United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-80-002
March 1980

Research and Development

Effects of Sludge Irrigation on Three Pacific Northwest Forest Soils

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-80-002
March 1980

EFFECTS OF SLUDGE IRRIGATION ON THREE PACIFIC NORTHWEST FOREST SOILS

by

David D. Wooldridge
and
John D. Stednick
College of Forest Resources
University of Washington
Seattle, Washington 98195

Grant No. R-802172

Project Officer

Gerald Stern
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

This study was conducted in cooperation with
Municipality of Metropolitan Seattle
Seattle, Washington 98104

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

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

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

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

Major metropolitan areas are encountering increasingly complex problems with disposal of wastes. This report addresses one phase of the problem--disposal of municipal-industrial sewage sludge. Cities in forested regions can dispose of sludge in forests with economic benefits and no significant environmental consequences.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

Forested regions of the United States offer an alternative for disposal of liquid wastes with the potential benefits to Society of economical waste disposal and accelerated forest growth. Digested liquid municipal sludges contain bio-degradable nutrients and sufficient water to enhance forest growth. Study was initiated in May 1974 of efficient methods of liquid sludge and chemical properties of forest soils and chemistry of soil water. A sprinkler irrigation system was developed for uniform applications of sewage sludge to forest plots.

The renovation capacity of the forest soil for most suspended and dissolved constituents in sewage sludge is very good (95 to 99+%). Nitrogen is the exception as nitrification rates increased with increased rates of sludge applications, resulting in significant leaching of NO_3-N and concomitant cation losses. Phosphorus in all forms was never found in significant amounts in soil solutions of tested soils.

Sludge applications generally increased the growth rate of the forest stand. Water applied after sludge irrigation may further enhance tree growth over sludge only applications. Heavy metals were either absorbed in the aluminum oxide lysimeter plates or tied up in the soil profile. Human pathogens of the bacteria and virus types were not isolated from the limited number of soil and soil solutions analyzed.

This report was submitted in fulfillment of grant R-802172 by the University of Washington under the sponsorship of the U. S. Environmental Protection Agency and the Municipality of Metropolitan Seattle, Washington cooperatively with the Weyerhaeuser Company. This report covers a period of May 1, 1974 to April 30, 1978, and work was completed as of September 29, 1978.

CONTENTS

Foreword iii
Abstract iv
Figures viii
Tables x
Abbreviations and Symbols xii
Acknowledgements xiv

1. Introduction 1
   Research Objectives 1
2. The Study Area 3
   Climate 3
   The Everett Soil Series 4
   The Mashel Soil Series 6
   The Wilkeson Soil Series 7
3. Methods of Plot Layout, Soil Sample and Analyses 10
   Plots on the Everett Soil Series 10
   Soil Solution Monitoring 12
   Sampling for Ground Water Nutrients 12
4. Sludge Treatment to Plots 15
   Plots on Mashel and Wilkeson Soils 15
5. Analytical Analyses of Soils, Soil Solutions and Ground Water . 17
   Soil Properties 17
   Soil Solution and Ground Water Analyses 18
   Virus Determination 19
   Total and Fecal Coliform Determinations 19
6. Total Organic Carbon Components 20
   Total Organic Carbon Measurements 20
7. Biological Decomposition 22
   Decomposition Analyses 22
8. Evaluation of Tree Growth 24
9. Liquid Waste Processing and Sludge Properties 26
   Chemical Composition of Sludge 26
10. Study of Sludge Application Methods 29
   Sprinkler Modifications 30
11. Summary of Tests of Sludge Application Methods 35
   Over-the-Canopy Application 35
   Trickle Irrigation Application 35
   Under-the-Canopy Irrigation 35

CONTENTS (Continued)

12. Initial Sludge Applications 39
Sludge Applications and Constituents 39

13. The Irrigation System and Sludge Application Rates 41
First Year Applications 41
Second Year Applications 41

14. Results of Sludge Applications on Soils and Soil Water 43
Renovation of Solids 43

15. Everett Soils, Soil Solution Nutrients 46

16. Properties of Everett Soils 54
Everett Soil Chemistry, First and Second Years 56
Everett Soils, Exchangeable Chemistry and Base Saturation, Second Year 59
Everett Soil Chemistry, Third Year 61
Everett Soils, Exchangeable Chemistry and Base Saturation, Third Year 63
Everett Soils, Reduced Sludge Applications 65
Everett Soil Chemistry, Reduced Sludge 65
Everett Soils, Exchangeable Chemistry and Base Saturation, Reduced Rates 68

17. Everett Soil Solution Nutrients, Water and Control Plots 70

18. Everett Soils--Soil Solution Nutrient Concentrations 72
Total Nitrogen 72
Base Nutrients 74
Everett Soils, Soil Solution Conductivity, pH and Alkalinity 74

19. Everett Soils, Ground Water Nutrients 77

20. Mashel Soils, Soil Solution Nutrients 79
Nutrient Renovation for the Mashel Soil Series 79

21. Mashel Soil Properties 82
Soil pH 82
Soil Organic Matter 82
Total Nitrogen 82
Cation Exchange Capacity 82
Carbon-Nitrogen Ratio 84
Mashel Soils, Exchangeable Cations and Base Saturation . . 84

22. Wilkeson Soils, Soil Solution Nutrients 86
Wilkeson Soils, Soil Properties 86
Wilkeson Soils, Exchangeable Cations and Base Saturation . 89

23. Mashel and Wilkeson Soils, Soil Solution Nutrient Concentration 91

24. Everett Soil, Total Organic Carbon 93
Total Organic Carbon Leaching 93

CONTENTS (Continued)

Identification of Specific Organics 96

25. Everett Soil, Biological Decomposition 105
    Soda Solubility 105
    Weight Loss Decomposition 108

26. Everett Soils, Virus and Bacteria 112

27. Everett Soils, Heavy Metals 113

28. Sludge Applications and Forest Growth 114
    Sludge Application and Forest Growth, Paried Trees 117
    Diameter Growth Rate, Paired Trees 117
    Basal Area Growth Rate, Paired Trees 121
    Volume Analysis 121
    Water Only Irrigation, Growth, Paired Trees 121
    Sludge vs. Sludge Plus Water, Growth, Paired Trees 121

29. Discussion of Sludge Applications to Forest Soils 126
    Sludge Application Methods 126
    Rates of Sludge Application 127
    Renovation of Nutrients 128
    Renovation of Base Nutrients 128
    Renovation of Phosphorus 129
    Renovation of Nitrogen 129
    Evaluation of Total Organic Carbon 131
    Evaluation of Biological Decomposition 131
    Sludge Applications and Forest Growth 132

30. Summary of Results of Sludge Applications 133

Literature Cited 135
Appendices 138

FIGURES

Number		Page
1	The Everett soil series is an immature, slightly podzolic soil developed on loose, poorly sorted glacial outwash.	5
2	Plots on the Wilkeson soil were in an old growth western hemlock stand with larger older trees and an understory of young hemlock. The plywood box contains the sample collection bottles for the lysimeter plates.	9
3	The Everett soil supports a 36-year old Douglas-fir stand with an average of 1580 trees per ha. Standing dead trees and cull hardwoods were removed from the plot (pile in lower righthand corner).	11
4	The arrangement of plots and treatments is shown for the study area on the Everett soils. Plot numbers are in parentheses while treatments indicate the mt/ha/yr. Locations of wells are shown with an X1, etc.	13
5	Sludge was transported from Metro's West Point Plant to Pack Forest in 19,000-liter quantities (5,000-gal.). Usually two trips were made each day sludge was applied.	30
6	A ramp was constructed so the tanker trucks could discharge sludge by gravity flow to the storage pond.	31
7	Adjacent to the storage pond, a small structure housed the combination Maz-o-rator and Moyno pump. Piping to the right is the suction line from the storage pond with the supply lines to plots underground.	32
8	The Rainbird 65D TNT sprinkler had the lower deflector arm removed and was teflon coated, following removal of rough projections in the brass casting.	34
9	Heavy rates of sludge application caused impeded infiltration resulting in ponding of sludge in depressions. This example from the trickle irrigation plot in an area of concentrated sludge applications.	36
10	Sprinklers were located on 5-ft. risers at each corner on the square plots.	38
11	Average TOC values versus depth for water, control, and sludge treatments.	94
12	Average TOC versus soil depth for the sludge followed by water sites.	95

FIGURES (Continued)

Number		Page
13	TOC versus date of sample collection for the 300 plot from the four soil depths	97
14	L layer and C horizon soil solutions from sludge control plots compared by gel filtration chromatography	98
15	Gel filtration chromatograms of soil solution samples from L and C layers of 10 series plots, C horizon of 300 plot and well water	99
16	Gas chromatogram of ether extract of soil from 300 and control plot A horizon using a DEGS column	101
17	Gas chromatogram of ether extract of soil from 300 and control plot B horizon using a DEGS column	102
18	Gas chromatogram of ether extract of 100 B horizon using a DEXSIL 300 column	103
19	Gas chromatogram of ether extract of the control plot B horizon using a DEXSIL 300 column	104
20	Changes in 1% NaOH solubility of wood blocks on top of the litter over time by sludge treatments	106
21	Changes in net weight of wood blocks on top of the litter over time by sludge treatments	110
22	Individual tree diameter pai following 3 years of irrigation as a function of pretreatment diameter pai per tree (paired trees)	118
23	Individual tree basal area pai following 3 years of irrigation as a function of pretreatment basal area per tree (paired trees)	122
24	Adjusted mean diameter pai following 3 years of irrigation as a function of weekly irrigation rates	124

TABLES

Number		Page
1	Maximum, minimum and average composition of sewage sludge applied to plots.	27
2	Tons of sludge applied by plots and soils and year in depth and total weights	45
3	First year nutrient loading and flux (kg/ha) through the Everett soil and percent renovation.	47
4	Second year nutrient loading and flux (kg/ha) through the Everett soil and percent cumulative renovation	49
5	Third year nutrient loading and flux (kg/ha) through the Everett soil and percent cumulative renovation	51
6	Total nutrients applied (kg/ha), flux and percent total renovation through Everett soil.	52
7	Total nutrient balance for pre- and post sludge applications and total percent flux on the Everett soil	55
8	Soil chemical properties following sludge applications on the Everett soil series and 95% confidence interval, second year.	57
9	Exchangeable cations and percent base saturation by horizons of the Everett soil, second year.	60
10	Soil chemical properties following sludge applications on the Everett soil series and 95% confidence interval, third year	62
11	Exchangeable cations and percent base saturation by horizons of the Everett soil, third year	64
12	Total nutrient loading and flux (kg/ha) through the Everett soil	66
13	Average soil chemical properties of Everett (new plots) soils with reduced rates of sludge application	67
14	Exchangeable cations and percent base saturation by horizons for pre- and post sludge applications for the Everett soil (reduced rates)	69
15	Nutrients applied in water and flux (kg/ha) from control and water only plot.	71

TABLES (Continued)

Number		Page
16	Minimum-maximum concentrations of nutrients in the soil solution at 2.1 m (7 ft.), Everett soils	73
17	Conductivity, pH, and alkaninity of the soil solution and ground water for Everett plots	75
18	Dissolved chemistry of ground water, Everett soils	78
19	Nutrient loading and flux (kg/ha) through the Mashel soil and percent renovation (applied nutrients in mt/ha and flux of nutrients in kg/ha)	80
20	Soil chemical properties following sludge applications on the Mashel soil series	83
21	Exchangeable cations and percent base saturation by horizons for pre- and post sludge applications for the Mashel soil	85
22	Nutrient loading and flux (kg/ha) through the Wilkeson soil and percent renovation	87
23	Soil chemical properties following sludge applications on the Wilkeson soil series and 95% confidence interval	88
24	Exchangeable cations and percent base saturation by horizons of the Wilkeson soil	90
25	Range in nutrient concentrations of the soil solution by plots for the Mashel and Wilkeson soils	92
26	Decomposition over time assessed by soda solubility extractions (percentage of dry weight) of wood blocks by various depths and treatments	107
27	Decomposition over time assessed by weight loss (percent of the dry weight) of wood blocks by depths and treatments	109
28	Average stand conditions before and after sewage sludge irrigation by plot and treatment	115
29	Average gross periodic annual increment for pretreatment, 2 and 3 years after irrigation by plot and treatment	116
30	A summary of average periodic annual increment for paired trees, before, 2 and 3 years after sludge applications by treatment	119
31	Comparisons of sludge treatments, water only and the control using individual paired trees	120
32	Comparison of tree growth slopes between sludge and sludge plus water treatments	123

ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ac.	-- acre
BA	-- basal area
cm	-- centimeter
DBH	-- diameter breast height (the 4.5 ft. or 1.4 m height on the bole)
ev	-- electron volts
ft.	-- foot/feet
ft^2/ac	-- square feet per acre
ft^3/ac	-- cubic feet per acre
g	-- gram
gal.	-- gallon
g/cm^3	-- grams per cubic centimeter
ha	-- hectare
hp	-- horsepower
in.	-- inch
kg	-- kilogram
kg/cm^2	-- kilograms per squre centimeter
km	-- kilometers
l	-- liter
lbs/ac.	-- pounds per acre
m	-- meter
meq	-- milli-equivalent
Metro	-- Municipality of Metropolitan Seattle
mg	-- milligram
mi.	-- mile
min.	-- minute
ml	-- milliliter
mm	-- millimeter
MPN	-- most probable number
m^2/ha	-- square meters per hectare
m^3/ha	-- cubic meters per hectare
mt/ha	-- metric tons per hectare
mt/ha/yr	-- metric tons per hectare per year
O.D.	-- oven dry
pai	-- periodic annual increment
ppm	-- parts per million
psi	-- pounds per square inch
rpm	-- revolutions per minute
sq. ft.	-- square foot/feet
sq. m	-- square meter

ABBREVIATIONS AND SYMBOLS (Continued)

vol	-- volume
yr.	-- year

SYMBOLS

Ca	-- calcium
Cd	-- cadmium
Cl	-- chlorine
Cn	-- copper
CO_2	-- carbon dioxide
Cr	-- chromium
K	-- potassium
Mg	-- magnesium
Na	-- sodium
NH_4^+	-- ammonium ion
NH_4-N	-- ammonium nitrogen
Ni	-- nickel
NO_3-N	-- nitrate nitrogen
Pb	-- lead
pH	-- acidity
PO_4-P	phosphate phosphorus
TOC	-- total organic carbon
Total N	-- total Kjeldahl nitrogen
Total P	-- total phosphorus
Zn	-- zinc

α	-- alpha
$<$	-- less than
μ	-- micro
%	percent

ACKNOWLEDGEMENTS

The cooperation of the Municipality of Metropolitan Seattle (Metro), Mr. Ralph Domenowske, project officer, and the Weyerhaeuser Company, Dr. Ronald L. Heninger, research silviculturalist, Western Forestry Research Center, Centralia, Washington, is gratefully acknowledged. Drs. Bjorn Hrutfiord and Charles Drive of the College of Forest Resources, respectively, provided the Total Organic Carbon and Biological Decomposition Analyses, Results and Discussion of findings. The Children's Orthopedic Hospital, as well as Metro, provided biological analyses and aided in interpretation of data.

The principal investigator would like to acknowledge personal contribution of Dr. John Stednick to the project as well as other staff personnel, Kathy McCreary and Bill Wilson, and numerous students who suffered through a lengthy series of immunization shots for typhoid, cholera, hepatitis, etc. The contributed secretarial services of my wife, Joyce, in completion of the final manuscript must also be acknowledged. The research project could not have been accomplished without their contributions.

Mr. Gerald Stern, project officer, U. S. Environmental Protection Agency, provided invaluable guidance throughout the three plus years required in the conduct and reporting of the study. Again, successful completion could not have been achieved without his help.

Section 1

INTRODUCTION

A national objective of improved quality of the Nation's waters has been implemented through state and federal laws and regulations. These laws and regulations have far reaching effects on disposal of wastes. Major municipalities concentrate both industrial and municipal solid and liquid wastes. Concentrations of urban population tend to concentrate problems with waste disposal. Rural and agricultural areas, both domestic and foreign, produce a host of products utilized in urban centers. Advent of the kitchen sink disposal unit transfers considerable of the solid waste disposal problems to the liquid waste system, with large quantities of organic wastes processed through liquid waste digestion rather than solid waste processes.

Burial, burning and disposal in water have become questionable solutions in waste disposal. Regions of the United States with extensive forest lands have the opportunity for beneficial use of certain of these liquid wastes in the forest. Water has an irrigation benefit during summer periods of soil moisture stress, and utilization of bio-degradable nutrients by the forest ecosystem will accelerate forest growth rates.

A research project funded in part by EPA and cooperative with the Weyerhaeuser Company, the Municipality of Seattle (Metro), and the College of Forest Resources, University of Washington studied application of liquid digested wastewater sludge in the forest environment. When applied to the forest, liquid digested municipal sludge can increase tree growth rates by adding nutrients and improving soil moisture. The renovation capacity of the forest soil and utilization of nutrients is dependent upon a series of physical, chemical and biological interactions in the forest ecosystem.

RESEARCH OBJECTIVES

To accurately interpret the impacts of sludge application on forest soils, as well as growth rate of trees on the forest plots, a very uniform liquid sludge application was required so that each area of each plot was receiving equal quantities of sludge and water.

1. Establish efficient methods of sludge application to forests.

2. Establish the short-term impacts of sludge application on the forest including effects on physical and chemical properties of the forest soil and chemistry of soil water.

3. Establish the rate of sludge application which has maximum benefits to forest growth with minimum impact on soil water quality and be non-polluting to surface or ground waters.

4. Establish the effects of application of sludge on forest growth rates.

The above objectives address applied sludge disposal problems, searching for economic solutions to liquid waste or sludge management. A variety of experimental designs would answer certain of the questions. These could include laboratory studies of leaching sludge in soil columns for soil and water chemistry; however, the complex interactions of weather, soils and related environmental factors suggested a field study, particularly for developing an effective method of sludge application in the forest environment and forest growth responses to applications of sludge.

The following report provides results of three years' study on applications of municipal-industrial sludge on a series of forest plots on soils with varying characteristics. By the very nature of the study, it was necessary to develop it in phases. The first year concentrated on development of the most feasible method of obtaining uniform application of the sludge to forested research plots.

The requirement for a uniform application of sludge over the experimental plots required a more complex sludge irrigation system than would be required for routine disposal of sludge in the forest environment. In the following sections, the results of the application phase of the study (Objective 1) will be reported prior to the other results, as this phase developed the final method of application which was used on plots established in later phases of the research.

The second year concentrated on determination of the impacts of varying rates of sludge application. The final phase investigated the impacts of both rates of sludge application to plots and impacts on three different forest soil types.

Section 2

THE STUDY AREA

The research sites are located 110 km (70 mi.) south of Seattle, Washington near the town of Eatonville and adjacent to and on Pack Demonstration Forest, College of Forest Resources, University of Washington. The initial work tested methods of liquid digested sludge application on a 1.6-ha (4-ac.) tract of Weyerhaeuser Company land at lower elevations on the Everett soil series. Later research assessed weekly rates of sludge application on the Everett, Mashel and Wilkeson soils series on Pack Forest. Forest growth, decomposition and aggregate impacts of three years of sludge application on soil and soil water chemistry were studied on the Everett soil series on Weyerhaeuser Company lands. Research on the Wilkeson and Mashel series was limited to impacts of rates of sludge application on soil and soil water chemistry.

CLIMATE

Climate in the vicinity of the study area has in general characteristics of the maritime climate of the Puget Sound Lowlands. Summers are relatively warm and dry followed by humid temperate winters with substantial winter rainfall. Annual precipitation increases markedly with increased altitude, an average of 25.4 cm (10 in.) per year per 305 m (1000 ft.) increase in elevation, with a marked decline in average annual temperature with increasing altitude. Air masses originate over the Pacific Ocean moderating both winter and summer temperatures. Precipitation is usually caused by orographic storms resulting in persistently high moisture content of winter air masses. Widespread precipitation of moderate to light intensity occurs as air masses cool and rise over land in winter. Fifty percent (60 cm or 24 in.) of the average total annual precipitation (120 cm or 48 in.) at Pack Forest falls in the four months of October through January. Total rainfall for July and August is usually less than 5% (11.9 cm or 4.7 in.) of the annual and often drought-like conditions may exist on well drained soils. At lower elevations (the Everett soil series), snow is common in the winter but seldom persists for over a few days. At higher elevations (the Wilkeson soil series), snow is more frequent and persistent.

During the warmest summer months, average maximum monthly temperatures are 21 to 24 °C (70 to 75 °F), while the coldest winter temperatures average slightly above freezing.

Annual evaporation from a Class A pan is estimated at 63.5 cm (25 in.) at nearby Puyallup, Washington 24 km (15 mi.) to the northwest. Monthly evaporation rates vary from 7.5 to 16.5 cm (3 to 6.5 in.). Based on average normal temperatures and precipitation, estimates of actual annual evapotranspiration range from 38 to 46 cm (15 to 18 in.) in the mountains to 38 to 56 cm (15 to 22 in.) in the lower valleys (Pacific Northwest River Basin Commission, 1970).

THE EVERETT SOIL SERIES

The Everett soil series is a light colored, podzolic soil developed on loose gravelly to slightly modified or poorly sorted glacial outwash. Stratification is usually poor with a wide range in particle sizes of rocky gravelly components. The research site has a gravelly outwash overburden of 9 to 12 m (30 to 40 ft.) of gravelly outwash deposits covering a fine textured lacustrine strata. The lacustrine strata is almost impermeable to vertically percolating soil water; thus, most ground water flows laterally along the interface forming several springs in the vicinity of the research plots.

The soil classified as an Everett type is very coarse textured, immature, formed from these outwash deposits of the last glaciation. Everett soils are light colored podzolic soils developed on loose, coarse, gravelly, slightly modified or poorly sorted glacial outwash materials, stratified in places and having a wide range of rocks (Figure 1).

The Seventh Approximation (SCS, 1960) groups the Everett series in the brown podzolic group as a gravelly loamy sand, with the class Haplorthod, coarse loamy over sandy, skeletal mixed mesic (Schlichte, 1968). The soil profile description is:

Horizon	Depth	Description
Litter	4-0 cm (1.5-0 in.)	Very dark grayish brown (10 YR 3/2) loose or very friable matted layer of forest litter. Strongly acid (pH 5.6).
A	0-15 cm (0-6 in.)	Pale brown or brown (10 YR 6/3, brown, 10 YR 4/3 moist) loose gravelly sandy loam. Structureless and with included hard rounded shot cemented with iron oxides.
B	15-60 cm (6 to 24 in.)	Light yellowish brown (10 YR 6/4, dark yellowish brown, 10 YR 4/4, or yellowish brown, 10 YR 5/4 moist) gravelly sandy loam with less shot.
C	60+ cm (24+ in.)	Light yellowish brown, light brownish-gray, gray with dark gray gravel, sand and cobbles, loose and porous, poorly sorted and somewhat stained with brown and reddish brown.

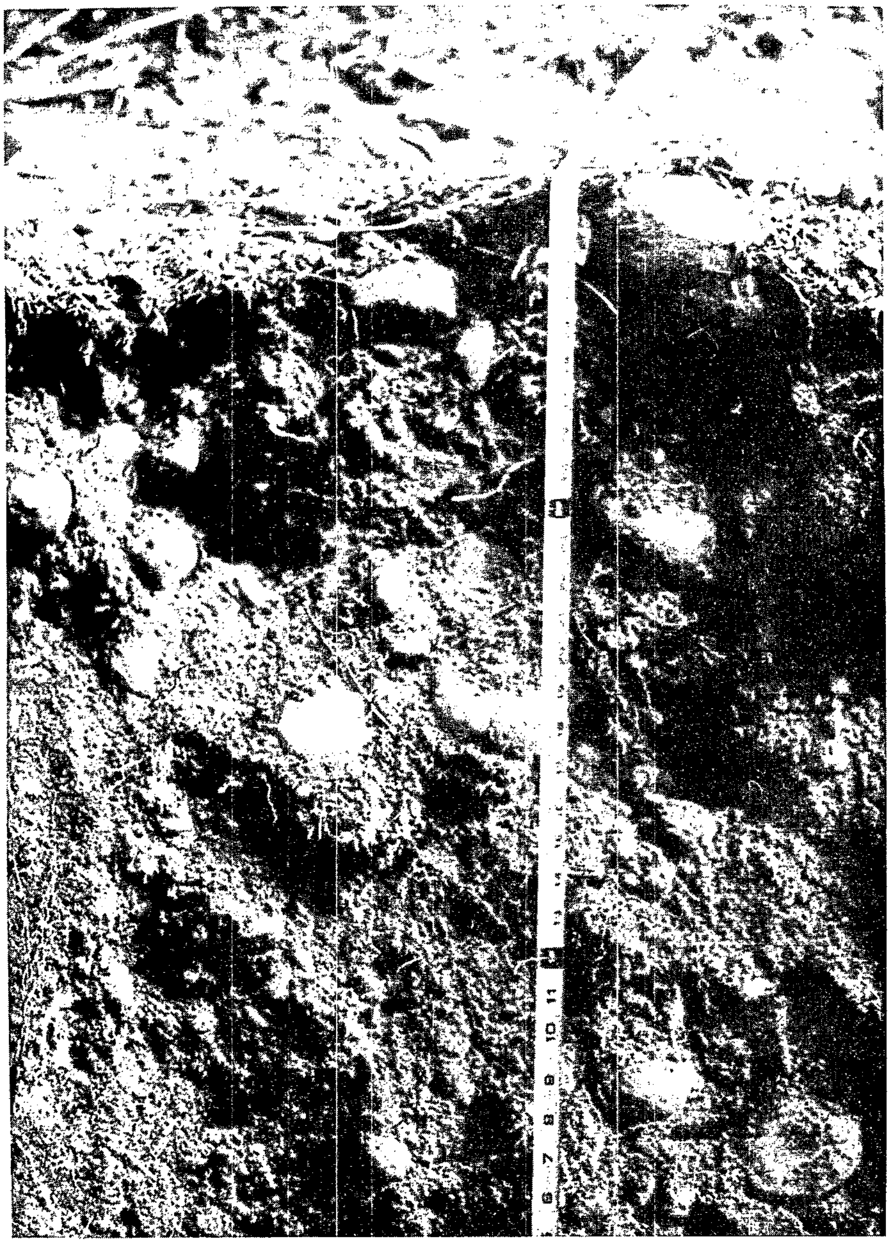

Figure 1. The Everett soil series is an immature, slightly podzolic soil developed on loose, poorly sorted glacial outwash.

The following lists the soil density, the percent larger than 2 mm (0.08 in) fraction, and percentage of sand, silt and clay for the Everett soil.

Depth (cm)	Density (g/cm^3)	% Larger Than 2mm	Texture of the 2mm Fraction Sand	Silt	Clay
				Percent	
0-15	0.71	82	62	31	7
15-30	1.46	80	72	23	5
30-60	1.65	84	80	16	5
60 +	1.74	95	88	9	3

THE MASHEL SOIL SERIES

The Mashel series consists of deep, moderately well drained soils formed in glacial till. Mashel soils occur on uplands with slopes of 5 to 65 percent. Elevations range from 210 to 550 m (700 to 1800 ft.). Mean annual precipitation is about 22 cm (55 in.). Mean annual air temperature is about 9°C (49 °F). The taxonomic class is a fine, halloysitic, mesic Ultic Haploxeralfs. (Colors are for moist soil unless otherwise noted.)

Horizon	Depth	Description
Litter	8-0 cm (3-0 in.)	Partially decomposed roots, leaves and twigs, 0 to 8 cm (0 to 3 in.) thick.
A	0-20 cm (0-8 in.)	Dark brown (10 YR 3/3) loam, brown (10 YR 5/3) dry; moderate fine and medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; 1 percent hard rounded pebbles; many fine pores, very strongly acid (pH 5.0); clear smooth boundary, 13 to 23 cm (5 to 9 in.) thick.
B	20-41 cm (8-16 in.)	Dark brown (10 YR 4/3) heavy loam, pale brown (10 YR 6/3) dry; few faint dark brown mottles; moderate medium subangular blocky structure; hard, firm, slightly sticky and slightly plastic; 1 percent hard rounded pebbles; many fine and medium roots; many fine pores; thin patchy clay films on some faces of peds; very strongly acid (pH 4.7); clear wavy boundary, 15 to 23 cm (6 to 9 in.) thick.
C	41-90 cm (16-36 in.)	Yellowish brown (10 YR 5/4) clay loam, light yellowish brown (10 YR 6/4) dry; common bleaches silt and sand particles on faces of some peds and within some peds; moderate medium and coarse subangular blocky structure; hard, firm, sticky and plastic; 2 percent

		strongly weathered rounded gravel, less than 1 percent hard pebbles; common fine and medium roots; common fine and medium pores, many thin to moderately thick dark brown clay films on faces of peds and in pores; few black stains; very strongly acid (pH 4.5); gradual wavy boundary, 25 to 56 cm (10 to 22 in.) thick.

Forest vegetation is dominantly western red cedar with some western hemlock. Subordinate vegetation is sword fern. The site is characteristically wet throughout the year.

THE WILKESON SOIL SERIES

The soils of the Wilkeson series are deep, well-drained soils formed in materials weathered from andesite and basalt. They are on slopes of the foothills. Mean annual precipitation is about 203 cm (80 in.) and mean annual air temperature is about 8 °C (49 °F) The taxonomic class is Eutric Glossoboralfs; fine loamy, mixed family. (Colors are for moist soil unless otherwise noted.)

Horizon	Depth	Description
Litter	5-0 cm (2-0 in.)	Partially decomposed needles, leaves, twigs and roots.
A	0-10 cm (0-4 in.)	Very dark grayish-brown (10 YR 3/2) gravelly silt loam, grayish brown (10 YR 5/2) when dry; weak, very fine, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine roots; 25 percent shot and angular pebbles; medium acid (pH 5.6); abrupt, smooth boundary, 7 to 13 cm (3 to 5 in.) thick.
B	10-69 cm (4-27 in.)	Dark brown (10 YR 3/3) gravelly silt loam, brown (10 YR 5/3) when dry; weak, fine, subangular blocky structure; slightly hard, friable, slightly sticky and plastic; many fine, medium and coarse roots; 30 percent shot and angular pebbles; strongly acid (pH 5.4); diffuse wavy boundary, 13 to 18 cm (5 to 7 in.) thick.
C	70-90 cm (27-36 in.)	Yellowish-brown (10 YR 5/4) gravelly silty clay loam, light yellowish-brown (10 YR 6/4) when dry; moderate, medium, prismatic, parting to moderate, medium, subangular blocky structure; hard, firm, sticky and plastic; few fine and coarse roots; common

very fine and fine pores; moderate thick clay film in fine pores; 10 percent angular pebbles; medium acid (pH 5.8); gradual, wavy boundary, 20 to 38 cm (8 to 15 in.) thick.

The forest stand was predominantly old growth western hemlock with a few young hemlock in the understory. Subordinate vegetation was a mixture of salal, red huckleberry and some grass species. The area of plot study was generally open as shown in Figure 2.

Figure 2. Plots on the Wilkeson soil were in an old growth western hemlock stand with larger older trees and an understory of young hemlock. The plywood box contains the sample collection bottles for the lysimeter plates.

Section 3

METHODS OF PLOT LAYOUT, SOIL SAMPLE AND ANALYSES

Study methods used for soil sampling and analyses, plot layout, etc. are conventional and accepted for similar phases of field forestry research. They involve the establishment of plots in the forest stand and random sampling of the forest soils. Tests of methods of sludge application resulted in design of an irrigation system for applications of sludge to experimental plots.

PLOTS ON THE EVERETT SOIL SERIES

Experimental plots were established on Weyerhaeuser Company land on the west edge of Pack Forest in Section 29, Township 16N, Range 4E, the Willamette Meridian (latitude 46^{o} 50' W; longitude 122^{o} 22' N). The elevation of plots on the Everett soil series is 230 m (750 ft.) above mean sea level. The bench (outwash on which the plots were located) breaks about 60 m (200 ft.) west of the plots, dropping steeply into the Nisqually River.

Plots on the Everett soil series were the most intensively studied. The first study phase developed a method of sludge application, and later phases studied forest growth rates and biological decomposition.

The forest stand was second growth Douglas-fir established in 1939 with an average density of 1580 trees per ha (640 stems per ac.) and average basal area of 35 sq. m per ha (150.7 sq. ft. per ac.). A few survivors of the old growth forest occurred randomly throughout the plot area. The understory consisted primarily of salal, Oregon grape and elderberry. Mosses and lichens are also numerous as soil cover and on downed organic materials (Figure 3).

Two areas were selected on the Everett soil series; one for initial testing of methods of sludge application, and the second for detailed studies of soils, soil solution chemistry, decomposition and forest growth as per the objectives. Square plots (0.04 ha or 0.1 ac.) were established using compass and tape for measurement of distances and angles. Three plots were established for testing methods of sludge application. Seventeen additional 0.04 ha (0.1 ac.) plots were established for testing rates of sludge application on soils, decomposition and impacts on forest growth rates.

Responsibility for assessment of effects of sludge applications on forest growth was assumed by the Weyerhaeuser Company as a cooperator. All trees in each plot were numbered with aluminum tags and measured for diameter breast height (DBH) to the nearest 0.25 mm (0.01 in.). Increment cores

Figure 3. The Everett soil supports a 36-year old Douglas-fir stand with an average of 1580 trees per ha. Standing dead trees and cull hardwoods were removed from the plot (pile in lower righthand corner).

were taken from dominant and co-dominant Douglas-fir to develop regression equations which estimated the previous rate of basal area growth. Stand biomass was estimated by DBH regressions (Dice, 1970) after testing the equations with additional trees.

The general layout of intensive studies on Everett plots is shown in Figure 4. Lysimeters were installed to sample volumes and chemistry of soil water under the forest floor at the boundary between the A and B horizons (15 to 25 cm or 6 to 10 in.) and the boundary of the B and C horizons (46 to 60 cm, or 18 to 24 in.). Lysimeters were also installed at a depth of 210 cm (7 ft.) below the C horizon. A continuous vacuum was maintained on each lysimeter at 0.1 atmospheres (3 in. or 76 mm of mercury) which approximates the tension of retention of gravitational water in the Everett soil matrix. A pressure sensitive switch operates on a central vacuum system activating the vacuum pump automatically to maintain constant tension on all lysimeters. Extracted soil water samples identified by plots and depths were taken to the lab at the University for analyses.

Pretreatment sampling of the forest soil by plots was made at the time of lysimeter plate installation. The forest floor and soil horizons were sampled for physical properties and chemical constituents.

SOIL SOLUTION MONITORING

A Metro-Data 616 data logger was coupled in the lysimeter soil water flow system with probes for field recording of pH, dissolved oxygen, conductivity and temperature of extracted soil water plots and at varying soil depths. These probes were scanned at frequent intervals depending on sludge applications or the dynamics of climatic events. Intermittent measurements for the above parameters of soil water extracted were taken with routine instrumentation to verify the accuracy of the recorded data.

Volumes of soil solution collected for laboratory analyses varied seasonally with rainfall; therefore, in calculating nutrient flux, irrigation and precipitation were assumed to be uniform over plots and infiltrated and percolated to sampled depth. Total flux of water was calculated for a given sample period including a correction factor for seasonal evapotranspiration. Chemical concentrations were averaged for a particular sampling period and then used in the determination of a nutrient flux. It should be noted that years 1, 2 and 3 are 10, 10 and 7 months, respectively.

Analyses for biological components (bacteria and virus) and heavy metals also were based on soil solution chemistry as monitored by lysimeter extracts for various soil horizons by plots.

SAMPLING FOR GROUND WATER NUTRIENTS

Wells were drilled as located in Figure 4 to study the chemistry of ground water adjacent to sludge treated plots. The glacial outwash overburden in the plot locations was approximately 10 m (33 ft.) thick overlying a relatively impermeable lacustrine substrata. Natural flow of water percolates through the Everett soil to the lacustrine outwash interface, then

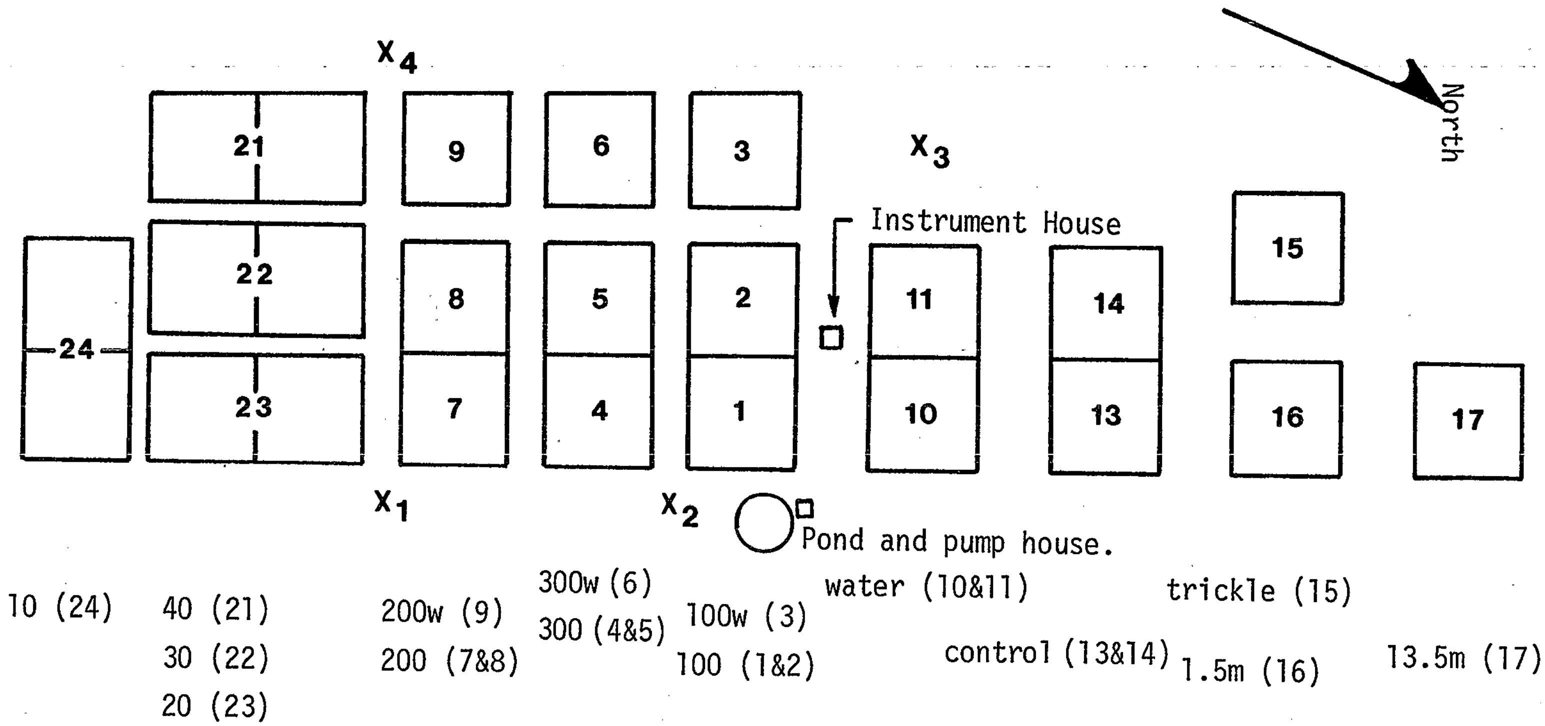

Figure 4. The arrangement of plots and treatments is shown for the study area on the Everett soils. Plot numbers are in parentheses while treatments indicate the mt/ha/yr. Locations of wells are shown with an X1, etc.

moves laterally to a number of springs on the slopes to the Nisqually River. Both the springs and water samples from the wells were monitored to assess impacts of sludge application on ground water chemistry.

Four wells were drilled to depths of 10+ m (33+ ft.). The wells were lined with 15 cm (6 in.) inside diameter PVC pipe and tops covered. Ground water samples were obtained by lowering sample containers into the free water and extracting a sufficient volume for total chemical analyses. Wells 1 and 2 provided a stable supply of water for chemical analyses. Wells 3 and 4 were frequently dry during drier periods, supplying only water during wet winter periods. The rates of flow of ground water through the well could not be measured; consequently, a measurement of nutrient flux in ground water was not possible. Only changes in concentration of ground water over time are reported.

Section 4

SLUDGE TREATMENTS TO PLOTS

The area of Weyerhaeuser forest land used for the testing of liquid digested sludge application was based on plot size spacing, proximity to an access road, and maximum replications possible within the constraints of transport of large quantities of sludge from Metro's West Point plant to Pack Forest. The plots were laid out with buffer strips separating different sludge treatment applications and the water only and control plots. Figure 4 shows the relative location of all plots on the Everett soil, the swimming pool sludge storage tank and pump house, and location of wells for sampling of ground water.

The initial study of the methods for liquid sludge application used plots 15, 16 and 17 (Figure 4) which are actually more remote from the study area than indicated. Plot 15 tested trickle sludge applications; 16 was under-the-canopy on 1.5 m (5 ft.) risers; and 17 was over-the-canopy on 9 m (30 ft.) risers.

The experimental design used duplicate plots with 100, 200 and 300 metric tons per ha per yr. of sludge application. Plots 1 and 2 are referred to as the 100 (100 mt/ha/yr or 44.5 t/ac/yr) series; 4 and 5 as the 300 (300 mt/ha/yr or 133.6 t/ac/yr) series; and 7 and 8 as the 200 (200 mt/ha/yr or 89 t/ac/yr) series. Plots 3 (100W), 6 (300W), and 9 (200W) each received 1.3 cm (0.5 in.) of irrigation water after the sludge application. Plots 10 and 11 received 1.3 cm (0.5 in.) of irrigation water only per inch, while plots 13 and 14 are untreated control plots.

Recognition of the need to reduce sludge application rates in the second year of study resulted in the establishment of plots with sludge application rates of 10, 20, 30 and 40 mt/ha/yr (4.5, 8.9, 13.3 and 17.8 t/ac.). These duplicate plots are identified as plots 24, the 10 series; plots 23, the 20 series; plots 22, the 30 series; and plots 21, the 40 series (Fig. 4).

PLOTS ON MASHEL AND WILKESON SOILS

The sludge study on the Mashel and Wilkeson soils was limited to the effects of sludge applications on soil solution chemistry. This investigation required a smaller plot area, reducing the problem of logistics for sludge transportation and applications.

Sludge was transported from the receiving area at the Everett plots to the sites of Mashel and Wilkeson soils on Pack Forest. Duplicate 0.01 ha plots (0.025 ac.) were established on a uniform slope to receive applications of 10, 20, 30 and 40 mt/ha/yr (4.5, 8.9, 13.3 and 17.8 t/ac.). Lysimeter plates were installed in a manner similar to that of the Everett plots to a depth of 60 cm (24 in.), a zone midway in the B horizon. As with the Everett plots, lysimeters were placed under the forest litter layers and at the interface of the A and B soil horizons. Soil solution sampling and soil chemistry were similar to those methods used on the Everett plots.

Section 5

ANALYTICAL ANALYSES OF SOILS, SOIL SOLUTIONS AND GROUND WATER

Soil pits excavated to the C horizon for lysimeter installations were sampled in duplicate by horizons, establishing pretreatment exchangeable and total soil chemistry. Post sludge treatment soil samples were taken from new pits in a similar manner. Soil samples were air dried, then sieved for the less than 2 mm (.08 in.) fraction prior to analyses.

SOIL PROPERTIES

Soil pH was determined with a glass electrode on a solution of 1:1 soil to distilled water, allowing time to come to equilibrium. Litter layers were mixed with a 1:2 ratio water (Forest Soils Committee, 1953).

A modified Kjeldahl method was used to determine total soil nitrogen. The form of most nitrogen in forest soils is protein as amino acid groups attached to carbon. Organic matter is oxidized in concentrated sulfuric acid, a slow reaction catalyzed by selenium and additions of sodium sulfate. After digestion, the solution is made strongly basic and ammonia distilled into a dilute acid. Titration of the distilled solution with a standard determines the amount of ammonia absorbed (Bremner, J. M., 1965).

Soil organic material was determined by the modified wet combustion method (Walkley and Black, 1934). Soil samples are treated with an excess of oxidizing agent, sulfuric acid in chromic acid. Excess chromic acid is determined by a back titration with a standard ferrous sulfate solution. Heat of dilution from added concentrated sulfuric acid speeds the reaction. Chromic acid is not carbon specific but will react with any readily oxidizable substance. Approximately 77% of the total carbon in soil organic matter is oxidized. Approximately 58% of soil organic matter is carbon.

Total cation exchange capacity for soil samples was determined by leaching samples with normal ammonium acetate buffered to neutral pH (Jackson, 1958). Determination of cation exchange capacity involves saturating the soil colloidal exchange complex with a known cation (NH_4) and will exchange cations on the soil exchange complex. Displacing NH_4 cations by another leaching solution (Na) allows determination of total soil cation exchange capacity as milli-equivalents per 100 grams of oven dry weight of soil (meq/100g O.D. soil).

The ammonium acetate solution containing the original displaced cations from the soil sample is analyzed for exchangeable cations (Ca, Mg, K and Na), which are also expressed as meq/100g O.D. soil. The sum of exchangeable cations divided by the total cation exchange capacity is termed 'base saturation' and expressed as percent.

Total chemistry of soils required digestion until dry (overnight) of a soil sample in a nitric-hydrofloric and hydrofulvic acid mixture (Jackson, 1958) in teflon beakers. The residue is then redissolved in distilled water and the solution analyzed for cations on the atomic absorption spectrophotometer. Pretreatment total soil chemistry values were used to define the statistical confidence intervals. Variability in total chemistry was high because less than 0.15 g of soil was digested. There are also large differences in actual soil particle sizes which make up the 0.15 g sample. It is assumed that chemical composition of less than 2 mm (0.08 in.) fraction is similar to the greater than 2mm (0.08 in.) fraction.

Carbon-nitrogen ratios are calculated from the average values for soil organic matter and total nitrogen. Organic matter is assumed to consist of 58% organic carbon. Dividing the percentage of soil organic carbon by the percentage of total nitrogen gives the carbon-nitrogen ratio.

SOIL SOLUTION AND GROUND WATER ANALYSES

Soil solution and ground water samples were transported to the University of Washington lab. One subsample is filtered through Whatman 1 filter paper and digested with sulfuric acid and hydrogen peroxide for total Kjeldahl nitrogen and total phosphorus determinations. Another subsample is filtered through Whatman glass fibre paper and used for anion and cation determinations. The remaining sample is used for pH measurement, alkalinity titration, conductance and TOC. All samples are stored at 2-4^{o} C (36-39^{o} F).

Total Kjeldahl nitrogen and total phosphorus are determined by a modified Kjeldahl (Standard Methods, 1971) which converts most forms of organic nitrogen and phosphorus into ammonium and phosphate. Ammonium and phosphate are then determined by Auto-analyzer methods. Total Kjeldahl nitrogen, nitrite and nitrate nitrogen are summed as total nitrogen. The difference between total Kjeldahl nitrogen and ammonium nitrogen is organic nitrogen.

Ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (Total N), phosphate phosphorus (PO_4P), total phosphorus (Total P), and sulfate sulfur are determined by use of a Technicon Autoanalyzer II. NH_4-N is determined according to Technicon Industrial Method No. 108-71W/ Preliminary. Ammonium in the prepared sample is complexed with sodium phenoxide followed by sodium hypochlorite resulting in a blue indophenol-type compound, which is determined colorimetrically and is directly proportional to the ammonium nitrogen concentration (NH_4-N).

NO_3N is determined according to Technicon Industrial Method No. 158-70W/ Preliminary. Nitrate is reduced to nitrite in a copper-cadmium column. Reaction with sulfanilamide and coupling with N-1 napthylethylene-diamine dihydiochloride produces a red compound which is measured colorimetrically. This method determines nitrite as well as nitrate nitrogen, but nitrite concentration in these water samples is assumed to be negligible.

Phosphate phosphorus is determined according to Technicon Industrial Method No. 155-71W. Phosphate reacts with ammonium molybdate in the presence of ascorbic acid and antinomy to form a blue phosphomolybdenum complex which is measured colorimetrically. This method determines only orthophosphate but contribution from other forms is negligible.

Sulfate sulfur is determined according to Technicon Industrial Method No. 226-72W. Interfering cations are first removed by a cation exchange column. Sulfate is then reacted with barium chloride. Excess barium forms a blue chelate with methylthymol blue, which is measured colorimetrically.

Calcium, sodium, potassium, and magnesium are determined by atomic absorption spectrophotometry using an Instrumentation Laboratory Model IL 353 atomic absorption spectrophotometer. Procedures described by the manufacturer are used (Procedure Manual for Atomic Absorption Spectrophotometry, Instrumentation Laboratory, Inc.).

Soil solution pH is determined using a Radiometer model 26 pH meter by methods outlined in Standard Methods (1971) and manufacturer's instructions. Total alkalinity is determined by an automated titration procedure (Standard Methods, 1971) with a Radiometer model II titrator and model II autoburette in conjunction with the pH meter, according to manufacturer's instructions. Conductivity is measured using a YSI model 31 conductivity bridge according to manufacturer's instructions and Standard Methods (1971). Chloride is determined on a Technicon Autoanalyzer II according to Technicon Industrial Method No. 99-70W Preliminary.

VIRUS DETERMINATION

Soil and soil water samples were analyzed for virus and certain bacteria by the Virology Lab. at the Children's Orthopedic Hospital, Seattle.

Soil and water samples were incubated at 35-36° C (95-97°F) for 2 weeks on a variety of cell lines to test for viruses. These cell lines included African Green Monkey, Rhesus Monkey Kidney; Heteroploids Hep II and HL; and Diploid, Human Embryonic Tonsil. Presence of enteric viruses was determined by cytopathetic effects on cell deformations (Lenette and Schmidt, 1969 or minor modifications).

TOTAL AND FECAL COLIFORM DETERMINATIONS

Coliform analyses were provided by Metro. Soil and water samples were tested for presence of total and fecal coliforms. Samples were incubated 24 hours on a lactose broth as a presumptive test. Transfer to brilliant green lactose bile broth and continued incubation was the confirmed test. Gas production in fermentation tubes is the positive visual interpretation of coliform presence. Dilution tubes offer an estimate of the most probable number (MPN) per sample volume (Standard Methods, 1971).

Section 6

TOTAL ORGANIC CARBON COMPONENTS

The majority of organic carbon analyses measures humic and fulvic acid fractions (Schnitzer and Kahn, 1972; Goring, 1972; Gieseking, 1975). Organic molecules smaller than fulvic acids in forest soils have received less attention but are of concern in sludge studies, since refractory organic compounds such as pesticides are in this classification. Organic compounds are isolated by extraction with solvents such as ether, chloroform and methanol (Braids and Miller, 1975). Identification of extracted organic materials is done in several ways: chromatographic separation by gas, thin layer or gel filtration chromatography in combination with spectral identification.

Soil samples were extracted by redistilled ether saturated with water and sodium chloride in a stoppered erlynmeyer flask and gently shaken for 42 hours. The ether extract was decanted, dried with magnesium sulfate, and concentrated on a rotoevaporator. For gas chromatographic analysis, diazomethane was added to the sample to make methyl esters or free acids, according to directions from Aldrich Chemical Company.

TOTAL ORGANIC CARBON MEASUREMENTS

Total organic carbon measurements were made on a Dohrmann-Envirotech DC-50 TOC analyzer. The unit receives a 30-microliter injection of acidified (pH 2) aqueous sample in a platinum boat containing manganese dioxide as an oxidation promoter. The boat is moved into a 90° C(194°F) zone where volatile carbon and CO_2 are removed. Volatile carbon components are trapped on a column of Porapak Q, while the CO_2 is vented. The column is heated and backflushed. Volatile organics are burned to CO_2. Residual organics in the boat are then moved to an 850° C (1560° F) zone where they are burned to CO_2.

Measurement is done by passing the CO_2 from pyrolsis over a Ni catalyst in a hydrogen-rich atmosphere. The CO_2 is reduced to methane, then bubbled through a humidifier and burned in a flame ionization detector. Response of the flame detector is integrated so total mg/l or ppm of carbon are read directly from the instrument.

