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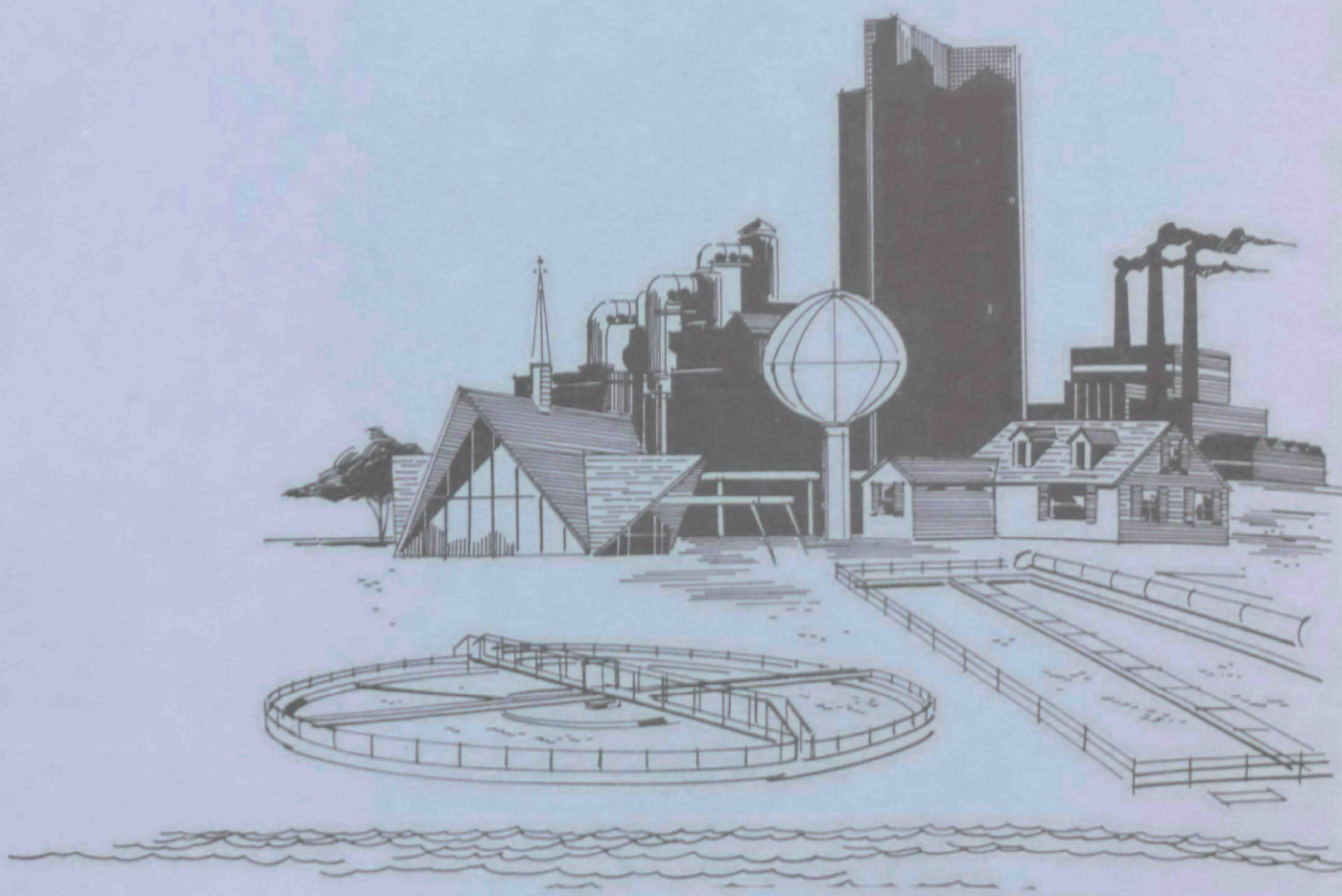

ENVIRONMENTAL PROTECTION AGENCY • WATER QUALITY OFFICE

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ONONDAGA LAKE STUDY

by

Onondaga County
Onondaga County Office Building
Syracuse, New York 13202

for the

WATER QUALITY OFFICE

ENVIRONMENTAL PROTECTION AGENCY

Project #11060 FAE 4/71

April 1971

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ABSTRACT

Physical, chemical, biological and geochemical investigations were conducted to determine the trophic status of Onondaga Lake, a saline lake on the edge of Syracuse, New York. Engineering evaluations were made to determine effects future pollution abatement facilities will have on the lake.

Major circulation patterns were determined from thermal transects of the lake, and distributions of chemical species within the lake with respect to time. The lake was found to be vertically stratified, but well-mixed horizontally. The lake is dimictic in that it undergoes two major periods of circulation per year.

The lake supports a wide variety of phytoplankton, zooplankton and fish, which is surprising in light of the lake's unusual chemistry.

Mineral-water equilibria studies showed phosphate bearing minerals form throughout the year in all zones of the lake. Calcite, which is prevalent throughout most of the year, constitutes most of the lake's sediments. It was determined projected waste treatment facilities will not significantly reduce formation of the above minerals in the lake.

Projected waste treatment facilities will result in significant increases in dissolved oxygen (DO) in the epilimnetic waters of the lake, and phosphate reductions in the lake. DO's in the upper waters are expected to be well above the New York State minimum classification for swimming and other recreational uses.

A recommended monitoring program is intended to lend insight into physiological factors to enable future projections of phyto- and zooplankton and to measure the effects of projected facilities on the lake.

This Report is part of a Federal Water Quality Administration (FWQA) Research and Development Grant (11060 FAE) to Onondaga County, New York.

TABLE OF CONTENTS

Section		Page
1	Conclusions	2
2	Recommendations	4
3	Introduction	6
	Location	6
	Impetus of Study	6
	Study Objectives	7
	Organization of Study	8
4	The Basin and Its Features	9
	General	9
	Geologic Setting	9
	Major Tributaries	12
	Water Quality	12
5	Water Pollution - Sources	14
	General	14
	Historical Review	14
	Sources of Pollution Considered	16
	Waste Discharge Survey	18
	Results	19
6	Literature Review	26
	General	26
	Early History	26
	Previous Reports (1920-1955)	29
	Additional Studies (1955-1970)	32
7	Sampling and Analyses	37
	General	37
	Open Water Sampling	37
	Waste Discharge Survey	39
	Coring	41
	Temperature Gradients	44
	Biological Studies	44
8	Gross Physical Features	45
	General	45
	Seismic Studies	46
	Results	46

TABLE OF CONTENTS - (Cont'd)

Section		Page
9	Other Physical Considerations - Temperature and Transparency	50
	General	50
	Temperature	50
	Thermal Transects	51
	Summary of Transects	53
	Transparency	55
10	Chemical Considerations	56
	General	56
	Lake Stratification vs "Overturn"	56
	Significance of Chlorides	58
	Horizontal Mixing	59
	Lake Buffering Capacity	60
	Statistical Routines	63
11	Biological Considerations	64
	General	64
	Sampling	65
	Phytoplankton - Results	65
	Zooplankton - Results	67
	Fish - Results	68
12	Geological Considerations	70
	General	71
	Basis of Mineral Equilibrium Model Treatment of Chemical Data	70
	Sources and Magnitude of Benthic Chloride Concentrations	77
	Sources and Magnitude of Dissolved Sulfide Concentrations	80
	Sediment Characteristics	81
	Heavy Metals	86
13	Engineering Considerations	88
	General	88
	Lake Assimilation Capacity (LASCAP)	88
	Calculation of LASCAP	91
	Pertinent Phosphorus Studies	92
	Phosphorus Interactions in Onondaga Lake	94

TABLE OF CONTENTS - (Cont'd)

Section		Page
14	Engineering Evaluations & Recommendations	96
	General	96
	Impact of New Metropolitan Sewage Treatment Facilities - Presently Under Design	97
	Storm Water Overflows	97
	Phosphorus Reductions	101
15	Summary	104
	Statement on Mercury	111
	Acknowledgments	112
	References	115
	Glossary	128

APPENDICES

Appendix		
A	Daily Accounts of Thermal Transects	131
	14 May 1968	132
	28 May 1968	132
	12 July 1968	132
	10 October 1968	133
	15 October 1968	133
	22 October 1968	133
	30 October 1968	133
	22 November 1968	134
	3 December 1968	134
	18 February 1969	135
	7 March 1969	135
	18 March 1969	136
	14 May 1969	136
	13 June 1969	137
	22 August 1969	137
	29 August 1969	137
	4 December 1969	138

TABLE OF CONTENTS - (Cont'd)

Appendix		Page
B	Chemical Considerations	149
	Alkalinity	153
	Biochemical Oxygen Demand	156
	Chlorides	159
	Carbon Dioxide	163
	Nitrogen	166
	Phosphorus	174
	pH	178
	Sulfates - Sulfides	181
	Dissolved Oxygen	186
	Calcium	189
	Sodium	191
	Potassium	194
	Magnesium	197
	Conductivity	200
	Trace Elements (Copper and Chromium)	204
	Trace Elements (Iron, Manganese, Zinc)	212
	Fluoride	219
	Silicon Dioxide	221
	Solids	223
	Escherichia Coli	228
	Statistical Analysis	231
C	Biological Considerations	311
	Phytoplankton Investigations	312
	Previous Studies	312
	Methods	314
	Results & Discussions - 1969	317
	Major Species	328
	Other Species	343
	Environmental Factors	351
	Relationship of Phytoplankton to Water Chemistry	354
	Grazing	358
	Bioassays	358
	Current State of Onondaga Lake with Respect to the Phytoplankton	358
	Zooplankton Investigations	361
	Methods	361
	Results	361
	Interpretation	381

