SOME IMPACTS OF SEPTIC EFFLUENT ON HYDROMORPHIC SOILS

SOME IMPACTS OF SEPTIC EFFLUENT ON THE SOIL ATMOSPHERE AND IONIC LEVELS OF HYDROMORPHIC SOILS IN THE ANCASTER AND GRINDSTONE CREEK WATERSHEDS

By

JAMES ALFRED CAMPBELL, B.A., B.ED.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

June 1974

MASTER OF SCIENCE (1974)
(Geography)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Some Impacts of Septic Effluent on the Soil Atmosphere and Ionic Levels of Hydromorphic Soils in the Ancaster and Grindstone Creek Watersheds

AUTHOR: James Alfred Campbell, B.A. (McMaster University)

B.Ed. (Queen's University)

SUPERVISOR: Professor B. T. Bunting

NUMBER OF PAGES: xiii, 129

ABSTRACT

Measurements of soil atmosphere, soil physical parameters, coliform levels and ionic levels were made at 15 soil sites along Ancaster and Grindstone Creeks in winter, 1972-73 and July, 1973. Multivariate analysis of the data indicated large fluxes of septic effluent resulted in soil fabric alterations, anaerobosis, and elevated coliform, nitrate, chloride and sodium levels. According to ecological and health criteria, these hydromorphic soils have very serious limitations as processors and absorbers of septic effluent.

PREFACE AND ACKNOWLEDGEMENTS

This thesis considers the effects of septic tank effluent and other contaminants upon the soil environment, especially the soil atmosphere. The surface layers of wet valley soils are considered as an absorbent of these pollutants of very limited capacity, acting temporarily to diminish the input of materials into local watercourses. The first part of the thesis is an elaboration of this hypothesis, and summarises the main aims of this research. The first chapter also outlines the basic need for research on this topic, reviews previous studies and, briefly, outlines the potential practical applications of the research method and the significance of the conclusions.

The methods of data collection are described in the second chapter. The methods used in the initial or pilot survey and the main survey differed--thus they are described separately. For clarity and coherence, detailed descriptions of original refinements of established methods have been included in the appendices. Chapters III and IV are concerned with observations and analyses of the soil data and describes the techniques and results of multivariate analysis of the pilot and main survey data. Some exploratory work on compacted surface layers of coarse sand texture overlying natural soil is discussed in Chapter V.

The conclusions, in Chapter VI, summarise the state of environmental quality and stability in these wet valley soils.

Impending crises which may result from increasing levels of pollution are identified.

The appendices consist of three sections: methods of soil analysis, data summaries and site descriptions.

Standard methods of collection and analysis of soil were used with four exceptions: the determination of organic carbon, total coliform levels, oxygen diffusion rates and soil gases. The technology for measuring soil ionic levels by specific ion electrodes is sufficiently recent that an adequate standard methodology has not yet developed. For this reason, the methodology used for determining soil ionic levels is also reported in detail. In the first appendix, these non-standard techniques are discussed in detail and the standard techniques are referenced.

The very large data matrices involved preclude reporting or tabulating raw data in the data summaries. For example, the main survey represents a data matrix of 45 variables on 94 cases, occupying 658 punched computer cards. The coliform data are reported in toto. The means and standard deviations of the other variables are reported. The ionic levels are reported as molar and parts per million concentrations. Also included in this appendix are the correlation matrix from the main survey and the variable loadings on the factors for the three factor solutions.

A considerable photographic record of these wet valleys has been accumulated over the past four years. The physical beauty as well as some of the physical damage from human impact is apparent in the

photographic selection included in the site descriptions, the last appendix.

I would like to express my appreciation to all those people who assisted with this research. This thesis owes much to the advice, assistance, financial support and patient editing of my supervisor, Dr. B. T. Bunting. I would like to thank Dr. K. A. Kershaw of the Biology Department for the loan of his oxygen electrode and advice in purchasing a gas chromatograph. Dr. K. L. Murphy of the Engineering Faculty was most helpful in providing facilities and instruction in measuring soil coliform levels. Dr. R. B. Anderson of the Chemical Engineering Department advised in the modification of the gas chromatograph. Dr. A. J. Thomson of the Institute of Animal Resource Ecology, University of British Columbia, permitted the use of his method of determining organic carbon. Dr. M. K. Woo, Dr. J. G. Cogley and Dr. J. J. Drake assisted with the Fortran programming. This thesis would not have been brought to its present finished form without the infinite patience of my wife who typed all the manuscripts. Many thanks are expressed to my father for the construction of the oxygen electrode meters and thin section boxes. The financial support of the Central Mortgage and Housing Corporation in the form of a fellowship, and the Geography Department's purchase of a gas chromatograph are gratefully acknowledged.

TABLE OF CONTENTS

		Page
	ABSTRACT	iii
	PREFACE AND ACKNOWLEDGEMENTS	iv
	TABLE OF CONTENTS	vii
	LIST OF FIGURES	ix
	LIST OF TABLES	x
	LIST OF COLOUR PLATES	xii
	LIST OF APPENDICES	xiii
CHAPTER		
I	INTRODUCTION: THE HYPOTHESIS, EXPERIMENTAL DESIGN, SCOPE AND BACKGROUND OF THE RESEARCH	1
	1. Hypothesis	1
	2. Experimental Design	1
	3. Scope and Background	3
II	METHODS OF DATA COLLECTION, FIELD AND LABORATORY RESEARCH	7
	1. Measurement of Soil Variables	7
	2. Instrumentation	14
III	MULTIPLE STEPWISE REGRESSION OF THE ORIGINAL SOIL DATA	15
	1. Pilot Survey (Fall and Winter, 1972-73)	15
	2. Results of the Main Survey (Summer, 1973)	19
	(a) Coliform Levels	22
	(b) Carbon Dioxide	25
	(c) Redox Potential	28
	(d) Oxygen Diffusion Rate	30
	(e) Nitrates	33

CHAPTER		Page
IV	FACTOR ANALYSIS OF THE SOIL DATA	37
	1. Factor Solution with Orthogonal Varimax Rotation	38
	2. Comparisons of the Different Factor Solutions	40
	3. Interpreting the Variables in the Multiple Regression Equations as Factors	45
	4. Multiple Regression of the Principal Components Solution	47
	5. Natural versus Human-induced Variation	56
V	THE NATURE AND INFLUENCES OF SURFACE LAYERS OF COMPACTED SAND	58
VI	CONCLUSIONS	66
	APPENDICES	68
	REFERENCES	126

LIST OF FIGURES

NUMBER	SUBJECT	Page
1	Grindstone Site Locations	8
2	Ancaster Site Locations	9
3	Grain Size Distribution for Site 2	59
4	Grain Size Distribution for Site 6	60
5	Oxygen Diffusion Rates in Sites 2 and 6	62
6	Thin section of soil from site 8 at 20 cm. depth	64
7	Oxygen Electrode Temperature Response	74
8	The components of the sampling system	82
9	Effect of Storage on Soil Atmosphere Samples	84
10	Pye 104 Katharometer Schematic	86
11	Schematic of a Modified Pye 104 Katharometer	87
12	Chromatogram of Soil Gases from a Modified Pye 104 Katharometer	88
13	CO_2 Peak Linearity	90
14	GC Calibration Curves for O_2, N_2 and CO_2	91
15	Calibration Curves for Specific Ion Electrodes	95
16	Sucrose Calibration Curve	100

LIST OF TABLES

NUMBER	SUBJECT	Page
1	Temporally Constant Variables	11
2	Temporally Dynamic Variables	12
3	Denitrification--Redox Changes Multiple Regression Summary	17
4	Denitrification--Nitrate Changes Multiple Regression Summary	18
5a	Coliforms per gm. of wet soil Multiple Regression Summary	23
5b	Coliforms per ml. of soil solution Multiple Regression Summary	24
6	Soil Carbon Dioxide Concentration Multiple Regression Summary	26
7	Redox Potential Multiple Regression Summary	29
8	Oxygen Diffusion Rate Multiple Regression Summary	31
9	Nitrate Concentration Diluted Multiple Regression Summary	34
10	Nitrate Concentration in Soil Multiple Regression Summary	35
11	Factor Solution Comparison: Extraction Order and % Variance Explained for each Factor	42
12	Factor Solution Comparison: Variables Loaded on each Factor	43
13	Schematic Factor Model	44
14	Principal Components: Factor Scores Correlation Matrix	48

NUMBER	SUBJECT	Page
15	Principal Components--Factor Scores Correlation Matrix (Correlations $\|r\| > 0.70$)	49
16	The Major Ionic Pollutant Component Multiple Regression Summary	51
17	The Coarse Textural Pollutant Component Multiple Regression Summary	52
18	The Coliform Component Multiple Regression Summary	53
19	The Ionic Chloride Pollutant Component Multiple Regression Summary	55
20	Comparison of Natural and Pollutant Variation in the Three Factor Solutions	57
21	Polarographic Oxygen Electrode Calibration	72
22	The Means, Standard Deviations and Units of Measurement for the Soil Variables Excluding Ionic Levels	104
23	The Means and Standard Deviations in Moles per Litre, Grams per Litre and Parts per Million for Soil Ionic Levels	105
24	Levels of Total Coliform Group of Soil Organisms from the Sampling Sites along Ancaster and Grindstone Creeks	107
25	The Correlation Matrix of the Data from Ancaster Sites	111
26	Principal Components Varimax Rotated Factor Matrix	112
27	Orthogonal Varimax Rotated Factor Matrix	113
28	Oblique Factor Structure Matrix After Rotation	114

LIST OF COLOUR PLATES

NUMBER	SUBJECT	Page
1	Land Use and the Septic Bed Locations.	4
2	Site A from above the south valley slope, summer 1969.	116
3	Site A looking up the valley from the southeast, summer 1969.	116
4	Site A--close-up of flora on the valley floor, summer 1969.	117
5	Low Humic Gleysol (National Soil Survey Committee, Canada Department of Agriculture, 1970) from site A, summer 1969.	117
6	Humic Gleysol (National Soil Survey Committee, Canada Department of Agriculture, 1970) from site A, summer 1969.	119
7	Grindstone Creek as it flows through Millgrove, 100 yards upstream from site 14, winter 1973.	119
8	Grindstone Creek in northeast Waterdown, site 15, winter 1973.	120
9	Ancaster Creek, site 1, facing north, early spring 1973.	120
10	Ancaster Creek, site 2, facing north, winter 1973.	122
11	Ancaster Creek, site 3, facing north, winter 1973.	122
12	Ancaster Creek, site 3, stream detail, winter 1973.	123
13	Ancaster Creek, site 5, facing north, winter 1973.	123
14	Ancaster Creek, site 6, facing south, winter 1973.	125
15	Ancaster Creek, site 6, facing north, winter 1973.	125

LIST OF APPENDICES

NUMBER	SUBJECT	Page
A	Methods of Data Collection, Field and Laboratory Research	68
B	Data Summaries, Correlation Matrix from the Main Survey and Factor Loadings on the Final Factor Solutions	103
C	Site Descriptions and Environmental Status	115

CHAPTER I

INTRODUCTION: THE HYPOTHESIS, EXPERIMENTAL DESIGN, SCOPE AND BACKGROUND OF THE RESEARCH

1. Hypothesis

It is known from previous research (Campbell, 1969) that there is a delicate aerobic-anaerobic balance in many hydromorphic soils in restricted valley areas. It is also known that coliform levels in such streams in the local area are high (Matheson, 1973) and in a previous study, the present author showed that these levels correlate highly with housing density. Therefore, it may be assumed that septic effluent is passing through the wet valley soils in appreciable quantities and that reducing conditions could result from high septic additions in certain states of soil wetness. The septic effluent is highly biodegradable, exhibiting a high COD and BOD (Matheson, 1973). Thus, the oxygen levels in the wet silt loam and silty clay loam soils of these naturally-wooded areas might be suppressed to the point where the soil atmosphere would approach toxic levels for the root systems of many tree species.

2. Experimental Design

The methods of analysis used are largely concerned with the field measurement of a large number of soil variables. These include

those which are indicators of septic pollution, such as coliform levels and ionic levels of nitrate, chloride and sodium. Also included are measures of soil oxygen status, determined by gas chromatography as well as the field use of platinum micro-electrodes of original design. Thirdly, measurements of substrate levels, for example, organic carbon, were made, as well as measures of soil factors which are held to control or influence oxygen status, such as soil moisture content, bulk density and compaction. Finally, measurements were made of soil factors which might interact with septic effluent, such as carbonate levels and grain size. Furthermore, routine analyses of other soil properties were taken in order to ascertain if fewer soil properties could be used to characterise the soil environment, and to use such easily-determined variables to predict oxygen status, nitrate levels and other ionic levels in multiple stepwise regressions. It was then intended that this soil data would be grouped using traditional classification and statistical techniques, repeating the multiple regressions on each group. Variations in regression coefficients and the order of inclusion of variables in the equation would indicate whether the various soil environments responded differently, either spatially or temporally, to septic effluent.

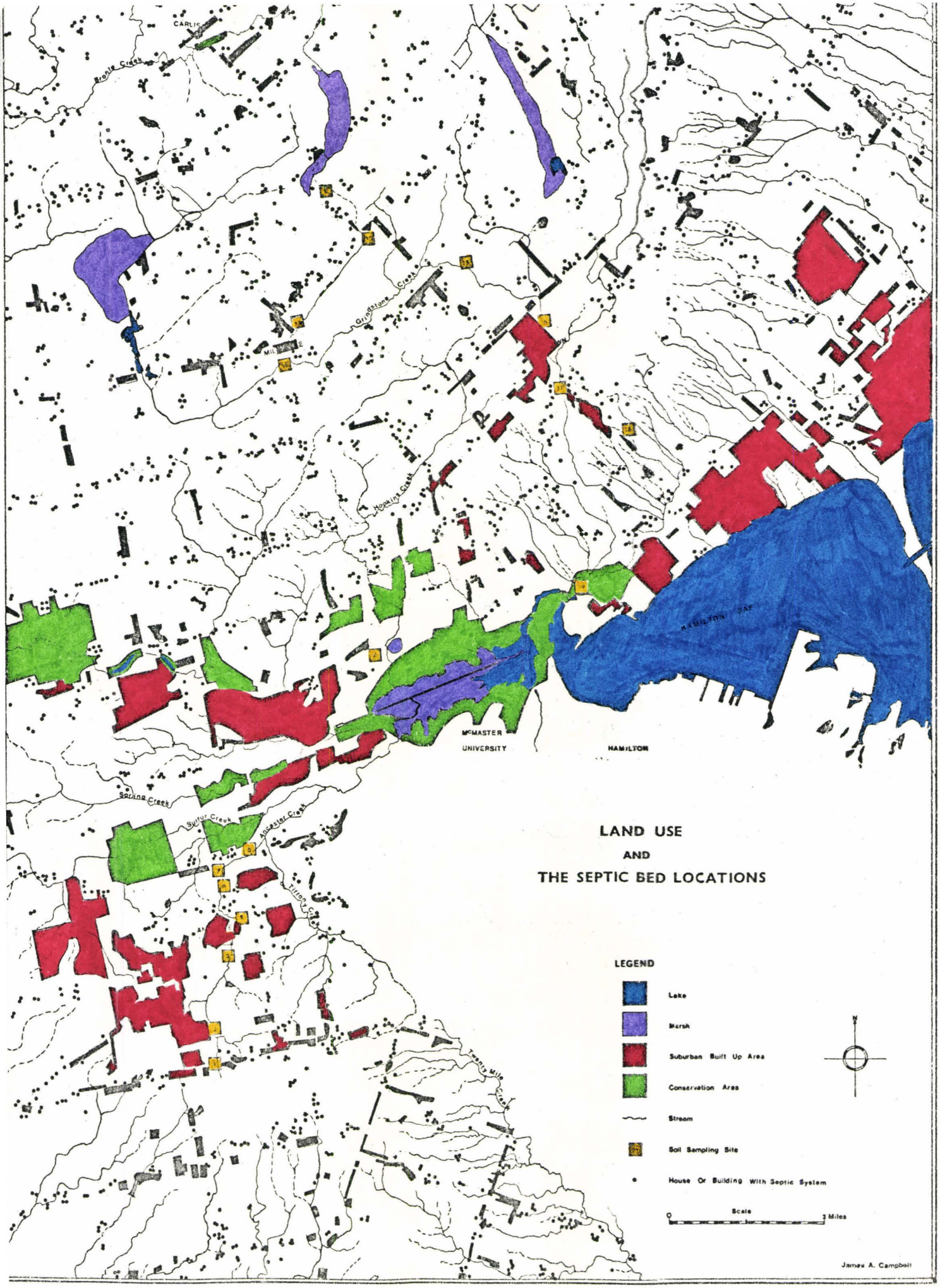
It was also anticipated that these final regression equations might be of use to environmental planners in predicting changes in soil oxygen status, nitrate levels and coliform levels which could be induced by a specific settlement pattern or recreational use of such wet valley soils.

3. Scope and Background

The natural beauty of the Hamilton area stems largely from the Niagara Escarpment and its associated ravines. These areas have resisted development and now represent virtually all of the naturally-wooded area within suburban Hamilton. Due to the concerted efforts of the Hamilton Region Conservation Authority, much of this land has been purchased and made accessible to the public. Despite considerable data on deteriorating water quality in these streams (Matheson, 1973), little or no attempt has been made to relate stream quality to settlement patterns. Even less work has been done on the impact of human phenomena on the remaining natural areas within the stream watersheds (Plate 1).

Approaching the problem from the opposite viewpoint, that is, pollutant sources, research on the effects of septic effluent has been limited. Much of the research has been done using laboratory columns of air-dried and sieved soil (McGauhey, 1963; Robeck, 1964). Extrapolation of these data to field situations is hazardous (Greenwood, 1968). The initial work was done mainly by engineers whose definition of septic efficiency and failure consisted of the respective magnitudes of effluent flux and effluent back-up (McGauhey, 1963; Hickey, 1966). This concept of septic processes fails to account for the complexity or even the main components of ecological dynamics in wet valley soils. That this approach still dominates the literature is aptly illustrated by Mokma and Whiteside's paper (1973).

Potential application of the research findings to land use planning could be concerned in extreme cases with averting such


CARLISLE
Bronte Creek
Grindstone Creek
MILLGROVE
Hopkins Creek
HAMILTON
HAMILTON BAY
McMASTER
UNIVERSITY
Spring Creek
Sulfur Creek
Ancaster Creek
Twenty Mile Creek
LAND USE
AND
THE SEPTIC BED LOCATIONS
LEGEND
Lake
Marsh
Suburban Built Up Area
Conservation Area
Stream
Soil Sampling Site
House Or Building With Septic System
Scale
3 Miles
N
James A. Campbell

environmental crises as pollution of water supplies and health hazards, and with the preservation of amenity values of these valley sites. One such application is the resolution of the conflict between lands reserved for recreational use and the adjacent areas of high-density housing using septic systems. In recreational land use, man's impact is essentially physical, promoting soil compaction and erosion, especially of wet or organic-rich soils. The presence of housing mainly affects the chemical and biological aspects of the soil environment, though it may also cause profound changes in the soil moisture regimes. In conjunction with soil survey information, this research into soil atmosphere would enable levels of soil and water quality to be predicted, controlled and planned in advance of changes in settlement and recreational use. Such use of soil surveys is not entirely new. Bartelli and others (1966) define the approach in detail, yet in most of the studies there cited, simple percolation tests are the only basis on which the soil is judged as an adequate environment for subsurface sewage disposal using septic systems. Thus the specific impact of septic effluent on the soil environmental ecology and especially the quality of the water issuing from it to streams is undefined and inadequately measured.

A second, less controlled approach to land use is to establish buffer zones between the two types of land use. An example of buffer zones appears in the Policy Recommendations Report of the Bronte Creek Provincial Park Advisory Committee (Blenkhorne, 1972). However, this defines the pollution sources only in terms of noise and visual

aesthetics. Potential suburban encroachment is recognized but its implications for water quality are not. Such buffer zones are a good idea, but their delineation should be based on scientific study of all the potential or probable impacts on the park area ecology.

These problems are coming to a head in the Hamilton area. The population expansion in both the suburban and metropolitan areas has increased the demand for recreational areas. This has intensified land acquisition by the regional conservation authorities. Ironically, the most scenic natural areas are also the most ecologically fragile, and most susceptible to septic pollution because they are in limited valley areas which are the receiving sites for septic-polluted drainage from surrounding areas.

This research is an attempt to link soil quality data to the existing housing densities and to the valley soil site characteristics. With this information, housing settlement could be located and septic absorbent fields provided such that the effects of pollutants on adjacent recreational land, streams or lake waters would be minimized. In other words, realistic buffer zones would be based on data of the environmental impact of septic effluent from adjacent developed areas. Conversely, if present septic systems are found to be totally inadequate (Robinson, 1971, personal communication), research into alternative sewage treatment systems might be encouraged. Intelligent planning based on such data might also avert impending health crises resulting from housing location on sites or soil types which are inherently unable to absorb septic effluent at the required rates.

CHAPTER II

METHODS OF DATA COLLECTION, FIELD AND LABORATORY RESEARCH

During the winter of 1972-73 a pilot survey was undertaken to test the feasibility of field sampling and the adequacy of the field site locations. Soil samples were collected from 15 soil sites along Ancaster and Grindstone Creeks (Figures 1 and 2). The sites were chosen to represent relatively unpolluted sites in rural areas, sites adjacent to farms, villages, roads and suburban housing and areas of natural, recreation-affected and disrupted vegetation. Fresh disturbed samples from five soil depths, 3, 6, 9, 12 and 18 inches, were obtained with a small soil corer. Measurements of redox potential, pH, electrical conductivity, nitrate concentration, organic carbon and gravimetric soil moisture were made on the samples. Soil oxygen diffusion rates and soil temperature were measured in situ. The methodology is elaborated in Appendix A.

1. Measurement of Soil Variables

After the experiences gained in collecting and analyzing the data gathered for the pilot survey, a second, more rigorous detailed sampling survey was undertaken during the summer of 1973. Eight soil sites along Ancaster Creek were sampled. The sites were sampled at

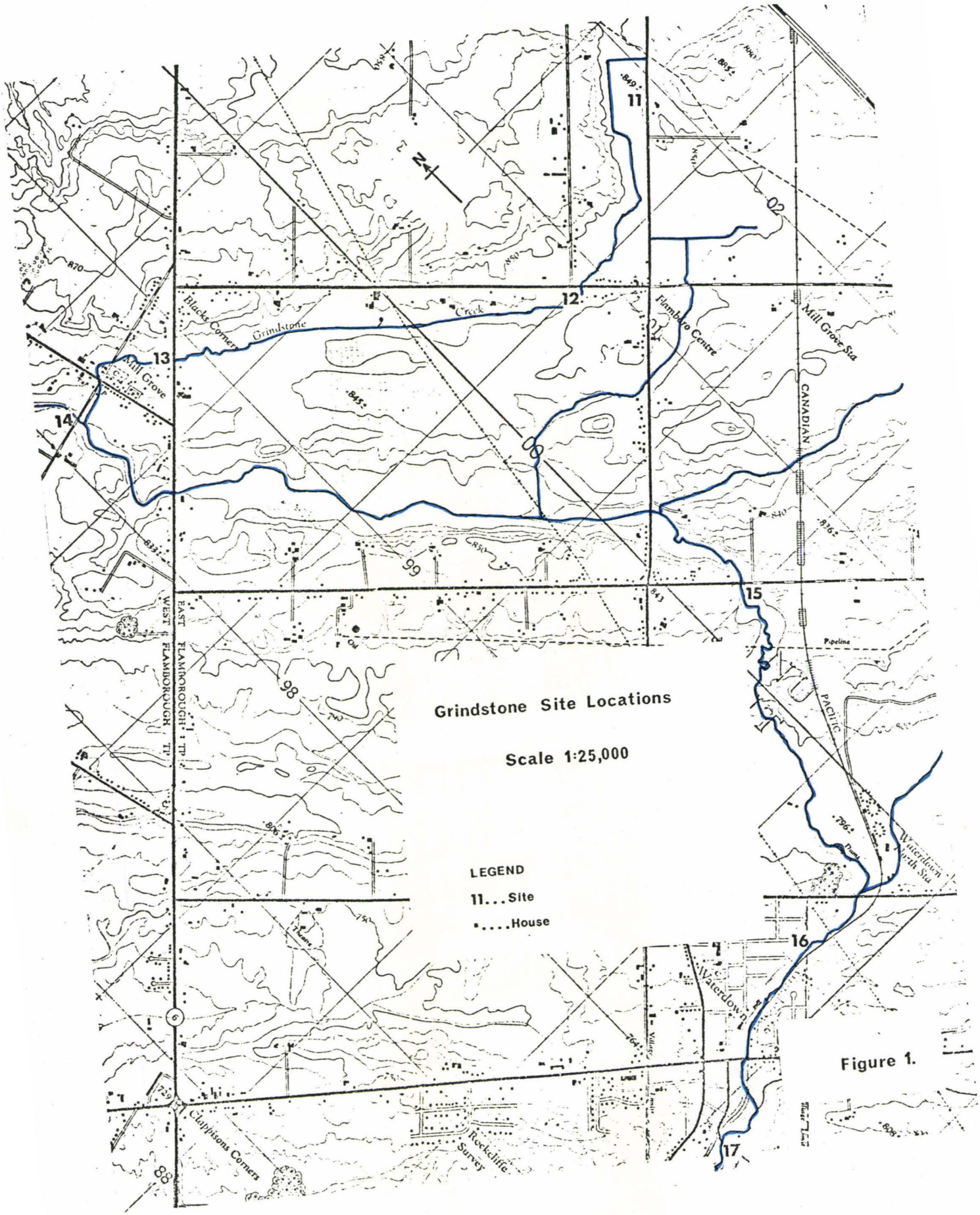

Grindstone Site Locations
Scale 1:25,000
LEGEND
11...Site
•....House
Blacks Corners
Grindstone Creek
Mill Grove
Flamboro Centre
Mill Grove Sta
CANADIAN PACIFIC
Waterdown
Waterdown North Sta
Clappisons Corners
Rockcliffe Survey
WEST FLAMBOROUGH TP
EAST FLAMBOROUGH TP
Pipeline
11
12
13
14
15
16
17

Figure 1.

