	0.00017	0.031	0.036	0.24	0.023	
Carbon tetrachloride	- -	0.39	- -	0.39	- -	- -	0.00045	
Trichloroethylene	1.60	- -	0.0039	- -	0.0065	0.0040	0.0025	
Toluene*	330	2.10	- -	17	9.9	15	2.6	
Tetrachloroethylene	0.61	0.15	0.169	0.10	0.18	1.0	0.25	0.130
Chlorobenzene	- -	- -	- -	- -	- -	- -	- -	
m-Xylene*	0.43	0.11	0.094	- -	0.020	0.29	0.074	
Bromobenzene	0.028	0.00088	- -	- -	- -	- -	- -	
m-Dichlorobenzene	0.045	- -	- -	- -	- -	- -	- -	
p-Dichlorobenzene	4.6	0.0049	0.208	0.078	0.11	0.053	0.025	
o-Dichlorobenzene	- -	- -	- -	- -	- -	- -	- -	
Acetophenone	- -	- -	- -	- -	0.021	0.071	0.017	
Naphthalene*	0.71	0.0330	0.833	0.030	0.032	0.20	0.018	0.015
Skatole	0.81	- -	0.023	0.022	- -	- -	- -	0.003
o-Phenylphenol	0.24	- -	0.0046	0.18	0.17	- -	- -	
Diethylphthalate	1.60	0.023	1.16	0.144	0.18	0.16	0.0560	0.025
2(Methylthio)-benzothiazole	0.16	- -	0.080	0.094	0.067	0.12	0.0029	0.040
(1,1,3,3-Tetramethyl-butyl)phenol	1.70	- -	0.033	0.0056	0.34	- -	- -	
Benzophenone	0.19	- -	0.0013	0.0060	0.015	- -	- -	
Butylbenzene sulfonamide	- -	- -	- -	- -	- -	- -	- -	0.009
Dibutylphthalate*	0.160	0.032	0.039	0.103	0.077	0.070	0.029	
bis(2-Ethylhexyl)-phthalate*	0.37	0.36	0.384	0.023	0.040	0.050	0.055	0.34

*Compounds found in the blank

**Tap water concentrations were determined by GC peak areas against standards (see text)

SITE #2, CISCO GROVE, CALIFORNIA

Background

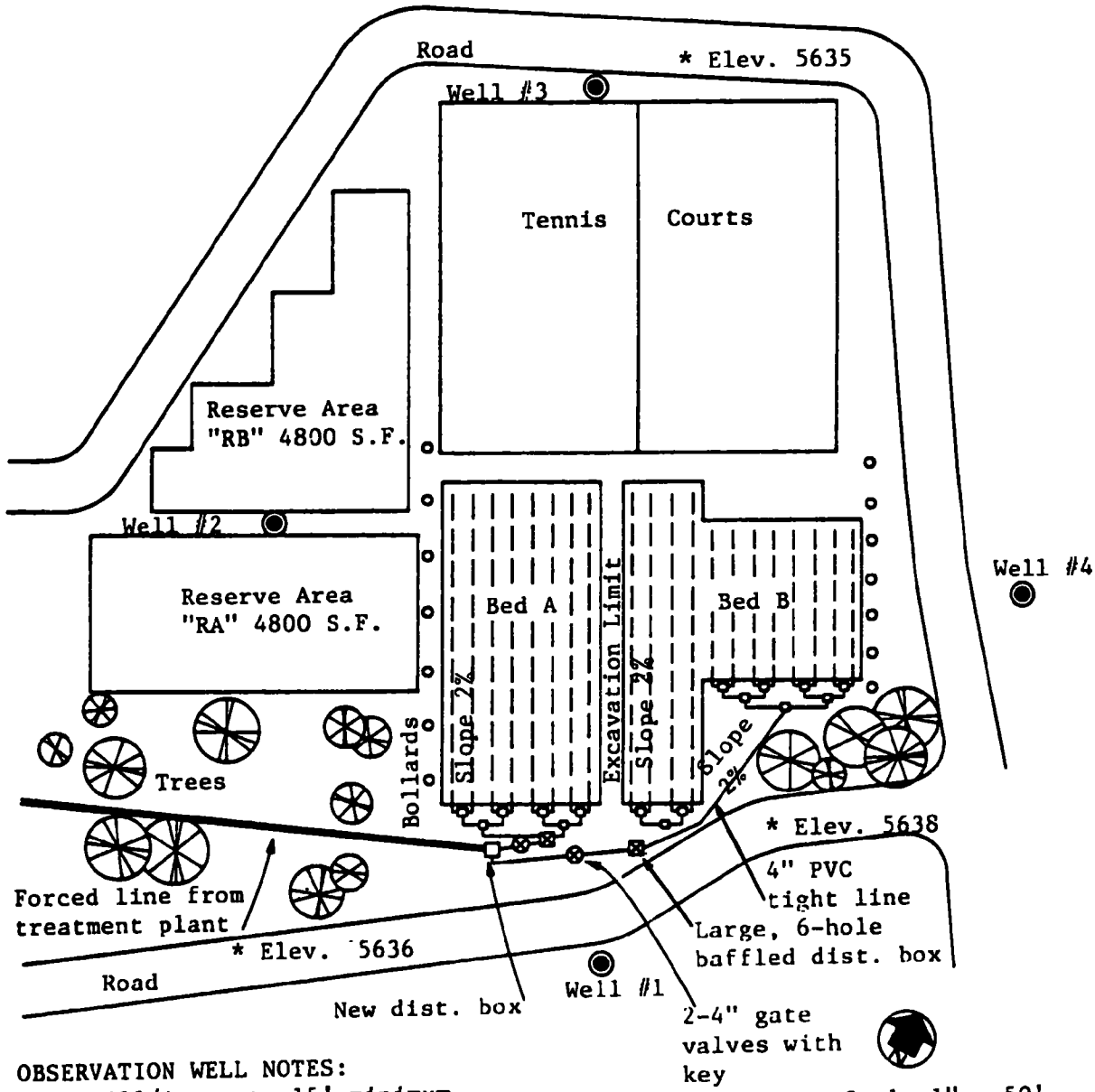
Cisco Grove, California, is located on the western slopes of the Sierra Nevada mountains off Highway 80 about 50 mi east of Reno, Nevada. The septic tank system studied on June 4, 1981, was at the Thousand Trails campsite on the northern bank of the South Fork of the Yuba River at the Cisco Grove exit off Highway 80. The soils in the area are sandy and highly permeable with less than 10 min in^{-1} percolation rates, and bedrock is at 15 to 25 ft. The campground is designed primarily for recreational vehicles; there are 144 camp sites, three bath houses, one lodge, one store, an office, and a seven unit motel. Waste water volume is estimated at 10,800 gpd in season. A 30,000 gpd extended aeration activated sludge package plant was installed in 1972. Effluent from the treatment plant clarifier is pumped to the leach field as shown in Figure 6. The trenches of the leach field are 3 ft deep or about 2 ft above seasonably high ground water table.

Results and Discussion

Inorganic, coliform, and virus data are presented in Table 3. From all indications well #2 at 50 ft from the leach field is quite contaminated. Metcalf and Eddy Inc. (personal communication) found similar nitrate contamination in well #2. The combination of such a shallow water table (~5 ft) and the occurrence of coliform and fecal coliform bacteria are of concern and may indicate a potential problem if surface wetting or breakthrough ever occurs.

Chromatographable data are indicated by the GC traces in Figure 7 and the 22 target compounds in Table 4. Three general observations can be made from these data:

1. The secondary sewage effluent contains a number of C-TLO compounds at the $\mu g l^{-1}$ and less level. The general absence of trihalomethanes is probably because the chlorinator of the package plant was not being used. Similar low levels of C-TLOs have been previously found in secondary treatment effluents in the Houston, Texas, area by the authors (unpublished results).
2. Well #2 at 50 ft from the leach field had the largest concentrations of C-TLOs. Still, most C-TLOs were removed to less than 0.02 $\mu g l^{-1}$, probably of no present health significance.
3. Well Nos. 1, 3, and 4, which were either updip from the ground water flow or further from the initial infiltrate, showed virtually no contamination. It is strongly suspected that the direction of ground water



OBSERVATION WELL NOTES:

1. Drill/Auger to 15' minimum.
2. Install slotted 4" dia. PVC pipe to 15' min. depth. Construct locking cap.
3. Backfill around PVC pipe with drain gravel with seal at ground level to prevent surface infiltration.

Figure 6. Diagram of leach field at Cisco Grove, California.

TABLE 3. CHARACTERISTICS OF WATER AT CISCO GROVE, CALIFORNIA (June 1-2, 1981)*

Parameter	Well No. 1	2	3	4	Tap	Lake	Dist. Box
Well Depth (ft)	14	12	13.2	14			
Water Depth (ft)	5.5	5	7.5	10			
Flush Volume (gal)	100	100	100	100	- -	- -	- -
Diameter (in)	4	4	6.5	6.5			
Total Chlorine**	0.03	0.05	- -	0.02	0.05	0.02	0.02
Conductivity (μmohms/cm)	85	160	- -	35	120	20	550
Alkalinity	34	68	- -	11	63	14	- -
pH	6.16	6.38	- -	5.91	7.43	7.30	7.74
NH_3	0.22	0.55	- -	0.20	0.17	0.15	- -
NO_3	0.40	1.00	- -	0.30	0.30	0.30	1.20
NO_2	0.007	0.009	- -	0.007	0.007	0.010	0.010
PO_4	0.50	0.65	- -	0.46	1.30	0.27	0.46
D.O.	6.8	2.9	5.6	6.0	4.5	9.0	2.2
Temp.(°C)	10	10	10	10	- -	12	14
Virus, PFU	- -	0	- -	0	- -	- -	- -
Coliforms, Total per 100 ml	<100	3400	<100	100	- -	- -	- -
Coliforms, Fecal per 100 ml	<100	200	<100	<100	- -	- -	- -

*Unless otherwise specified, all measurements in mg/l.

**These values are probably at the detection limit of the field method.

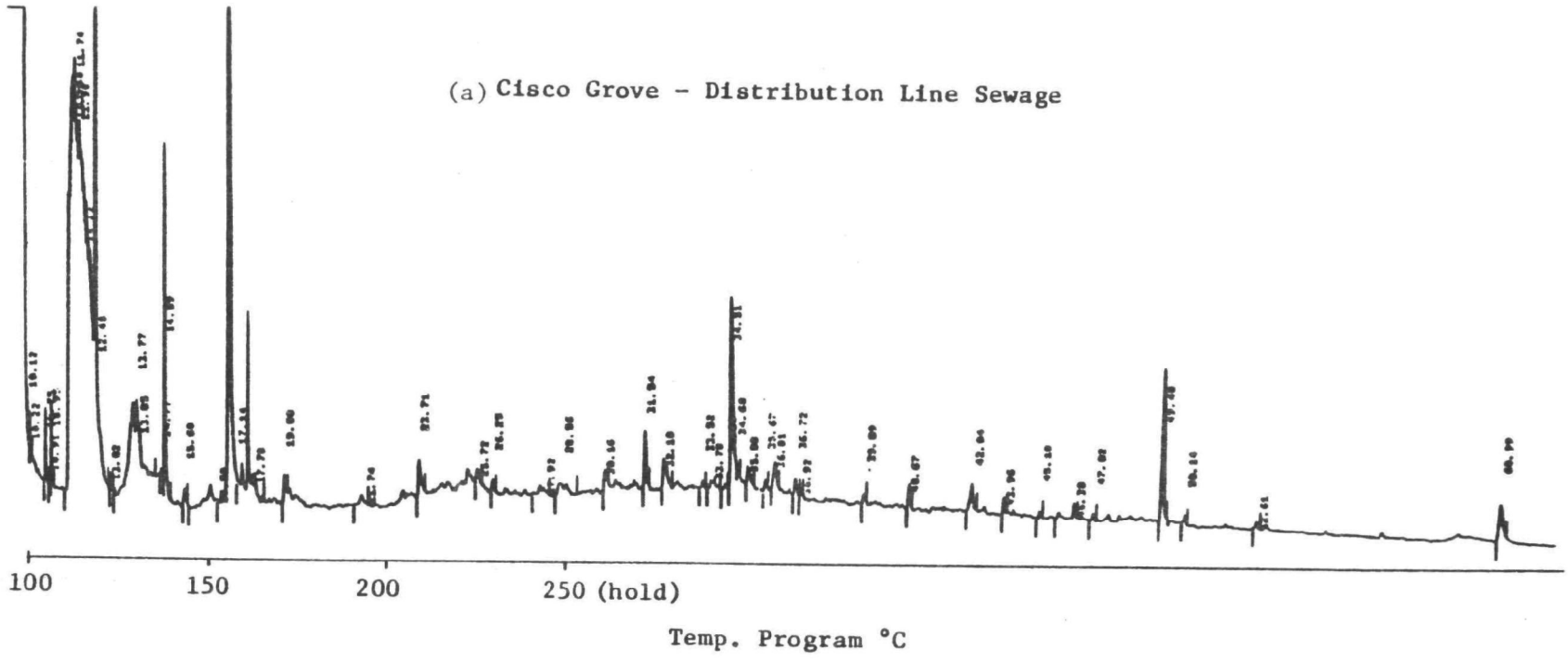


Figure 7. GC traces from sample obtained from Cisco Grove, California.

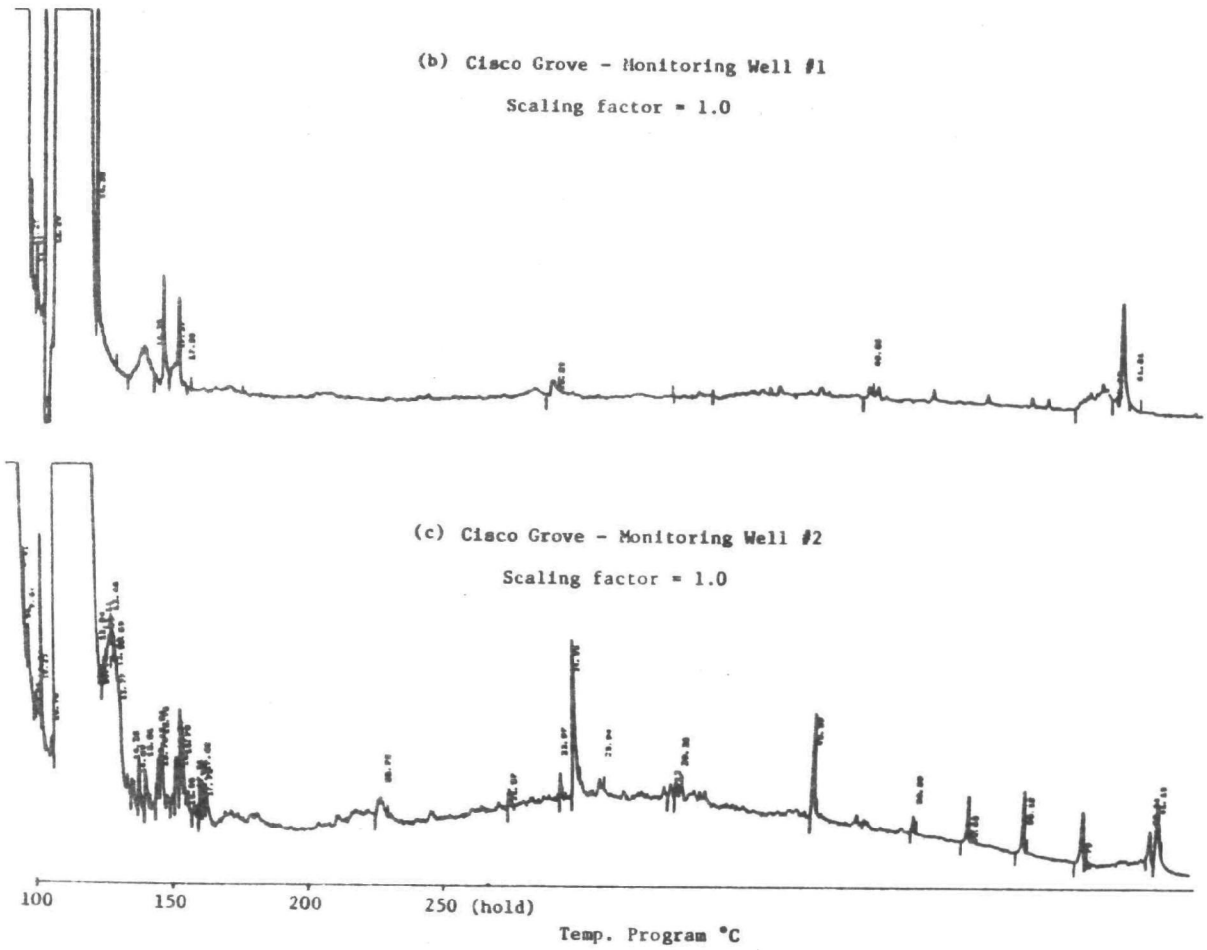
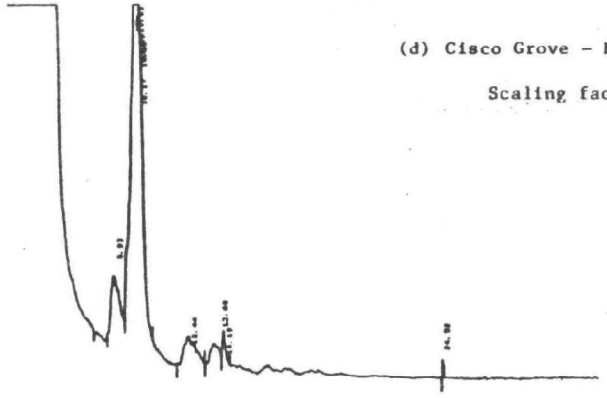