Gas Chromatography

A Perkin-Elmer model 990 gas chromatograph with flame ionization detection was used. Two columns were used with the following conditions:

	Column 1	Column 2
Column type	SCOT	SCOT
Column length	15.2 m (50 ft.)	15.2 m (50 ft.)
Injector temp.	200° C. (392° F.)	275° C. (527° F.)
Manifold temp.	200° C. (392° F.)	300° C. (572° F.)
Attenuation	x 40	x 80
Column phase	DEGS	DEXSIL-300
Program	90°-180° C. (194-356° F.)	180°-270° C. (356-518° F.)
Rate	4° C./min. (7.2° F/min.)	6° C./min. (11° F/min.)
Initial	1 min.	1 min.
Split ratio	10/1	10/1
Injection volume	.2 1	.2 1
Flow	5.5 ml/min.	5.5 ml/min.

Mass Spectrometry

The gas chromatograph was connected to a Perkin-Elmer Hitachi RMS-4 mass spectrometer. The units are interfaced with a gold jet separator with other connections being gold or glass. Ionization voltages were normally 70 ev. Output was achieved through a B&F oscillograph, model number 3006.

Gel Filtration Chromatography

Sephadex G-75 gel with a solvent of 0.01 N HaOH was used for gel filtration work. A chromatronix CMP-1 pump was used for solvent delivery. Injection into the system was through a valve and sample loop. Detection was done with ultraviolet detectors at 254 mm (10 in.). The columns were 100 cm x 6 mm (39.4 in. x 0.24 in.) glass with chromatronix teflon fittings. Typical conditions were:

	System 1	System 2
Solvent	0.01N NaOH	0.01N NaOH
Temp.	22.5° C. (72° F.)	22.8° C. (73° F.)
Flow	6 ml/hr.	11.8 ml/hr.
Sample size	1 ml	1 ml
Chart speed	1.5 cm/hr. (0.6 in./hr.)	1.5 cm/hr. (0.6 in./hr.)
Recorder	Varian A-25	ISCO, UA-5
Detector	Chromatronix	ISCO, UA-5
Wave length	254 mm (10 in.)	254 mm (10 in.)
Attenuation	0.04	0.05

Using gel filtration chromatography, the largest molecules are eluted first, with the smaller molecules later. This assumes small interactions between the column packing and the organics being analyzed.

Section 7

BIOLOGICAL DECOMPOSITION

Wood stakes (1 x 4 cm or 0.4 x 1.6 in.) prepared from sapwood of Douglas-fir (American Standard Testing Methods ASTM D1758-60T) were coded with a permanent identifying number and dried to a constant weight at 105° C (220° F) in a forced air oven (referred to as oven dried weights). Within the designated treatment plots, the stakes were placed at the following positions in the soil profile: 1) surface of the litter; 2) 1 cm (0.4 in.) below the litter; and 3) 10 cm (3.9 in.) below the litter layer. Five replicas of 10 stakes were placed at each position at the initiation of the test treatments. Representative wood stakes set aside as standard samples were stored in capped glass jars until needed for analysis.

At the prescribed sample time, one group of 10 stakes was recovered from the designated treatment site and soil profile positions. In the laboratory, extraneous debris clinging to the outside of the stake, such as soil particles, were removed. Immediately thereafter, the code number was recorded along with the wet weight of each stake. Samples were then oven dried at 105° C (220° F) for 24 hrs. and cooled in a vacuum desicator.

DECOMPOSITION ANALYSES

The percent stake moisture and weight losses were individually determined from the oven dry weight as follows:

$$\text{Moisture content} = \frac{\text{wet weight} - \text{oven dry weight}}{\text{oven dry weight}} \times 100$$

$$\text{Weight loss} = \frac{\text{initial oven dry weight} - \text{final oven dry weight}}{\text{final oven dry weight}} \times 100$$

1% Sodium Hydroxide Solubility

Solubility of wood in one percent sodium hydroxide, a measure of cellulose decomposition, was determined following the procedures of TAPPI Standard Methods (T4m-59) as modified by Cowling (1962). Stakes were ground in a Wiley mill until they passed through a 40-mesh screen (TAPPI T11m). Replicates from each treatment and profile position were combined to make a single sample.

One gram of the ground sample was added to a tared tall form 200 ml (6.8 oz.) Pyrex beaker. The sample was returned to the oven and its oven dry weight determined. To the beaker, 50 ml (1.7 oz.) of standardized 1%

sodium hydroxide were added. The beaker was covered with aluminum foil and placed in a boiling water bath for one hour. Every 15 minutes, the mixture was stirred to facilitate digestion.

Digested samplers were suction filtered using a tared cintered glass crucible of medium porosity. Quantitative transfer of the digestion mixture was accomplished by using two 50 ml (1.7 oz.) aliquots of hot distilled water to rinse the beaker. Next, the sample was washed with 50 ml (1.7 oz.) of 10% glacial acetic acid from the residue. The crucible and contents were removed to a 105^{o} C (220^{o} F) oven for 48 hours, cooled in a vacuum desicator and then weighed.

Solubility was expressed as a percentage of the moisture-free weight of the loss during digestion. Relative solubility was computed by comparing the solubility of untreated, unexposed stored standard samples with that of the treated sample as follows:

Relative solubility =

$$100 \times \frac{\text{solubility treated sample - solubility of untreated similar wood sample}}{\text{solubility of untreated similar wood sample}}$$

Above procedures are routine for analyses of biological decomposition of wood samples as per procedures of Minyard and Driver (1975).

Section 8

EVALUATION OF TREE GROWTH

The Weyerhaeuser Company used the twelve 0.04 ha (0.1 ac.) plots for forest growth rate research. Growth plots coincided with sludge treatments identified in Figure 4. All dead trees and cull hardwoods were felled and piled outside of the plot area. Remaining trees were tagged by number at 1.2 m (3.9 ft.) above the ground line. Diameters of each tagged tree were measured at DBH (1.4 m or 4.5 ft.) and identified by a paint mark. Total tree heights were measured to the nearest 0.3 m (1 ft.) on 7 trees in each plot plus 5 additional trees to complete the range of diameters encountered. Increment core borings were taken from 10 trees per plot to assess the past growth rates.

Analysis of tree growth rates tested changes in diameter growth, basal area and volume of individual trees within each treatment by the following regression models.

1. (DBH75 - DBH70) / 5 = a + b (DBH70)
2. (DBH76 - DBH75) / 2 = a + b [(DBH75 - DBH70) / 5]
3. (DBH77 - DBH75) / 3 = a + b [(DBH75 - DBH70) / 5]
4. (BA75 - BA70) / 5 = a + b (BA70)
5. (BA76 - BA75) / 2 = a + b [(BA75 - BA70) / 5]
6. (BA77 - BA75) / 3 = a + b [(BA75 - BA70) / 5]
7. (Volume 76 - Volume 75) / 2 = a + b (Volume 75)
8. (Volume 77 - Volume 75) / 3 = a + b (Volume 75)

Where DBH 75 is the diameter of the tree in 1975, likewise DBH 70 would be the diameter in 1970. BA 75 is the basal area of the plot in 1975 and volumes are spelled out.

Slopes of regression lines for each treatment were compared to the slope of the unirrigated control using a "t" test.

$$t = \frac{\hat{\beta} - \beta o}{SE_{\hat{\beta}}}$$

where

$\hat{\beta}$ = slope of treatment

βo = slope of unirrigated control

$SE_{\hat{\beta}}$ = standard error of treatment slope to test the null hypothesis that there were no differences in growth between each treatment and the control. A simple one-day analysis of variance DBH growth was conducted also with those plots that had replications to test for treatment effects.

A final analysis arrayed all trees by pretreatment diameter and periodic annual increment (pai). From this list, trees were selected and paired with each sludge treatment and with the control. Paired trees had equal pai and approximately the same initial DBH. Changes in growth rate were analyzed by DBH, basal area, and volume testing the sludge treated trees against equivalent control trees.

Section 9

LIQUID WASTE PROCESSING AND SLUDGE PROPERTIES

Metro serves approximately a million residents plus industry in the Greater Seattle area for treatment of domestic and industrial waste liquids. Several smaller outlying communities provide primary and secondary waste treatment; however, residual sludge solids are pumped to and stabilized at the Metro West Point plant. Over the year, average daily flow into the treatment plant at West Point is 475 million liters (125 million gallons) of raw sewage. Portions of the Metro sewer system are still combined, mixing municipal-industrial effluents with urban runoff. Large seasonal variations occur in volumes of effluent treated and the ratio of solid-organic constituents.

Anaerobic digestion reduces solids by 40% in an average digestion time of 21 days. Residence time in the digesters ranges from 14 to 35 days, dependent upon volumes of input to the plant. These conditions cause highly variable sludge composition over time. Average daily solids production over the year is 50 metric tons (55 tons) on a dry weight basis.

Treated sludge was discharged into Puget Sound through a deep water dissipator pipeline until the 1972 amendments to the Federal Water Pollution Control Act. The Clean Water Amendments banned discharges of solids but allowed continued discharges of primary treated waste waters. Sludge dewatering facilities were installed at West Point plant to facilitate sludge disposal as a dewatered cake. Dewatering and disposal are very expensive, leading to consideration of alternatives such as sludge irrigation for disposal at lesser costs and with possible benefits as a fertilizer and water supplement.

Liquid digested sewage sludge (3-7% solids) is trucked from West Point to Pack Forest (approximately 110 km or 70 mi.) in a closed 19,000-liter (5000-gal.) tanker. Sludge may be applied directly or diluted with river water to provide a sufficient volume at the design concentration to irrigate all plots on a weekly basis (Fig. 5).

CHEMICAL COMPOSITION OF SLUDGE

Table 1 summarizes maximum, minimum and average concentrations of various constituents in Metro sludge applied to research plots. Total solids are the oven dry product of evaporation of a given quantity of liquid sludge. Total nitrogen, phosphorus and heavy metal constituents are determined as portions of the dried sludge. Other chemical constituents are determined on sludge and makeup water.

Table 1. MAXIMUM, MINIMUM AND AVERAGE COMPOSITION OF SEWAGE SLUDGE APPLIED TO PLOTS

Component	Minimum	Concentration Maximum	Average
All values percent (%)			
Total Solids	2.10	3.40	3.20
Calcium	2.40	3.20	2.64
Magnesium	0.50	0.70	0.55
Potassium	0.15	0.48	0.29
Sodium	0.32	0.76	0.51
All values parts per million (ppm)			
Total Nitrogen	945	1,860	1,600
NH_4-N	674	1,090	895
NO_3-N	120	135	131
Total Phosphorus	625	922	900
Orthophosphate	150	900	850
Zinc	2,200	3,100	2,740
Copper	900	1,200	1,020
Chromium	500	800	620
Lead	240	400	356
Cadmium	50	62	55
Mercury	7	12	11

Total solids varied from 2.1 to 3.4% averaging 3.2%. Total nitrogen ranged from 945 to 1860 parts per million (ppm) with an average of 1600 ppm. The NH_4-N component of total nitrogen dominated and ranged from 674 to 1090 ppm with an average of 895 ppm. Nitrate levels remained fairly constant ranging from 120 to 135 ppm with an average of 131 ppm. Of the total phosphorus (625 to 922 ppm), orthophosphate was the dominant form (150 to 900 ppm). Quantities of orthophosphate were more variable than total phosphorus with an average of 900 ppm for total and 850 ppm for orthophosphate.

Limited determinations were made for the heavy metals, zinc, copper, chromium, lead, cadmium and mercury. Large concentrations of zinc found in Seattle's municipal sludge indicate the probable contribution of industrial zinc plating and galvanizing processes. Zinc concentrations are relatively constant ranging from 2200 to 3100 ppm with an average of 2740 ppm. In a like manner, copper concentrations are also fairly constant ranging from 900 to 1200 ppm, averaging 1020 ppm. Chromium averaged 620 ppm with a range of from 500 to 800 ppm. Lead occurs in reduced amounts averaging 356 ppm with a range of 240 to 400 ppm. Concentrations of cadmium were fairly constant with an average of 55 ppm and a range of 50 to 62 ppm. Mercury occurred in relatively low concentrations, usually around 11 or 12 ppm and occasionally 7 ppm.

The concentrations of calcium, magnesium, potassium and sodium are sufficiently large to report their values as a percentage. Calcium concentrations are large ranging from 2.4 to 3.2%, averaging 2.64%. Magnesium averages about 20% of that of calcium with an average of 0.55%, ranging from 0.5 to 0.7%. Potassium occurs in minimum concentrations for this group of elements, averaging 0.29% and ranging from 0.15 to 0.48%. Sodium concentrations are quite similar to magnesium averaging 0.51% with a range of 0.32 to 0.76%.

Section 10

STUDY OF SLUDGE APPLICATION METHODS

Initial calculations for proposed rates of sludge application were made for the plots on Everett soils on Weyerhaeuser Company lands. The proposed weekly application rates required transport of 38,000 l (10,000 gal) of (Fig. 5) liquid sludge per week from West Point to Pack Forest. The irrigation system used a 91,000 l (24,000 gal.) storage pond made from a backyard swimming pool 5.5 m (18 ft.) in diameter and 1.4 m (4.5 ft.) deep. A drain from a low spot in the center of the storage pond led to the pump and PVC piping system, sprinklers and trickle systems with gate valves and cold weather drains at spacings necessary to achieve uniform application of sludge over each test plot. Sludge discharged from the tanker under gravity (Fig. 6).

The system as designed was tested with water for the positioning of sprinklers as well as the adjustment of sprinkler heads and proper sizing of the nozzles. The three methods tested were over-the-canopy sprinklers on 9 m (30 ft.) risers, spray irrigation on 1.5 m (5-ft.) risers, and a uniform application through a trickle system which consisted of spaced 0.1 cm (0.25 in.) drain holes in PVC piping. Uniform coverage by sprinkler systems on plots was achieved by sprinklers placed 18.3 m (60 ft.) apart at corners of plots with 90^{o} coverage. A series of trials with water resulted in uniform application of rates of water over areas of the plots.

This irrigation system, as designed by a consultant, had been used successfully for irrigation water as well as distribution of dairy barn manures over fields. Sludge, however, is another product and the pump with a closed impeller plugged immediately with hair and other coarse solids when attempting to distribute sludge. Few investigators contacted had experience with the particular problem of uniform sludge application over relatively small plots. Many investigators had experience with large irrigation canons used for spreading of a variety of waste material on a large area. Many systems were easily eliminated with a narrowing to a few pumping systems which would have the greatest potential for success. A final choice of a Moyno positive displacement pump (model 2SWG12H-CDQ) was powered by a 3-phase 10-hp motor, operating at 1250 revolutions per minute (rpm). Problems with the quantities of miscellaneous solids of varying sizes in the sludge required a pregrinding by a Maz-o-rator before sludge was delivered to the pump. The Maz-o-rator was also powered by a 10-hp motor operating at 1800 rpm (Fig. 7).

The combination of the Maz-o-rator and Moyno pump required a considerable modification of the previously designed electrical system. Power demands of the 10-hp motor required that each operate on an individual

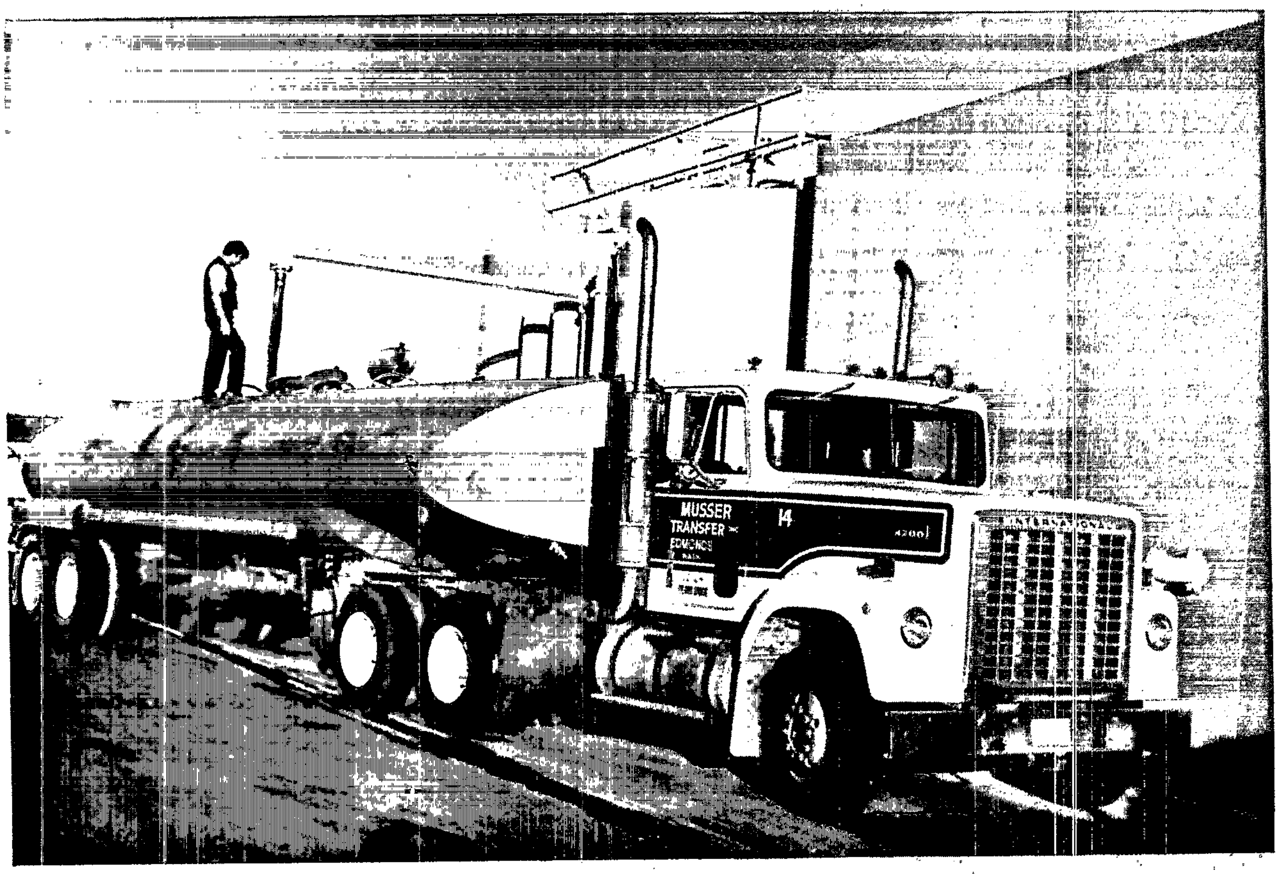

Figure 5. Sludge was transported from Metro's West Point Plant to Pack Forest in 19,000-liter quantities (5,000-gal.). Usually two trips were made each day sludge was applied.

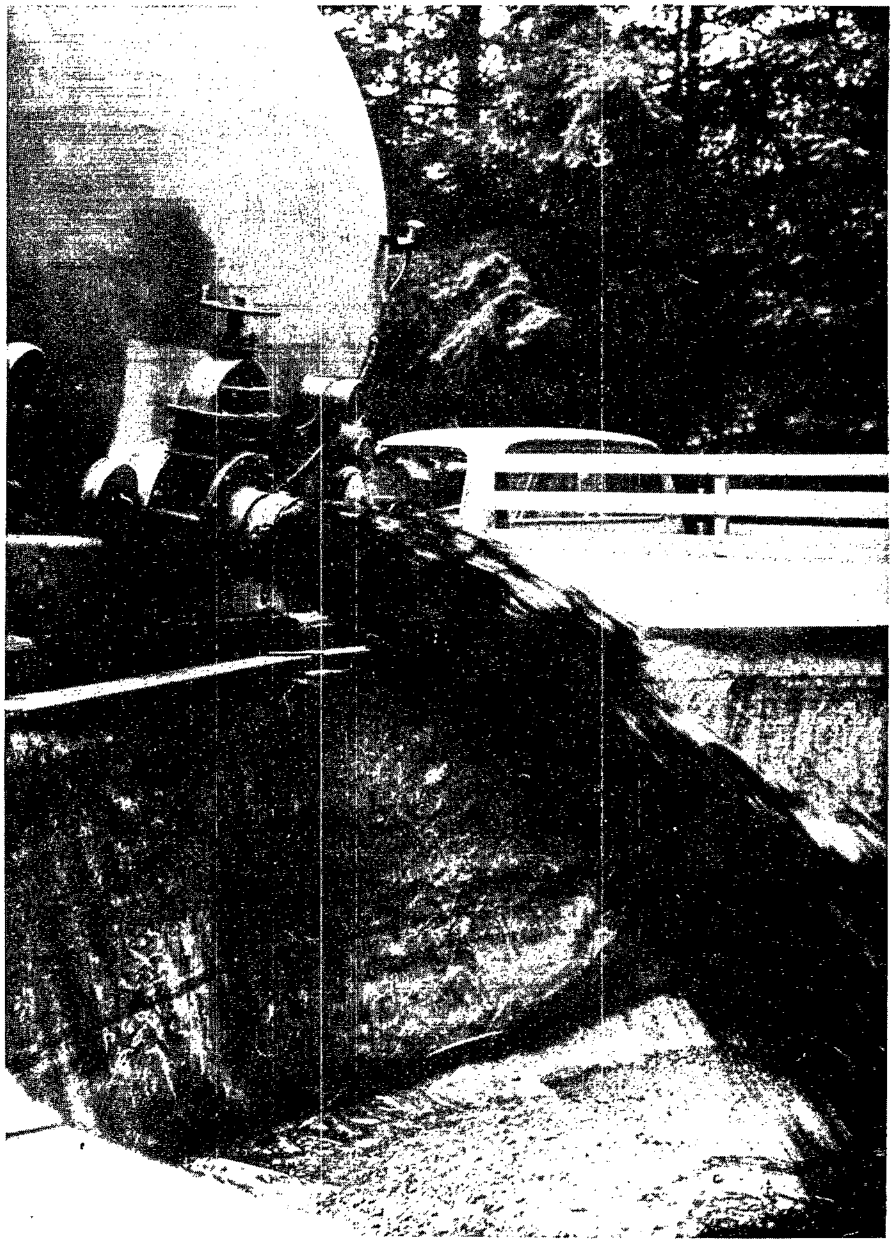

Figure 6. A ramp was constructed so the tanker trucks could discharge sludge by gravity flow to the storage pond.

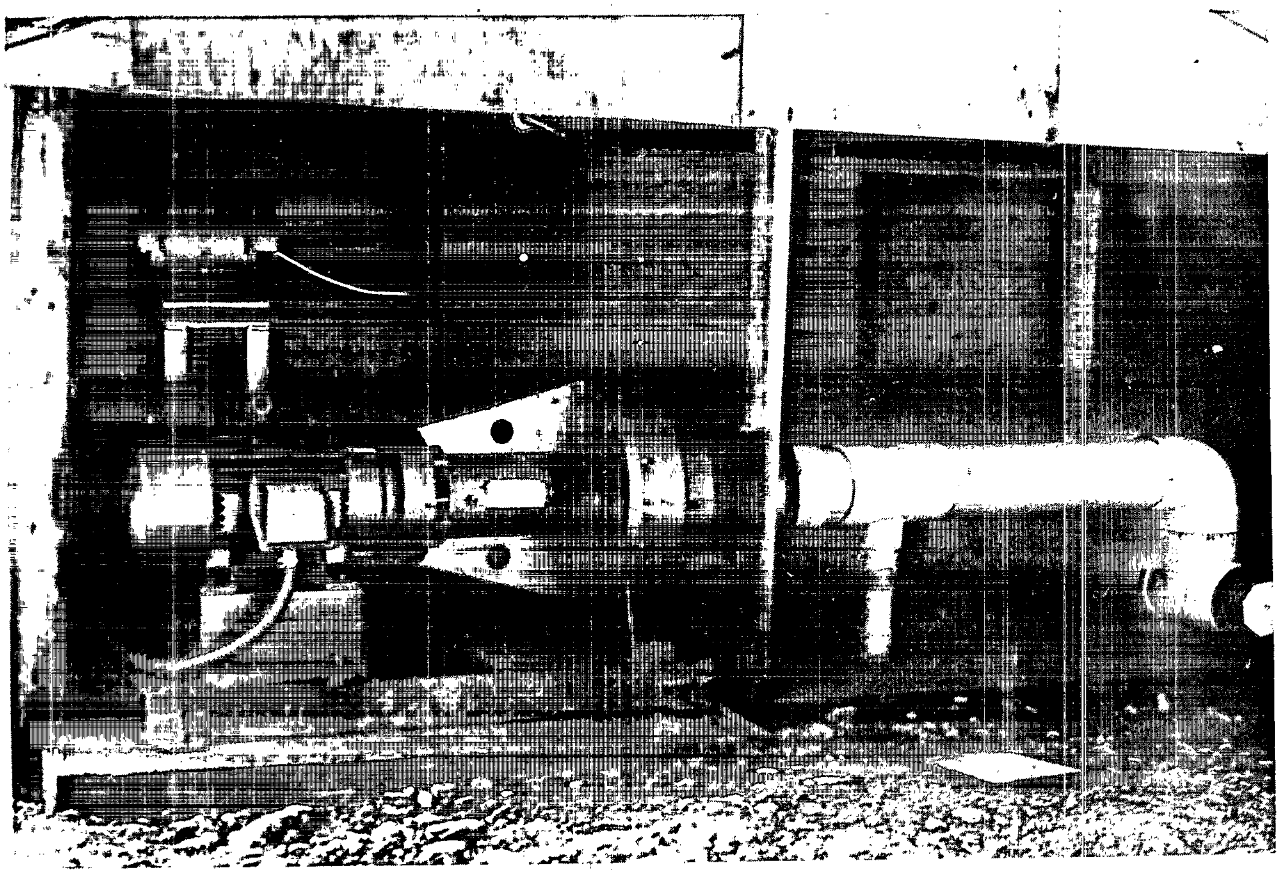

Figure 7. Adjacent to the storage pond, a small structure housed the combination Maz-o-rator and Moyno pump. Piping to the right is the suction line from the storage pond with the supply lines to plots underground.

switching and circuit system. As the Maz-o-rator initiates grinding and delivering of material to the pump, the Moyno pump is activated to distribute the ground sludge material to plots.

The above system very capably delivered sludge to the trial plots.

SPRINKLER MODIFICATIONS

The Maz-o-rator was a very effective grinder of solid materials, plastics, metals and stiffer paper products. The Maz-o-rator, however, was ineffective in grinding soft or limp materials, e. g., large quantities of hair. Care in installation of the plumbing distribution system with pipe connections and gate valves eliminated rough projections upon which hair would cling. The Rainbird 65D TNT sprinklers under trial, however, had many rough projections which retained hair, causing malfunction of the sprinklers. Malfunction included retention on spray deflectors, giving very poor distribution of sludge and obstruction of the mechanics of the sprinkler return mechanism necessary for achieving uniform distribution of sludge over plots. Occasionally, large solids would also obstruct the sprinkler nozzle orifice. The Rainbird 65D TNT sprinkler has a deflector arm with a lower bar upon which substantial amounts of hair would collect.

Modifications of the sprinkler head included removal of lower portions of the deflector arms and increasing the nozzle orifice size to 1.3 cm (0.5 in.) inside diameter. Rough projections on the brass casted sprinkler arm were ground smooth and the arm teflon coated. These modifications greatly reduced the accumulations of hair, allowing a uniform sweep and return of the sprinkler head under operation. Figure 8 shows the modified sprinkler after a year and a half of sludge applications without cleaning.

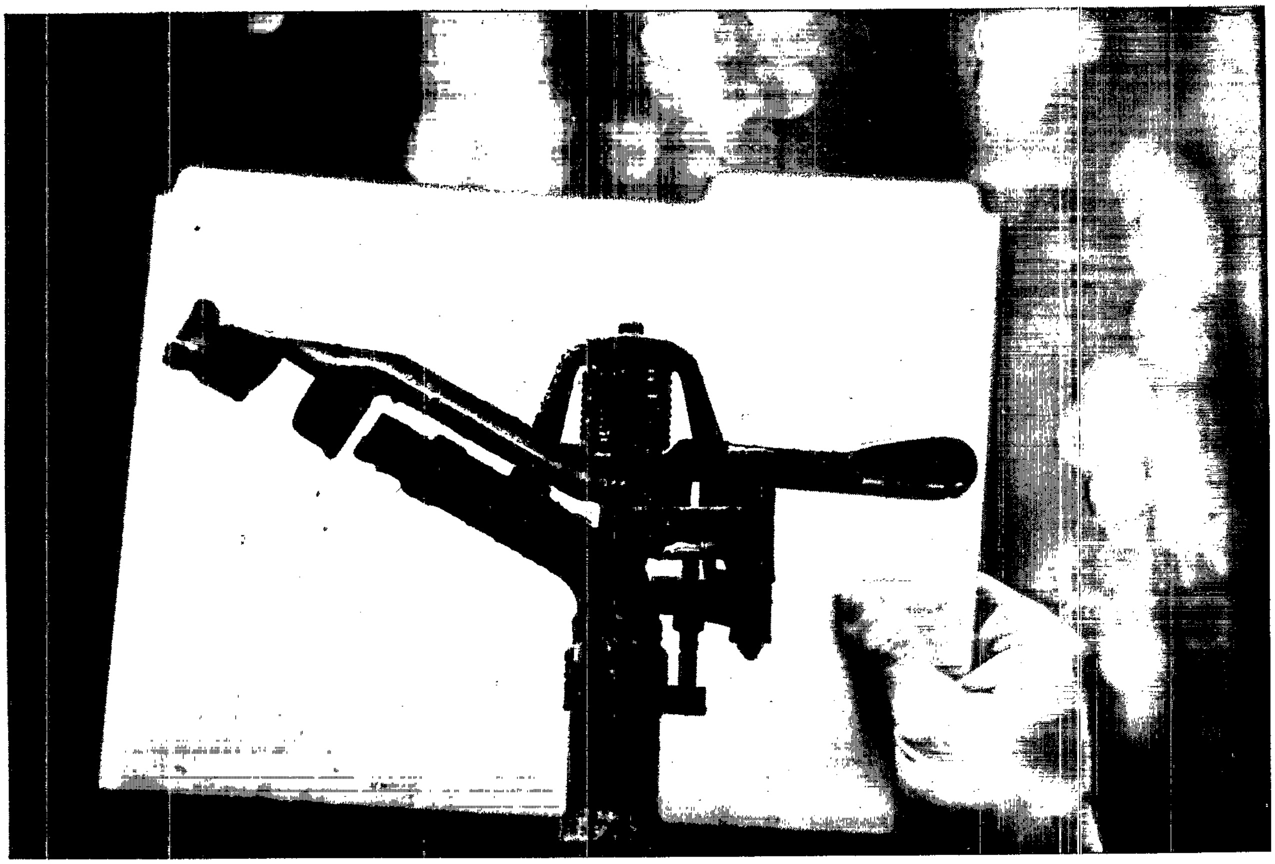

Figure 8. The Rainbird 65D TNT sprinkler had the lower deflector arm removed and was teflon coated, following removal of rough projections in the brass casting.

Section 11

SUMMARY OF TESTS OF SLUDGE APPLICATION METHODS

The aforementioned modifications of the pumping and sprinkler systems allowed reasonably trouble-free sludge applications over trial plots (plots 15, 16 and 17, Fig. 4). Testing of the three methods of sludge application--over-the-canopy, spray irrigation and trickle irrigation--took place simultaneously with modification of the sprinkler heads.

OVER-THE-CANOPY APPLICATION

Over-the-canopy sludge application was suggested based on possible use of sludge irrigation through a complete forest rotation. Retention of sludge in the crowns of young forest trees and certain growth related impacts were of interest in trial of this application method. It soon became apparent that problems of cleaning plugged sprinklers on 9 m (30 ft.) risers was a major disadvantage of this application method. While risers in the forest crowns achieved over-the-canopy application, the interference of tree crowns caused poorer distribution of sludge over plots. Sludge dripping on workers from the canopy, either following sludge irrigation or during periods of rainfall at later dates, was also undesirable. Aerosol drift from over-the-canopy application remains a problem of unknown consequences.

TRICKLE IRRIGATION APPLICATION

The designed trickle irrigation system used perforated PVC pipe with sufficient 0.6 cm (0.25 in.) holes to achieve uniform distribution during water trials over the plot. Pressures of less than 1.0 kg/cm^2 (15 psi) were used for tests of sludge application by the trickle system.

Even though topography of test plots was sloped very gently, slight changes in topography (depressions) caused significant differences in pressure and quantities of sludge applied to areas of the plot. A slight sag in a pipe would induce a disproportionately large delivery of sludge to the low spot. Successive plugging of perforations also resulted in great spatial differences in rates and quantities of sludge applied. Normally occurring solid materials would be transported to the lowest ends of perforated pipes, where they became plugged preventing the drainage of sludge from the distribution system. A pond of sludge in the trickle area is shown in Figure 9.

UNDER-THE-CANOPY SPRAY IRRIGATION

Under-the-canopy spray irrigation was much easier to work with and cleaner than over-the-canopy or trickle systems. Unplugging of sprinkler

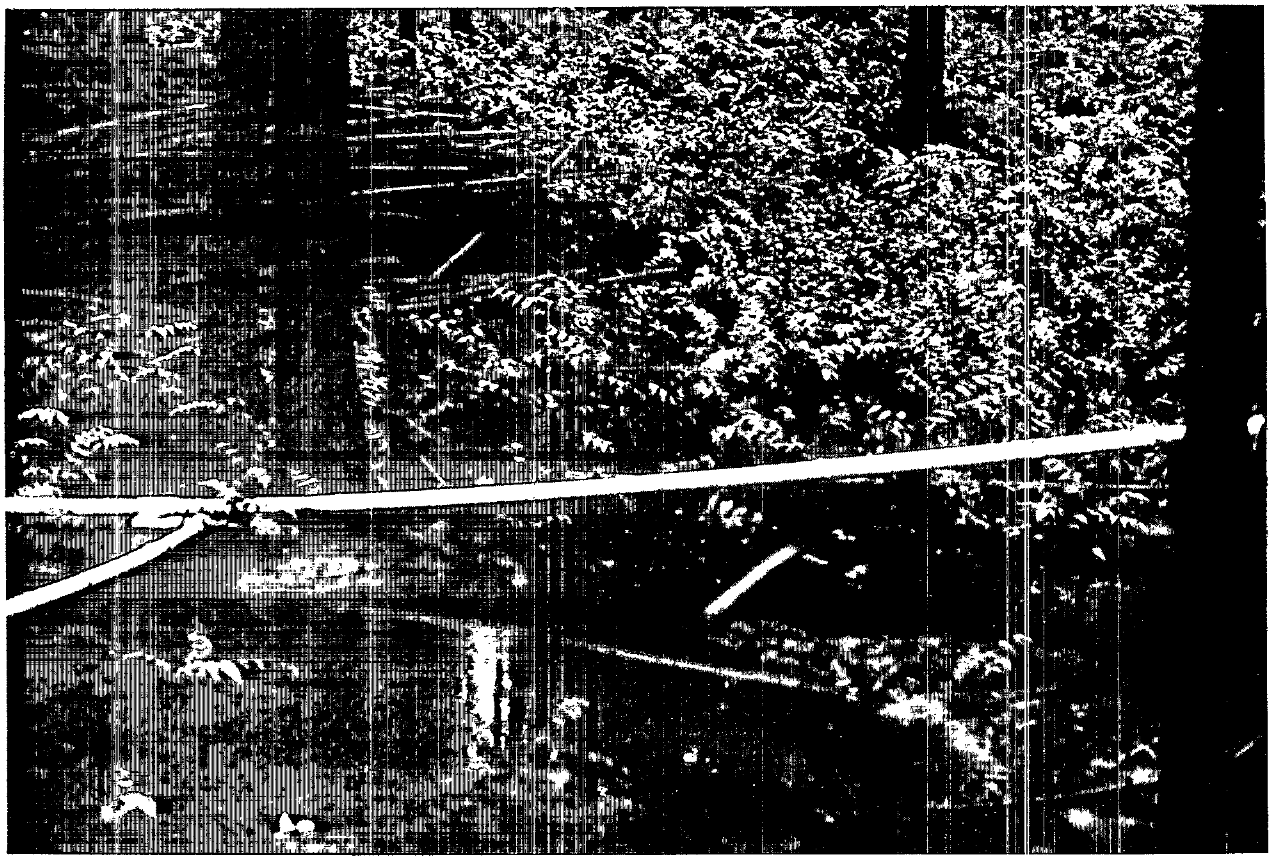

Figure 9. Heavy rates of sludge application caused impeded infiltration, resulting in ponding of sludge in depressions. This example from the trickle irrigation plot in an area of concentrated sludge applications.

heads on 1.5 m (5-ft.) risers was easily achieved. Distribution of sludge over the plots was also uniform without problems of sludge dripping from the forest canopy. Aerosol drift is also considerably less of a problem as wind movement under the canopy is significantly reduced.

The major disadvantage of under-the-canopy distribution is the increased amount of plumbing and more numerous sprinklers required for uniform unit area application. A final mode of operation evolved where grinding of sludge in all seasons of the year is definitely required. Metal bottle caps, all sorts of plastic, occasional dense hair mass, paper products and organic materials such as fruit pits are effectively ground to pass the plumbing system and sprinkler nozzles by the Maz-o-rator. The pumping system requires about 6.3 kg/cm^2 (90 psi) delivered by the pump on fairly level ground. Pressure drops within the pipe system result in about 2.8 to 3.2 kg/cm^2 (40 to 45 psi) delivered to the sprinkler orifice. This pressure is sufficient to operate the sprinkler efficiently and achieve good distribution of sludge over the plots. An operating sprinkler is shown in Figure 10.

Nozzle pressures of about 3.2 kg/cm^2 (45 psi) did not cause damage to the bole of Douglas-fir when over 3 m (10 ft.) from the sprinkler. Ideally, sprinklers should be farther from trees as poor distribution results from trees too close to sprinklers.

Initial rates of sludge application on the Everett plots were 0.6, 1.3 and 1.9 cm (0.25, 0.5 and 0.75 in.) weekly in one short application to duplicate plots. Irrigation through the large modified nozzles required 4.25 minutes to apply an area depth of 0.6 cm (0.25 in.) to a plot. The experimental design called for a third series of plots to receive an additional 1.3 cm (0.5 in.) of water. This water, in effect, washed off the sludge from subordinate and forest vegetation and provided an additional quantity of water to test the impacts of irrigation.

Figure 10. Sprinklers were located on 5-ft. risers at each corner on the square plots.

Section 12

INITIAL SLUDGE APPLICATIONS

Results of certain initial trials and development methods of sludge application have been summarized in preceding sections. Results described in the following section are a combination of visual observations of the physical impacts of sludge application at design rates to particular plots, as well as analyses of soil solution chemistry.

A range of initial rates of sludge application was calculated to adequately replace soil moisture lost by summer evapotranspiration. Solid loading was projected on the basis of carbon-nitrogen ratios and total chemical constituents expected in sludge.

SLUDGE APPLICATIONS AND CONSTITUENTS

Solids in sludge received from Metro averaged 3.2% compared to expected 2.1% average. Total nitrogen averaged 1.6% compared to an expected concentration of 0.9%. Average carbon-nitrogen ratio was 11:1, rather than 18:1 as expected.

Even had constituents been as expected, impairment of surface soil infiltration capacity would have occurred in plots when total applied sludge equalled about 25.4 cm (10 in.). Reduced infiltration occurred about 12 to 14 weeks after initiation of sludge application for the heaviest 1.9 cm (0.75 in.) weekly rates (300 series, 300 mt/ha/yr or 135 t/ac/yr) of sludge application. Ponding of sludge occurred over 5 to 25% of the plot area (300 plots) by surface flow of sludge from localized spots of impeded infiltration to low spots or micro-depressions. Sludge applications (300W plots) followed by 1.3 cm (0.5 in.) of irrigation water had considerably less problems with impeded infiltration, even at greater sludge application rates. Plots 200 developed similarly impaired infiltration problems as total sludge applications approached 25 cm (10 in.). Sludge applications were terminated for the winter in December 1975. Plots 100 and 100W maintained good infiltration over 98% of the plot area with only very minor ponding occasionally occurring in low spots. Total application to 100 plots was 12 to 13 cm (4.7 to 5.1 in.). Undoubtedly, if these coarse textured, gravelly Everett soils developed impeded infiltration with the 200 and 300 mt/ha (88 and 135 t/ac.) rates of waste and sewage sludge application originally used, most other forest soils would develop similar problems at equivalent application rates.

Initial heavy rates of sludge applications (1.9 cm or 0.75 in./wk.) established the upper limit of sustained short-term (in 12 to 14 weeks) sludge loadings. Impeded infiltration resulted from repeated heavy weekly applications of sludge which formed a nondrying film over the forest floor. Applications of sludge to the 100 series plot usually dried before a repeat application a week later. Short-term sludge applications to the 100 series plots were about one-half (12 to 13 cm or 4.7 to 5.1 in.) of the maximum short-term loadings (25 cm or 10 in.). Maximum loading rates have an economic advantage in that reduced forest areas as well as reduced amounts of plumbing would be required for maximum amounts of sludge disposal. Quantities of solid constituents in sludge and the percentage of total nitrogen content exceed estimated amounts used in designing initial sludge application rates. Nitrogen constituents were double those expected, based on Metro's chemical analyses, and the heterogeneous quantity and variety of solid constituents also was much greater than expected.

Large inherent variability in properties of forest soils, along with variability in sludge chemistry, makes interpretation of significant impacts of sludge application to soils difficult. When applications of sludge were terminated in December 1975, it appeared the 100 and 100W (100 mt/ha or 44 t/ac.) treatments were probably approaching the maximum short-term limit in rate of sludge application. Heavier sludge applications had resulted in excess nitrate concentrations in soil solutions. Modified rates of application were proposed at 10, 20, 30 and 40 mt/ha (4.5, 8.9, 13.3 and 17.8 t/ac.). On re-initiation of sludge application in 1976, these reduced rates were used on a series of new plots on the Everett soil and extended to the Mashel and Wilkeson soils. Applications of sludge continued on the original plots with the lowest rates (10 mt/ha or 4.5 t/ac.) going on plots which had received 100 mt/ha/yr (44 t/ac./yr.) rates during the first year. Heavier applications were applied to those plots which previously had received the heavier applications--20 mt/ha (8.9 t/ac.) on 200 plots and 30 mt/ha (13.3 t/ac.) on 300 plots.

Section 13

THE IRRIGATION SYSTEM AND SLUDGE APPLICATION RATES

No problems were encountered with Metro's delivery of sludge to the Pack Forest plots. Tankers unloaded the sludge in the storage reservoir (Fig. 5) from which it was pumped by the combination Moyno-Maz-o-rator system to research plots.

The final distribution system for uniform application of sludge to 0.04 ha (0.1 ac.) plots used the modified Rainbird 65D TNT sprinklers with 1.3 cm (0.5 in.) I. D. nozzle, spaced 18.3 m by 18.3 m (60 x 60 ft.). The combination grinder (Maz-o-rator) and positive displacement Moyno pump delivered a line pressure of 6.3 kg/cm^2 (90 psi) with 3.2 kg/cm^2 (45 psi) to the sprinklers. Sprinklers on 1.5 m (5 ft.) risers gave uniform area-depth sludge applications over plots (Figure 10).

FIRST YEAR APPLICATIONS

As explained in a previous section, first year trial applications were 0.6, 1.3 and 1.9 cm weekly (100, 200 and 300 mt/ha/yr series plots; 0.25, 0.5 and 0.75 in.) in one short application to duplicate plots. A third plot in each series received an additional 1.3 cm (100W, 200W and 300W plots) (0.5 in.) of water to wash off sludge remaining on subordinate vegetation and to establish effects of additional water. As shown in Figure 4, there were also plots of no treatment (controls) to test departures from normal as well as the duplicate plots which received 1.3 cm (0.5 in.) of water only per week.

Plots were irrigated with sludge from July 22, 1975 to December 15, 1975 applying 1.8 to 5.5 mt/ha (0.8 to 2.5 t/ac.) of solids per week. Irrigation was terminated (Dec. 1975) due to excess rain and re-initiated May 15, 1976 at reduced rates of sludge applications.

SECOND YEAR APPLICATIONS

Commencing May 15, 1976, sludge was diluted 3-fold with water, resulting in a solution with 1-2.3% solids. Application rates of 0.25, 0.50 and 0.75 cm (0.1, 0.2 and 0.3 in.) per week of this sludge were made to the 100, 200, 300 and W series plots. If sludge was applied each week all year, applied solids would range from 190 to 580 kg (420 to 1,270 lbs.) per week or approximately a range of 10 to 30 mt/ha (4.5 to 13.5 t/ac.) per year.

The series of new plots on the Everett, Wilkeson and Mashel soils also received total sludge application in the above ranges. Four rates of sludge were applied to duplicate plots--0.25, 0.50, 0.75 and 1.0 cm (0.1, 0.2, 0.3 and 0.4 in.). The plots were identified as the 10, 20, 30 and 40 series plots. Plots established on the Wilkeson and Mashel soil series are remote from electrical power. Diluted sludge was transported to Wilkeson and Mashel plots by a 2 1/2-ton, 6-wheel drive truck carrying a 7600-liter (2000-gal.) tank. Sludge was gravity fed into a Deming open impeller pump powered by a 15-hp Wisconsin gas engine. The Deming pump delivers approximately 380 liters (100 gal.) per minute at a line pressure of 6.3 kg/cm^2 (90 psi). Travel time between sites was approximately 20 minutes with 7600 liters (2000 gal.) applied over 0.16 ha (0.4 ac.) in approximately 40 minutes.

Section 14

RESULTS OF SLUDGE APPLICATIONS ON SOILS AND SOIL WATER

The following sections summarize the results of sludge applications on soils over time by describing changes in soil properties, soil water ions and related impacts. The forest soil provides renovation of suspended and dissolved constituents in soils through physical filtration and chemical reactions. The soil solution as sampled by the lysimeter plates estimates dissolved constituents intransient in the forest soil. The transient soil solution provides the mechanism for transfer of both suspended and dissolved materials from soil solution to ground water. The general term "flux" is used to indicate the transient condition of nutrients in soil or ground water.

Discussion of significant effects of sludge application on soil or soil water chemicals infers a statistically significant difference at the 95% confidence interval. An asterisk is used in the tables to indicate a significant departure in average values. Frequently, a trend in change is indicated. The interaction between limited numbers of samples and large variation in forest soils restricts a rigid interpretation of statistical significance. If additional degrees of freedom were available in sampling, statistically significant differences would be observed. The following sections first summarize the physical renovation of solids by the soil profile, followed by sections which summarize soil solution chemicals and soil properties. The Everett soils were studied over three years. Results are presented as a summary of the first and second years on Everett soils and the end impact of three years of sludge application. Only one year of data through one growing season is available for the Mashel and Wilkeson soils.

RENOVATION OF SOLIDS

Forest soils are a very efficient physical filter of the solids normally occurring in applied sludge. The Maz-o-rator ground most non-organic solids sufficiently fine so they were not apparent on plots. Large first year applications of sludge, as previously discussed, did impede infiltration causing ponding in low spots and depressions. Even these low spots eventually drained with a retention of the solids on the soil surface.

Slight penetration of solids into soils was indicated in places by a change in color of surface soils, particularly on plots which received water following sludge applications. Penetration was only a few millimeters; thus, the forest soil also effectively filtered for the usual size of organic solids in the sludge applied. Reduced rates (second year) of sludge application did not cause reduced infiltration. In fact, plots with lowest quantities of sludge application do not look significantly different from control plots.

Total quantities of sludge actually applied to plots by years are summarized in Table 2. Table 2 shows total quantities of sludge applied to older plots on Everett soils. Heavy first year application ranged in depth from 12.1 to 26.7 cm (4.7 to 10.5 in.). Equivalent weights of solids applied ranged from 38.7 to 85.4 mt/ha/yr (17.2 to 38 t/ac/yr.). Applications of sludge were continued during the first year until obvious signs of impaired infiltration were observed. Discontinuing sludge applications at varying times resulted in different quantities of sludge applied to individual plots, but in no case did the quantities applied approach design rates.

The second year of sludge application proceeded at reduced rates. Sludge was actually applied for only 10 months; thus, maximum rates again were only approached. Depth ranged from 0.8 to 5.3 cm (0.3 to 2.1 in.) with equivalent weights of 2.6 to 17 mt/ha/yr (1.2 to 7.6 t/ac/yr.).

In the final year, emphasis was placed on application of sludge to new plots on the Everett, Wilkeson and Mashel soils. Again, early termination of sludge application did not allow sludge to be applied at design annual rates. However, in most cases, weekly application rates for much of the year were at design rates; only early termination of sludge applications resulted in reduced total amounts. Heaviest third year applications were made on Everett soils with reduced applications on Wilkeson soils. Maximum total amounts of sludge were applied to the older plots on Everett soils with a range of 45.1 to 108.4 mt/ha (20.1 to 48.3 t/ac.) over the life of the study. In depth, this is a range from 14 to 33 cm (5.5 to 13 in.).

Older plots on Everett soils as well as all new plots were excellent physical filters of suspended organic solids common in sludge. An absolute distinction has not been made between organic solids from sludge and larger organic molecules identified in the total organic carbon analyses. Leaching organic carbons deeper in soils is assumed to be as secondary decomposition products of bio-degradable materials, as compared with organic materials common in sludge in their original form. Thus, forest soils may be considered a 100% effective physical renovator for total suspended solids from sludge. Flux of nutrients and colloidal organic molecules through the soil profile must take place, in part, in dissolved forms and, in part, from accelerated decomposition of naturally occurring organic carbon to colloid size.

Table 2. TONS OF SLUDGE APPLIED BY PLOTS AND SOILS AND YEAR IN DEPTH AND TOTAL WEIGHTS

Plot	First Year		Second Year		Third Year		Total	
	Depth (cm)	Tons/ ha	Depth (cm)	Tons/ ha	Depth (cm)	Tons/ ha	Depth (cm)	Tons/ ha
Everett Soil								
100	13.3	42.6	0.8	2.6	1.2	3.8	15.3	49.0
100W	12.1	38.7	0.8	2.6	1.2	3.8	14.1	45.1
200	26.7	83.2	2.5	8.0	1.4	4.5	30.6	95.7
200W	23.5	75.2	2.3	7.4	1.3	4.2	27.1	86.7
300	26.0	85.4	5.3	17.0	1.9	6.1	33.2	108.4
300W	21.6	69.1	5.3	17.0	1.5	4.8	28.4	90.9
10					2.0	6.4	2.0	6.4
20					6.2	19.8	6.2	19.8
30					8.2	26.2	8.2	26.2
40					9.3	29.8	9.3	29.8
Wilkeson Soil								
10					1.5	4.8	1.5	4.8
20					3.1	9.9	3.1	9.9
30					4.4	14.1	4.4	14.1
40					5.8	18.6	5.8	18.6
Mashel Soil								
10					1.5	4.8	1.5	4.8
20					3.3	10.6	3.3	10.6
30					4.8	15.4	4.8	15.4
40					6.5	20.8	6.5	20.8

Section 15

EVERETT SOILS, SOIL SOLUTION NUTRIENTS

Those treatments shown in Table 2 which received 1.3 cm (0.5 in.) of water following sludge application also received quantities of dissolved nutrients in the water, as listed on the bottom of Table 6 (kg/ha). The amounts are insignificant by comparison with the quantities of nutrients applied in the sludge.

Table 3 summarizes the first year nutrient loading applied in sludge and the flux of soil solution to deeper than 2.1 m (7 ft.) in the soil profile. Nutrients applied as a loading in the sludge (Table 3) are calculated from average concentrations (Table 1). Flux of nutrients past the 2.1 m (7 ft.) depths incorporates large variability in both volumes of soil solution leachate (as collected by lysimeters) and concentrations of nutrients in soil solution samples. Large concentrations of nutrients in the soil solution coincoide with low soil moisture and very slow rates of moisture flow. Conversely, low nutrient concentrations in soil solutions occur during wet conditions with large amounts of rapid flow of soil water through the soil profile.