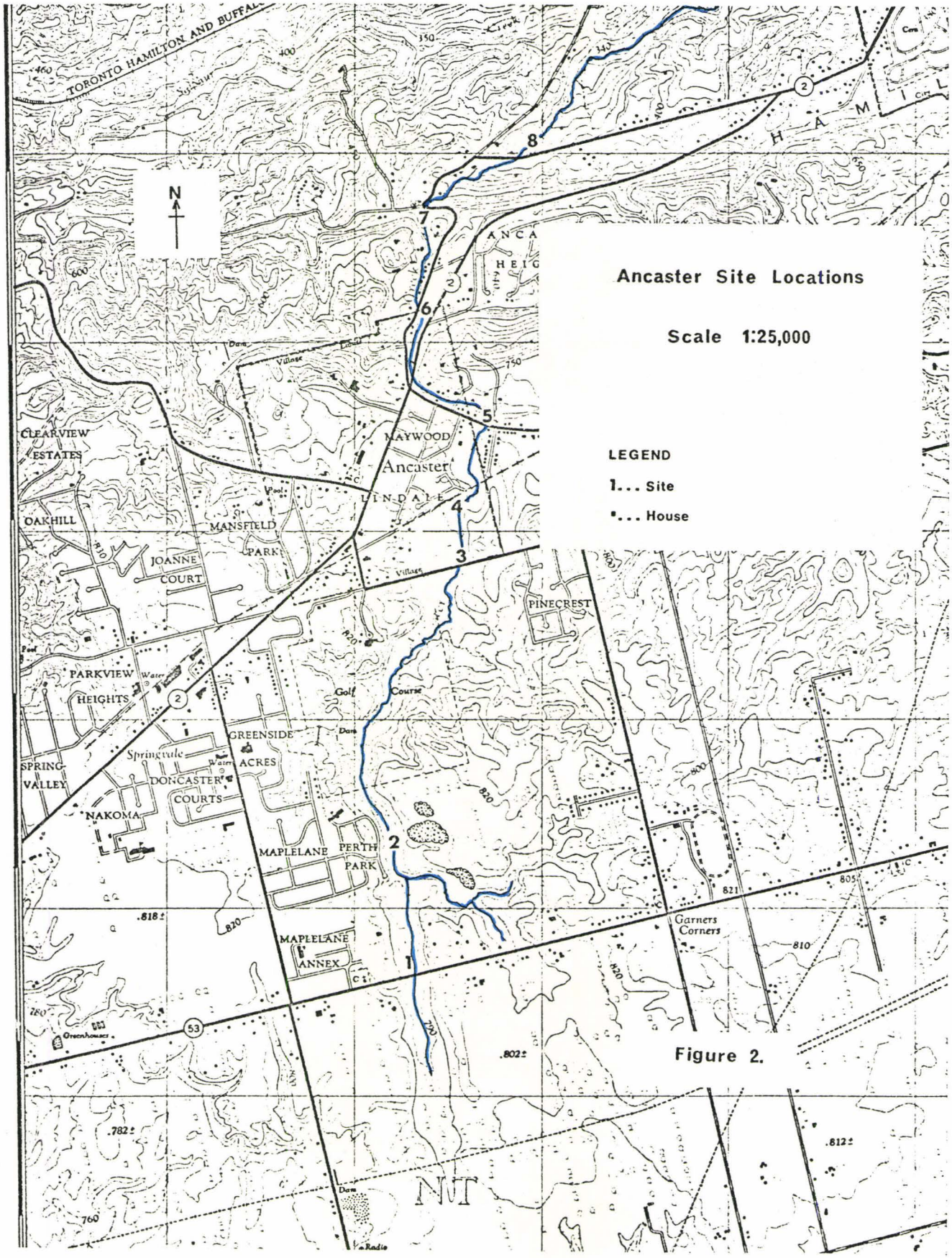

Ancaster Site Locations
Scale 1:25,000
LEGEND
1... Site
•... House
N
TORONTO HAMILTON AND BUFFALO
HAMILTON
ANCASTER HEIGHTS
MAYWOOD
Ancaster
LINDALE
CLEARVIEW ESTATES
OAKHILL
MANSFIELD
PARK
JOANNE COURT
PARKVIEW HEIGHTS
SPRING VALLEY
Springvale
GREENSIDE ACRES
DONCASTER COURTS
NAKOMA
MAPLELANE PERTH PARK
MAPLELANE ANNEX
PINECREST
Golf Course
Garners Corners
1
2
3
4
5
6
7
8

Figure 2.

three-inch intervals to 12-18 inches depth. All the soil variables measured may be regarded as varying spatially. Some soil characteristics vary over time, the others were regarded as temporally constant. The temporally dynamic variables were measured at various times throughout the summer. The temporally dynamic variables measured are ionic levels (Ca, Na, NO_3, Mg and Cl), Eh or redox potential, pH, electrical conductivity, oxygen diffusion rate (ODR), soil atmosphere composition (O_2, CO_2, N_2), soil temperature, soil moisture and bulk density. The temporally constant soil variables (or those assumed temporally constant) were measured only once. These are organic matter (organic carbon determined by a modified Walkley and Black procedure and loss on ignition at 550°C.), carbonates (L.O.I. at 850°C. - L.O.I. at 550°C.), texture (grain size fractions, specific surface area of the grains, and skewness and kurtosis values), hygroscopic moisture, total coliforms+, distance to the nearest house and number of houses draining into the sites. Coliform values are assumed to be temporally constant because of the impossibility of measuring them dynamically. The variables are summarised in Tables 1 and 2.

The obvious improvement in sampling design of the main survey over the pilot survey is the increased number of variables measured. The number of measures of oxygen status has been increased from redox potential alone to include Eh, ODR and gaseous concentrations of oxygen and carbon dioxide.

+ Coliforms were measured from a separate soil sample along with soil moisture (BHOV, BHOW) and bulk density (BBDV).

Table: 1.

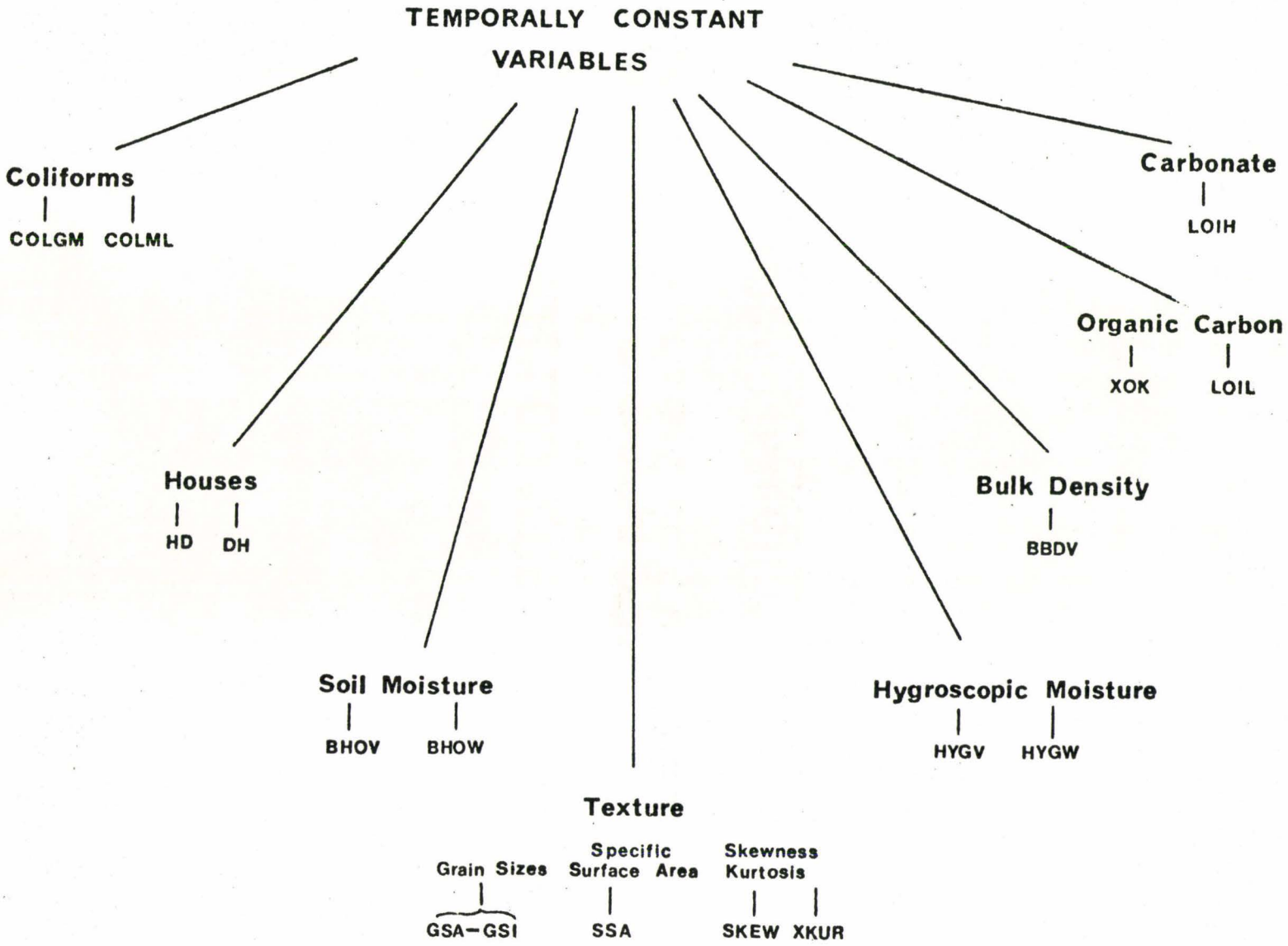
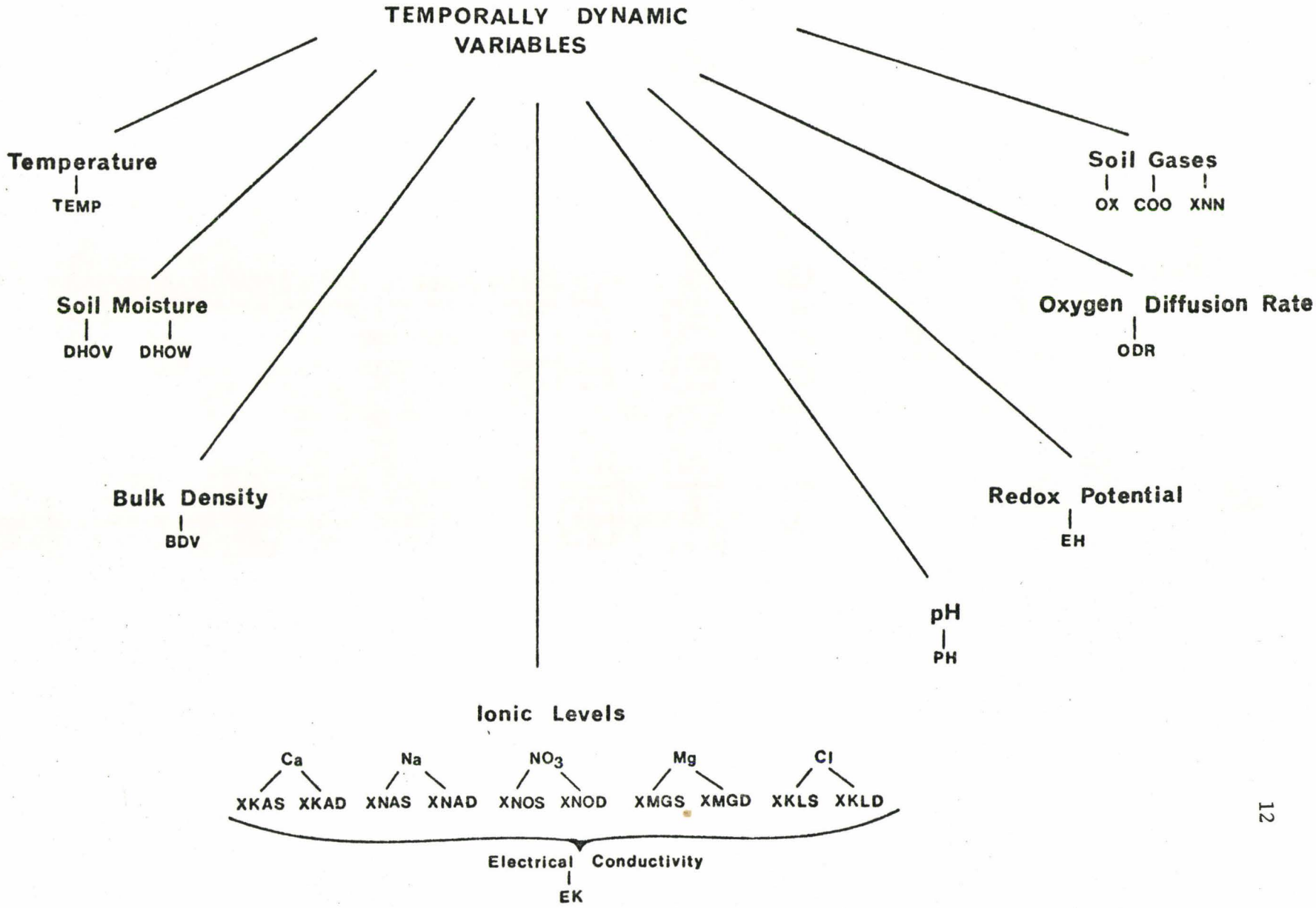

TEMPORALLY CONSTANT VARIABLES
Coliforms
COLGM COLML
Houses
HD DH
Soil Moisture
BHOV BHOW
Texture
Grain Sizes
GSA–GSI
Specific Surface Area
SSA
Skewness Kurtosis
SKEW XKUR
Hygroscopic Moisture
HYGV HYGW
Bulk Density
BBDV
Organic Carbon
XOK LOIL
Carbonate
LOIH

Table: 2.


TEMPORALLY DYNAMIC VARIABLES
Temperature
TEMP
Soil Moisture
DHOV DHOW
Bulk Density
BDV
Soil Gases
OX COO XNN
Oxygen Diffusion Rate
ODR
Redox Potential
EH
pH
PH
Ionic Levels
Ca
XKAS XKAD
Na
XNAS XNAD
NO3
XNOS XNOD
Mg
XMGS XMGD
Cl
XKLS XKLD
Electrical Conductivity
EK

KEY TO NAMES OF VARIABLES

TABLE 1: Temporally Constant Variables (from left to right)

1	COLGM	total coliforms per gm. of wet soil
2	COLML	total coliforms per ml. of soil solution
3	HD	number of houses draining into the site
4	DH	distance from the site to the nearest house
5	BHOV	volumetric soil moisture of coliform sample
6	BHOW	gravimetric soil moisture of coliform sample
7-15	GSA-GSI	grain size fractions one to nine
16	SSA	specific surface area of the mineral grains
17	SKEW	skewness of grain size distribution
18	XKUR	kurtosis of grain size distribution
19	HYGV	volumetric hygroscopic soil moisture
20	HYGW	gravimetric hygroscopic soil moisture
21	BBDV	bulk density of coliform sample
22	XOK	organic carbon percentage
23	LOIL	loss on ignition at 550°C.
24	LOIH	loss on ignition at 850°C.

TABLE 2: Temporally Dynamic Variables (from left to right)

25	TEMP	soil temperature
26	DHOV	volumetric soil moisture
27	DHOW	gravimetric soil moisture
28	BDY	bulk density
29	XKAS	calcium concentration per ml. of soil solution
30	XKAD	calcium concentration in 50 ml. of distilled water
31	XNAS	sodium concentration per ml. of soil solution
32	XNAD	sodium concentration in 50 ml. of distilled water
33	XNOS	nitrate concentration per ml. of soil solution
34	XNOD	nitrate concentration in 50 ml. of distilled water
35	XMGS	magnesium concentration per ml. of soil solution
36	XMGD	magnesium concentration in 50 ml. of distilled water
37	XKLS	chloride concentration per ml. of soil solution
38	XKLD	chloride concentration in 50 ml. of distilled water
39	PH	pH of soil solution in 50 ml. of distilled water
40	EH	redox potential in 50 ml. of distilled water
41	ODR	oxygen diffusion rate of soil (in situ)
42	OX	oxygen concentration in ¼" diffusion wells
43	COO	carbon dioxide concentration in ¼" diffusion wells
44	XNN	nitrogen concentration in ¼" diffusion wells
45	EK	electrical conductivity in 50 ml. of distilled water

2. Instrumentation

Two improved oxygen electrode meters have been constructed from the design of Letey and Stolzy (1964). Platinum micro-electrodes for measuring ODR were specially constructed for measurements in hydromorphic soils. Soil gases were sampled from diffusion wells made of Tygon tubing, ¼ inch diameter, and analyzed on a modified Pye Unicam 104 gas chromatograph. Total coliforms were measured as a more realistic measure of septic pollution than housing density. Total coliforms were determined by the standard filter membrane technique (Taras, 1971).

Soil scientists have traditionally placed great emphasis on soil texture as one of the most important factors determining the suitability of a soil for processing septic effluent (Bartelli, 1966). For this reason, soil texture was determined by various means. Measures of grain size distribution were achieved by sonic sifting the soil samples down to 37 microns; organic matter had first been removed from these samples. Thin sections were made of some typical soil fabrics (Fig. 6).

The denitrification processes were studied using incubation techniques similar to those of Bremner (1968). After electrode measurements of Eh, pH and electrical conductivity were made on fresh wet soil samples, the soil samples were air dried, rewetted and the same electrode measurements repeated. The change in soil environments from a wet anaerobic to a dry aerobic and then wet anaerobic environment provides ideal conditions for denitrification to occur (Tusneem, 1971).

CHAPTER III

MULTIPLE STEPWISE REGRESSION OF THE ORIGINAL SOIL DATA

1. Pilot Survey (Fall and Winter, 1972-73)

Reference will first be made to this pilot survey. In this survey, housing density was used as a crude measure of the potential septic pollution. Soil redox potential was used as a measure of oxygen status of the limited depth of soil over the high water table level. Multiple stepwise linear regression was used to predict redox potential and nitrate levels from the other variables measured. Using redox potential as the independent variable, the first variable entered into the equation, as expected, was soil moisture. Housing density was entered next, confirming the hypothesis that housing density and septic effluent influence soil oxygen status, both through increasing soil moisture levels and the COD and BOD levels. The multiple regression equation predicting nitrate levels yielded a multiple correlation coefficient significantly lower than the equation predicting redox potential (i.e. $r=0.55$ and $r=0.69$ respectively). This could be explained in two ways. Most of the nitrates probably leave the soil as gases formed by denitrification, implying that the nitrates are unstable in this soil environment (Bower, 1971; Broadbent, 1971; Bremner, 1968; Pratt, 1972). Secondly, the nitrate level could be related to pollutants

from farm sources in the form of nitrogen fertilizers and this complicates accurate prediction of nitrate levels.

Stepwise linear regression procedures were used to predict the change in nitrate levels and in redox potential. The data in Tables 3 and 4 present some of the results of this analysis. In the multiple regression equation predicting changes in redox potential (Table 3), it is clear that the initial redox potential level (MVEH) strongly influences subsequent redox potential change through the following cycle of wetting and drying. Nitrate levels (MVNO3) and electrical conductivity (ECMILI), which latter is a measure of the total salt content (Pierce, 1953), were entered into the equation as the second and third variables. Thus redox potential is also influenced by the levels of salts in the soils, including nitrates. Organic carbon (ORGCAR) and housing density (HOUSES) may also influence redox changes during denitrification.

The second multiple regression equation presented in Table 4 confirms the hypothesis that the effects of septic effluent on measured values of nitrates are complicated by those variables or influences affecting the intensity of denitrification. Housing density (HOUSES), the second variable entered into the equation, has a positive coefficient, which indicates that as housing density and the potential for septic pollution increases, so does the general level of denitrification. The other variables in the equation indicate the expected natural increase in anaerobosis and denitrification with increasing soil moisture (MOIST) and depth (DEPTH) (Taylor, 1972).

TABLE 3. Denitrification--Redox Changes

Multiple Regression Summary

Dependent Variable: Redox Loss

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
MVEH#	0.2666*	0.529	139.74	41.11
MVNO3	0.2861**	0.248	184.85	31.64
ECMILLI	0.3022**	0.062	215.28	167.05
ORGCAR	0.3183**	51.133	0.16	0.13
HOUSES	0.3367**	-0.09	47.76	75.00

* P=.01

** P=.05

Variables are designated by computer symbols explained in the text.

TABLE 4. Denitrification--Nitrate Changes

Multiple Regression Summary

Dependent Variable: Nitrate Loss

Variable Entered	Multiple R^2	Beta[+]	Variable Mean	Variable Standard Deviation
MVNO3[#]	0.3393*	0.108	184.85	31.64
HOUSES	0.4286*	0.108	47.76	75.00
MOIST	0.4596*	0.188	49.46	26.35
DEPTH	0.4804*	-0.525	9.44	8.19
ECMILI	0.4975**			
constant		-125.875		

* P=.01

** P=.05

+ The beta values are shown for the first 4 steps. ECMILI was excluded since it is in effect another measure of MVNO3.

Variables are designated by computer symbols explained in the text.

2. Results of the Main Survey (Summer, 1973)

Reference may now be made to the main survey, the data for which were gathered in early and late July, 1973 and analyzed in the fall and winter of 1973-74. The analysis of the main survey data is divided into three chapters, Chapters III, IV and V, on the basis of techniques employed in the analysis. In this chapter, multiple regression techniques were applied to the original soil variables. Chapter IV consists of factor analysis of the data and regression on principal components. Chapter V deals with some exploratory work as to the origin, nature and impact of surface concentrations of compacted sand which were discovered and are presumably related to former attempts to change the nature of the soils in the area, either accidentally or representing lot improvements and/or the infilling of wet or eroded areas.

In these chapters, reference is made to two types of variables or factors: those of 'artificial' pollution and those of natural origin. When the evidence suggests that the variation or source of a variable or factor is man-induced, the term 'pollutant' is used. Conversely, natural factors or variables exhibit a variation or a source which is natural--for example, related to the local limestone (Ca^{++} ionic levels) or to seasonal climate variations. With reference to ionic levels, all ions could be pollutants, whether their source is from natural or human wastes. In this report, only those ions assumed to be from septic effluent will be termed pollutant in nature.

This chapter deals with the multiple stepwise linear regression of the original soil data. A correlation matrix was constructed from

the data using a pair-wise deletion technique (Nie et al., 1970). The correlation matrix is reproduced in Table 25 in the appendices. In constructing the correlation matrix, transformations of the original soil data were not used. Analysis of skewness of the distributions of skewed values indicated five variables which were significantly skewed. All other variables exhibited skewness values < 1.0. Nitrate levels (XNOD, XNOS), electrical conductivity (EK), hygroscopic moisture (HYGW, HYGV), coliform levels (COLGM, COLML) and housing density (HD) exhibited skewed distributions > 4.6. Had these five variables been transformed, they might have been entered earlier or more frequently in the multiple regression equations. This does not however invalidate the existing equations.

The data matrix from which the correlation matrix was constructed consists of 45 variables measured on 94 cases. In a soil system, few variables are totally independent. Also, several methods or measures were used to characterise similar or closely related variables. This results in a high degree of intercorrelation within the correlation matrix. Separating the discrete variables or measurements which account for most of the variation from the rest of the data matrix reduces the number of variables from 45 to 10. For example, in many cases it is possible to measure soil variables by weight or volume. Usually volumetric and gravimetric measures of the same variable are highly correlated and it can be assumed that they operate as one variable, for example, for COLML and COLGM, r=0.97 (Table 25, Appendix B). One of the reasons for using many measures to describe a few discrete variables is to discern which measures best represent the discrete variables. For

example, 11 measures of grain size were used. Subsequent analysis indicated that the GSC and GSI grain size fractions were especially important. The correlation coefficients between SSA, and GSC and GSI are -0.712 and 0.94 respectively. SSA variation then represents most of the variation in these grain sizes and it could be used alone to characterise textural variation.

The influence of soil moisture on diluted ionic measures (XKAD, XNAD, XNOD, XMGD, XKLD) is eliminated when the ionic concentrations are corrected to the concentrations in the original soil solution. Thus the diluted measures can be eliminated. Some of the measurements represent composite variables. Electrical conductivity is a measure of total soluble salts. pH is a complex variable being influenced by soil moisture, ionic levels, clay content and organic matter. Bulk density is also a complex variable, being influenced by organic matter, the grain size distribution, the pore size distribution and the soil fabric. The problems preventing the use of gaseous oxygen and nitrogen measurements in the macropores are explained in section (b). These composite variables tend to correlate moderately with several variables, making interpretation more difficult, for example, PH correlates with EK (r=0.54), XKAS (r=0.48) and EH (r=0.78), also EK correlates with XKAD (r=0.77) and XNAS (r=0.69) (Table 25, Appendix B).

Reducing the data matrix to 10 major discrete variables, then, yields 1) organic matter consisting of LOIL and XOK; 2) coliforms--COLML, COLGM; 3) the surface area of the soil--HYGV, HYGW, SSA; 4) the degree of soil anaerobosis--ODR, COO, EH; 5) soil moisture--BHOV, BHOW, DHOV, DHOW; and the five major ionic levels: calcium--XKAD, XKAS;

sodium--XNAD, XNAS; magnesium--XMGD, XMGS; chloride--XKLD, XKLS and nitrate--XNOD, XNOS. The ionic levels are also highly intercorrelated. The ionic interrelationships are discussed in detail in Chapter IV on factor analysis. The fact that 10 or less discrete variables represent most of the variation in the data matrix alleviates the problem of the ratio of cases to variables. This reduction to 10 or less discrete variables will facilitate future research by allowing the number of variables measured to be reduced without loss of information.

The technique of multiple regression was then used to identify relationships between the variables, especially the variables which influence the aerobic-anaerobic balance of the soil and the soil ionic levels. Prediction of these levels from the multiple regression equations is of secondary concern.

From the correlation matrix, multiple stepwise regressions were computed with redox potential, carbon dioxide concentration, oxygen diffusion rate, nitrate level and coliform level as the dependent variables. These regressions are listed as follows according to their dependent variable.

(a) Coliform Levels (Tables 5a and 5b)

Coliform levels (Tables 5a and 5b) were found to be strongly associated with texture in the Ancaster sites, especially the coarse grain size fractions larger than 105 microns. Subsequent analysis indicated that the coarse grain size fractions were indicative of compacted surface layers of coarse sand. The origin, nature and extent of these features is the object of discussion in Chapter V. It is

TABLE 5a. Coliforms per gm. of wet soil

Multiple Regression Summary

Dependent Variable: Coliforms per gm. of wet soil

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
GSC#	0.14479*	-51.664	21.57	4.37
GSB	0.35037*	139.823	6.12	4.46
GSA	0.77508*	-130.650	2.11	2.53
GSD	0.99999*	113.783	6.83	2.10
constant		-102.333		

* P=.01

Variables are designated by computer symbols--see key to Tables 1 and 2.

TABLE 5b. Coliforms per ml. of soil solution

Multiple Regression Summary

Dependent Variable: Coliforms per ml. of soil solution

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
GSC#	0.13561*	-6.173	21.57	4.37
GSB	0.24998*	24.457	6.12	4.46
GSA	0.47230*	-37.388	2.11	2.53
XOK	0.63691*	-108.297	2.16	0.79
LOIH	0.99999*	15.215	8.56	5.11
constant		181.040		

* P=.01

Variables are designated by computer symbols--see key to Tables 1 and 2.

highly probable that these are not naturally-occurring features, but derive from attempts to alter the nature of wet soils in many instances.

Organic matter plays a secondary role in the equation predicting coliform variation. The inclusion of organic carbon in the equation and the positive coefficient indicates that the presence of a carbon source or organic substrate enhances microbial growth. Hence, high levels of organic carbon allow intense denitrification, coliform growth and carbon dioxide production. If organic carbon is deficient, limiting microbial growth, then the conditions for coliform proliferation are much more limiting.

(b) Carbon Dioxide (Table 6)

There are five variables controlling carbon dioxide levels: 1) soil moisture, 2) the organic carbon content, 3) the carbonate content, 4) soil texture and 5) the level of pollutant ions in the soil, especially sodium.

The dominant variable from among those listed is soil moisture (DHOW). Soil moisture influences the natural aerobic-anaerobic balance of the soil. More carbon dioxide would normally be produced from an anaerobic than an aerobic system. Since the organic carbon is converted to carbon dioxide by microbial growth, carbon dioxide levels correlate negatively with organic carbon levels (Table 5b). The influence of carbonate content on soil carbon dioxide levels is not as yet clear. The influence of texture on carbon dioxide levels is not easily interpreted from the inclusion of the grain size fraction GSE in the multiple regression equation. The model in Table 6 can be expanded to discern

TABLE 6. Soil Carbon Dioxide Concentration

Multiple Regression Summary

Dependent Variable: Soil Carbon Dioxide Concentration

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
DHOW#	0.59334*	0.0460187	29.87	9.31
XOK	0.75665*	-1.0725574	2.16	0.79
LOIH	0.82547*	0.14470724	8.56	5.11
GSE	0.92172*	-0.064839	15.79	4.63
XNAS	0.99999*	-31.6023	0.0108	0.0074
constant		1.5118		

* P=.01

Variables are designated by computer symbols--see key to Tables 1 and 2.

the influence of some of the variables not included in the regression equation by inspection of the partial correlations of these variables in the final steps of the stepwise regression procedure. Inspection of these partial correlations indicates that hygroscopic moisture (HYGW, r=-0.999), soil gases (XNN, r=-0.77) and other grain size fractions (GSA, r=-0.77; GSI, r=0.47) may be important. The interpretation of these two grain size fractions is clear. Plotted grain size distributions (Figures 3 and 4) indicate concentrations of coarse sand in the surface layers of some profiles (Figure 6). The positive coefficient for the coarse textural fraction indicates that carbon dioxide must be accumulating in the fine soil under these surface layers of coarse sand (Table 5b). The variation of the fine soil fraction is natural and probably influences the aerobic-anaerobic balance of the soil in a fashion similar to the soil moisture. The influence of the other soil gases, oxygen and nitrogen, is complicated by the measurement techniques. Since all three gases sum to 100%, the variation in one gas can always be explained by the sum of the variations in the other two. Measured values of carbon dioxide vary by more than one order of magnitude and are always less than 2% of the total (Data Summaries, Appendix B). Conversely, the variations in oxygen and nitrogen are very small (less than 5%), yet combined they represent 98% of the total composition. Thus the gross figures of carbon dioxide concentration could validly be regarded as independent variables for use in the analysis. It is known from previous work (Campbell, 1969) that oxygen concentration varies significantly in macro-diffusion wells. To obtain useful oxygen values would require continuous monitoring, which was not feasible in this study.

Hygroscopic moisture is a complex variable. It may be regarded as an adequate measure of the specific surface area in soil and as such can be further related to the potential water-holding capacity of the soil. This in turn influences the natural aerobic-anaerobic balance of the soil.

The most easily identifiable pollutant variable included in the original multiple regression equation is sodium concentration in the soil solution. The factor analysis in Chapter IV showed that sodium concentration shares a common behaviour pattern with some other associated ions--nitrate and chloride. This factor acted as a good overall indicator of the variation of the levels of all ionic pollutants, which it is presumed were derived from such sources as road salt and household chemicals as well as septic effluent.