Figure 7. (continued)



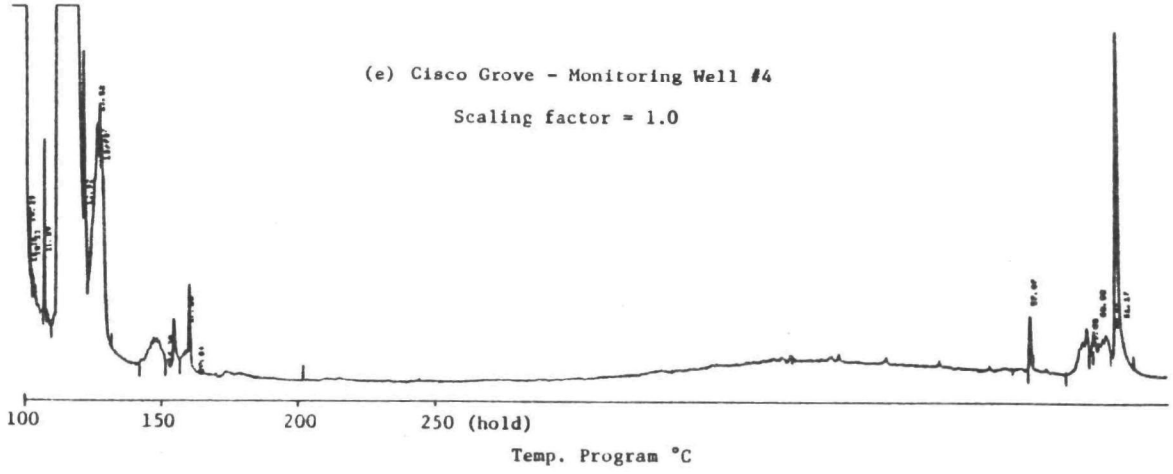


Figure 7. (continued)

TABLE 4. CISCO GROVE, CALIFORNIA, TRACE ORGANICS (μg/l)

Compound	Sewage	Well #1	Well #2	Well #3
Chloroform			0.0009	
Carbon tetrachloride			0.0008	
Trichloroethylene				
Toluene*	0.166	0.0473		0.275
Tetrachloroethylene				
Chlorobenzene				
m-Xylene*	0.0369		0.375	0.372
Bromobenzene				
m-Dichlorobenzene				
p-Dichlorobenzene	0.915		0.0105	
o-Dichlorobenzene			0.0007	
Acetophenone	0.0474		0.0102	
Naphthalene*	0.0577	0.0231	0.0143	0.0111
Skatole	0.0520			
o-Phenylphenol	0.0252			
Diethylphthalate	0.0238	0.0348	0.0101	0.0139
2(Methylthio)benzothiazole	0.230			
4(1,1,3,3-Tetramethyl-butyl)phenol	0.0539		0.0006	
Benzophenone	0.0460		0.0015	
Butylbenzene sulfonamide	0.0439			
Dibutylphthalate*	0.0449	0.0108	0.0793	0.0160
bis(2-ethylhexyl)phthalate*	6.80	0.844	1.39	5.44

*Compound found in the blank

flow was toward well #2 and that these other wells were probably not impacted at all. It would have been useful to have had additional monitoring wells in the direction of well #2 but further from the leach field.

In general, the effluent from the treatment plant appears to be of excellent quality except for fecal coliforms, and the soil adsorption system is probably sufficient. Chlorine could be added to the effluent to kill FCs, but this would probably produce additional chlorinated compounds.

SITE #3, SUN VALLEY, NEVADA

Background

Sun Valley is a deteriorated residential valley area 10 mi north of Reno, Nevada, consisting of 5000 trailer houses and a few permanent buildings. Water has been imported since 1967, and sewage infiltration, primarily from septic tanks, is a major source of ground water recharge. In some areas sewage is within 2 ft of the surface and may already be forming pools in places. Drainage ditches along roadways receive sewage exfiltration, and salt incrustations were noted. The top 10 in of soil is a brown sandy loam over a sandy clay loam at 10 to 30 in, which is over a sandy, gravelly loam down to several feet. The infiltration rate varies with depth: 0-10 in (2-20 in/hr); 10-30 in (0.06-0.6 in/hr); and 30-75 in (0.6-6 in/hr). Since 1967, 10,000 acre-feet of water has been pumped into the valley causing the water table to rise, as much as 50 feet in some areas. Sample location points from June 5, 1981, are indicated in Figure 8a. The increase in area from 1967 to 1981 wherein the water table is less than 10 feet is depicted in Figure 8b.

Results and Discussion

Inorganic and microbiological data are summarized in Table 5. From the high nitrate and conductivity levels and from the smell of samples, it is concluded that the shallow ground water in this general area is from recharge. The absence of coliforms or viruses is surprising, but due to instrumental problems, the virus datum may be in error.

The C-TLO data is summarized for the 22 target compounds in Table 6 and by GC-chromatographic traces in Figure 9. The presence of numerous compounds in the septic tank liquor indicates the potential for contamination of the ground water over the entire area. These data support the following observations:

1. As can be seen from columns 1 and 2, Table 6, most of the target compounds found in the septic tank were also found in the ditch about 30 ft away, and many are of similar concentration.
2. The concentrations in wells #2 and #4 were generally lower by about a factor of 5 to 10.
3. The general absence of the more volatile chlorinated hydrocarbons in either the sewage or the monitoring wells is probably due to a lack of chlorination.

In general, it appears that at least the top of the ground water in this whole area is contaminated with septic tank effluent. In places the effluent is freely standing in open ditches and may present a health risk. The impact of a

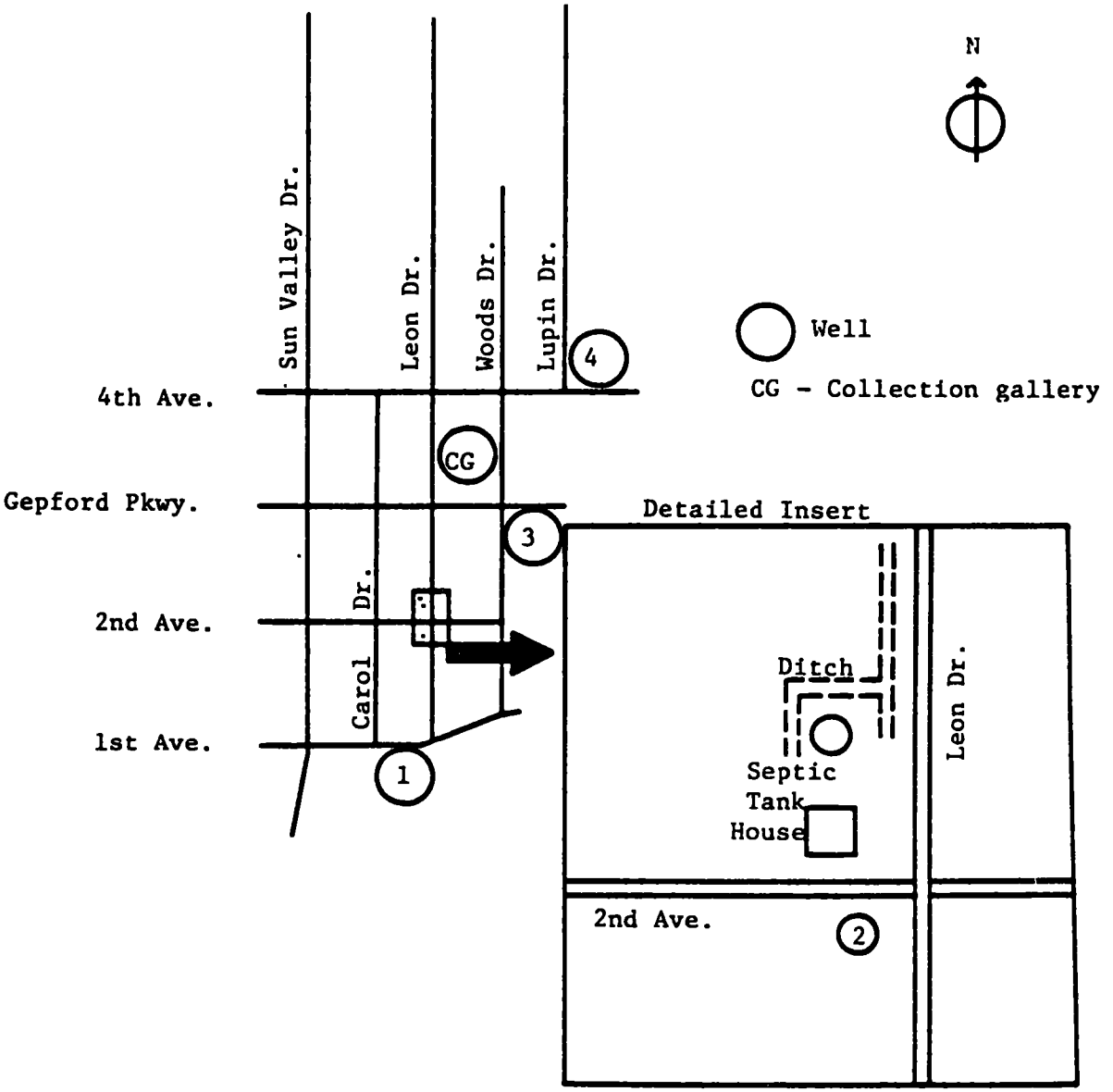


Figure 8a. Map showing location of monitoring wells and example of septic tank system in Sun Valley, Nevada.

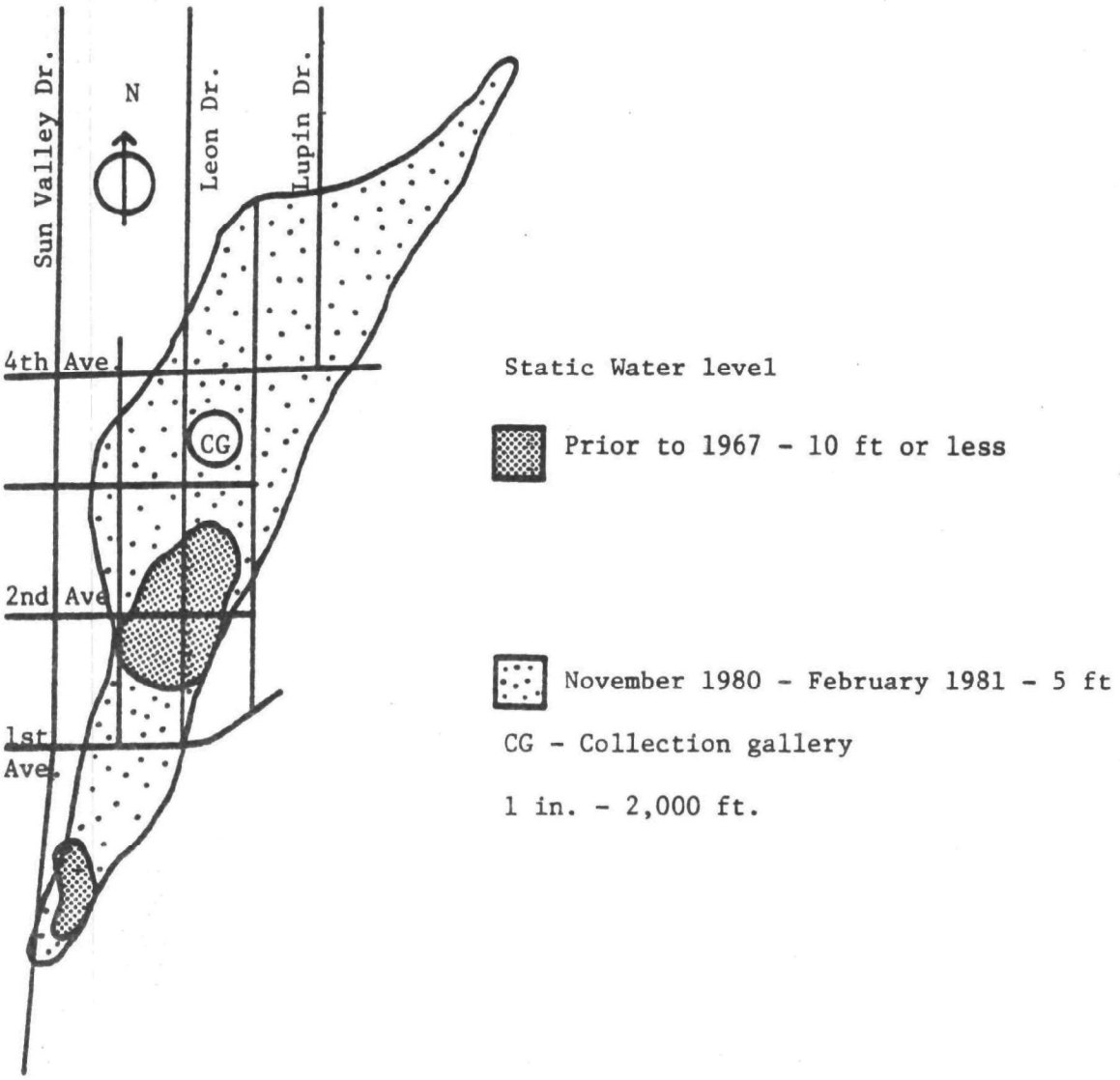


Figure 8b. Diagram of static water levels in Sun Valley, Nevada.