The renovation capacity of the soil is expressed as the percentage of an element applied and the quantity leaching (flux) deeper than 2.1 m (7 ft.) in the soil. A large percentage renovation (Total-P, 99+%, Table 3) indicates retention in the soil profile, with very little leaching or flux. Conversely, a large flux or high leaching losses indicates reduced renovation. Renovation of the Everett soil for total nitrogen was surprisingly efficient in view of the large quantities of total -N applied in sludge--1928 to 4261 kg/ha (1720 to 3801 lbs./ac.). The total -N flux or quantity leaching past the 2.1 m (7 ft.) depth in the soil profile was both largest and least of all treatments for the 300 and 300W treatments--221 to 2333 kg/ha (197 to 2081 lbs./ac.), respectively. Renovation of total -N also had a maximum range from 32% (300W) to 95% on the 300 plots. The 200 series plots reversed the impacts of water on the 300 plots with the 200W renovating 91% (340 kg/ha flux or 303 lbs./ac.) as compared to 65% (1500 kg/ha flux or 1338 lbs./ac.) for the 200 plot.

To date, there is no explanation for the reversal of renovation of total nitrogen between the 200 and 300 series plots with or without water. Great care was taken in obtaining these results with very careful checking for errors. Clues are not offered by the 100 series plots, as the renovation of the water added plot is not significantly different from the plot without water. The pattern established in the first year continued in future years,

Table 3. FIRST YEAR NUTRIENT LOADING AND FLUX (kg/ha) THROUGH THE EVERETT SOIL AND PERCENT RENOVATION

Plots		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
100	Applied	2,130	1,269	175	867	200	35,151	7,366	6,800	3,867
	Flux	863	290	573	2	2	617	102	46	105
	% Ren.	59	77	-	99+	99	98	99	99	97
100 + water	Applied	1,928	1,147	158	784	181	31,803	6,600	6,153	3,500
	Flux	738	1	730	1	T*	610	162	98	31
	% Ren.	62	99+	-	99+	99+	98	98	98	99
200	Applied	4,261	2,535	350	1,733	400	70,303	14,721	13,601	7,734
	Flux	1,500	2	1,493	T	T	1,108	345	139	12
	% Ren.	65	99+	-	99+	99+	98	98	99	99+
200 + water	Applied	3,754	2,234	308	1,527	352	61,933	12,969	11,982	6,813
	Flux	340	29	311	1	T	436	87	109	69
	% Ren.	91	99	-	99+	99+	99	99	99	99
300	Applied	4,160	2,475	341	1,692	390	68,628	14,371	13,277	7,550
	Flux	221	1	220	T	T	231	56	44	7
	% Ren.	95	99+	35	99+	99+	99+	99+	99+	99+
300 + water	Applied	3,450	2,053	283	1,403	323	56,911	11,918	11,011	6,261
	Flux	2,333	13	2,211	1	1	2.594	642	196	439
	% Ren.	32	99+	-	99+	99+	95	95	98	93

*T denotes trace levels

and the reversal between the 200 and 300 series plots was consistent for other elements (Ca and Mg). It can only be assumed that the differences represent random variation in soils and their renovation abilities.

This random variation in renovation capacity also shows in the NH_4-N differences with the 100 plot without water having significantly greater losses (290 kg/ha or 259 lbs/ac.) than any other plots. Losses of NH_4-N were insignificant on all other plots (1 to 29 kg/ha or 0.9 to 25.9 lbs/ac.).

Renovation of NH_4-N ranged from 77 to 99% (290 to 1 kg/ha or 259 to 0.9 lbs/ac.) with best renovation on those plots which received maximum amounts of NH_4-N.

The obvious and expected losses of nitrogen from plots occurred in the NO_3-N form. Leaching losses ranged from 220 to 2211 kg/ha (196 to 1972 lbs/ac.). Again, both of these values occurred on the 300 series plots.

Again, the reversal of nitrate leaching with additions of water on the 200 series plots occurred. Almost 5 times as much nitrate was leached through 2.1 m (7 ft.) of the soil profile on the 200 plot without water application. Differences on the 100 plots are probably not significant. Quantities of nitrate applied to the plots are relatively insignificant in comparison to the total quantity of nitrogen applied. The dynamics of plot chemistry are exhibited by the rapid changes in form of nitrogen and the large leaching losses in the soil solution as nitrate.

The renovation capacity exhibited by the Everett soil for total P, PO_4-P, calcium, magnesium, sodium and potassium is excellent even in spite of the very large quantities applied. Renovation of phosphate was 99+% with a maximum leaching loss of 2 kg/ha (1.8 lb/ac.). Applications of calcium in sludge ranged from 31,000 to over 70,000 kg/ha (27,660 to over 62,450 lbs/ac.). Leaching losses ranged from 231 to 2594 kg/ha (207 to 2314 lbs/ac.); however, renovation was excellent in view of the very large quantities applied. Very similar trends were exhibited for the other base nutrients with almost insignificant leaching losses.

The greatly reduced rates of sludge application and quantities applied (Table 2) and dilution of sludge with water resulted in significantly reduced applications of nutrients during the second year (Table 4).

Large first year applications of sludge to the Everett soils initiated leaching losses in the soil solution through 2.1 m (7 ft.) of the soil profile which continued in ensuing years, maintaining similar patterns. Greatly reduced rates of weekly nutrient applications and reduced total loadings reduced but did not stem leaching losses. The percent renovation, in general, was less--not because of increased losses but in calculating percentages, the greatly reduced amounts of nutrients applied cause even a reduced flux to show generally a lesser percentage of renovation.

Total nitrogen losses (flux) for the 100 series plots were approximately one-half of the losses sustained during the first year (800 kg/ha, YR 1, to

Table 4. SECOND YEAR NUTRIENT LOADING AND FLUX (kg/ha) THROUGH THE EVERETT SOIL AND PERCENT CUMULATIVE RENOVATION

Plots		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
100	Applied	125	70	10	51	12	2,055	431	398	226
	Flux	321	T*	447	T	T	388	54	19	17
	% Ren.	-	99+	-	-	99+	81	87	95	92
100 + water	Applied	125	70	10	51	12	2,055	431	398	226
	Flux	423	T	312	T	1.7	246	56	55	106
	% Ren.	-	99+	-	99+	86	88	87	86	53
200	Applied	398	224	38	162	37	6,559	1,374	1,270	722
	Flux	1,784	T	1,519	1.1	T	1,238	208	88	15
	% Ren.	-	99+	-	99+	99+	81	85	93	98
200 + water	Applied	374	211	31	152	35	6,164	1,292	1,193	679
	Flux	930	2	726	T	T	764	158	56	16
	% Ren.	-	99+	-	99+	99+	88	88	95	98
300	Applied	848	477	69	345	80	13,960	2,926	2,703	1,537
	Flux	785	T	639	.2	T	646	134	53	16
	% Ren.	7	99+	-	99+	99+	95	95	98	99
300 + water	Applied	848	477	69	345	80	13,960	2,926	2,703	1,537
	Flux	944	T	667	T	.1	584	101	45	9
	% Ren.	-	99	-	99+	99+	96	97	98	99

*T denotes trace levels

372 kg/ha, YR 2; or 713 lbs/ac., YR 1, to 332 lbs/ac., YR 2). Plot 200 sustained the continued high rate of total nitrogen loss initiated in YR 1 (1784 kg/ha or 1592 lbs/ac.). Plot 200W increased from 340 to 930 kg/ha (303 to 830 lbs/ac.). Plot 300 increased from 221 to 785 kg/ha (197 to 700 lbs/ac.) in the second year.

Again, NH_4-N losses were insignificant and nitrate leaching generally declined, particularly on the 300W plot, from an average of 2211 to 667 kg/ha (1973 to 595 lbs/ac.) in the second year. In the first year, nitrate leaching was the major form of loss of total nitrogen from the soils. However, in the second year substantial losses of nitrogen took place in other forms (as yet unidentified). Losses of total phosphate and PO_4-P continued to be insignigifcant. Leaching of calcium generally declined on all plots except for plot 200 which showed a slight increase over first year leaching losses. The very high leaching loss on plot 300W, 2594 kg/ha (2314 lbs/ac.), reduced to 584 kg/ha (521 lbs/ac.) in the second year. Leaching losses of other nutrients were not significantly different in the first and second years. The reduced rates of application make even reduced rates of leaching a lesser value in terms of renovation.

Applications of sludge to the Everett soil plots in the third year continued at reduced rates (comparing plot averages of Tables 4 and 5). With the exception of plot 100, total nitrogen leaching generally declined significantly in the third year. The decline in total -N flux generally results from reduced nitrate leaching with the average for the 100 series reducing from 380 to 290 kg/ha (338 to 259 lbs/ac.). The 200 series reduced from an average of both plots of 1120 to 690 kg/ha (999 to 616 lbs/ac.), and the 300 series reduced from 650 to 470 kg/ha (580 to 419 lbs/ac.: Table 5).

Losses of total P and PO_4-P continued to be insignificant. Changes in losses of other base nutrients are probably not significantly different during year 3 as compared to year 2. In general, there either are no significant differences or slight declines in leaching losses.

The total of nutrients applied in three years of sludge application and total nutrient losses are summarized in Table 6. The most significant losses from the soil profile are the nitrate form of nitrogen. Of the 4743 kg/ha (4233 lbs/ac.) of total nitrogen lost from the 200 plot, 4041 kg/ha (3605 lbs/ac.)--85%--were in the nitrate -N form. Losses of NH_4-N are insignificant by comparison. Retention of phosphate in the soil profile is excellent in all of its forms with losses at background levels.

Large quantities of dissolved base nutrients in Metro sludge provide a very significant loading when compared to the total quantities of suspended organic solids applied. For example, the 200 series plots average 115,120 kg/ha (102,202 lbs/ac.) of combined calcium, magnesium, sodium and potassium in comparison with an average of 91,200 kg/ha (81,168 lbs/ac.) of suspended solids (Table 2). Slightly greater quantities, 122,910 kg/ha (109,033 lbs/ac.) were applied to the 300 series plots. Suspended solids in sludge averaged 99,650 kg/ha (88,399 lbs/ac.) for the 300 series plots. Leaching

Table 5. THIRD YEAR NUTRIENT LOADING AND FLUX (kg/ha) THROUGH THE EVERETT SOIL AND PERCENT CUMULATIVE RENOVATION

Plots		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
100	Applied	192	107	15	108	102	3,168	660	612	348
	Flux	416	T*	414	T	T	426	62	19	18
	% Ren.	-	99+	-	99	99+	87	91	97	95
100 + water	Applied	192	107	16	108	102	3,168	660	612	348
	Flux	167	T	167	T	T	176	34	33	9
	% Ren.	13	99+	-	99+	99+	94	95	95	97
200	Applied	229	128	19	128	121	3,775	787	729	415
	Flux	1,459	T	1,029	T	T	904	134	66	10
	% Ren.	-	99+	-	99+	99+	76	83	91	98
200 + water	Applied	208	116	17	117	111	3,432	715	663	377
	Flux	353	T	352	T	T	265	44	37	22
	% Ren.	-	99+	-	99+	99+	92	94	94	94
300	Applied	304	170	25	171	162	5,016	1,045	969	551
	Flux	571	T	568	T	T	681	107	53	8
	% Ren.	-	99+	-	99+	99+	86	90	95	99
300 + water	Applied	243	136	20	137	129	4,013	836	775	441
	Flux	388	T	378	T	T	752	118	71	12
	% Ren.	-	99+	-	99+	99+	81	86	91	98

*T denotes trace levels

Table 6. TOTAL NUTRIENTS APPLIED (kg/ha), FLUX AND PERCENT TOTAL RENOVATION THROUGH EVERETT SOIL

Plots		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
100	Applied	2,447	1,446	200	1,026	314	40,374	8,457	7,810	4,441
	Flux	1,600	290	1,434	3	2.1	1,431	218	84	140
	% Ren.	35	80	-	99+	99+	96	97	99	97
100 + water	Applied	2,245	1,324	184	943	295	37,026	7,691	7,163	4,074
	Flux	1,328	1	1,209	1	2	1,032	252	186	146
	% Ren.	41	99+	-	99+	99	97	97	97	96
200	Applied	4,888	2,887	407	2,023	558	80,637	16,882	15,600	8,871
	Flux	4,743	2	4,041	2	.3	3,250	687	293	37
	% Ren.	3	99+	-	99+	99+	96	96	98	99+
200 + water	Applied	4,336	2,561	356	1,796	498	71,529	14,976	13,838	7,869
	Flux	1,623	31	1,389	1	T*	1,465	289	202	107
	% Ren.	63	99	-	99+	99+	98	98	99	99
300	Applied	5,312	3,122	435	2,208	632	87,604	18,342	16,949	9,638
	Flux	1,577	2	1,427	T*	.1	1,558	297	150	31
	% Ren.	70	99+	-	99+	99+	98	98	99	99+
300 + water	Applied	4,541	2,666	372	1,885	532	74,884	15,680	14,489	8,239
	Flux	3,665	13	3,256	1	1.1	3,930	861	312	460
	% Ren.	19	99+	-	99+	99+	95	95	98	94
Water	Applied	1.60	0.39	1.01	0.16	0.06	18.81	3.71	23.10	1.65
	Flux	2.87	0.17	0.08	0.47	0.11	8.57	2.52	3.89	0.68
	% Ren.	-	56	92	-	-	54	32	83	59

*T denotes trace levels

losses of dissolved constituents are almost insignificant by comparison to the quantities applied. With the exception of nitrogen compounds, total renovation on the Everett soil ranges from 95 to 99%.

Section 16

PROPERTIES OF EVERETT SOILS

Total chemical analyses of the Everett soil profile prior to sludge treatments identified the quantities of base nutrients per hectare. A balance sheet is presented in Table 7 where initial average total quantities of nutrients are compared with total quantities applied in sludge and nutrient flux through the soil profile. Post treatment soil chemistry would indicate accumulations of nutrients in the soil profile. In general, total amounts of nutrients show an increase following three years of sludge application; however, high statistical variation in Everett soils does not allow an exact balancing of the initial quantities of nutrients. This is particularly true with very high application rates of calcium added in the 200 and 300 series plots. Additional quantities of total calcium applied in sludge almost equalled the quantities determined in the forest soil (96.0 mt/ha, 43 t/ac. in pretreatment; 81.2 mt/ha, 36 t/ac. applied for the 300 plots).

The total nutrient flux through 60 cm (24 in.) of the Everett soils is shown as a percentage flux in Table 7. Highest percentage of base nutrient losses occurred with maximum calcium applications for the 300 series plots (2.2%). All other base nutrients--magnesium, sodium and potassium--had losses ranging from an insignificant amount to 0.8% (magnesium at the 200 level treatments). Renovation over three years for quantities of nutrients applied is good. Percentages are even more significant when calculated on total quantities of base nutrients in soil profiles.

Attempts to accurately account for initial quantities of base nutrients in the soil profile plus the quantities added by applied sludge achieved moderate success. For example, for the 100 series plots an average of 96 mt/ha (43 t/ac) of calcium existed in the surface 60 cm (24 in.) of the soil; 38.7 mt/ha (17 t/ac) were applied by sludge with a loss of 1.2 mt/ha (0.5 t/ac). Post treatment soil sampling calculated 121 mt/ha (54 t/ac) of total calcium. This is 12 mt/ha (5 t/ac) less than predicted by balancing input and outputs of calcium. It is, however, within the confidence limits for calcium determinations in soils which average $\pm$ 25%. Calcium estimations in the 200 and 300 series plots for post treatment quantities are much lower (110.8 and 126.1 mt/ha; 49 and 56 t/ac), when a predicted quantity should be about 175 mt/ha (78 t/ac).

Results for magnesium were somewhat similar to the calcium results. The quantity of 70.8 mt/ha (32 t/ac) of magnesium is predicted for the 100 series plots. The 69.8 mt/ha (31 t/ac) calculated from post treatment soil sampling is amazingly close. In fact, less post treatment magnesium was found than

Table 7. TOTAL NUTRIENT BALANCE FOR PRE- AND POST SLUDGE APPLICATIONS AND TOTAL PERCENT FLUX ON THE EVERETT SOIL

Plots		Ca	Mg	Na	K
		(metric tons per hectares)			
100	Pre	96.0	62.7	251.5	71.2
	Applied	38.7	8.1	7.5	4.3
	Flux	1.2	0.2	0.1	0.1
	Post	121.0	69.8	290.3	65.1
	% Flux	1.0	0.3	T	0.2
200	Pre	96.0	62.7	251.5	71.2
	Applied	76.1	15.9	14.7	8.4
	Flux	2.4	0.4	0.2	0.1
	Post	110.8	56.9	167.9	52.8
	% Flux	2.1	0.8	0.1	T
300	Pre	96.0	62.7	251.5	71.2
	Applied	81.2	17.0	15.7	8.9
	Flux	2.7	0.6	0.2	0.2
	Post	126.1	83.4	296.0	82.3
	% Flux	2.2	0.7	0.1	0.3

predicted, except the 300 series plots balance very well (83.4 mt/ha, 37 t/ac. found compared to 79.7 mt/ha, 36 t/ac. predicted).

Quantities of sodium found in post treatment plots exceeded the prediction for the 100 and 300 series and were significantly low for the 200 series plots. Total sodium was 290 mt/ha (129 t/ac.) following sludge application where only 259 mt/ha (115 t/ac.) are predicted. The 300 series plots had 296 mt/ha (132 t/ac.) following sludge applications, where 267 mt/ha (119 t/ac.) are predicted. The 200 series plots have almost 100 mt/ha (45 t/ac.) less than predicted. The variability in the sodium results are somewhat expected due to the very high variability in sodium concentrations in the soil plots. Quantities of sodium on the exchange capacity frequently had ± 100% variation.

Potassium following sludge application was close to predicted quantities for the 300 series plots (80 mt/ha, 36 t/ac. predicted; 82.3 mt/ha, 37 t/ac. found). Both pre- and post treatment potassium levels were highly variable in the surface soils. Confidence limits ranged to 5 times the average quantities in pretreatments reducing to ± 50% in post treatment sampling. Low estimation on 100 and 200 series plots may be attributed to natural variations.

Coarse alluvial soils are generally recognized as being highly variable in physical structure, texture, and chemical composition. The magnitude of the variability problem is amplified when large amounts of the soil matrix are larger than 2 mm (0.08 in.). Estimation of bulk density and accurate identification of the active soil fraction complicate the problems of estimation of a total base nutrient balance for pre- and post sludge applications.

EVERETT SOIL CHEMISTRY, FIRST AND SECOND YEARS

Detailed resampling of original plots for total chemistry for pre- and post treatment results of base nutrients is summarized in Table 7. The 2.1 m (7 ft.) depths were not resampled due to the extensive disturbance excavation to this depth would have caused to the surface of plots. Pretreatment soil analyses established average quantities of nutrient reserves in the soil. Quantities of nutrients applied in sludge should indicate the current total less plant uptake and flux.

Preliminary data compared pretreatment average analyses to post treatment averages for original Everett plots receiving sludge (Table 8). Confidence interval of the mean at a 95% confidence level is calculated on the statistics for either the pre- or post treatment, using maximum variability. The limited numbers of soil samples do not allow strict statistical analysis but are offered only as a relative comparison of variability of soil chemistry.

Applications of sludge during the first and second years have increased the variability for most soil properties analyses, as summarized in Table 8. Random sampling of plots prior to sludge treatment developed averages for pH, organic matter, total nitrogen and cation exchange capacity. These averages were determined for the forest litter layers (L), the surface soils termed the soil A horizons, and averages for soil B horizons, the 15 to 60 cm (5.9

Table 8. SOIL CHEMICAL PROPERTIES FOLLOWING SLUDGE APPLICATIONS ON THE EVERETT SOIL SERIES AND 95% CONFIDENCE INTERVAL, SECOND YEAR

	Horizon	Pretreatment	Post Treatment
pH	L	5.6 ± 0.1	4.8 ± 0.9
	A	5.9 ± 0.6	5.0 ± 1.0
	B	5.9 ± 0.5	5.3 ± 0.8
Organic Matter (percent)	L	38.1 ± 2.3	32.6 ± 11.6
	A	11.3 ± 0.6	16.4 ± 6.5
	B	3.4 ± 0.2	4.3 ± 2.0
Total Nitrogen (percent)	L	0.61 ± 0.04	0.82 ± 0.31
	A	0.27 ± 0.02	0.29 ± 0.15
	B	0.11 ± 0.01	0.09 ± 0.06
Cation Exchange Capacity (meq/100g O.D. wt)	L	50.9 ± 2.5	59.9 ± 11.3
	A	28.0 ± 1.0	43.5 ± 7.2*
	B	15.2 ± 0.6	18.4 ± 6.6
Carbon:Nitrogen (ratio)	L	36:1	23:1
	A	24:1	33:1
	B	18:1	28:1

*Significant difference

to 24 in.) depths. In general, the confidence limits are significantly less for pretreatment than post treatment data. For example, a confidence limit of ± 0.1 pH unit was found in the pretreatment analyses for the forest litter layers (L). This has increased 9-fold to 0.9 pH units for the post treatment soil chemical analyses.

Organic matter in the litter layer has an increased variability from ± 2.3% to ± 11.6%. Increased variability induced by sludge treatments results from variations in sludge application rates to plots. Initial analysis of sampling attempted to establish soil property differences between plots with different rates of sludge application; however, inherent variability of soils was much too great. Thus, soils from all sludge treated plots are analyzed independent of rates of sludge application. The only significant change in soil chemistry is an increase in average cation exchange capacity of soil A horizons, increasing from 28.0 to 43.5 milli-equivalents per 100 grams of oven dry soil (meq/100g O.D.), following two years of sludge application.

The following sections discuss briefly trends found in soil chemistry.

Soil pH

Soil pH is the negative logarithm of the hydrogen ion concentration. Soil pH values were converted to actual hydrogen ion concentrations for comparisons of increased acidity. Hydrogen ion concentrations increased from 26 to over 6000%. Increases in hydrogen ion concentrations are reported as a decrease in soil pH. Average soil pH decreased for the litter layers from 5.6 to 4.8. The large variation associated with post treatment analyses will not allow establishment as a significant difference (range 3.9 to 5.7). Assessment of only pretreatment results suggests there has been a real reduction in average pH of the forest litter layers due to sludge application. Additional soil sampling would be required to be sure of a statistically significant difference.

Soil Organic Matter

Average soil organic matter tends to decrease with sludge application in litter layers (38.1 to 32.6%) and increase slightly in the soil horizons (11.3 to 16.4%). Patterns of variability are similar in organic matter analyses as with pH determinations. There is a 5-fold increase in variability of organic material content of forest litter analyses and a 10-fold increase in variability of soil organic matter analyses in A and deeper horizons, following sludge treatments. Based on only the determination of pretreatment condition, we would suggest that there has been significant decreases in organic matter of the L layer and increases in organic matter in the soil. However, the high variability of the post treatment results does not allow statistically significant conclusions. The trends, however, are apparent and are supported by total organic carbon analyses and a theory of translocation of organic colloids deeper into the soil profile.

Using these average organic matter values, pretreatment soil analyses indicated an average of 123.7 mt/ha (55.2 t/ac.) of organic material (range

72.6 to 176 mt/ha or 32.4 to 78.8 t/ac.). Post treatment analyses show an average of 169 mt/ha (75.2 t/ac.) with a range of 96.6 to 318 mt/ha (43.1 to 142.0 t/ac.) for sludge treated plots.

Total Nitrogen

Percentages of total nitrogen tend to increase in the L layer (0.61 to 0.82%) and remain unchanged in soil horizons. Reductions in soil organic matter in the L layer suggest there should be a reduction in quantity of nitrogen also. Increases in organic matter in the surface soils (A horizon) suggest there should be an increase in the quantity of nitrogen in surface soils.

Cation Exchange Capacity

Cation exchange capacity of the A horizon of sludge treated plots is the only soil property to show a statistically significant ($P<.05$) change (28.0 to 43.5 meq/100 g O.D. soil). Increases are suggested for L and B horizons (L 50.9 to 59.9; B 15.2 to 18.4 meq/100g O.D. soil) with greatly increased variation since sludge application. A mineralogic analysis revealed no change in the type or quantity of clay minerals present in the surface soil layers; thus, changes in total exchangeable cations must be attributed to increases and/or the form of organic colloids.

Carbon-Nitrogen Ratio

The carbon-nitrogen ratio for pretreatment conditions on the Everett soils is about average for forest soils. Forest litter is relatively undecomposed; therefore, high in carbon. Advancing decomposition takes place with incorporation in the soil profile. Changes in the carbon-nitrogen ratio induced by sludge application reflect mainly a very significant increase in the quantities of total nitrogen in forest litter layers. Quantities of carbon in the organic matter layer have declined slightly; however, the significant reduction in the carbon-nitrogen ratio is explained by increased total nitrogen. Organic carbon is increasing in the soil profile in both A and B horizons without equivalent increases in total nitrogen content. The carbon-nitrogen ratio has increased in both the A and B soil horizons.

EVERETT SOILS, EXCHANGEABLE CHEMISTRY AND BASE SATURATION, SECOND YEAR

Applications of sludge over two years have significantly altered several exchangeable cation relationships (Table 9). With the exception of sodium, there is a general decline in the exchangeable cations in L layers. Calcium has reduced significantly from 12.8 to 9.8 meq/100g O.D. Potassium has also reduced significantly from 0.6 to 0.2 meq/100g O.D. while sodium has increased from 0.1 to 0.4 meq/100g O.D. Magnesium shows a general trend of decline in soil horizons with a significant reduction in the B horizon (0.8 to 0.4 meq/100g O.D.). Potassium indicates a significant decline in both the A and B horizons.

The sum of total exchangeable cations tends to decrease in the L layers exclusive of the hydrogen ion (14.9 to 11.7 meq/100g O.D.). Thus, a decrease

Table 9. EXCHANGEABLE CATIONS AND PERCENT BASE SATURATION BY HORIZONS OF THE EVERETT SOIL, SECOND YEAR

Horizon	Ca		Mg		K		Na		Base Saturation %	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Milli-equivalents per 100 g O.D. soil									
L	12.8±1.8	9.8±1.2*	1.4±0.3	1.3±0.2	0.6±0.1	0.2±0.1*	0.1±0.1	0.4±0.1*	31±3	23±13
A	7.3±1.5	7.8±1.1	1.1±0.2	0.8±0.2	0.3±0.04	0.1±0.1*	0.1±0.1	0.2±0.1	31±2	26± 6
B	2.8±1.0	3.4±0.4	0.8±0.1	0.4±0.1*	0.4±0.1	0.1±0.04*	0.2±0.2	0.2±0.2	26±3	38±14

*Significant difference

in exchangeable cations accompanied by an increase in cation exchange capacity effectively reduces the base saturation. Changes in the quantities of exchangeable cations in soil horizons are relatively insignificant; however, again the large increase in cation exchange capacity, particularly of the A horizon, results in an effective decrease in percentage of base saturation.

EVERETT SOIL CHEMISTRY, THIRD YEAR

Third year resampling of the original 100, 200, 300 series plots sampled litter layers and the A and B soil horizons (15 to 60 cm or 6 to 24 in.). Post treatment soil properties following three years of sludge application are again compared with the pretreatment samples. The sampling scheme attempted to establish the depth within the soil column where significant changes in soil properties might be taking place. Had significant differences been found in soil B horizons, then deeper soil horizons would have been sampled. Few significant changes in soil chemistry deeper than the B horizon were found. Table 10 compares soil chemical properties following three years of sludge application.

Soil pH

The pH of soil litter layers continues to decline with additional sludge applications. pH is now significantly lower than the pretreatment pH (5.6 compared to 4.3). pH of the third year is not significantly lower than the second year due to the high variability in second year pH results. Soil A horizons have also declined significantly from the pretreatment (5.9 to 4.7). pH of soil B horizon averages lower but is not significantly different from either pretreatment or second year results. (Compare Table 10 with Table 8.)

Organic Matter

Forest litter layers (L) show no significant changes in organic matter. The trend of apparent decrease in the second year has been reversed in the third year. Values for the three sampling times show normal variation. A significant increase in the organic matter content of the soil A horizon has taken place, while the average percentage organic matter is less (15.2%) in the third year than in the second (16.4%). The significant increase is established by reduced variability in the random process of sampling the soils. The confidence limits for the third year were ± 1% as compared to ± 6% for the second year samples. These data would suggest that a significant increase actually took place in the organic matter content with two years of sludge application, but it was obscured by the inherent random variation. Organic matter content of soil B horizons exhibits normal variation with no significant differences.

Total Nitrogen

Total nitrogen concentration in forest litter layers has also increased significantly over the pretreatment condition (0.61 to .78%). The third year of treatment appears to have allowed soil nitrogen to also increase in concentration in soil A horizons (0.27 to .42%). Neither of these increases

Table 10. SOIL CHEMICAL PROPERTIES FOLLOWING SLUDGE APPLICATIONS ON THE EVERETT SOIL SERIES AND 95% CONFIDENCE INTERVAL, THIRD YEAR

	Horizon	Pretreatment	Post Treatment
pH	L	5.6 ± 0.1	4.3 ± 0.04*
	A	5.9 ± 0.6	4.7 ± 0.2*
	B	5.9 ± 0.5	5.5 ± 0.3
Organic Matter (percent)	L	38.1 ± 2.3	41.2 ± 3.9
	A	11.3 ± 0.6	15.2 ± 1.0*
	B	3.4 ± 0.2	3.1 ± 0.5
Total Nitrogen (percent)	L	0.61 ± 0.04	0.78 ± 0.10*
	A	0.27 ± 0.02	0.42 ± 0.07*
	B	0.11 ± 0.01	0.11 ± 0.02
Cation Exchange Capacity (meq/100g O.D. wt)	L	50.9 ± 2.5	61.5 ± 5.0*
	A	28.0 ± 1.0	43.0 ± 4.0*
	B	15.2 ± 0.6	17.4 ± 1.7
Carbon:Nitrogen (ratio)	L	36:1	30:1
	A	24:1	21:1
	B	18:1	16:1

*Significant difference

are significantly different from the second year values. There have been no significant changes in the soil B horizons.

Cation Exchange Capacity

Soil cation exchange capacity has significantly increased in both the L layers and the soil A horizon (L, 50.9 to 61.5 meq/100 g O.D.; and A, 28 to 43 meq/100g O.D.). Increases in cation exchange capacity are attributed to the increased organic matter content of the L layer and the A horizon.

Carbon-Nitrogen Ratio

The carbon-nitrogen ratio is a function of both changes in organic matter content and changes in the total nitrogen percent. In the second year, highly variable litter layers were sampled with a reduced organic matter content. Total nitrogen content was even higher (0.82%) than in the third year (0.78%). This combination gave a greatly reduced carbon-nitrogen ratio in the litter layers in the second year (23:1; Table 8). Increased organic matter in the third year, along with a stable nitrogen content, results in an increase in the carbon-nitrogen ratio of the litter layer (30:1). The combination of a significant increase in total nitrogen in the A horizon with a slight decrease in organic matter results in a drastic reduction in the carbon-nitrogen ratio over the second year (33:1 to 21:1). In a like manner, the slight increase in nitrogen content of the B horizon accompanied by a reduction in organic matter results in a significantly lower carbon-nitrogen ratio (28:1 to 16:1) in the third year of the study. While significant changes have taken place between the second and third years, the carbon-nitrogen ratios currently are not significantly different from the pretreatment values.

EVERETT SOILS, EXCHANGEABLE CHEMISTRY AND BASE SATURATION, THIRD YEAR

The reduction in soil pH accompanied by an increase in organic matter and an increase in cation exchange capacity is generally reflected in a changing composition of exchangeable cations in the third year of sludge applications (Table 11). The initial decline of exchangeable calcium in L layers has stabilized at a slightly lower but not significantly decreased level. Increased amounts of calcium are becoming associated with the exchange capacity in the A horizon. In the third year of the study, exchangeable calcium almost doubled, resulting in a significant increase over pretreatment amounts. A trend to increase in calcium also occurs in the soil B horizon.

Exchangeable magnesium in the soil B horizon continues to decline accompanied by a nonsignificant increase in the A horizon. Exchangeable potassium increased significantly between the second and third years in the L layer and soil A horizon. Current values, however, are not significantly different from pretreatment values.

Exchangeable sodium continues to be significantly greater with both the L layer and A horizon showing an increase over pretreatment values. Increases are not significantly greater from the third year over the second.

Table 11. EXCHANGEABLE CATIONS AND PERCENT BASE SATURATION BY HORIZONS OF THE EVERETT SOIL, THIRD YEAR

Horizon	Ca		Mg		K		Na		Base Saturation %	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Milli-equivalents per 100 g O.D. soil									
L	12.8±1.8	10.9±1.9	1.4±0.3	1.3±0.4	0.6±0.1	0.7±0.1	0.1±0.1	0.3±0.1*	31±3	21±3
A	7.3±1.5	13.5±1.8*	1.1±0.2	1.2±0.2	0.3±0.04	0.4±0.1	0.1±0.1	0.3±0.1*	31±2	35±3
B	2.8±1.0	4.5±1.2	0.8±0.1	0.1±0.1*	0.4±0.1	0.4±0.1	0.2±0.2	0.2±0.1	26±3	33±11

*Significant difference

The accumulation of exchangeable cations in the soil A horizon has resulted in a significant increase in the percent base saturation between second and third year results. There are no significant changes between pre- and post treatment data or other horizons between the second and third years.

EVERETT SOILS, REDUCED SLUDGE APPLICATIONS

Application of sludge to the new plot series at reduced rates resulted in very similar nutrient flux and renovation during the first year of reduced sludge application rates. Table 12 provides a summary by nutrients of the quantities applied, losses and percent renovation by plots. Generally, losses of nutrients (in kg/ha) were quantitatively least on the 10 plots (minimum levels of sludge application) and generally greatest on the 30 and 40 plots which had increased sludge applications. Complex interactions remain in processes affecting total nitrogen leaching. Losses of NH_4-N are insignificant, again with rapid change of form of total nitrogen to NO_3-N where leaching losses occur in the soil solution.

Phosphorus losses again are insignificant with base nutrients closely paralleling results for heavier applications of nutrients. Renovation ranged from 96 to 99% with losses varying up to 613 kg/ha (547 lbs/ac.)--calcium--on the 40 plots. Maximum concentrations of nutrients in the soil solution occur during dry summer periods when volumes of soil solution are very low and losses are really insignificant. Minimum concentrations of nutrients in the soil solutions occur during the wet season and actually account for the major portion of nutrient losses.

EVERETT SOIL CHEMISTRY, REDUCED SLUDGE

Analyses of impacts of reduced rates of sludge application for the first year on the new Everett plots are summarized in Table 13. Again, average of analyses of all sludge treated plots is compared with the pretreatment soils analyses to assess significant impacts of sludge applications on soil chemistry.

Soil pH

There was a significant decrease in the average pH (5.8 to 4.4) of the forest litter layers following first year applications of sludge at reduced rates. Reductions in the soil A horizon (5.3 to 4.7) were not significant, but it may be anticipated that a significant reduction in soil A horizon pH will take place, as a marked decline has occurred. Large variability in pre-treatment pH of soil B horizons precludes any significant change caused by sludge treatments.

Soil Organic Matter

The series of plots selected for application of sludge at reduced rates had very large pretreatment variations in quantities of organic matter in both the forest litter layers (45.9 ± 17%) and the soil A horizon (17.7 ± 4.9%). No significant changes in soil organic matter have taken place in the

Table 12. TOTAL NUTRIENT LOADING AND FLUX (kg/ha) THROUGH THE EVERETT SOIL (REDUCED RATES)

Plots		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
10	Applied	326	182	26	183	173	5,385	1,122	1,040	591
	Flux	180	T*	179	T	T	213	40	31	12
	% Ren.	45	99+	-	99+	99+	96	96	97	98
20	Applied	993	555	81	558	527	16,394	3,415	3,167	1,800
	Flux	395	T	394	T	T	429	62	58	30
	% Ren.	60	99+	-	99+	99+	97	98	98	98
30	Applied	1,307	731	107	735	694	21,569	4,493	4,166	2,369
	Flux	696	T	615	T	T	565	109	99	73
	% Ren.	47	99+	-	99+	99+	97	98	98	97
40	Applied	1,480	828	121	833	786.3	24,420	5,088	4,718	2,683
	Flux	454	6	448	T	T	613	104	107	39
	% Ren.	70	99+	-	99+	99+	97	98	98	99

*T denotes trace levels

Table 13. AVERAGE SOIL CHEMICAL PROPERTIES OF EVERETT (New Plots) SOILS WITH REDUCED RATES OF SLUDGE APPLICATION

	Horizon	Pretreatment	Post Treatment
pH	L	5.8 ± 0.6	4.4 ± 0.3*
	A	5.3 ± 0.2	4.7 ± 0.7
	B	5.6 ± 1.3	5.8 ± 0.2
Organic Matter (percent)	L	45.9 ± 17.0	42.3 ± 9.0
	A	17.7 ± 4.9	15.9 ± 5.0
	B	1.8 ± 1.3	2.9 ± 0.2
Total Nitrogen (percent)	L	0.66 ± 0.43	0.64 ± 0.36
	A	0.24 ± 0.04	0.29 ± 0.02
	B	0.05 ± 0.03	0.07 ± 0.01
Cation Exchange Capacity (meq/100g O.D.wt)	L	42.4 ± 6.4	73.1 ± 8.6*
	A	29.2 ± 3.0	38.7 ± 3.5*
	B	15.3 ± 1.3	15.4 ± 1.3
Carbon:Nitrogen (ratio)	L	40:1	38:1
	A	43:1	32:1
	B	21:1	24:1

*Significant difference

soil surface, although there is possibly a trend to increase in the soil B horizon.

Total Nitrogen

Total nitrogen content may be increasing in the soil horizons but not significantly so following one year of sludge applications. Large variation in total nitrogen usually accompanies large variation in organic matter. Total nitrogen variation is very similar to that of organic matter with no significant differences in forest litter layers.

Cation Exchange Capacity

Cation exchange capacity of L layers and surface soil (A) horizons continues to be the soil property most significantly influenced by sludge applications. Litter layers of sludge treated plots increased an average of 30.7 meq/100g O.D. (from 42.4 to 73.1 meq/100g O.D.). Cation exchange capacity of soil A horizons has increased significantly as a result of sludge treatments; 38.7 as compared to 29.2 meq/100g O.D. soil. Soil B horizons largely are unaltered to date by sludge applications.

Carbon-Nitrogen Ratio

Carbon-nitrogen ratios have not departed significantly as a result of sludge treatments in L and B layers. The reduced organic matter with slightly increased nitrogen has lowered the carbon-nitrogen ratio of the A horizon following sludge treatment.

EVERETT SOILS, EXCHANGEABLE CHEMISTRY AND BASE SATURATION, REDUCED RATES

Few significant changes occurred as a result of sludge application at reduced rates on the Everett soil (Table 14). The only statistically significant change in exchangeable chemistry was an increase in the sodium content of the B horizon from 0.1 to 0.3 meq/100g O.D. It is probably more interesting to note the pretreatment values for the new Everett plots as compared to the pretreatment values for the old Everett plots. (See Table 9 and 11). Exchangeable calcium is significantly higher in both the L and A horizons. In a like manner, exchangeable magnesium is very close to being significantly greater.

Larger quantities of exchangeable cations for the particular location of the new plots result in a base saturation percent significantly greater than reported for the older Everett soil plots. The significant increases in cation exchange capacity of the L and A horizons result in a significantly reduced base saturation percentage following sludge treatments.

Table 14. EXCHANGEABLE CATIONS AND PERCENT BASE SATURATION BY HORIZONS FOR PRE- AND POST SLUDGE APPLICATIONS FOR THE EVERETT SOIL (REDUCED RATES)

Horizon	Ca		Mg		K		Na		Base Saturation %	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Milli-equivalents per 100 g O.D. soil									
L	17.8±1.9	16.2±4.7	2.1±0.6	2.5±0.6	0.4±2.6	1.0±0.2	0.2±0.3	0.7±0.2	48±4	28±4
A	13.4±3.8	9.9±3.1	1.5±0.3	1.1±0.4	0.3±1.6	0.5±0.2	0.1±0.2	0.4±0.2	52±4	31±7
B	4.1±0.5	4.2±1.0	0.4±0.1	0.8±0.3	0.2±0.7	0.4±0.1	0.1±0.03	0.3±0.03*	31±3	35±7

*Significant difference

Section 17

EVERETT SOIL SOLUTION NUTRIENTS, WATER AND CONTROL PLOTS

Quantities of nutrients applied in the water irrigation treatment over the three years of study, and the natural flux of nutrients from a control plot, indicate the natural levels of nutrient cycling (Table 15). The untreated control plot lost 1.6 kg/ha (1.41 lbs./ac.) of total -N composed predominantly of NO_3-N (0.9 kg/ha or 0.8 lb./ac.) or 56%. NH_4-N losses were about equal (0.2 kg/ha control; 0.17 kg/ha water only--0.17 and 0.15 lb./ac., respectively) on the two plots. Inputs of total N by water irrigation are relatively small; however, irrigation with water does accelerate total nitrogen losses (2.87 kg/ha water--2.56 lbs./ac.; 1.6 kg/ha control--1.4 lbs./ac.). Water applications apparently stimulate microbiological activity to the point of greatly reducing nitrate losses (0.08 kg/ha or 0.07 lb./ac.) on the water only plots.

Losses of total phosphorus were accelerated through irrigation with water as compared with the control. However, fractions of kg/ha loss are probably insignificant. Phosphate losses were reduced in the water only plot.

The flux of calcium, magnesium, sodium and potassium are slightly greater on the control plots than on the water irrigated plots. These losses are probably within the range of normal point to point variation for the Everett soil. In general, there is a conservation of base nutrient cations within the soil profile for the quantities applied in the irrigation water.

Table 15. NUTRIENTS APPLIED IN WATER AND FLUX (kg/ha) FROM CONTROL AND WATER ONLY PLOT

		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
Control	Flux	1.6	0.2	0.9	0.2	0.2	12.8	2.8	5.1	0.8
Water Only	Applied	1.60	0.39	1.01	0.16	0.06	18.8	3.7	23.1	1.65
	Flux	2.87	.17	.08	.47	.11	8.6	2.5	4.0	.68
	% Ren.	-	56	92	-	-	54	32	83	59

Section 18

EVERETT SOILS--SOIL SOLUTION NUTRIENT CONCENTRATIONS

An important phase of interpretation of the impacts of sludge disposal in the forest is nutrient concentrations transmitted to ground water. A major portion of the renovation of nutrients should take place in surface soil horizons, 2-3m (6-9 ft.). Measurement of the maximum and minimum concentrations of nutrients passing the 2.1 m (7 ft.) depth in the soil should provide an index of maximum potential contributions of sludge application to ground water.

A summary of the maximum and minimum concentrations of nutrients for all sludge treatment plots on Everett soils is provided in Table 16. Interpretation of the meanings of average concentrations could be very misleading, as they would be more an indices of the frequency of sampling rather than a true average concentration. Minimum concentrations of nutrients in the soil solution occur during rainy periods when high quantities of water are passing the soil profile. In these circumstances, large volumes of water are collected by the lysimeters and may be collected at frequent intervals. Averaging of these data would provide an unrealistic estimation of average nutrient concentrations.

Conversely, during very dry periods, particularly with low rates of sludge application, the soils are very dry with low volumes of soil solution extracted by the lysimeter plates. Frequently, field collections were made at 2 to 3-week or longer intervals--the time period required for an extraction of an adequate volume of soil solution for chemical analyses. These dry soil samples yielded the highest concentrations of nutrients in the soil solution. Samples would be relatively infrequent, even though concentration numbers would be large.

Generally, higher concentrations of nutrients were found in the 100, 200 and 300 series plots without the additions of additional water. As per the previous discussion, the 100W, 200W and 300W series plots with water following sludge application provided an additional dilution factor. Potassium values apparently deviate from this pattern.

TOTAL NITROGEN

Maximum concentrations of total N in the soil solution occurred on the 200 series plots. Both total N and NO_3-N exceeded 400 mg/l. In general, sludge applications followed by water and the reduced sludge application rates resulted in much lower total N and NO_3-N concentrations in soil solution.

Table 16. MINIMUM-MAXIMUM CONCENTRATIONS OF NUTRIENTS IN THE SOIL SOLUTION AT 2.1 m (7 ft.), EVERETT SOILS

Plots	Total -N	NO_3-N	Ca	Mg	Na	K
			(milligrams per liter)			
100	2 - 299	2 - 298	10 - 270	1 - 37	1 - 11	1 - 38
200	2 - 466	*T - 439	20 - 328	3 - 66	4 - 44	1 - 5
300	3 - 223	T - 222	3 - 278	1 - 38	2 - 19	1 - 5
100W	2 - 156	1 - 155	3 - 148	1 - 31	4 - 16	1 - 61
200W	2 - 144	2 - 156	5 - 171	2 - 43	5 - 15	1 - 12
300W	T - 250	T - 247	25 - 236	3 - 41	9 - 19	2 - 14
10	1 - 50	T - 49	8 - 45	3 - 10	4 - 7	1 - 3
20	3 - 136	3 - 135	10 - 127	1 - 17	1 - 7	4 - 12
30	2 - 103	1 - 101	9 - 81	1 - 30	3 - 13	2 - 12
40	T - 131	T - 128	6 - 178	2 - 23	2 - 8	4 - 16
Control	T - 13	T - 12	1 - 24	T - 3	T - 6	1 - 68
Water	T - 14	T - 12	1 - 19	1 - 21	1 - 9	T - 4

*Denotes less than 0.5 mg/l

Reduced rates of sludge applications (10 to 40 plot series) resulted in reduced total N and NO_3-N in soil solutions.

BASE NUTRIENTS

Patterns of concentrations of base nutrients in the soil solution are similar to that for total N and NO_3-N. Maximum concentrations of Ca, Mg and Na occurred on the 100, 200, 300 series plots with the maximum values occurring on the 200 plots. Applications of water following sludge resulted in increased minimum values of Ca and Na for the 300W plot.

Reduced rates of sludge application with the 10, 20, 30, 40 series plots resulted in significantly reduced concentrations of these nutrients in the soil solution. Patterns of base nutrient occurrence in the soil solution suggest a complex interaction between soils and applied sludge. Consistent patterns of increasing quantities of nutrients in the soil solution with increasing rates of sludge application are not evident for many nutrients.

Table 16 also compares maximum and minimum concentrations of nutrients in the soil solution for the control and water only plots. Water irrigation does not seem to accelerate nutrient losses nor contribute particularly to excessive quantities of nitrogen or base nutrients in the soil solution.

EVERETT SOILS, SOIL SOLUTION CONDUCTIVITY, pH AND ALKALINITY

Ranges of conductivity, pH and alkalinity of soil solutions by plot treatments and ground water are summarized in Table 17. Conductivity (specific conductance measured in micromhos per square centimeter) of sludge treated plots has maximum values on the 100, 200, 300 series. Minimum values are also higher for these sludge treatments. The control plot, however, has the maximum recorded conductivity (3427 micromhos) while both the control and water plots have the lowest minimum values recorded. The wide range in maximum conductivities for other plots suggests that sludge treatments are not adding more dissolved ions to the soil solution, as treated plots do not equal the control. There is an indication, however, that minimum values on the average are increased with sludge treatments. Ground water tends to buffer at a higher minimum and a lower maximum (142-194 micromhos) conductivity.

Patterns of soil solution pH are similar to nutrient concentrations and conductivities, with the 100, 200, 300 series plots showing increased maximum and reduced minimum values (range 4.0 to 8.4). The 100W, 200W, 300W series generally have high maximum pH values (average 7.9), but the low pH is a whole pH unit higher than sludge only series.

The control plot has a very narrow range of pH (7.0 to 7.4) indicating that sludge treatments are both depressing low pH values and increasing maximum pH values. Plots with reduced rates of sludge application appear to have lower minimum values, but on the average, maximum values have not been increased. Ground water ranges from 7.3 to 8.1 with an average value of 7.8.

Table 17. CONDUCTIVITY, pH, AND ALKALINITY OF THE SOIL SOLUTION AND GROUND WATER FOR EVERETT PLOTS

Plots	Cond. µ mhos	pH	Alka. mg/l
100	62 - 1856	4.0 - 8.4	0.1 - 8.8
200	175 - 2293	6.1 - 7.7	0.2 - 1.0
300	138 - 1536	5.5 - 7.6	0.1 - 0.4
100W	53 - 906	5.8 - 7.8	0.2 - 1.0
200W	52 - 970	5.0 - 8.0	0.1 - 2.3
300W	85 - 1087	6.7 - 7.9	0.5 - 1.0
10	132 - 1060	6.2 - 7.1	0.1 - 0.2
20	85 - 1013	6.0 - 7.2	0.1 - 0.3
30	102 - 368	6.5 - 7.4	0.2 - 0.6
40	71 - 974	6.9 - 7.4	0.3 - 0.5
Water	41 - 101	6.3 - 7.5	0.2 - 0.5
Control	45 - 3427	7.0 - 7.4	0.2 - 0.7
Ground Water	142 - 194	7.3 - 8.1	1.0 - 1.7
$\bar{X}$	171	7.8	1.3

Patterns of soil solution alkalinity are difficult to interpret. In general, it appears that sludge applications have had little impact on either maximum or minimum values. Two plots are exceptions to this statement--the 100 plot and 200W. In both cases, the maximums are significantly higher than other values, particularly for the water or control plots (0.5 and 0.7 mg/l, respectively).

The results of use of the Metro-data loggers for rapid scan of the concentration of dissolved oxygen, solution pH, conductivity and temperature resulted in complex computer plots. Examples of these plots are shown in figures in Appendix B.

Section 19

EVERETT SOILS, GROUND WATER NUTRIENTS

A well drilled to the interface of the outwash gravel and lacustrine deposits provided sampling of ground water adjacent to original Everett plot. Dissolved chemicals of ground water are summarized in Table 18. Total N averaged 0.8 mg/l with a range of 0.5 to 1.4 mg/l. Other forms of nitrogen, NH_4-N and NO_3-N, averaged 0.2 and 0.4 mg/l with no consistent relationship between the two nitrogen forms. The maximum NH_4-N concentration was 0.7 mg/l while the NO_3-N maximum concentration was 0.6 mg/l.

Forms of phosphorus are practically nonexistent in the ground water. A maximum of 0.18 mg/l occurred on one occasion as PO_4-P. Total P averaged 0.06 mg/l and PO_4-P averaged 0.03 mg/l. Concentrations of base nutrients are relatively stable in ground water showing slight seasonal variation. Anions of SO_4 and Cl exhibit considerably more variation with SO_4 ranging from 3 to 25 mg/l, averaging 11 mg/l. The range for Cl was 1 to 45 mg/l, with an average of 11 mg/l. The range of TOC was also large--4 to 40 mg/l.

Table 18. DISSOLVED CHEMISTRY OF GROUND WATER, EVERETT SOILS

Date	Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Na	K	Ca	Mg	SO_4	TOC	Cl
					(mg/l)							
2-26-76	0.6	T	.5	T	T	7	3.4	19	5	6	40	45
4-13-76	0.8	.7	.4	T	.01	16	2.3	17	3	13	6	15
6-3-76	1.3	.4	.1	.05	T	13	2.4	16	5	14	-	8
7-29-76	1.4	.4	.6	.07	T	6	1.8	11	2	16	-	6
8-17-76	0.8	T	.5	.03	T	11	2.6	15	5	-	-	-
11-9-76	0.7	.04	.6	.06	T	9	2.1	14	4	8	-	1
1-6-77	1.0	.2	.4	.04	.01	7	2.1	20	6	3	5	7
3-31-77	0.6	.1	.4	.06	.06	8	2.1	19	6	-	4	6
6-13-77	0.5	.1	.2	.04	T	8	1.6	17	6	4	10	6
9-12-77	0.6	T	.3	.18	.18	16	2.2	20	7	25	-	7
Ave.	0.8	.2	.4	.06	.03	9	2.3	15	5	11	13	11

Section 20

MASHEL SOILS, SOIL SOLUTION NUTRIENTS

Experimental designs parallel to the Everett soil studies evaluated impacts of sludge applications at reduced rates to Mashel and Wilkeson soils. Design rates of application were not achieved as sludge was only applied for 7 months. Table 19 indicates the design rate (by plot number) and actual rate of sludge applications with nutrient loading, flux (kg/ha) through the Mashel soil, and percent renovation achieved. Patterns of flux and renovation are very similar to reduced rates of sludge applications on the Everett soil.