TABLE OF CONTENTS - (Cont'd)

Appendix		Page
C	Biological Considerations (Cont'd)	
	Fish Survey of Onondaga Lake	385
	Introduction	385
	Methods	385
	Species Composition	387
	Distribution	391
	Benthos	391
	Summary & Recommendations	393
D	Geological Considerations	436
E	Engineering Considerations	459

FIGURES

Fig. No.		Page
1-1	Aerial View of Onondaga Lake	1
1-2	Onondaga Lake Sampling Locations	Pocket
4-1	Geologic Map, Onondaga Lake Basin	10
4-2	Onondaga Lake Contours and Drainage Basin	11
5-1	Air Pollutants During Ice Cover	17
7-1	Benthos Core	42
9-1	Infra-Red Imagry	54
A-1	Thermal Transects of Onondaga Lake	
	14 May 1968	140
	28 May 1968	140
	Thermal Cross Section of Onondaga Lake	
	28 May 1968	139
A-2	Thermal Transects of Onondaga Lake	
	12 July 1968	141
	10 October 1968	142
	15 October 1968	141
	22 October 1968	142
A-3	Thermal Transects of Onondaga Lake	
	30 October 1968	143
	22 November 1968	144
	3 December 1968	143
	18 February 1969	144
A-4	Thermal Transects of Onondaga Lake	
	7 March 1969	145
	18 March 1969	146
	14 May 1969	145
	13 June 1969	146
A-5	Thermal Transects of Onondaga Lake	
	22 August 1969	147
	29 August 1969	148
	4 December 1969	148

TABLE OF CONTENTS - (Cont'd)

Fig. No.		Page
B-1	Line Plot Temp. - Stations 1 & 2	234
B-2	Alkalinity - Stations 1 & 2	236
B-3	Biochemical Oxygen Demand - Stations 1 & 2	238
B-4	Chloride - Stations 1 & 2	240
B-5	Carbon Dioxide - Stations 1 & 2	242
B-6	Organic Nitrogen - Stations 1 & 2	244
B-7	Ammonia Nitrogen - Stations 1 & 2	246
B-8	Line Plot, Nitrate - Stations 1 & 2	248
B-9	Line Plot, Nitrite - Stations 1 & 2	250
B-10	Total Phosphorus - Stations 1 & 2	252
B-11	Ortho-Phosphorus - Stations 1 & 2	254
B-12	pH - Stations 1 & 2	256
B-13	Sulfates - Stations 1 & 2	258
B-14	Sulfides - Stations 1 & 2	260
B-15	Dissolved Oxygen - Stations 1 & 2	262
B-16	Calcium - Stations 1 & 2	264
B-17	Sodium - Stations 1 & 2	266
B-18	Potassium - Stations 1 & 2	268
B-19	Magnesium - Stations 1 & 2	270
B-20	Conductivity - Stations 1 & 2	272
B-21	Copper - Stations 1 & 2	274
B-22	Chromium - Stations 1 & 2	276
B-23	Iron - Stations 1 & 2	278

TABLE OF CONTENTS - (Cont'd)

Fig. No.		Page
B-24	Manganese - Stations 1 & 2	280
B-25	Zinc - Stations 1 & 2	282
B-26	Fluorides - Stations 1 & 2	284
B-27	Silicon Dioxide - Stations 1 & 2	286
B-28	Suspended Solids - Stations 1 & 2	287
B-29	Dissolved Solids - Stations 1 & 2	289
B-30	Secchi Disk - Stations 1 & 2	291
B-31	E. coli - Stations 1 & 2	293
B-32	Wind Velocity - Station 1	295
B-33	Nine Mile Creek - USGS Flow Data	296
B-34	Contour Plot - Temperature	297
B-35	Contour Plot - BOD	298
B-36	Contour Plot - Ortho-Phosphorus	299
B-37	Contour Plot - Dissolved Oxygen	300
B-38	Contour Plot - Chlorides, Station 1	301
B-39	Contour Plot - Chlorides, Station 2	302
B-40	Overnight Plot - Dissolved Oxygen June 10, 11, 1969	303
B-41	Overnight Plot - Dissolved Oxygen July 29, 30, 1969	304
B-42	Overnight Plot - Carbon Dioxide June 10, 11, 1969	305
B-43	Overnight Plot - pH - June 10, 11, 1969	306
B-44	Overnight Plot - Alkalinity June 10, 11, 1969	307

Fig. No.		Page
B-45	Overnight Plot - Temperature June 10, 11, 1969	308
B-46	Overnight Plot - Conductivity June 10, 11, 1969	309
B-47	Overnight Plot - Silicon Dioxide June 10, 11, 1969	310
C-1	Biological Sampling Locations	395
C-2	Biomass	396
C-3	Phytoplankton Diversity Index	397
C-4	*Chlamydomonas* (Tube Samples)	398
C-5	*Chlamydomonas* (Surface Samples)	399
C-6	Distribution of *Chlamydomonas* sp.	400
C-7	*Diatoma tenue* (Tube Samples)	402
C-8	*Diatoma tenue* (Surface Samples)	403
C-9	Distribution - *Diatoma tenue*	404
C-10	*Chlorella vulgaris* (Tube Samples)	407
C-11	*Chlorella vulgaris* (Surface Samples)	408
C-12	Distribution - *Chlorella vulgaris*	409
C-13	*Scenedesmus obliquus* (Tube Samples)	413
C-14	*Scenedesmus obliquus* (Surface Samples)	414
C-15	Distribution - *Scenedesmus obliquus*	415
C-16	*Scenedesmus quad.* (Tube Samples)	417
C-17	*Scenedesmus quad.* (Surface Samples)	419
C-18	Distribution - *Scenedesmus quad.*	420

TABLE OF CONTENTS

Fig. No.		Page
C-19	*Aphanizomenon flos-aquae* (Tube Samples)	421
C-20	*Aphanizomenon flos-aquae* (Surface Samples)	422
C-21	Distribution - *Aphanizomenon flos-aquae*	423
C-22	*Polycystis aeruginosa*	427
C-23	*Anabaena circinalis* *Fragilaria crotonensis*	428
C-24	*Melosira granulata* (Tube Samples)	429
C-25	*Melosira granulata* (Surface Samples)	430
C-26	Distribution - *Melosira granulata*	431
C-27	Euphotic Zone Determination	433
C-28	Onondaga Lake Zooplankton	434
D-1	Typical Distribution of Dissolved Iions and Iion Pairs	436
D-2	Stability Diag. for Hydroxyapatite	437
D-3	Stability Diag. for Fluorapatite	438
D-4	Stability Diag. for Fluorite	439
D-5	Calcite-Water Equilibrium Model	440
D-6	Fluoride Activity	441
D-7	Stability Diag. for Potassium Minerals, Kaolinite and Gibbsite - 20° C	442
D-8	Stability Diag. for Potassium Minerals, Kaolinite and Gibbsite - 10° C	443
D-9	Stability Diag. for Kaolinite - Ca-Montmorillonite	444

Fig. No.		Page
D-10	Least Squares Linear Regressions for Onondaga Lake Water	445
D-11	Least Squares Linear Regressions for Sediment Enclosed Waters	446
D-12	Sediment Profiles of Benthic Cores	447
E-1	Onondaga Lake Stabilization Zone	459
E-2	Lake DO vs BOD Input	460

TABLES

Table No.		Page
4-1	Major Tributaries of Onondaga Lake	13
5-1	Air Pollution Parameters - Average Annual Values	16
5-2	Waste Discharge Survey - Average Concentration mg/l	22
5-3	Waste Discharge Survey - Average Pounds per Day	23
5-4	Waste Discharge Survey - Percent of Total Pounds Per Day	24
5-5	Waste Discharge Survey - Lake Residence Equivalents mg/l	25
7-1	Onondaga Lake Analyses	37
7-2	Pore Water Analyses	41
7-3	Biological Analyses Stations	44
8-1	Annual Residence Time of Onondaga Lake	49
10-1	Comparative Water Densities	57
12-1	Minerals Tested	72
14-1	Comparison of Future Waste Loads to Onondaga Lake	98
B-1	Statistical Parameters - Depth Synoptic Data	151
	Frequency Distributions	
B-2	Alkalinity - Station 1	155
B-3	Biochemical Oxygen Demand - Station 1	158
B-4	Chloride - Station 1	162
B-5	Carbon Dioxide - Station 1	165
B-6	Total Nitrogen - Station 1	169

TABLE OF CONTENTS - (Cont'd)