TABLE 5. CHARACTERISTICS OF WATER AT SUN VALLEY, NEVADA*

Parameter	Well No. 1	Well No. 2	Well No. 3	Well No. 4	Ditch	Septic Tank
Well Depth (ft)	13	10	8	15.3	- -	- -
Water Depth (ft)	11	5.5	4	13.5	- -	- -
Diameter (in)	2	2	2	2	- -	- -
Flush Volume (gal)	50	35	45	50	- -	- -
Alkalinity	276	333	353	356	325	670
PO_4	0.27	0.20	0.26	0.90	0.45	1.00
NO_3	0.70	0.20	0.80	1.50	1.30	2.50
NO_2	0.005	0.002	0.17	0.005	0.25	0.045
NH_4	0	0.85	0	0	0	1.50
Total Chlorine	0	0.40	0.04	0.06	0.002	0
Conductivity (μmhos/cm)	1100	3500	2200	3200	1500	1500
pH	7.68	7.75	8.03	7.68	7.85	7.53
Virus, PFU/100 ml	0	- -	- -	- -	- -	- -
Coliforms, Total per 100 ml	<100	<100	- -	<100	<100	- -
Coliforms, Fecal per 100 ml	<100	<100	<100	<100	<100	- -
Bacteria other than coliforms	- -	- -	- -	**	**	- -

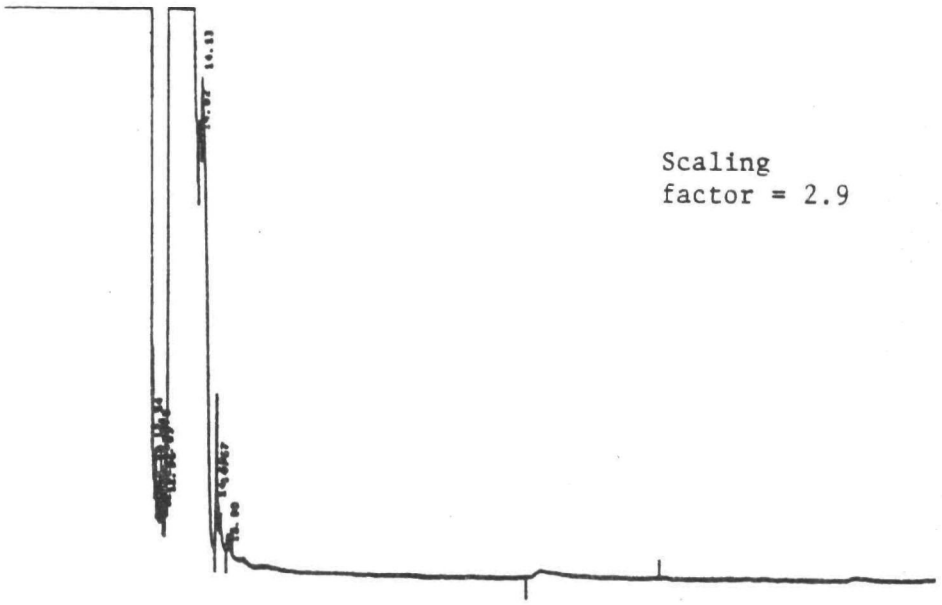
*All measurements in mg/l, unless otherwise specified

**Overgrowth - coliforms present

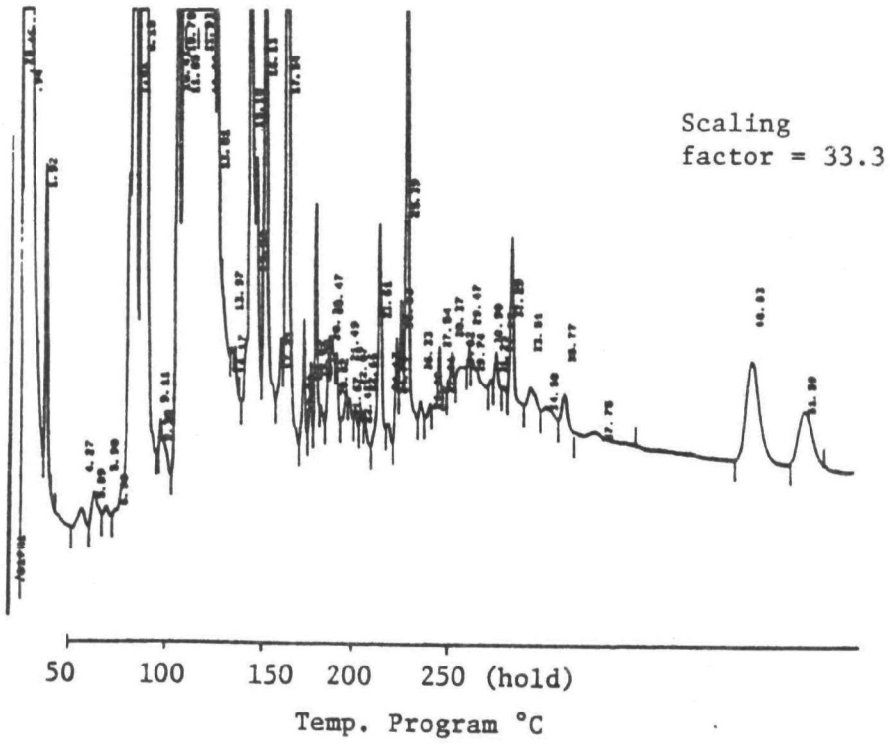
TABLE 6. SUN VALLEY, NEVADA, TRACE ORGANICS (μg/l)

Compound	Sewage	Ditch	Well #2	Well #4
Chloroform			0.0020	
Carbon tetrachloride				
Trichloroethylene	0.0368		0.0010	
Toluene*	2.83	0.139	0.0322	0.0537
Tetrachloroethylene	0.0997	0.228	0.0469	0.0576
Chlorobenzene	0.0357	0.0623	0.0097	0.0345
m-Xylene*	0.203	0.0670	0.0074	0.0853
Bromobenzene	0.0433	0.0541	0.0072	0.0116
m-Dichlorobenzene		0.0485		0.0629
p-Dichlorobenzene	0.144	0.0326	0.0028	0.0477
o-Dichlorobenzene	0.0244	0.0272	0.0041	0.0067
Acetophenone	0.0846		0.0009	0.0155
Naphthalene*	0.347	0.0095	0.0399	0.0072
Skatole	5.14			
o-Phenylphenol	2.19			
Diethylphthalate	0.419	0.0331	0.0083	0.102
2(Methylthio)benzothiazole	0.0919			0.0045
(1,1,3,3-Tetramethylbutyl)-phenol	0.200			0.0022
Benzophenone	0.0522			0.0242
Butylbenzene sulfonamide	0.0662			0.0261
Dibutylphthalate*	0.223	0.0640	0.0189	0.0556
bis(2-Ethylhexyl)phthalate*	1.71	3.46	3.37	5.12

*Compounds found in the blank



(a) Sun Valley - Ditch Sample



(b) Sun Valley - Septic Tank Sewage

Figure 9. GC traces from samples obtained from Sun Valley, Nevada.

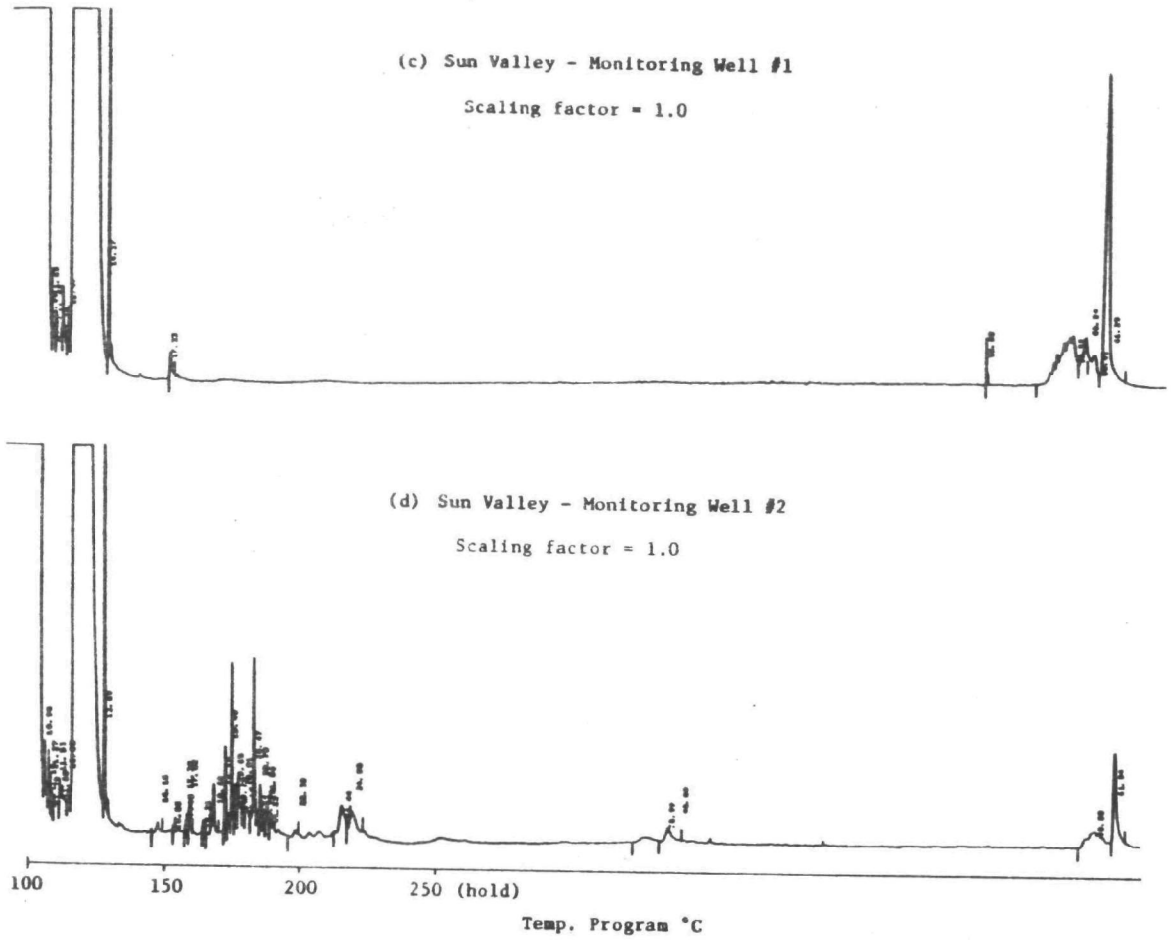


Figure 9. (continued)

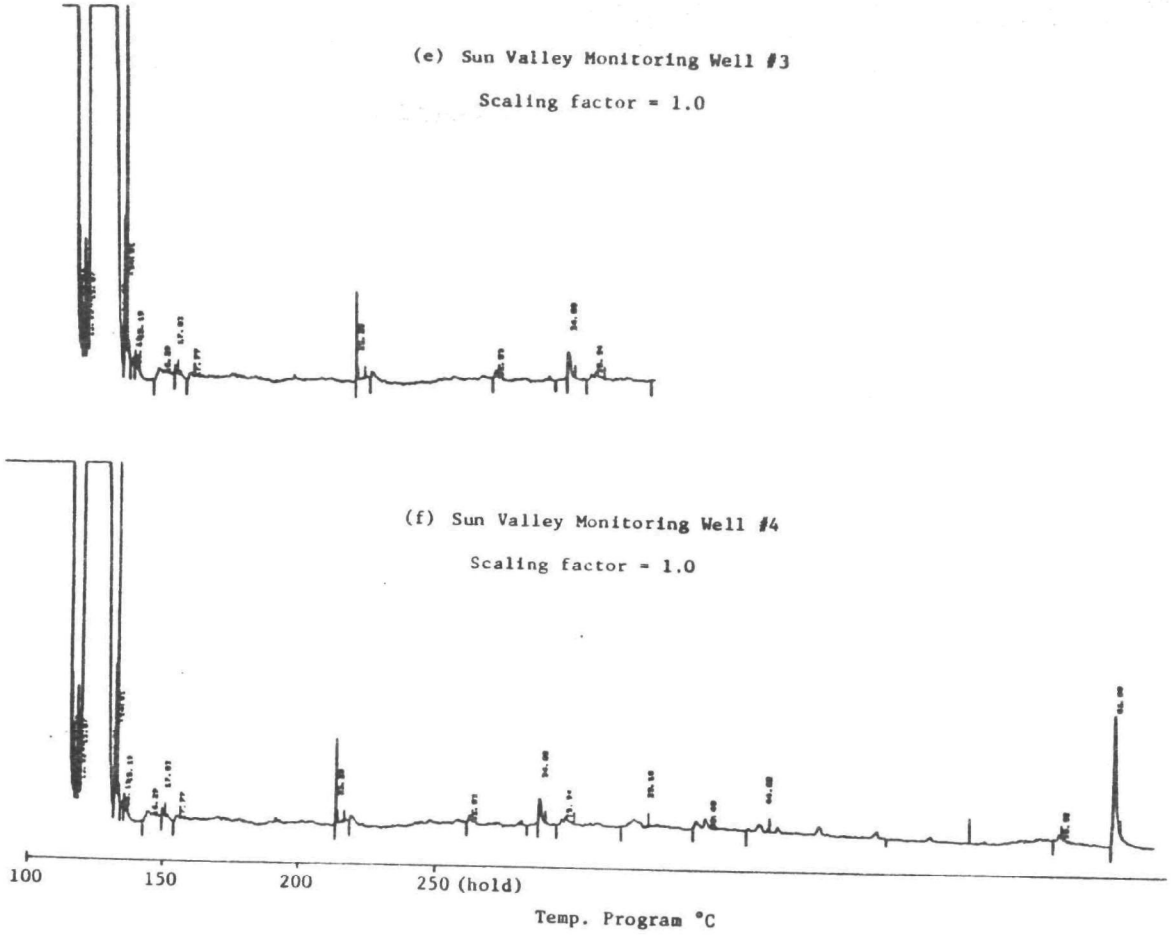


Figure 9. (continued)

large rain to mobilize shallow septic tank effluent contaminants may be of serious concern. The general problem appears to be a direct consequence of the importing to the valley water for domestic use in excess of that which can infiltrate into the ground water and flow as ground water out of the basin. David Carlson at William E. Nork, Inc., a Reno, Nevada, consulting firm, has studied the hydrology of the area and the possibility of collecting and pumping the excess ground water out of the valley.

SITE #4, STINSON BEACH, CALIFORNIA

Background

Stinson Beach is a small resort town about 20 mi northwest of San Francisco with a permanent population of 1416 (1975), which may swell to 30,000 on a summer weekend. Stinson Beach lies next to the San Andreas fault and is said to have the "finest public beaches in northern California" (Wilson et al., 1979). The community of Stinson Beach is located along the beach and on nearby mountain slopes. The soil type varies from sandy along the beach to clay silts on the upper slopes. The overall permeability varies from 6 to 45 gpd/ft^2, and the ground water gradient varies from 0.2 ft/ft in the upper slopes to 0.05 ft/ft along the beach.

In 1975 the Stinson Beach County Water District (SBCWD) conducted an extensive study of the efficiency of onsite waste disposal, as part of a 201 Construction Grant Program Facilities Planning study. A subsequent house-to-house study in 1977 showed that 34 to 43% of the septic tank systems had failed, mostly due to faulty construction and maintenance. Model legislation designed by the SBCWD was passed by the state of California to allow SBCWD personnel to conduct inspections on private property of onsite disposal systems. These inspections are conducted biennially. Approximately 70% of the original failing systems have been corrected, as of 1981. Both Olivieri et al., 1981, and Wilson et al., 1979, have thoroughly reviewed this site and concluded that on-site septic tank systems can work efficiently if properly managed and are less expensive per capita than a centralized sewerage system.

The layout of Stinson Beach and points where ground water samples were taken are in Figure 10.

Results and Discussion

Inorganic and coliform data are presented in Table 7. No virus data was possible because of slow recharge of the monitoring wells. Recharge of all of the wells was slow and little confidence can be placed on any of this data. Problems with the Hach apparatus in the field further casts doubt upon this data.

Results of C-TLOs are indicated in Table 8 and Figure 11. From Figure 11 it can be suggested that most of the C-TLOs were removed by the soil adsorption system of the general area. There were no monitoring wells located for which we had access in close proximity to individual septic tanks in the community, and hence, the GC traces can only be used to suggest that the whole area is not at present being impacted. It would have been useful to have monitoring wells systematically located near one or several individual septic tank systems.