(c) Redox Potential (Table 7)

In most soil samples the redox levels were low, with a mean value of 75, and it had a negative value in 1 sample. Ionic calcium levels are the single best predictor of redox potential. In the diluted measure of ionic calcium levels (XKAD), two soil variables determined the Ca concentration in the extracted soil solution and consequently the potential of the calcium ion electrode: 1) the Ca concentration in the soil solution and 2) the ratio of the volume of soil solution to the volume of dilution water. This dilution makes the interpretation of this variable difficult. Factor analysis in Chapter IV separated calcium behaviour from that of sodium, chloride and nitrate ions, indicating that calcium and presumably carbonate levels reflect the

TABLE 7. Redox Potential

Multiple Regression Summary

Dependent Variable: Redox Potential

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
XKAD[#]	0.24891[*]	-908.5695	0.0068	0.0083
XNAS	0.39244[*]	20770.591	0.0108	0.0074
XNAD	0.48877[*]	-203592.54	0.0011	0.0008
OX	0.60308[*]	-14.75126	21.46	1.16
BHOV	0.74373[*]	6.4181374	26.24	9.77
BBDV	0.99999[*]	-116.6035	0.87	0.24
constant		328.75748		

* P=.01

Variables are designated by computer symbols--see key to Tables 1 and 2.

natural rather than human-induced variation of pollution.

The same dilution effect is true of ionic sodium levels (XNAD). Since the variation in soil moisture exceeds the variation in soil ionic sodium, soil moisture exerts a greater influence on XNAD values than soil ionic sodium. As is well known, soil moisture varies directly as redox potential. Thus when regressed against redox potential, XNAD exhibits a negative coefficient. When XNAD values are corrected for soil moisture, resulting in XNAS values, the Na concentration in the soil solution determines the electrode potential. When regressed against redox potential, XNAS exhibits a positive coefficient.

The positive relationships among sodium concentration in the soil (XNAS), soil moisture (BHOV) and redox potential (EH) are contrary to expectations. This may reflect the limitations of measurement techniques for determining redox potential. The influence of soil oxygen (OX) is difficult to ascertain due to the difficulties discussed in the previous section (section (b)). The influence of soil bulk density on redox potential is not easy to discern since it is a composite of several other variables including texture, soil fabric and organic matter. Organic matter is not included in the multiple regression equation, which is surprising since it is usually held to have considerable effect on soil redox potential, especially in humic paddy soils and gleysoils (Anomine, 1962).

(d) Oxygen Diffusion Rate (Table 8)

The variables included in the equation predicting oxygen

TABLE 8. Oxygen Diffusion Rate

Multiple Regression Summary

Dependent Variable: Oxygen Diffusion Rate

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
XMGS[#]	0.20936*	-157.98016	0.0139	0.0257
BHOV	0.41390*	-10.31135	26.24	9.77
GSB	0.53551*	-11.878049	6.12	4.46
TEMP	0.65701*	14.34899	19.32	1.52
EH	0.69952*	-1.82419	75.08	26.45
BBDV	0.74464*	100.8835	0.87	0.24
XOK	0.78978*	139.38702	2.16	0.79
BDY	0.82784*	460.9856	1.07	0.21
XNAD	0.89051*	45612.686	0.0011	0.0008
COO	0.96199*	206.71026	0.44	0.28
DH[@]	0.99999*	-0.197098	391.29	252.97
constant		-704.419		

* P=.01

Variables are designated by computer symbols--see key to Tables 1 and 2.

@ Examining the partial correlations of the last step in the multiple regression indicates that coliforms per gm. of wet soil (COLGM) would have yielded the same increase in R^2 as distance to the nearest house (DH).

diffusion rate differ from those included in the other multiple regression equations. Temperature, distance to the nearest house and number of coliforms per unit weight of wet soil are variables which are not included in any other equation except the one predicting oxygen diffusion rate. The environment which oxygen diffusion rate measures is significantly different from that measured by the other parameters of the soil aerobic-anaerobic balance, namely redox potential and carbon dioxide. This is partly a function of the measurement technique. Oxygen diffusion rate must be related to soil micropores, a more fragile, sensitive environment than the macropores to which texture and other variables relate. Diffusion wells designed to sample macropores exhibit response lags and insensitivity to short term anaerobic fluctuations. The redox potential measurements were not made on in situ soils but on disturbed samples which disturb the whole micropore system. Consequently, it may be regarded as unrelated to in situ measurements, for example, soil temperature. Redox potential was strongly influenced by other simultaneous electrode measurements, for example, ionic concentrations.

The determined oxygen diffusion rates (Table 8 and Appendix B) respond to almost all the relevant variables; to in situ measurements (e.g. soil moisture and temperature) as well as laboratory measurements (e.g. specific ions, Eh, coliforms and texture). It is suggested that oxygen diffusion rates are the best measure for the detection of the degree of interaction between natural and human influences within this experimental design. Measurements of oxygen diffusion rate can detect oxygen suppression under conditions which appear aerobic with other

techniques. (Oxygen levels never went below 17% in the oxygen diffusion wells, which is greater than the traditionally accepted level of anaerobism (Taylor, 1972), namely, 10%.)

(e) Nitrates (Tables 9 and 10)

The data on diluted and corrected nitrate concentrations yields similar multiple regression equations. The ionic concentrations of nitrate, sodium and chloride show a common pattern of variation in the factor analysis (Chapter IV). This common variation is due to their being from a common origin--the septic effluent. Electrical conductivity is the most readily available summation of their total effect. Measures of coarse grain sizes are also included in these equations predicting nitrates. The effects of coarse grain sizes are consistent with those described in the equations predicting coliforms, carbon dioxide and oxygen diffusion rates. Textural distributions with concentrations of coarse grains indicate human-induced pollution resulting in decreased oxygen levels, elevated carbon dioxide and coliform levels, and intense denitrification. The equations predicting nitrate levels include some natural variables, for example, pH, redox potential, bulk density and volumetric soil moisture.

It was originally intended that grouping analysis would follow the application of multiple regression techniques. The data would have been subdivided into different groups by statistical and soil classification techniques. Multiple regression on the individual groups would have indicated whether the same variations affect different soils.

The very high multiple R^2 values obtained in the original

TABLE 9. Nitrate Concentration Diluted

Multiple Regression Summary

Dependent Variable: Nitrate Concentration Diluted

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
EK#	0.76838*	0.0000298	345.97	240.53
XNAD	0.79692*	81.828	0.0010917	0.0008502
XMGD	0.82307*	0.39207	0.0015762	0.0029479
DHOW	0.83637**	-0.0003166	29.87	9.31
XNAS	0.85715*	-8.626	0.0108295	0.00748
BHOV	0.89354*	-0.0026992	26.24	9.77
BBDV	0.97182*	0.0500	0.87	0.24
EH	0.99999*	0.0003064	75.08	26.45
constant		0.0074566		

* P=.01

** P=.05

Variables are designated by computer symbols--see Tables 1 and 2.

TABLE 10. Nitrate Concentration in Soil

Multiple Regression Summary

Dependent Variable: Nitrate Concentration in Soil

Variable Entered	Multiple R^2	Beta	Variable Mean	Variable Standard Deviation
EK[#]	0.74002*	0.00000841	345.97	240.53
DHOV	0.78591*	-0.0068306	31.78	10.06
TEMP	0.80469*	-0.0752229	19.32	1.52
ODR	0.82350*	0.0045785	38.85	25.59
GSD	0.84270*	0.000465959	6.83	2.10
BHOW	0.85940*	0.00936338	31.64	13.80
GSC	0.87140*	0.0293682	21.57	4.37
HYGW	0.88320*	-0.08108884	1.89	0.83
EH	0.90131*	0.002077624	75.08	26.45
COLML	0.91903*	0.003660132	15.03	23.19
SKEW	0.96986*	-9.41280	1.01	0.02
DHOW	0.99999*	0.013131229	29.87	9.31
constant		9.5787396		

* P=.01

Variables are designated by computer symbols--see key to Tables 1 and 2.

multiple regressions indicate that the equations are applicable to all the sites analyzed. This is confirmed by intuitive reasoning. Most of the soils in these watersheds are little-developed Entisols (USDA, Soil Survey Staff, 1960), or soils with little horizonation or vertical differentiation. Hence the soils are very similar and such grouping or subdivision was deemed unnecessary.

CHAPTER IV

FACTOR ANALYSIS OF THE SOIL DATA

The second technique applied to the data was factor analysis. With a large number--forty-five--of soil variables to interpret, simplification of the data makes the relationships between the soil variables easier to interpret. Factor analysis is one technique whereby soil variables which are similar in nature or which responded similarly to environmental changes can be grouped into a smaller number of discrete independent factors. The factor analysis facilitates the interpretation of the multiple regressions on the soil variables and frequent references to this factor analysis have already been made in Chapter III. Part 2 of this current chapter is devoted to the overall interpretation of the validity of the different approaches to the factor analysis.

The same correlation matrix used to construct the multiple regressions was used in the factor analyses. Means and standard deviations of the variables were also entered into the factor programs. Due to the degree of intercorrelation in the data, the largest off diagonal element in the correlation matrix was used as the initial communality estimate. Only factors with eigenvalues greater than 1.0 are reported (Tables 26, 27, 28) and interpreted. Three types of factor analysis from the SPSS program library (Nie et al., 1970) were

used--a principal components analysis, an orthogonal factor analysis with varimax rotation and an orthogonal factor analysis with oblique rotation. A delta value of zero, which gives a moderately-correlated solution, was used with the oblique rotation.

The factor analysis consists of five sections. Section 1 presents a detailed analysis of the factors extracted in an orthogonal varimax factor analysis. Section 2 compares the three factor solutions, their merits and liabilities. Section 3 applies the factor analysis to an interpretation of the multiple regression equations on the original data. Section 4 describes multiple multiple regressions on factor scores. In section 5, some inferences are drawn about the relative contribution of man and nature to the variation in the data.

1. Factor Solution with Orthogonal Varimax Rotation

The similarity between factor solutions makes repetition of the detailed breakdown of each factor unnecessary. The factor solution with orthogonal varimax rotation is presented in detail. The factor solutions are compared and summarised in Tables 11 to 13. The variables which correlate highly on the factor axes are used to describe and classify each factor. The factors are described in the order of their extraction from the data matrix.

Factor 1 consists of ionic levels, including the 'polluting' ions of sodium, nitrate and chloride. Since these three represent most of the ionic variation, electrical conductivity, a measure of the total salt content of the soil, is included in this factor. Soil moisture correlates

significantly with the factor because it is the agent diluting the ionic concentrations.

Factor 2 consists of measures of fine grain sizes. The variation in fine grain size is due to natural factors. This is a 'natural textural' factor, presumably influencing microporosity.

Factor 3 consists of the content of coarse grains in the soil. The variation in the coarse grain sizes is dependent on the degree of formation of surface layers of compacted coarse sand. This factor is not natural, rather a human-induced or 'textural pollution' factor. Chapter V deals with the nature and influences of this phenomenon in more detail.

Factor 4, a dynamic natural factor, is primarily the ionic calcium level. Calcium ions dominate the ionic exchange reactions in these soils; consequently, pH levels correlate highly with this factor and also reflect the presence of the local limestone, depth to bedrock, limestone content of soils and other easily assessable but largely unquantifiable variables when related to soil micro-environments.

Factors 5 and 6 are static natural factors. Static refers to or implies the limitations imposed by the measurement technique. Each of these variables was measured once, and its value assumed constant over time. Factor 5 includes measures of organic matter content, carbonate content and bulk density. For simplicity, factor 5 is referred to as the organic matter factor, while factor 6, the hygroscopic moisture factor, is assumed to be a measure of specific surface area (Banin and Amiel, 1970).

Factor 7, a static pollution factor, is the coliform count or

content. Coliform levels are actually very changeable. They were measured statically in this experimental design for practical reasons.

Factor 8 is the chloride level. It consists of the ionic chloride variation unaccounted for in factor 1. Subsequent evidence suggested this was a pollution factor, causing it to be termed the 'minor pollution' factor.

Factor 9 is the soil depth factor.

Of the other factors in the solution, factor 10 is the gaseous factor consisting of soil oxygen and nitrogen, while factor 11 is the housing factor, consisting of a measure of the distance to the nearest house.

2. Comparisons of the Different Factor Solutions

Factor solution with oblique rotation allows the factors to be correlated or reveals the extent of their interdependence. This may be regarded as a more realistic approach to the interpretation of soil data. In the orthogonal varimax rotation, chloride is split between factors 1 and 8 or 9. Ionic chloride shares some common variation with the other polluting ions, but it has enough unique variation to be represented as a separate factor in the oblique rotation.

The factor correlation matrix resulting from oblique rotation indicates the suggested degree of intercorrelation. These intercorrelations help to separate the 'natural' from the 'pollution' factors. Correlations of r=0.20 and above are cited. Factor 1 displays the highest degree of intercorrelation. It correlates with factors 9

(r=0.25), 10 (r=0.21) and 11 (r=0.25). Consequently, the ionic chloride, the housing and the coarse textural parameters are most closely linked to the ionic pollution factor. Factor 7 correlates with factor 2 (r=0.21) and 4 (r=0.20). The hygroscopic moisture content, not unexpectedly, provides a link to other natural factors--organic matter and ionic calcium.

The pattern of principal components is similar to the factor patterns described. The most radical difference in the principal components solution is the reduced percentage of variance explained. The principal components solution resembles the orthogonal varimax solution, as would be expected.

Based on these three factor solutions, it is possible to construct a generalized factor model. Tables 11 and 12 summarise the similarities and differences between the factor solutions. Table 13 presents the factor model in schematic form. Table 11 compares the distribution and order of extraction from the data matrix of each factor for the three factor solutions. Table 12 compares the variables correlated with each factor for the three factor solutions. Correlations of $|r| > 0.50$ are reported. The variable names used are the computer mnemonics listed in the key to Tables 1 and 2. Table 13 presents a model which classifies the factors according to the type of variables which they represent. The discrete factors are from the obliquely-rotated factor solution. The grouping of the factors into pollutant and natural factors is based on the relationships displayed in the factor correlation matrix, the multiple regressions and the literature on the sources and behaviour of the soil variables.

TABLE 11

Factor Solution Comparison: Extraction Order and % Variance Explained for each Factor

Factor Type	Factor Name	Factor Solution: Principal Components		Orthogonal Varimax		Orthogonal Oblique	
		Factor No.	% Variance	No.	%	No.	%
Ionic	major ionic pollution	1	21.6	1	26.1	1	26.1
	minor ionic pollution: chloride	9	3.5	8	4.0	9	3.5
	natural ionic: calcium	2	13.0	4	10.4	5	9.6
Textural	coarse textural pollution	3	11.0	3	13.0	11	2.9
	fine textural natural	4	9.2	2	15.5	3	13.0
	organic matter	5	8.4	5	9.6	2	15.5
	hygroscopic moisture	6	5.8	6	6.4	7	5.5
Other	gaseous	8	4.0	10	3.2	4	10.4
	depth	10	3.4	9	3.5	8	4.0
	coliforms	7	4.9	7	5.5	6	6.4
	housing	11	3.1	11	2.9	10	3.2

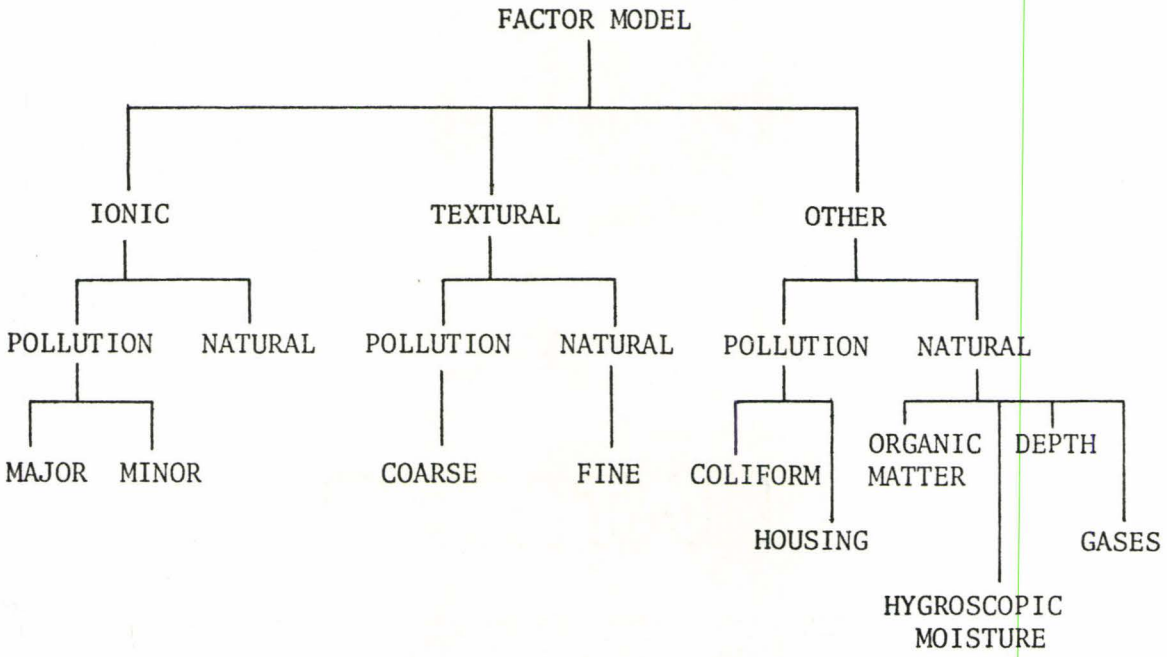
TABLE 12

Factor Solution Comparison: Variables Loaded on each Factor

Factor Type	Factor Name	Principal Components	Orthogonal Varimax	Orthogonal Oblique
Diagnostic Pollutant Ions	major ionic	XNOS* XNOD XNAD XNAS KLS EK COO BHOV BHOW DHOV DHOW	XNOS XNOD XNAD XNAS KLS KLD EK COO BHOV BHOW DHOV DHOW	XNOS XNOD XNAD XNAS EK COO DHOV DHOW
	minor ionic pollution: chloride	KLD KLS	KLD KLS	KLD KLS
	natural ionic: calcium	EH PH KAD KAS	KAD KAS EH	KAD KAS EH
Textural	coarse textural pollution	GSA GSB GSD GSE GSF	GSA GSB GSD GSE	GSA GSB GSD GSE GSF
	fine textural natural	GSH GSC GSI XKUR SSA	GSH GSI XKUR SSA	GSH GSI XKUR SSA
Other	organic matter	LOIL LOIH XOK BDY BBDV	LOIL LOIH XOK BDY BBDV	LOIL LOIH XOK BDY
	hygroscopic moisture	HYGV HYGW	HYGV HYGW	HYGV HYGW
	gaseous	OX XNN	OX XNN	OX XNN
	depth	DEPTH HD ODR TEMP	DEPTH	DEPTH
	coliforms	COLML COLGM	COLML COLGM	COLML COLGM
	housing	DH	DH	DH

* Variables are designated by computer symbols--see key to Tables 1 and 2.

TABLE 13. Schematic Factor Model



3. Interpreting the Variables in the Multiple Regression Equations as Factors

The variables in the multiple regression equations can be simplified into their factors by using the factor model. In constructing the regression models, the arrows indicate a statistically significant relationship. The direction of the arrow indicates the direction of the relationship, i.e., from dependent to independent variable. The number on the arrow indicates the order of entry or inclusion in the equation. The symbols are explained as follows:

Capital letters = factors or components

T = texture (f=fine, c=coarse)

I = ionic (m=major, o=minor)

OM = organic matter

D = depth

G = gases (oxygen and nitrogen)

A = hygroscopic moisture

C = coliforms

H = housing

Small letters = descriptive terms for factors

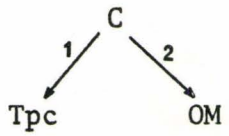
p = pollution

n = natural origin (presumed)

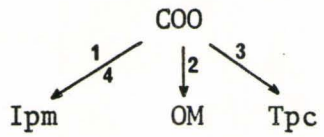
Other symbols are the computer variable symbols, as cited in Tables 1 and 2.

The regression models are shown for those equations discussed in Chapter III as follows:

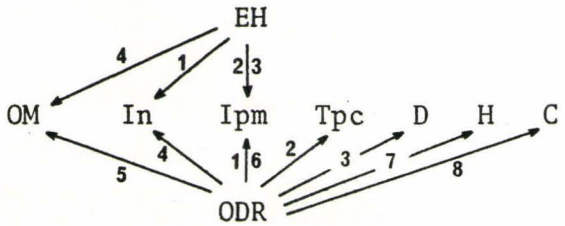
1. Coliforms



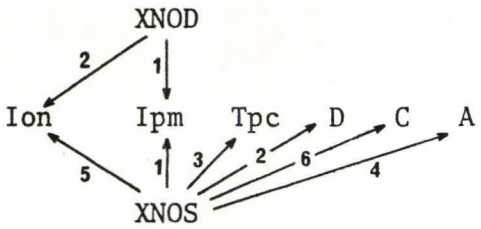
2. Carbon Dioxide Concentration



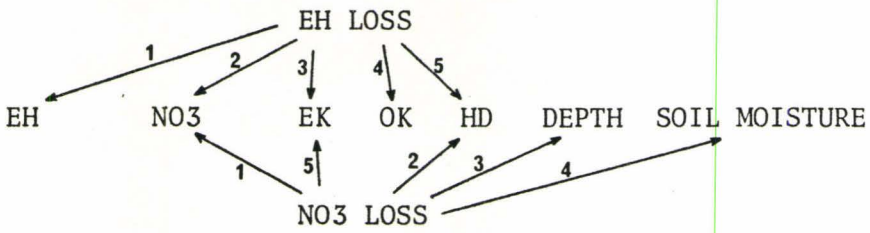
3. and 4. Redox and Oxygen Diffusion Rate



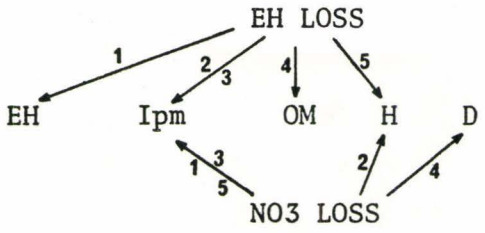
5. Nitrates



It is possible to extrapolate this modelling to the denitrification studies of the pilot survey. The original equations would yield this model:



Extrapolating this to the factor analysis yields:



4. Multiple Regression of the Principal Components Solution

The initial correlation matrix of the factor scores is shown in Tables 14 and 15. Table 14 shows the complete correlation matrix. Table 15 is a simplification of Table 14, showing those correlations greater than $|r| = 7.0$. (The decimals are omitted to make the tables more readable.) Regression on principal components yields much simpler equations than regression on the raw data variables. The correlation matrix indicates that with this type of model, more than 50% of the sample variation in any one component can be explained by a linear relationship with another component. Because of the high level of explanation for the initial component entered, subsequent components entered into the equation yield small increases in R^2. The F levels for inclusion and exclusion of components were preset in the computer program so that all variables included in the equation would be significant at the 5% level. The resultant models resemble those presented in Chapter III.

The pollution components are: component 1, the major ionic pollutant; 3, the coarse textural material added to the soil surface; 7, the coliform component and 9, the ionic chloride pollutant component. These components will now be considered in turn:

TABLE 14. Principal Components--Factor Scores Correlation Matrix

Components	1	2	3	4	5	6	7	8	9	10
11	-83*	85	-66	-54	-89	-71	65	55	-84	88
10	-78	88	-46	-51	-86	-74	72	49	-86	
9	87	-92	63	76	93	89	-52	-32		
8	-18	20	-04	-10	-38	-49	51			
7	-47	62	-31	-11	-59	-52				
6	79	-78	50	72	84					
5	92	-93	73	72						
4	73	-66	56							
3	81	-72								
2	-93									

* Decimals are omitted for clarity and ease of reading the matrix.

TABLE 15. Principal Components--Factor Scores Correlation Matrix
Correlations $|r| > 0.70$

Components	1	2	3	4	5	6	7	8	9	10
11	-83*	85			-89	-71			-84	88
10	-78	88			-86	-74	72		-86	
9	87	-92		76	93	89				
8										
7										
6	79	-78		72	84					
5	92	-93	73	72						
4	73	-66								
3	81	-72								
2	-93									

* Decimals are omitted for clarity and ease of reading the matrix.

The major ionic pollutant: Table 16

The first component entered is the natural ionic component. The next components entered are textural components. The coarse textural pollution component is entered second and the natural fines textural component is entered third. Six more components are entered but their individual contribution to change of R^2 is very small. The first three components included, then, produce a good model for predicting ionic levels, explaining 93% of the variation.

The coarse textural material added to the soil surface: Table 17

The surface layers of compacted coarse sand are represented by component 3 in the principal components solution. The coarse grain size fractions correlate highly with this factor. Component 3 was then termed the coarse textural pollution component. In the multiple regression equation predicting component 3, the first component entered is the major ionic pollution component. The next two components entered (10 and 11) also contribute substantially to the R^2 value. Component 10 is the depth component. Its influence could in part be due to the restriction of human-induced textural alterations to the soil surface. Component 11 is the housing component. Thus, textural alterations are accelerated near housing.

The coliform component: Table 18

Only three components are included in the equation at the 5% level of significance. The first component included is the depth

TABLE 16. The Major Ionic Pollutant Component

Multiple Regression Summary

Dependent Variable: Factor 1

Variable Entered	Multiple R^2	Beta	Factor Scores	
			Mean	Standard Deviation
Factor 2[#]	0.86912*	-0.116	-14.37	17.35
Factor 3	0.90916*	0.395	2.37	3.55
Factor 6	0.93117*	0.956	7.21	4.09
Factor 9	0.93706**	-0.578	12.10	8.13
Factor 7	0.94321*	0.768	0.77	1.31
Factor 11	0.95156*	-0.991	-5.49	3.32
Factor 8	0.96189*	0.206	-9.12	10.15
Factor 10	0.96847**	-0.487	-5.91	4.05
Factor 4	0.97217**	0.355	3.62	2.09
constant		-0.0249		

* P=.01

** P=.05

The factors are described in the text and in Tables 11 and 12.

TABLE 17. The Coarse Textural Pollutant Component

Multiple Regression Summary

Dependent Variable: Factor 3

Variable Entered	Multiple R^2	Beta	Factor Scores	
			Mean	Standard Deviation
Factor 1#	0.65819*	0.493	10.80	6.14
Factor 10	0.73245*	0.654	-5.91	4.05
Factor 11	0.78154*	-0.368	-5.49	3.32
Factor 6	0.81539*	-0.292	7.21	4.09
Factor 5	0.82065*	0.439	4.69	4.61
constant		-1.07		

* P=.01

The factors are described in the text and in Tables 11 and 12.

TABLE 18. The Coliform Component

Multiple Regression Summary

Dependent Variable: Factor 7

Variable Entered	Multiple R^2	Beta	Factor Scores Mean	Standard Deviation
Factor 10[#]	0.52385[*]	0.236	-5.91	4.05
Factor 4	0.61593[*]	0.319	3.62	2.09
Factor 6	0.65093[*]	-0.109	7.21	4.09
constant		1.81		

* P=.01

The factors are described in the text and in Tables 11 and 12.

component (number 10). In this instance, coliform levels are responding to temperature gradients with depth. The fine grain size component (number 4) and the hygroscopic moisture component (number 6) control the surface area of the mineral fraction of the soil. The large surface area of the fines may be impeding soil moisture and effluent flux, increasing coliform levels.

The ionic chloride pollutant component: Table 19

The results for chloride are somewhat atypical. The first four components entered into the equation are natural. These account for 94% of the sample variation. Of the next six entered, four are pollution components. These four account for less than 3% of the variation. The effect of the pollution components on the chloride component could be masked by a number of things. High r values between the ionic chloride component and the other components obscure the contribution of the components entered after the initial step. Chloride correlates with seven other factors at levels of $|r| > 0.70$. Chloride correlates significantly with housing distance ($r=-0.94$) and polluted ionic levels ($r=0.87$) (Table 15). A second factor obscuring the effect of the pollution components on the chloride component is the theoretical restrictions of a principal components solution. The orthogonal solution splits chloride into two components. Part of the chloride variation is included in the major ionic pollution factor; the rest is isolated in a separate ionic chloride factor. An oblique solution places all the ionic chloride variation in one factor which correlates with the major ionic factor. The oblique solution is more

TABLE 19. The Ionic Chloride Pollutant Component

Multiple Regression Summary

Dependent Variable: Factor 9

Variable Entered	Multiple R^2	Beta	Factor Scores	
			Mean	Standard Deviation
Factor 6[#]	0.87301[*]	1.230	7.21	4.09
Factor 2	0.90787[*]	-0.145	-14.37	17.35
Factor 4	0.94055[*]	0.567	3.62	2.09
Factor 11	0.94489[*]	-1.249	-5.49	3.32
Factor 1	0.95620[*]	-0.827	10.80	6.14
Factor 8	0.96746[*]	0.240	-9.12	10.15
Factor 7	0.97195[*]	0.881	0.77	1.31
Factor 10	0.97543[*]	-0.582	-5.91	4.05
Factor 3	0.97732[*]	0.240	2.37	3.55
constant		-1.343		

* P=.01

The factors are described in the text and in Tables 11 and 12.

realistic, but was not used to construct factor scores for multiple regression analysis.