The characteristic wetness of the Mashel site was obvious immediately after irrigation periods. Ponding occurred in depressions and would slowly infiltrate over a period of days. Ponding was more noticeable after a total 15 tons of solids were applied on a plot.

The lateral movement of subsurface soil water was greater than vertical soil water flux on sloping Mashel soils. Calculation of nutrient renovation was more difficult without exact measurements of downward water flux.

NUTRIENT RENOVATION FOR THE MASHEL SOIL SERIES

Table 19 shows the nutrient loading, flux and percent renovation for the four rates of sludge applications to Mashel soils. As seen with the Everett plots, renovation of total P, PO_4-P, and cations Ca, Mg, Na and K is excellent. Total N flux increases with increasing applications of sludge and is again dominated by the NO_3-N losses.

Renovation of total N varied from 46 to 82% with increased percent renovation on 40 treatment plots (82%). Losses of NH_4-N were greatest with the 20 and 30 series plots (39 and 59 kg/ha or 35 to 53 lbs/ac.). Losses of total N are dominated by NO_3-N leaching (65 to 80%). Other forms of nitrogen loss are operative though unexplained at this time, as up to 35% of total N losses are unaccounted for by the combination of NH_4-N and NO_3-N flux.

Excellent renovation (99+%) of phosphorus compounds continue with a maximum of 5 kg/ha (4.5 lbs/ac.) leached on the 30 series plots.

In a like manner, renovation of base nutrients continues to be very efficient with 93 to 99+% of applied base nutrients retained in the surface soil. Maximum losses occurred on the 20 and 30 series plots where total base

Table 19. NUTRIENT LOADING AND FLUX (kg/ha) THROUGH THE MASHEL SOIL AND PERCENT RENOVATION (APPLIED NUTRIENTS IN MT/HA AND FLUX OF NUTRIENTS IN KG/HA)

Plots	Total Applied (mt/ha)		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
10	4.8	Applied	240	134	19	135	127	3,960	825	765	435
		Flux	129	T	84	T	T	84	33	31	8
		% Ren.	46	99+	-	99+	99+	98	96	96	98
20	10.6	Applied	520	290	42	292	276	8,580	1,787	1,657	942
		Flux	152	39	113	1	T	144	52	117	23
		% Ren.	71	86	-	99+	99+	98	97	93	97
30	15.4	Applied	769	430	63	432	408	12,698	2,645	2,453	1,394
		Flux	175	59	116	5	5	211	59	59	30
		% Ren.	77	86	-	99	99	98	98	98	98
40	20.8	Applied	1,040	581	85	585	552	17,160	3,575	3,315	1,885
		Flux	185	11	151	T	T	113	22	46	17
		% Ren.	82	98	-	99+	99+	99+	99	99+	99+

nutrient flux was 336 kg/ha (300 lbs/ac.) for 20 plots and 359 kg/ha (320 lbs/ac.) for 30 plots.

Section 21

MASHEL SOIL PROPERTIES

Usual forest soil sampling problems with large inherent natural spatial variation in soil properties were even greater on plots on Mashel soils. Highly variable soil chemistry of pretreatment soils analyses, particularly soil organic matter and total nitrogen, made identification of significant changes in soil properties due to sludge application difficult. Again, all sludge treated plots were combined for test comparisons with pretreatment or control conditions (Table 20). The Mashel soil is inherently more acid, contains less organic matter, has lower average total N and cation exchange capacity than Everett soils.

SOIL pH

Sludge applications caused no significant changes in pH of the Mashel soil. A trend seems to indicate reduced pH in the L layer and increased pH (4.8 to 5.2) in the B horizon at 15 to 60 cm (6 to 24 in.) of depth; however, pre- and post treatment results broadly overlap.

SOIL ORGANIC MATTER

A nonsignificant trend to increased soil organic matter and organic matter of L layers exists. However, as previously noted, the very high natural variability of organic matter in the Mashel soils prevents establishment of significant differences from first year sludge treatments.

TOTAL NITROGEN

A trend to reducing total nitrogen in the L layers and increasing total nitrogen in soil horizons is suggested. Again, the highly variable results from pretreatment total N analyses preclude establishment of significant changes in total soil nitrogen of the Mashel soils.

CATION EXCHANGE CAPACITY

Statistically significant increases in cation exchange capacity were found in L (14.8 to 61.9 meq/100g O.D.) and A (6.9 to 23.1 meq/100g O.D.) soil layers following sludge treatments. Increases in soil organic matter may explain a portion of the increase in cation exchange capacity.

Table 20. SOIL CHEMICAL PROPERTIES FOLLOWING SLUDGE APPLICATIONS ON THE MASHEL SOIL SERIES

	Horizon	Pretreatment	Post Treatment
pH	L	4.9 ± 0.6	4.6 ± 0.4
	A	4.7 ± 0.9	4.7 ± 0.3
	B	4.8 ± 1.3	5.2 ± 0.5
Organic Matter (percent)	L	26.0 ± 27.9	35.0 ± 16.1
	A	3.4 ± 8.4	7.7 ± 4.3
	B	0.4 ± 1.2	1.8 ± 0.7
Total Nitrogen (percent)	L	0.49 ± 0.56	0.29 ± 0.12
	A	0.06 ± 0.04	0.14 ± 0.09
	B	0.03 ± 0.02	0.05 ± 0.01
Cation Exchange Capacity (meq/100g O.D. wt)	L	14.8 ± 8.8	61.9 ± 15.6*
	A	6.9 ± 3.5	23.1 ± 5.1*
	B	6.2 ± 6.3	9.3 ± 1.4
Carbon:Nitrogen (ratio)	L	31:1	70:1
	A	33:1	32:1
	B	8:1	21:1*

*Significant difference

CARBON-NITROGEN RATIO

An increase in organic matter content of the B horizon, without equivalent increases in total N, caused a significant increase in the carbon-nitrogen ratio (8:1 to 21:1). No significant change occurred in L or A layers. The highly variable organic matter content of L layers combined with equally variable amounts of total N make even the 70:1 post treatment value an insignificant difference.

MASHEL SOILS, EXCHANGEABLE CATIONS AND BASE SATURATION

Analyses of impacts of sludge applications on exchangeable soil chemistry and base saturation are summarized in Table 21. Applications of sludge have either stabilized the large natural variability in exchangeable calcium throughout the soil profile, or an improved random sample was obtained for post treatment. Highly variable pretreatment Ca analyses span the range of post treatment analyses. However, it appears that the large quantities of dissolved Ca in Metro sludge have increased exchangeable Ca throughout the soil. These cannot be claimed as significant increases at this time but a trend is indicated.

A significant increase in exchangeable Mg occurred in the L layer and B horizon. A trend to increased Mg also is indicated in the A horizon.

There are no apparent trends in exchangeable K resulting from sludge applications. A significant increase similar to Mg occurred with exchangeable Na, as increased Na occurred in the L layer with a definite trend to increase in the A horizon. Again, a smaller but significant increase occurred deeper in the soil profile of the B horizon. The large significant increase in exchangeable Na in the L layer (0.1 to 0.7 meq/100g O.D. soil) and trend to increased base nutrients in soil horizons suggest a substantial base nutrient leaching in the Mashel soils.

High variability in pretreatment base saturation analyses allows no conclusion as to impacts of sludge on the Mashel soil at this time.

Table 21. EXCHANGEABLE CATIONS AND PERCENT BASE SATURATION BY HORIZONS FOR PRE- AND POST SLUDGE APPLICATIONS FOR THE MASHEL SOIL

Horizon	Ca		Mg		K		Na		Base Saturation %	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Milli-equivalents per 100 g O.D. soil								(percent)	
L	4.9±22.3	13.7±2.6	0.2±0.6	2.6±1.2*	1.0±2.1	0.6±0.2	0.1±0.1	0.7±0.3*	35±35	28± 7
A	2.3±12.3	6.2±1.6	0.8±0.4	1.3±0.8	0.5±1.1	0.4±0.2	0.1±0.2	0.3±0.1	52±61	33±10
B	1.9± 9.0	3.0±0.3	0.9±0.3	1.5±0.2*	0.2±0.6	0.2±0.4	0.1±0.04	0.3±0.1*	35±20	50±64

*Significant difference

Section 22

WILKESON SOILS--SOIL SOLUTION NUTRIENTS

Similar analyses were made for interpretation of the impacts of reduced rates of sludge application on Wilkeson soils. These results are summarized in Tables 22, 23 and 24 which analyze nutrient loading and flux, pre- and post treatment soil chemistry, and analysis of exchangeable base cations.

Renovation of total nitrogen ranged from 69 to 89% (on plots 30 and 10, respectively; table 22). Losses of NH_4-N from the 30 series plots also are large (43 kg/ha; 38 lbs/ac.) on the Wilkeson soil. Losses of NO_3-N follow usual patterns (41 to 260 kg/ha; 37 to 232 lbs/ac.). However, a larger percentage (80 to 99%) of total -N loss is in the NO_3-N form.

Usual patterns with phosphorus compounds retention prevail with insignificant leaching or flux. Base nutrients--calcium, magnesium, sodium and potassium--also exhibit usual patterns with leaching losses varying from 6% (sodium, 44 kg/ha; 39 lbs/ac.) to less than 1% (17 kg/ha; 15 lbs/ac.) of magnesium. In general, the patterns of renovation for the three soil series tested are very similar. Maximum total flux of base nutrients (548 kg/ha; 489 lbs/ac.) was associated with maximum sludge applications (40 plots).

WILKESON SOILS--SOIL PROPERTIES

The pre- and post treatment analyses of soil chemical properties are summarized in Table 23.

Soil pH

The Wilkeson soil is naturally significantly more acid (pH 3.6 to 4.5) than either the Everett (pH 5.3 to 5.8) or the Mashel (pH 4.7 to 4.9). Sludge treatments induced a significant increase in pH on the Wilkeson soil (pH 3.6 to 5.6) in the L layers and surface soil horizons (pH 3.5 to 5.0). A trend to increasing pH is also indicated at greater depth than the soil profile.

Soil Organic Matter

A marked trend to increased organic matter of L layers also occurred on the Wilkeson soil (23.3 to 44.8%). A trend to increase soil organic matter appears in the A horizon but is insignificant.

Table 22. NUTRIENT LOADING AND FLUX (kg/ha) THROUGH THE WILKESON SOIL AND PERCENT RENOVATION

Plots	Total Tons Applied		Total -N	NH_4-N	NO_3-N	Total -P	PO_4-P	Ca	Mg	Na	K
10	4.8	Applied	240	134	19	135	127	3,960	825	765	435
		Flux	44	3	41	T	T	78	15	44	15
		% Ren.	89	97	-	99+	99+	98	98	94	97
20	9.9	Applied	499	279	40	280	268	8,236	1,701	1,591	904
		Flux	55	1	54	T	T	84	17	32	27
		% Ren.	89	99+	-	99+	99+	99	99+	98	97
30	14.1	Applied	699	391	57	393	376	11,536	2,889	2,228	1,290
		Flux	216	43	173	T	1	222	39	51	42
		% Ren.	69	89	-	99+	99+	98	99	98	97
40	18.6	Applied	920	514	75	517	488	15,180	3,162	2,932	1,667
		Flux	285	25	260	1	1	311	66	72	99
		% Ren.	70	95	-	99+	99+	98	98	98	94

Table 23. SOIL CHEMICAL PROPERTIES FOLLOWING SLUDGE APPLICATIONS ON THE WILKESON SOIL SERIES AND 95% CONFIDENCE INTERVAL

	Horizon	Pretreatment	Post Treatment
pH	L	3.6 ± 0.5	5.6 ± 0.6*
	A	3.5 ± 0.4	5.0 ± 0.6*
	B	4.5 ± 0.7	5.0 ± 0.2
Organic Matter (percent)	L	23.3 ± 16.7	44.8 ± 8.2
	A	13.6 ± 4.9	15.4 ± 6.1
	B	1.3 ± 0.7	1.7 ± 0.4
Total Nitrogen (percent)	L	0.36 ± 0.06	0.38 ± 0.04
	A	0.12 ± 0.08	0.20 ± 0.06
	B	0.05 ± 0.02	0.04 ± 0.01
Cation Exchange Capacity (meq/100g O.D. wt)	L	20.3 ± 14.6	77.4 ± 10.3*
	A	13.4 ± 6.3	36.9 ± 12.8*
	B	3.8 ± 4.1	12.6 ± 0.3*
Carbon:Nitrogen (ratio)	L	38:1	68:1*
	A	66:1	45:1*
	B	15:1	20:1

*Significant difference

Soil Nitrogen

Trends to increases in soil organic matter on the Wilkeson soil following sludge treatment suggests a quantitative increase in total nitrogen. A significant increase in the concentration of total nitrogen was not found. A trend to increasing total soil nitrogen in the A horizon is indicated (0.12% pretreatment to 0.20% post treatment). An increase in concentration of this magnitude in the soils would yield a significant quantitative increase in total nitrogen per hectare following sludge treatments.

Cation Exchange Capacity

Very significant increases in cation exchange capacity in all horizons resulted from sludge treatments on the Wilkeson soil. L layers increased from 20.3 to 77.4 meq/100g O.D. soil. Surface soil horizons (A) increased from 13.4 to 36.9 meq/100g O.D. soil. At greater soil depths, exchange capacity also increased significantly averaging 12.6 meq/100g O.D. soil.

Carbon-Nitrogen Ratio

The carbon-nitrogen ratio of L layers significantly increased with applications of sludge. Large increases in organic matter content of the L layer, without an equivalent increase in total nitrogen, resulted in a marked increase in the quantity of carbon (38:1 to 68:1). In contrast, soil A horizons significantly decreased in carbon-nitrogen ratio, caused by a marked increase in total N in the A horizons without an equivalent increase in the percentage of organic carbon (change was 66:1 to 45:1). No significant change occurred in the carbon-nitrogen ratio of the B horizon.

WILKESON SOILS, EXCHANGEABLE CATIONS AND BASE SATURATION

The large quantity of dissolved calcium in Metro sludge again causes a significant increase in exchangeable calcium in the L layers of the Wilkeson soil (7.1 to 24.2 meq 100/g O.D. soil; Table 24). Average increases occur in both A horizons and deeper soil horizons but are not significant. General increases also occur in exchangeable magnesium throughout the soil layers but are not of sufficient magnitude to be statistically significant. Potassium results are more variable in the surface soil but also tend to be increasing.

Sufficient amounts of sodium have been applied in sludge and have leached through soil profiles to add a significant amount to the cation exchangeable complex. In the L layers, exchangeable sodium has increased from 0.01 to 0.9 meq/100g O.D. soil. A horizons have increased from 0.1 to 0.5 meq/100g O.D. soil. The quantities of sodium leaching to greater depths have also been sufficient to provide a significant increase in exchangeable sodium in the 15 to 60 cm (6 to 24 in.) soil layers (0.1 to 0.3 meq/100g O.D. soil). Impacts of sludge application on the percentage of base saturation are variable and inconclusive at this time.

Table 24. EXCHANGEABLE CATIONS AND PERCENT BASE SATURATION BY HORIZONS OF THE WILKESON SOIL

	Ga		Mg		K		Na		Base Saturation %	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Milli-equivalents per 100 g O.D. soil									
L	7.1±6.1	24.2±5.0*	1.6±0.9	4.0±1.0*	0.5±0.6	1.2±0.1	0.01±0.1	0.9±0.2*	45± 3	39± 5
A	6.5±3.5	12.9±6.6	1.7±1.0	2.1±0.7	0.9±0.2	0.9±0.3	0.1 ±0.1	0.5±0.2*	65±14	48±18
B	1.7±3.2	4.7±0.9	0.9±0.9	1.9±0.3	0.1±0.1	0.6±0.1*	0.1 ±0.1	0.3±0.2*	31±33	60± 6

*Significant difference

Section 23

MASHEL AND WILKESON SOILS, SOIL SOLUTION NUTRIENT CONCENTRATION

Concentrations of nutrients in the soil solution of Mashel and Wilkeson soils expressed as mg/l are summarized in Table 25. Minimum values for total N are higher than those reported for the Everett soil; however, maximum concentration of total N tends to be less. The flux of total N is again dominated by NO_3-N losses. Concentrations of total N and NO_3-N are not significantly different in the two soils. Minimum values for retention of Ca are lower in the Mashel than the Wilkeson. Maximum values are also higher for the Wilkeson soil. In general, the Wilkeson appears to have an increased capacity to retain cations (Tables 21 and 24), even though all base nutrients in the soil solution have generally increased minimum values when compared to the Mashel soils. The significant increase in a cation exchange capacity (Table 23) is not yet reflecting in increased quantities of cations retained in the Wilkeson soil. There is little difference in the two soils in maximum concentrations for Mg and Na; however, maximum and minimum concentrations of K are significantly greater for all treatments in the Wilkeson soil.

Table 25. RANGE IN NUTRIENT CONCENTRATIONS OF THE SOIL SOLUTION BY PLOTS FOR THE MASHEL AND WILKESON SOILS

Soils & Plot	Total -N	NO_3-N	Ca	Mg	Na	K
			(milligrams per liter)			
Mashel						
10	7 - 55	7 - 54	10 - 52	4 - 18	5 - 19	1 - 5
20	11 - 55	11 - 54	9 - 58	3 - 19	8 - 31	1 - 8
30	5 - 124	4 - 124	10 - 146	5 - 34	9 - 27	4 - 15
40	5 - 127	3 - 126	7 - 71	3 - 10	8 - 16	1 - 16
Wilkeson						
10	6 - 73	6 - 73	23 - 93	6 - 16	17 - 29	4 - 18
20	6 - 52	6 - 52	15 - 74	4 - 13	9 - 18	7 - 23
30	31 - 82	30 - 82	34 - 105	8 - 18	14 - 23	13 - 20
40	9 - 128	8 - 128	18 - 158	6 - 31	12 - 27	16 - 39

Section 24

EVERETT SOIL, TOTAL ORGANIC CARBON

Study of total organic carbon (TOC) leaching by the soil solution was limited to plots on the Everett soils. Analyses of TOC are presented in three phases: First, the migration of TOC in soil solution through the soil profile, where organic constituents are not identified--only quantitatively related to depths in the soil profile.

A second phase of analysis identifies the molecular size fractions leached by the use of gel filtration chromatography. Identification of sizes allows evaluation of physical filtering by the soil matrix and preliminary indications of rate of leaching by molecular size.

The final analysis identifies specific organic compounds identifying their source. TOC analyses are confined to organic matter of colloidal size or smaller. Soil solution samples collected from L, A, B and C horizons of control, water only, and various sludge plots are analyzed for TOC to provide an overview of effects of treatment on amounts of organics leaching through forest soils.

TOTAL ORGANIC CARBON LEACHING

Leaching of TOC through soil profiles may be best summarized in a series of figures showing quantitative amounts of TOC with depth (Fig. 11). The water only and control plots are compared with the 100, 200 and 300 plot sludge treatments. A very significant increase in the quantity and depth of leaching of TOC occurs with sludge applications. Maximum transport of TOC through the soil profile occurred with the 200 series plots. A size fraction is apparently transported to the C horizon in the 200 series plots, as both the 100 and 300 series plots show a continuous decline in the quantity of TOC through the C horizon.

The control and water only plots have much lower quantities of TOC throughout the soil profile. Water applications have increased TOC in both the A and B horizons.

Leaching of TOC in the 100W, 200W and 300W plots significantly departed the patterns established with sludge only plot (Fig.12). Generally, reduced amounts of TOC occur in the litter layers, with even greater reduction in the soil A and B horizons. Large increases are generally identified in the C horizons with a maximum in the 300W (70 mg/1) which is nearly equivalent to the accumulation noted on the 200 plot (Fig. 11).

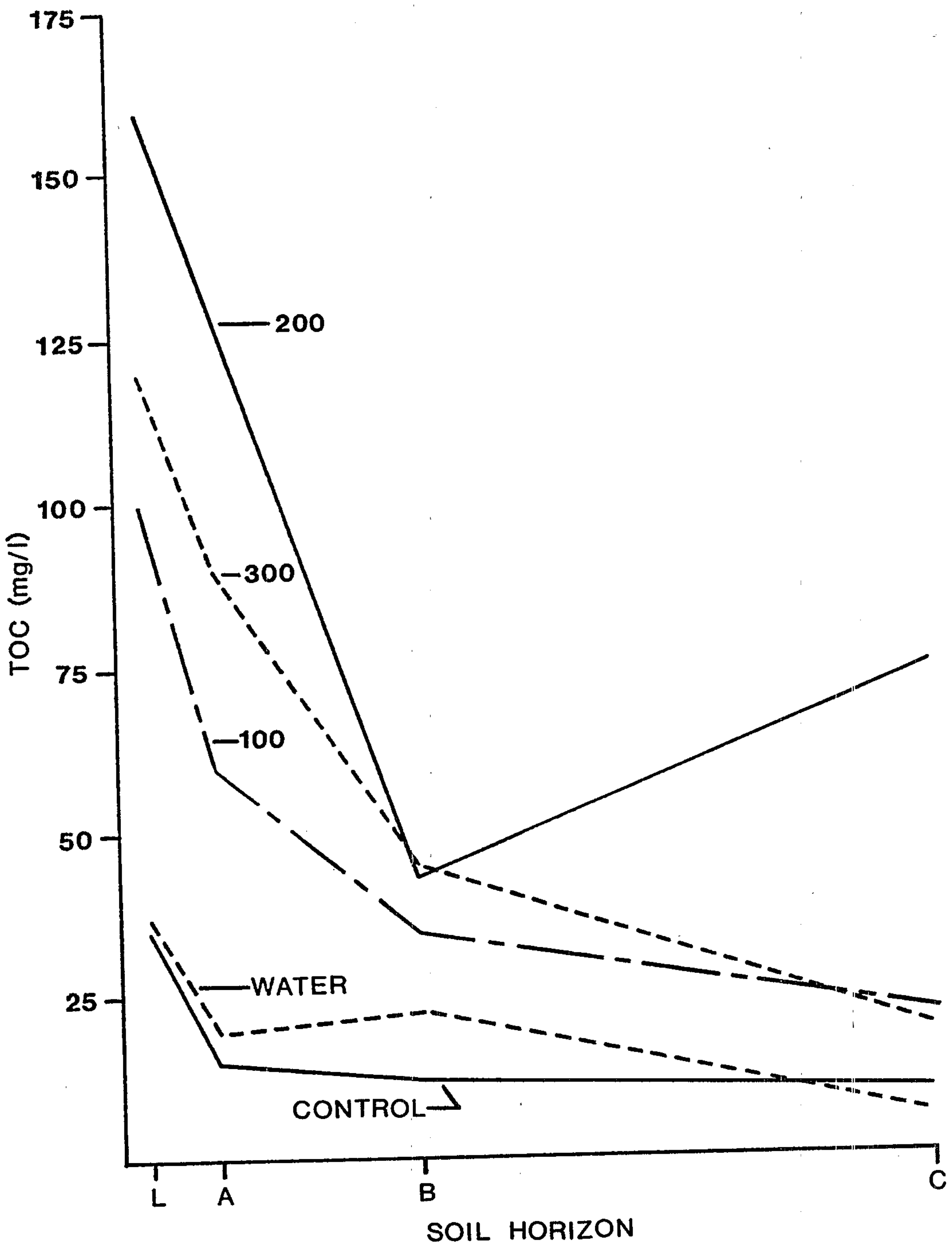

Figure 11. Average TOC values versus depth for water, control, and sludge treatments.

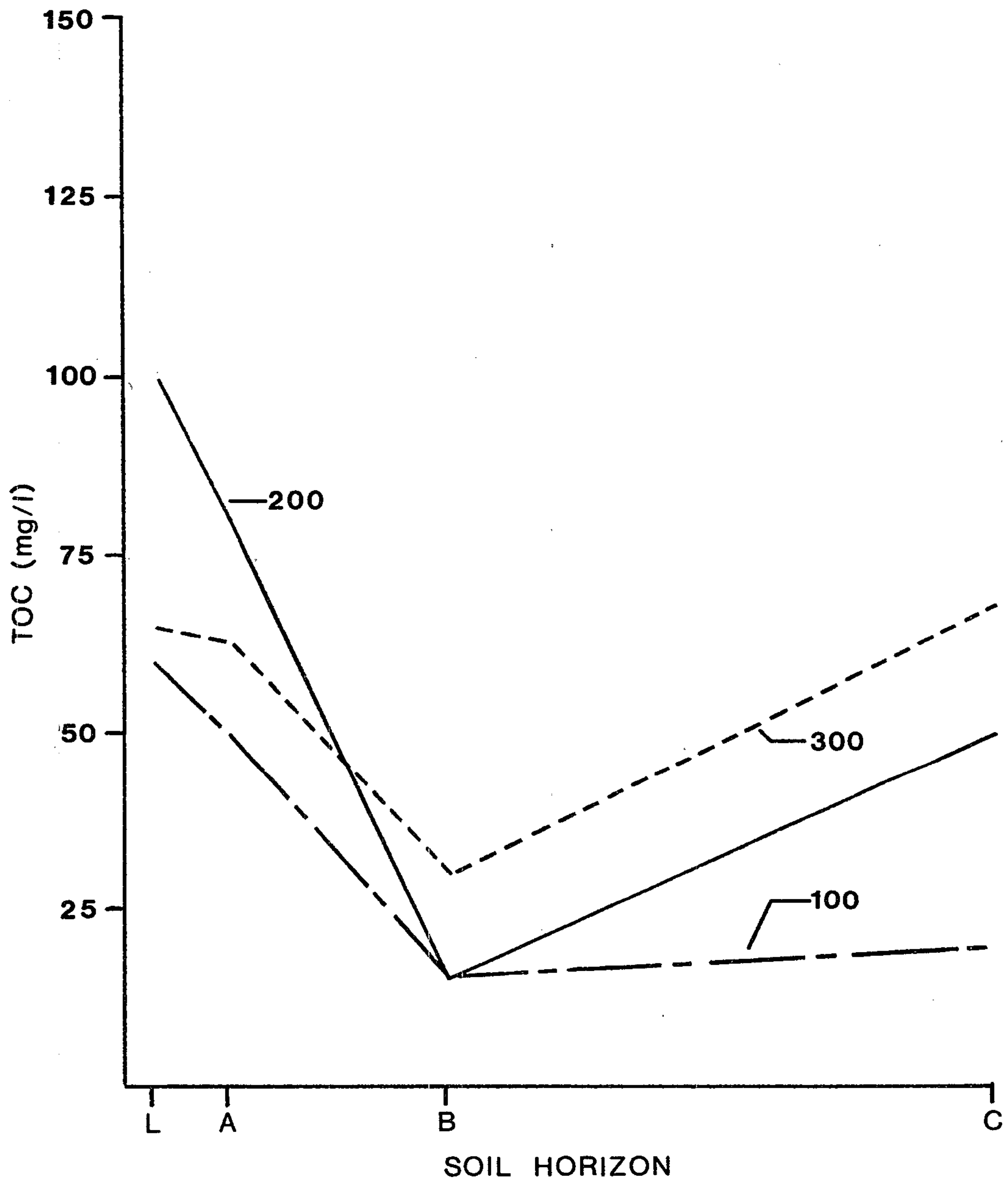

Figure 12. Average TOC versus soil depth for the sludge followed by water sites.

An example of changes in TOC over time with maximum sludge applications (300 series plot) is shown in Figure 13. Sampling is identified for the L, A, B and C horizons. Very significant reductions in TOC in the L layers occur with continued applications of sludge (250 mg/l pretreatment to 20 to 40 mg/l after 20 months of sludge applications).

Soil A and B horizons exhibit a similar early pattern of reduction in TOC declining from 165 mg/l in the A and 135 mg/l in the B to less than 30 mg/l in 20 months. Soil B horizons exhibit a somewhat inconsistent pattern of accumulation and depletion seasonally, while C horizons show irregular variations over time.

In general, the summer season has increased TOC with rapid decline in the winter and increases in the following summers. Patterns of movement were not consistent within the soil profile for equivalent times.

Gel Filtration Chromatography

Preliminary examination of the chemical nature of organic materials responsible for TOC values in the soil solution was done by fractionating the organic material according to molecular size using gel filtration chromatography. Detection by UV spectrometry at 254 mm identifies aromatic and other unsaturated structures.

Gel filtration chromatograms of the soil solution from several soil horizons in the control plot and sludge plots are compared in Figure 14. Litter samples from the control plot show a large quantity of higher molecular weight organic molecules (early peak on left), which is missing from the sludge plots (increased late peaks). The C horizon sample from the sludge plot contains a larger amount of low molecular weight organic materials.

Chromatograms for 1977 soil solutions are shown in Figure 15. The C horizon of the 300 series plot shows two large peaks which are not very evident in the C layer of the 10 series plots. These peaks tend to coincide with natural organic material in the L layer, indicating that sludge applications over time leach organic material in the soil solution to greater depths in the soil profile. The slight peaks in the well water coincide. These peaks were also identified in soil solution samples from the control plots (Figure 14, control C), indicating they are not organic contaminants from sludge application--only natural organic compounds leaching to ground water.

IDENTIFICATION OF SPECIFIC ORGANICS

Soil solutions from B and C horizons of 300 series sludge plots were composited, freeze dried, extracted with diethylether, methylated with diazomethane and analyzed by gas chromatography on a diethylene glycol succinate (DEGS) column. Organics could not be identified, other than phthalate esters--a common contaminant in this system and in trace work in general. An alternative method examined organics concentrated on soil particles. Soil samples were collected by horizons, extracted with moist ether and processed

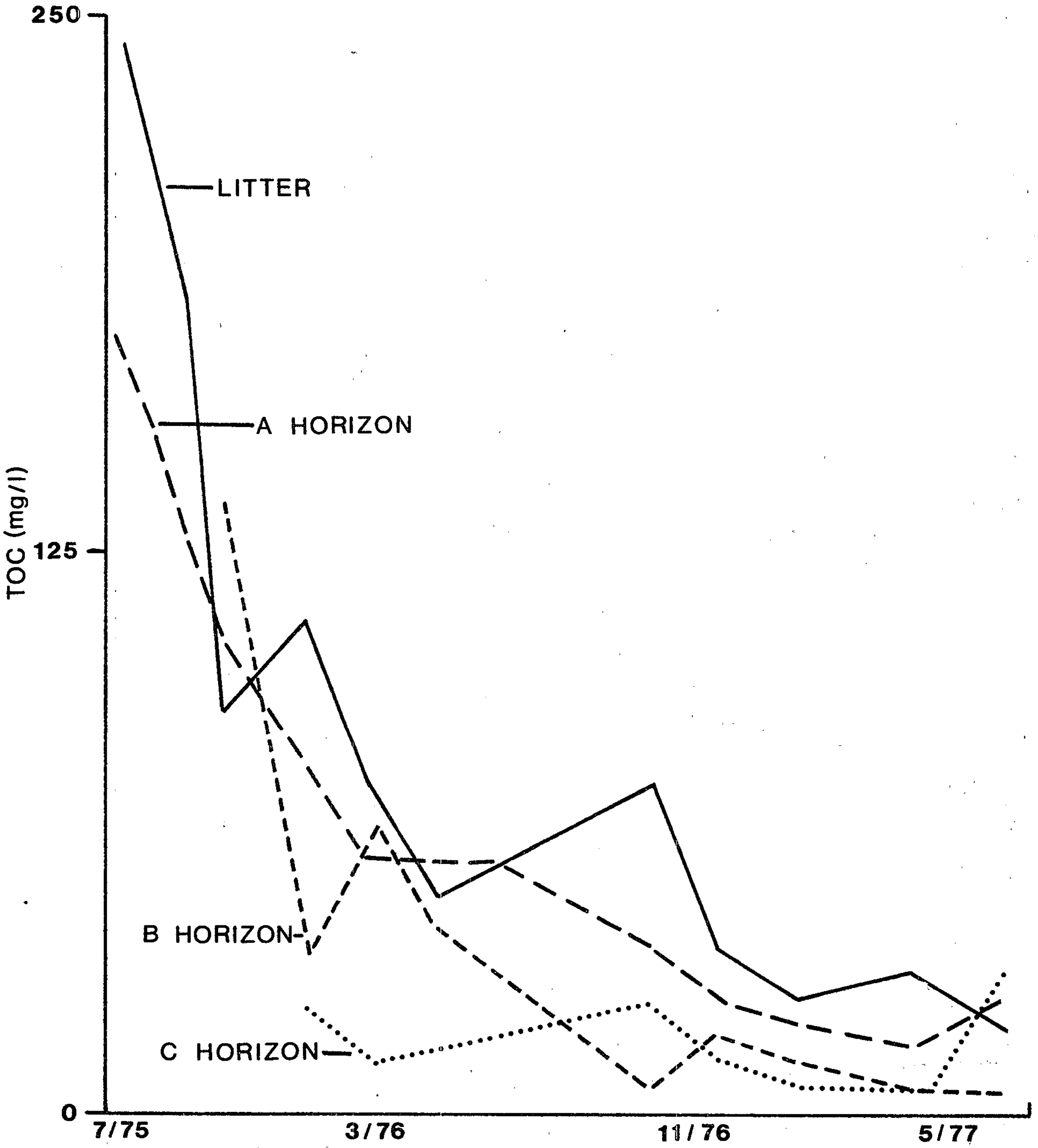

Figure 13. TOC versus date of sample collection for the 300 plot from the four soil depths.

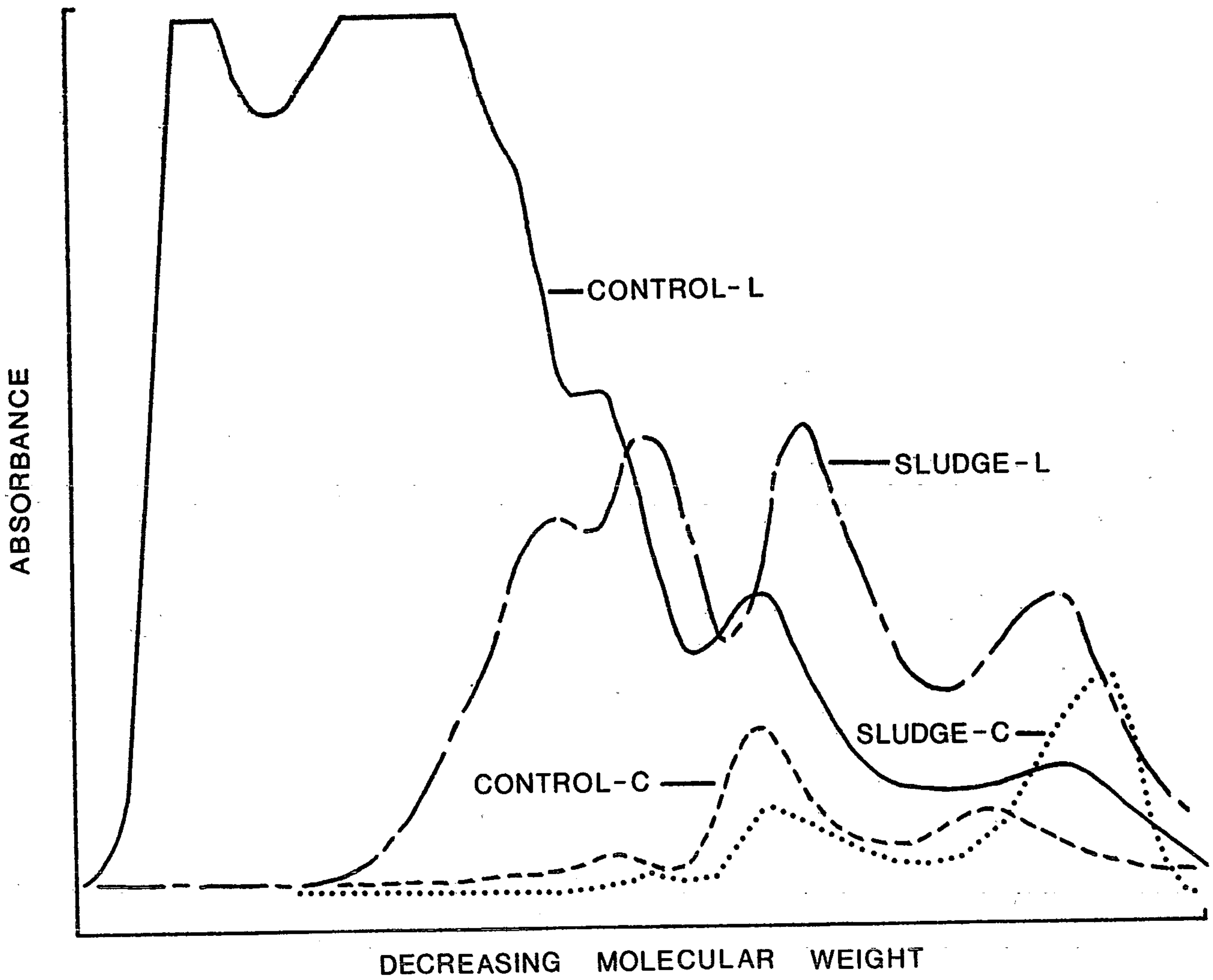

Figure 14. L layer and C horizon soil solutions from sludge control plots compared by gel filtration chromatography.

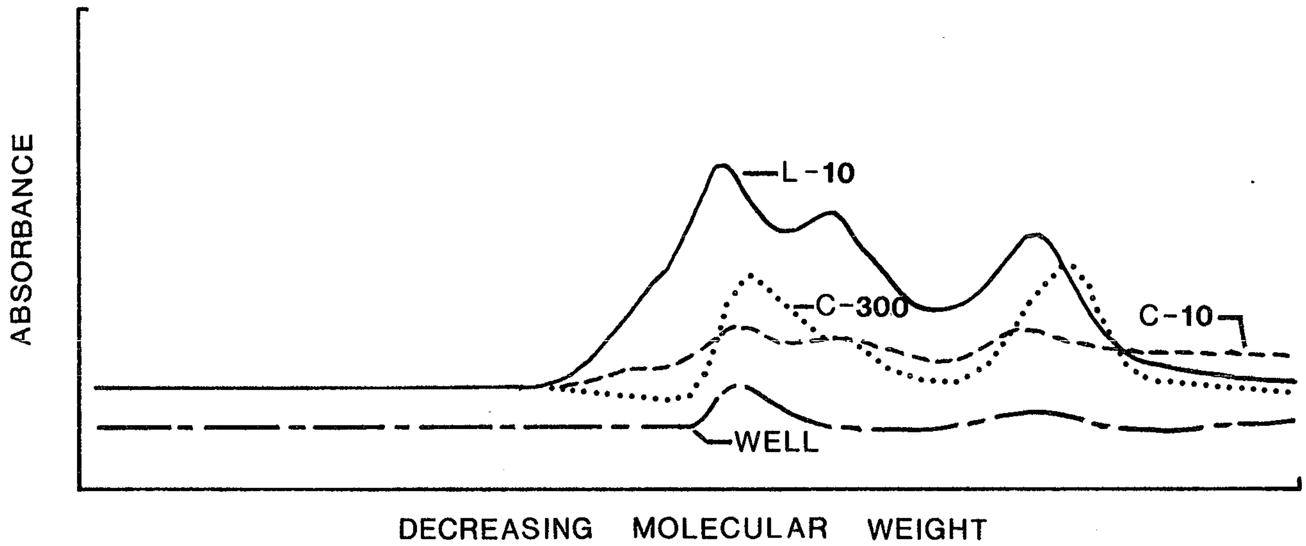

Figure 15. Gel filtration chromatograms of soil solution samples from L and C layers of 10 series plots, C horizon of 300 plot and well water.

by gas chromatography. The A horizon chromatograms from the 300 series sludge plot and control show very similar patterns (Fig. 16). After three years of sludge application, there are no major organic inputs from sludge detectable by gas chromatography.

In a similar manner, B horizon chromatograms are nearly identical except for an increase in compounds labeled H, I, and J in the 300 series sludge plots. A compound labeled X (Fig. 17) is present in small quantities on the sludge plot and not shown in the control plot. A further check on the organic constituents in control and sludge treated plots was tested by gas chromatography using ether extraction and a DEXSIL 300 column. This sampling compared gas chromatograms of ether extracts of the B horizon of the 100 series sludge plots with a similar extract from the B horizon from the control plot (Figs. 18 and 19).

Chromatograms show sludge and control plots qualitatively contain the same organic compounds, again indicating little or no movement of ether extractable organics from sludge through the soil profile.

Mass spectral analysis of the gas chromatograph effluents allowed the following identification to be made:

Peak	Molecular Weight	Identify
A	---	Unknown
B	256	Pentadecanoic acid methyl ester
C	270	Palmitic acid methyl ester
D	---	Unknown
E	---	Unknown
F	316	Isopimaric acid methyl ester
G	314	Dehydroabietic acid methyl ester
H	354	Diacosanoic acid methyl ester
I	368	Triacosanoic acid methyl ester
J	382	Lignoceric acid methyl ester

Fatty acids B, C, H, I and J have been reported previously as organic materials found in peat and various soils (Braids and Miller, 1975).

This is the first identification of isopimaric and dehydroabietic acids in forest soils; however, these organics are common oleoresins and undoubtedly form from foliage and litter decomposition.

The identified compounds are all either natural products (isopimaric, etc.) or have been previously reported in soil; therefore, the sludge applications introduce no major new organic compounds to the system.

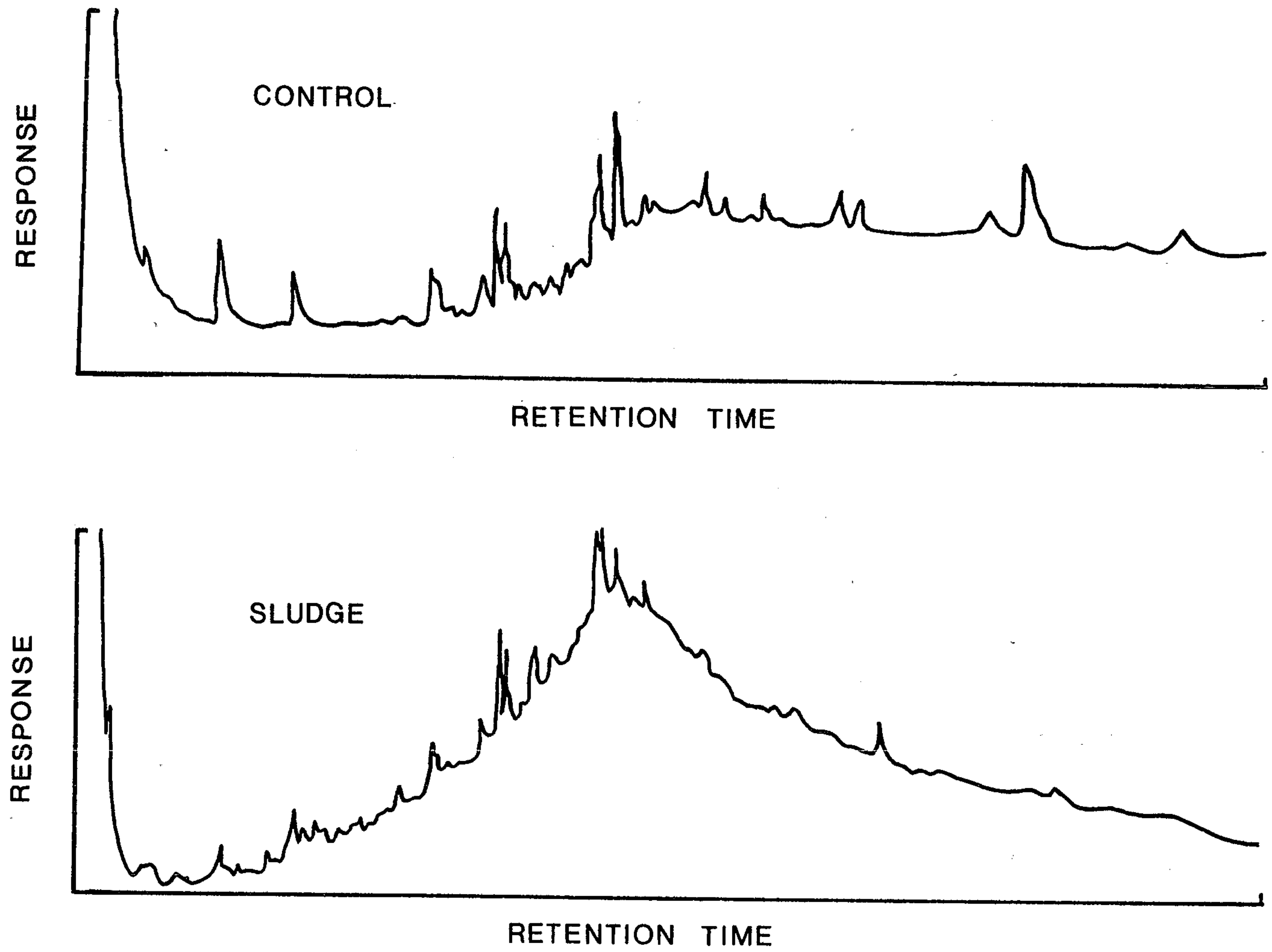

Figure 16. Gas chromatogram of ether extract of soil from 300 and control plot A horizon using a DEGS column.

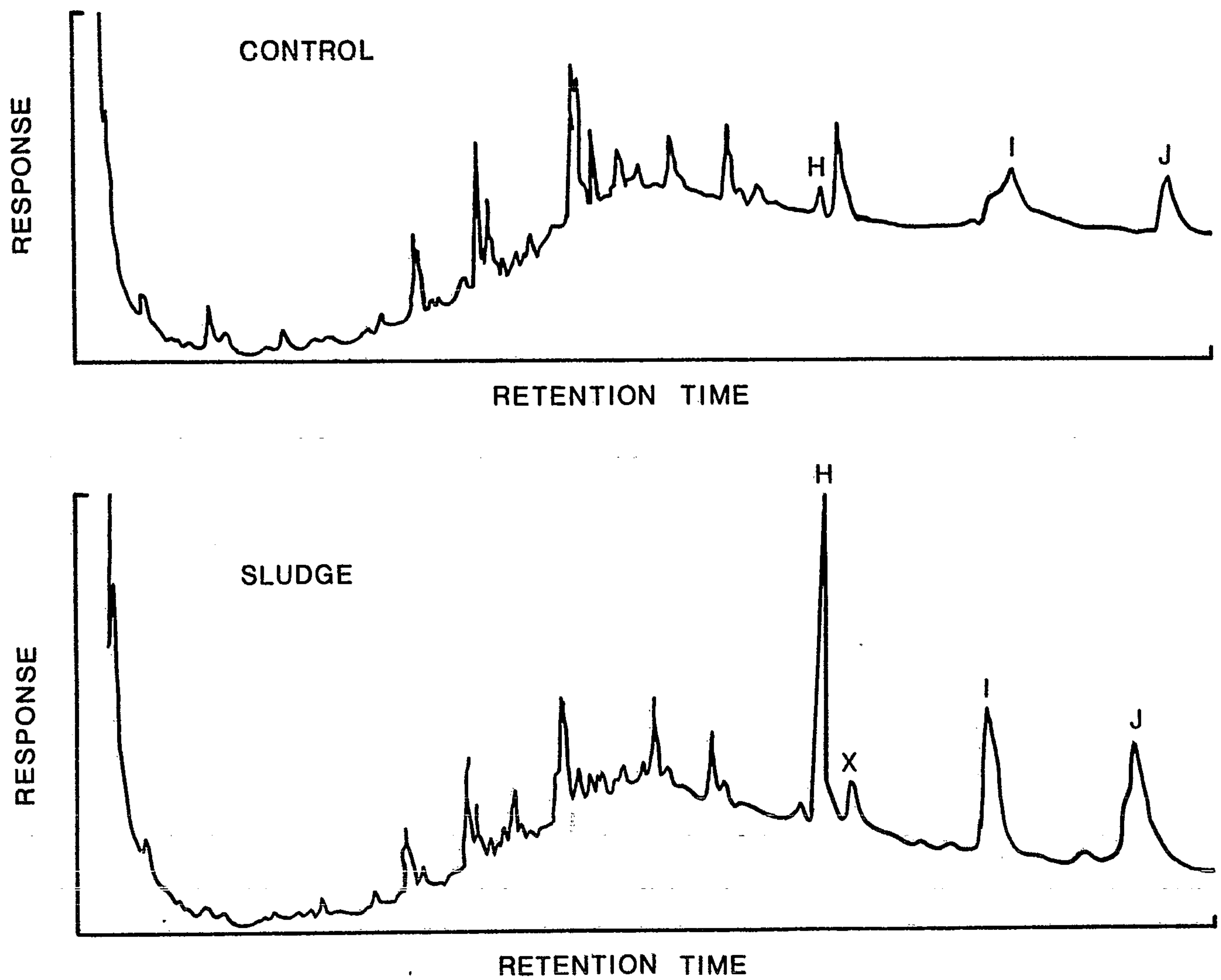

Figure 17. Gas chromatogram of ether extract of soil from 300 and control plot B horizon using a DEGS column.

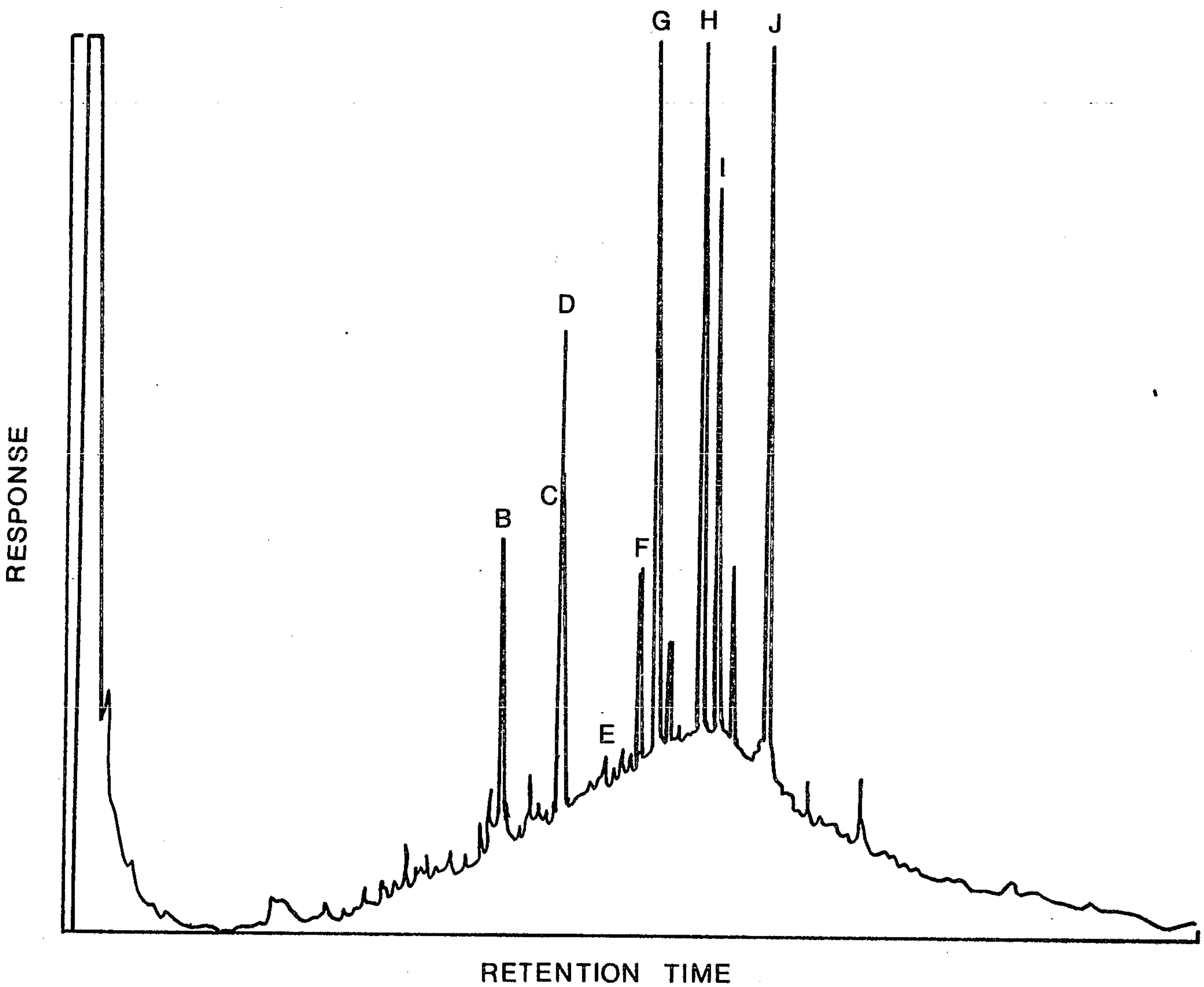

Figure 18. Gas chromatogram of ether extract of 100 B horizon using a DEXSIL 300 column.