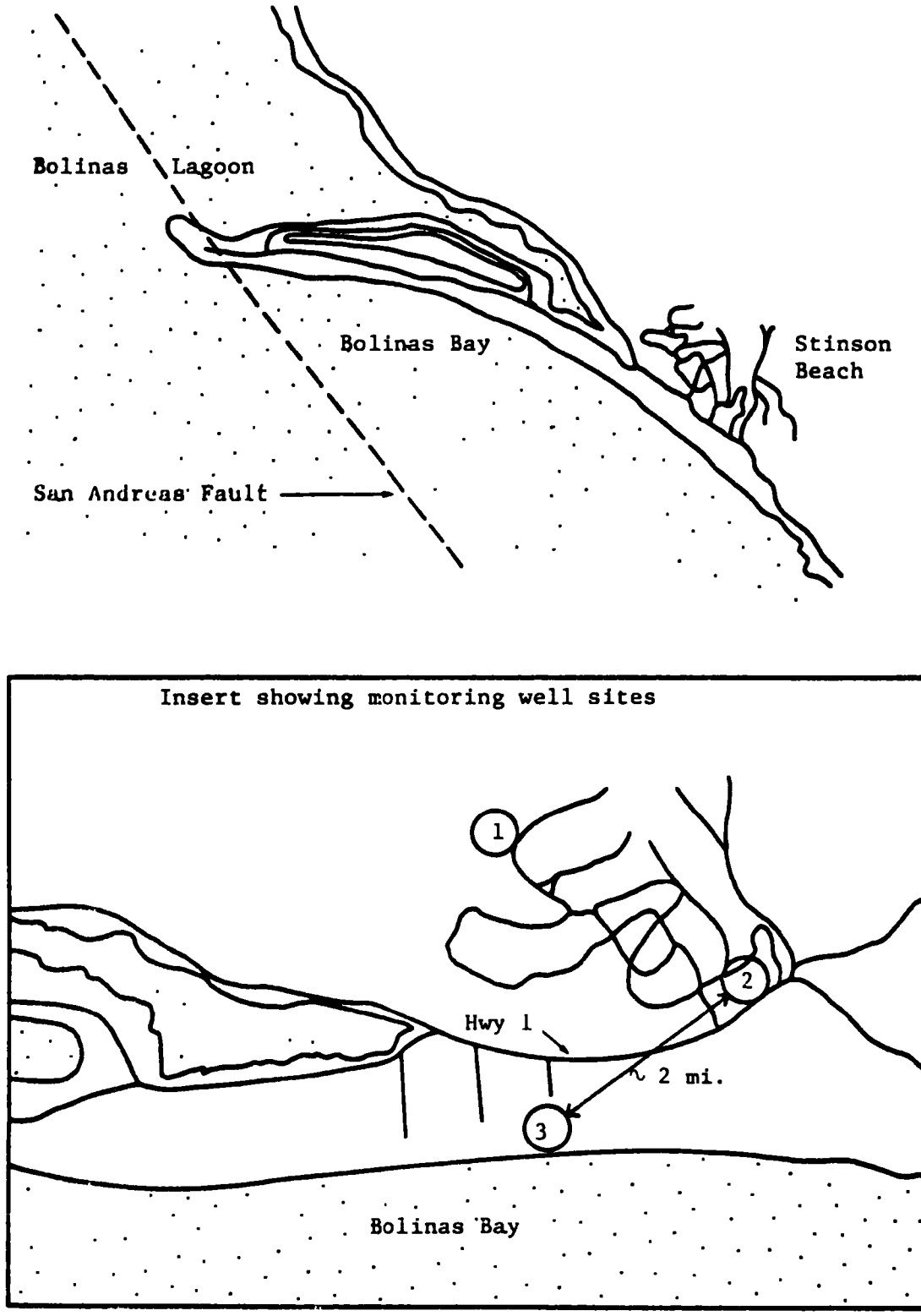


Figure 10. Map of Stinston Beach, California, showing monitoring well sites.

TABLE 7. CHARACTERISTICS OF WATER AT STINSON BEACH, CALIFORNIA*

Parameter	Well #3	Well #1	Well #2
Well Depth (ft)	10.5	19'3"	20'8"
Water Depth (ft)	2.5	4.5	6
Diameter (in)	3	3	3
PO_4	1.0	0.1	- -
Total Chlorine	0.002	0.005	- -
NO_3	0.5	0.0	- -
NO_2	0.065	0.010	- -
NH_4	0.30	0.50	- -
Conductivity (μhos/cm)	8.5	3.5	- -
pH	7.63	7.48	- -
Coliforms, Fecal per 100 ml	6	<4.5	<4.5
Coliforms, Total per 100 ml	6	<4.5	19

*Unless otherwise specified, all measurements in mg/l for the indicated ion. Problems with the Hach apparatus in the field may preclude use of some of this data.

TABLE 8. STINSON BEACH, CALIFORNIA, TRACE ORGANICS (μg/l)

Compound*	Well #3
Chloroform	
Carbon tetrachloride	
Trichloroethylene	
Toluene*	0.0924
Tetrachloroethylene	0.0409
Chlorobenzene	0.0347
m-Xylene*	0.0260
Bromobenzene	0.0261
m-Dichlorobenzene	
p-Dichlorobenzene	
o-Dichlorobenzene	0.0081
Acetophenone	0.0081
Naphthalene*	0.0024
Skatole	
o-Phenylphenol	
Diethylphthalate	0.0728
2(Methylthio)benzothiazole	
(1,1,3,3-Tetramethylbutyl)phenol	
Benzophenone	
Butylbenzene sulfonamide	
Dibutylphthalate*	0.0343
bis(2-Ethylhexyl)phthalate*	1.76

*Compounds found in the blank

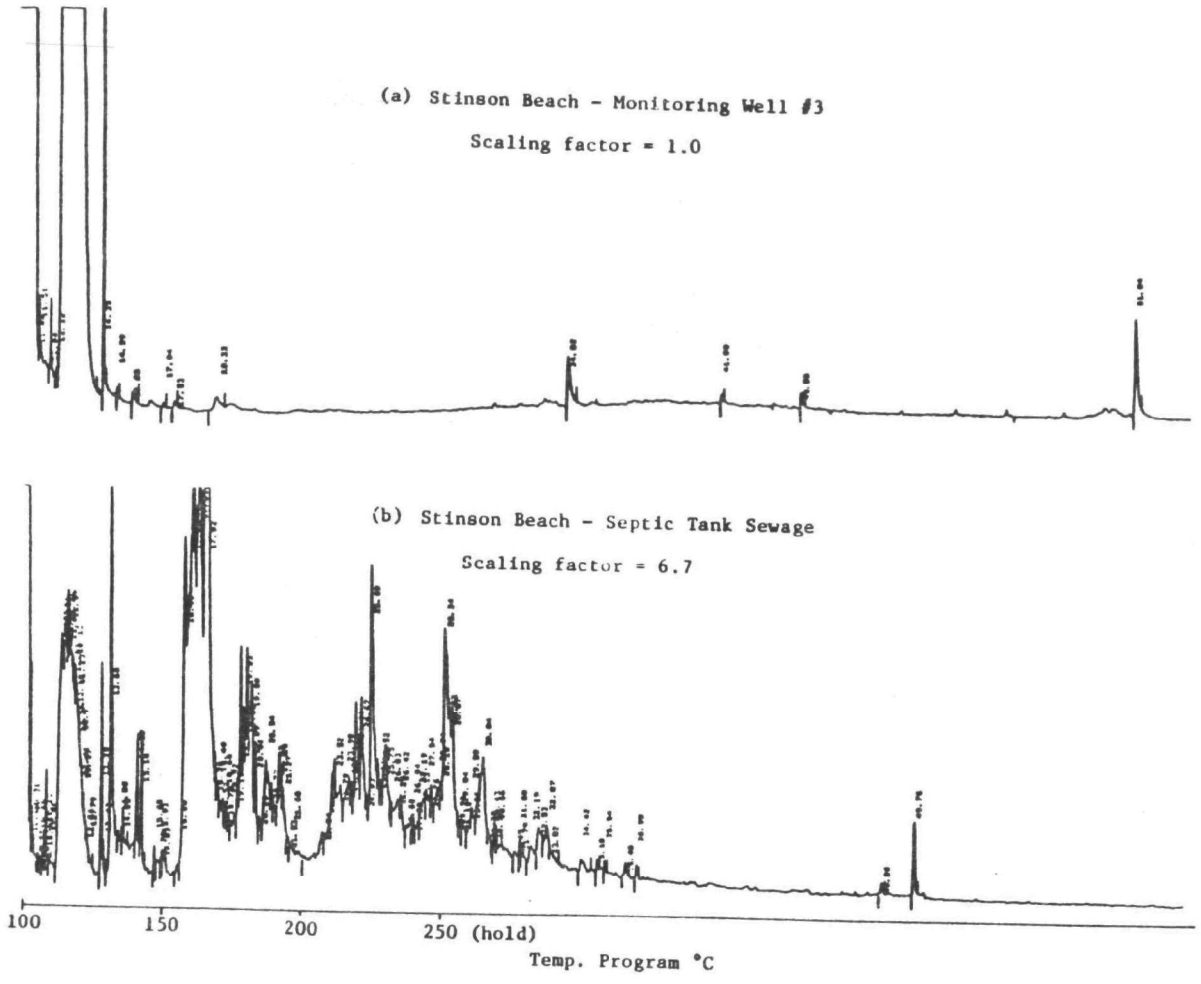


Figure 11. GC traces from samples obtained from Stinson Beach, California.

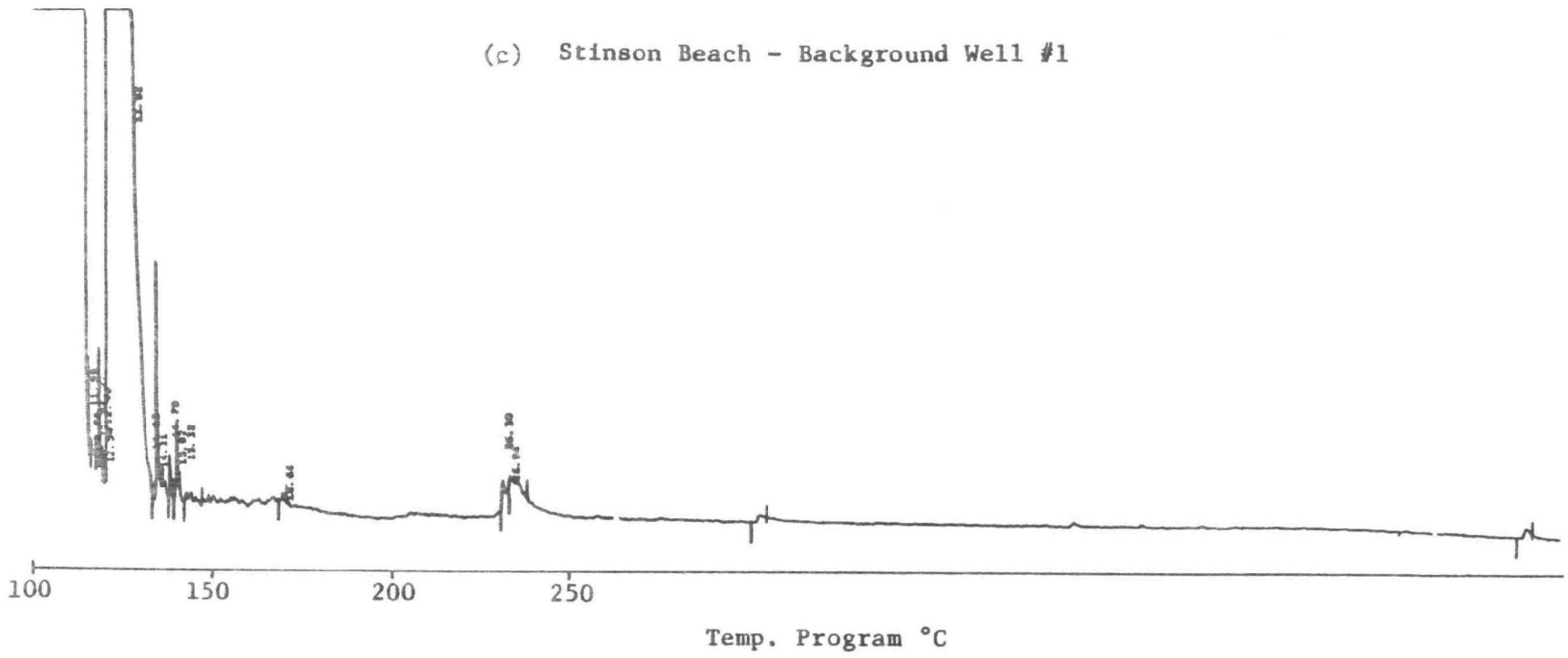


Figure 11. (continued)

SITE #5, PENWAUGH, TEXAS

Background

The Penwaugh campground septic tank site is located about 8 mi west of Livingston, Texas, on the southeastern shore of Lake Livingston. There are about 30 permanent trailers, with mostly retired couples, and a small motel with about 15 units, which is used primarily in the summer months on weekends. The soil down to about 3.5 ft is either sandy or sandy loam with 50 to 56% sand, 30 to 36% silt, and 12-18% clay. Below 3.5 ft the content changes significantly to 46% sand, 32% silt, and 22% clay.

A site plan of the campground is shown in Figure 12. There are several rows of trailers. Each row has a 2000 gal holding tank and several hundred feet of drainfield pipe around the periphery. Several sampling trips during December, 1980, and January and February, 1981, were made to this site to develop field procedures. Most of the data reported herein was from a trip made on January 22, 1981.

Results and Discussion

Results of inorganic and microbial analyses are presented in Table 9. The presence of FS and the absence of FCs in Well #2 suggest possible animal contamination down the casing; the area around of these wells was generally wet. The absence of identified bacteria in the sewage may suggest that it had been standing for several days. The low alkalinity, hardness, nitrate, and conductivity in Wells #1 and #2 relative to the sewage imply that area wide contamination is not taking place. Since this site is adjacent to Lake Livingston, the ground water flow is probably in the direction of Wells #2 or #3, but it is not known. No monitoring wells existed close to the sewage infiltration, and therefore, the extent of potential impact upon the ground water is difficult to assess.

A summary of the C-TLOs present in the ground water wells and sewage is presented in Table 10 and Figure 13. From the GC trace of the sewage sample (note the 200 scaling factor), it is clear that the sewage contains large quantities of C-TLOs which could impact upon the groundwater. It was not possible to sample the holding tank or the infiltration lines themselves, and thus, it is not known how many of the sewage C-TLOs are released to the subsurface. From the GC traces of Well #1, most likely to be impacted, it appears that either most of the C-TLOs are being removed by the soil adsorption system or that the monitoring wells are simply not in the path of the percolate from the infiltration field. If the percolate were to move straight downward even when the water table is encountered, as is possible in such a system, none of the monitoring wells

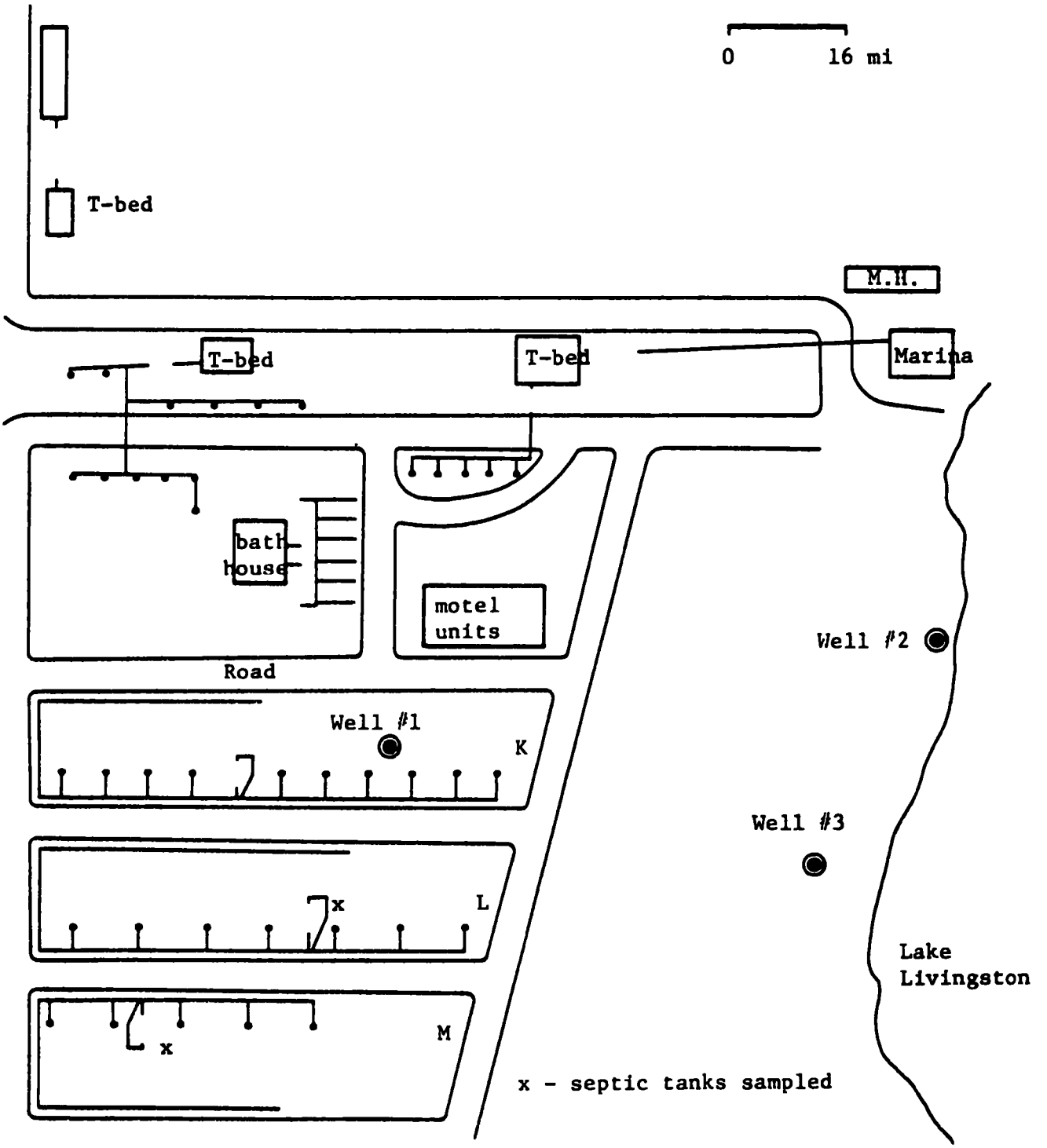


Figure 12. Schematic of Penwaugh, Texas, site.