5. Natural versus Human-induced Variation

Knowing which factors represent pollution factors and which are natural enables one to sum the variation for each type of factor (Table 20). Table 20 indicates that almost half of the variation of all measured environmental values is that imposed by the 'pollution factors', or those which are induced by human activity.

TABLE 20. Comparison of Natural and Pollutant Variation in the Three Factor Solutions

	Principal Components		Orthogonal Varimax		Orthogonal Oblique	
Type of Factor	No. of Components	% Variance	No.	%	No.	%
Natural	6	43.8	6	48.5	6	57.9
Pollution	5	44.1	5	51.5	5	42.1
Total	11	87.9	11	100.0	11	100.0

CHAPTER V

THE NATURE AND INFLUENCES OF SURFACE LAYERS OF COMPACTED SAND

This chapter represents some exploratory work which it is hoped may be developed in future research. Site 2, on Ancaster Creek, exhibits an unusual compacted surface layer of coarse sand. We are convinced that this layer is not of natural origin. Most of the soils in these watersheds are Entisols, or soils with poorly developed profiles exhibiting little natural horizonation or vertical reorganization. Site 2 is of recent alluvial origin. In this type of alluvial deposition, one should not expect much initial sorting. Once deposition of the parent material had occurred, consistent high moisture status would impede internal translocation of large mineral grains or removal by leaching processes. One might expect some movement of fines. Thus, there is no inherent natural basis for the occurrence of large textural variations within these soil profiles, especially of coarse grain size fractions. Most other sites show varying degrees of development of this compaction feature.

Figure 3 shows the textural distributions for three depths, 3, 6 and 12 inches, at site 2. There is an obvious accumulation of coarse sand grains to a depth of 3 inches or more. This does not occur in site 6 (Figure 4), for example, where the distribution of coarse sand

GRAIN SIZE DISTRIBUTION FOR SITE 2.

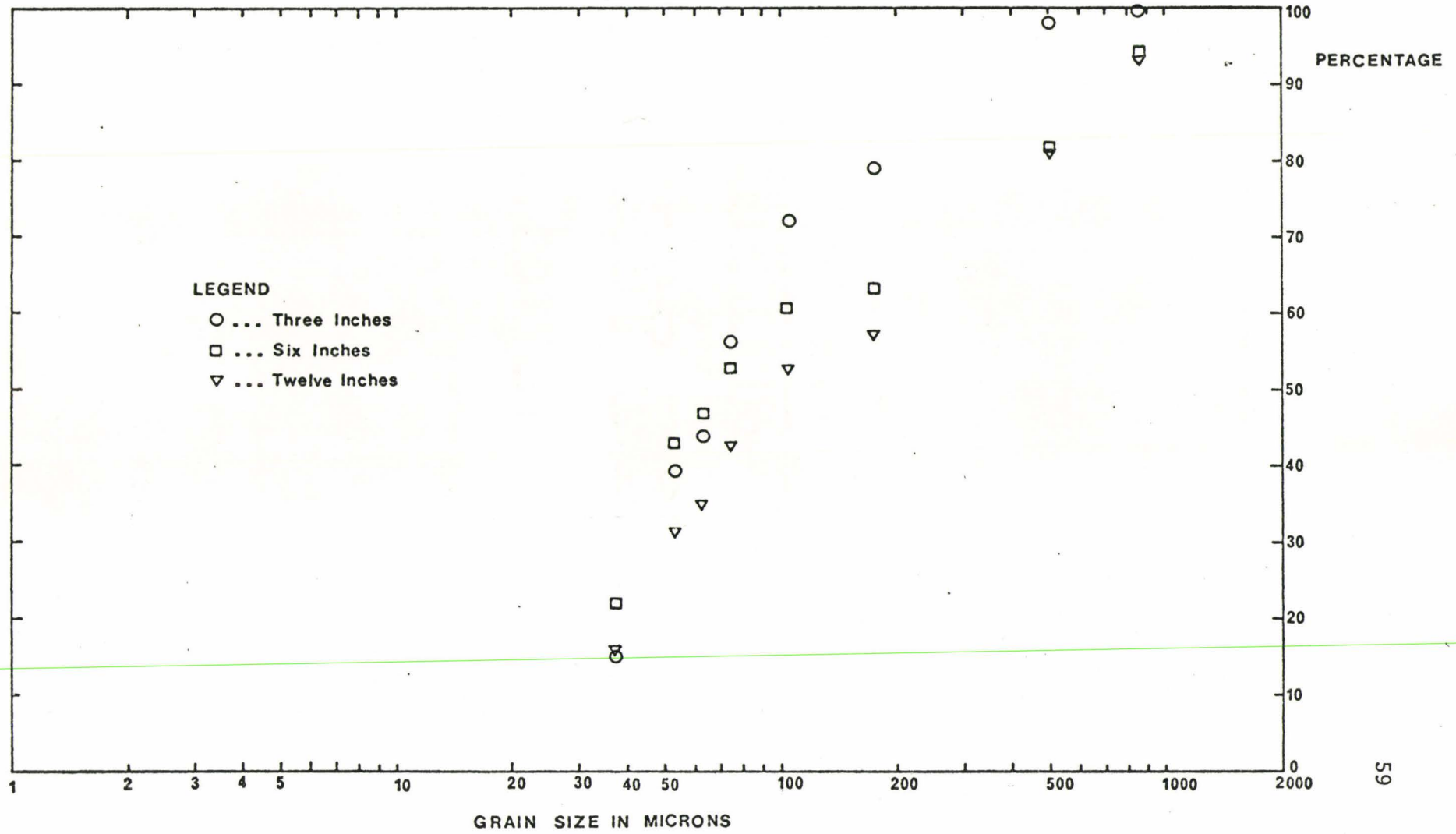


Figure 3.

GRAIN SIZE DISTRIBUTION FOR SITE 6.

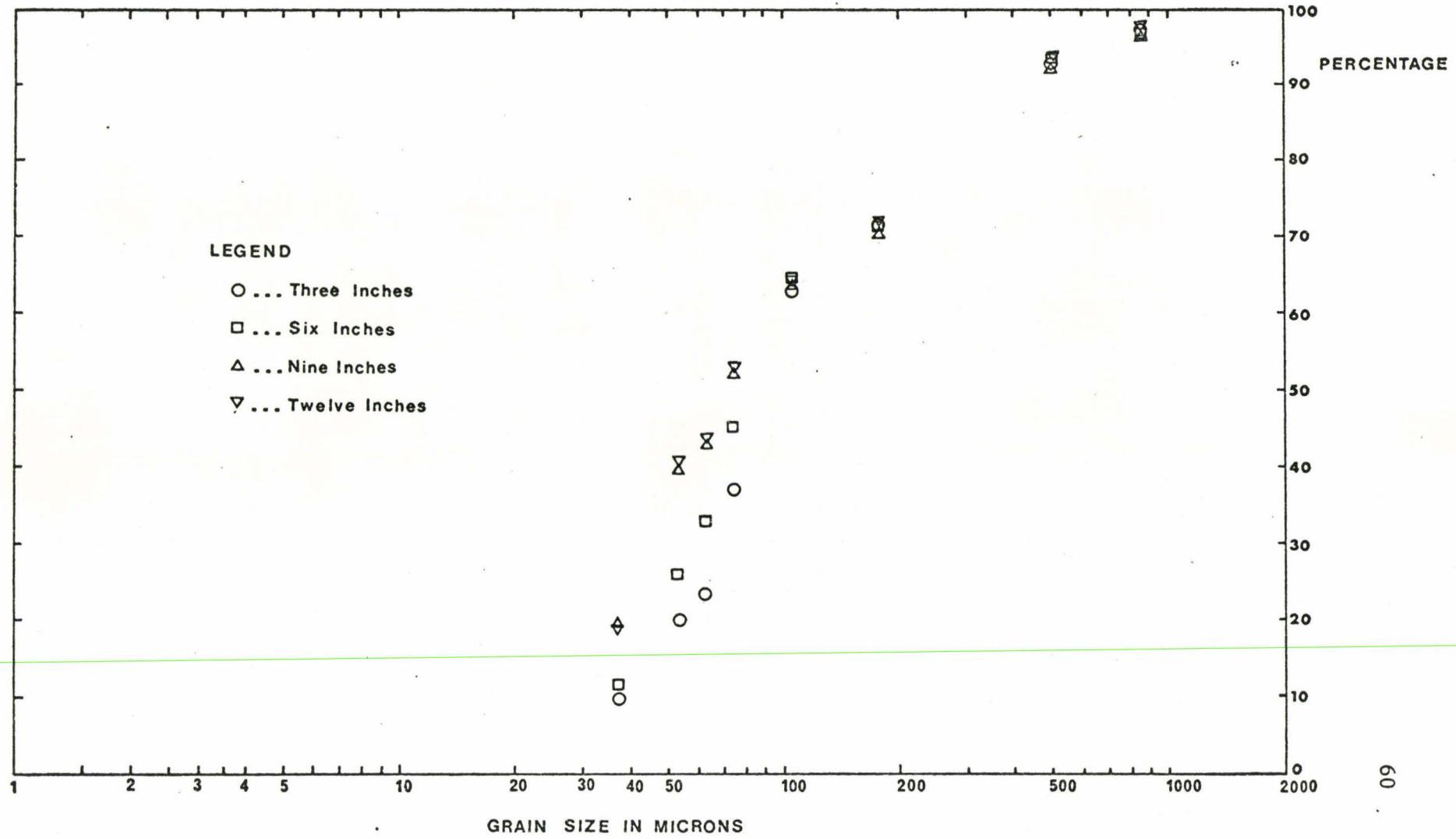


Figure 4.

grains is virtually uniform in the profile.

The effects of this surface accumulation of coarse grain sizes are apparent in the multiple regression equations predicting coliform levels, carbon dioxide levels, oxygen diffusion rates and nitrate levels. The coarse grain sizes are represented by a separate component or factor in the factor analysis. As a component, it is included in the multiple regression equations predicting the major ionic pollution component as the second component entered into the equation. Perhaps the most disconcerting indication that these coarse surface layers are related to septic pollution is the relationship between coliform levels and the coarse grain size distributions.

A comparison has already been made between the expected or natural textural distribution in site 6 and the man-induced textural distribution in site 2. The data in Figure 5 show the measured oxygen diffusion rates in both soils. The shaded area represents the reported critical levels for plant growth (Stolzy and Letey, 1964). Thus, it is hypothesized that the increase of coarse sand has formed a dense compacted layer close to the soil surface. Above the layer, or in the top few inches of the layer, oxygen levels and oxygen diffusion rates are enhanced due to the decreased downward flux and consumption of oxygen. Below the dense compacted sand layer, diffusion to the soil surface is virtually cut off. As oxygen is consumed, none is replaced by downward diffusion from the soil surface. This soil then becomes perpetually anaerobic. In site 6, lacking a compacted sand layer, unimpeded diffusion throughout the profile keeps the soil within a narrow range

OXYGEN DIFFUSION RATES IN SITES 2. & 6.

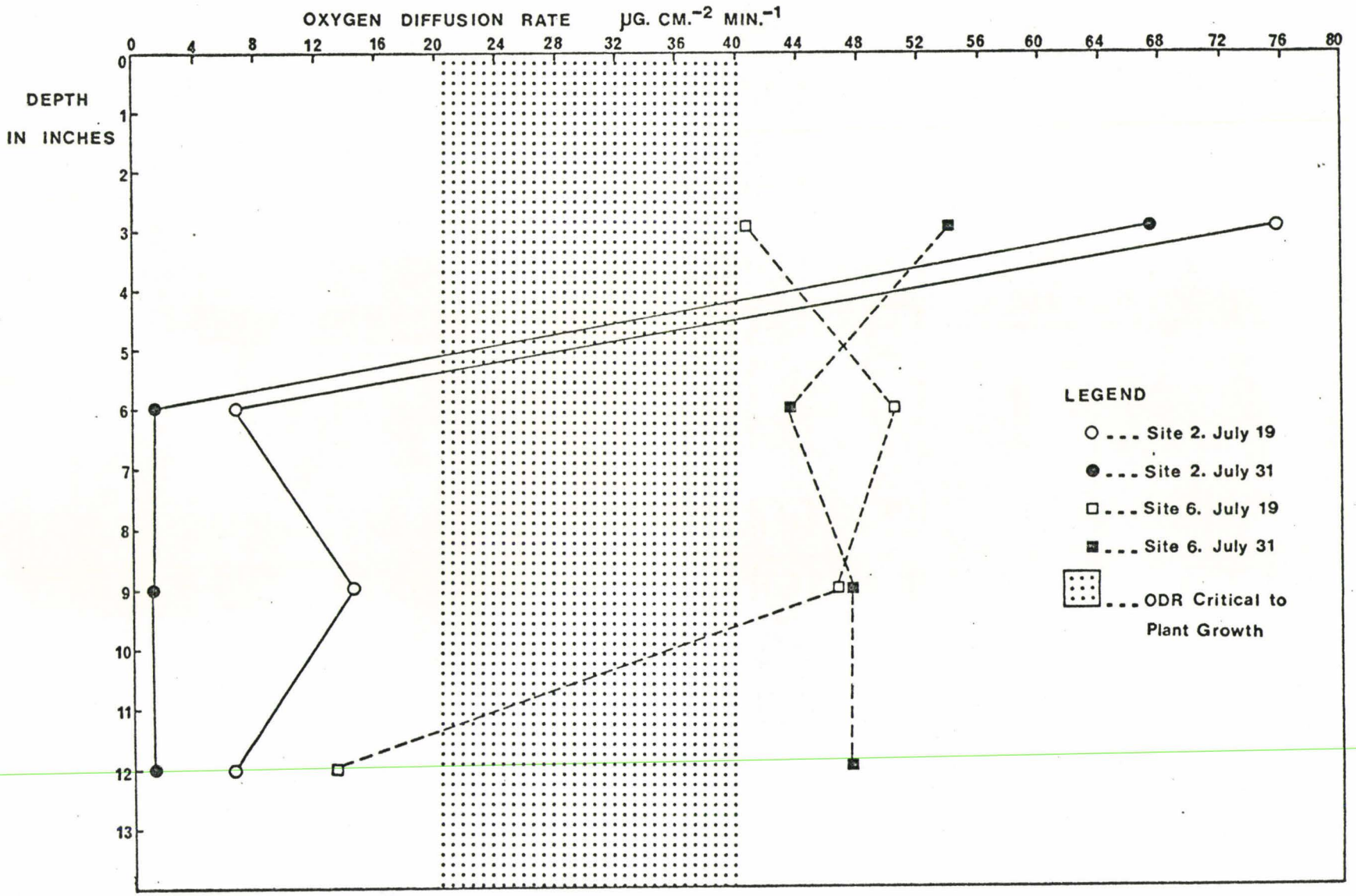


Figure 5.

of oxygen diffusion rates. At depth, due to soil moisture fluctuations, the soil may occasionally become anaerobic for short periods of time.

Soil fabrics, or thin sections, of many of these sites have been prepared. The soil fabrics of site 2 reveal that the coarse sand grains form plugs or infillings along the large root and earthworm channels, severely inhibiting aeration and presumably limiting the soil's natural capacity to function as a pollutant absorber and an environment for development of deep-rooted plants, especially trees.

Figure 6 is a thin section from site 8 on Ancaster Creek, taken at a depth of 20 cm. In this site, textural alteration is occurring but has not reached the state, as in site 2, where the subsurface layers have become anaerobic as a result. Three materials of differing grain size are evident in Figure 6: a silty clay mass--A, a silty fine sand nodule--B and coarse sand--C (along the left side of the figure). The silty clay and silty fine sand represent part of the original fabric and soil material. The coarse sand, a recent addition, has altered the soil fabric. Of the original soil materials, the silty clay is being altered the most rapidly. Numerous cracks occur as the soil dries out during the summer dry season (D). In many cases, these cracks are lined with organic stainings, indicating that they remain open for long periods of time. Gradually, sections of clay are separated from the main clay mass along these cracks and incorporated into the coarse sand as silty clay coatings and infillings around sand grains. The nodules exhibit varying degrees of cementation and are more resistant to incorporation than the clay masses. The cementing agent is most likely sesquioxides which appear as very small dark dots

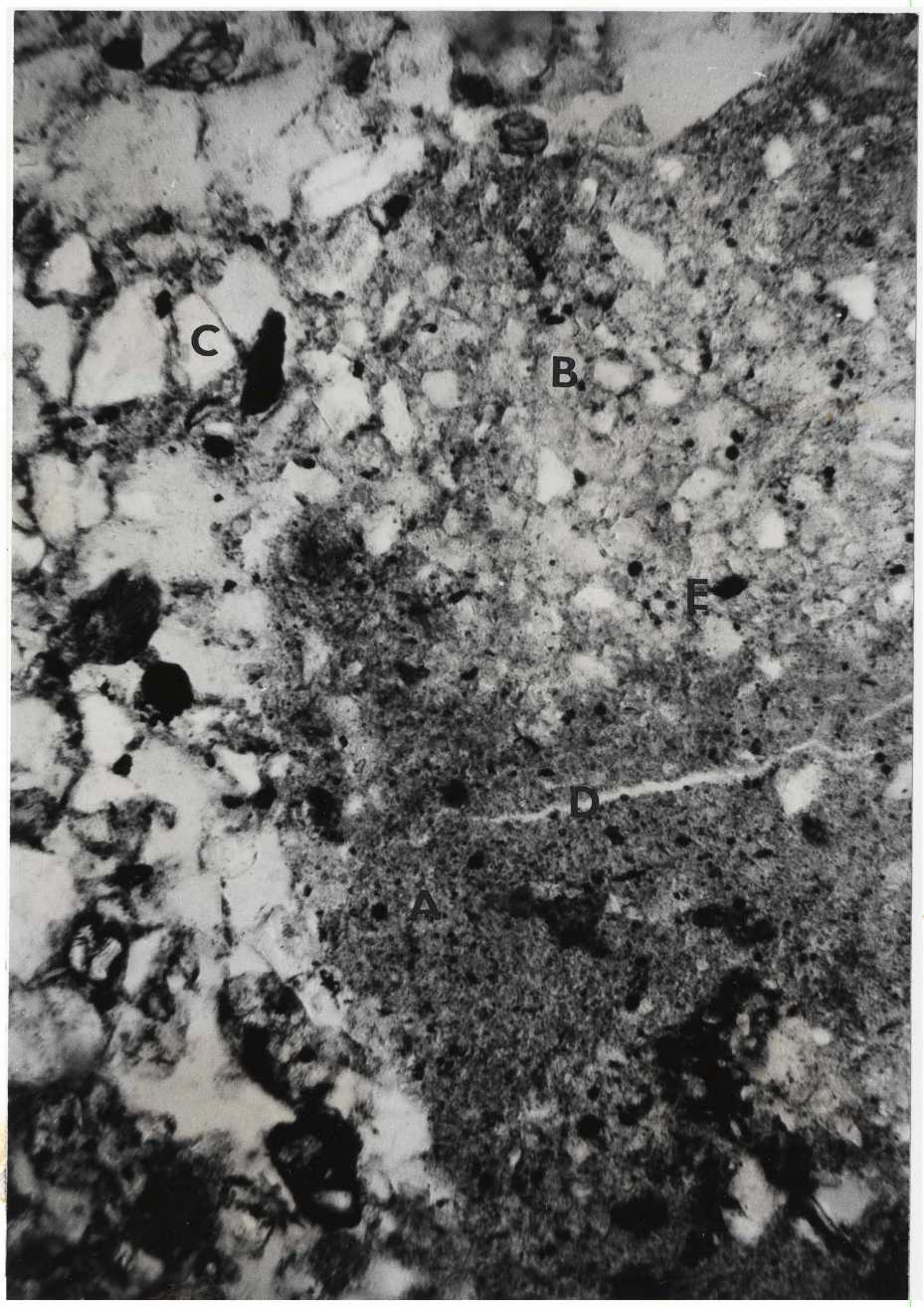


Figure 6. Thin section of soil from site 8 at 20 cm. depth.

Magnification x 120. The letters are explained in the text. The thin section shows the alteration of the soil fabric by recent additions of coarse sand.

and masses in the photograph (E).

CHAPTER VI

CONCLUSIONS

The impact of settlement on the ecological system is quite profound. The factor analysis indicates that almost half of the variation of all measured environmental values is that imposed by the 'pollution factors' or those which are induced by human activity (Table 20).

These impacts can be assessed as weak or strong links in the soil ecological system as follows: 1. The amount of soil organic carbon is not a limiting influence on denitrification processes but it does enhance and invigorate coliform growth and stream algal blooms. 2. The wet valley soils are good absorbers or 'processors' (degraders) of nitrogenous wastes. Most of the nitrates are removed by denitrification. 3. These soils are poor 'processors' of most other pollutant ions in housing wastes (septic effluent). These other measured ions -- sodium, magnesium and chloride -- pass through the soil without degradation, chelation or fixation. Some authors (e.g., Smith, 1972) report that, due to anion exclusion, these ions pass through the soil quicker than water molecules. 4. Oxygen levels are suppressed by large fluxes of septic effluent passing through the soil. Septic effluent

raises organic carbon levels. This increases microbial growth, increasing oxygen consumption and carbon dioxide evolution. In a delicately balanced system such as these wet soils, the result could be induced anaerobosis and dramatic changes in viable plant life, the death of trees, difficulty in establishing ornamental species and, in the end, possible further aggravation of the situation by this dead organic matter. 5. Additions of coarse sand to the surface of these wet valley soils, whether by design or accident, constitute a serious ecological threat. If their frequency and spatial extent is significant, the implication is that there is a) an impending ecological crisis due to induced anaerobosis and b) an impending health crisis due to elevated coliform levels.

This research opens some new areas of needed inquiry. One such area is the effects of texture and textural alterations on soil fabrics and soil ecology. The research also answers many questions, thus simplifying and focusing the design of future research. The multivariate analysis indicates that the number of variables can be reduced from 45 to 15 without loss of information. This reduction will facilitate more detailed analysis and measurement of other potentially relevant variables, for example, soil nitrogen, phosphorus, ammonia and phosphate levels. Similarily, since all the soil sites behave as one system, the number of sites analyzed can be reduced from 15 to 3. Using only three sites will permit continuous sampling and assessment of seasonal variation, which was not feasible when sampling 15 sites.

APPENDIX A

METHODS OF DATA COLLECTION,

FIELD AND LABORATORY RESEARCH

1. Introduction and Types of Measurements
2. *In situ* Measurement of Oxygen Diffusion Rate
3. *In situ* Measurement of the Total Coliform Group of Soil Organisms
4. *In situ* Measurement of Soil Gases by Gas Chromatography
5. Laboratory Measurements of Soil Variables by Electrode Potentials and Resistance
6. Laboratory Measurements of the Grain Sizes of the Mineral Component of the Soil
7. Laboratory Measurement of Soil Organic Carbon

APPENDIX A

METHODS OF DATA COLLECTION, FIELD AND LABORATORY RESEARCH

1. Introduction and Types of Measurement

Computer symbols are used to refer to specific measurements (see key to Tables 1 and 2, and Appendix B). Fresh disturbed samples were obtained with a small corer of 2 cm. internal diameter. Samples were extracted from the corer by a sampler 7 cm. long. Measurements from these fresh soil samples included: soil moisture (DHOV, BHOV, DHOW, BHOW), bulk density (BDY, BBDV), coliforms (COLGM, COLML), electrical conductivity (EK), redox potential (EH), pH (PH) and specific ionic levels (XKAS, XKAD, XNAS, XNAD, XNOS, XNOD, XMGS, XMGD, XKLS, XKLD).

Measurements from air dried soils included: hygroscopic soil moisture (HYGV, HYGW), grain size fractions of the soil mineral material (GSA, GSB, GSC, GSD, GSE, GSF, GSG, GSH, GSI), specific surface area of the mineral grains (SSA), skewness and kurtosis measures of the grain size distribution (SKEW, XKUR), percentage organic carbon (XOK), organic matter (LOIL) and carbonate content (LOIH).

Measurements made in situ included oxygen diffusion rate (ODR). soil temperature (TEMP) and soil air composition (OX, COO, XNN). Housing density (HD) and distance between soil sampling sites and the

nearest house (DH) were measured from 1:25,000 scale topographic maps of Wentworth County.

Standard procedures were used to determine organic matter content, carbonate content, bulk density, soil moisture and hygroscopic moisture (Soil Conservation Service, USDA, 1967). Non-standard or modified standard procedures were used to determine the other soil variables. These methods are discussed in the following sections of this appendix.

The large volume of data involved required that even the most elementary calculations be done on the computer. Computer programs were written to compute from raw data: bulk density, soil moisture values, coliform levels, ionic levels, soil gaseous composition, soil organic carbon, textural distributions of mineral grains, skewness and kurtosis values and specific surface area. The most important of these in terms of time saving and possibilities of wider use are the last three programs, which are related to soil texture, namely, TEXTUR, SKEWKUR and SURFACE. These three programs are listed in section 6 of this appendix.

2. In situ Measurement of Oxygen Diffusion Rate

Two oxygen electrode meters were constructed based on the design of Letey and Stolzy (1964). A number of platinum microelectrodes and reference electrodes were constructed of original design to be used in conjunction with the meter boxes. The microelectrodes consisted of insulated fine copper wire spot-welded to a 51 gauge platinum wire tip.

The wire was encased in a 1/16" O.D. steel tubing and the assembly was coated with epoxy, being careful to keep the platinum tip clear of epoxy and free from contacting the steel tube. Reference electrodes were made from broken Fisher reference electrode bodies. The glass bulbs were removed and replaced with plastic tubing connectors. A thick cord wick was threaded through the narrow end of the tubing connector and held in place by knots. Both types of electrodes proved rugged and reliable even under adverse field conditions. The modified reference electrode and a reference electrode designed by Poel (1960) were compared in the field. The modified electrode was smaller, more portable, rugged, easily installed, and, most important, produced a better, more stable electrical contact with the soil than the electrode designed by Poel.

The platinum microelectrodes were calibrated according to the method of Letey and Stolzy (1964) isothermally in distilled water against a commercial platinum electrode of known surface area. The microelectrodes' response characteristics in distilled water were also determined. These calibrations and response characteristics are listed in Table 21. The microelectrodes were tested for temperature response in distilled water from 3 to 23^{o}C. (Figure 7). The rate of change in Figure 7 can be used to convert oxygen diffusion rate measurements to a standard temperature (Birkle et al., 1964). Such a conversion for soil measurements entails some dubious assumptions (Letey et al., 1961) and since soil temperature measurements were being included in any multivariate analysis of the data, it was decided that such a conversion

TABLE 21. Polarographic Oxygen Electrode Calibration

I Surface Area of Reference Electrode

length 0.1835 inches

diameter 0.032 inches

Formula = $l\pi d$

$= ((0.1835)(2.54)) \cdot ((0.032)(2.54)(\pi))$

Surface Area = 0.11896 $cm.^2$

II Oxygen Diffusion Rate

$$ODR = \frac{i \times 10^{-6} \times 60 \times 32 \times 10^{8}}{4 \times 96{,}500 \times A} \ \mu g.\ cm.^{-2}\ min.^{-1}$$

where A is the surface area of the platinum electrode in $cm.^2$

i is current in microamperes (μa)

$$ODR = \frac{i}{A}\ (0.49740933)\ \mu g.\ cm.^{-2}\ min.^{-1}$$

III Calibration

Electrode	μa	A ($cm.^2$)	ODR Formula
Reference	5.25	0.11896	i (4.153440652)
#1	3.25	0.07364	i (6.754607958)
#2	7.75	0.07561	i (2.832465862)
#3	7.00	0.15861	i (3.136052771)

$$\text{Reference ODR} = \frac{5.25}{0.11896}\ (0.49740933)$$

$$= 21.951908\ \mu g.\ cm.^{-2}\ min.^{-1}$$

$$A = \frac{i\ (0.49740933)}{21.951908}$$

$$A = i\ (0.0226590477)$$

IV Response Times and Residual Drift

	Including electrode insertion disturbance		Excluding electrode insertion disturbance	
	Equilibration time		Equilibration time	
	2 min.	5 min.	1 min.	5 min.
Residual Drift	0.5 μa	0.1 μa	0.5 μa	0.1 μa

Measurements were made in distilled water at 23°C. and at an oxygen diffusion rate of 22 $\mu g.\ cm.^{-2}\ min.^{-1}$.