Table No.		Page
B-6A	Nitrogen Concentrations	167
B-7	Organic Nitrogen - Station 1	170
B-8	Ammonia Nitrogen - Station 1	171
B-9	Nitrite - Station 1	172
B-10	Nitrate - Station 1	173
B-11	Total Phosphorus - Station 1	176
B-12	Ortho Phosphate - Station 1	177
B-13	pH - Station 1	180
B-14	Sulfide - Station 1	183
B-15	Sulfate - Station 1	184
B-16	Sulfate - Station 2	185
B-17	Dissolved Oxygen - Station 1	188
B-18	Calcium - Station 1	190
B-19	Sodium - Station 1	193
B-20	Potassium - Station 1	196
B-21	Magnesium - Station 2	198
B-22	Magnesium - Station 1	199
B-23	Conductivity - Station 2	202
B-24	Conductivity - Station 1	203
B-25	Copper - Station 2	208
B-26	Copper - Station 1	209
B-27	Chromium - Station 2	210
B-28	Chromium - Station 1	211

Table No.		Page
B-29	Iron - Station 1	215
B-30	Manganese - Station 2	216
B-31	Manganese - Station 1	217
B-32	Zinc - Station 1	218
B-33	Fluoride - Station 1	220
B-34	Silicon Dioxide - Station 1	222
B-35	Total Solids - Station 1	225
B-36	Suspended Solids - Station 1	226
B-37	Dissolved Solids - Station 1	227
B-38	*E. coli* - Station 2	229
B-39	*E. coli* - Station 1	230
B-40	Correlation and Regression Analysis-Depth Synoptic Data	232
C-1	Dominant Species in 1967	312
C-2	Occurrence of *Polycystis aeruginosa* in 1969	339
C-3	Periods of Occurrence of 14 Species of Phytoplankton in 1969	348
C-4	Concentrations of *Synura uvella* in Surface Samples	350
C-5	Onondaga Lake Zooplankton - Abundant Species	363
C-6	Onondaga Lake Zooplankton - Mean Number per 100 Liters @ Each Station	368

Table No.		Page
C-7	Coefficients of Variation, Major Species	376
C-8	Summary of Fishery Research Activities	385
C-9	Age and Growth of White Perch in Onondaga Lake	389
C-10	Gill Net Catches, Onondaga Lake, 1969	392
D-1	Chemical Data for Sediment Enclosed Water - Piston Core, 1969	448
D-2	Chemical Data for Sediment Enclosed Water - Benthos Core, 1968	449
D-3	Chemical Data for Sediment Enclosed Water - Benthos Core, 1969	450
D-4	Chemical Data for Lake Water, Station 1 - 1969	451
D-5	Sediment Shaking Tests	452
D-6	Jenkins Samples	455

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AERIAL VIEW – ONONDAGA LAKE

FIGURE 1-1

SECTION 1 - CONCLUSIONS

Greater than 90% of the chlorides now present in Onondaga Lake can be accounted for by surface discharges entering the lake. While chloride diffusion from the bottom sediments is currently only a minor factor, early historical accounts do not clearly indicate that the lake proper was at one time considered either fresh or saline. Based on the geochemical nature of waters enclosed within the lake sediments and of the drainage basin itself, the lake might always have had a high mineral content. However, knowledge of the exact nature of the saline vs fresh-water nature of the lake may never be known.

The major portions of calcium, chloride, chromium, iron, nitrate, potassium and sodium entering the lake result from discharges along the western shore of the lake, not including Harbor Brook. The major portions of all other materials entering the lake, including BOD and phosphorus, emanate from the southeast shore of the lake.

Presently, the major BOD discharges emanate from the Ley Creek and Metropolitan Sewage Treatment Plants.

Significant BOD discharges emanate from the Ley Creek stream bed and/or leaching from the sanitary landfill operations in the vicinity of the Ley Creek discharge.

BOD and phosphorus discharges resulting from the combined sewer overflows will not significantly impair the quality of lake waters if the combined sewer system is operated in accordance with recommendations outlined in the 1961 O'Brien & Gere Report on the Main Intercepting Sewer. Bacterial concentrations in the open waters of the lake fall below limits prescribed by the New York State Department of Environmental Conservation for swimming. However, the occurrence of combined sewer overflows precludes these observations as a guarantee of public safety, when waters are used for such recreation.

The largest thermal inputs entering the lake are the "East Flume", Nine Mile Creek and the Metropolitan Sewage Treatment Plant discharges.

Onondaga Lake is a dimictic lake in that it undergoes two periods of circulation per year, with the major circulation occurring in the fall. Chemical contributions to the density structure of the lake tend to impede the rate of mixing of lake waters during overturn. Lake waters are well stratified vertically during summer and winter, but are well mixed along horizontal planes.

High concentrations of chemicals within the lake, with the exception of copper and chromium, are not adverse to a wide variety of biological species. Concentrations of principal nutrients such as phosphorus, nitrates and calcium compounds are not limiting nor inhibitory to algal growth in the lake, at this time. Copper and chromium concentrations in the lake may sometimes approach levels inhibitory to certain algae. In general, the lake supports a community of zooplankton typical for a saline lake at this latitude.

The lake supports a very diverse fish fauna typical of many warm-water lakes in central New York State. Sixteen species were identified and except for a large population of white perch, species composition does not appear to have changed appreciably from that shown in surveys of the lake in 1927 and 1946. The epilimnion is the primary habitat for fish in the lake and in general, waters proximate to discharges entering the lake are not preferred by the fish.

High calcium concentrations, primarily resulting from the Nine Mile Creek discharge, are a major factor in the year-round formation of phosphate bearing minerals, such as hydroxyapatite and fluroapatite, throughout the lake. These concentrations also favor the precipitation of calcite throughout the lake for all but a few months out of the year.

The mineralogical content of bottom sediments (0-approx. 4 meters deep) is largely calcite with an average organic composition of 10% by weight. Oxygen demand attributable to the bottom sediments is negligible at this time and phosphorus concentrations related to these same sediments are confined to the hypolimnetic waters of the lake.

The operation of the new Metropolitan Sewage Treatment Facilities is expected to result in a DO saturation within the epilimnion of the lake of greater than 50%, as opposed to present minima of 10%. Consequently, it is anticipated that projected DO concentrations in the lake will be above the minimum allowable limits for New York State Class "B" waters. The relative density of the discharge from these facilities will fall within the density range of the hypolimnetic waters of the lake.

The removal of other chemicals by the above facilities will not affect significantly the formation of phosphate-bearing minerals or calcite within the lake. These facilities will significantly reduce phosphorus discharges to the lake. Other studies have shown that the effluent phosphorus concentration of the new Metropolitan Sewage Treatment Plant will be equal to or less than 1.0 mg/l in total phosphorus in accordance with New York State Policy.

SECTION 2 - RECOMMENDATIONS

It is recommended:

1. That the new treatment facilities at the Metropolitan Sewage Treatment Plant be constructed as presently planned, to effect significant reductions in BOD and phosphorus.

2. That the effluent from the new Treatment Plant be discharged to the surface of the lake, thus increasing the mixing of this discharge with lake waters.

3. That additional measures be taken to reduce the BOD discharges now emanating from Ley Creek. Programs presently being undertaken, such as dredging of the creek bottom and sealing areas of the creek where portions of leachate enter the creek, will result in reductions. Further measures may need to be taken pending evaluations subsequent to these programs.

4. That the improvements now underway for the Syracuse Interceptor Sewer System be made to ensure the proper operations of all intercepting and overflow devices.

5. That measures be taken to prevent bacterial contamination of any lake waters from the Syracuse combined sewer overflows that periodically discharge to Onondaga Creek and Harbor Brook. This will require investigations of methods more economical than have been proposed for this interceptor system to date.

6. That measures be taken to prevent Cu and Cr concentrations in the lake from exceeding 0.04 and 0.02 mg/l respectively by monitoring and controlling the appropriate flows.

7. That the bottom sediments not be disturbed by any artificial means until such time as they may show adverse effects on the overlying waters.

8. That a monitoring program of Onondaga Lake be conducted for the continual measurement of chemical and biological parameters to define the physiological factors pertinent to lake biota and projections of the same.

9. That the above program include measurements of major discharges entering the lake for those parameters related thereto in order to assess the effects of improved waste treatment facilities on the lake, and to assist in water quality management of the lake.

10. That consideration be given to further study and management of fish populations commensurate with the anticipated improvement of water quality in the lake. The latter may result in intensive fishing in the lake, further necessitating a fish management program.

SECTION 3 - INTRODUCTION

Location

Onondaga Lake (20.5 meters maximum depth) is a waterbody situated at the northern edge of the City of Syracuse in Central New York State. Although the lake is only 11.7 sq. kms. (4-1/2 sq. mi.) in area, the drainage basin is 600 sq. kms. (240 sq. mi.), contains approximately 325,000 people, and essentially all of Onondaga County's 140 industries. The lake flows from southeast to northwest and ultimately discharges to the Seneca River. The confluence of the Seneca and Oneida Rivers form the Oswego River which discharges at the southeastern shore of Lake Ontario, 64 km. (40 mi.) north of the lake. The lake was once considered the major recreational asset of the metropolitan area. However, at the present time, recreation is primarily confined to picnicking along the upper northern edges of the lake.