TABLE 9. CHAR TERISTICS OF WATER AT PENWAUGH, TEXAS
January 22, 1981

Parameter	W	1 #1	Well #2	Lake Livingston	Dist. Box
Depth to water (ft)		9	9.5		
Alkalinity		80	236	97	544
pH		:.0	8.1	8.2	7.7
Conductivity (μhos)		25	150	250	500
Calcium		79	229	109	494
Chlorides		71	61	47	213
Hardness		90	223	117	245
Fluoride		11	0.20	0.50	1.37
Iron (total)		04	0.23	0.09	0.34
N, ammonia		).3	0.33	0.52	40.00 mg/l
N, nitrate		4	0.3	0.4	1.6
N, nitrite		-	- -	- -	- -
Phosphorus	0	2	0.40	1.25	35.0
Sulfate (mg/l)		-	11	52	55
Sulfide	0.	4	0.003	0.005	0.08
Coliforms, Total per 100 ml		0	10		0
Coliforms, Fecal per 100 ml		0	0		0
Fecal Strep./100 ml		0	50		0
Virus, PFU/100 ml		0	0		10

Comments: Lysimeter Wa r - 2.6 ml, Cond. 700; City Water - Cond. 100

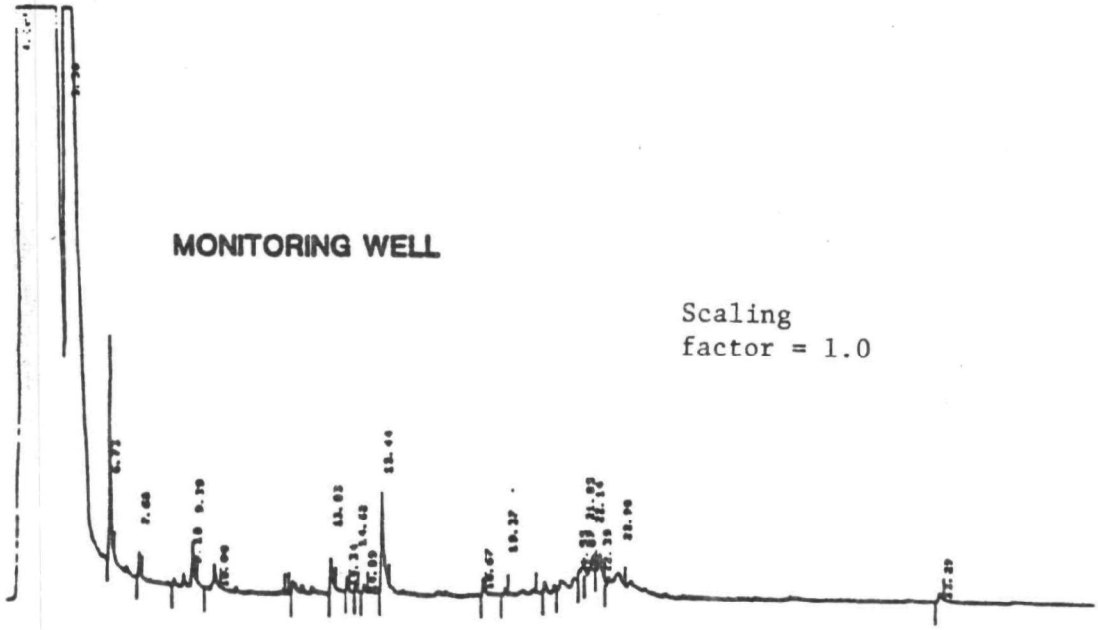
TABLE 10. SUMMARY OF C-TLOs FOUND AT PENWAUGH, TEXAS, SITE

Sampling: January 23, 1981

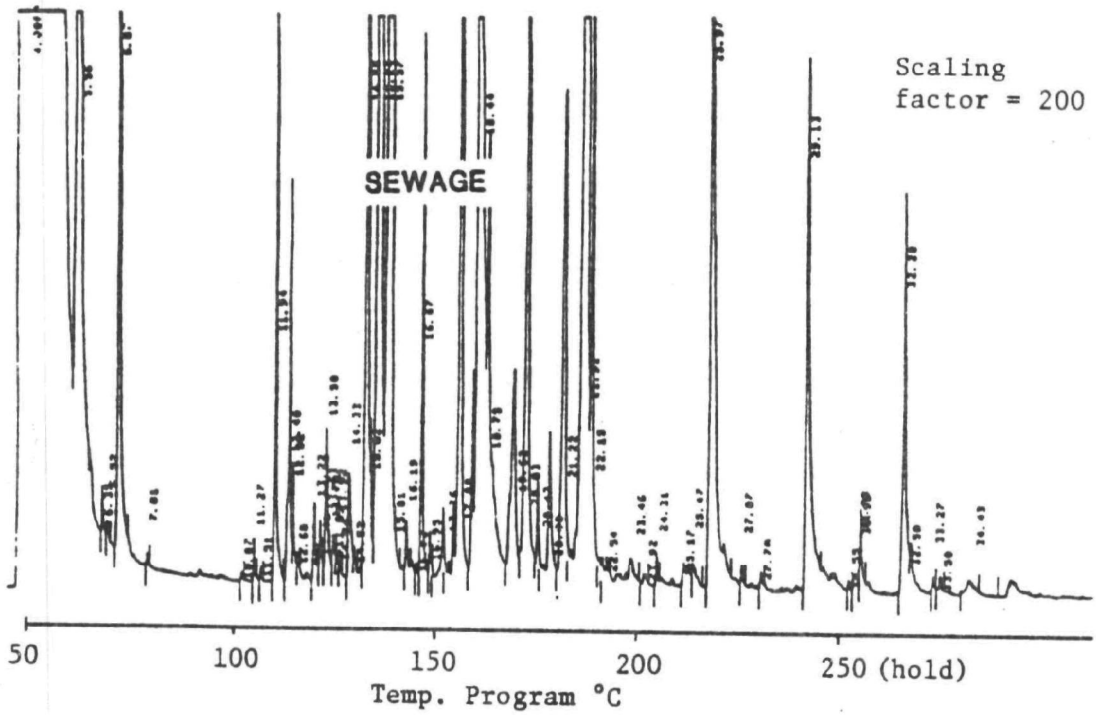
Compound	Ratio Well #1/Dist. Box
Toluene	6.4×10^{-5}
*C_2-benzene	1.3×10^{-2}
**C_2-benzene	1.4×10^{-2}
Dichlorobenzene	8.9×10^{-2}
o-Acetyltoluene	2.3×10^{-1}
2-Terpinol	1×10^{-3}
Indole	4×10^{-4}
Skatole	8×10^{-5}
Diethylphthalate	9.76×10^{-1}
D_8Naphthalene	- -

*C_2-benzene = possibly ethylbenzene

**C_2-benzene (second component) = either o-toluene or m,p-toluene or xylene

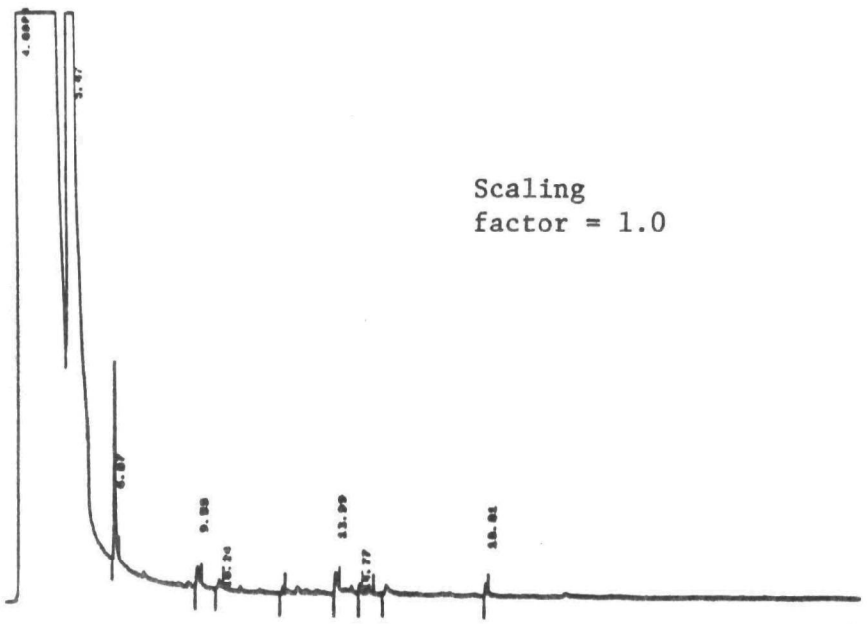


(a) Penwaugh - Monitoring Well #2

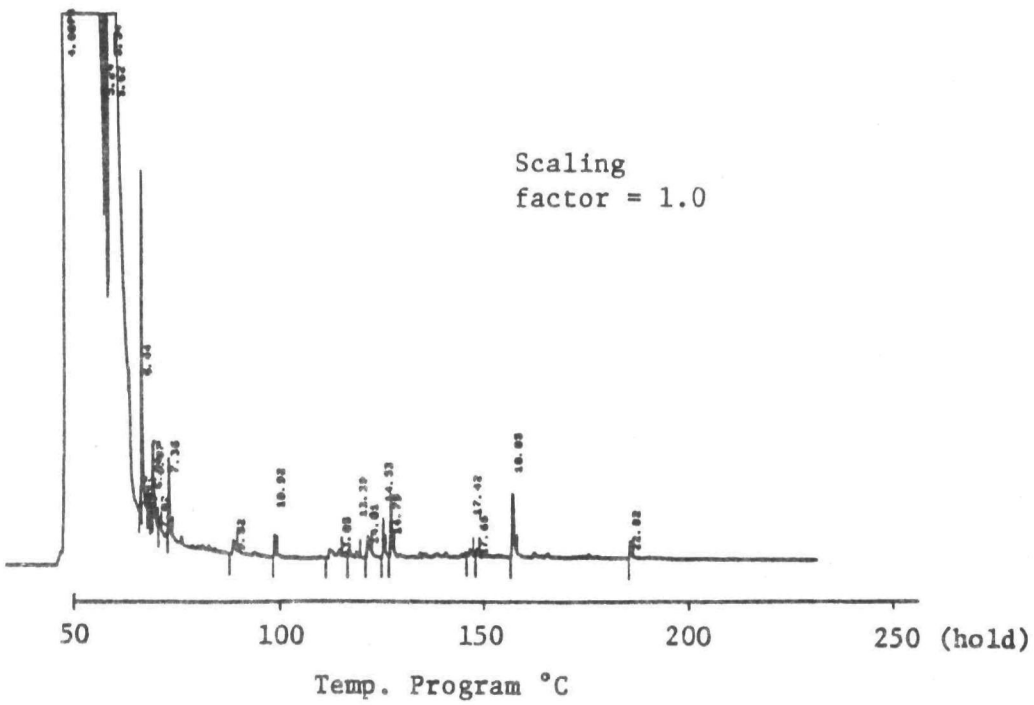


(b) Penwaugh - Septic Tank - Sewage

Figure 13. GC traces from samples obtained from Penwaugh, Texas.



(c) Penwaugh - Monitoring Well #1



(d) Penwaugh - Resin Column Blank

Figure 13. (continued)

would be impacted. To test this hypothesis, it would be necessary to sample the ground water, beneath a trench line, at various depths.

SITE #6, ALDINE KOA CAMPGROUND, HOUSTON, TEXAS

Background

The Aldine Mobile Home Village, a KOA Campground in north Houston, was sampled on December 11, 1980. The campground was less than five years old and served 75 to 100 permanent residents in trailers (see Figure 14). The waste water treatment was by a pressurized Hutsell system. A 350 ft deep water well was located on the property. The percolation rates in the area varied from 5 to 45 min/in. The soil was mostly a clay loam. This was one of the earlier sites sampled in order to help develop field sampling techniques.

Results and Discussion

The tap water from the well had 7.0 pH, 178 mg-$CaCO_3$ l^{-1} alkalinity, and 448 μmhos cm^{-1} conductivity. The sewage had numerous trace organics, probably at or below 1 $\mu g l^{-1}$, but the 350 ft ground water contained no detectable C-TLOs (Figure 15). Clearly, the sewage leachate has had no effect upon the ground water directly below the site. This is also an excellent example of just how clean and free from C-TLOs pollutants virgin ground water often is.