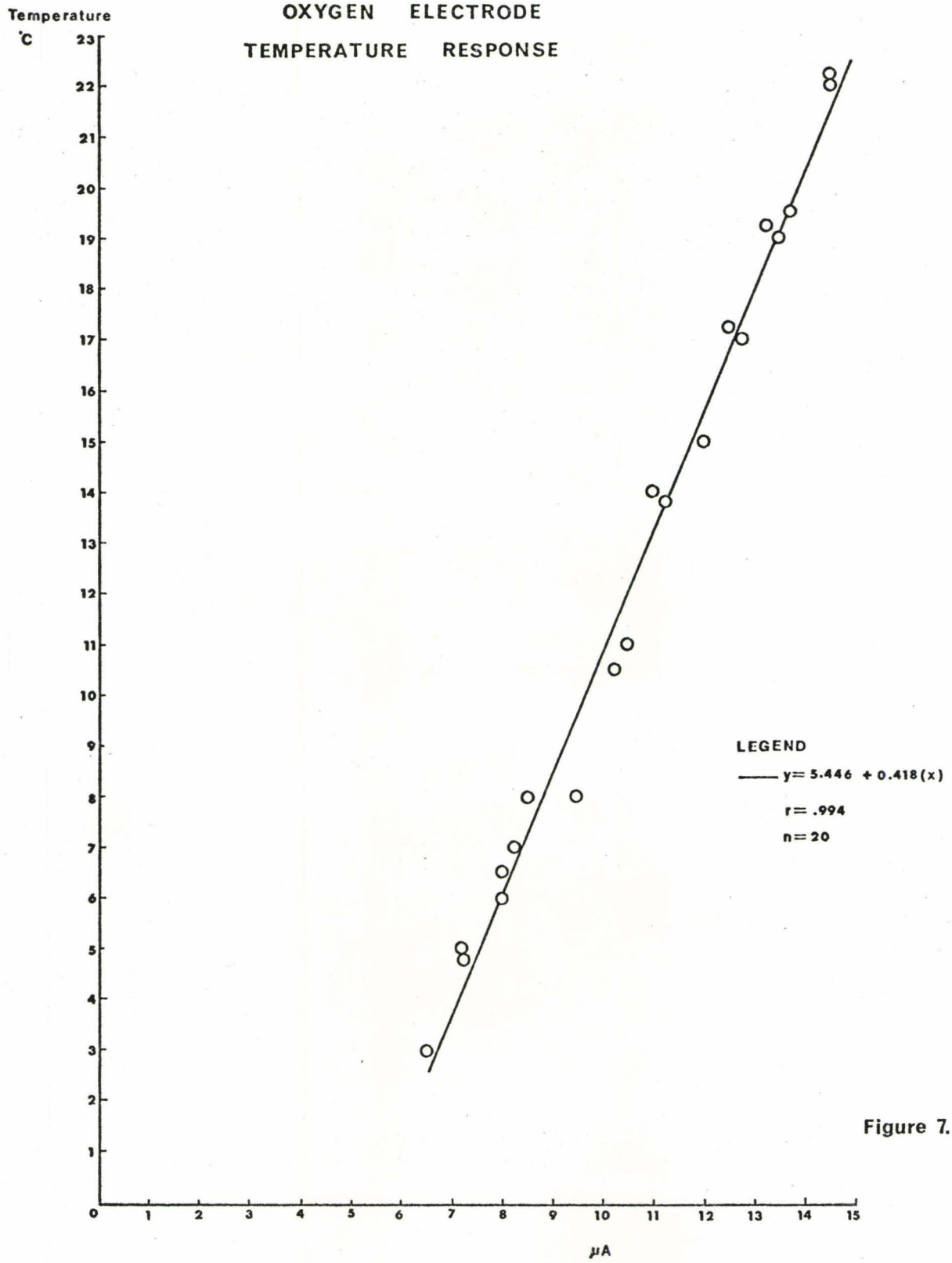

OXYGEN ELECTRODE
TEMPERATURE RESPONSE
Temperature
°C
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
µA
LEGEND
y= 5.446 + 0.418(x)
r= .994
n=20

Figure 7.

to a standard temperature was unnecessary. All measurements were made with an applied voltage of 0.50 volts as suggested by Birkle et al..

3. In situ Measurement of the Total Coliform Group of Soil Organisms

The standard procedure for measuring total coliforms in water (Taras, 1971) was modified for measuring total coliforms in soil. The details of the experimental method follow.

Coliform Levels (Total Coliform Group by Standard Membrane Filter Procedure)

I Laboratory apparatus (based on 3 dilutions per sample)

1. sterile sample containers: plastic bags (1 per sample)
2. sterile glass dilution bottles (3 per sample)
3. sterile disposable pipette, 10 ml. graduated to 1/10 ml. (3 per sample)
4. 100 ml. graduated cylinder
5. 500 ml. flask to contain culture medium
6. sterile disposable culture dishes (3 per sample)
7. sterile disposable filter membranes and culture pads (3 per sample)
8. filtration units consisting of vacuum pump, vacuum necked flasks and filter holding assembly
9. fine tweezers
10. incubator
11. bunsen burner
12. aluminum foil

13. autoclave or oven at 170°C.

14. Beach mixer and mixing cups

II Reagents

1. Culture medium: MF or MFC Endo Broth--follow proportions on bottle label for making culture medium.

2. Buffered dilution water. To prepare stock phosphate buffer solution, dissolve 34.0 gm. potassium dihydrogen phosphate KH_2PO_4 in 500 ml. of distilled water, adjust to pH 7.2 with 1N NaOH and dilute to 1 liter with distilled water. Add 1.25 ml. stock phosphate buffer solution to 1 liter distilled water.

3. 95% ethyl alcohol

III Procedure

A Introduction

The accuracy of the method depends on a) the sterility of the procedure and b) the speed with which the analysis is carried out. The following are pre-sterilized: 1. sample bags, 2. pipettes, 3. culture dishes, 4. filter membranes and culture pads. The following must be sterilized and kept as sterile as possible: 1. dilution bottles containing dilution water, 2. culture medium, 3. filtration units, 4. tweezers and 5. work surfaces.

B Sampling Procedure

Unfortunately, there is no easy way to obtain sterile sub-surface soil samples. The best sampling method is to dig a soil pit,

sample the pit face with sterile sample cans, which are then placed in sterile plastic bags, labelled and placed in a cooler for transport to the laboratory. Store samples awaiting analysis in the refrigerator.

C Laboratory Procedure

1. All work surfaces are sterilized by washing with ethyl alcohol.

2. The culture medium is prepared.+ The necessary volume is computed as 6 ml. per sample plus 50 ml. extra. The correct weight of medium is dissolved in the correct volume of distilled water and the solution is brought to a boil slowly. The medium is removed from the heat as soon as it boils and covered with aluminum foil. When cool, it is stored in the refrigerator.

3. 1.8 to 2.2 ml. of culture medium is plated onto each pad in the culture dishes (3 per sample).+ Too little medium results in poor contact with the filter membrane and inhibits colony growth. Too much medium floats the colonies around on the filter membrane making distinct counts impossible. The culture dishes are sealed and stored in the refrigerator.

4. Using the graduated cylinder, 90 ml. of buffered dilution water is put into each dilution bottle.

5. The following are autoclaved or sterilized: 1. the dilution bottles and dilution water in them and 2. the filter membrane apparatus wrapped in aluminum foil.

+ Culture medium and culture dishes with the medium in them may be prepared 2-3 days in advance.

6. This step is done as quickly as possible. The soil sample is removed from the refrigerator. 0.5 gms. are weighed into an aluminum weighing dish. It is transferred immediately to 500 ml. of sterile distilled water in a flask. The sample and water are mixed with the Beach mixer. The aluminum mixing cup is rinsed thoroughly first with alcohol, then with distilled water, between samples. The mixed suspension is placed back in its flask.

7. Using a sterile pipette, 10 ml. of mixed sample suspension from step 6 is placed in a dilution bottle.# The pipette is rinsed with buffered dilution water. The bottle is shaken vigorously 25 times; 10 ml. are pipetted into the next bottle (using the same pipette). The preceding steps are repeated until the desired number of dilutions are obtained for the sample. The pipette is labelled with the sample number and stored between sterile paper towels.

8. Step 7 is repeated for each sample.

9. Using the correct pipette for the sample, 20 ml. of sample from the first dilution is pipetted into the filter membrane apparatus. The sample is filtered under suction onto the filter membrane. The tweezers are dipped in alcohol and flamed. The filter membrane is removed with the sterile tweezers and placed in a culture dish on the pad. The culture dish lid is closed and the dish labelled with the dilution and sample numbers.

Coliforms settle out of suspension very quickly (1-2 minutes). Thus the sample must be mixed before any transfer by pipette is made.

10. Step 9 is repeated for each sample dilution.

11. Steps 9 and 10 are repeated for each sample.

12. The culture dishes are placed in the incubator at $35^{o}C. \pm 0.5^{o}C.$ for 22-24 hours. The resultant colonies are counted by eye or magnifying glass. Those plates which result in 20 to 120 colonies are counted. The ideal count is around 60. The coliform density may be expressed as coliforms per gram of wet soil or coliforms per ml. of soil solution or coliforms per 100 ml. of water.

13. Calculations. Coliforms per gm. of wet soil may be calculated as follows:

$$\frac{\text{colonies counted} \times \text{dilution in flask } (10^{3}) \times \text{dilution pipetted } (10^{1}\text{-}10^{3})}{\text{ml. of sample filtered (20)}}$$

Coliforms per ml. of soil solution were computed with a Fortran program, COLML.

14. The filter membranes with the colonies may be preserved for a short time by placing them in the freezer. They may be preserved permanently by drying the filter membrane.

4. In situ Measurement of Soil Gases by Gas Chromatography

(a) Introduction

A review of the literature was made in an attempt to find a routine isothermal method capable of measuring the major gaseous components of saturated and moist soils. Two major problems appear to limit the application of gas chromatography to the measurement of soil gases both in the field and in monitoring systems for artificial soils

in the laboratory. The initial problem is in the sampling, transport and storage of soil gases using a system which ensures no change in the soil atmosphere composition; the second is the present apparent over-specialization of gas chromatography (GC) techniques, for those developed so far are usually highly specific to narrow experimental designs not normally relatable to the special problems of analytical work in soils.

The problem then was two-fold: (i) to develop a simple technique which solved the sampling and storage problems and (ii) to develop an adaptation of GC techniques which was more specifically applicable to the routine analysis of soil gases under isothermal conditions and of use in both saturated and moist soils.

(b) Sampling and Storage

Many types of diffusion wells and sampling containers have been developed. Most sampling systems are complicated and expensive, requiring special machining, as in Raney (1949), Yurkevich et al. (1966), Burford and Millington (1968) and Tackett (1968). Some systems are too large or cumbersome to enable detailed or repetitive sampling--for example, Boynton and Reuther (1938) and Hack (1956)--or else their application involves a complex experimental design which ultimately aims at providing an averaged value from many individual determinations (Rodgers and King, 1965), which is the antithesis of what is required in work on soils.

In general, sophisticated inert wells specific to one gas, as used by Dowdell et al. (1972), are not necessary for routine analysis

of the major gaseous components of hydromorphic soils: O_2, N_2, CO_2, CH_4. Macro- and micro-wells similar to those of Tackett (1968), but much simpler in design, were developed for routine field sampling (Fig. 8). Stainless steel, Tygon and glass were used for the tube shafts of the macro-wells, which were sealed by serum caps at the top, and by glasswool and fiberglass at the bottom, epoxied to the tube wall. Glasswool was used to fill the micro-wells and the steel walls were then pinched to prevent blockage on insertion into the soil (Fig. 8). The stainless steel shafts of the micro-wells have the same diameter as the oxygen microelectrodes so that both instruments measured the same micro-environment, and oxygen diffusion rates and gaseous oxygen concentration were directly comparable.

Designs for storage containers are as prolific as those for samplers. Most early storage systems (Kurayev, 1967) were cumbersome and expensive and required custom-built pipette-like apparatus. The recent trend is for storage in syringes, for example, Dowdell et al. (1972). Various types of bottles have also been used--Boynton and Compton (1944), Yurkevich et al. (1966). A wide variety of commercial storage bottles is available (Chromatographic Specialties Ltd., Brockville, Ontario). Efficient transfer of samples from the storage apparatus to the gas-tight syringe for GC analysis is difficult to achieve. A gas-tight valve (Hamilton Co., Whittier, California, GTS valve, product no. 86560), fitted to the needle hub, virtually eliminates diffusion losses during transfer of the sample from the storage apparatus to the GC injection port.

Usually samples have to be analyzed as soon as possible after

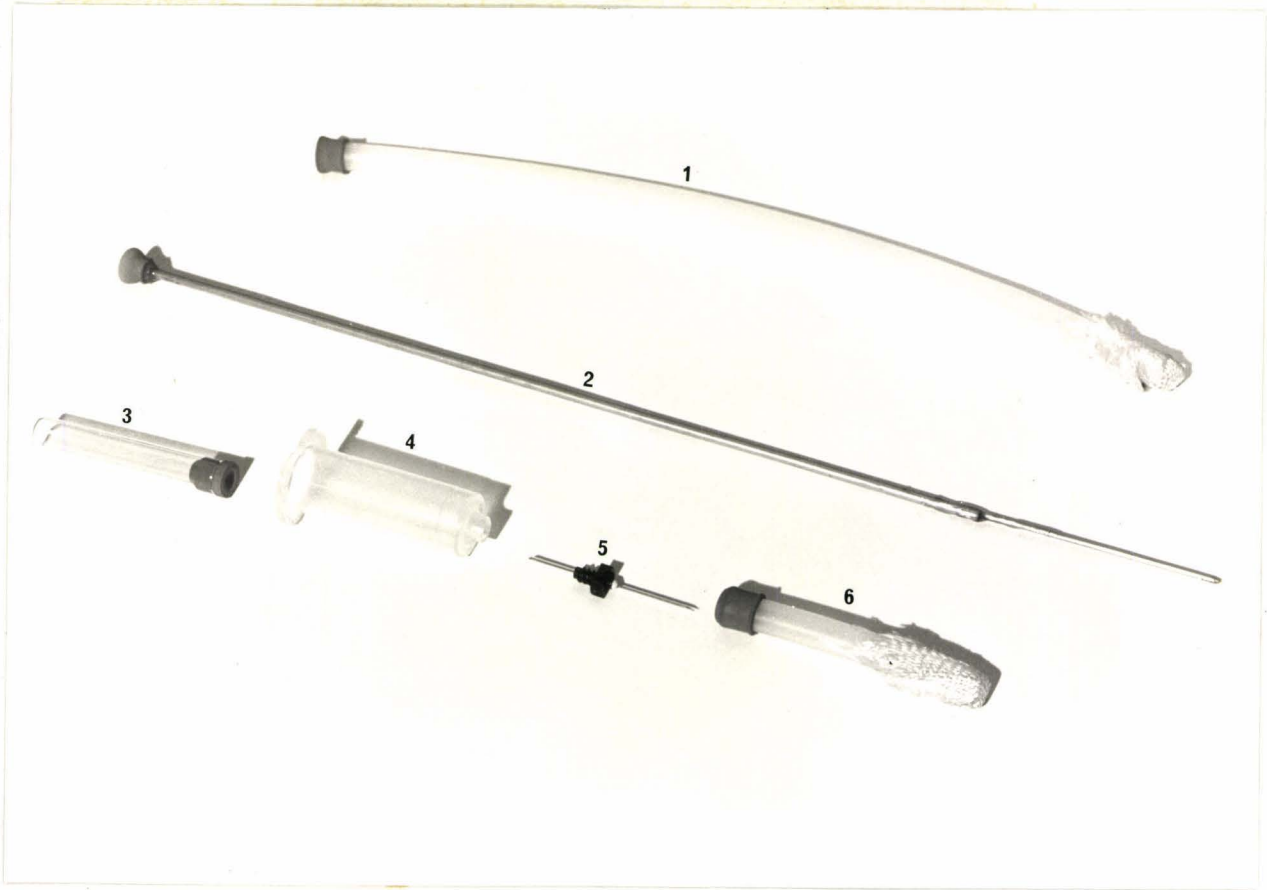


Figure 8. The components of the sampling system.

1. macro-diffusion well, ¼" O.D. x 12" (6.25 mm. x 30 cm.)
2. micro-diffusion well, 1/16" O.D. x 15" (1.56 mm. x 37.5 cm.)
3. 3 ml. Vacutainer
4. Vacutainer holder
5. Vacutainer needle
6. macro-diffusion well, ¼" O.D. x 3" (6.25 mm. x 7.5 cm.)

field sampling. Very little precise information has been published concerning the effect of storage on gas samples. Most authors assume or hope the effects are small. Initial attempts by the author at storing gases met with limited success. Soil gases were stored over oil in 1 cm. diameter glass incubation tubes. The CO_2 content in air samples at 25°C. rose from 0.2% to 0.4% in six hours, but storage for up to five days produced little further change. After five days, the measured changes were significant and unpredictable. Long-term storage of soil gases over oil in glass tubes at low temperature (-20°C.) was also unsuccessful.

A second approach was to borrow the technology developed for sampling and storing blood serum. Evacuated glass tubes stoppered with serum caps--Vacutainers (Becton-Dickinson & Co. (Canada) Ltd., Clarkson, Ontario)--were used to extract the soil air from the sampling wells and for storing the samples for long periods of time. A special double-ended needle in a holder is inserted into the sampling well. The Vacutainer is inserted over the upper needle and the soil air is drawn up into it. For GC analysis, the gas-tight syringe is filled directly from the Vacutainer containing the soil air sample (Fig. 8). Soil gases stored in Vacutainers at -6 to -12°C. for 3 weeks showed no detectable changes in composition (Fig. 9).

(c) Adaptation of GC Techniques for Soil Gas Analysis

A simple, cheap, sensitive, isothermal system for the analysis of soil gases should incorporate the most well-known and versatile packing materials, Molecular Sieve 5A and Porapak Q, and should elute

Effect Of Storage On Soil Atmosphere Samples

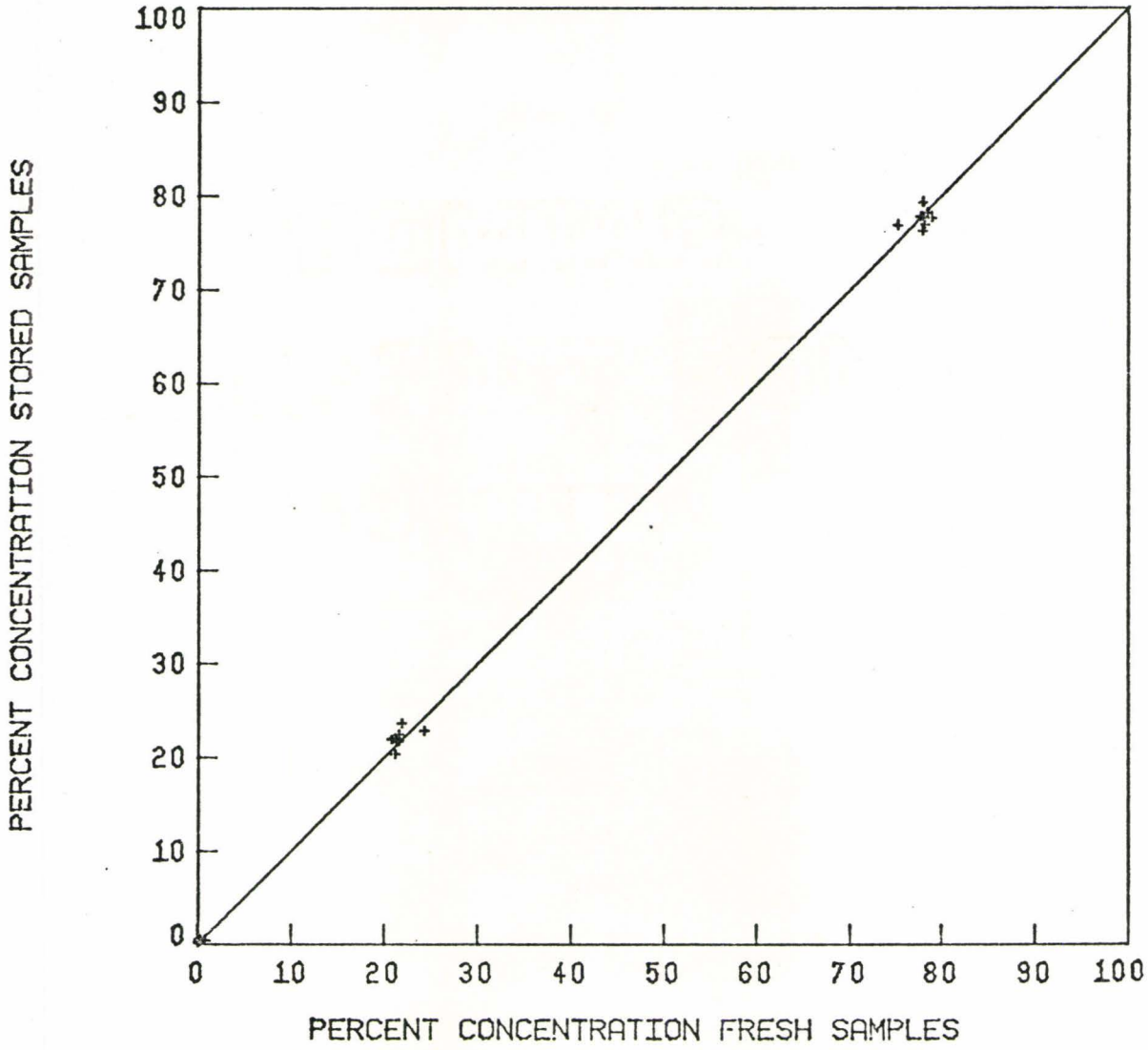


Figure 9.

all the gases on to one chromatogram. Such a system has been developed utilizing the different packing materials in an isothermal tandem arrangement. The cost involved is minimal, i.e. the cost of tubing and fittings alone. The columns are easily packed by hand and most of the gases of interest in soil atmosphere analysis can be measured.

The normal katharometer arrangement is to have two columns and two detectors arranged in parallel (Fig. 10). The sample is injected into one column and passes through one detector. The other column and detector are used as a reference. The columns must be identical in length and packing materials. The parallel arrangement in the Pye Unicam 104 was altered by connecting the detectors and columns in tandem, enabling the use of two different packing materials, one in each column (Fig. 11). The first column is 80-100 mesh Porapak Q and the second is 60-80 mesh Molecular Sieve 5A. The sample from the gas-tight syringe is injected on to the Porapak Q column at 20°C. The O_2 and N_2 elute simultaneously as a composite curve (Fig. 12). The CO_2 is adsorbed and held for about 2 minutes. Thus the second curve (Fig. 12) is the CO_2 peak. While the CO_2 is adsorbed on the Porapak Q, the sample is delayed from entering the second column by passing it through 20 meters of copper tubing (Fig. 11). After the CO_2 is eluted and passes the first detector, the sample enters the Molecular Sieve column. The adsorption-desorption sequence in this column is very rapid. The Molecular Sieve separates the O_2 and N_2. As the O_2 and N_2 pass the second detector, these peaks follow closely upon the CO_2 peak (Fig. 11).

PYE 104 KATHAROMETER SCHEMATIC

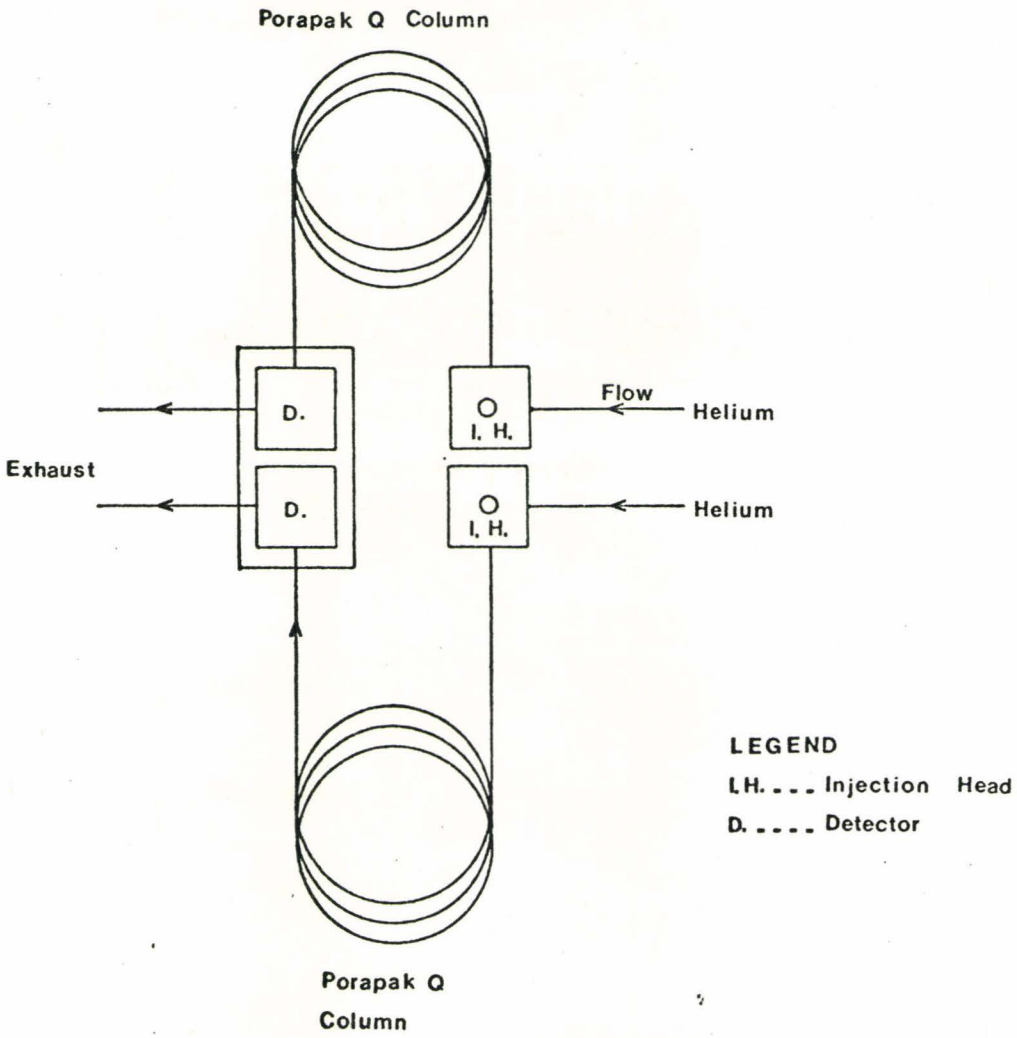
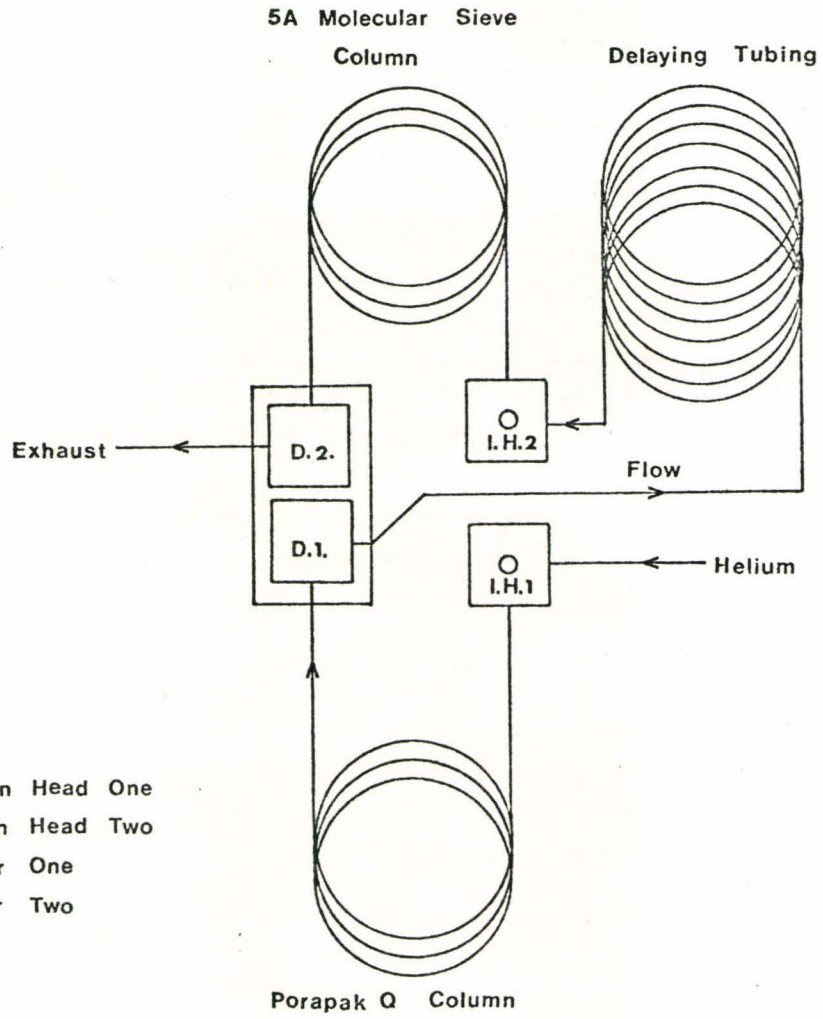


Figure 10.