Impetus of Study

Interest in Onondaga Lake can be related directly to the present public awareness of environmental pollution, an awareness that has become more acute in the last several years. In the case of Onondaga Lake, this can best be illustrated by the following popular comments:

- The lake has been used for years as a receptacle for municipal and industrial wastes
- Extensive organic bottom deposits impair the quality of lake water
- It has one of the highest salinities and solids content of lakes in the northeast United States
- Periodic algal blooms are objectionable
- The lake is not suitable for swimming or fishing
- The aesthetic qualities leave much to be desired
- The lake's potential for multiple use is not realized to capacity.

Some of these comments have been substantiated by limited technical investigations, while others are based primarily on cursory observations of the lake. In answer to the

growing concern, Onondaga County adopted a comprehensive pollution abatement program to improve conditions in the watershed. In 1967, the Onondaga County Department of Public Works applied for, and obtained, a Federal Water Quality Administration Research and Development Grant (11060 FAE) to determine the feasibility of a cooperative municipal-industrial approach to the wastewater problems.

Study Objectives

A study of Onondaga Lake was an essential part of the above program. The major objectives of this study were to:

- Ascertain the present trophic status of the lake.
- Evaluate the impact of engineering programs.
- Provide baseline data for ongoing evaluations.
- Establish a program for continuous monitoring of the lake.

The Study entailed measuring physical, chemical, geological and biological variables important to the above considerations. The most important objective of the Study was to evaluate the impact of various pollution abatement programs with respect to the best uses of the lake. The "best uses" of the lake are dependent upon the extent to which the "benefited" public is willing to finance improvement programs in conjunction with the availability of State and Federal Funds. Evaluations of programs focused on:

1. The extent to which the lake's bottom deposits affect the overlying waters.
2. The impact that the new Metropolitan Sewage Treatment Facilities, now under design, would have on the lake.
3. The extent to which interceptor sewer overflows affect the lake.
4. Identification and analyses of major wastewater flows into the lake.

On the basis of the above evaluations, engineering recommendations with respect to additional pollution abatement facilities were to be made.

It is anticipated that a monitoring program will be conducted following the sampling phase of this Study. The fund of information collected and processed herein will serve as the

basis and "plane of reference" for succeeding data, thus allowing for a cohesive managerial program for the lake. Such a monitoring program, in conjunction with the Study, will no doubt be a valuable contribution to the field of limnology and be of benefit to the abatement of lake pollution in general.

Organization of Study

In order to permit an orderly development of the sampling and analytical program, the Study was divided into two sections, namely, preliminary and detailed phases. All lakes are unique and require a distinct program of sampling and analysis for their evaluation. The objective of the preliminary phase was to determine what sampling and analytical techniques should be employed to assess the trophic status of the lake. More specifically, this phase included the following:.

- Review of the literature dealing directly with Onondaga Lake, including processing of previously collected data

- Determination of gross physical features of the lake such as: areas, volume, general benthic characteristics and flow volumes of the lake's major tributaries.

- The collection of physical, chemical, geological and biological data in various forms and at assorted locations for the purpose of establishing permanent sampling locations.

The Literature Review concentrated on those studies dealing directly with Onondaga Lake. This information is reviewed in detail under Section 6 of this Report. The major portion of data, processed under this phase, was collected by Onondaga County and covered the period 1959 to 1967. Under this Study, measurements were begun in April of 1968, many parameters being gradually introduced as results dictated.

The preliminary phase was continued until December 1968, at which time the detailed phase began. The latter extended to December 1969.

During this phase, emphasis was placed on sampling those locations most representative of the major portion of the lake and hence reflecting changes of a relatively long duration.

Locations representative of the deepest portions of the lake were found to reflect the lake proper. During this phase consistency was maintained for sampling locations, parameters measured and frequency of measurement. The development of engineering recommendations, as well as the establishment of a basis for continuous monitoring of the lake was part of this phase.

SECTION 4 - THE BASIN AND ITS FEATURES

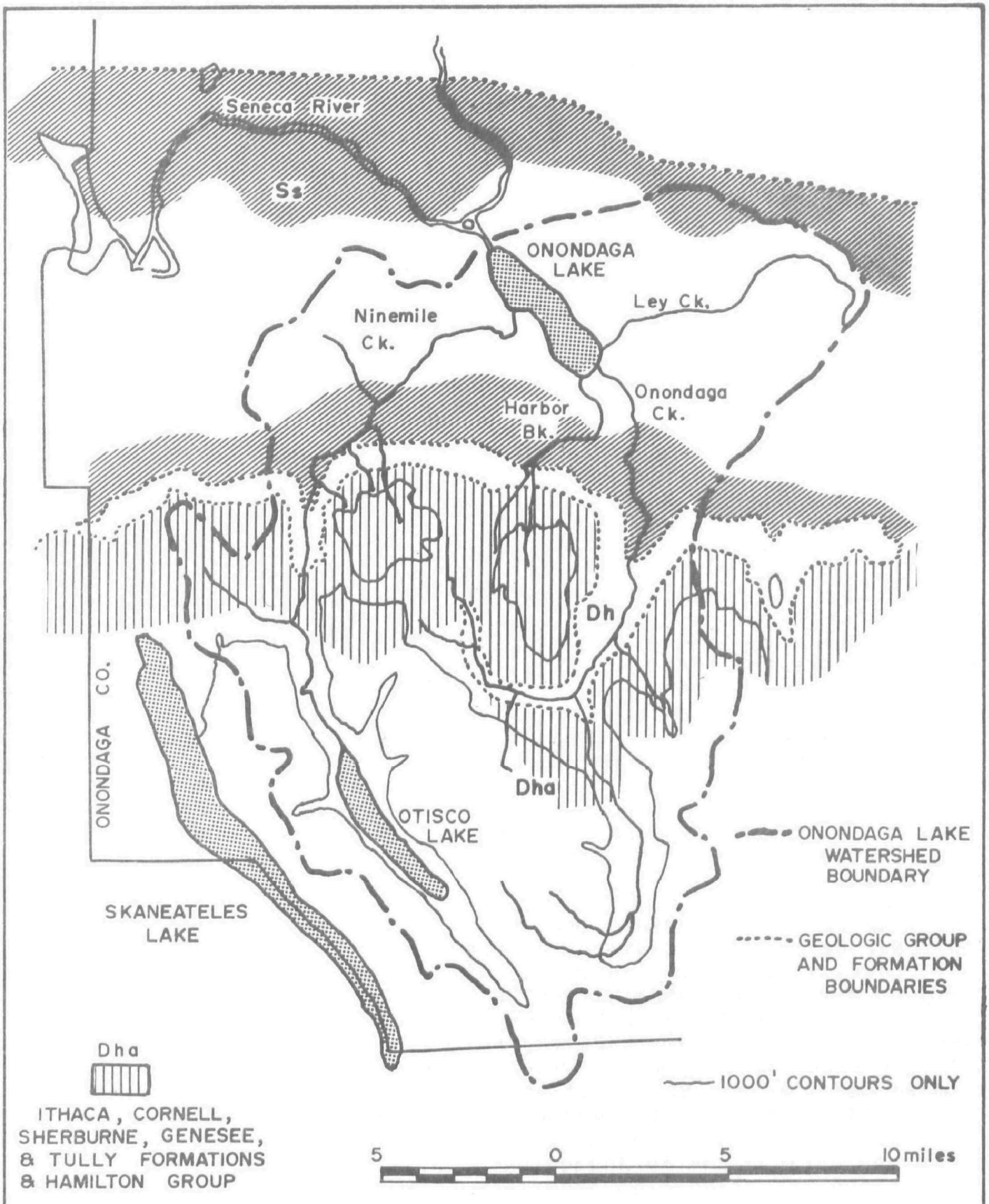
General

Onondaga Lake is the largest lake totally within the boundaries of Onondaga County, that is also situated in the Lake Ontario Plain. The average annual precipitation for the period of record, 1931 to 1960 inclusive was 95.5 cm. (37.6 inches). The average maximum and minimum annual temperatures for the same period were measured at 13.8° C (56.9° F) and 4.0° C (39.2° F) respectively. The average annual snowfall for the same period was calculated to be 315 cm (124 inches) (US Weather Bureau, Syracuse, N. Y.). As part of the New York State Barge Canal System, the water surface elevation of Onondaga Lake is controlled at 363.0 NYS Barge Canal Datum, by a dam on the Oswego River at Phoenix, New York, approximately 15.7 km. (4.8 mi.) downstream from the lake outlet. During the period from 1930 to 1968, the lowest elevation of the lake was 362.8 Barge Canal Datum, (USGS Datum equal to NYS Barge Canal Datum plus 1.444). The maximum level of the lake occurred in 1936 when a flood level of 113 m (371.6 ft.) Barge Canal Datum, was recorded.

Geologic Setting

Onondaga Lake and lower Nine Mile and Onondaga Creek discharges lie within the southern Ontario lowlands province. The lake lies in the Limestone Belt, which travels east-west and is bounded on the south by the highlands of the northern Appalachian Plateau and on the north by the Lake Ontario Plain. The Helderberg group rocks, mostly limestones and dolomites, form the moderately steep north-facing scarp, the Onondaga Lake Drainage Basin disects the northern plateau upland. The longitudinal axis of the lake runs from the southeast to the northwest.