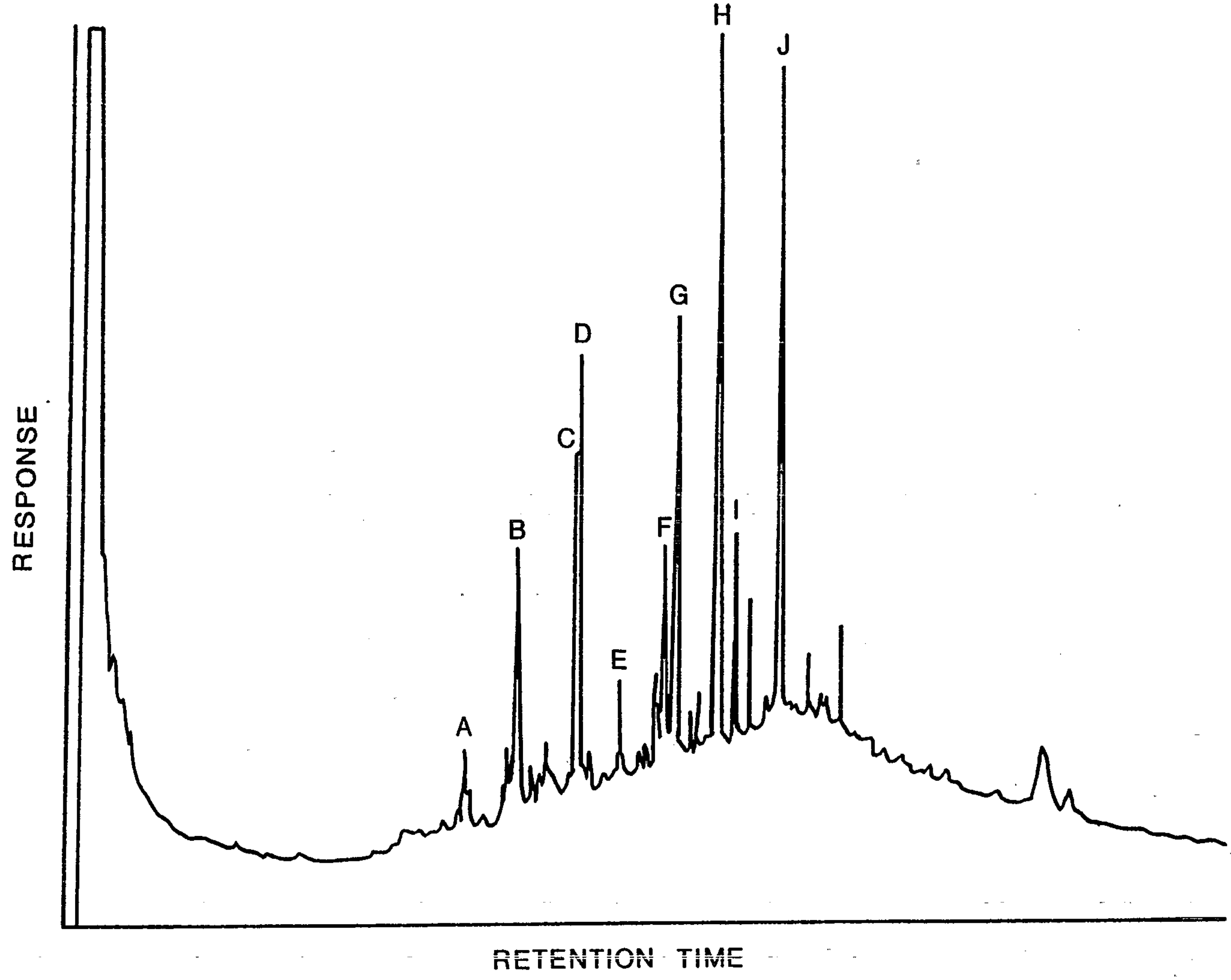

Figure 19. Gas chromatogram of ether extract of the control plot B horizon using a DEXSIL 300 column.

Section 25

EVERETT SOIL, BIOLOGICAL DECOMPOSITION

Sludge applications in the forest environment potentially may alter rates of biological decomposition of naturally occurring plant residues, lignin and cellulose materials. Study of impacts of sludge applications on biological decomposition rates investigated soda solubility and weight loss of wood blocks. Results of decomposition studies are summarized by type of analyses with trends over time in the following sections.

SODA SOLUBILITY

Soda solubility is defined by the weight loss of decaying cellulose as extracted by a 1% sodium hydroxide solution (1% NaOH). Changes in soda solubility as examined by this extraction and tested against standard samples must be interpreted. As standard wood block samples are used as a base and extracted weight subtracted from the test samples, a gain in weight shows as a negative or decrease in relative soda solubility. A loss in weight shows up as a plus or increase in soda solubility. Increases in soda solubility represent increasing decomposition, as summarized in Figure 20 and Table 26.

Decomposition on Litter Surface

All sludge treated plots decreased (13 to 24%) rapidly in relative soda solubility in the first 30 days (Sept. to Oct., 1975) of exposure (Fig. 20, Table 26). Declines (1.9 to 2.5%) in soda solubility were generally maintained in all treated plots until May 1976. An exception to this general trend is the 100 series plots where there was an increase (12.6 to 13.7%) in soda solubility which occurred between October and February. This increase was followed by a slight decline (1.2%) between February and May.

The control sample did not differ significantly in soda solubility from the standard between October and May.

Decomposition in all plots increased significantly between May and July. Soda solubility increased 3% for the control plots; 2.8%, 1.6% and 3.8% for the 100, 300 and 300W plots, respectively.

Resampling a year later in July 1977 again showed significant increases in decomposition as indexed by increased soda solubility. Different rates of sludge application did not significantly alter decomposition rates on the surface of the litter layers for the wood blocks. Soda soluble weight increases were 5.3%, 7.6%, 7.9% and 6.9% for the control, 100, 300 and 300W plots, respectively.

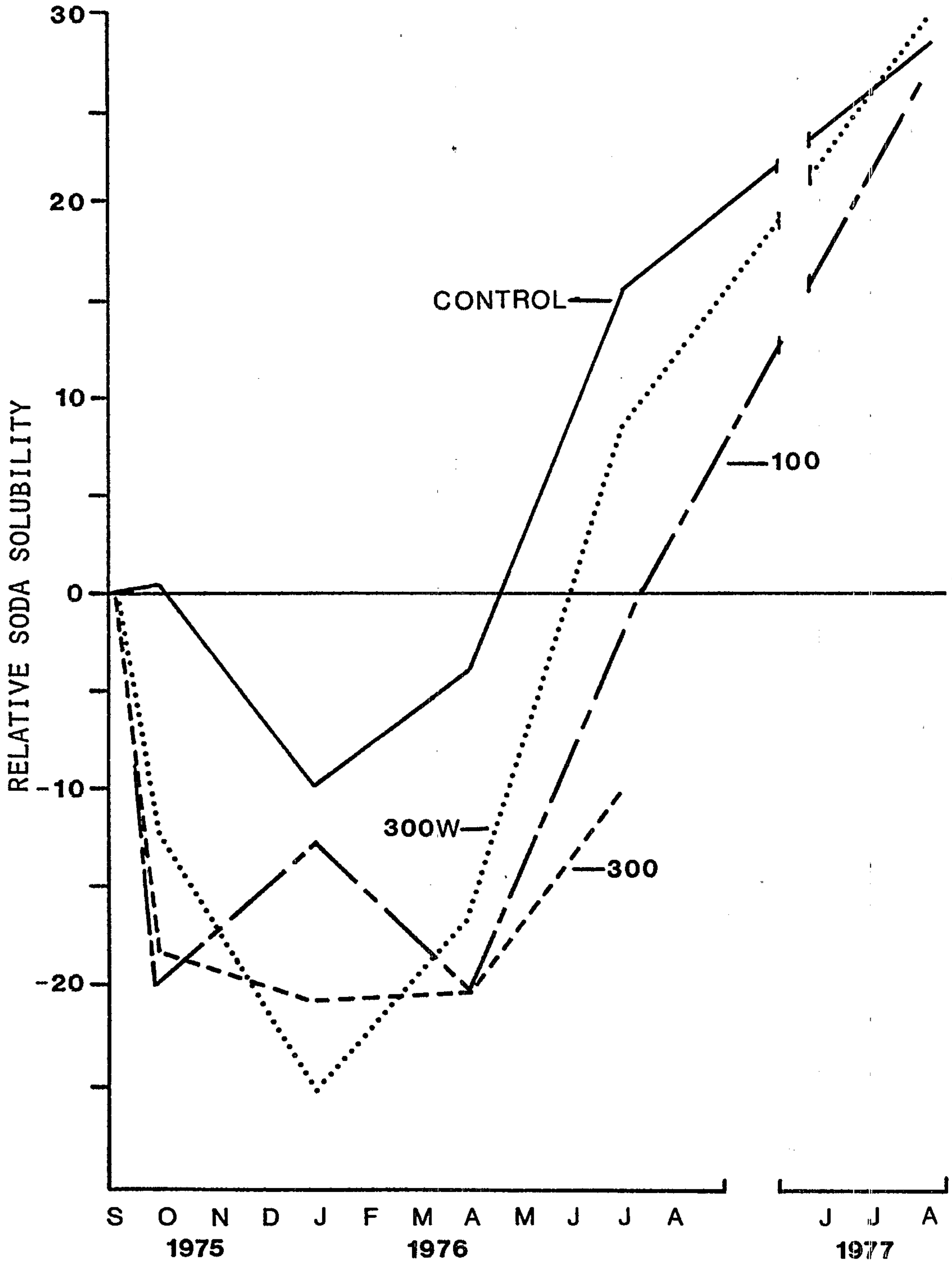

Figure 20. Changes in 1% NaOH solubility of wood blocks on top of the litter over time by sludge treatments.

Table 26. DECOMPOSITION OVER TIME ASSESSED BY SODA SOLUBILITY EXTRACTIONS (PERCENTAGE OF DRY WEIGHT) OF WOOD BLOCKS BY VARIOUS DEPTHS AND TREATMENTS[1/]

Plots and Horizons	Sampling Dates				
	Oct. '75	Feb.	May	July '76	July '77
Control Plot					
L	15.7±0.9	14.1±0.5	15.0±0.2	18.0±0.5	23.3±1.7
A	14.6±1.4	15.5±0.2	13.2±0.3	14.9±0.2	22.3±0.4
B	15.3±0.8	16.1±0.5	15.4±0.1	14.3±0.2	--- [3/]
100 Plots					
L	12.6±0.7	13.7±0.2	12.5±0.5	15.3±0.0	22.9±0.3
A	12.1±0.7	13.1±0.5	12.1±0.2	15.5±0.1	22.7±0.0
B	12.6±0.3	14.4±0.3	14.0±0.1	16.9±0.2	---
300 Plots					
L	12.8±0.6	12.4±0.4	12.5±0.3	14.1±0.2	22.0[2/]
A	12.3±0.3	11.1±0.3	12.5±0.0	14.9±0.2	24.0±0.2
B	13.5±0.3	11.8±0.1	12.5±0.7	15.5±0.0	---
300W Plots					
L	13.7±0.0	11.7±0.2	13.1±0.3	16.9±0.4	23.8±1.3
A	13.6±0.2	11.7±0.2	13.1±0.5	16.6±0.0	23.0[2/]
B	15.3±0.5	14.4±0.0	13.5±0.2	17.0±0.0	---

1/ Standard sample solubility 15.6±0.3% (September 1975)

2/ Estimated from A or B horizon samples

3/ Samples lost from B horizons for last sampling date.

Decomposition in A Horizons

Patterns of soda solubilities in A horizons were similar for all sludge treated plots. Decline in soda solubility (interpreted as a resistance to decomposition) occurred for all sludge treatments between September 1975, when the experiment was initiated, and the following May (1976).

Wood blocks in the control plot showed increased (0.9%) soda solubility in soil A horizons between October and February, with a decline (2.3%) between February and May. The control and all sludge treated plots showed significant increases in decomposition between May and July. Increases were: control, 1.7%; 100 plots, 3.4%; 300 plots, 2.4%; and 300W plots, 3.5%.

Sampling in July 1977 again revealed marked increases in decomposition. Increased decomposition did not vary significantly between plots and was equivalent to decomposition at the surface of the litter layer. Values were: control, 7.4%; 100 plots, 7.2%; and 300 plots, 9.1%.

Decomposition in B Horizons

In general, patterns of decomposition in the soil B horizons were very similar to the litter surface and A horizons. Only the 300W plot showed no significant decline in soda solubility in the first month of exposure. Between October and May, both the 300 and 300W plots showed a decline (13.5 to 12.5% and 15.3 to 13.5%) in soda solubility.

The 100 plots declined 3% in the first month of exposure (Sept. through Oct.). A significant increase in soda solubility occurred between October and February; however, no significant change took place between February and May. Patterns of increased soda solubility for treatment plots were very similar in A and B soil horizons. Soda solubility increased 2.9%, 100 plots; 3.0%, 300 plots; and 3.5%, 300W plots from May to July 1976.

The control plot showed a decline (15.4 to 14.3%) in soda solubility between May and July.

WEIGHT LOSS DECOMPOSITION

Assessment of decomposition by comparison of net weight loss with standard wood block samples provides another index of impacts of sludge applications on forest decomposition rates. In general, the control and 100 plots responded in a very similar fashion if weight loss is a guide to rates of decomposition. The 300 and 300W plots also responded in a very similar fashion; however, the response of the two sets of plots was significantly different. Results of weight losses over time are summarized in Table 27 and shown graphically for the litter surface in Figure 21.

Decomposition on Litter Surface

The first 30 days of exposure resulted in a weight loss of 4.6% and 3.4% for the control and 100 plots (Table 27). In the September through October

Table 27. DECOMPOSITION OVER TIME ASSESSED BY WEIGHT LOSS (PERCENT OF THE DRY WEIGHT) OF WOOD BLOCKS BY DEPTHS AND TREATMENTS

Plots and Horizons	Sampling Date				
	Oct. '75	Feb.	May	July '76	July '77
	(percent net weight loss)				
Control Plot					
L	4.6	7.5	2.7	15.3	29.7
A	3.8	7.9	2.7	17.9	25.2
B	5.5	9.6	3.8	16.3	--[3]
100 Plots					
L	3.4	6.7	1.8	14.3	22.7
A	4.7	7.2	3.0	16.1	22.9
B	3.5	10.6	5.1	17.5	--
300 Plots					
L	+0.1[1]	2.3	0.02	9.3	16.0[2]
A	0.4	2.0	+0.5[1]	11.6	23.0
B	1.3	3.1	0.8	11.3	--
300W Plots					
L	0.9	2.6	0.3	11.4	18.9
A	1.4	3.0	0.7	12.6	22.0[2]
B	3.3	6.5	3.8	13.8	--

1/Weight gain noticed

2/Estimated from A or B horizon samples

3/Samples lost from B horizons for last sampling date.

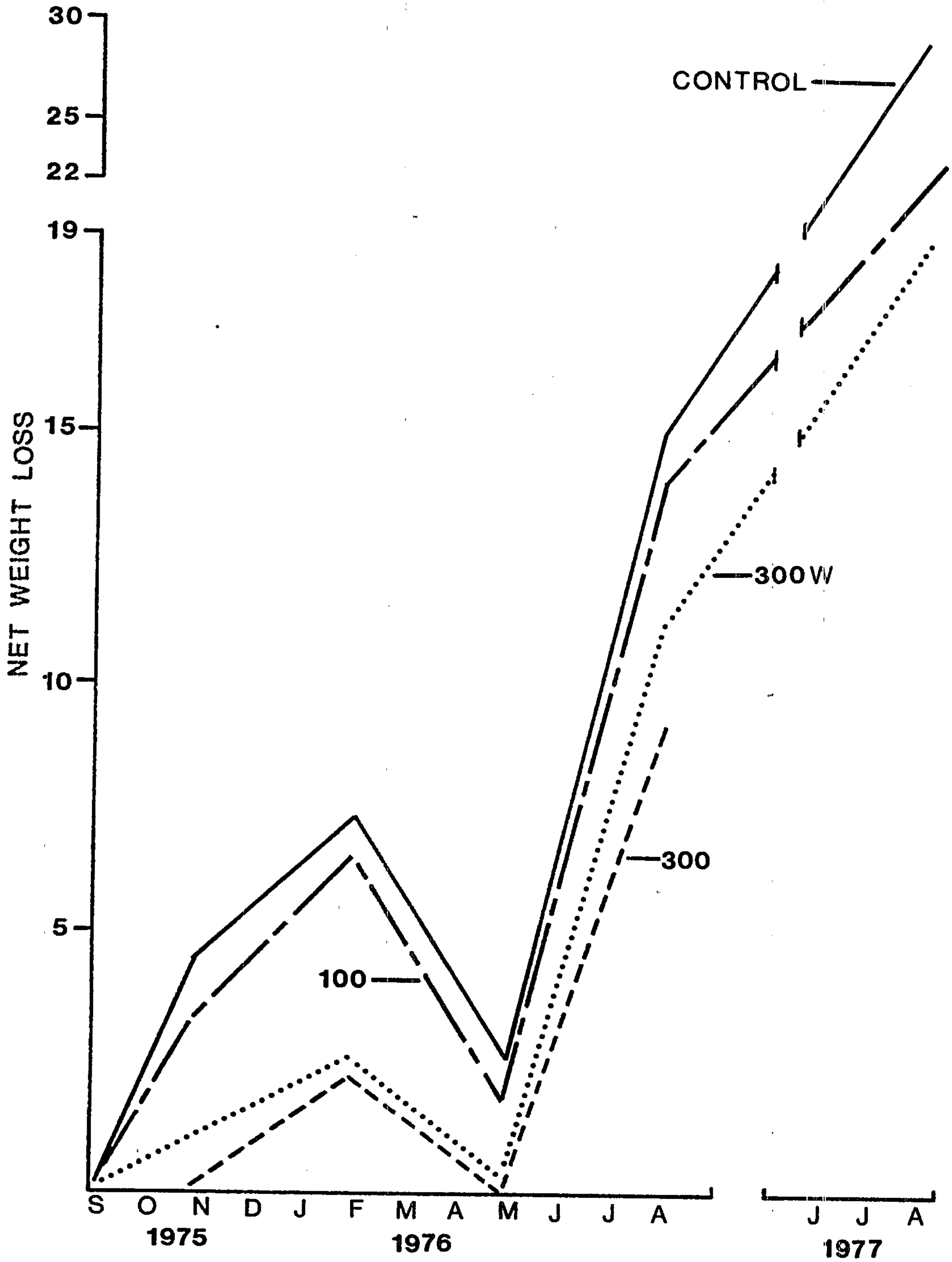

Figure 21. Changes in net weight of wood blocks on top of the litter over time by sludge treatments.

exposure, wood blocks in the 300 plot gained 0.1% in weight, while 300W lost 0.9% in weight. During the winter from October to February, decomposition continued in both the control and 100 plots (2.9% and 3.3%) and was initiated in the 300 and 300W plots (2.4% and 1.7%).

Decomposition was evidently arrested between February and May as all plots showed an increase in net dry weight of exposed wood blocks. The consistency of this phenomena suggests rapid growth of fungal hyphae with translocation of metabolic products into the wood blocks. Large net weight losses between May and July indicate accelerated rates of decomposition. Net weight loss was 12.6%, 12.5%, 9.3% and 11.1% for L layer blocks in the control, 100, 300 and 300W plots, respectively.

Decomposition on the control plot was significantly greater (14.4%) the following year than in sludge treated plots (100 plots, 8.4%; 300, 6.7%; and 300W, 7.5%).

Decomposition in A Horizons

Patterns of decomposition from September 1975 through July 1976 in A horizons were very similar for the control and 100 sludge plots (17.9 and 16.1%). Both had more rapid decomposition than the 300 and 300W plots (11.6 and 12.6%). From September through May, heavy sludge applications (300 and 300W plots) impeded decomposition in soil A horizons, while the trend of initial accelerated decomposition (Sept. through Feb.) was again reversed in the February through May period with a weight gain (+0.5%) on the 300 plot.

All plots showed significant decomposition between May and July; control plot, 15.2%; 100, 13.1%; 300, 12.1%; 300W, 11.9%.

Decomposition continued at a reduced rate for the next year in control and 100 plots (control, 7.3; 100, 6.8%). Accelerated decomposition occurred on the 300 series plots with a weight loss of 11.4% in the A horizon of the 300 plot and estimated at 9.4% for the 300W plot.

Decomposition in B Horizons

Again, samples were lost for the final sampling period of the soil B horizons; however, trends in the data suggest the results should be very similar to decomposition in soil A horizons. Decomposition trends of control and 100 plots are very similar, as are plots 300 and 300W, and significantly different from A horizons.

Section 26

EVERETT SOILS, VIRUS AND BACTERIA

Sampling either the soil or soil solutions for virus and bacteria is complexed by the interaction of these organisms with the soil or soil solution sampling system. Swartz[1], in a study of retention of coliform, strain, E.coli by lysimeter plates concluded that bacteriological data derived from sampling soil solutions with lysimeter plates is of questionable value. He identified very marked retention of bacteria in the plates. For example, a control solution containing 1.2×10^6 organisms were passed through 6 different lysimeter plates. Colonies in the extracted solution varied from 0 to 1.2×10^3, a reduction of 1000-fold greater in the numbers of colonies.

With these limitations in mind, the following information was developed in this study. Soil samples in the upper 5 cm from control plots developed 430 colonies of total coliform per gram of wet weight. Composite soil solutions typically average less than 20 organisms of total or fecal coliform per 100 mls. No significant differences were found between control and sludge plots.

Litter surfaces have 4.3×10^4 colonies per gram of wet weight immediately after spray irrigation. Coliform are evidently endemic as resampling of early sludge application on plots which studied methods of sludge application retained 3.9×10^4 colonies per gram of wet weight.

Soils and soil solutions analyzed for other bacteria and virus by the Virology Lab of Children's Orthopedic Hospital have not identified virus in any samples. Unidentified bacteria have been found throughout the soil profile. Results to date suggest that experimental designs which utilize aluminum oxide lysimeters may produce questionable results for study of bacteria and virus in forest soils.

---

[1]R. Swartz, Bacteriological Evaluation of Lysimeter Plates, Metro memo (April 18, 1975) to G. Farris and R. Domenowske.

Section 27

EVERETT SOILS, HEAVY METALS

The fate of heavy metals in the Everett soils is somewhat complex. It may be assumed that acid Northwest forest soils have a very strong affinity for heavy metals and provide excellent renovation. This conclusion is supported by certain analytical data; however, the exact value of these field data is unknown.

Earlier laboratory experiments with tension lysimeter plates indicate aluminum oxide, like soil, has an affinity for many heavy metals and will remove certain heavy metals from the soil solution as it passes the plate. In the laboratory, known concentrations of heavy metals were passed through lysimeter plates, and the recovery in the extracted solution determined. The following briefly summarizes the results (all values in mg/l).

	Cu	Cr	Cd	Pb	Ni	Zn
Original Solution	0.18	0.18	0.036	0.19	0.20	0.048
Average of Extracted Solution	<0.01	<0.01	<0.004	0.06	<0.02	0.039

There was variation in retention by individual plates, suggested to be a function of the aluminum oxide matrix making up the plate. The strong interaction of solution concentration and affinity of heavy metals for aluminum oxide would make interpretation of field soil solution data for heavy metals impossible. Trace concentrations of the above heavy metals were found in soil solutions extracted in the field. Interpretation of these data is impossible at this time.

Section 28

SLUDGE APPLICATIONS AND FOREST GROWTH

Even the relatively uniform second growth Douglas-fir stand selected for sludge application treatments had high variability between average diameter, numbers of trees per plot, and average growth rates by plots (Table 28).

Applications of sludge did not significantly alter tree growth as studied by growth on a plot basis. Analysis of variance showed no treatment effects when tested as a difference between treatment means. The analysis of variance tested plot means for effects of sludge treatments with two replications using DBH or periodic annual increment (pai) after irrigation minus DBH or pai before irrigation as the test parameter.

Source of Variation	df	SS	MS	F	
Between treatments	3	0.48375	0.16125	0.3368	NS (α=0.10)
Error (within treatments	4	1.91500	0.47875		
TOTAL	7	2.39875			

where

standard error of difference = 0.49 mm

coefficient of variation = 73.8%

The large error (within treatment) indicates the variability within treatments is greater than the variability between treatments (Table 28). Numbers of trees per hectare varied from 963 (390/ac) on the control plot to over 2000 (810/ac) on a 200 series sludge plot. The usual inverse relationship between numbers of trees and DBH is apparent. The control plot averaged 21.5 cm (8.5 in.) in diameter while the 200 series sludge plot averaged 14 cm (5.5 in.). Basal area and volume are frequently less variable than the numbers of trees or their average diameters. Basal areas ranged from 35.0 to 43.8 m^2/ha (151 to 191 ft^2/ac.). Volumes ranged from 305.3 to 455.9 m^3/ha (4363 to 6515 ft^3/ac.).

The post treatment results (Table 28) exhibit similar patterns of large variation between plots; however, mortality on plots with numerous trees (200 plot) reduced the ratio considerably.

Gross pai also varied considerably for all plots before and after treatments (Table 29). Average annual increments for all treatments generally

Table 28. AVERAGE STAND CONDITIONS BEFORE AND AFTER SEWAGE SLUDGE IRRIGATION BY PLOT AND TREATMENT

	Pretreatment				Post Treatment			
Plots	Trees/ha	DBH (mm)	Basal Area (m^2/ha)	Volume (m^3/ha)	Trees/ha	DBH (mm)	Basal Area (m^2/ha)	Volume (m^3/ha)
100	1383	165	36.2	305.3	1358	176	37.5	371.7
100	1111	187	35.0	360.3	1037	207	39.3	433.8
100W	1407	167	34.6	347.8	1259	177	35.6	382.9
200	2123	140	38.5	353.5	1852	156	41.9	420.6
200	1852	155	40.0	387.9	1704	170	44.2	467.4
200W	1852	142	36.5	353.5	1679	163	42.6	442.0
300	1531	174	40.9	401.1	1506	187	46.6	488.9
300	1358	171	36.5	353.5	1333	182	41.0	432.7
300W	1556	168	38.8	380.6	1457	182	43.2	456.3
Water	1235	178	36.3	353.0	1185	191	40.1	426.8
Water	1259	198	43.8	455.9	1185	216	49.1	549.7
Control	963	215	37.9	386.3	938	229	42.2	454.9

Table 29. AVERAGE GROSS PERIODIC ANNUAL INCREMENT FOR PRETREATMENT, 2 AND 3 YEARS AFTER IRRIGATION BY PLOT AND TREATMENT

Plots	Diameter 70-75	Diameter 75-76 (mm/yr)	Diameter 75-77	Basal Area 70-75	Basal Area 75-76 (m^2/yr)	Basal Area 75-77	Volume 75-76 (m^3/yr)	Volume 75-77
100	2.6	3.8	3.4	1.06	1.70	1.57	27.2	23.1
100	2.4	4.0	3.9	0.88	1.60	1.60	28.8	25.8
100W	2.4	3.4	3.2	0.96	1.65	1.53	28.0	24.6
200	1.8	3.0	2.5	0.98	1.90	1.67	32.5	26.0
200	2.6	3.0	3.0	1.36	1.85	1.83	33.8	29.8
200W	1.8	3.6	3.6	1.04	2.20	2.20	32.6	30.3
300	2.0	3.8	3.9	1.02	2.00	2.03	32.8	30.4
300	2.8	3.6	3.2	1.10	1.75	1.57	32.8	27.1
300W	2.2	3.5	3.6	1.02	1.85	1.93	32.4	29.8
Water	2.4	3.1	2.8	0.96	1.45	1.37	30.2	25.3
Water	2.6	4.1	4.0	1.06	2.10	2.00	38.2	33.1
Control	2.8	3.8	3.9	0.94	1.55	1.57	26.2	24.2

increased between 1975 and 1977 as compared to the pretreatment period, 1970 to 1975, the control plot. Increased growth rates are probably due to the aerial fertilizer application in March 1974 and/or summer rainfall in 1975.

SLUDGE APPLICATION AND FOREST GROWTH, PAIRED TREES

The average pai for all plots is summarized in Table 30. Analysis of variance showed significant difference in growth rates when tested using paired trees. For most parameters tested, growth rates nearly doubled when comparing 1970-75 rates with 1975-77 rates.

Table 31 uses regression analyses to compare paired tree growth for sludge treated, water only, and control plots for diameter, basal area, and volume growth. The 200W treatment significantly increased diameter, basal area, and volume growth for both the 2 and 3-yr. growing periods.

The 300W treatment increased diameter growth in the 1975-76 year and increased basal area and volume growth for all years. Volume growth for all analyses was significantly increased for all sludge treatments except the 300 for 1975-77.

Irrigation with water only did not increase growth over the control (Table 31).

DIAMETER GROWTH RATE, PAIRED TREES

An analysis of variance for paired trees within treated plots and the control used DBH pai after treatment minus DBH pai before treatment as a test of change in growth rate. Sludge applications significantly increased diameter growth rate at the 95% confidence level (Table 30).

Source of Variation	df	SS	MS	F
Between treatments	4	33.359	8.3398	2.62*(α = 0.05)
Error (within treatment)	168	534.948	3.1842	
TOTAL	172	568.307		

Simple linear regression equations were developed from these paired individual trees (Table 2, Appendix C). Equations for pretreatment growth over initial size were compared with the control and were found to be homogenous. Therefore, the use of pretreatment pai as an independent variable in the other equations tested is not confounded by pretreatment growth differences, and treatment effects can be assessed (Table 31).

Comparisons of diameter growth showed 2 years of sludge applications (200W and 300W) significantly increased diameter growth rates over control. After 3 years of irrigation only, the 200W treatment had significantly greater diameter growth rates. Growth rates after 3 years of irrigation as a function of before irrigation growth are shown in Figure 22 for 200 W and control

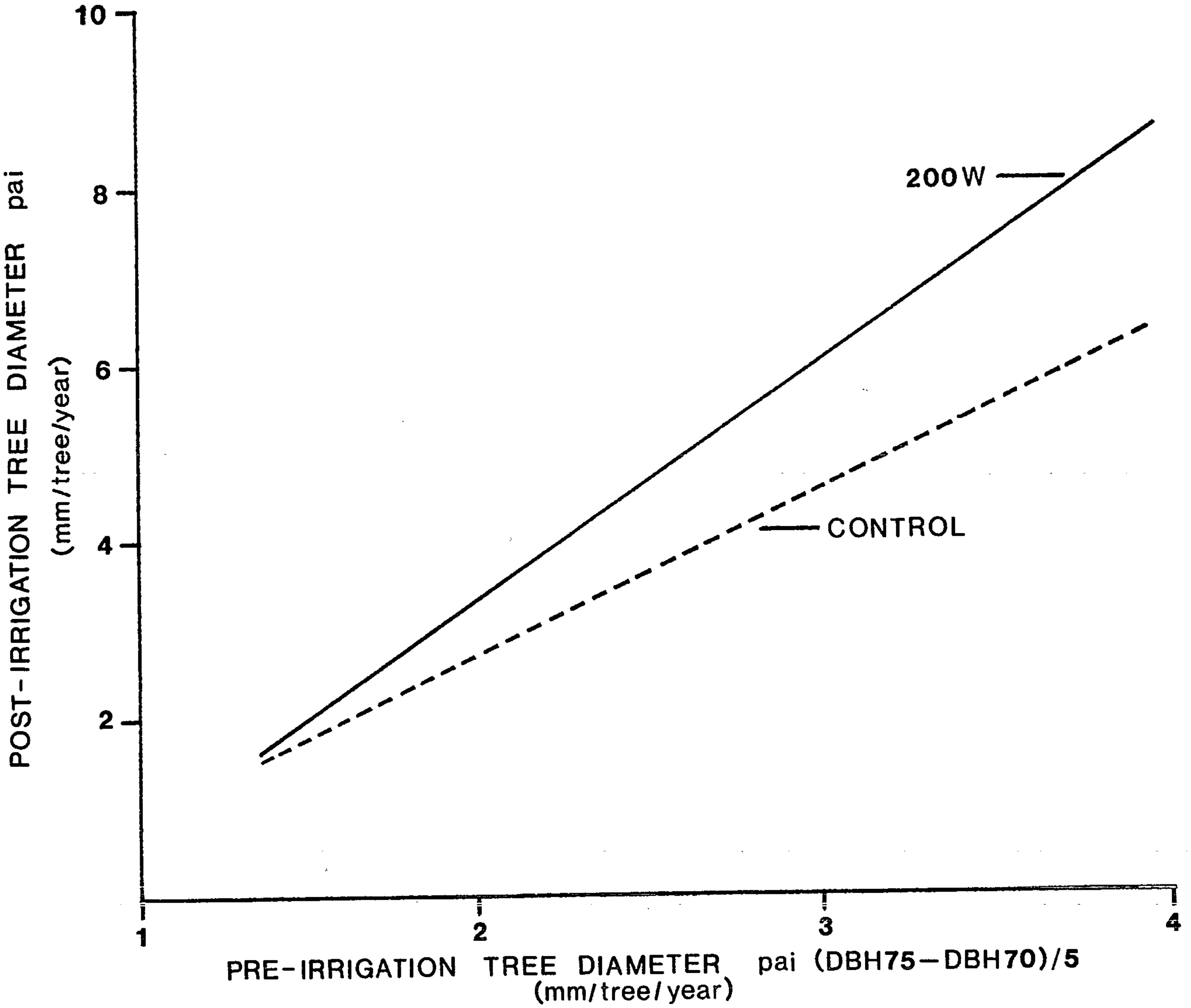

Figure 22. Individual tree diameter pai following 3 years of irrigation as a function of pretreatment diameter pai per tree (paired trees).

Table 30. A SUMMARY OF AVERAGE PERIODIC ANNUAL INCREMENT FOR PAIRED TREES, BEFORE, 2 AND 3 YEARS AFTER SLUDGE APPLICATIONS BY TREATMENT

	Diameter			Basal Area			Volume	
Plots	70-75	75-76	75-77	70-75	75-76	75-77	75-76	75-77
		(mm/yr)			(cm^2/yr/tree)		(m^3/yr/tree x 10)	
100	2.8	5.2	4.9	.10	.19	.18	.314	.282
100W	2.4	4.8	4.4	.08	.18	.16	.298	.255
200	2.7	5.4	4.7	.09	.18	.16	.299	.248
200W	2.4	4.5	4.4	.07	.16	.15	.225	.215
300	2.7	5.1	4.9	.10	.20	.19	.340	.305
300W	2.6	4.7	4.8	.09	.17	.18	.303	.280
Water	2.8	4.4	4.1	.10	.17	.16	.341	.279
Control	2.7	4.0	4.1	.10	.16	.17	.285	.263

Table 31. COMPARISONS OF SLUDGE TREATMENTS, WATER ONLY AND THE CONTROL USING INDIVIDUAL PAIRED TREES

Equation	Treatments						
	100	100W	200	200W	300	300W	Water Only
(DBH76 - DBH75)/2 = a + b [(DBH75 - DBH70)/5]	NS	NS	NS	*	NS	*	NS
(DBH77 - DBH75)/3 = a + b [(DBH75 - DBH70)/5]	NS	NS	NS	*	NS	NS	NS
(BA76 - BA75)/2 = a + b [(BA75 - BA70)/5]	NS	*	NS	*	*	*	NS
(BA77 - BA75)/3 = a + b [(BA75 - BA70)/5]	NS	NS	NS	*	NS	*	NS
(Vol. 76 - Vol. 75)/2 = a + b (Vol. 75)	*	*	*	*	*	*	NS
(Vol. 77 - Vol. 75)/3 = a + b (Vol. 75)	*	*	*	*	NS	*	NS

NS = nonsignificant difference in slopes

* = significant difference in slopes $\alpha = 0.05$.

trees. Slopes show a significant treatment effect for only the 200W sludge treatment.

BASAL AREA GROWTH RATE, PAIRED TREES

Basal area growth for individual paired trees showed trends similar to DBH growth. All sludge plus water treatments (100W, 200W and 300W) had significantly greater basal area growth rates than control trees after 2 years. After 3 years, only the 200W and 300W treatments maintained significantly greater growth rates. Growth during the 3 years of treatment, as a function of pretreatment basal area pai, is shown in Figure 23. Slopes of basal area growth rate were significantly different with the 200W, 300W treatments having the greatest growth rates. Again, the sludge plus water treatments all had increased growth rates over sludge only treatments (Table 31).

VOLUME ANALYSIS

Volume growth of all sludge treated trees was significantly greater than the control trees after 2 years. However, the 300 treated trees did not continue to show greater growth rates at the end of the third year (Table 31).

WATER ONLY IRRIGATION, GROWTH, PAIRED TREES

Water only irrigation did not significantly alter growth rates, whereas water plus sludge did (Table 31). Actual growth in DBH, basal area, and volume are almost identical for the paired tree analyses.

SLUDGE VS. SLUDGE PLUS WATER, GROWTH, PAIRED TREES

Growth comparisons of sludge treated trees versus sludge plus water treated trees (Table 32) indicate sludge treatments followed by water significantly increased tree growth rates. Growth rates of trees receiving water plus sludge treatments seem to increase with increased sludge applications.

Adjusted diameter pai (mm per year) as a function of weekly irrigation rates (cm) over 3 years (Figure 24) shows sludge increased diameter growth. When sludge is followed by water, diameter pai growth increased up to 25% over control diameter pai at a weekly irrigation level of 0.5 cm (0.2 in.) and then growth decreased slightly with increased irrigation.

Results from this limited study indicate that irrigation with stabilized municipal-industrial sewage sludge has increased the growth rate of individual paired trees. The 200W had the greatest effect on growth. Generally, the addition of water applied after sludge irrigation significantly increased growth over sludge-only irrigation. Therefore, to obtain the maximum growth effect of sludge application, a water irrigation treatment would be recommended to wash the sludge into the rooting zone.

Disposal of sewage sludge on this forested site has apparently had a positive effect on increasing tree growth. However, longer term studies are needed to assess impacts on soils, chemical breakdown of grease and hair

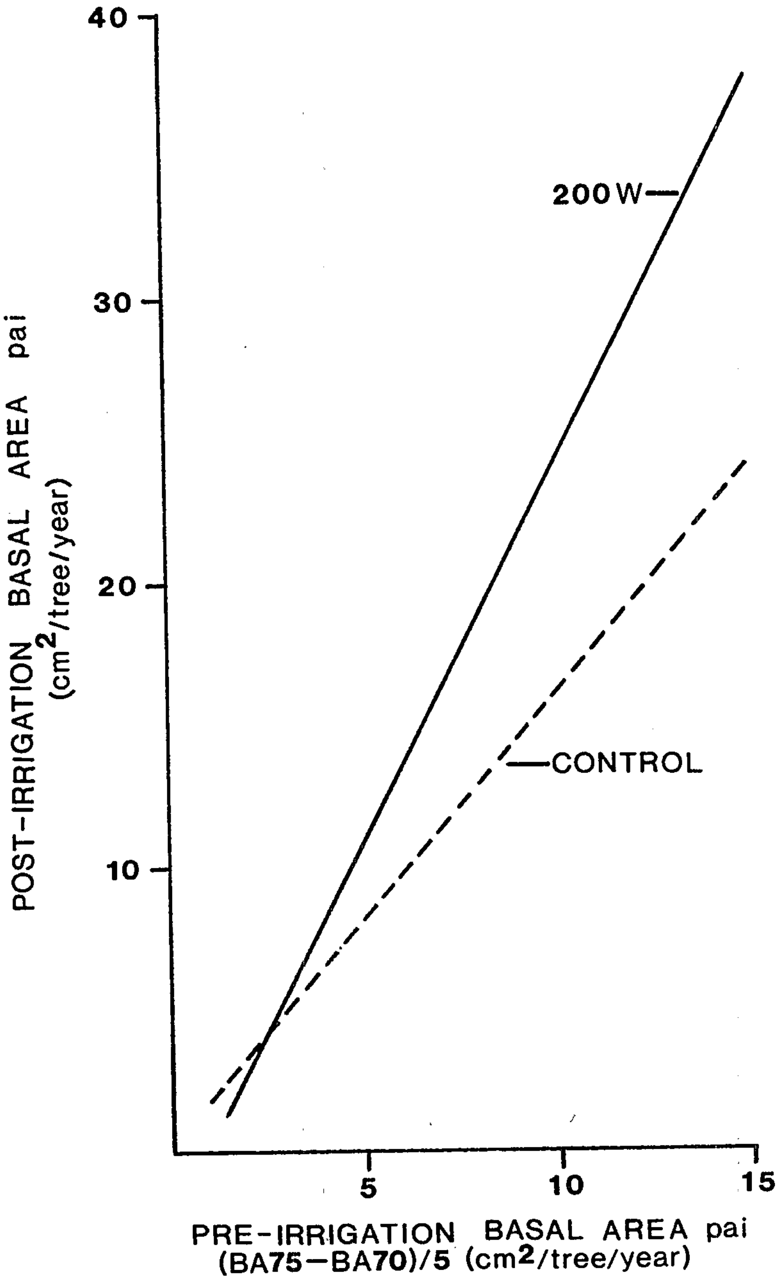

Figure 23. Individual tree basal area pai following 3 years of irrigation as a function of pretreatment basal area pai per tree (paired trees).

Table 32. COMPARISON OF TREE GROWTH SLOPES BETWEEN SLUDGE AND SLUDGE PLUS WATER TREATMENTS

Equation	Treatments		
	100 vs. 100W	200 vs. 200W	300 vs. 300W
2-year diameter pai	NS	*	*
3-year diameter pai	NS	*	*
2-year BA pai	*	*	*
3-year BA pai	NS	*	*
2-year Vol. pai	NS	NS	*
3-year Vol. pai	NS	*	*

NS = nonsignificant difference in slopes

* = significant difference in slopes $\alpha = 0.05$

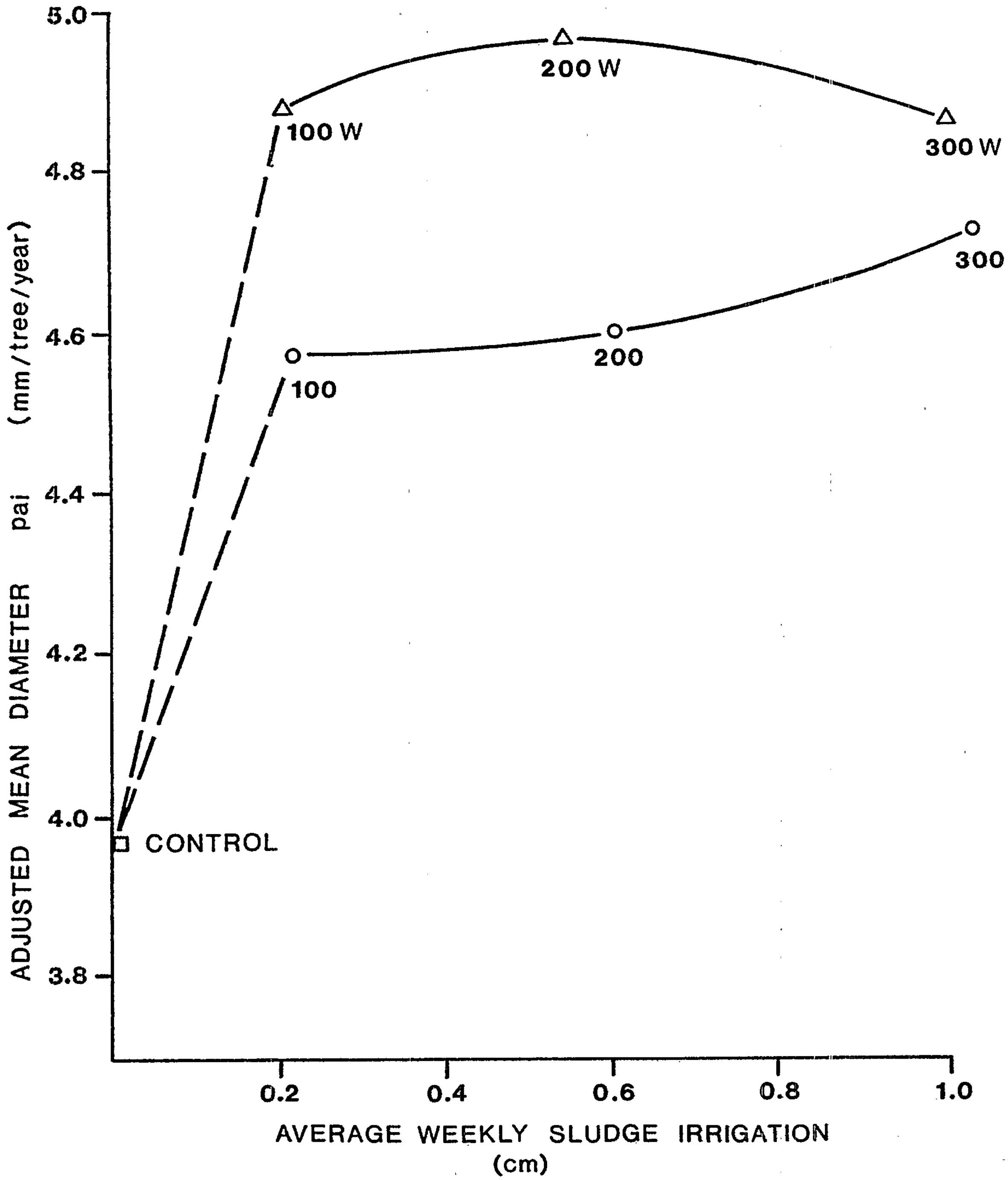

Figure 24. Adjusted mean diameter pai following 3 years of irrigation as a function of weekly irrigation rates.

applied, and impacts on microbial populations, before this technology becomes a standard silvicultural tool for intensive forest management.

Section 29

DISCUSSION OF SLUDGE APPLICATIONS TO FOREST SOILS

A discussion evaluating the results of three years of testing of sludge applications in the forest must be concerned with: First, is it economically feasible as a potentially useful method; and second, what are the environmental consequences, particularly potential eutrophication of ground water? The following sections contain both a discussion and conclusions relative to the impacts of sludge applications. Few equivalent studies are available for comparison with these results.

SLUDGE APPLICATION METHODS

Disposal of sludge in Pacific Northwest forests could have either of two major objectives. A community or outlying urban area might have an objective of the disposal of maximum amounts of sludge on a minimum forest area. Investments in forest land and irrigation system would be minimum. In this case, the community would like to apply the maximum quantity of sludge per acre per year without degradation of environmental quality or eutrophication of ground water.

On the other hand, the forest industries might be interested in intensive management of a substantial forest acreage with the prime objective of accelerated forest growth. In this case, the enhancement of growth from both applied water and sludge would be spread over a many-fold greater area and use a greatly diluted sludge and a substantial quantity of effluent treatment water.

In either case, an effort would be made to keep capital investments to a minimum in the sludge application systems. This research concludes that spray irrigation is one of the most effective and possibly efficient means of distribution of sludge in the forest environment. Spray irrigation of sludge may be achieved from mobile tankers, such as truck-mounted units, under-the-canopy spray irrigation as used in this study, or over-the-canopy with the large high-powered water canons.

Costs of development of irrigation systems for sludge application to forests may be estimated to a degree by the costs of similar developments for agricultural land. Troemper (1974) developed a spray irrigation system for application of 12.1 cm (4.75 in.) of anaerobically digested sludge at a cost of $17,900/ha($7245/ac.). The system installed included pipe, sprinkler, a pumping system, a drain system to intercept soil solution percolate for recycling. Average costs for sludge disposal by the system were $56.02 per thousand gallons of sludge (about $260/dry ton at 5% solids in sludge).

Costs of installing a forest irrigation system would vary depending on soil types, slopes and the forest stand. Estimated costs for a system as used at Pack Forest, including pipe, sprinklers, drain valves and certain soil water monitoring equipment, are $5000/ha ($2000/ac.) for application of 13.3 cm (5.25 in.) of 3% solids sludge or an average cost of $14 per thousand gallons. These costs do not include the pumping system or delivery of sludge to the disposal site. Obviously, the costs of pumps and/or transportation of sludge to the disposal site could be highly variable but probably could be capitalized over a long-term application. A minimum cost of $110/dry ton is projected based on above cost estimates, not including a pump or hauling.

Installation of a sludge application system before establishment of the young forest would probably be the most economical. Heavy equipment could be used for burying the pipe without damage to the forest stand. As the young forest grows, a supply of water may be necessary to wash sludge from the foliage after each sludge application.

Piping at Pack Forest rested on the soil surface. Burying would be an improved alternative for a permanent system but would also add to the cost. It would have the advantages, however, in preventing freezing as well as gradual deterioration of the surface pipe and restrictions imposed on moving equipment through the forest because the pipe is on the soil surface.

In a system where uniform application of sludge is not necessary, more efficient distribution could be achieved with the use of large water canons. Sludge would be applied followed by water to wash sludge from tree crowns.

RATES OF SLUDGE APPLICATION

First year sludge applications in this study were obviously too large. Impeded infiltration occurred after sludge applications exceeded 25 cm (10 in.). Excessive amounts of nitrogen applied resulted in a very large total loading with rapid conversion to nitrate forms and leaching in the soil solution. The reduced rates which applied from 10 to 40 mt/ha (4.5 to 18 t/ac.) appear to be a reasonable range of sludge loadings. For the three soils, Everett, Mashel and Wilkeson, loadings varied from 4.8 to 29.8 mt/ha/yr (2.1 to 13.3 t/ac/yr). Physical renovation by each soil for the loadings through the given range was excellent. The total organic carbon analyses indicated no contamination within the soil profile of materials in sludge.

The original Everett soils plots had sludge applications ranging from 45 to 108 mt/ha (20 to 48 t/ac) during the study. The physical renovation capacity for selectively filtering solids was still excellent on completion of the study. Careful analyses of sludge composition are required to establish average solid content of sludge in designing a system and rates of application. This study anticipated and designed for an average solids content of 2.1%, assuming random variation during the life of the study. Solids actually averaged 3.2% over the life of the study; thus, design applications for a depth of sludge had significantly greater loadings of solids than anticipated. In most cases, rates of sludge application to a given area will not be limited by quantities of solids but rather by the chemical constituents.

RENOVATION OF NUTRIENTS

Intensive management of second growth forest stands often requires application of numerous chemicals for control of insects, competing brush species, and in recent years, fertilizers to accelerate forest growth. Foresters are concerned with the fate of applied chemicals and potential environmental impacts, particularly in the hydrologic system from the soil solution to ground water or streamflow. Detailed forest ecosystem studies have identified nutrient leaching (Cole, et al. 1976) and impacts of forest fertilization (Gessel and Cole, 1965).

Sludge applications of this study provided nutrients in quantities greatly in excess of most other cycling studies of either fertilization or waste water management.