SCHEMATIC OF
A MODIFIED PYE 104 KATHAROMETER



LEGEND

I.H.1	Injection Head One
I.H.2	Injection Head Two
D.1.	Detector One
D.2.	Detector Two

Figure 11.

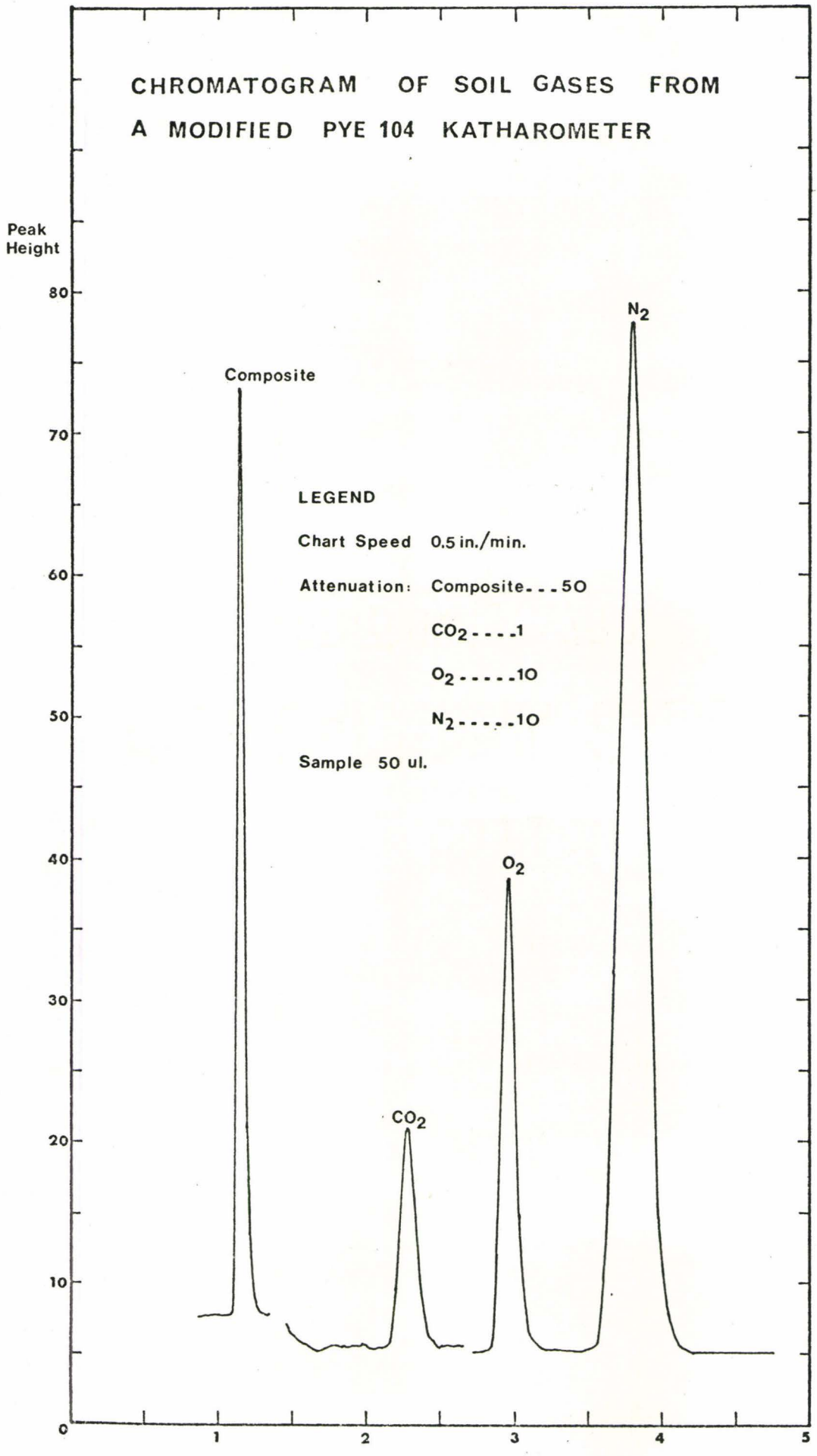

CHROMATOGRAM OF SOIL GASES FROM
A MODIFIED PYE 104 KATHAROMETER
Peak Height
80
70
60
50
40
30
20
10
0
1
2
3
4
5
Composite
N_2
O_2
CO_2
LEGEND
Chart Speed 0.5 in./min.
Attenuation: Composite...50
CO_2....1
O_2.....10
N_2.....10
Sample 50 ul.

Figure 12.

Despite differing resistances to carrier gas flow in the columns, the system is balanced by arranging the columns in tandem and separate flow controllers are unnecessary. In order to minimize temperature fluctuations, the delaying tubing is placed in the oven with the columns. The second injection port can be used to inject samples onto the second column separately if so desired. The Molecular Sieve adsorbs moisture, resulting in a loss of resolution between the O_2 and N_2 peaks. To restore the separation of O_2 and N_2, this column has to be baked at 300°C. Since Porapak Q has a temperature limit of 250°C., it must be disconnected if the GC oven is used to restore the Molecular Sieve columns. Using an external oven enables the preparation of spare dry columns, avoiding delays waiting for the Molecular Sieve column to bake. Since it is difficult to find an oven large enough and with sufficient heating capacity to accommodate commercially-prepared columns, the copper columns were coiled small enough to fit into a muffle furnace.

A tracing of a chromatogram of an air sample from a natural gleyed soil site at a depth of 10 cm. is provided (Fig. 12). No attempt has been made to show an artificially stable baseline and the breaks in the baseline are due to changes in attenuation and polarity. The gaseous concentrations in this sample are, approximately, CO_2--1%, O_2--21%, N_2--78%. Peak area and standards were used to determine the gaseous concentrations. The response of the Porapak Q column to carbon dioxide is stable over time as is shown in Figure 13. Thus peak height could be used to determine carbon dioxide concentrations. Figure 14 shows the response characteristics of the GC when the Molecular Sieve

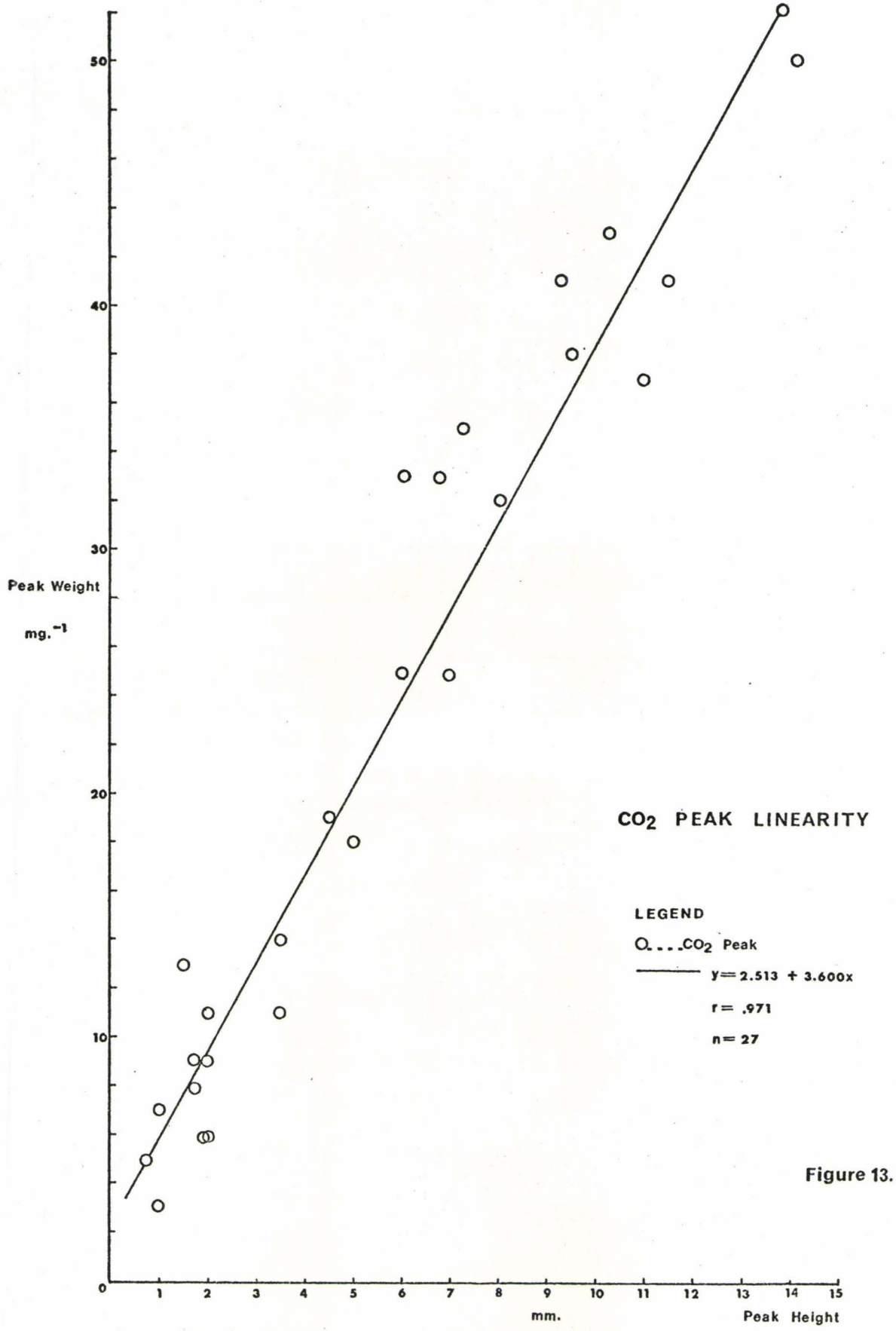

50
40
30
20
10
0
Peak Weight
mg.⁻¹
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
mm.
Peak Height
CO2 PEAK LINEARITY
LEGEND
O . . . CO2 Peak
y = 2.513 + 3.600x
r = .971
n = 27

Figure 13.

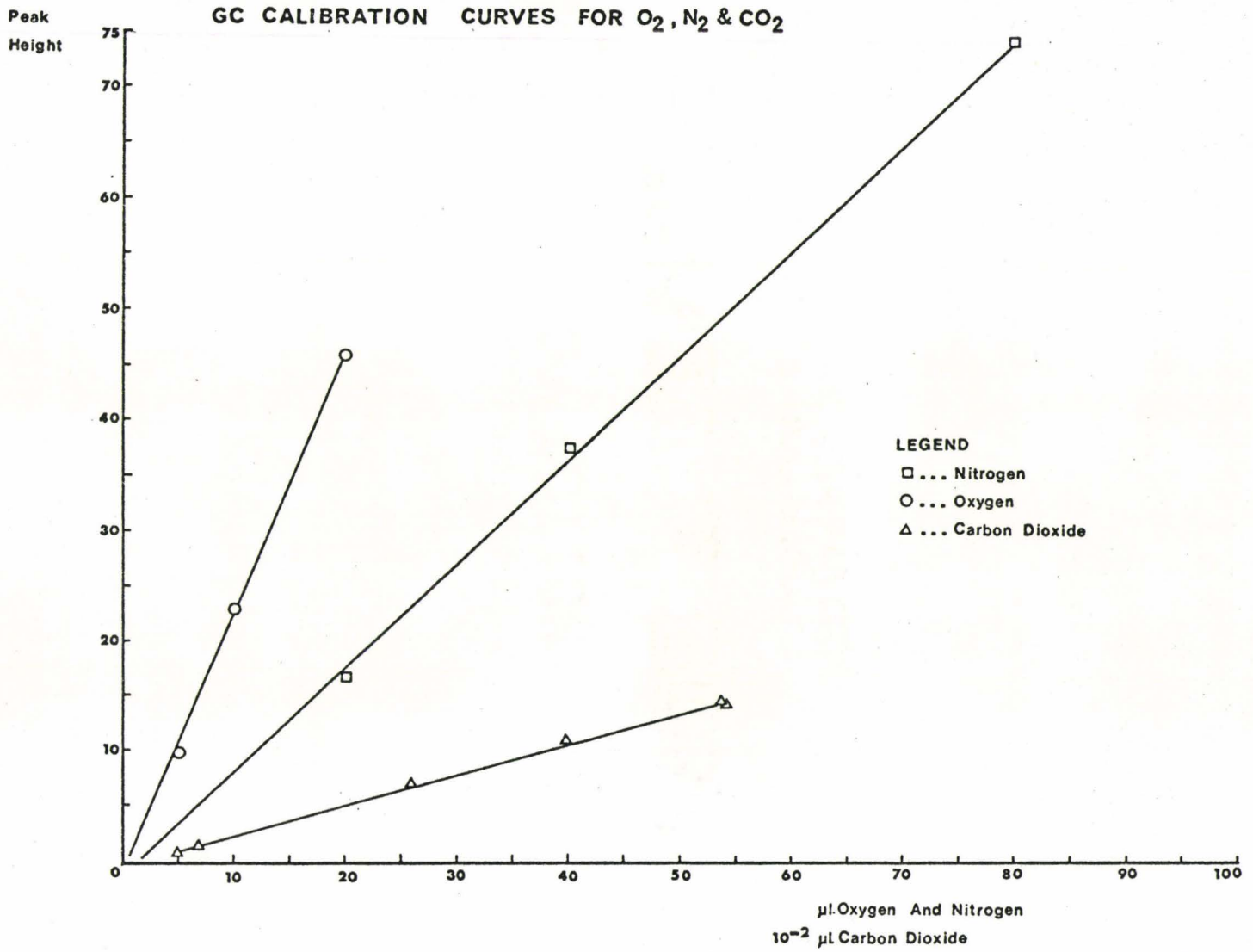

GC CALIBRATION CURVES FOR O_2, N_2 & CO_2
Peak Height
75
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
LEGEND
□ ... Nitrogen
○ ... Oxygen
△ ... Carbon Dioxide
µl. Oxygen And Nitrogen
10^{-2} µl Carbon Dioxide

Figure 14.

column has just been baked.

The system is more versatile than our application would indicate. A soil solution could be analyzed on this system by operating the Porapak Q column at elevated temperatures of 150°C.; CH_4 and H_2 can be measured directly on the same system, though such are not normally present in detectable quantities in aerobic soils. To detect other peaks eluted from the Porapak Q column--in elution order, NO, NO_2, N_2O, C_2H_4, C_2H_6, PH_3, H_2S, H_2O--might require alteration of the elution of the O_2 and N_2 peaks to fall between two of the peaks from the Porapak Q column. The rapid adsorption-desorption sequence on the Molecular Sieve 5A makes this feasible, most probably between the N_2O and C_2H_4 peaks. The elution time of the O_2 and N_2 peaks can be changed by altering the length of the delaying tubing. The detection of low concentrations of hydrocarbons and oxides of nitrogen in the ppm range would also require lowering the temperature of the Porapak Q column, as described by Bailey and Beauchamp (1973).

5. Laboratory Measurement of Soil Variables by Electrode Potentials and Resistance

The most common procedures for measuring electrical conductivity, redox potential, pH and specific ionic levels use extracts from saturated soil pastes (Mack and Sanderson, 1971). Electrical conductivity, redox potential and pH can also be measured *in situ* by standard techniques (Pierce, 1953; van Praag *et al.*, 1970). The preparation of saturated soil pastes is time consuming (Allison, 1973). *In situ* measurement of electrical conductivity, redox potential and pH requires

hand construction of field electrodes, since they are not available commercially. These standard procedures were not feasible when measuring simultaneously 8 sites at 5 or more levels. Measuring electrode potentials or resistance in soil solutions consisting of fresh moist soil diluted with distilled water was chosen as a feasible alternative. Diluting the original soil solution reduces the measurable lower limit of detection. In natural soils exhibiting low levels of many ionic species this would be a serious methodological limitation. Diluting the soil solution presents no serious problems in polluted soils where ionic concentrations are high and where high concentrations are of primary concern.

Specific ion electrodes are not totally ion selective and are subject to interferences from other ionic species of similar hydrodynamic radii to the one being measured. Diluting the solution tends to reduce the interference effects (Woolson, 1970). Diluting the solution may increase measurement accuracy in polluted soils where several ionic species are present in high concentrations.

Electrical conductivity, redox potential, pH and specific ionic levels were measured in soil solutions. The soil solutions were made by mixing a fresh sample of known volume in 50 ml. of distilled water. Electrical conductivity was measured with a conductivity cell and Wheatstone Bridge. The other electrode measurements were completed on the digital Orion Ion Analyzer, accurate to $\pm$ 0.1 mv. and $\pm$ 0.001 pH units, within 1 week of sampling. Samples and soil solutions were refrigerated when measurements were not in progress. The measurements

for electrical conductivity, redox potential and pH were recorded as the electrode potential or resistance developed in the soil solution.

Solutions of known ionic species and molar concentrations, prepared in the laboratory and commercially, were used to construct calibration curves (Fig. 15). Molar concentrations in the soil solution were calculated from electrode potentials using these calibration curves. The soil solutions were dried on a water bath and the air dry weights of soil determined. The volume of original soil solution in the sample was determined from the air dry weight and the volume and weight of the fresh soil sample. The molar concentrations of specific ions were recalculated to concentrations in the original soil solution and recorded as a second set of ionic levels.

6. Laboratory Measurement of the Grain Sizes of the Mineral Component of the Soil

The grain size distribution of the mineral component of the soil was analyzed down to 37 microns by sonic sifting pretreated soil. Time constraints prevented analysis of the grain sizes less than 37 microns. The textural distributions displayed in Figures 1 and 2 suggest grain sizes less than 37 microns are not an important component of the total grain size distribution.

Samples of air dried < 2 mm. soil were pretreated to remove organic matter and carbonates, which bind mineral particles together. Organic matter and carbonates were removed by loss on ignition at 550°C. (LOIL) and 850°C. (LOIH) respectively. Five to ten grams of pretreated soil were then sieved in the sonic sifter (Allen-Bradley Co., Milwaukee,

Calibration Curves For Specific Ion Electrodes

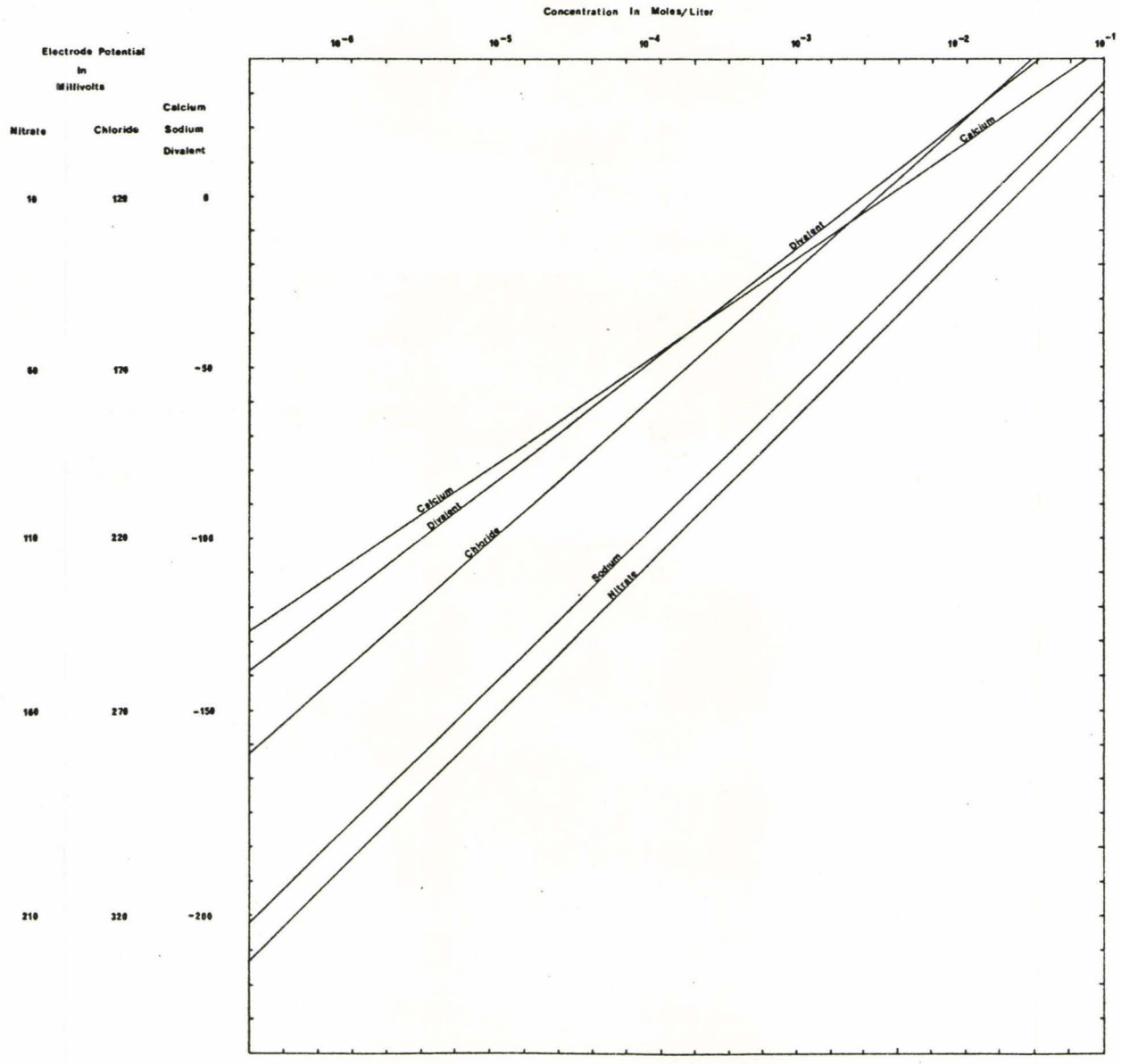


Figure 15.

```
      PROGRAM TEXTUR (INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7
     1=PUNCH)
C     PROGRAM TO COMPUTE TEXTURE IN PERCENT
C     WR=CRUDE WT. GMS.  ST=STACK WTS.  WT=NET WTS.  WN,WA=TEXTURE PERCENT
      K=10 $ L=6 $ M=4 $ N=72
      DIMENSION WR(K),ST(K),WT(K),WN(M),WA(L),WAP(L)
      DATA ST/435.70,396.26,358.76,279.92,35.723,34.294,33.365,32.189,
     1 34.010,154.330/
      WRITE (6,29)
  290 FORMAT (1H1,74H SITE    850    500    210    PAN    177    105
     174    63    37    FINES)
      NCOUNT=1
   11 READ (5,70) ISITE,WR
   70 FORMAT (I3,10F7.0)
      SUMU=0.
      SUMW=0.
      DO 20 I=1,K
      WT(I)=WR(I)-ST(I)
      IF(WT(I).LT.0.)WT(I)=0.
   20 CONTINUE
      DO 22 I=1,L
      IF (I.GT.M) GO TO 21
      SUMU=SUMU+WT(I)
   21 WA(I)=0
      J=I+M
      SUMW=SUMW+WT(J)
   22 CONTINUE
      DO 24 I=1,L
      IF (I.GT.M) GO TO 23
      WN(I)=100.*(WT(I)/SUMU)
   23 J=I+M
      WA(I)=100.*(WT(J)/SUMW)
   24 CONTINUE
      DO 25 I=1,L
      WAP(I)=WA(I)*(WN(M)/100.0)
   25 CONTINUE
      WRITE (6,35) ISITE,WN,WAP
      PUNCH (7,35) ISITE,WN,WAP
   35 FORMAT (1X,I4,10F7.2)
      NCOUNT=NCOUNT + 1
      IF (NCOUNT.LE.N) GO TO 11
      STOP
      END
```

```
      PROGRAM SKEWKUR (INPUT,OUTPUT,TAPE 5=INPUT,TAPE 6=OUTPUT)
C     X=TEXTURAL INTERVALS IN PERCENT
C     N=NUMBER OF CLASS INTERVALS OR NUMBER OF GRAIN SIZE FRACTIONS
C     SUMX=MEAN OF A SAMPLE=1ST MOMENT
C     SUMVAR=2ND MOMENT
C     SUMSKV=3RD MOMENT
C     SUMKRT=4TH MOMENT
C     SDEVX=STANDARD DEVIATION
C     COSKV=COEFFICIENT OF SKEWNESS
C     COKRT=COEFFICIENT OF KURTOSIS
C     SZ=MID POINT OF CLASS INTERVAL IN PHI UNITS
      DIMENSION X(9),SZ(9)
      DATA SZ/-0.625,0.375,1.625,2.375,2.875,3.5,3.875,4.375,5.7/
      WRITE (6,80)
  800FORMAT (1H1,75H SITE  SUMX       SUMVAR     SUMSKV      SUMKRT    SDEV
     1X       COSKV      COSKRT )
      NCOUNT=1
      N=9
   90 READ (5,100) ISITE,(X(I),I=1,N)
  100 FORMAT (1X,I4,3F7.2,7X,6F7.2)
      SUMX=0
      DO 10 I=1,N
   10 SUMX=SUMX + X(I)*SZ(I)
      SUMX=SUMX/100
      SUMVAR=0.
      SUMSKV=0.
      SUMKRT=0.
      DO 20 I=1,N
      SUMVAR=SUMVAR+((SZ(I)-SUMX)**2)*X(I)
      SUMSKV=SUMSKV+((SZ(I)-SUMX)**3)*X(I)
   20 SUMKRT=SUMKRT+((SZ(I)-SUMX)**4)*X(I)
      SDEVX=SQRT(SUMVAR)
      COSKV=SUMSKV/(SDEVX**3)
      COKRT=(SUMKRT/(SDEVX**4))-3.
      WRITE (6,200) ISITE,SUMX,SUMVAR,SUMSKV,SUMKRT,SDEVX,COSKV,COKRT
  200 FORMAT (1X,I4,5F10.2,2F10.5)
      NCOUNT=NCOUNT+1
      IF (NCOUNT.LE.72) GO TO 90
      STOP
      END
```

```
      PROGRAM SURFACE (INPUT,OUTPUT,TAPE 5=INPUT,TAPE 6=OUTPUT)
C     PROGRAM TO COMPUTE SPECIFIC SURFACE AREA FROM TEXTURAL DATA
C       MS=SOIL WEIGHT PER 100 GMS.  PD=PARTICLE DENSITY GMS./CC.
C     SZ=AVERAGE SIZE OF SUBSAMPLE  AS=SPECIFIC SURFACE AREA OF A SUBSAMPLE
C     AT=SPECIFIC SURFACE AREA OF A SITE SAMPLE (SUM OF SUBSAMPLES)
      DIMENSION MS(9),SZ(9),AS(9)
      REAL MS
      DATA SZ/1425.,675.,355.,193.5,141.,89.5,68.5,50.,18.5/
      WRITE (6,4)
    4 FORMAT (1H1,18H     AS       AT     )
      NCOUNT=1
   11 READ(5,5) MS
    5 FORMAT (5X,3F7.2,7X,6F7.2)
      AT=0.
      PD=2.507
      DO 10 I=1,9
      AS(I)=400.*MS(I)/(PD*SZ(I))
      AT=AT+AS(I)
      PRINT 25,AS(I),AT
   25 FORMAT (1X,2F10.4)
   10 CONTINUE
      NCOUNT=NCOUNT+1
      IF (NCOUNT.LE.72) GO TO 11
      STOP
      END
```

Wisconsin, U.S.A.). Two sieve stacks of four sieves each were used. The sieve sizes in microns from coarse to fine were: 850, 500, 210, 177, 105, 74, 63 and 37. Sieves and soil were weighed on an electronic balance to ± 1 mg. The percentage textural distributions were calculated from the weighings by the computer and Fortran program TEXTUR listed in this section.

Skewness and kurtosis values of the grain size distributions and the specific surface area of the mineral grains were calculated from the Fortran programs SKEWKUR and SURFACE respectively, which are also listed in this section. The calculation of the surface area of the mineral grains was based on the formula reported in Physical Edaphology (Taylor, 1972).

7. Laboratory Measurement of Soil Organic Carbon

A modified Walkley and Black (1934) method was used to measure organic carbon. Thomson (1972) modified the procedure of Walkley and Black to eliminate the titration by using adsorption spectrophotometry and sucrose calibration curves. One such sucrose calibration curve is shown in Figure 16. The details of the experimental method follow.