The lake and its watershed are situated upon upper Silurian to upper Devonianage sedimentary rocks which include shale, siltstone, sandstone, limestone, dolomite and gypsum beds (Figure 4-1). In general, rock units dip very gently southward beneath sequentially younger strata. The regional east-west strikes of broadly expolsed rock groups and the similarity of rock exposure patterns to the elevation shown, (Figure 4-2). A more detailed discussion of the geological characteristics of the lake and its basin appears in Section 12.

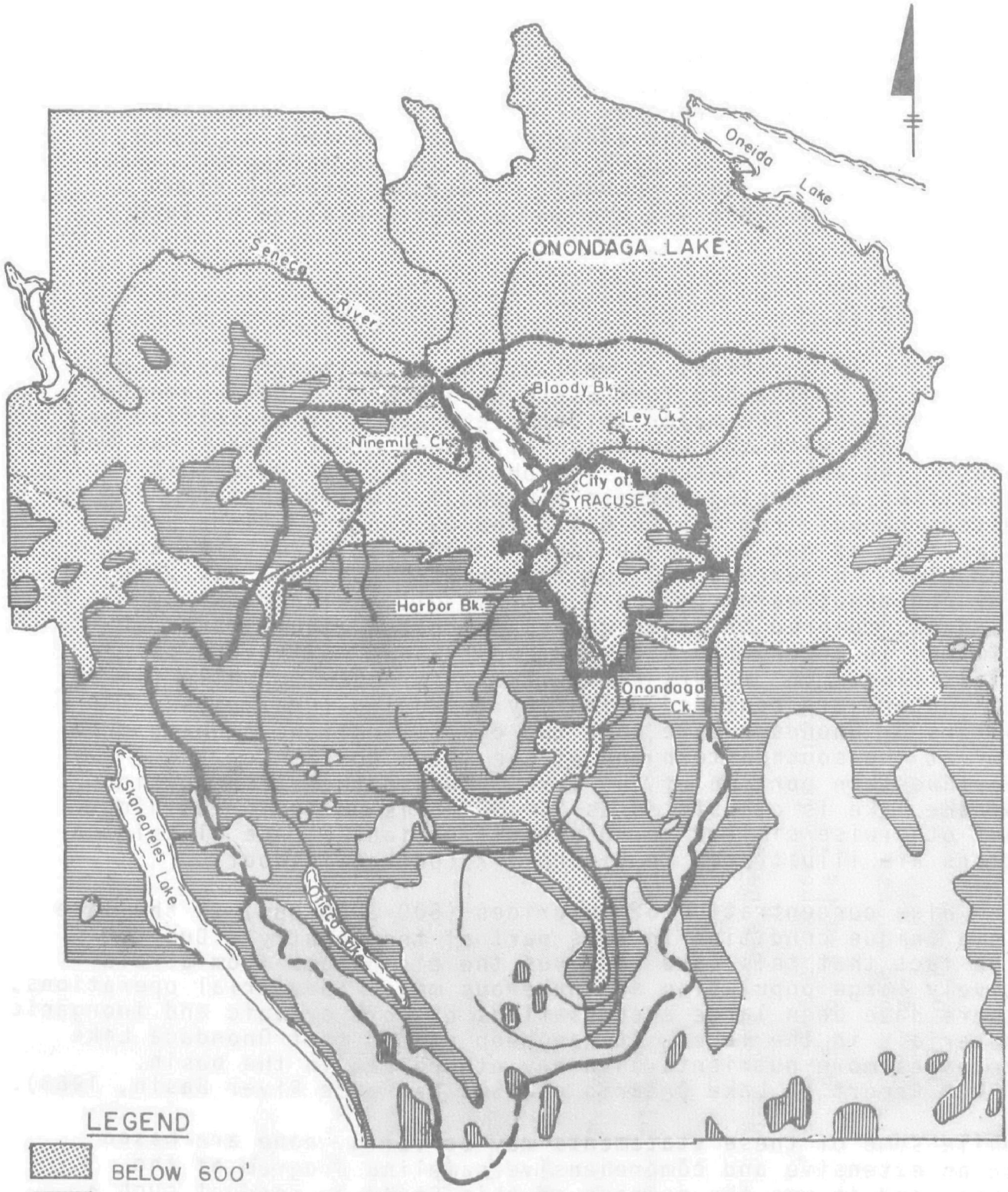


GEOLOGIC MAP
ONONDAGA LAKE BASIN

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

4-1



ONONDAGA LAKE CONTOURS AND DRAINAGE BASIN

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SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

4-2

Major Tributaries

The major tributaries to Onondaga Lake, in the order of their total flow contribution, appear in Table 4-1. Flows represent records through the years 1965, 1967 and 1968. These are the only years in which records of all the major tributaries were available. However, the average annual rainfall of these three years was 96 cm (36.2 inches), approximating a 57-year average of 90 cm (36.6 inches). Thus, the average flows illustrated in Table 4-1 are quite representative of lake inflows.

Water Quality

The major tributaries, as well as the lake itself, have been classified by the New York State Department of Environmental Conservation. The major tributaries have been classified as "D" waters, with the exception of Bloody Brook, which has been classified as "B" waters. The pH of Class "D" waters is specified as ranging between 6.0 and 9.5 while that of "B" waters ranges from 6.5 to 8.5. The DO concentrations are specified as not less than 3 ppm for Class "D" waters, and for Class "B" waters 5.0 ppm for trout waters and 4.0 ppm for non-trout waters. Toxic wastes, oil, deleterious substances, colored or other wastes or heated liquids are limited in accordance with the "best usage" of waters as classified. "B" waters are suitable for bathing while Class "D" waters are confined primarily to agricultural uses. The waters of Onondaga Lake have two classifications ranging from "C" at the southeastern end of the lake; to "B" for the northwestern portion of the lake. The southeastern portion of the lake is classified as "C" which is unfit for bathing, but otherwise similar to "B" specifications. Lake classifications are illustrated in Figure 1-2 (pocket foldout).

The high concentration of chlorides (500-3000 ppm) in the lake is a unique condition in this part of the country. Due to the fact that this lake receives the discharges from a relatively large population and numerous major industrial operations, there have been large accumulations of both organic and inorganic materials in the lake. It has been stated that Onondaga Lake receives more nutrients than any other lake in the basin. (FWQA Report on Lake Ontario and St. Lawrence River Basin, 1968).

While some of these statements may be valid, none are based on an extensive and comprehensive sampling program of the lake; and it was the purpose of this Study to conduct such a program.

TABLE 4-1

ONONDAGA LAKE STUDY

Major Tributaries of Onondaga Lake

Tributary	+ Watershed Area (mi^2)	+ Watershed Area (Km^2)	+ Mainstream Length (Mi)	+ Mainstream Length (Km)	* Annual Flow (cfs)	* Annual Flow (M^3/sec)
Nine Mile Creek - including Otisco Lake drainage area	124.8	323.0	34.3	55.2	88.4	2.5
Onondaga Creek	102.5	265.0	27.5	44.2	145.4	4.1
Ley Creek	26.2	68.8	9.5	15.3	62.7	1.8
Harbor Brook	13.2	34.2	7.5	12.1	17.4	0.5
Bloody Brook	4.5	11.7	2.2	3.5	Negligible	
Seneca River	----------		Outlet	------	No Gauging Station	

+ New York State Department of Health, 1951

* USGS, Annual Reports to Onondaga County, Department of Public Works 1965, 67 and 68.

The average annual rainfall for the years 1965, 67 and 68 was determined to be 92 cm (36.22 inches) as compared to 90.4 cm (35.6 inches) from 1931 to 1968.

SECTION 5 - WATER POLLUTION - SOURCES

General

Although it was not within the scope of this Study to determine the cause-effect relationships that brought Onondaga Lake to its present condition, a cursory review of the historical events that have taken place can serve as a guide in determining what the lake's future condition will be. This Section deals with pertinent events that have taken place during the "period of record" and reviews the present status of pollutants discharging into the lake. Before embarking on a review, it is necessary to define some basic terms as they are used in this text. A complete glossary for this Study may be found following the Bibliography.

Lakes are classified in many ways. One such classification is by their trophic (food or nourishment) level which gives a rough measure of their productivity or their actual capacity to produce. An oligotrophic lake is a lake low in nutrients while a eutrophic lake is rich in nutrients. Onondaga Lake is very rich in nutrients and thus is highly eutrophic. The trophic nature and productivity of a lake depend on many factors, the most important of which are nutrients received from the environment in which the lake resides. Other factors such as color, depth, surface area, latitude rainfall and temperature, play additional but usually secondary roles. Eutrophication is defined herein as the process of enrichment by nutrients (Stewart and Rohlich, 1967) and was considered originally as limited to phosphorus and nitrogen. Such limitation may be too restrictive for some lakes but the basic definition should still be kept in mind.

Historical Review

In 1812, the Syracuse area began to develop industrially by taking advantage of salt or brine deposits located along the southern edge of Onondaga Lake. Exploitation of this resource resulted in this area becoming the major salt supplier of the nation during the 1800's reaching a peak in 1862. It was this industry that prompted the construction of the Erie Canal System which was then the major mode of transportation to as far west as Ohio (Wright, R. 1969). In the late 1800's other industries located in this area and began manufacturing such products as soda ash, steel, vehicular accessories and pottery. In the first four decades of the 1900's this area witnessed the development of major pharmaceutical, air conditioning, general appliance and electrical manufacturing facilities.