RENOVATION OF BASE NUTRIENTS

The renovation capacity of the three soils studied has been expressed as the percentage of retention of the total applied nutrients. In general, the percent renovation capacity for base nutrients is excellent, expressed as a percentage. Renovation by the soil retains large quantities of nutrients in the soil profile, but when very large quantities are applied, the flux or loss from the soil profile could still be significant. For example, the original 200 series plots on the Everett soil received 80.7 mt/ha (36 t/ac) of base nutrients. Renovation was 96% of that applied; however, 3.2 mt/ha (1.4 t/ac) did leach below the 2 mm (7 ft.) depth in the soil profile.

Analyses of the dissolved chemicals in ground water in wells adjacent to the plots did not reveal a trend of increasing dissolved calcium or other base nutrients in ground water. Maximum concentrations of calcium found in the soil solution of sludge treated plots ranged to 14 times that of the soil solution of control plots.

Maximum base nutrient concentrations in the soil solution were observed during driest portions of the summer. Fall rains increased the supply of soil water, thus, diluting the nutrient concentrations. It is expected that flux of the soil solution to ground water transporting the dissolved nutrients would then be greatly diluted, thus, resulting in insignificant changes in the composition of dissolved ions in the ground water. Calcium was applied in largest quantities and had the largest flux through the soil profile of any of the base nutrients. Concentrations of magnesium, potassium and sodium were greatly reduced in the ground water, and frequently were only a few-fold greater than concentrations in the soil solution of any control or water plots. In fact, the highest concentration of potassium found in any plot was in the soil solution of the control plot.

RENOVATION OF PHOSPHORUS

Renovation on all soils and plots of total P and PO_4-P was consistently excellent. The maximum loss was on the Mashel soil (30 series application) where a flux of 5 kg/ha/yr (4.5 lbs./ac./yr.) was identified when 432 kg/ha (385 lbs./ac.) of total P had been applied. On the Everett series, after three years of sludge application with quantities of total P applied in excess of 2 mt/ha (1 t/ac.), losses were a maximum of 2.0 kg/ha (1.8 lbs./ac.).

Large quantities of total P and PO_4-P can be applied to forest soils without impacts on ground water or the soil solution.

RENOVATION OF NITROGEN

Nitrogen may well be the most critical element in land disposal of sludge, either forests or agricultural. Concentrations of nitrogen are frequently high in sludge, ranging from 0.9 to 1.8% in this study. The soil solution and organisms in the forest soils provide environmental conditions for a very rapid conversion of total N or NH_4-N forms to NO_3-N. Frequently, the renovation of NH_4-N appears excellent (ranging from 80 to 99+%). However, soil chemical reactions convert NH_4-N to NO_3-N with subsequent leaching in the soil solution, making contributions of NO_3 to ground water one of the most important implications in land disposal of sludge.

The underestimation of the average total N composition of Metro sludge resulted in large total nitrogen applications. The original Everett plots received 5.3 mt/ha (2.4 t/ac.) of total N in the 300 series with renovation of 70% (1.6 mt/ha; 0.7 t/ac. lost). Renovation by other plots was considerably less. The 200 series plots received 4.9 mt/ha (2.2 t/ac.) over the three years and had a flux of 4.7 mt/ha (2.6 t/ac.), achieving 3% renovation (Table 6).

The flux of nitrogen from the soil profile is dominated by water soluble NO_3-N. In the previous two examples, the total N flux of 1.6 mt/ha (0.7 t/ac.) on the 300 series plots was accounted for by 1.4 mt/ha (0.6 t/ac.) of NO_3-N. The 200 series plots had a very similar percentage NO_3-N flux. Of the 4.7 mt/ha (2.1 t/ac.) flux, loss of 4.0 mt/ha (1.8 t/ac.) was NO_3-N (Table 6).

Renovation of NH_4-N is excellent in these forest soils. A maximum loss of 290 kg/ha (259 lbs./ac.) was measured on the 100 series Everett plots which had received 1.4 mt/ha (0.6 t/ac.) of NH_4-N. The range for the rest of the original plots was from 1 to 31 kg/ha (0.9 to 28 lbs./ac.) over the three years of study of the original series of plots. The new series of plots established on the Everett, Mashel and Wilkeson soils had maximum NH_4-N flux of 59 kg/ha (53 lbs./ac.) on the 30 series plots on the Mashel soils (Table 19). A range of near zero to 43 kg/ha (38 lbs./ac.) occurred with the other soils and plots. The Everett soils had the best overall renovation with 6 kg/ha (5 lbs./ac.) occurring on the 40 series plots where the applied quantity was 828 kg/ha (739 lbs./ac.)(Table 12).

A volatilization loss of NH_4-N, identified by odor, was often noticed as spray irrigation of sludge commenced. Forms other than NH_4-N and NO_3-N of nitrogen in sludge were not identified. Nitrification processes with exposure of the anaerobically digested sludge to oxygen suggest a dynamic mechanism of conversion in form. Alexander (1965) studied nitrification reactions identifying exothermic and chemoautotrophic along with the groups of micro-organisms involved in biosynthetic reactions. The oxidation of NH_4-N is:

$$2NH_4 + 3O_2 = 2NO_2^- + 4H^+ + 2H_2O$$

then

$$2NO_2^- + O_2 = 2NO_3^-$$

Micro-organisms required for the above process are Nitrosomnoas and Nitrobacter. Processes of oxidation of NH_4-N are very rapid as conversion of total N and NH_4-N proceeded rapidly enough that significant increases in nitrogen could not be identified in the soil profile in the second year (Table 8). Third year analyses of Everett soils, however, did indicate increased concentrations of total nitrogen in the forest litter layer and the soil A horizon (Table 10). All sludge treated plots were averaged and tested against the pretreatment analyses to identify this significant increase in total N.

Reduced rates of sludge application (10-40 plot series) had best total nitrogen retention on the Wilkeson soils (average 79%) with the Mashel and Everett averaging 69 and 55%, respectively. Trends to increasing quantities of soil nitrogen are indicated in all three soils; however, differences are not quite statistically significant (Tables 13, 20 and 23). Retention of nitrogen applied to the soil ranged from 111 kg/ha (99 lbs/ac) on the Mashel soil (10 series plots) to 1026 kg/ha (914 lbs/ac) on Everett soils (40 series plots). In the forest ecosystem, conservation of nitrogen is related to accumulation of carbon. Micro-organisms decomposing the carbon supply require nitrogen for vital life processes. A large supply of available soil carbon frequently indicates a limited supply of available nitrogen to micro-organisms.

Applications of sludge provide a readily available source of nitrogen accelerating plant growth. As additional amounts of organic debris become available for decomposition from stimulated growth, the soil nitrogen will accumulate increasing amounts of total N.

The carbon-nitrogen ratio is an interaction of both the quantity of organic carbon, and the amount of total nitrogen shows wide variation on sludge plots at this time. The fine textured Mashel and Wilkeson soils had marked increases in the carbon-nitrogen ratio of the forest litter layer (from 31:1 to 70:1 for the Mashel and 38:1 to 68:1 for the Wilkeson). Increased organic matter occurred in L layers on these two soils without significant change in total N percentage. These data suggest that both soils will accumulate nitrogen until the carbon-nitrogen ratio is reduced.

The very coarse textured Everett soil had slight reductions in the organic matter content of the forest litter layer and A horizon. Nitrogen contents did not change significantly, thus, a slight reduction in the carbon-nitrogen ratios following sludge applications. Applied sludge and water should accelerate forest ecosystem productivity, thus, increasing the supply of carbon. With time, increased growth will increase carbon supplies and provide the mechanism for increasing the quantities of nitrogen stored in the forest floor and soil.

Quantities of NO_3-N have increased significantly in the soil solution as compared with the control and water plots. As with base nutrients, maximum concentrations occur during times of minimum soil water, thus, greatly concentrating both NO_3-N and total N concentrations. Rainfall or irrigation increases the supply of soil water, diluting the concentration of dissolved materials. The dissolved chemistry of ground water (well water) does not reveal any significant trends or a departure from normal concentration over time.

EVALUATION OF TOTAL ORGANIC CARBON

The trend to increasing quantities of the soil organic matter is verified by the analyses of total organic carbon (TOC). Increases in TOC in the C horizon with sludge applications were identified; however, analyses detected only natural decomposition organic compounds. These compounds were also identified in the ground water well samples. Large applications of sludge (45 to 108 mt/ha; 20 to 48 t/ac.) have not increased organic matter contents of the forest litter layers (Table 10). This suggests a marked increase in biological decomposition of fine or colloidal organic materials. TOC analyses also identify increased metabolism when sludge is applied. Marked increases in amounts of aliphatic fatty acids found in the soils are related to acids of normal metabolic products of micro-organisms. Increases in TOC appear to be the result of increased metabolic activities and do not represent, for an example, the appearance of refractory compounds in the ground water resulting from sludge applications.

EVALUATION OF BIOLOGICAL DECOMPOSITION

Rates of biological decomposition depend on inherent organic matter structure and chemical composition, decay organisms, and environmental conditions, interacting with action of extra cellular enzymes and physical weathering. Processes which degrade wood include immobilization, incorporation, leaching, physical damage and enzymatic dissolving. Tests used in this study include relative weight changes and the solubility of woody material in 1% N_aOH. Relative changes in weight loss do not accurately measure the decomposition process, as identified in this study. Frequently, there is a slight gain in block weight attributed to micro-organisms invading the wood sample. This occurred on the 300 series plots (Table 27) and is suggested by the decrease in solubility of the wood blocks over time when extracted with 1% N_aOH. With initiation of the growing season in May 1976, rates of decomposition as measured by both weight loss and soda solubility increased rapidly. There are apparently no significant differences between treatments for the duration of the study (July 1977). However, some differences in response by horizons were noted.

SLUDGE APPLICATIONS AND FOREST GROWTH

The study of forest growth by plots and treatments yielded negative responses to sludge applications. Statistically significant increases in growth could not be identified because of the very high variability in numbers of trees, sizes and basal area from plot to plot.

Re-analysis of the data on a paired tree basis using trees of approximately equal growth rate and initial diameter developed significant growth responses from sludge applications. The addition of water after sludge irrigation provided the most significant growth increases. The applications of sludge alone significantly increased growth over the control or water irrigated treatments.

Though the short-term results of sludge treatments to forest trees show promising growth acceleration, several important questions remain to be answered. Chemical breakdown of suspended materials in sludge should occur in a short time. If greases, hair, etc. are not attacked by microbial populations, then accumulations could be detrimental. To date, heavy metals seem to be no problem. In a highly organic system, they should be effectively chelated or fixed in the soil. Applied water and nutrients should stimulate biomass productivity, increasing the production of carbon which would allow greater retention of nitrogen. Increased quantities of nitrogen would continue to provide accelerated growth, thus, increasing ecosystem productivity over the long term.

Section 30

SUMMARY OF RESULTS OF SLUDGE APPLICATIONS

The initial very large amounts of sludge application to the 200 and 300 series Everett soils resulted in ponding of sludge on 5 to 25% of the surface area of certain plots. Even these very large applications did not result in noxious odors nor a generally unsightly condition in the forest. Reduced rates of sludge application (10 to 40 mt/ha/yr or 4.5 to 18 t/ac.) are almost unobservable. Excellent renovation of suspended and dissolved materials in sludge has been achieved with the exception of nitrate nitrogen. All rates of sludge application have resulted in significant nitrification and leaching of NO_3-N in the soil solution. Ground water samples taken from wells at over 10 m (30 ft.) deep show no enrichment in dissolved ions from sludge applications. Significant renovation takes place in the surface 2 m (7 ft.) of the forest soil. It is quite possible that the additional 8 m (26 ft.) between the deepest sampling and the ground water table continue to renovate the soil solution.

Impacts of nutrient flux through the soil profile to ground water and/or the stream will require studies on a watershed basis.

A few significant changes in soil chemical properties were identified. While statistically significant, the ecological significance is as yet unknown. Cation exchange capacity was frequently the most significantly influenced soil property. Sludge applications generally increase cation exchange capacity of the forest litter layer and the A horizon. A general trend to increasing soil organic matter, decreasing pH, and increasing total cation exchange capacity has been identified. Large applications of calcium have generally resulted in increases in exchangeable calcium in litter and A horizons. Other changes in exchangeable cations are sporadic--statistically significant, but again ecologically inconsequential.

Modified rates of sludge application in the range of 10 to 30 mt/ha/yr (4.5 to 13 t/ac./yr.) could be received by many forest soils. Additional quantities of waste water applied following sludge applications would be beneficial. Further research should isolate impacts on a watershed basis to evaluate leaching to ground water and potential eutrophication of streams.

This short-term study did not identify significant increases in forest growth on a plot basis. Natural variability in stand densities and growth rates obscured short-term growth responses. A more sensitive analysis of paired trees of equal size resulted in significant growth increases of the paired tree receiving sludge applications. Sludge applications followed by water seemed to be the most beneficial with the 200W treatments probably enhancing forest growth to the greatest extent. Longer term studies are necessary to adequately answer questions relative to long-term impacts of sludge application in the forest environment. These studies, if conducted on a watershed basis, would have the opportunity for a greatly expanded plot network for sludge versus no sludge treatments.

This short-term study of sludge applications in the forest provides encouraging results for the ability of forest soils to renovate constituents in sludge, along with initial indications of enhanced forest growth based on paired tree comparisons. It is also encouraging that human pathogens of the bacteria and virus natures were not isolated, and heavy metals were either absorbed in the aluminum oxide lysimeter plates or tied up in the soil profile.

LITERATURE CITED

Aldrich Chemical Company. 1969. Diazomethane. Aldrich Chemical Co., Milwaukee, Wis. 4 pp.

Alexander, M. 1965. Nitrification in Soil Nitrogen. ed, W. V. Bartholomew and F. E. Clark. Amer. Society of Agronomy. Madison, Wis. 615pp.

American Standard for Testing Materials (ASTM DI758-60T). 1961. Evaluating wood preservatives by field tests with stakes. Amer. Society for Testing and Materials. Philadelphia, Pa. pp1003-1012.

Braids, O. and R. Miller. 1975. Fats, waxes and resins. IN: Soil. pp343-368 IN: Soil Components, Vol. 1, J. Gieseking (ed). Springer-Verlag, New York, N. Y. 526pp.

Bremner, J. M. 1965. Total nitrogen. IN: Methods of Soil Analysis, Part 2. Chemical and biological properties. Am. Soc. Agronomy, Madison, Wis. pp1149-1160.

Cole, D., S. Gessel, L. Fritschen, B. Hrutfiord and P. Schiess. 1976. A study of the interaction of wastewater with terrestrial ecosystems. U.S. Army Corps of Engineers, Wash., D. C. 170pp.

Cowling, E. B. 1962. Comparative biochemistry of the decay of sweetgum sapwood by white rot and brown rot fungi. USDA technical bulletin No. 1258. pp1-79.

Dice, S. F. 1970. The biomass and nutrient flux in a second growth Douglas-fir ecosystem; a study in quantitative ecology. Ph.D. thesis. Univ. of Wash., Seattle. 165pp.

Forest Soils Committee of the Douglas-Fir Region. 1953. Sampling procedures and methods of analysis for forest soils. Univ. of Wash., Seattle. 38pp.

Gessel, S. P. and D. W. Cole. 1965. Influence of removal of forest cover on movement of water and associated elements through soil. Journ. of Amer. Water Works Assoc., 57:1301-1310.

Gieseking, J. (ed) 1975. Soil Components, Vol. 1, Springer-Verlag, New York, N. Y. 526pp.

Goring, C. and J. Hamaker. 1972. Organic chemicals in the soil environment. Marcel Dekker, New York, N. Y. 968pp.

Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Inc. Englewood Cliffs, N. J. 498pp.

Lenette, E. H. and N. J. Schmidt. 1969. Diagnostic procedures for viral and rickettsial infection. Amer. Publ. Health Assoc., 946pp.

Minyard, P. and C. Driver. 1975. Methods of analyses for biological decomposition of wood. Unpublished. Univ. of Wash., Seattle.

Pacific Northwest River Basin Commission. 1970. Water Resources - Appendix V - Columbia-North Pacific Region Comprehensive Framework Study. Pacific Northwest River Basins Commission.

Schlichte, A. K. 1968. Mineralogy of the Everett Soil. M. S. Thesis. Univ. of Wash., Seattle. 59pp.

Schnitzer, M. and S. Kahn. 1972. Humic substances in the environment. Marcel Dekker, Inc., New York, N. Y. 327pp.

Soil Conservation Service. 1973. A soil survey of King Co. Washington. Washington Agricultural Experiment Station. 100pp.

Standard Methods. 1971. J. Taras, A. E. Greenberg, R. D. Hoak, and M. C. Rand (eds.), Amer. Pub. Health Assoc., Wash., D. C. 874pp.

TAPPI Standard (T4m-59). 1961. One percent caustic soda solubility of wood. Technical Assoc. of the Pulp and Paper Industry. New York, N. Y.

TAPPI Standard (T11m-59). 1961. Sampling and preparing wood for analysis. Technical Assoc. of the Pulp and Paper Industry, New York, N. Y.

Troemper, A. P. 1974. The economics of sludge irrigation. IN: Municipal Sludge Mgmt., Proc. Nat. Conference. Sponsored by Office of Research and Dev., U. S. Env. Prot. Agency, Env. Quality Systems, Inc. and Information Transfer, Inc. 257pp.

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

APPENDIX A

Computer printout of all soil solution analyses by treatments, sample date, cm of sludge, water and precipitation for sample period, sample pH, total nitrogen, ammonium nitrogen, nitrate nitrogen, total phosphorus, orthophosphate phosphorus, sodium, potassium, calcium and magnesium as mg/l.

S25 = 100
S25W5 = 100W
S50 = 200
S50W5 = 200W
S75 = 300
S75W5 = 300W

Wonly = water
Contl = control

P21 = 40 on Everett
P22 = 30
P23 = 20
P24 = 10

P31 = 40 on Mashel
P32 = 30
P33 = 20
P34 = 10

P41 = 40 on Wilkeson
P42 = 30
P43 = 20
P44 = 10

			Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
S25	A	377	761109.	7.2000	5.670	NNNNN	.021	60.970	NNNNN	.0010	7.3000	3.470	69.960	10.380
S25	B	378	761109.	7.2000	7.700	NNNNN	.175	279.580	NNNNN	.0010	20.3000	14.470	280.060	36.170
S25	C	379	761109.	7.2000	4.170	NNNNN	.046	210.680	NNNNN	.0160	9.7700	10.440	192.580	26.870
S25	LTR	406	770106.	7.3500	6.940	47.104	.434	46.560	3.0000	4.1300	5.8500	8.210	64.510	10.540
S25	A	407	770106.	7.3500	4.740	73.172	.001	72.310	.2440	.0130	5.8500	2.580	71.520	13.520
S25	B	408	770106.	7.3500	7.180	284.874	.001	284.110	.0440	.0140	6.2800	13.650	368.800	44.250
S25	C	409	770106.	7.3500	4.090	298.572	.178	297.690	.1200	NNNNN	6.1600	4.520	269.900	36.560
S25	LTR	436	770331.	20.6100	5.920	6.084	.110	5.420	NNNNN	3.4900	2.3100	1.330	18.380	2.720
S25	A	437	770331.	20.6100	5.430	9.128	.001	8.550	NNNNN	.5170	6.8400	1.220	31.400	5.030
S25	B	438	770331.	20.6100	5.860	113.462	.001	113.060	NNNNN	.1010	19.1000	9.700	233.020	33.580
S25	C	439	770331.	20.6100	4.030	194.412	.174	193.640	NNNNN	.0680	10.8000	9.070	222.470	35.960
S25	LTR	465	770613.	17.1200	6.170	16.610	.078	15.970	1.9900	3.7700	3.7200	1.080	25.130	3.400
S25	A	467	770613.	17.1200	5.240	37.890	.063	37.370	.0700	.0010	4.6900	.840	41.180	6.540
S25	B	468	770613.	17.1200	6.240	223.508	.001	223.270	.0340	.0290	13.3400	8.280	193.390	22.480
S25	C	466	770613.	17.1200	4.150	216.282	.134	215.690	.1000	.0660	8.5800	9.080	193.390	24.020
S25W5LTR		74	750806.	12.2500	7.370	NNNNN	28.000	7.850	.6100	.7000	13.0000	9.900	13.750	1.800
S25W5A		75	750806.	12.2500	7.080	49.600	1.750	13.920	.1000	.0010	18.4500	8.900	18.800	2.800
S25W5B		76	750806.	12.2500	6.640	5.110	.220	4.470	.0740	.0120	8.6000	2.800	6.050	1.200
S25W5C		77	750806.	12.2500	6.540	1.700	.100	1.250	.0300	.0060	4.5500	.750	5.800	1.000
S25W5LTR		93	750826.	13.0800	7.680	352.790	167.000	135.000	9.2200	11.2110	26.8000	45.200	73.850	13.900
S25W5A		94	750826.	13.0800	7.290	39.500	21.600	12.500	.0240	.0121	23.8500	59.850	93.350	17.100
S25W5B		95	750826.	13.0800	7.270	41.680	14.800	22.200	.1630	.0290	13.1500	27.950	24.300	3.750
S25W5C		284	750826.	13.0800	6.540	1.700	.100	1.250	.0300	.0060	4.5500	.750	5.800	1.000
S25W5LTR		114	750918.	8.8300	7.580	NNNNN	152.940	221.000	NNNNN	19.0000	28.5000	32.700	170.650	38.400
S25W5A		115	750918.	8.8300	4.830	200.870	9.740	188.500	.3700	.1100	21.6500	23.750	203.100	23.650
S25W5B		116	750918.	8.8300	5.500	268.660	12.160	258.000	.2640	.1100	22.8000	28.250	217.000	36.850
S25W5C		117	750918.	8.8300	7.270	40.350	.461	38.100	.2360	9.2000	12.5500	4.600	50.100	8.450
S25W5LTR		134	751014.	9.7100	6.980	NNNNN	.524	372.220	NNNNN	28.9100	15.1500	39.350	225.350	47.750
S25W5A		135	751014.	9.7100	4.650	522.241	37.680	472.620	.3000	.0170	12.3000	37.700	368.300	43.850
S25W5B		136	751014.	9.7100	4.780	532.862	34.680	476.680	.1560	.0100	12.3000	33.450	351.500	53.850
S25W5C		137	751014.	9.7100	7.290	59.254	.280	57.710	.1080	.0010	NNNNN	3.950	54.450	13.750
S25W5LTR		153	751113.	18.9000	6.140	331.830	103.160	164.830	29.0900	28.3530	31.4000	22.050	129.600	30.300
S25W5A		154	751113.	18.9000	4.580	NNNNN	32.180	200.670	NNNNN	.0200	28.3500	26.900	190.750	24.550
S25W5B		155	751113.	18.9000	4.550	632.840	21.240	500.780	10.1900	.0260	46.0000	26.900	498.550	81.750
S25W5C		156	751113.	18.9000	7.050	80.670	.154	79.890	.1550	.0140	11.2500	3.800	53.600	20.050
S25W5LTR		178	760106.	33.1800	7.020	234.264	66.170	71.970	20.2350	21.5000	3.6000	12.800	9.600	8.500
S25W5A		179	760106.	33.1800	5.260	100.610	39.040	87.280	.0800	.0350	3.1000	14.800	10.800	6.300
S25W5B		180	760106.	33.1800	4.660	243.908	16.070	242.060	.0960	.0290	4.0000	12.800	4.400	29.000
S25W5C		285	760106.	33.1800	7.050	80.670	.154	79.890	.1550	.0140	11.2500	3.800	53.600	20.050
S25W5LTR		200	760226.	19.9600	6.300	62.420	.715	55.750	9.9300	12.6400	2.6700	3.500	67.400	15.700
S25W5A		201	760226.	19.9600	4.500	42.160	.887	39.320	.0420	.1730	.7700	3.500	39.600	8.500
S25W5B		202	760226.	19.9600	4.670	106.850	.298	106.220	.0060	.0120	12.1000	13.100	115.500	15.200
S25W5C		203	760226.	19.9600	7.040	155.880	.001	155.160	.0280	.0010	15.9000	3.500	148.400	30.900
S25W5LTR		229	760413.	11.9700	6.510	NNNNN	.881	27.280	NNNNN	10.7200	4.7200	3.870	45.100	8.110
S25W5A		230	760413.	11.9700	5.010	17.189	.181	16.230	.1980	.2210	3.3400	3.240	19.300	3.890
S25W5B		231	760413.	11.9700	6.420	91.356	.001	71.010	.0340	.0010	9.8100	11.200	97.100	12.400
S25W5C		232	760413.	11.9700	6.370	119.406	.001	119.100	.0240	.0010	13.8000	4.190	97.100	19.700
S25W5LTR		256	760603.	19.3200	6.750	NNNNN	2.350	49.710	NNNNN	7.7700	5.4300	9.080	64.090	9.100
S25W5A		257	760603.	19.3200	6.010	28.430	.230	26.620	.0700	.0620	3.2800	4.520	29.220	5.120
S25W5B		258	760603.	19.3200	4.900	73.666	.070	73.360	.0360	.0010	10.1000	2.280	72.540	8.650
S25W5C		259	760603.	19.3200	6.920	NNNNN	.056	80.840	.0270	.0010	16.3800	3.960	79.300	16.280

			Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
S50	LTR	209	760226.	19.9600	5.570	NNNNN	.078	56.720	NNNNN	14.7100	27.6000	14.300	100.300	19.700
S50	A	210	760226.	19.9600	6.170	153.710	4.160	144.220	.2800	.1740	37.8000	22.700	168.700	26.000
S50	B	211	760226.	19.9600	6.180	NNNNN	77.910	436.710	.0820	.0460	51.1000	38.300	343.400	53.300
S50	C	212	760226.	19.9600	7.120	405.400	.279	404.050	.0420	.1780	28.3000	1.100	315.000	67.600
S50	LTR	238	760413.	11.9700	5.190	NNNNN	1.950	27.280	NNNNN	16.8400	11.4000	9.010	50.000	10.100
S50	A	239	760413.	11.9700	6.440	NNNNN	.357	79.010	NNNNN	.5980	11.1000	12.400	58.100	8.700
S50	B	240	760413.	11.9700	5.250	NNNNN	24.550	263.500	.0580	.0190	34.4000	19.800	221.000	33.900
S50	C	241	760413.	11.9700	6.560	NNNNN	.103	438.680	.4620	.0440	44.1000	3.660	369.000	80.200
S50	LTR	265	760603.	9.6400	6.090	NNNNN	1.070	56.060	NNNNN	8.9900	8.0300	6.560	82.680	15.460
S50	A	266	760603.	9.6400	6.630	NNNNN	1.620	53.530	NNNNN	.3440	14.2200	12.520	77.610	16.700
S50	B	267	760603.	9.6400	5.620	146.670	45.200	140.460	.0600	.0100	17.0100	12.710	150.260	22.440
S50	C	268	760603.	9.6400	6.780	342.177	.052	341.670	.2220	.0010	23.2900	3.120	327.660	65.970
S50	LTR	353	760727.	13.8500	6.090	NNNNN	1.070	56.060	NNNNN	8.9900	8.0300	6.560	82.680	15.460
S50	A	354	760727.	13.8500	6.630	NNNNN	1.620	53.530	NNNNN	.3440	14.2200	12.520	77.610	16.700
S50	B	306	760727.	13.8500	4.960	212.260	4.970	206.400	.0420	.0010	10.1000	9.800	122.160	19.390
S50	C	355	760727.	13.8500	6.780	342.177	.052	341.670	.2220	.0010	23.2900	3.120	327.660	65.970
S50	LTR	329	760721.	13.9300	5.760	NNNNN	.317	83.520	NNNNN	10.5290	8.8700	5.680	100.010	16.680
S50	A	330	760721.	13.9300	7.430	93.110	2.101	84.610	.4240	.2160	12.8000	12.700	132.910	22.630
S50	B	345	760721.	13.9300	5.620	146.670	45.200	140.460	.0600	.0100	17.0100	12.710	150.260	22.440
S50	C	331	760921.	13.9300	7.550	NNNNN	.001	375.430	NNNNN	.0010	23.2800	4.520	253.050	29.520
S50	LTR	392	761109.	9.7700	6.270	NNNNN	.178	97.260	NNNNN	9.7500	8.9800	6.270	112.380	20.260
S50	A	393	761109.	9.7700	6.430	91.260	.273	87.480	.1500	.1200	11.3700	6.110	119.670	23.490
S50	B	394	761109.	9.7700	6.360	NNNNN	.355	280.590	NNNNN	.0620	16.4100	6.610	261.840	37.010
S50	C	434	761109.	9.7700	7.550	NNNNN	.001	375.430	NNNNN	.0010	23.2800	4.520	253.050	29.520
S50	LTR	421	770106.	8.1300	5.410	146.544	.729	142.240	NNNNN	7.3700	5.4200	11.110	241.000	32.710
S50	A	422	770106.	8.1300	6.390	117.084	5.372	109.710	.1380	.0210	6.1000	12.960	166.800	25.030
S50	B	423	770106.	8.1300	6.050	244.622	.140	242.710	.0620	.0340	4.9300	12.960	311.100	42.970
S50	C	424	770106.	8.1300	7.090	318.594	.001	317.030	.0820	.0010	6.6500	2.810	319.300	58.340
S50	LTR	451	770331.	21.6400	4.830	43.098	.495	40.780	NNNNN	11.4700	10.8000	7.710	85.240	11.460
S50	A	452	770331.	21.6400	5.170	130.078	.092	128.440	NNNNN	1.2600	19.8500	11.690	148.570	21.670
S50	B	453	770331.	21.6400	5.320	191.308	.016	190.220	NNNNN	.0010	18.5300	9.590	313.950	37.550
S50	C	454	770331.	21.6400	6.130	313.732	.001	313.280	NNNNN	.0010	21.5500	3.210	282.280	45.490
S50	LTR	480	770613.	17.9100	5.500	NNNNN	.362	65.880	NNNNN	7.5600	7.6100	6.680	86.660	10.680
S50	A	481	770613.	17.9100	5.930	97.512	.163	95.360	.0920	.0410	10.9600	9.560	155.190	19.040
S50	B	482	770613.	17.9100	6.400	NNNNN	.225	382.790	NNNNN	.0010	18.5200	12.440	340.510	4.010
S50	C	483	770613.	17.9100	6.810	NNNNN	.001	377.240	NNNNN	.0270	22.5200	3.320	322.680	43.180
S50W5LTR		80	750806.	4.3700	7.180	1.810	.700	.520	.6180	.0010	7.5000	3.150	4.950	1.050
S50W5A		81	750806.	4.3700	7.230	3.510	.290	2.760	.0730	.0010	7.8500	2.700	7.350	2.200
S50W5B		82	750806.	4.3700	6.850	2.420	.300	2.010	.0440	.0010	5.3000	1.100	4.300	1.050
S50W5C		83	750806.	4.3700	7.240	NNNNN	.190	1.730	NNNNN	.0010	6.7500	.850	4.700	1.450
S50W5LTR		105	750826.	15.0400	8.280	NNNNN	162.000	.631	NNNNN	10.3130	23.5500	35.700	27.800	4.650
S50W5A		106	750826.	15.0400	7.860	132.670	6.960	33.200	-.0010	.0557	19.9500	34.850	31.350	5.200
S50W5B		107	750826.	15.0400	6.150	63.090	4.890	57.600	.0480	.0545	14.4500	5.500	82.700	10.250
~~S50W5C~~		~~108~~	~~750826.~~	~~15.0400~~	~~7.380~~	~~NNNNN~~	5.190	.147	NNNNN	.0010	14.4500	11.550	20.700	4.250
S50W5LTR		123	750918.	12.2100	8.130	NNNNN	208.511	82.800	NNNNN	18.5000	28.1000	~~31.850~~	~~59.400~~	~~13.150~~
S50W5A		124	750918.	12.2100	7.650	27.950	170.210	18.000	1.1100	.2900	27.7500	38.100	91.850	17.050
S50W5B		125	750918.	12.2100	6.620	NNNNN	4.140	14.190	NNNNN	.0400	19.4000	13.150	138.200	31.400
S50W5C		286	750918.	12.2100	7.380	NNNNN	5.190	.147	NNNNN	.0010	14.4500	11.550	20.700	4.250
S50W5LTR		143	751014.	12.8900	7.120	NNNNN	209.930	153.150	NNNNN	21.9900	14.2000	33.460	81.400	23.950
S50W5A		144	751014.	12.8900	7.840	498.360	217.870	243.410	2.4100	1.0480	13.2500	38.500	118.400	23.950
S50W5B		145	751014.	12.8900	6.820	307.910	7.100	303.250	.1440	.0010	10.4000	19.050	267.400	98.400
S50W5C		287	751014.	12.8900	7.380	NNNNN	5.190	.147	NNNNN	.0010	14.4500	11.550	20.700	4.250

		Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
S25W5LTR	352	760729.	21.5300	6.750	NNNNN	2.350	49.710	NNNNN	7.7700	5.4300	9.080	64.090	9.100
S25W5A	298	760729.	21.5300	6.710	28.300	.138	26.590	.0700	.0150	3.9300	62.740	40.070	4.580
S25W5B	299	760729.	21.5300	5.950	61.562	.108	61.230	.0360	.0100	4.0000	9.150	40.070	4.260
S25W5C	300	760729.	21.5300	7.360	38.810	.135	30.460	.1560	.1470	5.5600	7.580	2.870	4.100
S25W5LTR	344	760921.	13.9300	6.750	NNNNN	2.350	49.710	NNNNN	7.7700	5.4300	9.080	64.090	9.100
S25W5A	321	760921.	13.9300	7.690	9.853	.140	8.300	.1510	.1270	4.9300	30.980	30.950	35.150
S25W5B	322	760921.	13.9300	6.450	NNNNN	.356	80.180	.0270	.0100	8.9400	14.080	79.970	10.110
S25W5C	323	760921.	13.9300	7.750	NNNNN	.049	64.660	.1180	.0740	12.7300	35.430	70.860	12.300
S25W5LTR	380	761109.	9.7400	7.480	NNNNN	1.345	43.440	NNNNN	2.0600	9.8600	96.750	59.720	8.140
S25W5A	381	761109.	9.7400	7.300	4.500	.001	2.680	.1600	.0010	4.2900	10.440	22.390	2.650
S25W5B	382	761109.	9.7400	5.500	97.390	.227	77.010	.0800	1.4400	10.3900	13.200	72.290	9.580
S25W5C	383	761109.	9.7400	7.350	68.940	.001	60.420	.0800	.0170	12.1600	29.800	34.930	11.780
S25W5LTR	410	770106.	7.3500	6.660	NNNNN	7.948	113.160	NNNNN	1.9500	5.5400	242.600	162.700	18.620
S25W5A	411	770106.	7.3500	6.430	82.238	5.143	76.680	.0680	.1150	4.7400	15.260	105.300	14.800
S25W5B	412	770106.	7.3500	5.620	47.482	.264	47.060	.0226	.0240	5.4200	8.110	50.080	7.120
S25W5C	413	770106.	7.3500	7.580	NNNNN	.001	51.680	NNNNN	.0010	4.1300	61.150	67.810	11.980
S25W5LTR	440	770331.	20.6100	6.000	20.012	.943	17.090	NNNNN	6.0500	5.1000	40.460	27.880	3.680
S25W5A	441	770331.	20.6100	4.760	23.104	.159	22.370	NNNNN	.0010	4.3900	5.200	33.150	4.070
S25W5B	442	770331.	20.6100	5.750	66.798	.001	66.520	NNNNN	2.6700	22.8700	10.850	71.160	10.190
S25W5C	443	770331.	20.6100	5.790	70.232	.001	70.030	NNNNN	.0510	12.6900	4.150	67.640	13.680
S25W5LTR	469	770613.	27.2800	6.050	28.260	2.270	24.770	3.1120	3.6300	5.6600	15.000	28.700	3.700
S25W5A	470	770613.	27.2800	6.140	26.150	.153	25.470	.0600	.0010	4.9100	6.040	27.810	3.170
S25W5B	471	770613.	27.2800	6.020	27.754	.074	27.520	.0620	.1120	5.4500	6.680	31.380	4.010
S25W5C	472	770613.	27.2800	6.090	32.150	.001	31.760	.0400	.0880	7.2800	1.560	38.510	6.770
S50 LTR	66	750703.	4.8000	7.040	NNNNN	.001	.017	NNNNN	.1040	9.2500	8.500	21.000	2.400
S50 A	67	750703.	4.8000	7.140	NNNNN	.001	.001	NNNNN	.0280	10.0000	4.000	21.000	1.600
S50 B	68	750703.	4.8000	7.620	NNNNN	.001	.009	NNNNN	.0010	NNNNN	NNNNN	NNNNN	NNNNN
S50 C	69	750703.	4.8000	7.720	NNNNN	.001	.056	NNNNN	.0010	NNNNN	NNNNN	NNNNN	NNNNN
S50 LTR	10	750806.	5.6900	7.500	NNNNN	50.000	25.000	NNNNN	.5000	15.0000	30.000	40.000	6.000
S50 A	12	750806.	5.6900	7.800	NNNNN	25.000	12.000	NNNNN	.5000	20.0000	30.000	30.000	4.000
S50 B	15	750806.	5.6900	8.000	NNNNN	75.000	7.000	NNNNN	.0010	10.0000	20.000	15.000	2.000
S50 C	17	750806.	5.6900	7.500	NNNNN	.001	.200	NNNNN	.0010	5.0000	.750	20.000	3.000
S50 LTR	101	750826.	11.1800	8.050	NNNNN	107.000	47.200	NNNNN	1.1050	23.5500	67.600	65.000	11.400
S50 A	102	750826.	11.1800	8.320	NNNNN	55.000	25.100	NNNNN	.0635	25.8000	61.550	41.950	7.350
S50 B	103	750826.	11.1800	8.370	158.590	115.000	13.300	-.0010	.0010	24.5000	44.350	34.900	5.100
S50 C	104	750826.	11.1800	7.440	NNNNN	.181	.451	NNNNN	.0010	11.2000	1.500	36.700	5.650
S50 LTR	11	750918.	5.8600	7.900	NNNNN	250.000	140.000	NNNNN	3.0000	20.0000	65.000	75.000	26.000
S50 A	13	750918.	5.8600	7.900	NNNNN	100.000	150.000	NNNNN	.0800	50.0000	75.000	110.000	25.000
S50 B	122	750918.	5.8600	8.140	NNNNN	191.810	74.500	NNNNN	3.5000	23.9500	38.100	47.800	6.700
S50 C	18	750918.	5.8600	7.200	NNNNN	.200	20.000	NNNNN	.0010	13.0000	1.600	45.000	15.000
S50 LTR	21	751014.	7.4400	7.730	NNNNN	396.160	232.260	NNNNN	5.1500	16.0500	63.050	85.600	21.900
S50 A	14	751014.	7.4400	7.900	NNNNN	100.000	150.000	NNNNN	.9000	75.0000	90.000	195.000	40.000
S50 B	16	751014.	7.4400	7.800	250.000	193.000	200.000	NNNNN	1.5000	40.0000	45.000	140.000	20.000
S50 C	19	751014.	7.4400	7.200	NNNNN	.200	40.000	NNNNN	.0010	15.0000	1.700	70.000	30.000
S50 LTR	22	751113.	17.3600	7.090	NNNNN	265.310	253.420	NNNNN	9.0430	81.5000	62.100	129.600	32.300
S50 A	163	751113.	17.3600	7.490	NNNNN	141.730	342.010	NNNNN	.1090	97.5000	104.150	242.150	48.250
S50 B	164	751113.	17.3600	7.590	481.520	196.940	376.840	.0140	.0580	55.5000	55.250	198.150	36.400
S50 C	165	751113.	17.3600	7.090	NNNNN	.336	57.690	NNNNN	.0010	16.0000	1.900	86.950	39.700
S50 LTR	185	760106.	31.2700	5.320	NNNNN	150.210	214.760	NNNNN	16.4140	7.1000	46.100	172.000	35.300
S50 A	186	760106.	31.2700	7.250	NNNNN	152.840	358.560	NNNNN	.8240	9.4000	76.400	24.000	47.200
S50 B	20	760106.	31.2700	7.200	NNNNN	.150	100.000	NNNNN	.0010	9.0000	1.300	60.000	38.000
S50 C	225	760106.	31.2700	7.430	NNNNN	.042	156.690	NNNNN	.0010	3.8000	.700	34.000	36.600

			Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
S25	LTR	60	750703.	4.8000	6.850	NNNNN	.001	.004	NNNNN	.3030	4.3500	8.150	19.000	1.750
S25	A	61	750703.	4.8000	7.120	NNNNN	.001	.058	NNNNN	.0010	10.3500	5.150	19.000	1.750
S25	B	2	750703.	4.8000	7.300	NNNNN	NNNNN	NNNNN	NNNNN	.1000	10.1000	54.000	19.000	2.300
S25	C	62	750703.	4.8000	7.380	NNNNN	.091	.032	NNNNN	.0010	7.9500	.900	15.500	1.400
S25	LTR	1	750806.	3.8000	6.850	.004	NNNNN	.004	.0000	.3030	4.3500	8.150	19.000	1.750
S25	A	5	750806.	3.8000	7.140	NNNNN	60.000	50.000	NNNNN	.7500	15.0000	25.000	35.000	4.500
S25	B	279	750806.	3.8000	7.300	NNNNN	.100	.700	NNNNN	.0010	9.0000	80.000	21.000	2.500
S25	C	73	750806.	3.8000	6.590	NNNNN	.090	.076	NNNNN	.0010	5.6500	1.050	11.300	1.400
S25	LTR	90	750826.	9.2600	7.780	NNNNN	102.000	76.600	NNNNN	4.0570	25.1500	40.000	68.550	8.550
S25	A	91	750826.	9.2600	7.790	NNNNN	137.000	74.800	NNNNN	1.6720	25.8000	47.750	47.300	8.250
S25	B	3	750826.	9.2600	7.300	NNNNN	NNNNN	NNNNN	NNNNN	.1000	8.4000	162.000	29.000	2.500
S25	C	92	750826.	9.2600	7.350	NNNNN	.823	1.050	NNNNN	.0010	6.3000	1.150	9.850	1.050
S25	LTR	4	750918.	3.9600	7.630	NNNNN	201.300	173.600	NNNNN	6.0270	20.9300	43.100	85.620	19.350
S25	A	6	750918.	3.9600	6.000	NNNNN	60.000	175.000	NNNNN	.7500	20.0000	60.000	175.000	25.000
S25	B	8	750918.	3.9600	7.450	NNNNN	.343	1.398	NNNNN	.0010	7.6500	163.950	33.900	2.700
S25	C	113	750918.	3.9600	7.110	NNNNN	.386	11.400	NNNNN	.0010	6.1500	1.550	18.490	2.500
S25	LTR	132	751014.	5.9000	7.520	NNNNN	303.568	264.710	NNNNN	8.0150	16.0500	47.850	100.750	30.650
S25	A	7	751014.	5.9000	5.070	NNNNN	16.170	253.560	NNNNN	.0160	13.2500	68.150	225.350	41.250
S25	B	9	751014.	5.9000	6.000	NNNNN	10.000	25.000	NNNNN	.0100	15.0000	75.000	36.000	5.000
S25	C	133	751014.	5.9000	7.350	NNNNN	.466	21.810	NNNNN	.0310	1.3000	2.900	29.250	4.200
S25	LTR	224	751113.	13.8200	7.250	272.570	106.180	77.650	12.7000	11.5000	27.0000	15.900	45.550	16.800
S25	A	280	751113.	13.8200	4.700	337.380	60.807	245.460	.1140	.0270	48.0000	66.000	194.150	32.750
S25	B	151	751113.	13.8200	7.170	93.610	28.700	54.470	.0940	.0220	22.0000	14.900	40.450	8.650
S25	C	152	751113.	13.8200	7.090	81.920	.040	81.580	.0710	.4400	8.2000	38.150	99.900	14.750
S25	LTR	175	760106.	28.7300	8.230	31.400	99.280	25.860	12.0800	13.0000	5.3000	14.800	2.500	3.800
S25	A	281	760106.	28.7300	7.500	NNNNN	56.710	228.780	NNNNN	.0250	4.8000	40.000	33.200	23.300
S25	B	176	760106.	28.7300	8.040	127.920	79.050	30.150	2.2900	NNNNN	3.2000	20.900	2.500	4.400
S25	C	177	760106.	28.7300	8.410	98.360	105.060	3.400	.5970	.4180	3.1000	16.800	4.500	4.400
S25	LTR	196	760226.	19.9600	7.320	36.540	19.850	22.680	6.7200	12.6700	3.6200	5.900	24.400	8.100
S25	A	199	760226.	19.9600	4.400	173.910	24.080	166.810	.0770	.0380	15.9000	20.300	151.000	23.300
S25	B	197	760226.	19.9600	4.320	119.600	46.470	77.730	.0590	.1550	10.2700	15.500	24.400	4.900
S25	C	198	760226.	19.9600	5.950	221.180	38.070	216.110	.0980	.0590	8.3700	11.900	219.000	30.900
S25	LTR	226	760413.	11.9700	6.850	19.350	2.030	17.290	NNNNN	7.8700	3.5000	2.610	26.600	7.370
S25	A	282	760413.	11.9700	5.640	NNNNN	.926	41.910	NNNNN	1.6000	9.0100	151.000	40.200	7.940
S25	B	227	760413.	11.9700	4.090	115.820	5.550	109.740	.6160	1.3200	8.1200	9.740	80.900	20.200
S25	C	228	760413.	11.9700	4.480	152.210	2.380	151.080	.1360	.0770	7.2300	7.750	149.000	28.400
S25	LTR	253	760603.	9.2400	7.250	22.570	.343	20.200	NNNNN	5.3900	3.1900	2.470	32.090	787.000
S25	A	283	760603.	9.2400	7.820	NNNNN	.940	21.210	NNNNN	9.5600	17.1900	572.570	50.580	6.430
S25	B	254	760603.	9.2400	6.210	NNNNN	3.250	239.120	.0940	.1060	19.1600	54.460	200.950	35.580
S25	C	255	760603.	9.2400	4.510	71.010	.315	69.380	NNNNN	.0560	6.5100	5.450	65.780	9.590
S25	LTR	296	760727.	13.9100	7.480	NNNNN	.322	18.420	NNNNN	3.8300	3.0200	1.970	39.260	8.980
S25	A	341	760727.	13.9100	7.820	NNNNN	.940	21.210	NNNNN	9.5600	17.1900	572.570	50.580	6.430
S25	B	342	760727.	13.9100	6.210	NNNNN	3.250	239.120	.0940	.1060	19.1600	54.460	200.950	35.580
S25	C	~~297~~	~~760727.~~	~~13.9100~~	~~4.590~~	~~88.360~~	~~.203~~	~~27.230~~	~~.1320~~	~~.0660~~	~~3.8500~~	.960	68.520	11.180
S25	LTR	318	760921.	13.9300	7.620	NNNNN	.326	13.790	NNNNN	5.9520	5.8200	.960	30.780	6.210
S25	A	319	760921.	13.9300	6.910	NNNNN	.040	57.420	NNNNN	.0010	8.4900	4.610	59.930	10.420
S25	B	370	760921.	13.9300	6.210	NNNNN	3.250	239.120	.0940	.1060	19.1600	54.460	200.950	35.580
S25	C	320	760921.	13.9300	4.310	NNNNN	.101	195.250	NNNNN	.0010	9.7600	10.660	161.960	21.380
S25	LTR	376	761109.	7.2000	7.280	14.800	.199	14.240	.1200	4.5600	3.4900	2.000	32.790	5.230

		Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
S50W5LTR	166	751113.	21.4400	5.430	NNNNN	100.890	105.630	NNNNN	26.4330	35.9000	24.000	90.650	24.950
S50W5A	167	751113.	21.4400	7.430	330.520	115.010	153.890	2.9900	2.9030	37.0000	26.900	111.050	23.750
S50W5B	168	751113.	21.4400	6.180	490.520	4.700	484.340	.1150	.0010	38.7500	49.400	480.000	85.850
S50W5C	169	751113.	21.4400	7.390	NNNNN	.001	.100	NNNNN	.0010	5.7500	.800	20.600	3.250
S50W5LTR	187	760106.	35.0800	7.360	103.740	56.710	64.760	12.3900	20.1310	3.4000	14.800	52.000	11.400
S50W5A	188	760106.	35.0800	7.810	120.240	58.810	67.600	5.5100	6.6590	3.6000	22.000	54.000	9.300
S50W5B	189	760106.	35.0800	5.850	207.810	5.880	205.810	.1400	.0070	3.2000	12.800	180.000	19.000
S50W5C	288	760106.	35.0800	7.380	NNNNN	5.190	.147	NNNNN	.0010	14.4500	11.550	20.700	4.250
S50W5LTR	213	760226.	19.9600	6.830	85.580	.342	32.340	15.8800	20.1800	.7700	4.700	44.600	9.000
S50W5A	214	760226.	19.9600	7.070	62.050	1.420	58.220	2.3400	5.8400	5.5000	4.700	64.900	13.900
S50W5B	215	760226.	19.9600	5.160	151.214	.782	150.380	.0800	.0120	15.9000	13.100	143.400	16.600
S50W5C	216	760226.	19.9600	7.450	112.030	.171	110.800	.0600	.0340	4.5000	-.001	102.800	19.700
S50W5LTR	242	760413.	11.9700	7.060	NNNNN	.328	17.730	NNNNN	11.6200	2.1800	13.700	25.600	4.120
S50W5A	243	760413.	11.9700	7.270	NNNNN	.512	28.460	NNNNN	3.8400	5.5300	4.400	38.600	8.240
S50W5B	244	760413.	11.9700	5.180	99.540	.272	79.160	-.0010	.0870	10.6000	11.800	64.600	7.320
S50W5C	245	760413.	11.9700	7.440	NNNNN	.001	155.360	NNNNN	.0090	9.8100	2.610	139.000	29.300
S50W5LTR	360	760603.	19.2800	7.060	NNNNN	.328	17.730	NNNNN	11.6200	2.1800	13.700	25.600	4.120
S50W5A	269	760603.	19.2800	7.410	NNNNN	1.240	59.400	NNNNN	3.1300	6.2400	3.120	69.160	16.280
S50W5B	270	760603.	19.2800	5.380	74.624	.080	74.400	.0260	.0010	11.0800	11.780	77.610	10.540
S50W5C	271	760603.	19.2800	7.350	NNNNN	.047	174.250	NNNNN	.0010	13.4200	3.400	190.810	40.510
S50W5LTR	307	760729.	21.4700	7.010	NNNNN	.592	73.090	NNNNN	10.2000	4.3400	4.250	62.020	11.380
S50W5A	308	760729.	21.4700	7.350	NNNNN	1.100	69.810	2.8700	2.8700	4.2300	4.120	55.510	10.180
S50W5B	309	760729.	21.4700	5.980	76.684	.001	76.420	.0440	.0010	4.0800	6.140	45.760	7.570
S50W5C	310	760729.	21.4700	7.660	143.991	1.070	143.380	.0570	83.0900	8.4700	1.700	90.460	17.990
S50W5LTR	332	760921.	13.9300	7.390	NNNNN	.968	49.660	NNNNN	9.0740	7.1600	8.170	79.970	11.980
S50W5A	333	760921.	13.9300	7.850	NNNNN	.421	18.520	NNNNN	2.8120	5.1500	3.990	43.540	6.350
S50W5B	335	760921.	13.9300	6.710	NNNNN	.001	77.510	.0360	.0140	9.4600	13.330	94.550	12.610
S50W5C	336	760921.	13.9300	8.120	NNNNN	.151	89.600	NNNNN	.0010	10.5000	3.360	132.810	22.000
S50W5LTR	395	761109.	11.0400	6.010	80.390	1.595	73.640	7.5900	8.7900	8.7100	9.300	83.220	11.980
S50W5A	396	761109.	11.0400	7.230	59.990	.313	56.460	2.2200	2.1300	7.3800	7.460	63.730	8.770
S50W5B	397	761109.	11.0400	6.320	NNNNN	.001	81.600	NNNNN	.5550	9.0700	11.070	83.220	11.390
S50W5C	398	761109.	11.0400	7.650	105.166	.054	104.310	NNNNN	.0260	10.5700	3.630	108.740	22.630
S50W5LTR	425	770106.	8.1300	4.140	162.788	12.859	150.180	7.6000	9.5900	6.4000	18.030	203.900	26.310
S50W5A	426	770106.	8.1300	4.930	119.786	5.455	113.080	1.9000	1.7500	6.2800	18.490	335.800	30.150
S50W5B	427	770106.	8.1300	5.690	80.006	.049	79.580	.0540	.0010	5.9400	3.040	47.210	25.030
S50W5C	428	770106.	8.1300	7.280	89.658	.051	89.160	.1000	.3310	3.9400	3.040	170.900	42.970
S50W5LTR	455	770331.	21.1300	4.490	51.144	1.783	47.570	NNNNN	11.7800	8.3500	6.660	57.430	8.680
S50W5A	456	770331.	21.1300	4.670	57.028	1.312	54.990	NNNNN	4.8900	9.2900	7.400	64.120	8.360
S50W5B	457	770331.	21.1300	4.960	113.792	.001	113.590	NNNNN	.0010	10.8000	10.850	113.390	1.450
S50W5C	458	770331.	21.1300	5.020	65.378	.001	65.200	NNNNN	.0010	10.6100	10.640	10.610	1.450
S50W5LTR	484	770613.	28.0700	4.350	57.322	3.740	52.760	6.3000	8.4400	7.6100	8.440	59.020	7.690
S50W5A	485	770613.	28.0700	4.660	46.738	1.040	44.080	2.5100	3.4500	6.6400	7.480	52.770	5.770
S50W5B	486	770613.	28.0700	6.120	66.004	.001	65.880	.0340	.0120	7.6100	10.360	71.500	8.920
S50W5C	487	770613.	28.0700	6.410	116.264	.001	115.960	.0360	.0010	9.4500	2.360	116.080	19.420
S75 LTR	63	750703.	4.8000	4.890	NNNNN	.377	.561	NNNNN	.1230	8.9500	3.800	15.500	1.300
S75 A	64	750703.	4.8000	4.120	NNNNN	.345	.197	NNNNN	.0010	7.4000	2.250	5.550	.600
S75 B	65	750703.	4.8000	NNNNN	NNNNN	.042	.023	NNNNN	.0480	NNNNN	NNNNN	NNNNN	NNNNN
S75 C	366	750703.	4.8000	NNNNN	NNNNN	.151	.306	NNNNN	.0010	4.6000	.750	11.100	2.350
S75 LTR	290	750806.	7.6000	4.890	NNNNN	.377	.516	NNNNN	.1230	8.9500	3.800	15.500	1.300
S75 A	26	750806.	7.6000	6.750	NNNNN	26.000	.230	NNNNN	.0410	18.4500	18.800	18.800	3.550
S75 B	27	750806.	7.6000	NNNNN	NNNNN	.042	.023	NNNNN	.0480	NNNNN	NNNNN	NNNNN	NNNNN
S75 C	367	750806.	7.6000	NNNNN	NNNNN	.151	.306	NNNNN	.0010	4.6000	.750	11.100	2.350

			Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
875	LTR	96	750826.	13.0800	8.240	NNNNN	199.000	57.000	NNNNN	6.8750	30.3500	53.800	36.700	6.900
875	A	97	750826.	13.0800	7.780	NNNNN	96.700	48.200	NNNNN	NNNNN	27.4500	46.900	22.500	3.450
875	B	28	750826.	13.0800	NNNNN	NNNNN	.042	.023	NNNNN	.0480	NNNNN	NNNNN	NNNNN	NNNNN
875	C	369	750826.	13.0800	NNNNN	NNNNN	.151	.306	NNNNN	.0010	4.6000	.750	11.100	2.350
875	LTR	118	750918.	5.8600	7.920	NNNNN	164.167	92.400	NNNNN	8.1000	29.6500	39.900	47.800	11.600
875	A	23	750918.	5.8600	7.800	NNNNN	150.000	110.000	NNNNN	.0010	22.0000	60.000	40.000	11.000
875	B	29	750918.	5.8600	NNNNN	NNNNN	.042	.023	NNNNN	.0480	NNNNN	NNNNN	NNNNN	NNNNN
875	C	368	750918.	5.8600	NNNNN	NNNNN	.151	.306	NNNNN	.0010	4.6000	.750	11.100	2.350
875	LTR	138	751014.	7.1700	7.780	NNNNN	259.590	266.740	NNNNN	8.5000	17.0000	56.300	122.600	31.600
875	A	139	751014.	7.1700	7.890	NNNNN	201.220	203.240	NNNNN	.0520	16.0500	53.750	64.600	21.150
875	B	30	751014.	7.1700	NNNNN	NNNNN	.042	.023	NNNNN	.0480	NNNNN	NNNNN	NNNNN	NNNNN
875	C	371	751014.	7.1700	NNNNN	NNNNN	.026	.032	NNNNN	.0180	NNNNN	NNNNN	NNNNN	NNNNN
875	LTR	157	751113.	14.4600	7.820	348.860	131.900	126.330	12.6800	12.4030	37.5000	29.850	86.950	22.100
875	A	158	751113.	14.4600	7.310	426.560	161.900	244.460	.0400	.0950	65.0000	57.200	125.850	26.600
875	B	159	751113.	14.4600	4.710	NNNNN	111.480	155.790	NNNNN	.0770	52.5000	46.450	85.100	15.150
875	C	33	751113.	14.4600	NNNNN	NNNNN	.151	.306	NNNNN	.0010	4.6000	.750	11.100	2.350
875	LTR	181	760106.	30.0000	8.080	NNNNN	100.860	60.240	NNNNN	10.2200	4.0000	20.000	6.700	6.700
875	A	31	760106.	30.0000	6.660	NNNNN	39.460	243.070	NNNNN	.0470	7.0000	59.200	38.400	40.800
875	B	24	760106.	30.0000	4.730	NNNNN	95.000	225.000	NNNNN	.0500	52.0000	43.000	150.000	30.000
875	C	32	760106.	30.0000	7.590	NNNNN	.058	7.720	NNNNN	.0010	2.3000	-.001	3.000	.780
875	LTR	204	760226.	19.9600	7.100	54.990	13.210	43.490	.6490	5.6200	4.5000	7.100	49.700	14.800
875	A	34	760226.	19.9600	5.720	67.130	5.980	58.780	.1140	.0470	15.0000	16.700	80.100	15.700
875	B	205	760226.	19.9600	4.750	342.190	77.250	275.190	.0200	.0460	52.0000	39.500	194.000	40.300
875	C	35	760226.	19.9600	7.100	70.422	.065	67.780	.0080	.0150	8.3000	1.100	75.000	18.800
875	LTR	233	760413.	11.9700	6.750	37.720	6.190	34.090	7.5400	6.0400	4.8800	4.710	33.700	8.240
875	A	36	760413.	11.9700	5.630	41.760	4.350	37.630	.0900	.0570	7.3100	11.500	43.400	6.410
875	B	234	760413.	11.9700	4.710	NNNNN	48.740	264.020	NNNNN	.0830	35.9000	27.700	146.000	31.200
875	C	37	760413.	11.9700	5.880	104.942	.283	104.640	.0340	.5260	11.6000	2.930	79.200	18.800
875	LTR	260	760603.	11.6800	6.940	94.740	8.630	81.700	4.8000	4.9500	5.4300	4.050	82.680	19.160
875	A	291	760603.	11.6800	5.630	41.760	4.350	37.630	.0900	.0570	7.3100	11.500	43.400	6.410
875	B	261	760603.	11.6800	4.530	NNNNN	39.010	187.380	NNNNN	.0460	21.4000	24.670	146.880	32.710
875	C	38	760603.	11.6800	6.540	125.316	.053	125.050	.0280	.0010	14.5800	3.120	114.780	31.480
875	LTR	301	760729.	8.7900	6.370	NNNNN	8.860	187.290	NNNNN	.0520	7.5300	6.930	134.350	20.990
875	A	356	760729.	8.7900	5.720	59.210	2.660	53.530	.1140	.0180	6.6900	11.500	62.400	10.950
875	B	357	760729.	8.7900	4.530	NNNNN	39.010	187.380	NNNNN	.0460	21.4000	24.670	146.880	32.710
875	C	358	760729.	8.7900	6.540	125.316	.053	125.050	.0280	.0010	14.5800	3.120	114.780	31.480
875	LTR	324	760921.	13.9300	7.130	53.962	.346	49.750	3.9160	5.4070	7.3000	4.790	78.150	12.610
875	A	325	760921.	13.9300	7.300	99.122	.102	95.910	.1240	.0100	9.9800	11.280	129.160	21.380
875	B	346	760921.	13.9300	4.530	NNNNN	39.010	187.380	NNNNN	.0460	21.4000	24.670	146.880	32.710
875	C	326	760921.	13.9300	6.970	NNNNN	.075	157.710	NNNNN	.0010	14.1400	4.250	143.740	21.510
875	LTR	384	761109.	10.2600	7.090	78.780	.127	76.380	.9600	.5190	7.6500	7.180	83.220	14.850
875	A	385	761109.	10.2600	6.640	92.800	.086	91.380	.0800	.0650	8.6200	8.950	79.580	14.350
875	B	386	761109.	10.2600	5.170	NNNNN	.604	134.720	NNNNN	.0010	13.1400	16.880	112.380	20.770
875	C	387	761109.	10.2600	6.320	155.520	.056	155.360	.0300	.0010	14.7300	4.480	170.710	34.480
875	LTR	414	770106.	11.1200	5.360	162.355	.367	160.530	.2650	.4220	4.9300	9.730	179.200	23.750
875	A	415	770106.	11.1200	5.060	159.330	.025	158.890	.0540	.0010	5.3600	10.880	220.400	31.150
875	B	416	770106.	11.1200	4.600	123.840	.094	123.500	.0280	.0130	4.2500	14.340	112.300	19.930
875	C	417	770106.	11.1200	6.470	NNNNN	.094	185.350	NNNNN	.0010	4.8700	3.500	216.300	42.970
875	LTR	444	770331.	20.8700	5.290	89.722	.082	88.790	NNNNN	.8070	11.1800	4.670	99.310	16.900
875	A	445	770331.	20.8700	5.070	71.388	.039	70.230	NNNNN	.0140	11.9300	4.570	99.310	12.930
875	B	446	770331.	20.8700	4.510	112.678	.001	112.080	NNNNN	.0010	13.8200	11.060	166.170	28.020
875	C	447	770331.	20.8700	5.460	NNNNN	.044	172.640	NNNNN	.0010	19.1000	3.940	197.830	35.960

		Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
S75W5LTR	477	770613.	26.7900	4.920	33.598	1.660	31.530	2.3140	4.2200	5.9900	5.240	37.620	5.700
S75W5A	478	770613.	26.7900	5.730	50.440	.141	48.720	NNNNN	.3590	6.4200	8.600	56.790	7.380
S75W5B	479	770613.	26.7900	5.280	130.654	.001	130.380	.0340	.0010	9.8800	16.440	133.020	14.750
WONLYLTR	70	750703.	4.8000	6.170	3.276	.001	.322	.2930	.0550	9.2500	6.600	12.000	1.250
WONLYA	71	750703.	4.8000	6.770	1.002	.142	.192	.1040	.0350	6.8000	3.800	4.450	.550
WONLYB	39	750703.	4.8000	7.000	NNNNN	.001	.001	-.0010	.0010	9.5000	1.200	8.900	1.400
WONLYC	72	750703.	4.8000	6.830	NNNNN	.044	.028	NNNNN	.0010	8.8500	.900	19.000	1.950
WONLYLTR	84	750806.	9.7800	7.020	1.940	.050	.210	.3330	.0640	6.4000	6.200	6.900	1.050
WONLYA	85	750806.	9.7800	6.760	1.832	.020	.032	.1200	.0050	6.0000	3.550	4.300	.700
WONLYB	40	750806.	9.7800	7.000	NNNNN	.001	.001	-.0010	.0010	8.5000	1.500	8.900	1.400
WONLYC	86	750806.	9.7800	6.670	NNNNN	.160	.220	NNNNN	.0010	6.7500	.550	13.300	1.950
WONLYLTR	109	750826.	10.3900	7.250	NNNNN	2.720	.216	NNNNN	.1580	9.2500	5.200	5.750	.850
WONLYA	110	750826.	10.3900	7.020	1.477	2.740	.173	.0680	.0010	9.2500	4.150	5.050	.750
WONLYB	41	750826.	10.3900	7.000	NNNNN	.001	.001	-.0010	.0010	7.5000	1.800	8.900	1.400
WONLYC	42	750826.	10.3900	6.800	NNNNN	.190	1.250	NNNNN	NNNNN	6.6000	1.100	12.700	1.870
WONLYLTR	126	750918.	7.6400	7.130	NNNNN	1.510	1.727	NNNNN	.2300	6.5000	5.950	8.500	1.200
WONLYA	127	750918.	7.6400	6.620	14.545	.266	3.185	3.5700	.0010	7.2500	3.650	5.000	.850
WONLYB	128	750918.	7.6400	6.920	2.210	.377	.530	.0600	.0010	6.1500	1.950	8.700	1.300
WONLYC	129	750918.	7.6400	7.190	NNNNN	.214	2.775	NNNNN	.0010	6.5000	1.400	12.200	1.800
WONLYLTR	146	751014.	7.1700	7.310	8.703	.479	5.240	.2900	.0870	6.5500	3.700	11.500	2.050
WONLYA	147	751014.	7.1700	7.040	2.921	.315	.221	.3080	.0170	5.7500	3.600	3.850	.900
WONLYB	148	751014.	7.1700	7.150	NNNNN	1.130	1.410	NNNNN	.0010	5.3000	1.750	5.800	1.200
WONLYC	43	751014.	7.1700	7.250	NNNNN	.001	2.500	-.0010	.0010	3.5000	.800	11.000	1.700
WONLYLTR	170	751113.	16.3600	6.890	2.050	.066	.270	.2580	.0380	2.9000	2.450	5.300	.800
WONLYA	171	751113.	16.3600	6.810	1.965	.263	.165	.1440	.0160	3.2500	3.250	3.550	.650
WONLYB	172	751113.	16.3600	7.050	1.079	.049	.499	.0640	.0010	2.6000	1.300	4.050	.750
WONLYC	44	751113.	16.3600	7.250	NNNNN	.001	1.700	-.0010	.0010	4.5000	1.000	9.500	1.500
WONLYLTR	190	760106.	31.2700	7.160	.793	.006	.165	.3380	.2370	1.3000	1.280	3.000	.160
WONLYA	191	760106.	31.2700	7.210	.653	.001	.165	.0980	.0460	.8000	1.480	1.700	-.001
WONLYB	192	760106.	31.2700	7.370	.910	.068	.554	.2790	.2430	1.3000	.570	2.300	.120
WONLYC	45	760106.	31.2700	7.250	NNNNN	.001	.760	-.0010	.0010	5.5000	1.200	8.200	1.300
WONLYLTR	217	760226.	19.9600	7.110	1.023	.171	.123	.2060	.4490	1.1000	2.800	5.700	.890
WONLYA	218	760226.	19.9600	7.200	.543	.001	.074	.0800	.0690	1.0000	2.800	2.900	.500
WONLYB	219	760226.	19.9600	7.190	.579	.001	.147	.0220	.0010	1.1000	1.100	3.400	.590
WONLYC	220	760226.	19.9600	7.360	1.357	.001	.053	.1080	.0010	2.6000	.620	7.000	1.100
WONLYLTR	246	760413.	11.9700	7.120	NNNNN	.001	NNNNN	.2420	.2040	1.7500	1.940	4.650	7.670
WONLYA	247	760413.	11.9700	7.120	2.565	.001	2.140	.0830	.0290	1.6800	2.200	2.490	.496
WONLYB	248	760413.	11.9700	7.270	NNNNN	.001	NNNNN	.0440	.0010	2.0100	1.100	3.140	.604
WONLYC	249	760413.	11.9700	7.420	12.632	.001	12.190	.0400	.0010	2.4000	.548	4.410	.756
WONLYLTR	272	760603.	14.2000	6.980	.935	.001	.043	NNNNN	.1960	2.0200	2.840	6.240	.850
WONLYA	278	760603.	14.2000	7.030	.749	.043	.001	.1060	.0190	1.9300	2.930	3.880	.520
WONLYB	273	760603.	14.2000	7.070	NNNNN	.032	.516	NNNNN	.0010	2.6500	1.070	4.210	.560
WONLYC	274	760603.	14.2000	7.250	NNNNN	.045	.040	NNNNN	.0010	3.5500	.330	5.730	.850
WONLYLTR	311	760729.	13.8500	7.190	NNNNN	.133	NNNNN	.3800	.3200	1.1600	2.360	3.600	.520
WONLYA	312	760729.	13.8500	7.230	.548	.078	.042	.0840	.0710	1.0800	1.440	1.890	.300
WONLYB	313	760729.	13.8500	7.180	.327	.031	.015	.0340	.0100	1.2700	.600	1.980	.300
WONLYC	314	760729.	13.8500	7.480	NNNNN	.001	.001	NNNNN	.0280	1.9500	.400	4.250	.580
WONLYLTR	349	760921.	13.9300	7.190	NNNNN	.133	NNNNN	.3800	.3200	1.1600	2.360	3.600	.520
WONLYA	350	760921.	13.9300	7.230	.548	.078	.042	.0840	.0710	1.0800	1.440	1.890	.300
WONLYB	337	760921.	13.9300	7.310	NNNNN	.001	.021	.0420	.4710	4.9300	1.760	5.450	.670
WONLYC	338	760921.	13.9300	7.500	NNNNN	.001	.007	NNNNN	.0010	4.7800	.610	10.730	1.450

		Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
S75 LTR	473	770613.	17.3900	6.430	62.176	.317	60.630	.4880	.4510	6.6400	6.520	75.060	9.230
S75 A	474	770613.	17.3900	5.710	77.350	.881	75.580	.0620	.0010	7.6100	10.040	95.570	11.830
S75 B	475	770613.	17.3900	4.580	NNNNN	4.050	128.680	NNNNN	.0010	11.5000	15.800	128.120	20.190
S75 C	476	770613.	17.3900	548.000	222.516	.094	222.260	.0010	.0270	17.0100	1.240	278.100	37.820
S75W5LTR	79	750806.	5.0100	6.950	1.890	1.000	1.090	.1030	.0070	7.1000	3.050	6.900	1.450
S75W5A	78	750806.	5.0100	7.150	NNNNN	.240	9.760	NNNNN	.0050	8.9500	4.350	17.250	3.750
S75W5B	292	750806.	5.0100	NNNNN	NNNNN	.042	.023	NNNNN	.0480	NNNNN	NNNNN	NNNNN	NNNNN
S75W5LTR	98	750826.	16.9400	7.630	188.802	92.900	.342	3.2540	3.5310	23.5500	38.300	26.050	3.550
S75W5A	99	750826.	16.9400	7.670	142.200	79.800	35.200	.1260	.0629	22.5500	36.550	34.900	4.800
S75W5B	293	750826.	16.9400	NNNNN	NNNNN	.042	.023	NNNNN	.0480	NNNNN	NNNNN	NNNNN	NNNNN
S75W5C	100	750826.	16.9400	7.290	NNNNN	.979	.262	NNNNN	.0010	11.8500	2.000	25.250	3.150
S75W5LTR	119	750918.	10.9400	8.180	NNNNN	195.840	42.200	NNNNN	5.0000	27.0000	25.550	32.600	7.100
S75W5A	120	750918.	10.9400	7.350	272.670	162.510	232.500	.5740	.1000	27.3500	35.400	121.950	17.800
S75W5B	121	750918.	10.9400	7.060	182.910	88.440	176.500	.3150	.1000	29.2500	49.800	121.950	24.450
S75W5LTR	140	751014.	10.9800	7.130	NNNNN	152.840	115.630	NNNNN	7.4300	13.2500	28.350	80.550	27.300
S75W5A	141	751014.	10.9800	6.650	519.730	138.760	360.050	5.8840	.0480	13.2500	37.700	242.200	36.600
S75W5B	142	751014.	10.9800	4.840	650.796	33.790	618.660	.1360	.2850	16.0500	67.300	477.650	113.250
S75W5LTR	160	751113.	18.9000	7.880	191.260	60.550	75.570	11.4400	10.1740	25.5000	15.200	72.100	20.900
S75W5A	161	751113.	18.9000	6.840	245.090	59.290	137.870	.0340	.0540	30.0000	21.050	118.150	25.400
S75W5B	162	751113.	18.9000	4.590	875.990	10.500	855.610	.0600	.0010	73.0000	91.450	906.450	155.700
S75W5LTR	182	760106.	35.0800	7.950	70.080	31.220	40.560	7.6180	8.2070	3.0000	7.800	6.300	6.700
S75W5A	183	760106.	35.0800	6.490	90.340	7.140	78.210	.3660	.1410	3.1000	8.800	15.600	14.000
S75W5B	184	760106.	35.0800	4.720	NNNNN	8.140	828.210	NNNNN	.0100	7.6000	64.300	156.000	101.800
S75W5LTR	206	760226.	19.9600	7.450	31.200	.393	28.230	4.9700	5.5000	-.0010	-.001	32.000	6.300
S75W5A	207	760226.	19.9600	6.460	47.210	.482	44.250	.0090	.3140	1.7000	3.500	47.200	6.300
S75W5B	208	760226.	19.9600	4.870	192.976	.369	192.490	.0140	.0010	15.0000	16.700	158.600	15.200
S75W5LTR	235	760413.	11.9700	6.850	NNNNN	2.320	26.220	NNNNN	5.4500	3.3400	2.400	34.700	5.950
S75W5A	236	760413.	11.9700	6.790	21.150	.101	19.700	.5660	.5750	3.5000	3.560	31.900	3.660
S75W5B	237	760413.	11.9700	5.700	95.016	.001	94.440	.0220	.0010	10.9000	14.500	100.000	9.160
S75W5LTR	262	760603.	19.3200	7.450	NNNNN	28.700	63.670	NNNNN	5.2000	9.8300	11.030	70.850	13.410
S75W5A	263	760603.	19.3200	7.140	91.250	3.960	83.370	.5240	.3450	6.9600	9.080	89.440	13.820
S75W5B	264	760603.	19.3200	6.530	75.992	.053	75.420	.0300	.0010	10.9900	14.010	79.300	8.070
S75W5LTR	302	760727.	10.0600	7.720	NNNNN	42.410	70.420	NNNNN	.0530	8.3600	8.360	40.070	8.980
S75W5A	303	760727.	10.0600	6.230	156.170	13.350	138.890	.2530	.0580	8.8500	9.210	76.640	10.980
S75W5B	304	760727.	10.0600	6.870	68.690	.001	67.880	.0380	.0010	5.1400	7.710	52.260	45.030
S75W5C	305	760727.	10.0600	7.850	NNNNN	.001	150.000	NNNNN	.0110	8.5500	2.100	114.030	19.390
S75W5LTR	347	760921.	13.9300	7.720	NNNNN	42.410	70.420	NNNNN	.0530	8.3600	8.360	40.070	8.980
S75W5A	327	760921.	13.9300	7.280	75.964	.333	70.720	.2840	.1220	10.9500	10.930	79.970	12.610
S75W5B	328	760921.	13.9300	6.780	NNNNN	.001	170.490	.0400	.0010	14.0700	14.970	189.280	21.060
S75W5C	348	760921.	13.9300	7.850	NNNNN	.001	150.000	NNNNN	.0110	8.5500	2.100	114.030	19.390
S75W5LTR	388	761109.	13.5600	7.090	71.550	10.800	55.700	4.3700	4.3400	12.6900	10.360	65.920	12.740
S75W5A	389	761109.	13.5600	6.940	74.150	.405	70.910	.4900	.0630	10.5700	10.080	75.930	11.810
S75W5B	390	761109.	13.5600	5.300	290.490	.001	290.170	-.0010	.0010	15.1700	19.310	276.420	30.250
S75W5C	391	761109.	13.5600	6.670	NNNNN	.001	247.390	NNNNN	.0160	18.7100	3.350	236.320	41.240
S75W5LTR	418	770106.	7.3600	5.390	NNNNN	10.205	92.060	NNNNN	3.4000	6.2200	12.960	114.000	20.570
S75W5A	419	770106.	7.3600	4.250	152.744	.586	150.540	.1540	.1410	4.3100	7.190	82.240	11.980
S75W5B	420	770106.	7.3600	4.690	162.260	.136	161.750	.0340	.0210	5.0500	18.950	241.000	26.310
S75W5C	435	770106.	7.3600	6.670	NNNNN	.001	247.390	NNNNN	.0160	18.7100	3.350	236.320	41.240
S75W5LTR	448	770331.	20.8700	4.210	39.444	1.466	36.380	NNNNN	4.8400	10.0500	6.350	53.570	9.950
S75W5A	449	770331.	20.8700	4.640	65.272	.141	63.590	NNNNN	.1530	11.5600	8.440	78.200	11.700
S75W5B	450	770331.	20.8700	4.860	NNNNN	.001	123.800	NNNNN	.0240	14.0100	15.870	152.090	16.900

		Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
WONLYLTR	399	761107.	8.4900	6.880	1.102	.046	.092	NNNNN	.3040	3.6700	2.290	7.080	1.090
WONLYA	400	761107.	8.4900	6.750	.803	.001	.001	NNNNN	1.5900	5.4400	2.500	3.430	.500
WONLYB	401	761107.	8.4900	6.690	.739	.001	.001	NNNNN	.0010	3.8500	1.220	3.930	.540
WONLYC	402	761107.	8.4900	6.830	1.851	.001	.001	NNNNN	.0010	3.5800	.730	6.170	.880
WONLYLTR	429	770106.	NNNNN	6.840	.987	.004	.001	.3220	.2970	2.6800	2.350	9.670	58.340
WONLYA	430	770106.	NNNNN	6.740	.485	.001	.001	.0640	.0820	2.5900	2.350	5.130	36.560
WONLYB	431	770106.	NNNNN	6.780	.249	.001	.001	.0340	.0290	2.8900	.970	4.310	48.090
WONLYC	432	770106.	NNNNN	7.180	.529	.001	.001	.0300	.1510	2.8900	.270	5.130	21.340
WONLYLTR	459	770331.	NNNNN	6.530	NNNNN	.069	NNNNN	NNNNN	.0010	9.0800	2.650	9.080	17.980
WONLYA	460	770331.	NNNNN	6.440	NNNNN	.033	NNNNN	NNNNN	.2440	1.8200	3.380	1.820	1.080
WONLYB	461	770331.	NNNNN	6.580	.200	.001	.038	NNNNN	.0010	2.7600	.660	2.760	.610
WONLYC	462	770331.	NNNNN	6.330	.265	.001	.001	NNNNN	.0010	2.8500	.400	2.850	.690
WONLYLTR	488	770613.	26.0300	6.560	.825	.001	.071	.2840	.2580	3.0700	4.760	7.300	.940
WONLYA	489	770613.	26.0300	6.630	.331	.001	.017	.0360	.0010	2.5300	1.560	4.180	.640
WONLYB	490	770613.	26.0300	6.040	.184	.115	.014	.0260	.0010	2.9600	.840	2.840	.250
WONLYC	491	770613.	26.0300	6.390	.243	.001	.001	.0340	.0310	3.3900	.520	5.070	.560
CONTLLTR	87	750806.	1.8300	7.070	NNNNN	4.000	.610	NNNNN	.0010	10.0500	1.200	11.300	2.200
CONTLA	88	750806.	1.8300	7.140	4.190	.580	3.470	.0300	.0010	4.5500	4.200	8.250	1.150
CONTLB	46	750806.	1.8300	6.760	1.832	.020	.032	.1200	.0050	6.0000	3.550	4.300	.700
CONTLC	89	750806.	1.6300	7.310	NNNNN	3.000	.530	NNNNN	.0010	11.1500	1.300	17.900	3.050
CONTLLTR	112	750826.	7.4200	6.950	2.028	.484	.232	.0770	.0353	5.0000	2.100	11.300	1.300
CONTLA	111	750826.	7.4200	7.140	9.560	1.161	8.430	.0400	.0010	5.3500	6.400	15.350	2.300
CONTLB	54	750826.	7.4200	7.020	1.477	2.740	.173	.0680	.0010	9.2500	4.150	5.050	.750
CONTLC	294	750826.	7.4200	7.310	NNNNN	3.000	.530	NNNNN	.0010	11.1500	1.300	17.900	3.050
CONTLLTR	130	750918.	2.0500	6.740	NNNNN	.172	.780	NNNNN	.0010	4.6000	2.200	8.950	1.000
CONTLA	131	750918.	2.0500	7.330	NNNNN	.170	1.644	NNNNN	.0010	9.1500	6.250	15.900	2.300
CONTLB	47	750918.	2.0500	6.920	2.210	.377	.530	.0600	.0010	6.1500	1.950	8.700	1.300
CONTLC	55	750918.	2.0500	7.190	NNNNN	.214	2.775	NNNNN	.0010	6.5000	1.400	12.200	1.800
CONTLLTR	149	751014.	3.3600	7.250	NNNNN	.288	.190	NNNNN	.0020	5.0500	3.850	8.050	1.300
CONTLA	150	751014.	3.3600	7.460	NNNNN	.027	11.680	NNNNN	NNNNN	5.4500	5.650	12.350	2.100
CONTLB	48	751014.	3.3600	7.150	NNNNN	1.130	1.410	NNNNN	.0010	5.3000	1.750	5.800	1.200
CONTLC	56	751014.	3.3600	7.150	NNNNN	1.130	1.410	NNNNN	.0010	5.3000	1.750	5.800	1.200
CONTLLTR	173	751113.	11.2800	6.950	.777	.001	.017	.2140	.1290	2.0000	3.150	5.050	.650
CONTLA	174	751113.	11.2800	7.270	5.410	.113	4.630	.1300	.0010	2.2500	3.900	8.900	1.700
CONTLB	49	751113.	11.2800	7.050	1.079	.049	.499	.0640	.0010	2.6000	1.300	4.050	.750
CONTLC	57	751113.	11.2800	7.050	1.079	.049	.499	.0640	.0010	2.6000	1.300	4.050	.750
CONTLLTR	193	760106.	26.1900	7.130	.752	.202	.238	.1780	.1440	1.2000	1.080	1.300	-.001
CONTLA	194	760106.	26.1900	7.410	2.427	.316	1.595	.0740	.0680	1.2000	1.480	3.200	.300
CONTLB	50	760106.	26.1900	7.370	.910	.068	.554	.2790	.2430	1.3000	.570	2.300	.120
CONTLC	195	760106.	26.1900	7.420	NNNNN	.266	.768	NNNNN	.0070	1.4000	.470	2.700	.200
CONTLLTR	221	760226.	19.9600	7.040	.625	.099	.073	.0900	.0630	-.0010	2.600	3.000	.400
CONTLA	222	760226.	19.9600	7.230	1.616	.078	1.210	.0600	.0290	-.0010	2.500	5.000	.800
CONTLB	51	760226.	19.9600	7.190	.579	.001	.147	.0220	.0010	1.1000	1.100	3.400	.590
CONTLC	223	760226.	19.9600	NNNNN	NNNNN	.001	2.460	NNNNN	.0300	1.9000	1.200	4.700	.970
CONTLLTR	250	760413.	11.9700	7.070	NNNNN	.001	NNNNN	.0680	.0280	1.5200	1.570	2.820	.420
CONTLA	251	760413.	11.9700	7.330	.872	.001	.492	.0460	.0250	1.1800	2.440	3.800	.659
CONTLB	52	760413.	11.9700	7.270	NNNNN	.001	NNNNN	.0440	.0010	2.0100	1.100	3.140	.604
CONTLC	252	760413.	11.9700	7.120	NNNNN	.001	NNNNN	.0440	.0250	2.0500	1.070	3.570	.724
CONTLLTR	275	760603.	9.1200	7.180	.201	.001	.001	NNNNN	.2750	2.9500	54.460	5.730	.560
CONTLA	276	760603.	9.1200	7.330	1.118	.030	.300	NNNNN	.2170	1.3900	27.470	6.270	.560
CONTLB	53	760603.	9.1200	7.070	NNNNN	.032	.516	NNNNN	.0010	2.6500	1.070	4.210	.560
CONTLC	277	760603.	9.1200	6.940	6.864	.031	6.430	.0240	.0010	2.7400	4.420	4.720	.730

		Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
CONTLLTR	315	760729.	6.2300	7.660	NNNNN	.301	.004	NNNNN	.7300	1.9200	35.320	4.900	.480
CONTLA	317	760729.	6.2300	7.640	NNNNN	.031	.001	NNNNN	.7890	1.7300	30.100	5.060	.280
CONTLB	372	760729.	6.2300	7.070	NNNNN	.032	.516	NNNNN	.0010	2.6500	1.070	4.210	.560
CONTLC	359	760729.	6.2300	6.940	6.864	.031	6.430	.0240	.0010	2.7400	4.420	4.720	.730
CONTLLTR	339	760921.	13.9300	7.490	NNNNN	.001	.007	.2600	.3760	2.8500	22.970	10.000	.850
CONTLA	340	760921.	13.9300	7.810	NNNNN	.140	.001	.2060	.1760	3.1400	21.190	9.090	.600
CONTLB	373	760921.	13.9300	7.070	NNNNN	.032	.516	NNNNN	.0010	2.6500	1.070	4.210	.560
CONTLC	351	760921.	13.9300	6.940	6.864	.031	6.430	.0240	.0010	2.7400	4.420	4.720	.730
CONTLLTR	403	761109.	NNNNN	7.460	NNNNN	.001	.001	NNNNN	.4250	2.7800	51.400	12.360	1.080
CONTLC	404	761109.	NNNNN	NNNNN	NNNNN	.042	.001	NNNNN	.0010	5.9700	68.400	24.360	.540
CONTLLTR	433	770106.	NNNNN	7.360	.795	.001	.001	.4940	.4250	2.0600	29.330	10.910	1.610
CONTLLTR	463	770331.	NNNNN	6.770	.651	.001	.001	NNNNN	.1320	1.4400	8.770	1.440	.850
CONTLA	464	770331.	NNNNN	6.420	.925	.042	.001	NNNNN	.0150	3.4200	17.620	3.420	1.160
CONTLLTR	494	770613.	15.8700	6.700	1.699	.001	.001	.6860	.6170	4.0400	5.560	10.420	1.630
CONTLA	495	770613.	15.8700	6.910	.002	.001	.001	.0010	.0570	5.3400	2.840	6.860	1.400
CONTLB	496	770613.	15.8700	7.070	.002	.001	.001	.0010	.0010	2.4200	.760	4.180	1.020
CONTLC	497	770613.	15.8700	7.150	.105	.001	.001	.0010	.0010	3.2900	.760	9.090	1.250

			Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
P21	LTR	11	761107.	8.7200	7.53000	2.024	16.0800	1.730	1.1700	.9360	10.0000	8.6600	12.330	2.2600
P21	A	12	761107.	8.7200	6.76000	7.740	3.3100	3.680	.1200	.0410	8.1800	4.9800	14.370	2.8200
P21	B	13	761107.	8.7200	6 68000	.381	.0440	.001	.1030	.0970	5.7900	1.7900	8.170	3.0100
P21	C	14	761107.	8.7200	7.23000	.381	.0370	.001	.0300	.0010	5.5300	1.5800	5.980	1.6800
P21	LTR	25	770106.	10.6400	7.56000	NNNNN	NNNNN	70.090	NNNNN	6.1800	7.2000	21.0300	71.520	.9700
P21	A	26	770106.	10.6400	7.07000	144.130	10.7000	127.130	NNNNN	1.2600	7.3300	16.4200	158.500	1.3500
P21	B	27	770106.	10.6400	7.43000	7.818	.1260	7.180	.0380	5.5200	5.0500	2.1200	16.680	3.1900
P21	C	28	770106.	10.6400	7.39000	6.524	.6640	5.090	.0460	2.7000	4.6800	1.6600	15.440	3.2700
P21	LTR	47	770331.	23.1400	6.03000	89.258	22.1170	77.000	7.1300	10.7000	13.2500	14.5100	13.250	10.9000
P21	A	48	770331.	23.1400	6.68000	112.596	1.7990	111.050	.3300	.2640	14.2000	11.2700	14.200	16.9000
P21	B	49	770331.	23.1400	6.81000	8.274	.0010	8.010	NNNNN	.0040	24.5700	12.0000	24.570	37.5500
P21	C	50	770331.	23.1400	6.86000	NNNNN	.0010	10.020	NNNNN	.0560	11.7400	3.3100	11.740	11.3000
P21	LTR	69	770613.	26.9800	6.18000	NNNNN	58.3800	121.620	10.1200	13.9700	15.0700	20.1200	86.660	16.6600
P21	A	70	770613.	26.9800	6.08000	NNNNN	28.6500	170.280	.5220	.4100	14.2000	22.3600	148.810	18.7300
P21	B	71	770613.	26.9800	6.95000	188.098	.0010	187.850	NNNNN	.0010	18.2000	8.9200	175.560	29.3800
P21	C	72	770613.	26.9800	7.08000	130.620	2.4500	127.670	.0780	.0010	15.9300	8.2800	177.610	23.2500
P22	LTR	1	760729.	NNNNN	6.38000	NNNNN	NNNNN	NNNNN	.1240	.0620	2.2500	4.6200	7.320	.7600
P22	A	2	760729.	NNNNN	6.46000	NNNNN	NNNNN	NNNNN	.0600	.0010	2.7700	3.3000	9.080	1.1900
P22	B	3	760729.	NNNNN	6.22000	NNNNN	NNNNN	NNNNN	.0580	.0010	4.6800	3.3900	20.300	4.3300
P22	LTR	4	760721.	NNNNN	6.92000	1.829	.0210	.067	.0960	NNNNN	6.7800	4.6100	8.540	.7300
P22	A	5	760721.	NNNNN	7.07000	3.372	.0570	1.740	.0780	.0010	2.2500	3.9000	9.090	1.1000
P22	B	6	760721.	NNNNN	7.09000	11.022	.0320	10.420	.0010	.0010	4.0300	3.3600	15.280	2.9800
P22	LTR	15	761107.	12.2900	7.09000	NNNNN	37.9900	32.700	1.3500	1.3000	11.1000	12.7700	31.680	5.0200
P22	A	16	761107.	12.2900	6.74000	85.410	7.4400	75.090	.1300	.0060	10.3100	19.5900	72.840	12.4000
P22	B	17	761109.	12.2900	7.09000	23.110	.3690	21.730	.0700	.0010	5.7900	4.7700	23.850	5.0600
P22	LTR	29	770106.	9.6400	4.66000	125.480	15.5610	109.350	NNNNN	.7630	5.7900	16.4200	146.200	23.7500
P22	A	30	770106.	9.6400	5.32000	133.516	3.2200	127.310	.0860	.0010	6.0300	20.3400	282.200	34.0000
P22	B	31	770106.	9.6400	6.52000	86.930	.1430	86.320	.0260	.0010	4.1900	10.6500	96.230	21.0800
P22	LTR	51	770331.	22.3900	6.83000	NNNNN	4.2360	18.270	NNNNN	1.6900	5.3300	5.9300	5.330	3.8300
P22	A	52	770331.	22.3900	5.90000	NNNNN	.0010	33.110	NNNNN	NNNNN	8.5400	8.9700	8.540	6.1400
P22	B	53	770331.	22.3900	6.17000	NNNNN	.0010	67.440	NNNNN	.0010	13.4400	8.8600	13.440	15.1900
P22	LTR	73	770613.	24.2300	5.16000	93.970	33.1900	75.140	1.1000	8.4200	10.7400	17.7200	63.030	10.3000
P22	A	74	770613.	24.2300	4.67000	132.290	1.3300	130.100	.0900	.0340	12.1500	22.5200	139.900	17.2800
P22	B	75	770613.	24.2300	6.38000	148.768	.0010	148.470	.0340	.0010	17.9800	12.2800	117.610	21.7200
P23	LTR	7	760721.	NNNNN	6.95000	2.534	.0570	.550	.0480	.0010	3.2900	3.8100	9.640	.8900
P23	A	8	760721.	NNNNN	6.73000	2.931	.1760	1.470	.0400	.0010	3.0700	2.3000	9.820	1.0100
P23	B	9	760721.	NNNNN	7.05000	1.858	.0510	1.550	.0010	.0010	2.3300	2.8300	7.630	.9800
P23	C	10	760721.	NNNNN	7.21000	3.750	.0320	3.280	.0280	.0010	3.7400	1.1400	9.820	1.2300
P23	LTR	18	761109.	9.7700	7.01000	130.440	43.1300	61.300	.0010	NNNNN	14.2000	16.7600	37.850	5.3900
P23	A	19	761107.	9.7700	7.05000	102.560	20.7600	71.600	.2400	.0690	12.9600	18.7400	86.870	10.7100
P23	B	20	761107.	9.7700	6.42000	44.720	.0010	44.240	.2300	.0160	10.3900	7.5500	48.420	8.0900
P23	C	21	761107.	9.7700	6.92000	45.890	.0480	45.050	.1050	.1550	10.5700	7.1000	46.230	7.9300
P23	LTR	32	770106.	8.6400	6.04000	133.852	17.1660	117.150	NNNNN	6.9300	5.8500	15.2600	154.400	21.1800
P23	A	33	770106.	8.6400	4.34000	102.008	4.3140	74.460	NNNNN	.1580	5.5400	17.1100	241.000	27.5900
P23	B	34	770106.	8.6400	4.47000	163.920	.0600	163.430	.0620	.0010	9.2300	14.1100	253.400	42.9700
P23	C	35	770106.	8.6400	7.14000	33.746	.0010	33.340	.0340	.0010	3.7900	3.0400	49.660	7.7600
P23	LTR	54	770331.	21.6600	5.97000	32.432	3.2910	30.770	.6260	4.5800	12.3100	5.4100	34.210	4.9500
P23	A	55	770331.	21.6600	5.38000	NNNNN	.7200	36.820	NNNNN	1.0800	5.5200	5.5100	45.120	5.5000
P23	B	56	770331.	21.6600	5.80000	108.928	.0010	108.710	NNNNN	.0010	17.9700	9.2800	102.830	14.7900
P23	C	57	770331.	21.6600	6.18000	135.206	.0010	134.890	.0700	.0530	7.8500	6.4200	127.070	17.1900

			Date	Cm	pH	Tot-N	NH_4-N	NO_3-N	Tot P	PO_4-P	Na	K	Ca	Mg
P23	LTR	76	770613.	21.4800	4.15000	102.380	16.9800	92.410	6.1740	8.9900	9.6600	11.8000	84.870	11.8300
P23	A	77	770613.	21.4800	4.29000	100.570	4.2400	95.840	1.5200	1.6300	9.0100	12.2800	99.780	10.7600
P23	B	78	770613.	21.4800	6.27000	114.314	.0010	114.140	.0360	.0010	14.2000	10.0400	113.150	13.2100
P23	C	79	770613.	21.4800	5.98000	62.788	.0010	62.650	.0580	.0010	11.5000	4.9200	65.260	10.0700
P24	LTR	22	761109.	NNNNN	6.73000	1.955	.0010	.035	.0200	.0050	6.2300	2.6400	12.360	3.5800
P24	A	23	761109.	NNNNN	6.90000	1.001	.0230	.001	.6000	.3860	5.0000	1.9300	5.980	1.5500
P24	B	24	761109.	NNNNN	6.81000	.561	.0010	.001	.1200	.0280	7.3800	2.4300	8.170	2.6100
P24	LTR	36	770106.	7.8500	6.81000	2.679	.0180	.001	.2080	.0820	3.8800	3.2700	25.340	4.0400
P24	A	37	770106.	7.8500	6.95000	1.036	.0310	.008	.0600	.0250	3.4800	2.1200	11.730	2.6300
P24	B	38	770106.	7.8500	7.35000	4.074	.0010	3.330	.0320	.0010	3.6600	1.2000	12.560	2.8900
P24	LTR	58	770331.	21.0400	6.14000	NNNNN	.7610	NNNNN	.5240	.6150	4.8300	6.7800	25.200	3.4700
P24	A	59	770331.	21.0400	6.74000	NNNNN	.0880	NNNNN	.0640	.0010	5.2100	3.4400	18.510	3.9000
P24	B	60	770331.	21.0400	6.45000	41.084	.0010	40.730	.0260	.1230	6.1500	2.4400	42.620	9.2400
P24	LTR	80	770613.	18.6200	6.15000	96.800	1.1100	73.420	.5600	.6880	8.4700	18.6800	113.150	13.6700
P24	A	81	770613.	18.6200	4.49000	43.574	.0830	42.630	.0320	.0010	6.7400	9.2400	47.870	9.6100
P24	B	82	770613.	18.6200	6.58000	49.472	.0660	47.120	.0300	.0010	5.7700	2.5200	44.750	9.7600
P31	LTR	61	770331.	25.5400	5.87000	2.505	.1990	.923	.6000	.5550	8.5400	4.6700	9.930	3.6000
P31	A	62	770331.	25.5400	6.36000	5.098	.0010	4.720	.0560	.1110	7.7800	.7000	7.120	2.7200
P31	LTR	83	770613.	25.9700	4.58000	NNNNN	50.2700	71.810	NNNNN	8.2800	11.5000	13.0800	29.150	10.7600
P31	A	84	770613.	25.9700	6.58000	6.740	.8310	5.910	.0700	.1290	8.1500	.6000	6.860	3.0900
P32	LTR	63	770331.	23.7900	7.24000	11.850	10.8010	3.290	NNNNN	2.6900	6.2700	11.2700	12.750	3.9900
P32	A	64	770331.	23.7900	7.10000	10.474	5.7680	4.790	.2360	.2100	8.9100	4.1500	10.990	4.6300
P32	LTR	85	770613.	23.4700	6.64000	54.770	13.0700	44.250	7.1300	11.3900	6.7400	4.1200	61.240	16.3900
P32	A	86	770613.	23.4700	7.09000	24.730	16.3300	12.810	.7880	.9520	10.8500	4.6000	19.340	9.6100
P33	LTR	65	770331.	22.0400	6.98000	11.584	5.0470	5.080	.3000	.1470	7.9700	6.1400	12.390	4.8700
P33	A	66	770331.	22.0400	7.18000	6.372	1.1690	4.830	.0440	.0110	13.2500	1.4300	9.230	2.8000
P33	LTR	87	770613.	20.9700	6.64000	111.330	24.9300	75.770	1.3240	2.2600	11.1700	17.2400	76.400	21.1100
P33	A	88	770613.	20.9700	6.89000	13.820	8.2100	8.040	.0980	.5640	17.9800	4.1200	15.330	7.4600
P34	LTR	67	770331.	20.2200	6.31000	10.328	2.9110	7.350	.2040	.2530	5.1400	5.7200	10.630	2.8800
P34	A	68	770331.	20.2200	6.30000	6.668	.0010	5.670	.1660	.0010	5.1400	1.1200	9.580	4.1500
P34	LTR	89	770613.	18.3700	6.58000	33.390	.3700	31.550	.6980	.7890	6.2000	9.7200	35.830	11.1400
P34	A	90	770613.	18.3700	6.68000	29.490	.2980	28.730	.0660	.0010	8.0100	2.5200	25.380	12.0600
P41	LTR	91	770613.	26.9800	6.80000	48.110	33.4500	16.810	5.4940	8.2300	10.3100	17.5600	26.030	5.8500
P41	A	92	770613.	26.9800	7.04000	28.280	5.4900	23.280	.1080	.0100	12.9000	23.0000	30.930	10.9100
P41	B	93	770613.	26.9800	7.69000	13.810	4.0800	8.370	.0780	.1680	11.6100	15.6400	17.560	5.7700
P42	LTR	94	770613.	24.2300	7.68000	NNNNN	65.5200	82.040	NNNNN	8.9900	17.2300	26.5200	63.920	13.1400
P42	A	95	770613.	24.2300	7.26000	38.390	9.2900	28.730	.0880	.0430	13.5500	12.7600	39.400	9.7600
P42	B	96	770613.	24.2300	7.43000	54.220	23.1500	30.340	.0860	.0010	13.7700	12.6000	33.610	8.3100
P43	LTR	97	770613.	21.9900	6.51000	11.900	8.5200	3.340	1.3340	1.9600	8.1500	13.7200	23.130	5.3100
P43	A	98	770613.	21.9900	6.53000	16.296	.1310	15.200	.0740	.0240	10.2000	11.8000	26.030	7.2300
P43	B	99	770613.	21.9900	6.76000	6.140	.0010	5.490	.0340	.0010	8.4700	6.6800	15.330	4.0100
P44	LTR	100	770613.	19.1200	6.69000	11.000	5.0600	5.100	.3380	.3320	12.4700	6.0400	12.210	2.4800
P44	A	101	770613.	19.1200	7.20000	3.182	.0010	1.680	.1020	.0010	10.8500	5.0800	13.540	3.4700
P44	B	102	770613.	19.1200	6.86000	NNNNN	.2540	5.630	NNNNN	.0010	16.6900	4.4400	23.350	5.7000

APPENDIX B

A computer program was written to automatically plot conductivity, temperature, dissolved oxygen and pH for data recorded on mag tape from the Metro-data units. Several scans were run during initial stages of the project. Large short-term variations in monitored parameters were found, particularly in the forest litter and soil A horizons. For the scans used as an example in Figures B-1 to B-4, 0 hours were mid-day on a warm day in mid-June. An irrigation with sludge and water took place at about 18 hours. Temperature was depressed, conductivity increased, dissolved oxygen increased and pH was significantly depressed in the litter layers.

FIELD RECORDING OF SOIL SOLUTION PARAMETERS

Soil solution extracts from the lysimeter plates at various depths were passed through sensing cells where temperature, dissolved oxygen, specific conductivity and pH were recorded at 10-minute intervals. Data were recorded on Metro-data magnetic tapes which were programmed for display of average hourly values through computer printout. A complex scaling format provided for scaling each variable between its maximum and minimum range for the duration of a scan. Computer output for simultaneous runs of the litter, A, B and C horizons is shown in figures in Appendix B. Figure B-1 (forest litter) shows diurnal variation in soil solution temperature (T), scaled from 6.38^{o} to 14.76^{o} C. The line D shows parts per million of DO cencentration varying from minimum values of 6.23 to 9.36 mg/l. The C line is micromhos of specific conductivity with variation from 76.3 to 125.9. Soil solution pH (P) is scaled from 6.38 to 8.72. The inverse relationship between DO and temperature shows daily periods of maximum temperature, show minimum DO levels, and inversely hours of coldest temperature show maximum DO. pH and conductivity generally show similar trends, though different magnitudes of change, suggesting that bicarbonate is probably influential in pH measurement with increasing quantities of free ions releasing additional cations to solution.

The four figures show declining variability in each parameter with increasing depth, as upper soil horizons and litter layers are the most dynamic. At lower depths, there is less variation in temperature, DO and conductivity.