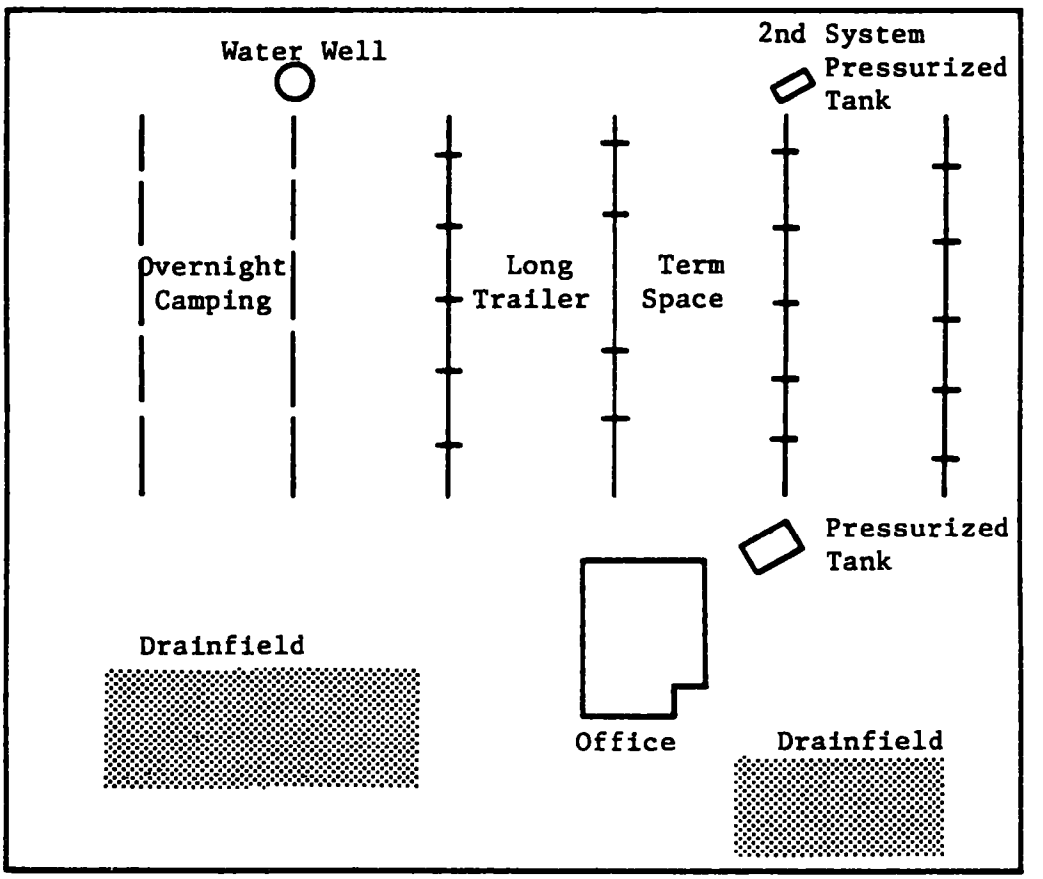
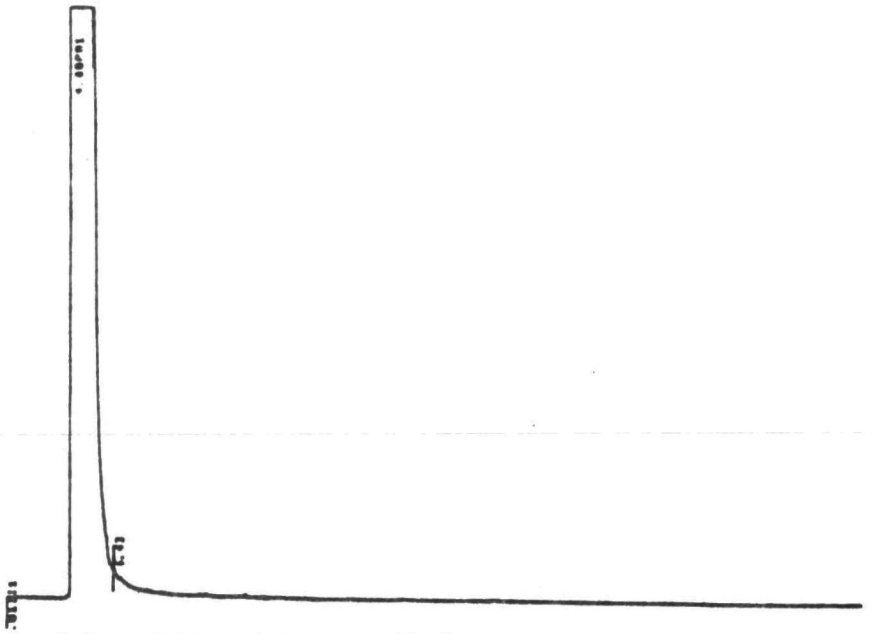
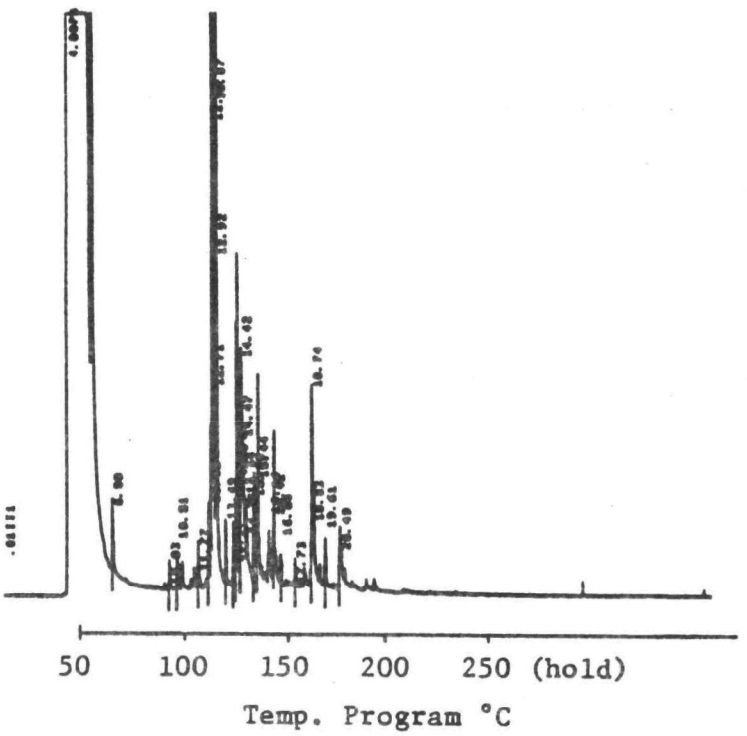


Figure 14. Diagram of Aldine, Texas, site.

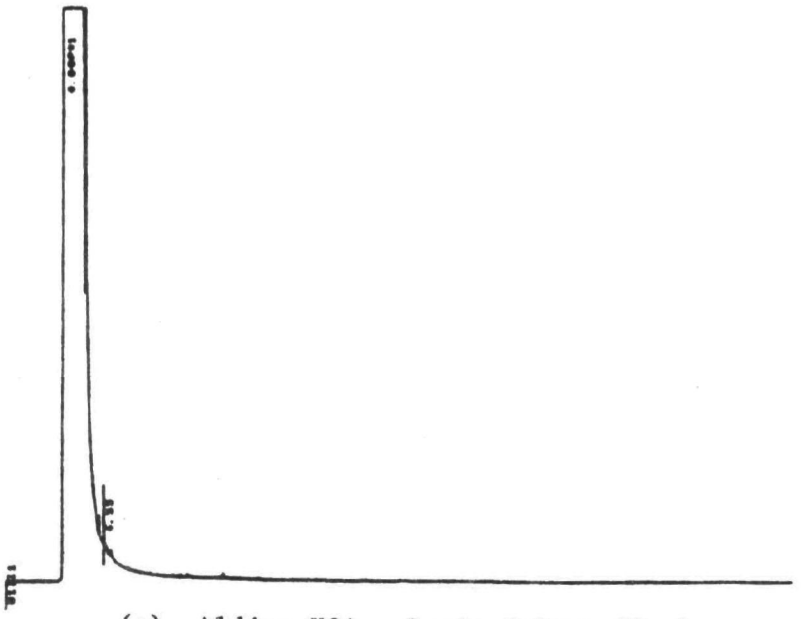


(a) Aldine-KOA - Well Water

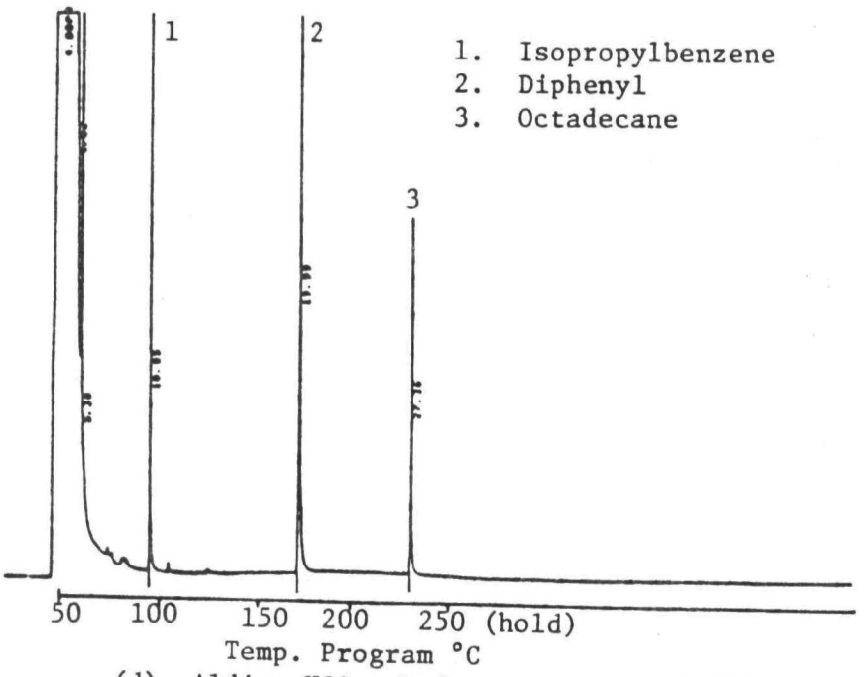


(b) Aldine-KOA - Septic Tank Sewage

Figure 15. GC traces from samples obtained from Aldine, Texas.



(c) Aldine-KOA - Resin Column Blank



(d) Aldine-KOA - Reference Standard (100 ppm)

Figure 15. (continued)

SITE #7, PEARLAND, TEXAS, MOBILE HOME PARK

Background

This mobile home park located 4 mi southeast of Pearland, Texas, is about 20 mi from the Gulf of Mexico. There are 50 to 75 permanent residents. The topography of this area is extremely flat, and the soil is a clay "black gumbo" with a percolation rate of 48-60 min/in. Being high in clay content, it tends to shrink and swell extensively upon wetting and drying, and it is probably sensitive to changes in ionic strength of the infiltrate water, although this was not tested. The onsite drinking water well located 100 yards from the septic tank pits is 125 ft/deep, probably into the upper Chicot aquifer. The drainfield for the site is located between three pits, 14 ft deep, containing gravel and rock. Sewage is collected from individual tanks and brought to a mixing box before addition to the three pits (Figure 16).

Samples were collected from this site on October 28, 1980. To sample the sewage a 2 ft deep hole was dug into the drainfield and a few liters of water pumped into a glass jar, which was returned to the laboratory for extraction and analysis.

Results and Discussion

Chromatographic traces depicting C-TLOs in the tap water and the drainfield water are presented in Figure 17. The ground water was apparently free from C-TLO contamination--the peak at 8.21 min probably corresponds to the 8.31 min. peak in the blank and is thus disregarded. The sewage pit sample has several C-TLOs which could potentially impact upon the Chicot aquifer ground water, but due to the adsorptive capacity of clay or the microbial activity, none had impacted upon the drinking water well. It is expected that the three 14 ft deep pits filled with gravel have a major role in degradation of the C-TLOs from the septic tanks. It would be useful to sample the pits at various depths looking for both applied C-TLOs and probable microbial degradation products. This system might be thought of as a gravity feed anaerobic analog of a trickling filter or septic tank sand filter system and could be quite useful in other regions of the country where classical septic tanks are not appropriate (Troyan and Norris, 1977).

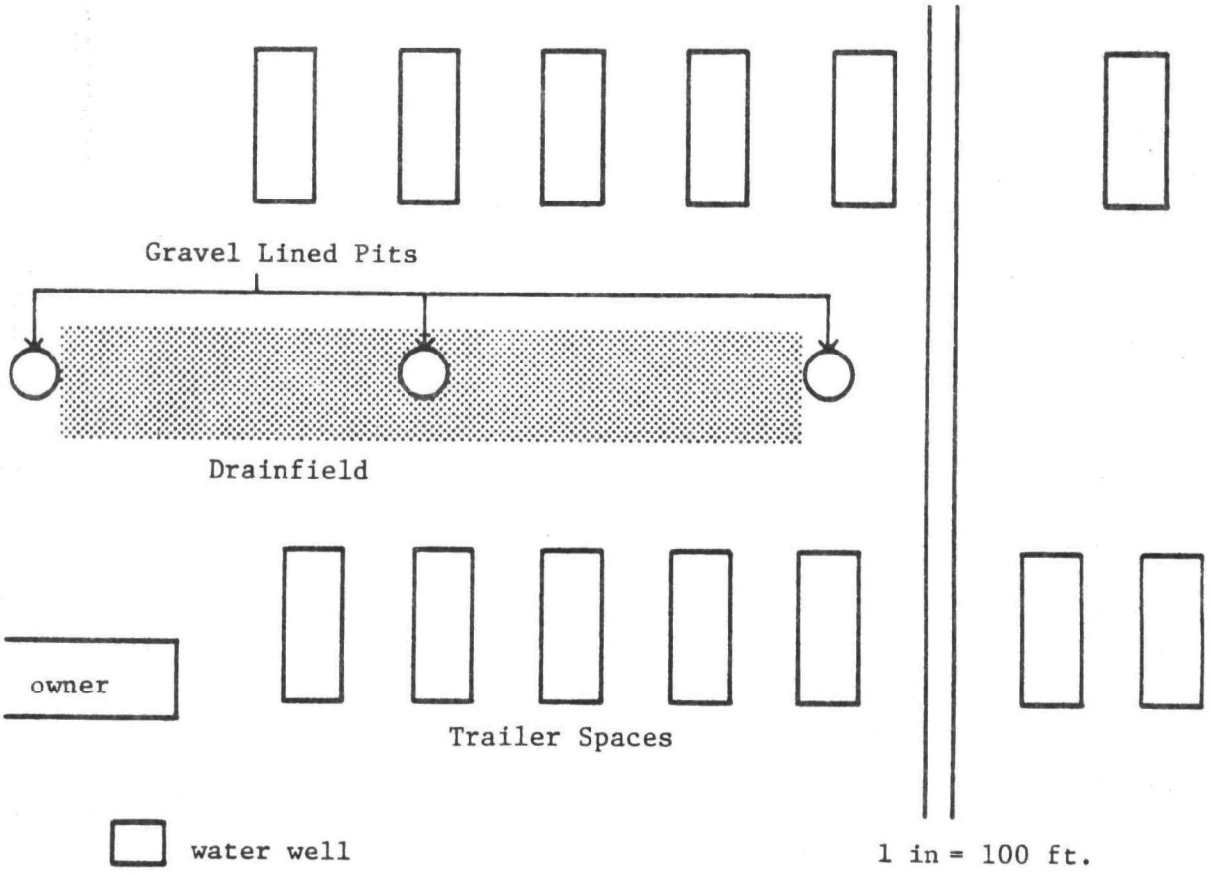


Figure 16. Diagram of Pearland, Texas, site.

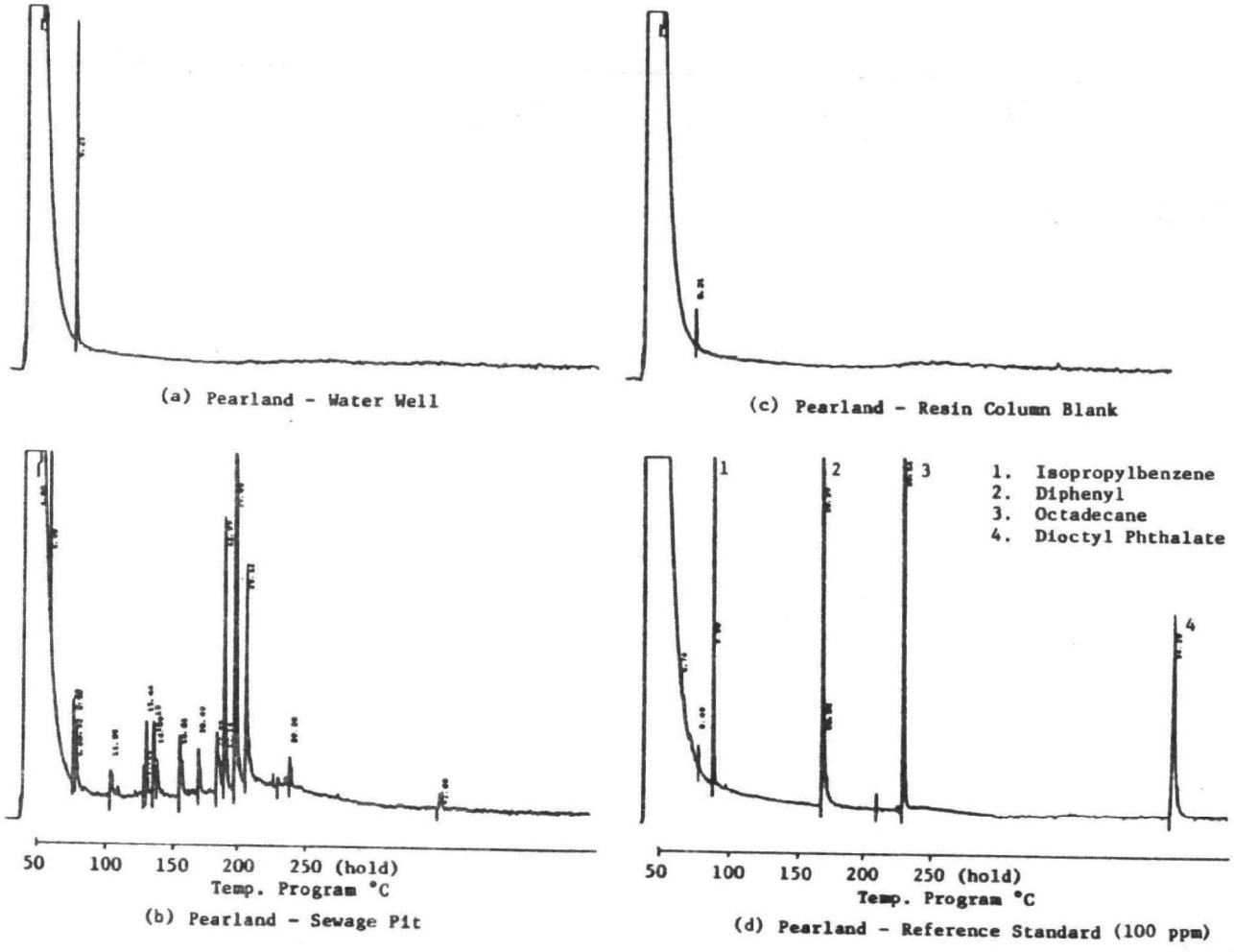


Figure 17. GC traces from samples obtained from Pearland, Texas.