The metropolitan area of Syracuse has developed from a population of 110,000 in 1900 to a metropolitan area with a present population in excess of a half million people.

Onondaga Lake has served as the receptacle for major portions of the domestic and industrial waste discharges of this area. In common with many large cities, Syracuse constructed combined sewer systems which resulted in discharges to the tributaries of Onondaga Lake. Industries and suburban villages outside the City of Syracuse constructed sewer systems that discharged directly to Onondaga Lake.

In 1899 real concern was expressed about pollution in Onondaga Lake. Interest was focused on the fate of the Onondaga Lake white fish, a one-time delicacy, which was never recorded after the first decade of the twentieth century.

The Syracuse Intercepting Sewer Board was established in 1907 under State Law for the primary purpose of improving stream conditions through the City by the construction of intercepting sewers. Under a subsequent ammendment to the act, the Board was authorized to construct sewage treatment works. Two main interceptors were constructed, and in 1922 an outfall sewer was constructed to convey the sewage directly into Onondaga Lake, approximately 518 meters (1700) feet off the southern shore. In 1925 the first sewage treatment plant operated by the City of Syracuse was constructed at the southern end of the lake just west of the present Onondaga Creek discharge location. The sewage was chlorinated and pumped to sedimentation tanks and then discharged into the lake by the outfall sewer. This condition continued until 1960, with the exception of the period from 1950 to 1953, at which time a change in the location of sludge disposal resulted in untreated sewage being discharged via the outfall sewer. In 1960 the present Metropolitan plant was put into operation and included more sedimentation basins which were equipped for chemical coagulation.

The domestic and industrial sewage from the Ley Creek drainage basin has been discharged to Ley Creek and thereto the lake with little or no treatment. The Ley Creek drainage area now comprises a major portion of the Metropolitan Syracuse industries, some of which discharge wastes with a very high BOD. Although the first (1940) treatment plant was doubled in 1949 the plant is unable to produce an effluent which is acceptable for discharge into the dilution afforded by Ley Creek. The 1952 O'Brien & Gere report recommended pumping the Ley Creek Treatment Plant effluent to the Seneca River in conjunction with the Metropolitan Plant effluent. Neither force main was constructed. In 1961 a force main was constructed from the Ley Creek Treatment Plant to the Metropolitan Plant, in order to effect some additional treatment at the Metropolitan Plant and

in anticipation of the tertiary facilities being designed for the latter. The Metropolitan Plant now treats 48 mgd plus 14 mgd from the Ley Creek Treatment Plant for a total of 62 mgd.

Sources of Pollution Considered

The sources of lake pollutants considered can be catagorized under three main headings, namely:

1. Air pollutants
2. Benthic Deposits
3. Stream and wastewater discharges

The first two are discussed under this subsection.

Air Pollutants

In October 1966 Onondaga County sponsored a County Air Pollution Survey conducted by the Syracuse University Research Corporation for the purpose of defining the nature, extent and causes of air pollution in the County. By using such equipment as the Dustfall Jar, the Lead Peroxide Candle and the High Volume Air Sampler, critical air pollution parameters were measured, namely; settleable particulate matter, sulfates derived from rates of sufation, and suspended particulate matter. Three sampling locations located proximate to the lake were used to determine the significance of air pollution. Suspended particulate matter was not considered. Table 5-1 shows the annual average values for the parameters measured:

TABLE 5-1

AIR POLLUTION PARAMETERS

AVERAGE ANNUAL VALUES

PARAMETER	VALUE	UNIT
Total Settleable Particulate Matter	0.67	$mg/cm^2/30$ days
Volatile Settleable Particulate Matter	0.23	$mg/cm^2/30$ days
Sulfates	0.24	$mg/cm^2/30$ days

AIR POLLUTANTS DURING ICE COVER

FIGURE 5-1

Volatile settleable particulate matter (VSPM) was considered as a BOD input source and to be 100% degradable. On the basis of 0.23 mg/cm^2/30 days, the total quantity corresponding to the surface area of the lake (4.5 sq. mi., 11.7 sq. km.) per 30 days is equal to 58,500 lbs. or 26,700 kilograms. On the basis of a lake volume of 37.08 X 10^9 gallons (140 X 10^9 liters) this is equivalent to a concentration throughout the entire lake of 0.191 mg/l. If VSPM accumulate over a 150 day period, approximately the residence time of the lake, the resulting concentration would be 0.97 mg/l. The corresponding sulfate concentrations are nearly the same -- 1.05 mg/l. Figure 5-1 demonstrates air pollutants on the lake.

Benthic Deposits

Benthic deposits are evaluated with respect to mineral composition, gas development and interfacial chemistry in Section 12. Approximations of oxygen demand rates are included under Section 13.

Wastewater Discharge Survey

In order to assess the total input of chemical species from the major tributary streams as well as major waste discharges, a sampling program was initiated in June of 1969. Eight major discharges, shown in Figure 1-2, were monitored for some 24 chemical parameters, as outlined in Section 7. Samples were taken at two-week intervals allowing a total of 19 sampling days thoughout the period. Tables 5-2 through 5-5 illustrate the results.

Staff gauge readings for the major tributaries were recorded by the Onondaga County Department of Public Works at the time of discharge sampling and interpreted by the United States Geological Survey. Flows for Bloody Brook were estimated from its drainage area in relationship to that of Nine Mile Creek. Industrial discharge flows entitled "East Flume" and "Steel Mill" were estimated from water consumption figures through correspondence with the respective industries. Metropolitan Sewage Treatment Plant flows were available from daily records.

Table 5-2 shows averages of individual concentrations of each chemical species measured. Table 5-3 shows average pounds derived from cencentrations and corresponding flows at the time of each measurement. Percentages of materials discharged were calculated from average pounds and are shown in Table 5-4. In order to compare chemical species discharged to those concentrations in the lake, values from Table 5-3 were multiplied by the calculated residence time of the lake in 1969 of 150 days and divided by the estimated volume of the lake of

37.078 X 10^3 million gallons. The results, herein referred to as Lake Residence Equivalents (LRE), are shown in Table 5-5.

It should be pointed out that the "East Flume", Nine Mile Creek and "Steel Mill" discharges contain quantities of coolant waters derived from the southwestern portion of the lake, and in the vicinity of sampling Station No. 1. The soda ash manufacturing plant utilizes approximately 110 mgd of lake water and discharges 80 and 30 mgd to the "East Flume" and Nine Mile Creek discharges respectively. The entire flow of the former is purportedly coolant water. Approximately 5.3 mgd of the 6.5 mgd discharged by the "Steel Mill" represents coolant waters.

The above discharges were corrected for chemical quantities resident in the lake by subtracting the average of the epilimnion and hypolimnion means for Station No. 1, shown in Table B-1, (Appendix B) multiplied by the appropriate flows. Hence Tables 5-2 to 5-5 reflect net amounts discharged.

Results

The southeastern end of Onondaga Lake receives the major domestic and industrial waste discharges of the metropolitan area, with the exception of a major soda ash producer and a major specialty steel manufacturer both discharging off the western shore of the lake.

Table 5-4 shows that greater than 85% of the total BOD, NH_3N, OPO_4 and T-P can be accounted for by the combined discharges of Ley Creek, Onondaga Creek, Harbor Brook and the Metropolitan Sewage Treatment Plant. It should be pointed out that starting in October 1969, the Ley Creek Treatment Plant discharge was pumped to the Metropolitan Treatment Plant, thus reducing the chemical constituents measured in Ley Creek. Concentrations reflected this condition on five of the nineteen sampling dates. Comparison was made of data collected before and after the Metropolitan Plant received the Ley Creek Plant discharge (not shown). All chemical species measured in Ley Creek showed only slight reductions with the exception of BOD. Whereas the BOD from Ley Creek represented 54.8% of the total measured as of the end of the Study, Ley Creek accounted for 76.0% during the period when the Ley Creek Treatment Plant entered the stream. The Metropolitan Treatment Plant discharged 18.0% prior to receiving the additional plant flow, whereas it now shows 39.1% of the BOD discharged to the lake. This indicates little additional BOD reduction through the Metropolitan Facilities. However, it is anticipated that significant reductions in both the Metropolitan and Ley Creek discharges will result when the upgraded Metropolitan Treatment facilities go into operation.

Although nitrogen analyses were performed on only three of the nineteen sampling dates, the results were consistent, and showed that Ley Creek was the major contributor of both ammonia and organic nitrogen. An unusually high organic nitrogen concentration (6.9 mg/l - 19 mgd) was measured on August 25, 1969. The source of this nitrogen was not determined.

Separate chemical analyses were conducted on a stream emanating from an extensive landfill operation located just north of the Ley Creek discharge. These analyses showed high BOD and nitrogen concentrations. It was noted that amounts discharged by Ley Creek substantially exceed amounts discharged from the Ley Creek Treatment Plant in many cases. These differences could be accounted for by leaching of this landfill operation. The flow from the landfill stream was not gauged and thus amounts discharged could not be determined.