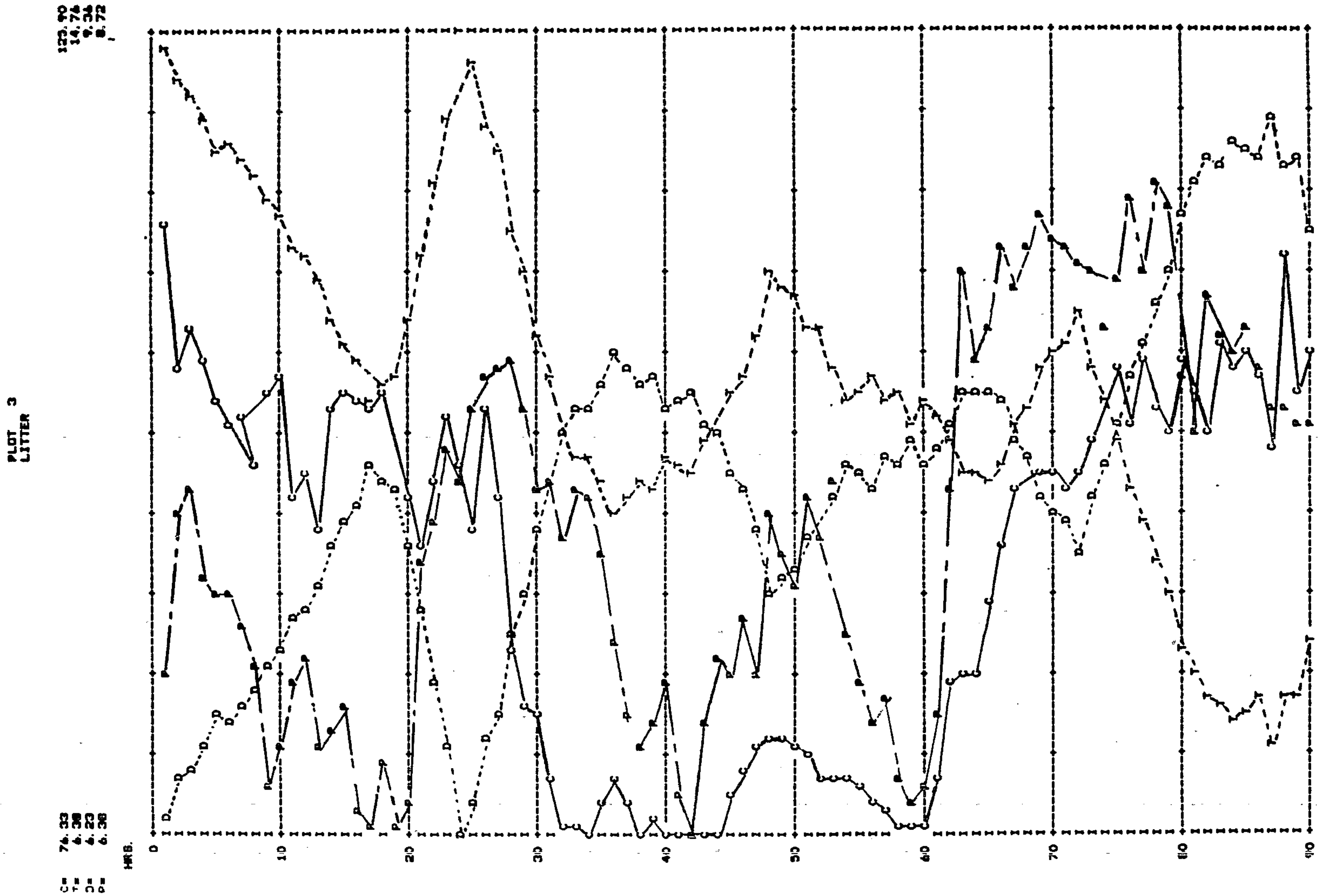

Figure B-1. Short-term variations in conductivity (C), temperature (T), dissolved oxygen (D), and pH (P) for the forest litter layer of the 100W treatment plot.

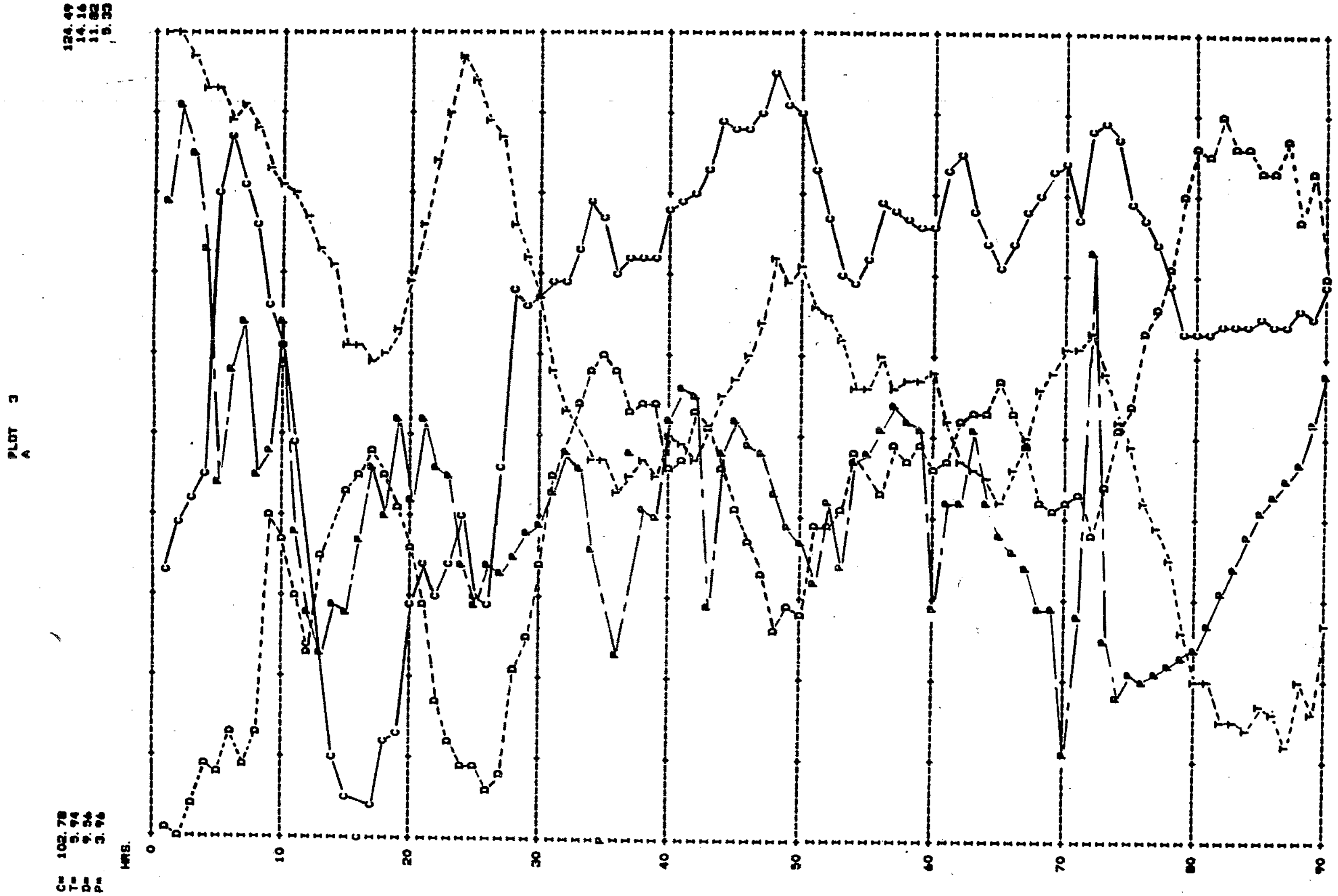

Figure B-2. Short-term variations in conductivity (C), temperature (T), dissolved oxygen (D), and pH (P) for the soil A horizon of the 100W treatment plot.

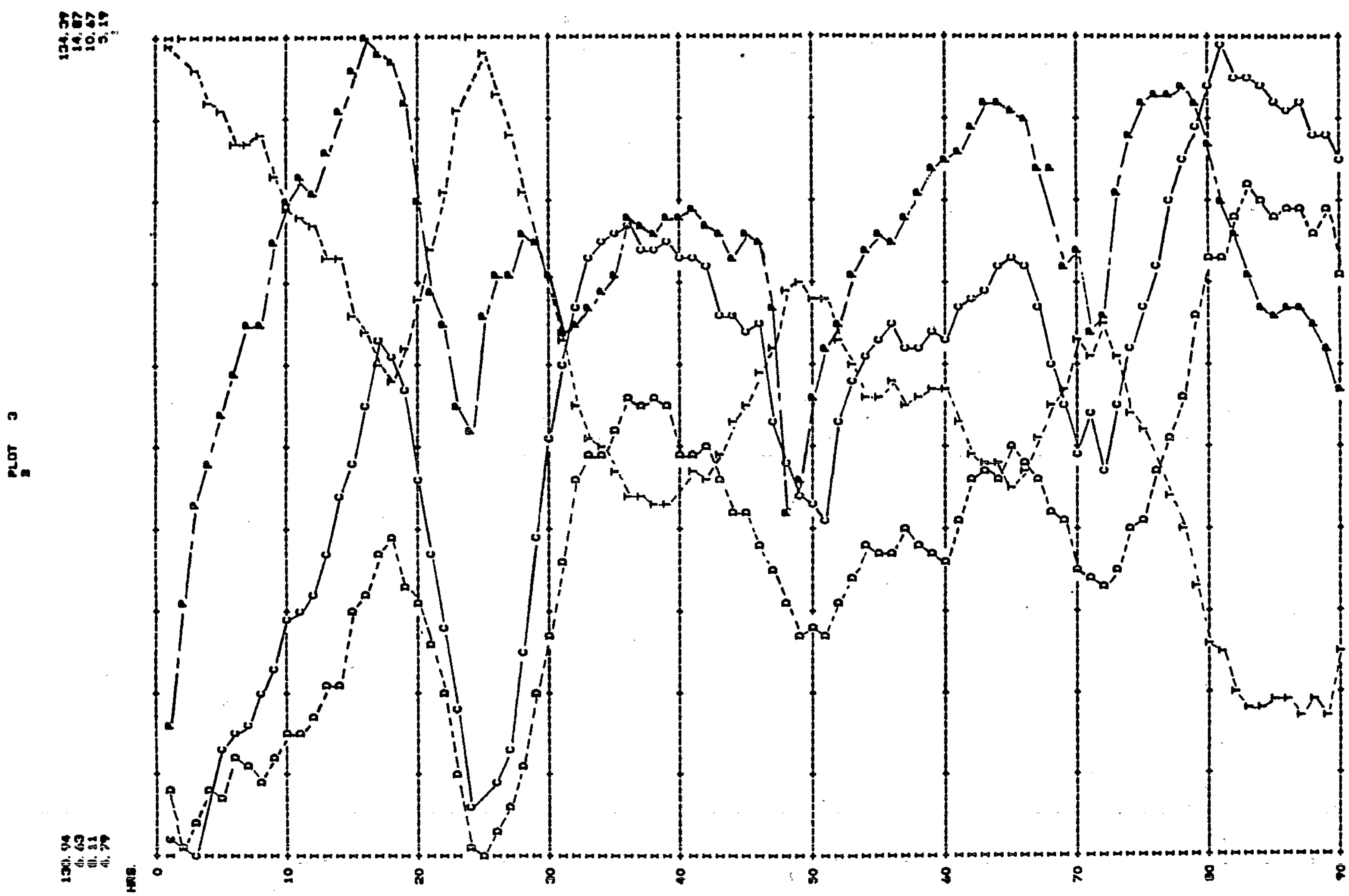

Figure B-3. Short-term variations in conductivity (C), temperature (T), dissolved oxygen (D), and pH (P) for the soil B horizon of the 100W treatment plot.

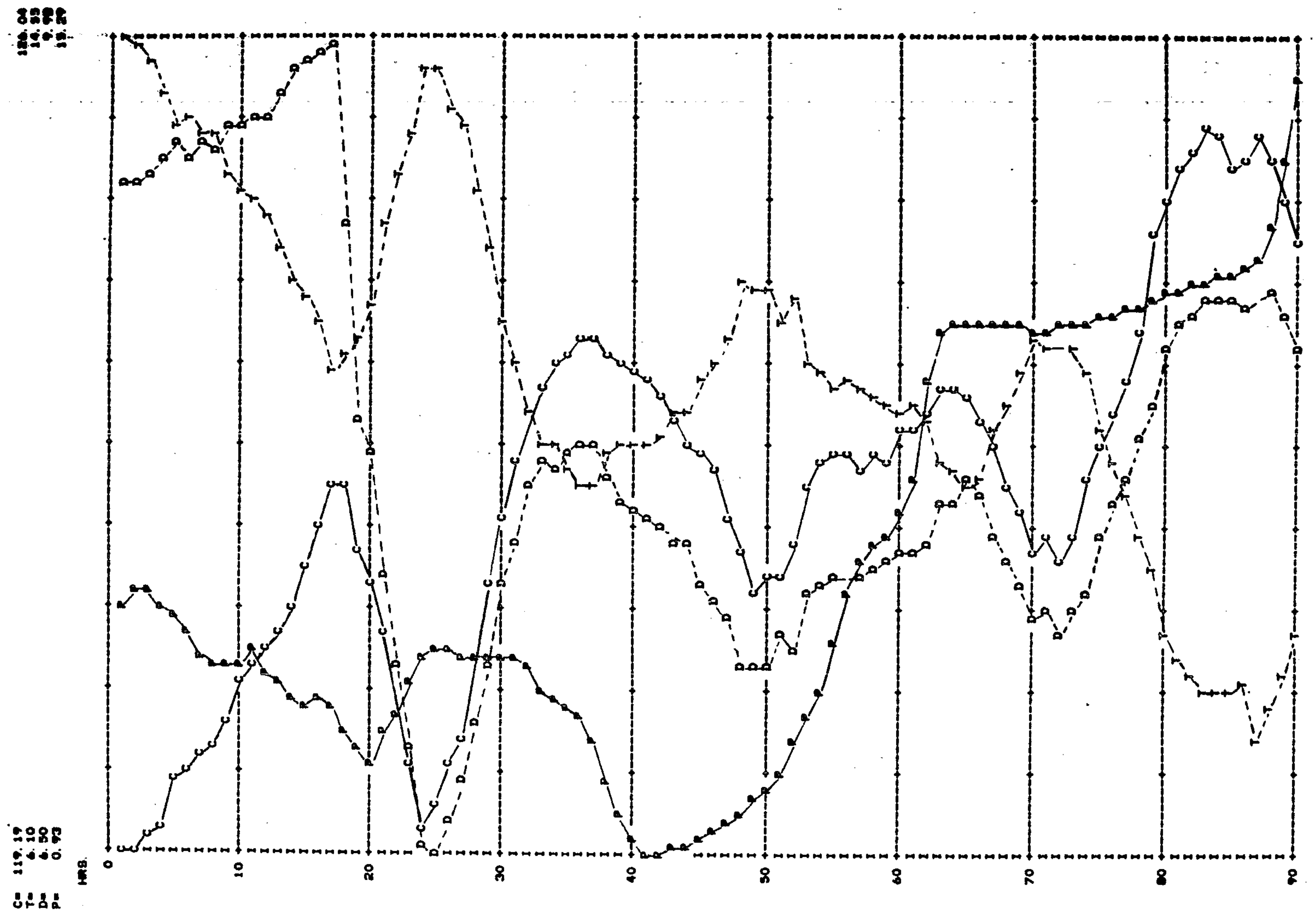

Figure B-4. Short-term variations in conductivity (C), temperature (T), dissolved oxygen (D), and pH (P) for the soil C horizon of the 100W treatment plot.

APPENDIX C

Pretreatment diameter equations based on increment cores.

Initial diameter measurements of the Pack Forest Sludge Project began after the 1974 growing season. At that time, increment cores were taken from ten trees per plot. The sample of ten was to be representative of the plot: four site trees, two trees of intermediate diameter, and four trees representing the lower diameter classes.

X-ray photos were taken of each increment core and measurements were obtained from these photos. The measurements, to the nearest 0.02 in., represented the last 2, 5, and 10 years of growth for each tree.

Marshall Murray's Inside and Outside Bark DBH Equations for Plantation Douglas-fir (shown below) were used to transform the increment core measurements to DBH outside bark (o.b.).

DBH (o.b.) * .920 = DBH inside bark (i.b.)
DBH (i.b.) * 1.088 = DBH outside bark (o.b.)

Shown below are the steps taken to calculate DBH (o.b.) for the years 1964, 1969 and 1972. These steps were repeated for each individual tree.

Step 1. 1974 DBH (o.b.) * .920 = 1974 DBH (i.b.)

2. 1974 DBH (i.b.) - (2-yr. increment * 2) = 1972 DBH (i.b.)

3. 1972 DBH (i.b.) * 1.088 = 1972 DBH (o.b.)

4. 1974 DBH (i.b.) - (5-yr. increment * 2) = 1969 DBH (i.b.)

5. 1969 DBH (i.b.) * 1.088 = 1969 DBH (0.b.)

6. 1974 DBH (i.b.) - (10-yr. Increment * 2) = 1964 DBH (i.b.)

7. 1964 DBH (i.b.) * 1.088 = 1964 DBH (o.b.)

Table C-1

Regression equations for all trees by irrigation treatment

Equation		100 Low level (n = 97)	100W Low + Water (n = 51)	200 Mid level (n = 144)	200W Mid + Water (n = 68)	300 High level (n = 115)	300W High + Water (n = 59)	Water (n = 96)	Unirrigated control (n = 38)
(DBH75 - DBH70)/5 =	b	0.015444	0.022054	0.023834	0.024498	0.015520	0.021632	0.011350	0.019772
a + b(DBH70)	a	0.091371	-1.234813	-1.116251	-1.392205	-0.031551	-1.270902	0.526691	-1.299486
	SE[1]	0.0011	0.0013	0.0009	0.0003	0.0008	0.0006	0.0008	0.0019
	r^2	0.69	0.86	0.83	0.99	0.75	0.95	0.66	0.75
(DBH76 - DBH75)/2 =	b	2.098700	2.367967	1.729283	2.143671	2.075038	2.323145	2.303655	1.850338
a + b[(DBH75 - DBH70)/5]	a	-1.549147	-1.385977	-0.613604	-0.480665	-1.352659	-1.326979	-2.135855	-1.077760
	SE	0.1732	0.2343	0.1032	0.1269	0.1523	0.1626	0.2166	0.1615
	r^2	0.61	0.68	0.66	0.81	0.62	0.78	0.55	0.78
(DBH77 - DBH75)/3 =	b	1.922543	2.223593	1.616477	1.808484	2.322421	2.322421	2.231804	1.868898
a + b[(DBH75 - DBH70)/5]	a	-1.331659	-1.375565	-0.677416	-0.846618	-1.274568	-1.274558	-2.199403	-1.040446
	SE	0.1713	0.2140	0.0843	0.1569	0.1666	0.1666	0.2186	0.1383
	r^2	0.57	0.69	0.72	0.80	0.54	0.77	0.53	0.84
(BA75 - BA70)/5 =	b	0.032181	0.038438	0.043387	0.041636	0.033469	0.037304	0.024466	0.036193
a + b(BA70)	a	0.000021	-0.000154	-0.000134	-0.000153	-0.000036	-0.000151	0.000130	-0.000229
	SE	0.0010	0.0018	0.0014	0.0007	0.0008	0.0010	0.0011	0.0020
	r^2	0.91	0.91	0.88	0.98	0.94	0.96	0.83	0.90

(cont'd)

Table C-1 (continued)

Equation		100 Low level (n = 97)	100W Low + Water (n = 51)	200 Mid level (n = 144)	200W Mid + Water (n = 68)	300 High level (n = 115)	300W High + Water (n = 59)	Water (n = 96)	Unirrigated control (n = 38)
(BA76 - BA75)/2 =	b	1.648437	2.398586	1.772201	2.270126	2.064710	2.213354	2.061667	1.800101
a + b[(BA75 - BA70)/5]	a	0.000076	-0.000256	-0.000094	-0.000058	-0.000215	-0.000212	-0.000266	-0.000252
	SE	0.0972	0.1865	0.0772	0.1122	0.0766	0.1324	0.1384	0.1479
	r^2	0.75	0.77	0.79	0.86	0.87	0.83	0.70	0.80
(BA77 - BA75)/3 =	b	1.504326	2.227958	1.613280	2.214242	1.859052	2.292921	2.034952	1.875561
a + b[(BA75 - BA70)/5]	a	0.000123	-0.000235	-0.000083	-0.000510	-0.000123	-0.000227	-0.000314	-0.000259
	SE	0.0986	0.1697	0.0620	0.1104	0.0826	0.1409	0.1412	0.1096
	r^2	0.71	0.78	0.83	0.86	0.82	0.82	0.69	0.89
(Vol76 - Vol75)/2 =	b	0.074716	0.119257	0.112099	0.110014	0.099606	0.111691	0.090916	0.081969
a + b(Vol75)	a	0.002766	-0.007834	-0.004221	-0.003667	-0.003252	-0.006706	-0.001882	-0.005481
	SE	0.0032	0.0048	0.0025	0.0036	0.0020	0.0041	0.0032	0.0051
	r^2	0.85	0.93	0.93	0.94	0.96	0.93	0.90	0.88
(Vol77 - Vol75)/3 =	b	0.059414	0.104051	0.093390	0.097248	0.081868	0.102272	0.081602	0.079673
a + b(Vol75)	a	0.003991	-0.006525	-0.003329	-0.002288	-0.001415	-0.005460	-0.002952	-0.006712
	SE	0.0032	0.0050	0.0022	0.0043	0.0027	0.0050	0.0030	0.0043
	r^2	0.78	0.90	0.93	0.89	0.89	0.88	0.89	0.91

[1]SE = Standard error of b coefficient.

Table C-2

Regression equations for paired trees by irrigation treatment.

Equation		100 Low level (n = 35)	100W Low + Water (n = 27)	200 Mid level (n = 37)	200W Mid + Water (n = 27)	300 High level (n = 37)	300W High + Water (n = 33)	Water (n = 27)	Unirrigated control (n = 37)
(DBH75 - DBH70)/5	b	0.018855	0.021239	0.025284	0.024451	0.020106	0.023085	0.017227	0.021642
a + b(DBH70)	a	-0.712716	-1.231359	-1.609345	-1.403748	-1.172949	-1.588449	-0.546116	-1.743038
	SE	0.0028	0.0014	0.0020	0.0005	0.0008	0.0010	0.0013	0.0017
	r^2	0.59	0.90	0.82	0.99	0.95	0.94	0.88	0.83
(DBH76 - DBH75)/2 =	b	1.951750	2.252687	1.761001	2.749107	2.021593	2.417146	2.153193	1.859155
a + b[(DBH75 - DBH70)/5]	a	-0.318911	-0.537911	0.636425	-2.038610	-0.377513	-1.615903	-1.538215	-1.048305
	SE	0.2436	0.2965	0.2261	0.1912	0.1575	0.2439	0.2644	0.1585
	r^2	0.66	0.70	0.63	0.89	0.82	0.76	0.73	0.80
(DBH77 - DBH75)/3 =	b	1.829662	2.114383	1.707798	2.722826	1.762675	2.352021	1.986358	1.878875
a + b[(DBH75 - DBH70)/5]	a	-0.257320	-0.688487	0.086809	-2.062345	0.072813	-1.354091	-1.404181	-1.007116
	SE	0.2194	0.2838	0.1957	0.1980	0.1642	0.2514	0.2853	0.1321
	r^2	0.68	0.69	0.69	0.88	0.77	0.74	0.66	0.85
(BA75 - BA70)/5 =	b	0.036275	0.036420	0.042227	0.041106	0.035357	0.038329	0.032967	0.037290
a + b(BA70)	a	-0.000121	-0.000115	-0.000175	-0.000180	-0.000147	-0.000169	-0.000055	-0.000282
	SE	0.0033	0.0018	0.0028	0.0012	0.0010	0.0012	0.0023	0.0019
	r^2	0.79	0.94	0.87	0.98	0.97	0.97	0.89	0.91

(contd)

Table C-2 (continued)

Equation		100 Low level (n = 35)	100W Low + Water (n = 27)	200 Mid level (n = 37)	200W Mid + Water (n = 27)	300 High level (n = 37)	300W High + Water (n = 33)	Water (n = 27)	Unirrigated control (n = 37)
(BA76 - BA75)/2 =	b	1.963537	2.444350	2.110571	2.832737	2.058824	2.343178	1.783088	1.792263
a + b[(BA75 - BA70)/5]	a	0.000012	-0.000232	-0.000015	-0.000419	-0.000045	-0.000417	-0.000098	-0.000235
	SE	0.2090	0.2786	0.1815	0.1626	0.1158	0.1952	0.2226	0.1502
	r^2	0.73	0.75	0.79	0.92	0.90	0.82	0.72	0.80
(BA77 - BA75)/3 =	b	1.966495	2.238534	1.887084	2.759162	1.836350	2.368171	1.629902	1.862848
a + b[(BA75 - BA70)/5]	a	-0.000048	-0.000215	-0.000019	-0.000411	-0.000092	-0.000369	-0.000037	-0.000232
	SE	0.1796	0.2569	0.1529	0.1702	0.1338	0.2110	0.2362	0.1096
	r^2	0.78	0.75	0.81	0.91	0.84	0.80	0.66	0.89
(Vol76 - Vol75)/2 =	b	0.107828	0.116060	0.122271	0.125976	0.099637	0.113689	0.098879	0.082687
a + b(Vol75)	a	-0.005095	-0.006246	-0.004896	-0.007524	-0.003679	-0.007172	-0.003111	-0.005905
	SE	0.0065	0.0060	0.0067	0.0066	0.0040	0.0064	0.0073	0.0053
	r^2	0.89	0.94	0.90	0.94	0.95	0.91	0.88	0.87
(Vol77 - Vol75)/3 =	b	0.093941	0.099226	0.102549	0.121253	0.085581	0.103725	0.079926	0.080438
a + b(Vol75)	a	-0.003671	-0.005336	-0.004371	-0.007423	-0.001791	-0.006173	-0.002224	-0.007163
	SE	0.0059	0.0055	0.0051	0.0080	0.0049	0.0080	0.0071	0.0044
	r^2	0.88	0.93	0.92	0.90	0.90	0.84	0.84	0.90

[1]SE = standard error of b coefficient.

Key to

Tables C3 &C4

Variable	Labels	Parameter
1	DB70	DBH 1970
2	DB75	DBH 1975
3	DB76	DBH 1976
4	DB77	DBH 1977
5	BA70	Basal Area 1970
6	BA75	Basal Area 1975
7	BA76	Basal Area 1976
8	BA77	Basal Area 1977
9	V75	Volume 1975
10	V76	Volume 1976
11	V77	Volume 1977
12	D5-0	(DBH75 - DBH70)/5
13	D7-5	(DBH77 - DBH75)/3
14	D6-5	(DBH76 - DBH75)/2
15	B5-0	(BA75 - BA70)/5
16	B7-5	(BA77 - BA75)/3
17	B6-5	(BA76 - BA75)/2
18	V7-5	(Volume 77 - Volume 75)/3
19	V6-5	(Volume 76 - V-lume 75)/2

Table C-3

Treatment means all trees

Treatment: Low Level Sludge 100

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	164.9691	59.2251	7.6000E 01	4.9000E 02
2	DB75	178.1649	63.8735	8.3000E 01	5.2700E 02
3	DB76	186.1443	68.7330	8.4000E 01	5.4500E 02
4	DB77	189.3918	70.7252	8.4000E 01	5.4800E 02
5	BA70	0.0242	0.0215	5.0000E-03	1.8900E-01
6	BA75	0.0281	0.0250	5.0000E-03	2.1800E-01
7	BA76	0.0309	0.0274	6.0000E-03	2.3300E-01
8	BA77	0.0321	0.0283	6.0000E-03	2.3600E-01
9	V75	0.2753	0.3016	3.2000E-02	2.7030E 00
10	V76	0.3220	0.3471	3.4000E-02	3.0350E 00
11	V77	0.3363	0.3564	3.4000E-02	3.0690E 00
12	D5-0	2.6392	1.1044	6.0000E-01	7.4000E 00
13	D7-5	3.7423	2.8122	0.	1.0000E 01
14	D6-5	3.9897	2.9747	0.	1.2000E 01
15	B5-0	0.0008	0.0007	0.	5.8000E-03
16	B7-5	0.0013	0.0013	0.	6.0000E-03
17	B6-5	0.0014	0.0014	0.	7.5000E-03
18	V7-5	0.0203	0.0202	3.3333E-04	1.2200E-01
19	V6-5	0.0233	0.0244	5.0000E-04	1.6600E-01

Treatment: Low Level Sludge + Water 100W

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	155.7451	53.4202	9.0000E 01	3.0300E 02
2	DB75	166.7451	59.3599	9.3000E 01	3.3100E 02
3	DB76	174.3922	65.8076	9.4000E 01	3.4700E 02
4	DB77	177.2941	68.3580	9.4000E 01	3.5400E 02
5	BA70	0.0212	0.0158	6.0000E-03	7.2000E-02
6	BA75	0.0245	0.0189	7.0000E-03	8.6000E-02
7	BA76	0.0272	0.0221	7.0000E-03	9.5000E-02
8	BA77	0.0283	0.0234	7.0000E-03	9.8000E-02
9	V75	0.2466	0.2169	4.6000E-02	9.0600E-01
10	V76	0.2898	0.2690	4.6000E-02	1.1080E 00
11	V77	0.3040	0.2855	4.6000E-02	1.1430E 00
12	D5-0	2.2000	1.2731	6.0000E-01	6.2000E 00
13	D7-5	3.5163	3.4133	0.	1.2000E 01
14	D6-5	3.8235	3.6672	0.	1.3000E 01
15	B5-0	0.0007	0.0006	0.	2.8000E-03
16	B7-5	0.0012	0.0016	0.	6.3333E-03
17	B6-5	0.0013	0.0017	0.	6.5000E-03
18	V7-5	0.0191	0.0238	-3.3333E-04	9.1333E-02
19	V6-5	0.0216	0.0269	-5.0000E-04	1.0900E-01

(cont'd)

Table C-3 (continued)

Treatment: Mid Level Sludge 200

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	142.3472	52.7329	5.2000E 01	2.8300E 02
2	DB75	153.7292	59.0864	5.2000E 01	3.1300E 02
3	DB76	160.3750	64.2980	5.3000E 01	3.3500E 02
4	DB77	162.7361	66.1230	5.3000E 01	3.4000E 02
5	BA70	0.0180	0.0135	2.0000E-03	6.3000E-02
6	BA75	0.0213	0.0164	2.0000E-03	7.7000E-02
7	BA76	0.0234	0.0188	2.0000E-03	8.8000E-02
8	BA77	0.0242	0.0196	2.0000E-03	9.1000E-02
9	V75	0.2029	0.1747	6.0000E-03	7.7900E-01
10	V76	0.2400	0.2141	7.0000E-03	9.6000E-01
11	V77	0.2498	0.2241	7.0000E-03	9.7000E-01
12	D5-0	2.2764	1.3812	0.	6.6000E 00
13	D7-5	3.0023	2.6284	0.	1.0333E 01
14	D6-5	3.3229	2.9313	0.	1.1000E 01
15	B5-0	0.0006	0.0006	0.	2.8000E-03
16	B7-5	0.0010	0.0011	0.	4.6667E-03
17	B6-5	0.0011	0.0012	0.	5.5000E-03
18	V7-5	0.0156	0.0169	-3.3333E-04	6.3667E-02
19	V6-5	0.0185	0.0203	-5.0000E-04	9.0500E-02

Treatment: Mid Level Sludge + Water 200W

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	140.7500	60.1918	4.5000E 01	2.9800E 02
2	DB75	151.0294	67.5700	4.5000E 01	3.2800E 02
3	DB76	158.8824	74.0146	4.7000E 01	3.4600E 02
4	DB77	162.6471	77.0628	4.8000E 01	3.5500E 02
5	BA70	0.0184	0.0161	2.0000E-03	7.0000E-02
6	BA75	0.0214	0.0194	2.0000E-03	8.4000E-02
7	BA76	0.0241	0.0226	2.0000E-03	9.4000E-02
8	BA77	0.0253	0.0240	2.0000E-03	9.9000E-02
9	V75	0.2092	0.2141	6.0000E-03	9.0000E-01
10	V76	0.2479	0.2615	7.0000E-03	1.0600E 00
11	V77	0.2633	0.2775	8.0000E-03	1.1160E 00
12	D5-0	2.0559	1.4842	0.	6.0000E 00
13	D7-5	3.8725	3.4804	0.	1.2667E 01
14	D6-5	3.9265	3.5305	0.	1.3500E 01
15	B5-0	0.0006	0.0007	0.	2.8000E-03
16	B7-5	0.0013	0.0016	0.	6.3333E-03
17	B6-5	0.0013	0.0017	0.	6.5000E-03
18	V7-5	0.0181	0.0221	3.3333E-04	8.5000E-02
19	V6-5	0.0193	0.0244	5.0000E-04	1.0150E-01

(cont'd)

Table C-3 (continued)

Treatment: High Level Sludge 300

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	161.4957	60.3884	7.3000E 01	3.3400E 02
2	DB75	173.8696	65.1306	7.9000E 01	3.6000E 02
3	DB76	181.4348	70.1706	8.1000E 01	3.7900E 02
4	DB77	184.7565	72.0171	8.4000E 01	3.8500E 02
5	BA70	0.0233	0.0181	4.0000E-03	8.8000E-02
6	BA75	0.0271	0.0212	5.0000E-03	1.0200E-01
7	BA76	0.0297	0.0238	5.0000E-03	1.1300E-01
8	BA77	0.0308	0.0248	6.0000E-03	1.1600E-01
9	V75	0.2640	0.2319	3.2000E-02	1.1170E 00
10	V76	0.3101	0.2783	3.3000E-02	1.3160E 00
11	V77	0.3246	0.2896	3.7000E-02	1.3070E 00
12	D5-0	2.4748	1.0821	4.0000E-01	6.0000E 00
13	D7-5	3.6290	2.6618	0.	9.3333E 00
14	D6-5	3.7826	2.8478	0.	1.0500E 01
15	B5-0	0.0007	0.0006	0.	3.2000E-03
16	B7-5	0.0013	0.0013	0.	5.3333E-03
17	B6-5	0.0013	0.0014	0.	6.0000E-03
18	V7-5	0.0202	0.0202	0.	8.4333E-02
19	V6-5	0.0230	0.0236	0.	1.0100E-01

Treatment: High Level Sludge + Water 300W

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	159.3559	54.9259	6.7000E 01	2.8100E 02
2	DB75	170.2373	60.8810	6.8000E 01	3.0500E 02
3	DB76	177.6949	66.5959	6.8000E 01	3.2200E 02
4	DB77	181.5763	69.5352	7.0000E 01	3.2800E 02
5	BA70	0.0222	0.0147	4.0000E-03	6.2000E-02
6	BA75	0.0256	0.0175	4.0000E-03	7.3000E-02
7	BA76	0.0282	0.0200	4.0000E-03	8.1000E-02
8	BA77	0.0296	0.0215	4.0000E-03	8.4000E-02
9	V75	0.2522	0.1903	2.3000E-02	7.6300E-01
10	V76	0.2964	0.2331	2.3000E-02	8.9500E-01
11	V77	0.3132	0.2496	2.5000E-02	9.5400E-01
12	D5-0	2.1763	1.2172	2.0000E-01	4.8000E 00
13	D7-5	3.7797	3.2149	0.	1.0333E 01
14	D6-5	3.7288	3.1980	0.	1.0500E 01
15	B5-0	0.0007	0.0006	0.	2.2000E-03
16	B7-5	0.0013	0.0014	0.	4.6667E-03
17	B6-5	0.0013	0.0014	0.	4.5000E-03
18	V7-5	0.0203	0.0207	0.	7.3000E-02
19	V6-5	0.0221	0.0221	0.	7.7500E-02

(cont'd)

Table C-3 (continued)

Treatment: Water only

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	180.1042	69.0003	5.3000E 01	3.8300E 02
2	DB75	192.9583	72.9698	5.6000E 01	4.0300E 02
3	DB76	200.5313	78.1973	5.7000E 01	4.2100E 02
4	DB77	203.5729	80.7160	5.7000E 01	4.3000E 02
5	BA70	0.0292	0.0226	2.0000E-03	1.1500E-01
6	BA75	0.0334	0.0254	2.0000E-03	1.2800E-01
7	BA76	0.0363	0.0281	3.0000E-03	1.3900E-01
8	BA77	0.0376	0.0295	3.0000E-03	1.4500E-01
9	V75	0.3381	0.2807	1.0000E-02	1.3600E 00
10	V76	0.3958	0.3322	1.0000E-02	1.5620E 00
11	V77	0.4120	0.3503	1.0000E-02	1.6860E 00
12	D5-0	2.5708	0.9629	6.0000E-01	5.6000E 00
13	D7-5	3.5382	2.9635	0.	1.0333E 01
14	D6-5	3.7865	3.0015	0.	1.1000E 01
15	B5-0	0.0008	0.0006	0.	3.0000E-03
16	B7-5	0.0014	0.0015	0.	5.6667E-03
17	B6-5	0.0015	0.0015	0.	5.5000E-03
18	V7-5	0.0246	0.0243	-6.6667E-04	1.0867E-01
19	V6-5	0.0289	0.0269	-1.0000E-03	1.0100E-01

Treatment: Unirrigated control

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	203.0789	58.0644	1.0700E 02	3.0900E 02
2	DB75	216.6579	63.8928	1.1200E 02	3.3400E 02
3	DB76	224.5526	68.6226	1.1200E 02	3.4800E 02
4	DB77	228.7632	71.1414	1.1300E 02	3.5600E 02
5	BA70	0.0348	0.0187	9.0000E-03	7.5000E-02
6	BA75	0.0400	0.0221	1.0000E-02	8.8000E-02
7	BA76	0.0432	0.0246	1.0000E-02	9.5000E-02
8	BA77	0.0450	0.0260	1.0000E-02	1.0000E-01
9	V75	0.4075	0.2391	8.4000E-02	9.2000E-01
10	V76	0.4633	0.2787	8.6000E-02	1.0400E 00
11	V77	0.4848	0.2968	8.8000E-02	1.0960E 00
12	D5-0	2.7158	1.3296	6.0000E-01	5.0000E 00
13	D7-5	4.0351	2.7188	3.3333E-01	9.3333E 00
14	D6-5	3.9474	2.7773	0.	9.5000E 00
15	B5-0	0.0010	0.0007	2.0000E-04	2.6000E-03
16	B7-5	0.0017	0.0014	0.	4.6667E-03
17	B6-5	0.0016	0.0014	0.	4.5000E-03
18	V7-5	0.0258	0.0200	1.3333E-03	6.9000E-02
19	V6-5	0.0279	0.0209	1.0000E-03	7.0500E-02

(cont'd)

Table C-4
Treatment means paired trees

Treatment: Low Level Sludge 100

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	186.6000	53.8796	8.4000E 01	2.7800E 02
2	DB75	200.6286	59.1136	9.1000E 01	3.0300E 02
3	DB76	210.9429	64.7597	9.3000E 01	3.2200E 02
4	DB77	215.2571	67.1015	9.6000E 01	3.2900E 02
5	BA70	0.0296	0.0158	6.0000E-03	6.1000E-02
6	BA75	0.0344	0.0187	7.0000E-03	7.2000E-02
7	BA76	0.0382	0.0214	7.0000E-03	8.1000E-02
8	BA77	0.0399	0.0228	7.0000E-03	8.5000E-02
9	V75	0.3339	0.2039	4.2000E-02	7.3500E-01
10	V76	0.4017	0.2484	4.6000E-02	8.8400E-01
11	V77	0.4233	0.2622	5.1000E-02	9.1500E-01
12	D5-0	2.8057	1.3271	6.0000E-01	5.0000E 00
13	D7-5	4.8762	2.9485	3.3333E-01	1.0000E 01
14	D6-5	5.1571	3.1872	5.0000E-01	1.2000E 01
15	B5-0	0.0010	0.0006	0.	2.2000E-03
16	B7-5	0.0018	0.0014	0.	4.6667E-03
17	B6-5	0.0019	0.0015	0.	5.5000E-03
18	V7-5	0.0282	0.0204	1.6667E-03	7.1333E-02
19	V6-5	0.0314	0.0233	2.0000E-03	9.1500E-02

Treatment: Low Level Sludge + Water 100W

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	170.6296	64.1172	9.0000E 01	3.0300E 02
2	DB75	182.5926	70.9617	9.3000E 01	3.3100E 02
3	DB76	192.2963	78.0320	9.4000E 01	3.4700E 02
4	DB77	195.7037	80.8564	9.4000E 01	3.5400E 02
5	BA70	0.0259	0.0195	6.0000E-03	7.2000E-02
6	BA75	0.0301	0.0231	7.0000E-03	8.6000E-02
7	BA76	0.0337	0.0270	7.0000E-03	9.5000E-02
8	BA77	0.0350	0.0284	7.0000E-03	9.3000E-02
9	V75	0.3107	0.2661	4.6000E-02	9.0600E-01
10	V76	0.3703	0.3283	4.6000E-02	1.1080E 00
11	V77	0.3872	0.3460	4.6000E-02	1.1430E 00
12	D5-0	2.3926	1.4342	6.0000E-01	5.6000E 00
13	D7-5	4.3704	3.6519	3.3333E-01	1.2000E 01
14	D6-5	4.8519	3.8676	5.0000E-01	1.3000E 01
15	B5-0	0.0008	0.0007	0.	2.8000E-03
16	B7-5	0.0016	0.0019	0.	6.3333E-03
17	B6-5	0.0018	0.0021	0.	6.5000E-03
18	V7-5	0.0255	0.0274	0.	9.1333E-02
19	V6-5	0.0298	0.0319	0.	1.0900E-01

(cont'd)

Table C-4 (continued)

Treatment: Mid Level Sludge 200

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	170.7568	48.1805	9.0000E 01	2.5400E 02
2	DB75	184.2973	54.3455	9.4000E 01	2.7500E 02
3	DB76	195.1081	59.4730	9.6000E 01	2.9200E 02
4	DB77	198.4324	61.6079	9.6000E 01	2.9500E 02
5	BA70	0.0246	0.0125	6.0000E-03	5.1000E-02
6	BA75	0.0289	0.0151	7.0000E-03	5.9000E-02
7	BA76	0.0326	0.0176	7.0000E-03	6.7000E-02
8	BA77	0.0338	0.0134	7.0000E-03	6.8000E-02
9	V75	0.2843	0.1617	4.9000E-02	5.7700E-01
10	V76	0.3440	0.2016	5.3000E-02	7.0600E-01
11	V77	0.3586	0.2119	5.3000E-02	7.3100E-01
12	D5-0	2.7081	1.3438	6.0000E-01	5.0000E 00
13	D7-5	4.7117	2.7724	3.3333E-01	1.0333E 01
14	D6-5	5.4054	2.9717	5.0000E-01	1.1000E 01
15	B5-0	0.0009	0.0006	0.	1.8000E-03
16	B7-5	0.0016	0.0012	0.	4.0000E-03
17	B6-5	0.0018	0.0013	0.	4.5000E-03
18	V7-5	0.0248	0.0173	6.6667E-04	5.9333E-02
19	V6-5	0.0299	0.0208	1.0000E-03	6.9500E-02

Treatment: Mid Level Sludge + Water 200W

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	154.9630	50.8841	8.6000E 01	2.5300E 02
2	DB75	166.8889	57.1081	8.9000E 01	2.7700E 02
3	DB76	175.9259	63.9945	9.0000E 01	3.0400E 02
4	DB77	180.1852	67.3853	9.0000E 01	3.1500E 02
5	BA70	0.0208	0.0132	6.0000E-03	5.0000E-02
6	BA75	0.0243	0.0160	6.0000E-03	6.0000E-02
7	BA76	0.0274	0.0191	6.0000E-03	7.3000E-02
8	BA77	0.0239	0.0206	6.0000E-03	7.8000E-02
9	V75	0.2385	0.1746	4.4000E-02	6.4100E-01
10	V76	0.2835	0.2189	4.7000E-02	8.1700E-01
11	V77	0.3030	0.2391	4.7000E-02	8.7500E-01
12	D5-0	2.3852	1.2501	6.0000E-01	4.8000E 00
13	D7-5	4.4321	3.6219	3.3333E-01	1.2667E 01
14	D6-5	4.5185	3.6387	0.	1.3500E 01
15	B5-0	0.0007	0.0006	0.	2.0000E-03
16	B7-5	0.0015	0.0016	0.	6.0000E-03
17	B6-5	0.0016	0.0016	0.	6.5000E-03
18	V7-5	0.0215	0.0223	1.0000E-03	7.8000E-02
19	V6-5	0.0225	0.0228	5.0000E-04	8.8000E-02

(cont'd)

Table C-4 (continued)

Treatment: High Level Sludge 300

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	193.2973	64.4601	8.1000E 01	3.0100E 02
2	DB75	206.8649	70.9570	8.4000E 01	3.2500E 02
3	DB76	217.0811	76.2647	8.5000E 01	3.4200E 02
4	DB77	221.4324	77.9550	8.5000E 01	3.4700E 02
5	BA70	0.0324	0.0195	5.0000E-03	7.1000E-02
6	BA75	0.0374	0.0230	6.0000E-03	8.3000E-02
7	BA76	0.0415	0.0259	6.0000E-03	9.2000E-02
8	BA77	0.0432	0.0269	6.0000E-03	9.5000E-02
9	V75	0.3779	0.2508	3.8000E-02	8.7400E-01
10	V76	0.4458	0.3010	3.8000E-02	1.0340E 00
11	V77	0.4695	0.3159	3.3000E-02	1.0530E 00
12	D5-0	2.7135	1.3321	6.0000E-01	5.0000E 00
13	D7-5	4.8559	2.6811	3.3333E-01	8.6667E 00
14	D6-5	5.1081	2.9654	5.0000E-01	9.5000E 00
15	B5-0	0.0010	0.0007	2.0000E-04	2.4000E-03
16	B7-5	0.0019	0.0014	0.	4.6667E-03
17	B6-5	0.0020	0.0015	0.	5.0000E-03
18	V7-5	0.0305	0.0227	0.	8.4333E-02
19	V6-5	0.0340	0.0257	0.	8.6000E-02

Treatment: High Level Sludge + Water 300W

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	182.4848	53.7146	9.0000E 01	2.8100E 02
2	DB75	195.6061	59.9348	9.3000E 01	3.0500E 02
3	DB76	205.0606	66.2471	9.4000E 01	3.2200E 02
4	DB77	210.0606	69.2220	9.4000E 01	3.2800E 02
5	BA70	0.0283	0.0157	6.0000E-03	6.2000E-02
6	BA75	0.0328	0.0187	7.0000E-03	7.3000E-02
7	BA76	0.0363	0.0216	7.0000E-03	8.1000E-02
8	BA77	0.0382	0.0232	7.0000E-03	8.4000E-02
9	V75	0.3294	0.2054	5.3000E-02	7.6300E-01
10	V76	0.3899	0.2526	5.5000E-02	8.9500E-01
11	V77	0.4133	0.2707	5.5000E-02	9.5400E-01
12	D5-0	2.6242	1.2784	6.0000E-01	4.8000E 00
13	D7-5	4.8182	3.4991	3.3333E-01	1.0333E 01
14	D6-5	4.7273	3.5446	0.	1.0500E 01
15	B5-0	0.0009	0.0006	2.0000E-04	2.2000E-03
16	B7-5	0.0018	0.0016	0.	4.6667E-03
17	B6-5	0.0017	0.0016	0.	4.5000E-03
13	V7-5	0.0280	0.0232	6.6667E-04	7.3000E-02
19	V6-5	0.0303	0.0245	1.0000E-03	7.7500E-02

(cont'd)

Table C-4 (continued)

Treatment: Water only

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	192.5185	62.0089	8.7000E 01	2.9700E 02
2	DB75	206.3704	67.3790	9.3000E 01	3.1900E 02
3	DB76	215.2222	72.4565	9.4000E 01	3.2900E 02
4	DB77	218.6667	74.5773	9.4000E 01	3.3000E 02
5	BA70	0.0320	0.0135	6.0000E-03	6.9000E-02
6	BA75	0.0370	0.0216	7.0000E-03	8.0000E-02
7	BA76	0.0404	0.0240	7.0000E-03	8.5000E-02
8	BA77	0.0418	0.0251	7.0000E-03	8.6000E-02
9	V75	0.3764	0.2399	4.5000E-02	8.4500E-01
10	V76	0.4447	0.2378	4.4000E-02	9.5500E-01
11	V77	0.4600	0.2935	4.4000E-02	9.6100E-01
12	D5-0	2.7704	1.1391	6.0000E-01	5.0000E 00
13	D7-5	4.0988	2.7855	3.3333E-01	8.6667E 00
14	D6-5	4.4259	2.8730	0.	8.5000E 00
15	B5-0	0.0010	0.0008	0.	2.2000E-03
16	B7-5	0.0016	0.0013	0.	4.0000E-03
17	B6-5	0.0017	0.0014	0.	4.0000E-03
18	V7-5	0.0279	0.0210	-6.6667E-04	7.0000E-02
19	V6-5	0.0341	0.0253	-1.0000E-03	7.9500E-02

Treatment: Unirrigated control

VAR	LABEL	MEAN	STD-DEV	MIN	MAX
1	DB70	205.6757	56.5843	1.0900E 02	3.0900E 02
2	DB75	219.2162	62.7699	1.1200E 02	3.3400E 02
3	DB76	227.1892	67.5898	1.1200E 02	3.4800E 02
4	DB77	231.4595	70.1267	1.1300E 02	3.5600E 02
5	BA70	0.0355	0.0184	9.0000E-03	7.5000E-02
6	BA75	0.0408	0.0219	1.0000E-02	8.8000E-02
7	BA76	0.0440	0.0244	1.0000E-02	9.5000E-02
8	BA77	0.0459	0.0258	1.0000E-02	1.0000E-01
9	V75	0.4158	0.2368	8.4000E-02	9.2000E-01
10	V76	0.4727	0.2764	8.6000E-02	1.0400E 00
11	V77	0.4946	0.2946	8.8000E-02	1.0960E 00
12	D5-0	2.7081	1.3471	6.0000E-01	5.0000E 00
13	D7-5	4.0811	2.7413	3.3333E-01	9.3333E 00
14	D6-5	3.9865	2.8050	0.	9.5000E 00
15	B5-0	0.0010	0.0007	2.0000E-04	2.6000E-03
16	B7-5	0.0017	0.0014	0.	4.6667E-03
17	B6-5	0.0016	0.0014	0.	4.5000E-03
18	V7-5	0.0263	0.0200	1.3333E-03	6.9000E-02
19	V6-5	0.0285	0.0209	1.0000E-03	7.0500E-02

(cont'd)

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

1. REPORT NO. EPA-600/2-80-002	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE EFFECTS OF SLUDGE IRRIGATION ON THREE PACIFIC NORTHWEST FOREST SOILS		5. REPORT DATE March 1980 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) David D. Wooldridge and John D. Stednick		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Municipality of Metropolitan Seattle, Exchange Building, 821 Second Avenue, Seattle, Washington 98104		10. PROGRAM ELEMENT NO. 1BC821, SOS #1, Task C/09
		11. CONTRACT/GRANT NO. R-802172-03
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Gerald Stern (513) 684-7654

16. ABSTRACT

A sprinkler irrigation system developed for uniform applications of anerobically digested, municipal-industrial sewage sludge initially applied up to 5.8 mt/ha/wk. Reduced infiltration of sludge occurred due to physically blocking of soil pores, causing ponding of sludge in the micro-depressions. Sludge loading rates were decreased to 10, 20, 30 and 40 mt/ha/yr.

The renovating capactiy of forest soils for most suspended and dissolved constituents in sludge was very good (95 to 99+%). Nitrogen was the exception as nitrification rates increased with increased rates of sludge applications, resulting in leaching of NO_3-N and concomitant cation losses in soil wa ter through the surface 2 m of soil. Leaching losses did not alter dissolved ions in ground water at 10 m. Phosphorus in all forms was never found in significant amounts in soil solutions of tested soils.

Optimum loading rates of 20 to 30 mt/ha/hr. of sludge show trends to increased surface soil total N, organic material and cation exchange capacity.

Analyses for virus at all depths in the soil and from the soil solution at corresponding depths were negative, nor were human pathogens of the bacteria type isolated from the limited numbers of soils and soil solutions analyzed.

Sludge applications increased the growth rate of treated trees. Water applied after sludge irrigation also may enhance tree growth over sludge only applications.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sludge, Sludge disposal, Waste disposal, Forestry, Forest land, Trees (plants), Soils, Soil analysis, Soil chemistry, Irrigation, Sprinkler irrigation, Surface irrigation		13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 184
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980 -657-146/5646

United States
Environmental Protection
Agency

Environmental Research Information
Center
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA-335

Official Business
Penalty for Private Use, $300

Special Fourth-Class Rate
Book

Please make all necessary changes on the above label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

EPA-600/2-80-002