SITE #8, LAWRENCE, KANSAS, SINGLE FAMILY DWELLING SEPTIC TANK SYSTEM

Background

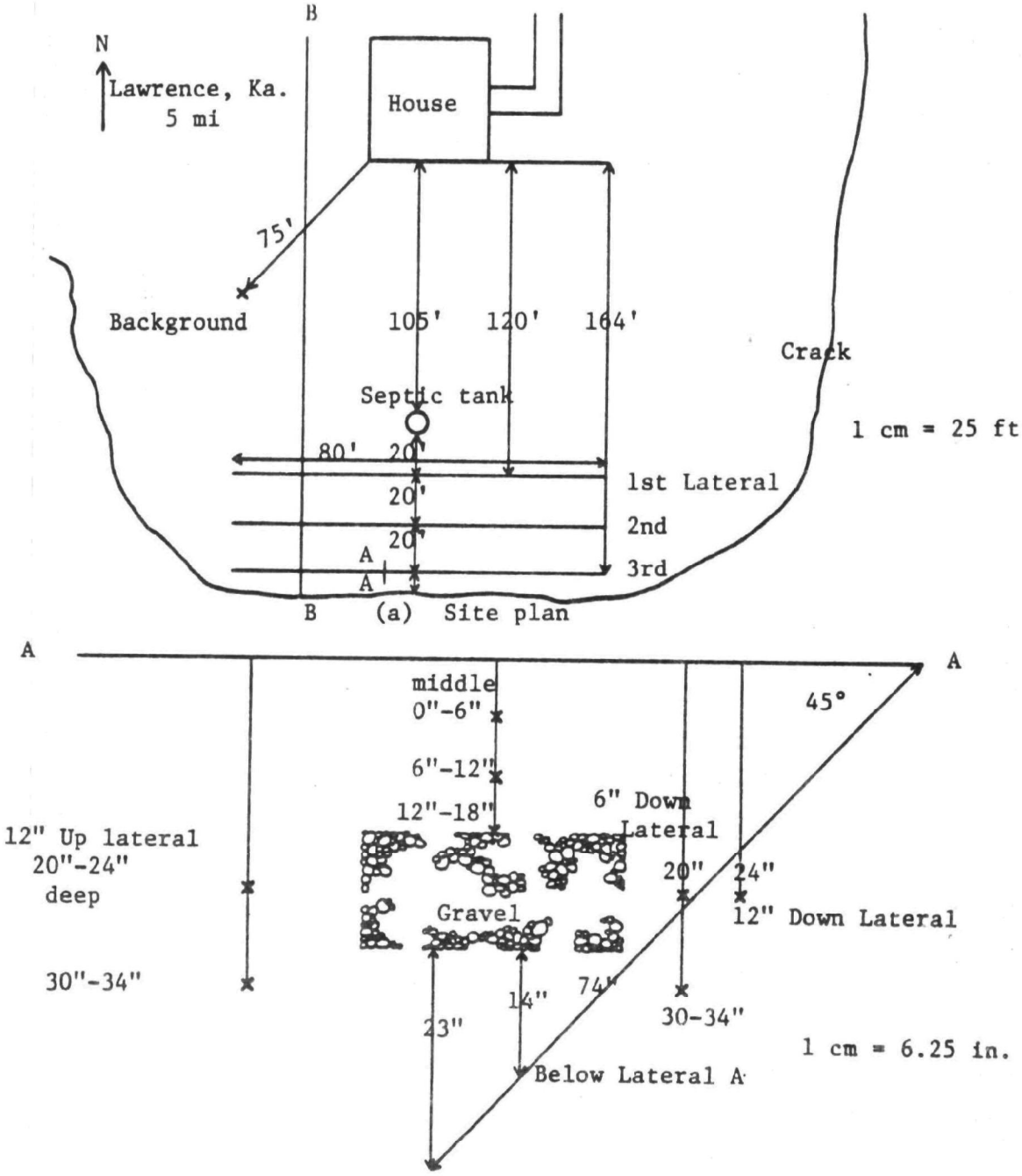
The septic tank system for a Kansas University professor's modern brick house in a subdivision about 5 mi south of Lawrence was sampled. The soil was a heavy black clay down to about 30 ft. The subdivision was using unchlorinated ground water. This septic tank system had been in operation several years with few problems.

The overall layout of the lot was as shown in Figure 18a. Numerous soil samples (marked "x" in Figure 18a) were taken at various places around the lot as well as below and adjacent to the third lateral (Figure 18b). Holes were drilled to depth with a one inch auger and a cleaned piece of 3/4 in aluminum tubing used to obtain water-saturated clay soil cores. Water from the lateral was obtained by augering directly into the gravel in the trench and pumping with a peristaltic pump.

Results and Discussion

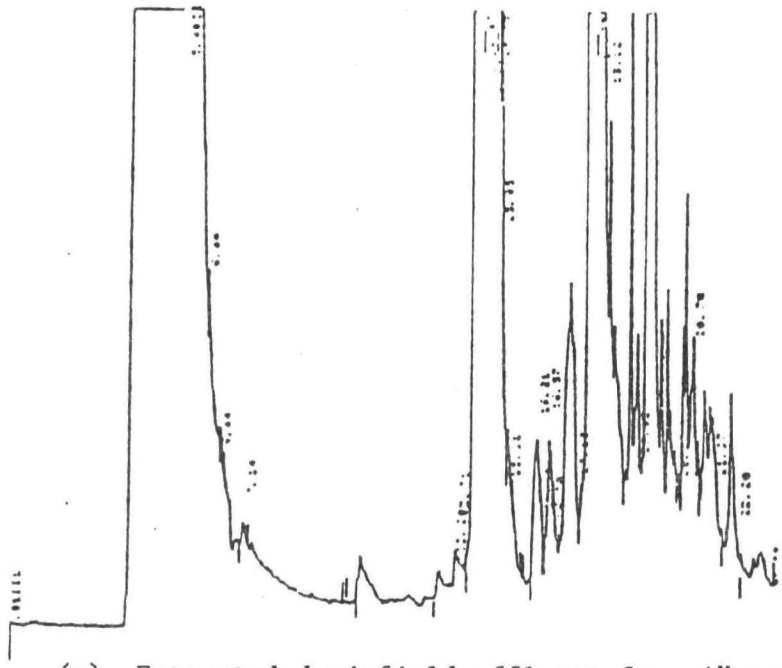
Inorganic analyses of the tap water and the third lateral grey water are presented in Table 11. The high chlorine value may have been due to clothes washing. Most other changes were as expected for domestic use of water.

A chromatographic summary of the C-TLOs in the waste water are presented in Figure 19. The general absence of C-TLOs in the early part of the chromatograms just after the solvent peak is probably a consequence of a long residence time in the lateral trench before infiltrating. Numerous attempts were made to extract the soil cores; various dispersants, acids, bases, solvents, and procedures were tried with little success. A typical soil core extract is depicted in Figure 19b. It is still not known if C-TLOs are in the soil. Soil cores from only a couple inches away from the lateral wall yielded similar results.

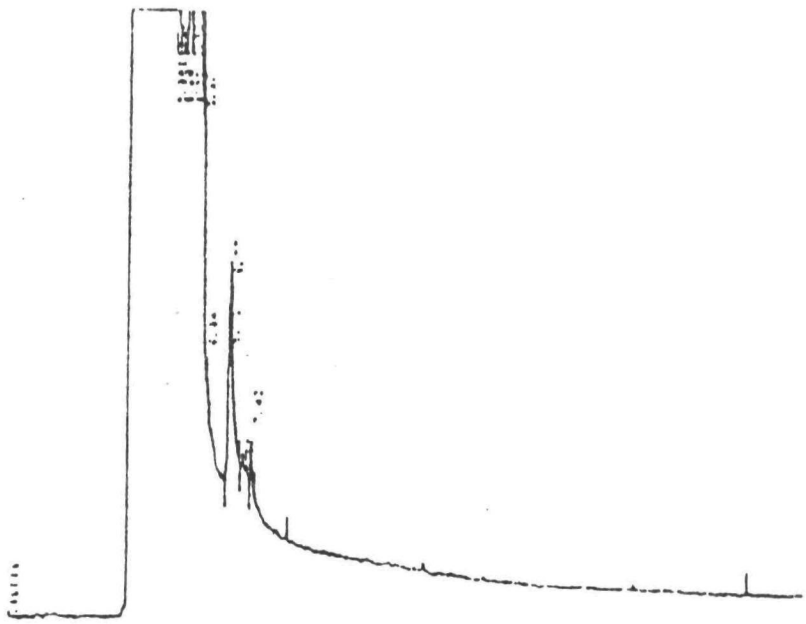


(b) Cross section of lateral line with sampling points marked by x.

Figure 18. Diagrams of Lawrence, Kansas, site.



(a) Extracted drainfield effluent from 4" auger hole



(b) Soil extract from below the drainfield lateral

Figure 19. GC traces from samples obtained from Lawrence, Kansas.

TABLE 11. ONSITE CHEMICAL ANALYSES OF WATER AND WASTE WATER FROM HOME SEPTIC TANK SYSTEM, LAWRENCE, KANSAS, MAY 8, 1981

Parameter (units)	House Fresh Water	Septic Effluent 3rd Lateral
Temperature (°C)	22.5	23.5
pH	7.30	7.04
Nitrate-N (mg/l N)	0.7	1.4
Ammonia-N (mg/l N)	0	10.0
Nitrite-N (mg/l N)	0.64	0.56
Alkalinity (mg/l $CaCO_3$)	336	489
Total Chlorine (mg/l)	0.07	1.50
Hardness (mg/l $CaCO_3$)	4	347
Total Iron (mg/l)	0.27	3.5
COD (mg/l)	21	97
Conductance (μmhos/cm)	650	2000

SITE #9, SOUTHERN BIBLE COLLEGE, HOUSTON, TEXAS

Background

Southern Bible College, located at Oates Road and U. S. Highway 90 in northeast Houston, has a resident population of 90-110. The college has an administration building, a gymnasium, a classroom building, and several permanent resident buildings. The sewer pipes of these buildings feed into a septic tank and then into a drainfield located to the south approximately 100 meters. The common septic tank and drainfield, believed to be approximately 50 years old, are located on Harris County maintenance camp property. The drainfield is located beneath a well traveled dirt road leading out of the maintenance camp. Due to the age of this septic system and the fact that the drainfield lies beneath a road, there is a high probability that it is not fully functional.

There are three water wells in this area that have been considered as possible sampling wells. Two of these wells have been excluded because of their depth. Well #1 is located on the Southern Bible College campus and is approximately 800-1,000 feet deep. Well #2 is located in a nearby cemetary south of the septic system and is 560 feet deep. Well #3 is located to the north of U. S. Highway 90 in a brick manufacturing industry; it is approximately 100-150 feet deep and is the only existing well which could possibly be used. For this reason, this site has not yet been sampled. If funds for drilling were available, it might be an interesting site because of its age and size.

SITE #10, STELLACOOM, WASHINGTON

Background

Dr. Foppe DeWalle, a professor at University of Washington, was contacted in regards to locating a septic tank system site near Tacoma, Washington. With his and others' assistance, a potential site was located just south of Tacoma at Stellacoom, Washington, at the intersection of 97th Avenue and Onyx Road. There were no appropriate monitoring wells on the site and so Rice University personnel visited the site to coordinate drilling of one or two monitoring wells. It was thought that the depth to ground water was well known. After expenditure of several thousand dollars on drilling without hitting the water table, the site, as a prospect, was abandoned.

SECTION 6

DISCUSSION AND SUMMARY OF C-TLOs FOUND IN SEPTIC TANK SYSTEMS

Most of the 22 target compounds in this study are in common use in a normal household. Major uses along with water solubility are listed in Table 12. It is interesting to note that the lowest water solubility reported in Table 12 is 0.4 mg l^{-1} for bis(2-ethylhexyl)phthalate. This may imply that our analytical procedure misses compounds with a low water solubility, or it may imply that these compounds are removed by some portion of the septic tank system before sampling. Similar observations have been made in relation to land application systems (Hutchins, 1982). Further research to test these notions is being conducted at Rice University.

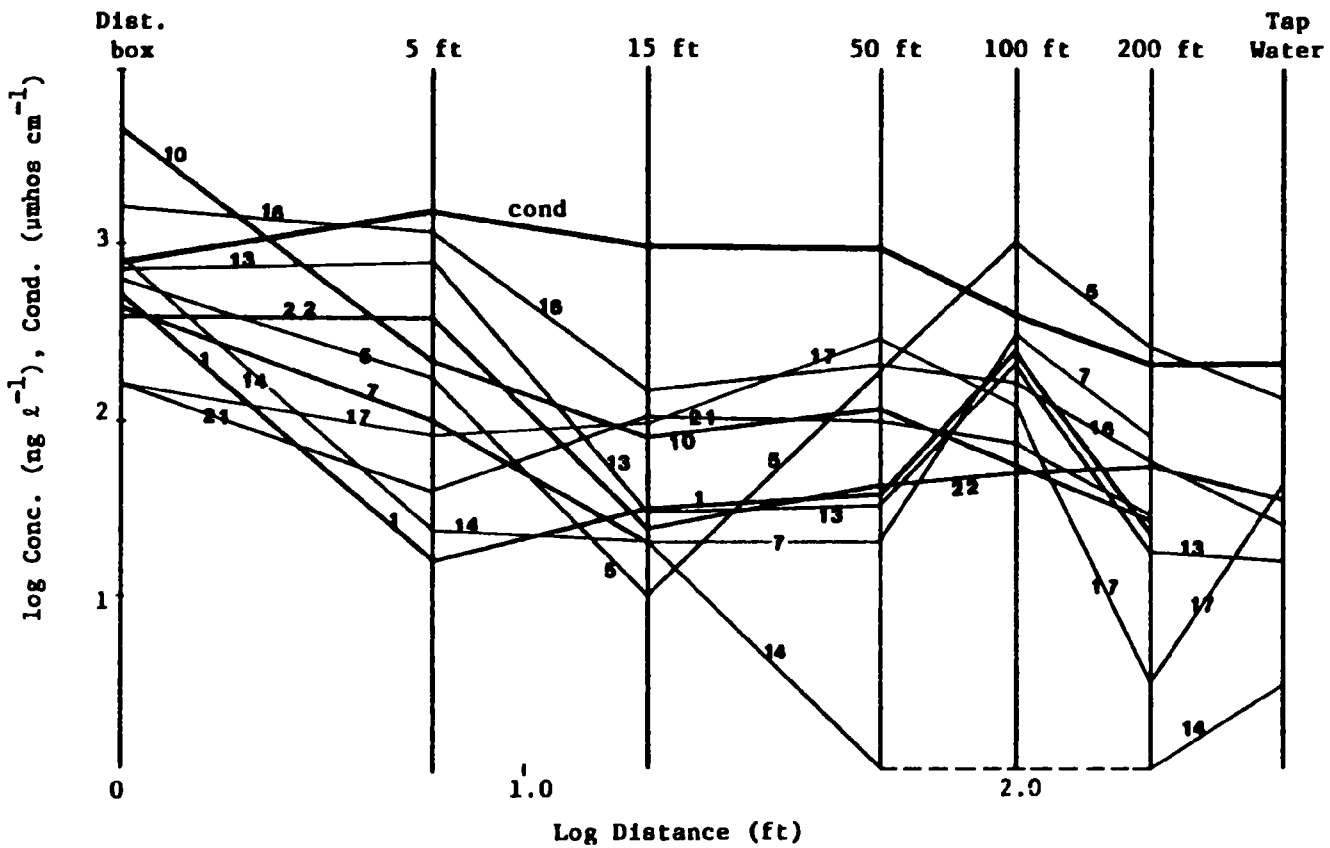
A summary compilation of the concentrations of target compounds from the different sites is presented in Table 13 for comparison. The log (Conc.) vs distance has been plotted in Figure 20 for selected compounds found at the Speonk, N.Y., site. The overall trend appears to be about 1.5 log units removal in about 220 ft, but there is considerable variation in removal vs distance. But when this is contrasted with the many log units removal normally encountered with bacteria and virus removal, the potential for potable ground water contamination is clear.