Nine Mile Creek is the major contributor for many of the inorganic chemical species in Onondaga Lake. This stream discharges the major portion of calcium, chloride, sodium, iron and potassium in that order. Table 5-5 illustrates that the LRE values of calcium and chloride are 724.4 and 846.3 mg/l respectively. The LRE value for sodium from this creek is 480.2 mg/l. The LRE values of chloride and sodium for Nine Mile Creek closely approximate and, in the case of calcium exceed the mean concentration observed in the Lake. Although these results cannot be interpreted as meaning Nine Mile Creek is solely responsible for the presence of these species in Onondaga Lake, it does indicate the relative impact this creek has on the lake with respect to the other discharges. The fact that the LRE value of calcium exceeds the observed mean concentration in the lake can be explained on the basis of precipitation of calcite ($CaCO_3$). This is in accordance with results of the geochemical studies.

A major steel manufacturer contributed major portions of the chromium and nitrate. Thirty nine and one half percent (39.5%) of the chromium measured can be accounted for by this discharge, equivalent to an LRE value of 0.01 mg/l. High nitrate values were also measured in this discharge, possibly owing to the use of nitric acid (HNO_3) in their pickling operations. Approximately five percent (4.8) of the total copper measured was attributable to this discharge having an LRE value of 0.01 mg/l.

Table 5-4 shows that Onondaga Creek is a major contributor of magnesium, total phosphorus, organic nitrogen and ortho-PO_4 in that order. The high percentages of total phosphorus and OPO_4 appears to be related to the interceptor overflows into Onondaga Creek as was determined by a comparison of Onondaga Creek and the Metropolitan Treatment Plant concentrations on individual sampling dates, and corresponding

rainfall data (not shown). Although one would expect similar relationships for BOD values, Onondaga Creek shows a small percentage in relation to the Metropolitan Plant due to the high BOD additions of Ley Creek measured for the last five sampling dates.

High magnesium values are a result of extremely high concentrations measured on the 3rd and 17th of November of 271 and 341 mg/l respectively. Unusually high concentrations of calcium (409 and 1,810 mg/l), and sodium (823 and 1,500 mg/l), were also observed on these days. The cause of these high concentrations was not determined.

Harbor Brook and Onondaga Creek receive the storm water overflows from the City of Syracuse. These overflows are reviewed in greater detail under Section 14, entitled, "Engineering Evaluations".

Although the "East Flume" flow ostensibly represents coolant water only, significant quantities of several chemicals were measured in this discharge. Relatively low percentage contributions, (Table 5-4), may be attributable to actual lake concentrations or local conditions higher than accounted for by the "mean" corrections applied to the "East Flume" data. The bottom sediments of the flume discharge are similar to those which were observed for Nine Mile Creek and would indicate discharge of some materials in the coolant waters. With regard to chromium however, the coolant water intake is located approximately 762 m (2,500 ft.) north of the "Steel Mill" discharge. Hence the high percentage contributions of chromium from the "East Flume" may be attributable to the intake of portions of the "Steel Mill" discharge. Such a condition is in accordance with observed photographs of these discharges.

TABLE 5-2

ONONDAGA LAKE STUDY - WASTE DISCHARGE SURVEY

Average Concentrations (mg/l)

Parameter	Ley Creek	Bloody Brook	Onondaga Creek	Harbor Brook	East Flume	Steel Mill	Nine Mile Creek	Metro Plant
Alkalinity	274.0	156.7	217.7	227.7	34.8	16.3	147.	214.2
BOD_5	198.7	0.0	5.7	19.3	0.0	13.4	2.7	90.1
Chloride	252.0	655.7	446.7	1916.2	805.9	1158.1	3282.3	838.7
Ammon Nitr	7.5	0.3	0.5	3.2	0.9	0.0	0.0	8.8
Org Nitr	4.0	0.1	1.6	3.5	1.5	1.0	0.0	1.4
Nitrate	0.5	0.5	0.9	1.8	0.4	10.9	0.2	0.4
Nitrite	36.0	0.0	34.0	52.8	0.0	0.0	53.1	64.0
Total Phos	5.7	1.8	3.7	4.7	1.1	1.0	1.0	11.4
OPO_4	3.2	0.6	0.6	1.9	0.3	0.1	0.1	3.5
Sulfate	312.1	163.5	189.2	358.1	40.1	107.7	221.4	182.5
Diss Oxy	2.5	6.0	9.5	6.2	15.1	4.4	5.3	1.1
Calcium	217.8	178.7	282.5	389.3	252.3	623.3	2227.2	183.2
Sodium	379.8	53.2	380.7	1306.7	355.8	830.9	1490.0	367.8
Magnesium	37.0	25.6	65.2	67.1	5.2	38.6	28.2	32.0
Potassium	20.5	13.6	7.3	13.4	18.5	48.4	21.1	23.7
Copper	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.1
Chromium	0.1	0.1	0.0	0.0	0.1	2.6	0.0	0.1
Iron	1.4	1.0	0.6	0.7	0.8	14.0	1.8	0.9
Manganese	0.4	0.4	0.8	1.1	0.0	0.0	0.0	0.1
Zinc	0.5	2.4	0.2	0.2	0.5	0.5	0.1	0.1
Fluoride	2.2	4.2	2.1	2.3	1.0	3.1	1.5	1.1
Silicate	12.4	6.7	8.2	10.3	1.6	2.4	5.2	14.0

TABLE 5-3

ONONDAGA LAKE STUDY - WASTE DISCHARGE SURVEY

Average Pounds Per Day

Parameter	Ley Creek	Bloody Brook	Onondaga Creek	Harbor Brook	East Flume	Steel Mill	Nine Mile Creek	Metro Plant	Total
Alkalinity	82266	4770	138725	13636	23219	882	90801	86716	441015
BOD_5	53576	0	3614	1300	0	726	1506	38503	99230
Chloride	67869	25997	271905	171611	537687	62779	1744830	350058	3232736
Ammon Nitr	1286	5	210	110	603	0	0	3097	5311
Org Nitr	686	2	561	184	994	54	0	537	3018
Nitrate	93	10	305	118	298	590	104	160	1678
Nitrite	26041	1	52538	11685	22	1	71779	32090	194157
Total Phos	1760	73	2434	308	703	55	732	4883	10948
OPO_4	961	24	405	119	200	6	116	1374	3205
Sulfate	101619	5422	112524	20604	26768	5839	138734	73567	485077
Diss Oxy	974	212	6361	422	10084	236	2938	420	21647
Calcium	73189	5844	217596	25248	168321	33787	1493598	76640	2094223
Sodium	127891	1787	284165	115551	237371	45045	990170	151892	1953872
Magnesium	12338	859	46851	3774	3457	2090	21169	13267	103805
Potassium	5697	281	5897	976	12356	2623	14134	10015	51979
Copper	42	4	90	9	105	18	73	35	376
Chromium	28	2	23	4	80	142	28	52	359
Iron	427	34	409	43	533	756	942	354	3498
Manganese	140	15	472	70	0	0	0	41	738
Zinc	174	96	145	16	329	25	122	56	963
Fluoride	385	117	1151	163	661	166	492	399	3534
Silicate	3993	235	5383	586	1074	132	3183	5542	20128

TABLE 5-4

ONONDAGA LAKE STUDY - WASTE DISCHARGE SURVEY

Percent of Total Pounds Per Day

Parameter	Ley Creek	Bloody Brook	Onondaga Creek	Harbor Brook	East Flume	Steel Mill	Nine Mile Creek	Metro Plant
Alkalinity	18.7	1.1	31.5	3.1	5.3	0.2	20.6	19.7
BOD_5	54.8	0.0	3.7	1.3	0.0	0.7	1.5	39.1
Chloride	2.1	0.8	8.4	5.3	16.6	1.9	54.0	10.8
Ammon Nitr	24.2	0.1	4.0	2.1	11.3	0.0	0.0	58.3
Org Nitr	22.7	0.1	18.6	6.1	32.9	1.8	0.0	17.8
Nitrate	5.5	0.6	18.1	7.1	17.8	35.2	6.2	9.5
Nitrite	13.4	0.0	27.1	6.0	0.0	0.0	37.0	16.5
Total Phos	16.1	0.7	22.2	2.8	6.4	0.5	6.7	44.6
OPO_4	30.0	0.7	12.6	3.7	6.2	0.2	3.6	42.9
Sulfate	20.9	1.1	23.2	4.2	5.5	1.2	28.6	15.2
Diss Oxy	4.5	1.0	29.4	2.0	46.6	1.1	13.6	1.9
Calcium	3.5	0.3	10.4	1.2	8.0	1.6	71.3	3.7
Sodium	6.5	0.1	14.5	5.9	12.1	2.3	50.7	7.8
Magnesium	11.9	0.8	45.1	3.6	3.3	2.0	20.4	12.8
Potassium	11.0	0.5	11.3	1.9	23.8	5.0	27.2	19.3
Manganese	19.0	2.1	63.9	9.5	0.0	0.0	0.0	5.6
Zinc	18.1	10.0	15.1	1.7	34.2	2.6	12.6	5.8
Fluoride	10.9	3.3	32.6	4.6	18.7	4.7	13.9	11.3
Copper	11.2	1.0	24.0	2.4	27.9	4.8	19.4	9.3
Chromium	7.7	0.6	6.5	1.0	22.4	39.5	7.8	14.6
Silicate	19.8	1.2	26.7	2.9	5.3	0.7	15.8	27.5
Iron	12.2	1.0	11.7	1.2	15.2	21.6	26.9	10.1