Organic Carbon Determination

Acid Dichromate Digestion: Spectrophotometric Method

I Reagents

1. Potassium dichromate $K_2Cr_2O_7$ 1.0 N, dissolve 49.04 gms. $K_2Cr_2O_7$ in 1 l. distilled water.

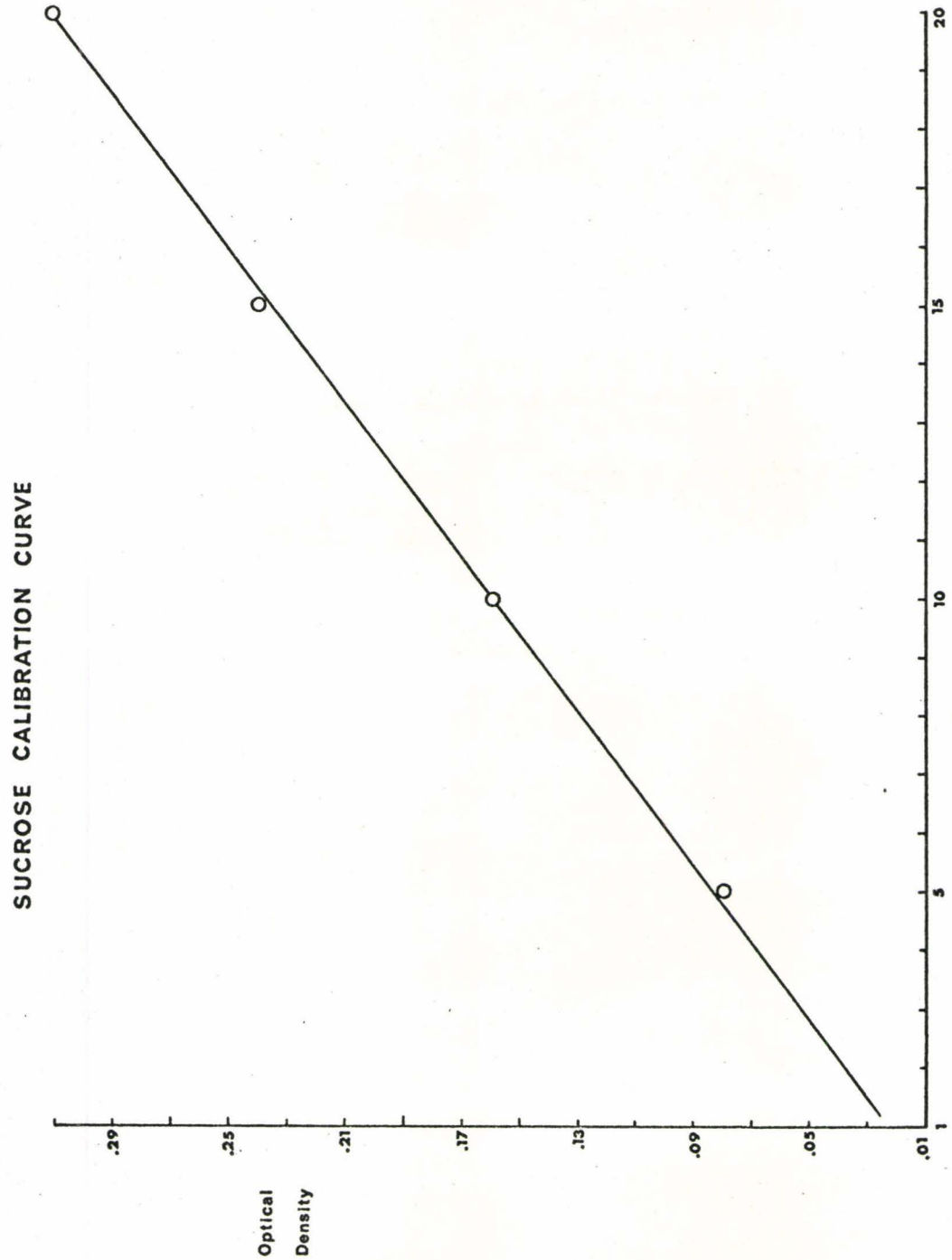

SUCROSE CALIBRATION CURVE
Optical Density
.29
.25
.21
.17
.13
.09
.05
.01
1
5
10
15
20
Milligrams Carbon

Figure 16.

2. Sulfuric acid H_2SO_4 (96%)

II Procedure

1. Use 0.100 to 0.500 gms. of pretreated soil (air dry, ground and sieved to less than 2 mm.). Use 0.500 gms. soil for samples with low organic matter contents and less soil for samples with high organic contents. Place soil in a clean 500 ml. Erlenmeyer flask.

2. Add 10 ml. of reagent (1) potassium dichromate.

3. Add 20 ml. of reagent (2) sulfuric acid. Swirl vigorously for 1 minute. Let flask stand on a sheet of asbestos for 30 minutes.

4. Add 150 ml. of distilled water.

5. Filter part of the solution. Suction may be used.

6. Transfer a small portion of the filtrate to a spectrophotometer curvette. The curvette should be half full.

7. With the wavelength set at 620 mμ, calibrate the spectrophotometer+ against the blank supplied or make a blank. Blanks can be made by repeating the experiment, steps 1-6, but without using any soil. The blank should read 0.0 absorbance on optical density. The machine must be properly zeroed first.

8. Place the sample in the curvette into the spectrophotometer and read off the absorbance.

9. Using the absorbance or optical density of the sample, find the mg. of carbon in the sample from the sucrose calibration curve supplied.

+ Spectrophotometer readings were made on a Bausch and Lomb Spectronic 20.

If a calibration curve is not supplied, construct one from the procedure in step 10.

10. A sucrose calibration curve is constructed by repeating the experiment, steps 1-6, with known carbon samples. 2.38 gms. of sucrose are dissolved in 100 ml. of distilled water, resulting in a 2.38% sucrose solution with a 1% carbon content. Aliquots of 0.5 ml., 1.0 ml., 1.5 ml. and 2.0 ml. of sucrose solution containing 5.0 to 20.0 mg. of carbon are pipetted into Erlenmeyer flasks. The experiment, steps 1-9, is repeated using the aliquots as samples. The calibration curve is constructed from the absorbance readings and known carbon contents of the aliquots.

Calculations:

Organic Carbon Content in percent

$$= \frac{\text{total carbon (mg.)} \times 100}{\text{wt. of sample (mg.)}^{*}}$$

* 1 gm. = 1000 mg.

APPENDIX B

DATA SUMMARIES, CORRELATION MATRIX FROM THE MAIN SURVEY AND FACTOR LOADINGS ON THE FINAL FACTOR SOLUTIONS

TABLE 22. The Means, Standard Deviations and Units of Measurement for the Soil Variables Excluding Ionic Levels

TABLE 23. The Means and Standard Deviations in Moles per Litre, Grams per Litre and Parts per Million for Soil Ionic Levels

TABLE 24. Levels of Total Coliform Group of Soil Organisms from the Sampling Sites along Ancaster and Grindstone Creeks

TABLE 25. Correlation Matrix of the Data from Ancaster Sites

TABLE 26. Principal Components Varimax Rotated Factor Matrix

TABLE 27. Orthogonal Varimax Rotated Factor Matrix

TABLE 28. Oblique Factor Structure Matrix After Rotation

TABLE 22. The Means, Standard Deviations and Units of Measurement for the Soil Variables Excluding Ionic Levels

Variable (Computer Symbol)	Mean	Standard Deviation	Units of Measurement
DEPTH	10.29	5.71	inches
LOIL	6.93	2.75	percent by weight
LOIH	8.56	5.11	percent by weight
COLML	15.03	23.19	10^7 per ml. of soil solution
COLGM	140.94	231.18	10^7 per gm. of wet soil
BHOV	26.24	9.77	percent by volume
BHOW	31.64	13.80	percent by weight
BBDV	0.87	0.24	gms./cc.
HYGV	1.54	0.52	percent by volume
HYGW	1.89	0.83	percent by weight
XOK	2.16	0.79	percent by weight
HD	33.12	53.84	houses
DH	391.29	252.97	feet
GSA	2.11	2.53	percent by weight
GSB	6.12	4.46	percent by weight
GSC	21.57	4.37	percent by weight
GSD	6.83	2.10	percent by weight
GSE	15.79	4.63	percent by weight

Variable (Computer Symbol)	Mean	Standard Deviation	Units of Measurement
GSF	10.39	2.22	percent by weight
GSG	4.46	1.35	percent by weight
GSH	16.47	3.63	percent by weight
GSI	16.50	3.74	percent by weight
SKEW	1.01	0.02	dimensionless
XKUR	7813.63	300.71	dimensionless (-2.9×10^{-5})
SSA	259.32	38.77	$cm.^2$
BDY	1.07	0.21	gms./cc.
DHOW	29.87	9.31	percent by weight
DHOV	31.78	10.06	percent by volume
ODR	38.85	25.59	$\mu g.\ cm.^{-2} min.^{-1}$
OX	21.46	1.16	percent by volume
XNN	78.10	1.17	percent by volume
COO	0.44	0.28	percent by volume
TEMP	19.32	1.52	$^{o}C.$
PH	7.33	0.37	pH units
EH	75.08	26.45	millivolts
EK	345.97	240.53	micromohs

TABLE 23. The Means and Standard Deviations in Moles per Litre, Grams per Litre and Parts per Million for Soil Ionic Levels

Variable (Computer Symbol)	moles/litre		gms./litre		ppm	
	mean	standard deviation	mean	standard deviation	mean	standard deviation
XKAD	0.0068499	0.0083118	0.0274	0.0332	27	33
XNAD	0.0010917	0.0008502	0.0250	0.00195	25	2
XNOD	0.0007868	0.0015684	0.0487	0.0974	49	97
XMGD	0.0015762	0.0029479	0.0382	0.717	38	72
XKLD	0.0000684	0.0000449	0.00485	0.00318	5	3
XKAS	0.0586495	0.0649402	0.234	0.260	234	260
XNAS	0.0108295	0.0074842	0.248	0.172	248	172
XNOS	0.0070286	0.0138954	0.435	0.862	435	862
XMGS	0.0139251	0.025727	0.339	0.624	339	624
XKLS	0.0006514	0.0003851	0.0471	0.0273	47	27

TABLE 24. Levels of Total Coliform Group of Soil Organisms from the Sampling Sites along Ancaster and Grindstone Creeks

Site	DEPTH (in.)	COLGM ($\times 10^7$ per gm. of wet soil)	COLML ($\times 10^7$ per ml. of soil solution)
1	3	3.4	29.2
	6	24.0	188.8
	9	6.8	42.7
	12	4.8	33.4
	15	4.2	29.2
	18	2.2	16.5
2	3	38.0	266.1
	6	30.0	220.2
	9	36.0	232.1
	12	52.0	359.4
	15	4.8	23.7
3	3	1.4	10.1
	6	11.0	92.0
	9	1.16	11.9
	12	4.8	57.3
	15	58.0	690.0

Site	DEPTH (in.)	COLGM ($\times 10^7$ per gm. of wet soil)	COLML ($\times 10^7$ per ml. of soil solution)
4	3	10.0	64.7
	6	9.2	75.4
	9	4.8	46.2
	12	104.0	966.4
	15	4.8	46.2
	18	0.54	3.9
5	3	5.4	44.0
	6	2.8	28.4
	9	5.0	39.6
	12	9.0	67.6
6	3	12.0	117.5
	6	1.2	16.1
	9	0.1	1.4
	12	0.26	3.0
7	3	5.4	140.8
	6	3.0	56.8
	9	3.2	54.0
	12	1.6	35.0
	15	3.2	----

Site	DEPTH (in.)	COLGM ($\times 10^7$ per gm. of wet soil)	COLML ($\times 10^7$ per ml. of soil solution)
8	3	78.0	930.8
	6	11.6	166.0
	9	0.34	5.2
	12	46.0	425.6
	15	0.4	4.4
	18	0.18	1.9
11	3	86.0	1150.88
	6	0.04	0.61
	9	0.52	8.49
	12	0.50	13.24
12	3	146.0	2339.51
	6	260.0	3502.70
	9	140.0	1715.16
	12	1.86	44.56
13	3	120.0	1508.89
	6	1.00	13.74
	9	0.40	7.52
	12	3.90	124.94

Site	DEPTH (in.)	COLGM ($\times 10^7$ per gm. of wet soil)	COLML ($\times 10^7$ per ml. of soil solution)
14	3	110.0	953.82
	6	100.0	598.75
	9	130.0	684.80
	12	170.0	835.73
	15	0.70	3.47
	18	2.10	20.59
15	3	100.0	819.42
	6	0.58	6.49
	9	0.20	2.17
	12	1700.0	17575.98
	15	0.22	1.74
	18	1900.0	13478.31
16	3	0.06	1.61
	6	17.50	241.77
	9	0.0	0.0
	3	0.90	10.40
	6	51.8	438.54
	9	2.0	17.01
	12	25.2	135.16

Table 25.

Correlation Matrix Of The Data From Ancaster Sites

	DEPTH	LOIL	LOIH	COLML	COLGM	PHOV	BHOW	BBDV	HYGV	HYGW	XOK	HD
LOIL	-.27633											
LOIH	-.19307	.68147										
COLML	-.06745	-.18809	-.22230									
COLGM	-.09252	-.09905	-.10146	.97209								
PHOV	.18348	-.16779	-.59344	.07333	-.06183							
BHOW	.18734	-.12984	-.26121	.07640	-.03981	.80973						
BBDV	-.00755	-.34648	-.55233	-.04485	-.06548	.13553	-.43086					
HYGV	-.06263	.24886	.29564	-.04485	-.02739	.09523	.09338	.07278				
HYGW	.00077	.37149	.48539	-.02823	-.00724	-.02482	.33674	-.57286	.75075			
XOK	-.21117	.89722	.85665	-.22875	-.09403	-.26429	-.11368	-.31230	.25619	.32610		
HD	.61526	-.05148	.08267	-.01505	-.04351	.24349	.39746	-.24993	.04381	.17623	.00712	
DH	-.01417	.45673	.11523	-.13336	-.02337	-.35442	-.35410	.07650	.27484	.21326	.34488	-.17940
GSA	-.06559	.07207	.18346	-.01388	.06237	-.42394	-.40353	-.10473	-.05968	.04795	.11389	-.27554
GSB	-.16474	.19427	.26398	-.19833	-.18303	-.28221	-.36125	.12519	-.04712	.00198	.22518	-.40409
GSC	-.12141	.17351	.20620	-.36825	-.33051	.00299	.05400	.01757	.22395	.19666	.01473	-.34266
GSD	.06297	.11747	.14636	.01524	.03226	.20548	.41798	-.23999	.10746	.14762	.06869	.35592
GSE	-.13808	.04964	.20536	-.03539	-.01343	.09555	.18909	-.09009	.02480	-.00932	-.00927	.19836
GSF	-.05852	.00823	-.10854	.17157	.17225	.12842	-.00500	.18054	-.15386	-.22971	-.11655	.02896
GSG	.31073	-.25246	-.07101	.05012	.05565	.12727	-.01394	.21534	-.37175	-.42157	-.16048	.25582
GSH	.24799	-.38603	-.33402	.25770	.13595	.25011	.23516	.09031	-.07306	-.10550	-.38442	.22585
GSI	.45246	-.14569	-.06076	.19826	.20097	.04320	.06499	.01811	.06689	.06575	.10235	.26217
SKEW	-.15713	.36197	.25725	-.02195	-.00723	.23928	.47786	-.36644	.12402	.23512	.28749	.15449
XKUR	.27935	-.07355	-.00961	.19419	.23177	.05654	.25115	.27033	.07335	.23779	.18949	.17130
SSA	.46683	-.22261	-.12986	.25765	.26540	.17015	.18305	.06432	-.00294	-.03222	-.03724	.33331
BDY	.28356	-.56459	-.70831	.10487	.04229	.25328	-.06125	.59085	-.07625	-.37404	-.61134	-.20704
DHOW	.07146	.14008	-.00947	-.03347	-.14260	.56032	.59537	-.47384	.02499	.30348	.16893	.37008
DHOV	.25511	-.21384	-.41833	-.01908	-.10333	.70129	.59761	-.06151	-.07184	.00650	-.16234	.20151
OOR	-.31446	.06125	.30720	-.11669	-.01932	-.38215	-.32376	.04415	.01900	-.03491	.04325	-.12991
OX	-.01564	.11460	.13150	-.06621	-.06254	-.12629	-.21590	.20153	-.02513	-.04786	.18605	-.08669
XNN	.02968	-.02723	-.26961	.04445	.02453	.01041	.08501	-.13158	-.03295	.03319	-.09874	.04375
COO	-.05912	-.36362	-.26148	.09025	.01622	.48253	.54435	-.28910	.03667	.20450	-.36457	.17743
TEMP	-.33114	-.11932	-.12316	.27946	.22345	.19519	.17602	.02655	-.00442	-.02189	-.20065	-.09161
PH	.20393	-.19747	-.35696	.00003	.00918	-.01764	-.13099	.19574	-.20200	-.28932	-.14348	-.00553
EH	.05962	.19388	.15737	.03260	.05699	-.24126	-.21779	.03136	-.11157	.07035	.16800	-.00600
EK	-.09057	-.24009	-.06550	-.03979	-.03743	.29972	.33569	-.20374	-.22387	-.07517	-.18634	.12285
XKAD	-.07231	-.04682	-.11602	.05820	.00943	.27580	.32548	-.17008	-.02176	.07305	-.01310	.07305
XNAD	-.13731	-.29939	-.22885	-.04062	-.03623	.47686	.45637	-.15355	-.31706	-.16575	-.23689	.11111
XNOD	-.05075	-.29718	-.32319	-.03361	-.11747	.52118	.39569	-.01353	-.25375	-.20534	-.25273	.05767
XMGD	-.13750	-.11667	-.12344	-.01097	-.05255	-.13324	.23793	-.29847	-.03290	-.14524	-.09467	.09407
XKLD	-.07084	-.01463	-.10336	-.08536	-.01462	.34382	.44331	-.28031	-.09136	-.08196	-.03222	.13807
XKAS	-.07743	-.03406	-.08770	-.06593	-.02834	.24435	.27605	-.14592	-.03180	-.05859	-.03274	.07247
XNAS	-.02556	-.28140	-.32584	-.07401	-.01261	.62306	.59288	-.19269	-.25579	-.09393	-.19490	.17291
XNOS	.06514	-.23959	-.44469	-.01587	-.08677	.72385	.61285	-.08842	-.22131	-.11268	-.22841	.15828
XMGS	.11388	-.08248	-.28285	-.02709	-.04794	.55570	.52786	-.18705	-.06307	-.06945	-.01108	.17639
XKLS	.05157	-.09903	-.33312	-.08599	-.01935	.66444	.68207	-.27086	-.12580	-.06321	-.08415	.21643

	DH	GSA	GSB	GSC	GSD	GSE	GSF	GSG	GSH	GSI	SKEW	XKUR
GSA	-.20192											
GSB	.02728	.85778										
GSC	.33686	.14242	.35527									
GSD	.03725	-.59826	-.80542	-.18009								
GSE	-.05944	-.62842	-.73454	-.22233	.91375							
GSF	.03827	-.60139	-.57472	-.21559	.55310	.72564						
GSG	.30934	-.34844	-.44421	-.49795	.22019	.46021	.55567					
GSH	.14737	-.22723	-.29014	-.51313	-.09503	-.28626	-.23503	-.01654				
GSI	.01091	-.01041	-.02995	-.58642	-.22603	-.44190	-.39837	.01439	.72442			
SKEW	.07681	-.44565	-.36175	.31725	.72977	.59250	.36319	.03937	-.47333	-.52722		
XKUR	.02979	.18222	.27134	-.27388	-.31877	-.63356	-.59476	-.23860	.58275	.77579	-.26196	
SSA	.02867	-.26027	-.31737	-.71243	-.02387	-.20712	-.15089	.18934	.81324	.94369	-.44473	.64010
BDY	.08145	-.08673	-.09827	.00757	-.23863	-.29704	-.26676	.01094	.34687	.18652	-.38551	.07611
DHOW	.08435	-.48674	-.41549	.02423	.58357	.34006	.14544	.35485	-.05213	-.07025	.66099	.07968
DHOV	.05171	-.46752	-.33257	.06702	.33349	.22375	.23099	.28735	-.01459	-.09168	.44501	-.06271
OOR	.01273	-.24720	-.39130	-.18643	.24481	.38863	.21343	.25248	.04371	-.15447	.09249	-.27439
OX	.02749	.08439	-.00367	-.26555	-.03183	.02235	.12527	.18531	.02547	.07601	-.18815	-.01652
XNN	.00233	-.01372	.08239	.26773	-.01533	-.05196	-.10336	-.19284	-.09310	-.08495	.10635	-.02944
COO	-.12549	-.29548	-.30559	.00582	.13797	.11734	-.07142	-.02332	.27309	.03747	.34030	-.19204
TEMP	-.22760	.24253	.14474	-.00427	-.24382	-.19907	-.08315	-.21560	.28891	-.14290	-.27385	.07584
PH	-.08950	.09724	.35761	-.04527	-.13676	-.00136	-.05547	-.45753	-.09536	-.02900	-.00112	-.03534
EH	.21439	-.09375	.08678	-.01864	-.04983	-.11531	-.09232	-.18537	.02347	-.12297	-.14179	.06213
EK	-.40826	-.31705	-.39845	-.14218	-.23797	-.37330	-.26445	-.47056	.00395	-.15571	-.30570	-.17033
XKAD	-.12363	-.02883	-.09495	-.05154	-.06746	-.08071	-.07515	-.24348	-.05151	-.01447	-.07523	-.13335
XNAD	-.44114	-.45017	-.41755	-.09878	-.30270	-.34304	-.29276	-.40783	-.10332	-.14454	-.40231	-.10140
XNOD	-.35972	-.29270	-.23512	-.01910	-.13053	-.22224	-.25979	-.38834	-.02558	-.21115	-.25485	-.18132
XMGD	-.08909	-.17131	-.08710	-.15386	-.03777	-.12288	-.00804	-.10698	-.00482	-.09331	-.19025	-.05900
XKLD	-.26131	-.00417	-.01055	-.14649	-.14751	-.05632	-.03681	-.24625	-.22459	-.06948	-.05957	-.19405
XKAS	-.11693	-.01647	-.05472	-.03342	-.07676	-.02442	-.02239	-.15515	-.01711	-.01751	-.07544	-.07626
XNAS	-.35168	-.52533	-.43238	-.08646	-.36325	-.30451	-.24941	-.28312	-.17249	-.05593	-.45610	-.02350
XNOS	-.28481	-.44869	-.32749	-.01612	-.26843	-.24501	-.23384	-.27442	-.07358	-.11967	-.38917	-.04261
XMGS	-.08897	-.38868	-.24801	-.06112	-.27632	-.16450	-.11952	-.05467	-.04664	-.00141	-.38363	-.05750
XKLS	-.25331	-.25613	-.18477	-.10455	-.31889	-.09541	-.09500	-.07941	-.18733	-.00703	-.32470	-.16058

	BDY	DHOW	DHOV	OOR	OX	XNN	COO	TEMP	PH	EH	EK
BDY	.20896										
DHOW	.02155	-.39177									
DHOV	.01943	-.14191	.75453								
OOR	-.01931	-.26146	-.10147	-.22768							
OX	.09944	-.10589	-.20090	-.35619	.15190						
XNN	-.13474	.12258	.05777	.22693	-.14024	-.97104					
COO	.14441	-.07227	-.59334	.53362	-.01903	-.11434	-.12630				
TEMP	-.10286	.06052	-.05116	-.02321	-.13425	-.11906	.08798	.12979			
PH	-.01810	.34245	-.18859	-.14577	-.01134	-.15603	.11314	.15239	.00373		
EH	.08224	-.26576	-.10453	-.11830	-.03967	-.10474	.17332	-.29462	.05278	.32105	
EK	-.01140	.14013	.45369	.47351	-.23748	-.28325	.18249	.41438	.10497	.34028	-.07813
XKAD	-.04153	-.32158	.35470	.05926	-.09605	.24149	-.28290	.17721	-.00382	-.54443	-.78359	-.23219
XNAD	.02449	-.04851	.51965	.55220	-.08855	-.28118	.15455	.50252	.10373	.20009	-.10753	.77003
XNOD	-.09880	.14083	.38505	.56133	-.07872	-.27039	.18249	.36275	.17348	.37536	.09520	.71654
XMGD	-.07612	-.34055	.29746	.10573	-.05944	-.01217	-.04367	.23083	-.14451	-.43851	-.49300	-.05443
XKLD	-.10361	-.01534	.33437	.25162	-.28391	-.33177	.30551	.10433	.34162	-.00417	.37802	-.28673
XKAS	-.03314	-.32252	.31359	.06943	-.01404	-.20850	-.24152	.17574	.00312	-.44363	-.69742	-.20414
XNAS	-.10669	-.00778	.67963	.70071	-.00427	-.26773	.11576	.52499	.09431	.12356	-.20855	.69332
XNOS	.01037	.13853	.56008	.78145	-.14744	-.26567	.12561	.58376	.03327	.20322	-.16569	.63939
XMGS	.06550	-.12078	.58481	.64813	-.12229	-.09524	-.02578	.51469	-.09570	-.25002	-.57167	.17100
XKLS	.09517	.03472	.65003	.63375	-.33285	-.36206	.25870	.42837	.20942	.02240	.07707	.40546

	SSA	BDY	DHOW	DHOV	OOR	OX	XNN	COO	TEMP	PH	EH	EK
XNAD	-.08147											
XNOD	-.24970	.77087										
XMGD	.58091	.12437	-.07237									
XKLD	-.11077	.31907	.44845	-.23238								
XKAS	.93702	-.09755	-.23846	.56783	-.13363							
XNAS	.10024	.92416	.70775	.18375	.32453	.08061						
XNOS	.09415	.74819	.84946	.12283	.37491	.09179	.87475					
XMGS	.63120	.32443	.16624	.53763	-.01131	.66741	.58355	.59787				
XKLS	.13882	.52159	.56877	-.00673	.82508	.11629	.66568	.74010	.40256			

	XKAD	XNAD	XNOD	XMGD	XKLD	XKAS	XNAS	XNOS	XMGS

Table 26.