If waste water from a septic tank leach field is not breaking through the soil to the surface, it is generally assumed that the septic tank system is "working." A working system is more easily accomplished as the permeability or percolation rate increases. The more sandy the soil, the higher the percolation rate. Unfortunately, sandy soils generally have lower specific surface areas, lower clay content, and lower percent organic, all of which tend to decrease the retardation of C-TLOs. Thus, if an error in septic tank siting is made, it will probably be made opposite the side of ground water protection from C-TLOs.

Finally, as was noted in the Methods section, numerous additional C-TLOs were identified by GC/MS/DS. A partial list of additional compounds identified in the Speonk, New York, ground water is reproduced in Table 14 along with a list of wells in which each compound was identified. For a compound

TABLE 12. MAJOR USES OF C-TLOs TARGETED FOR STUDY

	Compound	Water Solubility (mg/l)	Major Uses
1	Chloroform	7950	Solvent, as cleaning agent, in fire extinguishers, in the rubber industry
2	Carbon tetrachloride	800	Solvent, as fire extinguisher, for cleaning clothes, insecticide, manufacture of organic chemicals
3	Trichloroethylene	1470	Solvent, degreasing, in dry cleaning, manufacture of organic chemicals
4	Toluene	470	Solvent, in manufacture of organic chemicals, dyes, explosives
5	Tetrachloroethylene	483,400,200	Degreasing metals, as solvent
6	Chlorobenzene	448	Manufacturing of organics, solvent
7	m-Xylene	- -	Solvent, manufacture of dyes, etc.
8	Bromobenzene	446	In organic syntheses, solvent, additive to motor oils
9	m-Dichlorobenzene	79	Solvent, manufacture of dyes, in organic synthesis
10	p-Dichlorobenzene	79	Insecticidal fumigant
11	o-Dichlorobenzene	154	Insecticidal fumigant
12	Acetophenone	5420	In perfumery, as catalyst in syntheses
13	Naphthalene	31.7	As raw ingredient in organic syntheses
14	Skatole	- -	In feces, beetroot and coal tar
15	o-Phenylphenol	700	As pesticide, in rubber industry
16	Diethylphthalate	7040,1000	As solvent, fixative for perfumes
17	2(Methylthio)benzothiazole	- -	Used in fungicide, pesticide preparations
18	(1,1,3,3-Tetramethylbutyl)phenol	- -	Surfactant
19	Benzophenone	148	In perfumery, soaps, in manufacture of drugs and insecticides
20	Butylbenzene sulfonamide	- -	Plasticizer
21	Dibutylphthalate	4.5	Insect repellent
22	bis(2-Ethylhexyl)phthalate	0.4	In vacuum pumps



cond = conductance
1 Chloroform
5 Tetrachloroethylene
7 Xylene(s)
10 pCl_2-Benzene
13 Naphthalene
14 Skatole
16 Diethylphalate
17 2(methylthio)benzothiazole
21 Dibutylphthalate
22 Bis(2-ethylhexyl)phthalate

Figure 20. Plot of the logarithm of C-TLC concentrations (ng ℓ^{-1}) and conductance (μmhos cm^{-1}) vs the logarithm of distance for selected compounds found in the ground water at Speonk, New York. (The position of the distribution box, at 0 ft, has been arbitrarily located.)

TABLE 13. SUMMARY OF C-TLO CONCENTRATIONS (μg/l) FOUND AT FOUR PRIMARY SEPTIC TANK SYSTEM SITES

SPEONK, NEW YORK

Compound*	Dist. Box (0 ft)	Well #1 (? ft)	Well #9 (5 ft)	Well #10 (15 ft)	Well #13 (50 ft)	Well #15 (100 ft)	Well #16 (200 ft)	Tap Water* (220 ft)
Chloroform	0.52	0.14	0.00017	0.031	0.036	0.24	0.023	- -
Carbon tetrachloride	- -	0.39	- -	0.39	- -	- -	0.00045	- -
Trichloroethylene	1.60	- -	0.0039	- -	0.0065	0.0040	0.0025	- -
Toluene*	330	2.10	- -	17	9.9	15	2.6	- -
Tetrachloroethylene	0.61	0.15	0.169	0.010	0.18	1.0	0.25	0.13
Chlorobenzene	- -	- -	- -	- -	- -	- -	- -	- -
m-Xylene*	0.43	0.11	0.094	- -	0.020	0.29	0.074	- -
Bromobenzene	0.028	0.00088	- -	- -	- -	- -	- -	- -
m-Dichlorobenzene	0.045	- -	- -	- -	- -	- -	- -	- -
p-Dichlorobenzene	4.6	0.0049	0.208	0.078	0.11	0.053	0.025	- -
o-Dichlorobenzene	- -	- -	- -	- -	- -	- -	- -	- -
Acetophenone	- -	- -	- -	- -	0.021	0.071	0.017	- -
Naphthalene*	0.71	0.0330	0.833	0.030	0.032	0.20	0.018	0.015
Skatole	0.81	- -	0.023	0.022	- -	- -	- -	0.003
o-Phenylphenol	0.24	- -	0.0046	0.18	0.17	- -	- -	
Diethylphthalate	1.60	0.023	1.16	0.144	0.18	0.16	0.0560	0.025
2(Methylthio)-benzothiazole	0.16	- -	0.080	0.094	0.067	0.12	0.0029	0.040
(1,1,3,3-Tetramethyl-butyl)phenol	1.70	- -	0.033	0.0056	0.34	- -	- -	- -
Benzophenone	0.19	- -	0.0013	0.0060	0.015	- -	- -	- -
Butylbenzene sulfon-amide	- -	- -	- -	- -	- -	- -	- -	0.009
Dibutylphthalate*	0.160	0.032	0.039	0.103	0.077	0.070	0.029	- -
bis(2-Ethylhexyl)-phthalate*	0.37	0.36	0.384	0.023	0.040	0.050	0.055	0.34

TABLE 13. (Continued)

	CISCO GROVE, CALIFORNIA				SUN VALLEY, NEVADA				STINSON BEACH, CALIFORNIA
Compound	Dist. Box	Well #1	Well #2	Well #3	Sewage	Ditch	Well #2	Well #4	Well #4
Chloroform			0.0009				0.0020		
Carbon tetrachloride			0.0008						
Trichloroethylene					0.0368		0.0010		
Toluene*	0.1660	0.0473		0.2751	2.8320	0.1394	0.0322	0.0537	0.0924
Tetrachloroethylene					0.0997	0.2281	0.0469	0.0576	0.0409
Chlorobenzene					0.0357	0.0623	0.0097	0.0345	0.0347
m-Xylene*	0.0369		0.3751	0.3720	0.2030	0.0670	0.0074	0.0853	0.0260
Bromobenzene					0.0433	0.0541	0.0072	0.0116	0.0261
m-Dichlorobenzene						0.0485		0.0629	
p-Dichlorobenzene	0.9152		0.0105		0.1444	0.0326	0.0028	0.0477	
o-Dichlorobenzene			0.0007		0.0244	0.0272	0.0041	0.0067	0.0081
Acetophenone	0.0474		0.0102		0.0846		0.0009	0.0155	0.0081
Naphthalene*	0.0577	0.0231	0.0143	0.0111	0.3475	0.0095	0.0399	0.0072	0.0024
Skatole	0.05204				5.1440				
o-Phenylphenol	0.0252				2.1930				
Diethylphthalate	0.0238	0.0348	0.0101	0.0139	0.4191	0.0331	0.0083	0.1023	0.0728
2(Methylthio)-benzothiazole	0.2300				0.0919			0.0045	
(1,1,3,3-Tetramethyl-butyl)phenol	0.0539		0.0006		0.200			0.0022	
Benzophenone	0.0460		0.0015		0.0522			0.0242	
Butylbenzene sulfon-amide	0.0439				0.0662			0.0261	
Dibutylphthalate*	0.0449	0.0108	0.0793	0.0160	0.2225	0.0640	0.0189	0.0556	0.0343
bis(2-Ethylhexyl)-phthalate*	6.7999	0.8439	1.3920	5.4410	1.7130	3.4610	3.3720	5.1190	1.7590

*Compounds found in the blank

TABLE 14. COMPOUNDS IDENTIFIED BY REVERSE ION SEARCH IN WATER SAMPLES FROM SPEONK, NEW YORK, SITE

Compound Class	Sample or Well Number
I. Alkyl-aromatics	
Benzene	D,13
C_3-Benzene	D,1,9,10,13
C_4-Benzene	D,1,9,13
(2,2-Dimethoxyethyl)benzene	9,13
α-Ethylbenzenemethanol	13
C_4-phenol	D,9,10,13
C_1-Naphthalene	D,1,9,10,13,15,16
1,1'-oxybis(benzene)	10,13
C_2-Naphthalene	D,1,9,10,13,15,16
(1,1'-Biphenyl)-2-ol	D
Methylbenzoate	1,15,16
C_3-Naphthalene	1
(2-hydroxy-4-methoxy-phenyl)phenylmethanone	15
Toluene	D,1,10,13,15,16
Xylene	D,1,9,13,15,16
Acetophenone	13,15,16
Naphthalene	D,1,9,10,13,15,16
o-Phenylphenol	D,9,10,13
(1,1,3,3-Tetramethylbutyl)phenol	D,9,10,13
Benzophenone	D,9,10,13
Butylbenzene sulfonamide	D,9,10,13
Skatole	D,9,10
II. Alkanes	
C_9	D,1,13,15,16
C_{10}	D,1,10,13,15,16
C_{11}	13,15,16
C_4-cyclohexanol	D,9,13
C_4-cyclohexanone	13
C_4ester of 2-methylpropanoic acid	13
C_{14}	13,15
C_{16}	1,13,15,16
C_{18}	1,13,16
hexatriacontane	1,13
11-Decyldocosane	1,13,15,16
pentacosane	13,15
C_8	D,1,9,10,15,16
1,1-Diethoxyethane	9
1,1'-Oxybisdecane	9

TABLE 14. (Continued)

Compound Class	Sample or Well Number
III. Sulfur Containing	
Isothiazole	13
Benzothiazole	13
Dimethyldisulfide	D,1
S_8	D
Diethyldisulfide	1
2(Methylthio)benzothiazole	D,9,10,13,15,16
IV. Bicyclo-compounds	
1-Methyl-4-(isopropyl)-7-oxa-bicyclo[2.2.1]heptane	13
1,3,3-Trimethylbicyclo[2.2.1]-heptan-2-one	13
1,3,3-Trimethylbicyclo[2.2.1]-heptan-2-ol	13
1,7,7-Trimethylbicyclo[2.2.1]-heptan-2-one	13
1,3,3-Trimethyl-2-oxa-bicyclo-[2.2.2]octane	D,9,10
2,6,6-Trimethylbicyclo[3.1.1]-heptane	10
cis-p-menthan-4-ol	9
2,2-Dimethyl-3-methylenebicyclo-[2.2.1]heptane	D,9
V. Chlorinated hydrocarbons	
Chloroform	D,1,9,10,13,15,16
Trichloroethylene	D,9,13,15,16
Carbon tetrachloride	1,10,16
Tetrachloroethylene	D,1,9,10,13,15,16
Chlorobenzene	- -
(Bromobenzene)	D,1
α-Chlorotoluene	D
Dichlorobenzene	D,1,9,10,13,15,16
VI. Phthalate Esters	
Diethyl phthalate	D,1,9,10,13,15,16
Dibutylphthalate	D,1,9,10,13,15,16
bis(2-Ethylhexyl)phthalate	D,1,9,10,13,15,16

to be added to this list, the mass spec./data system identification had to be >700 "purity" and >700 "fit". Thus, there is a rather high degree of certainty about the identity of most of these compounds. From this list, several additional compounds, such as methylnaphthalene, or some of the bicyclo-compounds, might be suggested for inclusion in future studies.

REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater, 15th ed. American Public Health Association, Washington, D.C., 1980.

Chanlett, E. T. Environmental Protection, 2nd ed. McGraw-Hill Book Co., New York, New York, 1979.

Dunlap, W. J. et al. Isolation and Identification of Organic Contaminants in Ground Water. In: Identification and Analysis of Organic Pollutants in Water, L. H. Keith, ed. Ann Arbor Science Publishers, Ann Arbor, Michigan, 1976.

Gerba, C. P. and B. H. Keswick. Viruses in Ground Water. Environmental Science and Technology 1290-1297, 1980.

Hutchins, S. R., M. B. Tomson, and C. H. Ward. Trace Organic Contamination of Ground Water from a Rapid Infiltration Site: A Laboratory-Field Coordinated Study. Society for Environmental Toxicology and Chemistry, in press, 1982.

Imhoff, K. and G. M. Fair. Sewage Treatment. John Wiley and Sons, Inc., New York, New York, 1940.

Junk, G. A. et al. Use of Macroreticular Resins in the Analysis of Water for Trace Organic Contaminants. Journal of Chromatography 99:745-763, 1974.

Olivieri, A. W., R. J. Roche, and G. L. Johnston. Guidelines for Control of Septic Tanks. Journal of Environmental Engineering Division, ASCE, 107:1025-1035, 1981.

Otis, R. J. et al. Alternatives for Small Wastewater Treatment Systems. EPA Technology Transfer, EPA-625/4-77-011, 1977.

Rich, L. G. Low-Maintenance, Mechanically Simple Wastewater Treatment Systems. McGraw-Hill Book Co., New York, New York, 1980.

Salvato, J. A. Environmental Engineering and Sanitation, 3rd ed. A Wiley-Interscience Publication, New York, New York, 1982.

Scalf, M. R., W. J. Dunlap, and J. F. Kreissl. Environmental Effects of Septic Tank Systems. EPA-600/3-77-096, August, 1977.

Stiles, C. W., H. R. Crohurst, and G. E. Thomson. Experimental Bacterial and Chemical Pollution of Wells via Ground Water, and the Factors Involved. U.S. Public Health Service Bulletin 147, Department of Health, Education and Welfare, Washington, D.C., 1927.

Tomson, M. B. et al. Ground Water Contamination by Trace Level Organics from a Rapid Infiltration Site. Water Research 15:1109-1116, 1981.

U.S. Environmental Protection Agency. Waste Disposal Practices and Their Effects Upon Ground Water, The Report to Congress. Washington D.C., January, 1977, p. 39. See also Salvato, 1982, p. 176, for Summary.

U.S. Public Health Service. Manual of Septic Tank Practice. USPHS Publication 526, Washington, D.C., 1967.

Vaughn, James M. Report, Speonk Virus Study, Department of Energy and Environment, Brookhaven National Laboratory, Upton, New York, September, 1980.

Vaughn, James M., Edward F. Landry, McHarrel Z. Thomas. The Lateral Movement of Indigenous Enteroviruses in a Sandy Sole-Source Aquifer. In: Conference on Microbial Health Considerations of Soil Disposal of Domestic Wastewaters. Conducted by the National Center for Ground Water Research, sponsored by U.S. Environmental Protection Agency, pp. 126-143. Department of Energy and Environment, Brookhaven National Laboratory. 1981.

Wilson, G. E., J. Y. C. Huang, G. Tchobanoglous, and G. Wheeler. Managed On-Site Disposal in Unsewered Areas. Journal of Environmental Engineering Division, ASCE, 105:583-596, 1979.