Principal Components

Varimax Rotated Factor Matrix

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8	FACTOR 9	FACTOR 10	FACTOR 11
DEPTH	-.01003	-.08503	.03561	.34636	-.18802	-.00191	-.09359	.03052	-.07050	.81603	-.08839
LOIL	-.20174	.00828	.00125	-.15764	.78102	.08318	-.03596	-.05817	.16833	-.05090	.42068
LOIH	-.29914	-.12362	.08122	-.05185	.88719	.16999	-.09964	-.03724	-.14509	-.06710	-.09273
COLML	.01228	.03609	-.00309	.15290	-.11907	-.00115	.96549	.04466	.05072	-.05265	-.07307
COLGM	-.06594	-.01596	.00292	.15075	-.00379	-.01806	.98496	.02381	-.01369	-.07129	.00695
BHOV	.68251	.22087	.07660	.04761	-.39443	.15890	-.00184	-.12886	.35838	.20786	-.02122
BHOW	.65128	.28207	.13079	.12635	.00460	.35446	.03261	.05268	.34976	.23667	-.19922
BOOV	-.21778	-.19718	.05824	-.04998	-.70477	-.22128	-.08931	-.27887	-.04906	-.07130	.26500
HYGV	-.15159	-.07069	.07120	-.01841	.05791	.84379	-.02647	-.07575	.01296	-.00632	.18454
HYGW	.01422	.06377	-.03582	.02172	.41794	.82704	.01250	.08678	.02215	.06302	-.01276
XOK	-.12052	-.02562	-.07711	-.00611	.85898	.01660	-.09388	-.17081	.09421	.02999	.39031
HO	.11882	.06689	.30809	.29819	.14743	.15167	-.06108	.08732	.08503	.55073	-.34007
OH	-.26251	-.08931	.07887	-.02232	.08010	.22819	-.05058	.06127	-.12496	-.02525	.79313
GSA	-.40082	-.07310	-.78481	-.19220	.13762	-.04522	.04955	-.04667	.05589	-.00347	-.31661
GSB	-.27725	-.00551	-.88747	-.25271	.08228	-.08307	.25190	.00849	.07351	-.01749	.08700
GSC	.04564	.10012	-.32270	-.64685	-.10456	.29398	-.29952	.26309	-.06684	-.12822	.33067
GSD	.23227	.10245	.84698	-.08015	.20081	.15621	.05268	.03258	.13106	.14039	.02820
GSE	.18019	-.01081	.86813	-.29329	.14778	-.02365	.04246	-.05114	-.08834	-.00047	-.11125
GSF	.10906	-.03258	.76512	-.28960	-.08487	-.28598	.23419	-.16446	.05308	.00206	.09346
GSG	.25885	-.23206	.41873	.04516	-.05683	-.48006	.07647	-.28910	-.38318	.27485	-.24350
GSH	.06851	.05579	.01232	.87594	-.33217	.05546	.05625	.01946	.11670	-.15989	-.12504
GSI	-.06868	-.03837	-.19202	.92428	.00013	.01543	.06607	-.04458	-.01127	.21808	.07151
SKEW	.48333	.10821	-.41363	-.46172	.38688	.21551	.09700	.08699	-.03615	.11230	.17895
XKUR	.09836	.05371	-.49603	.72140	.18163	.16079	.12495	.00813	.05805	.15965	.09033
SSA	.03800	-.04335	.07947	.95898	-.08355	-.02638	.11327	-.08092	-.00720	.16224	.03726
BOY	.01860	-.31790	-.16878	.13358	-.80618	-.05935	.03045	.05275	.03251	.10742	.22891
BHOW	.73160	.34605	.24915	.00541	.29899	.18251	-.07882	.06009	.15973	.16348	.05591
BHOV	.79657	.08306	.15806	-.07385	-.16589	.02405	-.01664	.13120	.06382	.28450	.16986
OOR	-.12904	-.06085	.44960	.07542	.15233	-.03577	-.10372	-.07505	-.38569	-.58394	-.15935
OX	-.25898	.12937	.04587	.06730	.05185	-.05199	-.04126	-.91893	-.06845	-.02912	.00606
XNN	.08471	-.17538	-.04617	-.10422	-.02511	-.03458	.02634	.92453	.12431	.05451	.02813
COO	.72283	.19488	-.00369	.15031	-.11445	.36529	.06095	-.02796	-.23052	-.10480	-.14233
TEMP	.07926	-.05636	-.17305	-.00448	-.18833	.13867	.19288	.01381	.35237	-.55108	-.35647
PH	.29284	-.65707	-.18170	-.08910	-.10497	-.17623	.05029	-.04067	-.33545	.16996	-.10233
EH	-.15733	-.76710	-.02993	.09919	.09266	.06080	.02538	.29383	.29113	.00812	.18178
EK	.70655	-.23079	.22034	-.02889	.09587	-.16900	-.06660	.10863	-.14209	-.16369	-.35014
XKAD	.03437	.93516	-.03737	-.00837	.02659	.02844	.03437	-.18059	.11175	.02964	-.04003
XNAD	.81344	-.05696	.22538	.01051	-.00200	-.23171	-.00448	.12431	-.03866	-.18305	-.21223
XNOD	.78144	-.29024	.06703	-.15043	-.12783	-.22996	-.06288	.03260	.14087	-.06872	-.15989
XMGD	.11177	.75233	.05266	-.03333	.16643	-.00968	-.03879	.15986	-.18839	-.02239	.01812
XKLD	.35421	-.21451	-.05444	.13324	.11259	-.00624	.02052	.19994	.80252	-.07839	-.17203
XKAS	.02234	.90246	-.04453	-.00791	.03693	-.01136	.05478	-.14931	.06099	.01320	-.04594
XNAS	.90286	.11343	.20067	.08472	-.03345	-.13610	.02564	.09491	.01751	-.08091	-.06339
XNOS	.91752	.06381	.10087	-.04617	-.15913	-.11875	-.02025	.02934	.13046	.05011	-.00450
XMGS	.55666	.71264	.09589	.02996	-.03515	.00569	.01362	.04385	-.09194	.16545	.17037
XKLS	.69590	.05154	.03651	.07934	.00423	-.00163	.04152	.15463	.62548	.07951	-.03249

Table 27.

Orthogonal Varimax

Rotated Factor Matrix

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8	FACTOR 9	FACTOR 10	FACTOR 11
DEPTH	.00170	.33258	.02025	-.08363	-.17594	-.02251	-.08009	-.04965	.72478	.02008	-.05135
LOIL	-.20447	-.15649	-.00124	.01806	.77160	.09720	-.03669	.14540	-.06371	-.04288	.45238
LOIH	-.29660	-.05005	.08385	-.11862	.88726	.16894	-.09507	-.13896	-.05965	-.04764	-.09365
COLML	.01339	.15456	-.00440	.03620	-.11814	-.00458	.96747	.05684	-.05460	.04473	-.07785
COLGM	-.09311	.15142	.00074	-.01752	-.00151	-.02099	.98770	-.01203	-.07272	.01977	.00594
BHOV	.68575	.05004	.05997	.21434	-.38272	.16577	.00175	.35408	.20392	-.13953	.01135
BHOW	.63962	.13028	.12584	.28935	.01032	.33316	.02944	.35344	.24705	.08106	-.18125
BBDV	-.19046	-.04879	.03340	-.20508	-.65617	-.18232	-.07053	-.06601	-.07827	-.30802	.24911
HYGV	-.13105	-.01446	.05023	-.06049	.07043	.81995	-.02445	.00303	-.01693	-.08203	.18504
HYGW	.01334	.02571	-.03914	.08148	.41528	.78302	.00652	.01994	.06269	.12261	-.02295
XOK	-.11128	-.00993	-.08932	-.02773	.85364	.04319	-.08764	.07108	.02537	-.19022	.42434
HD	.13680	.28821	.27194	.06603	.14520	.10294	-.04339	.09052	.49715	.06634	-.24896
DH	-.27385	-.04183	.06801	-.07009	.07020	.22093	-.05823	-.14117	-.01591	.09047	.63397
GSA	-.40045	-.18935	-.77843	-.07144	.13977	-.05312	.04316	.06822	-.00797	-.04592	-.31487
GSB	-.27196	-.25054	-.88502	-.00949	.07601	-.07404	.23753	.05882	-.04114	.01601	.09424
GSC	.02852	-.57865	-.27996	.09328	-.07883	.24638	-.25745	-.07024	-.13250	.26567	.26892
GSD	.21996	-.07586	.83556	.11528	.19929	.14164	.04980	.13449	.15880	.05503	.02838
GSE	.18109	-.28536	.85614	-.00969	.15219	-.02669	.03958	-.06790	.01585	-.07177	-.10849
GSF	.11851	-.27520	.73225	-.03746	-.08032	-.26000	.21074	-.04440	.00156	-.18647	.10113
GSG	.25871	.04383	.39884	-.23402	-.05818	-.43764	.06591	-.30187	.25816	-.32901	-.20959
GSH	.06244	.85825	.01476	.05998	-.32426	.04540	.06057	.12263	-.15043	.02321	-.13507
GSI	-.05524	.92706	-.20148	-.04528	.00055	.01998	.06747	-.01792	.23030	-.06034	.07584
SKEW	.46354	-.44053	.41206	.11897	.37382	.19848	.07791	-.02864	.11104	.12265	.16392
XKUR	.08346	.69708	-.48189	.05973	.16745	.15814	.11578	.06002	.15923	.03493	.07232
SSA	.03384	.96328	.07552	-.04901	-.08214	-.02382	.11492	-.00307	.17549	-.10298	.03990
BDY	.01589	.12924	-.16722	-.30669	-.75726	-.05888	.02560	.02161	.08875	.06000	.19180
DHOW	.71018	.00189	.24702	.34833	.28844	.17034	-.07374	.15652	.17984	.09230	.05445
DHOV	.78278	-.07849	.15148	.07823	-.16580	.02221	-.01759	.06452	.29893	.14231	.16575
ODR	-.11838	.03117	.40851	-.05972	.14860	-.04732	-.06763	-.29840	-.44507	-.12505	-.15128
OX	-.25864	.07359	.04826	.14430	.04699	-.04365	-.03393	-.09010	-.03350	-.70960	.00187
XNN	.10216	-.10712	-.05732	-.19280	-.02571	-.02092	.02590	.11668	.04853	.74088	.03764
COO	.67599	.14352	.02588	.20784	-.10274	.29968	.04263	-.16241	-.07327	.02361	-.17822
TEMP	.08144	-.00182	-.16621	-.04363	-.15159	.08664	.17128	.30077	-.43612	.01903	-.27241
PH	.24398	-.07314	-.13458	-.59380	-.10871	-.18420	.02597	-.22096	.14297	-.03098	-.10083
EH	-.16168	.08534	-.03938	-.68325	.07356	.05847	.02321	.22980	.00110	.28808	.15390
EK	.69298	-.03129	.22904	-.23254	.09940	-.17068	-.05510	-.09342	-.14036	.08474	-.35269
XKAD	.03773	-.01041	-.10418	.95189	.02504	-.02018	-.03014	.10997	.02900	-.19133	-.03452
XNAD	.81785	.01775	.23309	-.06403	.00750	-.23931	-.00165	-.03027	-.19463	.12762	-.22223
XNOD	.77583	-.14793	.06381	-.29525	-.12311	-.22025	-.05517	-.16217	-.07010	.02295	-.15167
XMGD	.12355	-.03534	.05343	.70141	.15909	-.00314	-.03429	-.19377	-.02294	.13284	.01120
XKLD	.32412	.13537	-.04848	-.19221	.10535	-.00731	.02199	.80391	-.08114	.24669	-.14780
XKAS	.02657	-.01338	-.05211	.91775	.03613	-.02218	.05105	.06395	.02049	-.17177	-.04018
XNAS	.90605	.08869	.20433	.11103	-.03345	-.14302	.02660	.01948	-.08609	.10832	-.06570
XNOS	.91405	-.04885	.09853	.05936	-.15765	-.11623	-.01785	.14223	.05592	.03174	.00250
XMGS	.54915	.02126	.09308	.67839	-.03629	.00826	.00870	-.09279	.17280	.03746	.15320
XKLS	.66837	.07828	.03839	.06589	-.00255	-.00394	.03782	.62786	.08393	.19645	-.01429

Table 28.

Oblique Factor Structure

Matrix After Rotation

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8	FACTOR 9	FACTOR 10	FACTOR 11
DEPTH	-.03013	-.21511	.40263	.00620	.10059	-.10082	-.04461	.52821	.05231	-.49107	-.03421
LOIL	-.28560	.88914	-.17630	.06055	-.04473	-.10441	.25859	.04968	.04242	.21892	-.02677
LOIH	-.26272	.87560	-.12232	-.00871	-.08582	-.12706	.26374	-.33043	.30776	-.20690	-.01951
COLML	.01312	-.15326	.16574	-.01251	-.02795	.98525	-.03456	-.04788	-.12349	-.02677	.02286
COLGM	-.06034	-.01541	.15729	-.01262	.02818	.99218	-.03469	-.04977	-.01345	.02521	.02125
BHOV	.59738	-.42698	.09468	-.01388	-.29212	.01803	.15089	.36690	-.60700	-.14712	-.19702
BHOW	.55409	-.09131	.13996	.21701	-.39183	.04525	.37498	.19194	-.59555	-.42434	-.23039
BOV	-.17944	-.54870	-.00486	-.38835	.28007	-.06508	-.30905	.16940	.14190	.42007	-.02192
HYGV	-.19856	.15278	.01930	-.00215	.03142	-.08201	.80729	.04403	.04122	.15153	-.05026
HYGW	-.04984	.40992	.03572	.23464	-.14861	-.04361	.84416	-.04556	-.04222	-.14545	.03175
XOK	-.19436	.93779	-.02685	-.06377	-.01858	-.14740	.22321	.10589	.08345	.10057	.03887
HO	.13217	.05556	.28509	.08130	-.09682	-.03744	.11946	.19101	-.12179	-.63221	-.27585
OH	-.33344	.24659	-.00594	.09792	.09734	-.14019	.28063	.27991	.28300	.47541	-.09797
GSA	-.42360	.09919	-.13959	-.04571	.12052	.05152	-.05962	-.20770	.03102	-.00964	.87539
GSB	-.35628	.11250	-.16307	.05973	.04955	.20556	-.02778	.06054	-.00246	.31814	.90368
GSC	-.01998	.01498	-.53195	.33086	-.10025	-.33912	.27978	.11569	.04585	.44230	.23781
GSD	.24511	.20880	-.14293	.07748	-.16647	.02432	.16688	.07118	-.12870	-.29993	-.86464
GSE	.27930	.14451	-.37963	-.08602	-.03292	.01693	-.05878	-.11099	.08067	-.25605	-.85239
GSF	.18157	-.03143	-.33422	-.21807	.03240	.19355	-.30350	.05338	.00297	-.01762	-.74469
GSG	.36870	-.14364	-.00038	-.36488	.20880	.07696	-.51834	.09532	.24078	-.41003	-.41479
GSH	.06129	-.40021	.84692	-.05438	-.04255	.18137	.00624	-.15965	-.22323	-.09106	-.00627
GSI	-.11709	-.04538	.96210	-.08982	.05949	.12736	.05292	.18413	.00055	-.20747	.18524
SKEW	.45120	.38593	-.47411	.25429	-.22204	-.00841	.27967	.18136	-.07734	-.11413	-.51325
XKUR	-.01255	.10961	.74824	.08921	-.08328	.15181	.24242	.16491	-.14740	-.13933	.43233
SSA	.01830	-.13859	.96817	-.15123	.05428	.19243	-.01923	.13118	-.04130	-.25288	-.09647
BOY	-.01593	-.76910	.21189	.02671	.36033	.03561	-.18462	.32041	-.07376	.27928	.14724
DHOW	.65349	.22554	-.02005	.24148	-.47298	-.09423	.28823	.23452	-.38378	-.30330	-.39548
DHOV	.72529	-.20626	-.04906	.27907	-.17696	-.05394	.05268	.49124	-.34089	-.15980	-.32142
ODR	.01352	.13160	-.07582	-.21593	.05932	-.02991	-.04938	-.52028	.34031	.06593	-.34533
OX	-.24046	.09008	.06497	-.75471	-.11936	-.02052	-.06181	-.06949	.22551	.02714	-.01565
XNN	.08325	-.04327	-.09522	.76490	.19301	.00707	-.00084	.07190	-.18034	.01749	.04969
COO	.68617	-.21999	.12960	.10444	-.31424	.06179	.29504	-.02304	-.16568	-.18752	-.13023
TEMP	.08340	-.20719	-.02682	.03459	.03687	.24645	.02749	-.42479	-.37968	.13056	.20189
PH	.28420	-.17504	-.05911	.02519	.56315	.01375	-.28254	.11401	.11986	-.12135	.11125
EH	-.20168	.11005	.09709	.34585	.69792	.01821	.01540	.02513	-.13382	.11517	.07066
EK	.77876	-.06486	-.11316	.16416	.12567	-.01084	-.21335	-.22918	-.17531	-.32844	-.29350
XKAD	-.00760	.02903	.00454	-.23065	-.94852	.04017	.14590	.04839	-.14437	-.04852	.06976
XNAD	.88031	-.14054	-.05834	.20777	-.04644	.04990	-.25017	-.14929	-.28899	-.21603	-.33482
XNOD	.78688	-.23368	-.17786	.15856	.19591	-.02231	-.27164	.02377	-.43557	-.13817	-.17748
XMGD	.13797	.14442	-.05557	.08774	-.71971	-.04925	.12091	-.00798	.11508	-.05272	-.09459
XKLD	.22913	.03709	.11962	.38125	.14623	.09648	.01405	-.10236	-.87981	-.14760	.02008
XKAS	-.00275	.03777	-.00719	-.22337	-.91214	.06049	.09830	.02836	-.09303	-.05756	.02344
XNAS	.91889	-.15527	.04184	.21404	-.23180	.06219	-.11427	.05411	-.36982	-.18546	-.35624
XMOS	.89382	-.24964	-.05504	.17512	-.17453	-.00331	-.10386	.24351	-.47662	-.14780	-.26606
XMGS	.51058	-.06036	.03544	.07716	-.74544	-.01629	.12575	.33789	-.12949	-.10662	-.23580
XKLS	.56381	-.07322	.08166	.35880	-.15284	.07744	.04994	.18548	-.83951	-.19004	-.15805

APPENDIX C

SITE DESCRIPTIONS AND ENVIRONMENTAL STATUS

There are several reasons for studying the impact of septic pollution on these wet valley soils: the health hazards arising from intense pollution as indicated by the levels of coliform bacteria, pollution of groundwater (especially wells), fouling of streams, lake and reservoir pollution, as well as ecological changes in the valley fauna and flora and the aesthetic damage to the inherent physical beauty of the valleys.

The sites are arranged along the valleys but no total assessment of input-output and site to site absorption of pollutants has been made as yet. Some of the impacts listed have been assessed quantitatively and ultimately considered as components of various multivariate models. The inherent natural beauty of these valleys is qualitative and some of the aspects have not been quantified. The best iconic models of the aesthetic qualities of the valleys are colour photographs and visual evidence over long time periods needed to register environmental change. The locations of sampling sites (where the photographs were taken) are shown in Figures 1 and 2. The first five colour plates are from a small isolated valley adjacent to Hopkins Creek Valley (marked site A on Plate 1). Plates 2 through 4 indicate the lush dense vegetation characteristic of relatively unpolluted valleys. Preliminary soil

PLATE 2

Site A from above the south valley slope, summer 1969.

PLATE 3

Site A looking up the valley from the southeast, summer 1969.

PLATE 4

Site A--close-up of flora on the valley floor, summer 1969.

PLATE 5

Low Humic Gleysol (National Soil Survey Committee, Canada Department of Agriculture, 1970) from site A, summer 1969.

atmosphere research on the valley bottom soils indicated a delicately balanced soil-plant environment. Plates 5 and 6 show profiles which were analyzed in detail. Plate 5 shows the common clay variant, Low Humic Gleysol (National Soil Survey Committee, Canada Dept. of Agriculture, 1970), located along the edge of the valley floor. Plate 6 is a profile of the dominant silt loam Humic Gleysol possessing a typically shallow water table. In light of the ecological frailty of the wet valley floor, it will require considerable effort and control to prevent rapid environmental deterioration of this valley as displayed by many of the sites along Grindstone and Ancaster Creeks.

As examples of the relationships between the nature of the site, the pollution sources and ecological or visual balance, one may cite Plate 7 located about 100 yards upstream from site 14. It shows a portion of Grindstone Creek as it flows through Millgrove. This represents a relatively unpolluted site with evidence of wildlife.

Plate 8 shows site 15 on the northeastern edge of Waterdown. The physical beauty of the site is illusory. A few hundred feet to the south is the CN rail line on an elevated grade, and above the site on the north is a residential side street. The surface layers of the soil at the site have been disturbed by road and housing construction and 'lot improvements'. The stream at times develops a malodorous brown frothy scum, which is possibly related to the gravel pit upstream.

The last seven plates, taken at sampling sites along Ancaster Creek, are ordered in sequence from the headwaters downstream. Plate 9 is from site 1 and faces north. The area should never have been cleared.

PLATE 6

Humic Gleysol (National Soil Survey Committee,
Canada Department of Agriculture, 1970) from site A, summer 1969.

PLATE 7

Grindstone Creek as it flows through Millgrove,
100 yards upstream from site 14, winter 1973.

PLATE 8

Grindstone Creek in northeast Waterdown, site 15, winter 1973.

PLATE 9

Ancaster Creek, site 1, facing north, early spring 1973.

The level, poorly drained soil is useless for agriculture, artificial drainage being uneconomical. These marshy creek headwaters under natural vegetation would provide a) a water reservoir, ameliorating flood, drought and erosion cycles in the stream valley, b) a wildlife and bird sanctuary and c) a potential recreation area. At present, it serves no useful purpose. Plate 10 was taken at site 2 looking north. This site was among the most polluted. The backyards and septic systems of the adjacent housing development literally flow into the west side of the stream. The visible physical inputs are almost as great as the less visible biological and chemical inputs. The stream is littered by various non-biodegradable refuse.

Plate 11, looking north from site 3, represents an undeveloped, though not undamaged, natural remnant within Ancaster. Not all of the dead and dying trees in this plate and Plate 13 are elms. It is probable, and the multiple regression equations so predict, that some of this tree senescence is due to septic-induced anaerobosis. Plate 12 is a close-up of the stream at site 3. The green colour in the water represents an algal growth anchored to the sandy stream floor. One week previous to this photograph, 90% of the stream floor at this site was covered with a dense algal growth. Recent snow melt had induced a sudden increase in stream discharge, and silt and sand erosion along the stream floor had reduced the density of the algal mat.

Plate 13, from site 5 looking north, shows a narrow wooded strip between two residential areas in Ancaster. The broad, shallow stream flowing over bedrock indicates a thin soil mantle. Advanced tree senescence suggests the wooded area on the shallow soil is

PLATE 10

Ancaster Creek, site 2, facing north, winter 1973.

PLATE 11

Ancaster Creek, site 3, facing north, winter 1973.

PLATE 12

Ancaster Creek, site 3, stream detail, winter 1973.

PLATE 13

Ancaster Creek, site 5, facing north, winter 1973.

declining and deteriorating. Plates 14, near the old Ancaster Mill, and 15, viewed from site 6, display healthier tree stands. The area in Plate 15, facing north, has been cleared, but recent healthy second growth indicates that this site has not yet been affected by septic pollution. The road causeway to the east of the site is probably partially responsible for this, reducing the septic effluent flux from the housing development to the east of the highway.

The photographs lend credence to the multivariate models. Within Ancaster and in other areas adjacent to large fluxes of septic effluent, there is an apparent increase in tree senescence. In areas remote or isolated from septic effluent, tree stands appear more healthy. The photographs also document both the natural aesthetic qualities of these valleys, and their deterioration in the face of unrestricted development.

It is perhaps ironic that settlement has been attracted by the natural beauty of the valleys. The impact of this settlement on this environment not only detracts from this natural beauty but is in part destroying the major components of this natural beauty and ultimately may be injurious to human health as well, not only near to the developed sites, but downstream in more densely populated areas with sewage systems and in the conservation areas as well.

PLATE 14

Ancaster Creek, site 6, facing south, winter 1973.

PLATE 15

Ancaster Creek, site 6, facing north, winter 1973.

REFERENCES

Anomine, S., 1962. A review of research on redox potentials of paddy soils in Japan. Soil Sci., 94: 6-13.

Allison, L. E., 1973. Oversaturation method for preparing saturation extracts for salinity appraisal. Soil Sci., 116: 65-69.

Bartelli, L. J., et al., 1966. Soil Surveys and Land Use Planning. Soil Sci. Soc. Amer. (Madison, 1966).

Birkle, D. E., et al., 1964. Measurement of oxygen diffusion rates with the platinum microelectrode: II, Factors influencing the measurement. Hilgardia, 35: 555-566.

Blenkhorne, D. M., 1972. Bronte Creek Provincial Park, Policy Recommendations Report, Bronte Creek Provincial Park Advisory Committee.

Bower, H., 1971. Land disposal of sewage effluents. Proceedings of a Symposium on Nitrogen in Soil and Water, 1971. Dept. of Soil Sci., Univ. Guelph, Guelph, Ontario.

Boynton, D., and Compton, O. C., 1944. Normal seasonal changes of oxygen and carbon dioxide percentages in gas from the larger pores of three orchard subsoils. Soil Sci., 57: 107-117.

Boynton, D., and Reuther, W., 1938. A way of sampling soil gases in dense subsoils and some of its advantages and limitations. Soil Sci. Soc. Amer. Proc., 3: 37-42.

Bremner, J. M., and Nelson, D. W., 1968. Chemical decomposition of nitrite in soils. Trans. 9th Int. Congr. Soil Sci., 2: 495-503.

Broadbent, F. E., 1971. Nitrogen in soil and water. Proceedings of a Symposium on Nitrogen in Soil and Water, 1971. Dept. of Soil Sci., Univ. Guelph, Guelph, Ontario.

Burford, J. R., and Millington, R. J., 1968. Nitrous oxide in the atmosphere of a Red-Brown Earth. Trans. 9th Int. Congr. Soil Sci., 2: 505-511.

Campbell, J. A., 1971. A study of hydromorphic ravine soils with specific reference to the soil atmosphere regime. Unpublished B.A. thesis, McMaster University, Hamilton, Ontario.

Dowdell, R. J., et al., 1972. Field studies of ethylene in the soil atmosphere--equipment and preliminary results. Soil Biol. Biochem., 4: 325-331.

Greenwood, D. J., 1968. The Measurement of Microbial Metabolism in Soil in Ecology of Soil Bacteria, An Internat. Sympos., Univ. Toronto Press.

Hack, H. R. B., 1956. An application of a method of gas micro-analysis to the study of soil air. Soil Sci., 82: 217-231.

Hickey, J. L. S., and Duncan, D. L., 1966. Performance of single family septic tank systems in Alaska. Journal WPCF, 38: 1298-1309.

Kurayev, V. N., 1967. Gas regime in gleyed Sod-podzolic soils. Sov. Soil Sci. 1967: 1772-1780.

Letey, J. L., et al., 1961. Effect of temperature on oxygen diffusion rates and subsequent shoot growth, root growth, and mineral content of two plant species. Soil Sci., 92: 314-321.

Letey, J. L., and Stolzy, L. H., 1964. Measurement of oxygen diffusion rates with the platinum microelectrodes: I, Theory and equipment. Hilgardia, 35: 545-554.

Mack, A. R., and Sanderson, R. B., 1971. Sensitivity of the nitrate ion membrane electrode in various soil extracts. Can. J. Soil Sci., 51: 95-104.

Matheson, D. H., 1967-73. Annual Sanitary Surveys of the Creeks within the Region, Hamilton Region Conservation Authority, Dept. of Municipal Lab., Corp. of the City of Hamilton.

McGauhey, P. H., and Wineberger, J. H., 1963. Studies of the failure of septic tank percolation systems. Journal WPCF, 35: 593-606.

Mokma, D. L., and Whiteside, E. P., 1973. Performance of septic tank disposal fields in representative Michigan soils. Research Report, 157, Farm Science, from the Michigan State University Agricultural Experiment Station, East Lansing.

National Soil Survey Committee, Canada Department of Agriculture, 1970. The System of Soil Classification for Canada. Queen's Printer.

Nie, N. H., et al., 1970. Statistical Package for the Social Sciences, McGraw-Hill (New York, 1970).

Pierce, R. S., 1953. Oxidation-reduction potential and specific conductance of ground water: their influence on natural forest distribution. Soil Sci. Soc. Amer. Proc., 17: 61-65.

Poel, L. W., 1960. The estimation of oxygen diffusion rates in soils. Jour. Ecol., 48: 165-173.

van Praag, H., et al., 1970. Mesures du potentiel d'oxydo-reduction dans les sols forestiers ardennais. Pedologie, 20: 101-107.

Pratt, P. F., et al., 1972. Nitrate in deep soil profiles in relation to fertilizer rates and leaching volume. J. Environ. Quality, 1: 97-102.

Raney, W. A., 1949. Field measurement of oxygen diffusion through soil. Soil Sci. Soc. Amer. Proc., 14: 61-65.

Robeck, G. G., et al., 1964. Factors influencing the design and operation of soil systems for waste treatment. Journal WPCF, 36: 971-983.

Robinson, J. B., 1971. Personal communication at the Symposium on Nitrogen in Soil and Water, Univ. Guelph, Guelph, Ontario, March 30-31, 1971.

Rodgers, J. A., and King, J., 1972. The distribution and abundance of grassland species in hill pasture in relation to soil aeration and base status. J. Ecol., 60: 1-18.

Soil Survey Staff, Soil Conservation Service, U. S. Dept. of Agriculture, 1960. Soil Classification: A Comprehensive System, 7th Approximation. U. S. Govt. Printing Office.

Smith, J. S., 1972. Relative rate of chloride movement in leaching of surface soils. Soil Sci., 114: 259-263.

Stolzy, L. H., and Letey, J. L., 1964. Measurement of oxygen diffusion rates with the platinum microelectrode: III, Correlation of plant responses to soil oxygen diffusion rates. Hilgardia, 35: 567-576.

Tackett, J. L., 1968. Theory and application of gas chromatography in soil aeration research. Soil Sci. Soc. Amer. Proc., 32: 346-350.

Taras, M. J., et al., 1971. Standard Methods for the Examination of Water and Wastewater, 13th ed. American Public Health Assoc., Washington, D. C.

Taylor, S. A., and Ashcroft, G. L., 1972. Physical Edaphology. Freeman (San Francisco, 1972).

Thomson, A. J., 1972. The ecology of Pollenia rudis (Diptera: Calliphoridae) and its host earthworms (Lumbricidae), with special reference to the host-parasite relationship between P. rudis and Eisenia rosea. Ph. D. Thesis, McMaster University, Hamilton, Ont.

Tusneem, M. E., and Patrick, W. H., 1971. Nitrogen transformation in waterlogged soil. Louisiana State University, Dept. of Agronomy, Agricultural Experiment Station, Bulletin No. 657.

Walkley, A., and Black, I. A., 1934. An examination of the Degtjareff method for determining organic matter, and a proposed modification of the chromic acid titration method. Soil Sci., 37: 29-38.

Woolson, E. A., et al., 1970. Soil calcium determination using calcium specific ion electrode. Soil Sci., 109: 270.

Yurkevich, I. D., et al., 1966. Content of oxygen in the soil water and of carbon dioxide in the soil air of forest bogs. Sov. Soil Sci., 1966: 159-167.