TABLE 5-5

ONONDAGA LAKE STUDY - WASTE DISCHARGE SURVEY

Lake Residence Equivalents (mg/l)

Parameter	Ley Creek	Bloody Brook	Onondaga Creek	Harbor Brook	East Flume	Steel Mill	Nine Mile Creek	Metro Plant
Alkalinity	39.9	2.3	67.3	6.6	11.3	0.4	44.0	42.1
BOD_5	26.0	0.0	1.8	0.6	0.0	0.2	0.7	18.7
Chloride	32.9	12.6	131.9	83.2	260.8	30.4	846.3	169.8
Ammon Nitr	0.6	0.0	0.1	0.1	0.3	0.0	0.0	1.5
Org Nitr	0.3	0.0	0.3	0.1	0.5	0.0	0.0	0.3
Nitrate	0.0	0.0	0.1	0.1	0.1	0.3	0.1	0.1
Nitrite	12.6	0.0	25.5	5.7	0.0	0.0	34.8	15.6
Total Phos	0.9	0.0	1.2	0.1	0.3	0.0	0.4	2.4
OPO_4	0.5	0.0	0.2	0.1	0.1	0.0	0.1	0.7
Sulfate	49.3	2.6	54.6	10.0	13.0	2.8	67.3	35.7
Diss Oxy	0.5	0.1	3.1	0.2	4.9	0.1	1.4	0.2
Calcium	35.5	2.8	105.5	12.3	81.6	16.4	724.4	37.2
Sodium	62.0	0.9	137.8	56.0	115.1	21.8	480.2	73.7
Magnesium	6.0	0.4	22.7	1.8	1.7	1.0	10.3	6.4
Potassium	2.8	0.1	2.9	0.5	6.0	1.3	6.9	4.9
Copper	0.02	0.00	0.04	0.00	0.15	0.01	0.04	0.02
Chromium	0.01	0.00	0.01	0.00	0.04	0.07	0.01	0.02
Iron	0.2	0.0	0.2	0.0	0.3	0.4	0.5	0.2
Manganese	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Zinc	0.1	0.0	0.1	0.0	0.2	0.0	0.1	0.0
Fluoride	0.2	0.1	0.6	0.1	0.3	0.1	0.2	0.2
Silicate	1.9	0.1	2.6	0.3	0.5	0.1	1.5	2.7

SECTION 6 - LITERATURE REVIEW

K. M. Stewart

General

This Section deals with a review of historical records, newspaper articles, reports and studies related to and describing Onondaga Lake and its environs. Although the historical records and newspaper articles are not in all cases scientific in approach, they represent the major sources of information prior to 1920. Although previous reports and studies in many cases do not deal with an analysis of lake waters in their entirety, collected data provide the only means of comparison with existing lake conditions.

Early History

Perhaps the earliest recording of Onondaga Lake and its salt springs was by a Jesuit Missionary, Father Simon LeMoyne. LeMoyne visited the lake in 1653[1].

> "... with a party of Huron and Onondaga Chiefs, as an envoy to ratify a treaty of peace between the two nations, in which the French of Canada were interested,..." (Clark, 1849).

LeMoyne's account of the lake, which at that time was called Ganentaha by the Onondaga Indians, was:

> "We arrive at the entrance of a small lake in a large half dried basin; we taste the water of a spring that they (the Indians) durst not drink, saying that there is a demon in it, which render it fetid. Having tasted it, I found it a fountain of salt water; and, in fact, we made salt from it as natural as that from the sea, of which we carried a sample to Quebec." (Geddes, 1860)

[1] Geddes (1860) gave the date of this first visit as 16 Aug. 1654.

A detailed history concerning the gradual utilization of salt by the Indians, the white man's influence in the development of a salt industry and the eventual takeover of the lands around the lake to the exclusion of the Indians, is provided by Geddes (1860) and Clark (1859). The latter author also related some interesting features of the shoreline of Onondaga Lake as follows:

> "The shores of the Onondaga Lake, at an early period of the settlement of the Country, were composed of soft, spongy bog, into which a pole could be thrust to an almost interminable depth. Since the clearing up of the hills in the neighborhood, sand gravel and other substances, have been washed down, and by the action of the waves, have become so solid that loaded teams can now be driven along the beach, without making scarecely any indentation, while but forty years ago, the same ground could only be traversed by flat bottomed boats."

Schultz (1810), in a portion of his travelogue which concerned Onondaga Lake,[2] described the local belief that the lake was bottomless and that the lower waters were extremely saline. Schultz examined these local beliefs by having some boatmen row him around to different areas of the lake in an attempt to find an area where the bottom could not be found. However, most of their soundings produced only 9.2 m to 15.1 m of water with one final sounding giving them 19.5 m of water[3]. Schultz also lowered a bottle in such a manner that he could withdraw a cork when it arrived at the bottom, then drew it up, and "found the water a little cooler, but not otherwise different from that on the surface". This implies that the lake did not have a deep saline layer in those early years as was mistakenly believed.

An important event in the lake's history occurred in 1822 at which time the level of the lake was lowered.

> "Four thousand five hundred dollars was appropriated for the purpose of lowering Onondaga Lake. The Canal Commissioners were instructed to cut a channel, of such width and depth as in their opinion would be necessary to permit the waters of the lake to subside to a level with the Seneca River. This operation was considered quite an improvement in the navigation

[2] Called Onondaga or Salt Lake at that time.
[3] Geddes (1860) mentioned soundings in the early years of 16.7 and 19.8 m.

> of the Onondaga River, and in laying bare a wide surface of the salt marsh, which at high water was innundated." (Clark, 1849)

The exposed shoreline occupied 20% of the former lake surface (as determined by planimetry of a map of Sweet, 1874, which outlined the original and modified shoreline). The new land was subdivided into lots and used by the salt works. It may be that the lowering of the lake is recorded in the sediments, and thus it might provide evidence for the rate sedimentation since that time.

The Whitefish

In the late 1800's and early 1900's, newspaper articles discussed the rise and fall of the whitefish population. For example, The Post Standard (1894) of Syracuse, N. Y., described the huge numbers of whitefish in Onondaga Lake at that time as follows:

> "There are whitefish in our lake without number. Never having been disturbed to a very great extent, they have propagated in such numbers until now it is almost impossible to estimate the quantity..."

The article also describes the efforts to elude the law and take as many whitefish as possible by seine or gill net. This may have lead to overfishing, for example,

> "With the market value at $.25/lb. the poacher can well afford to stand guard over his hidden net with a 44 caliber rifle"...

and further,

> "A gentleman told a Standard Reporter yesterday that every Sunday morning a wagonload of white-fish is carried away from the shores of Onondaga Lake. They average from two to three and one-half pounds in weight."

If this heavy fishing pressure increased each year during the spawning season, it is possible that the whitefish population was depleted severely.

Shortly thereafter, the whitefish disappeared from the lake. The Sunday Herald (Syracuse, N. Y. newspaper, 1901) mentions that the whitefish disappeared four years earlier from the previous November (therefore putting it at 1896) at which

time, "Foxey", a famous fish pirate was unable to obtain even one fish...for a "bottle of grog". Newspaper articles are frequently misleading, but it is of note that a most sought after fish in 1894 was not even caught in 1896, merely two years later!

The question is raised, why did the whitefish disappear when they did? Was the heavy and illegal overfishing at the time of spawning too much for the development of a survivable year class? Were the increased sewage and low oxygen conditions beginning in those early years? Was the decrease a result of competition from other fish for food or spawning areas? Were the whitefish subject to predation by other fish? Did disease, or parasites or a fungal infection wipe them out? All these questions may never be answered but it appears that a combination of reasons, important among which are the probable overfishing and rapidly increasing human population around the lake, with the latter's discharges into the lake, being responsible for the demiss of the famous Onondaga Whitefish.

Salt Water

Two squid were caught alive in Onondaga Lake, each by nets and each by a different person in 1902 (Clarke, 1902). They were found, supposedly, where the first salt springs were discovered. Clarke wondered if the squid could have been remnants from some bygone era when the lake was believed in some way connected to Lake Champlain and the St. Lawrence Valley or whether they were put in as "fakes", or whether they developed from eggs off marine oyster and clam shells that were thrown in the lake from a hotel on the shore. Whatever the reason, the fact that they survived to be caught attests to the relative salinity of the lake.

Previous Reports (1920-1955)

Metcalf & Eddy Report (1920)

By far the most comprehensive report to date on the condition of Onondaga Lake as well as upon the treatment and disposal of sewage at Syracuse was the Metcalf and Eddy Report. One of their engineering conclusions was: The condition of the Barge Canal Harbor, with its decomposing solids and bubbles rising to the surface is poor and is a consequence of the Harbor acting as a settling basin for the discharge of the main intercepting sewer into Onondaga Creek.

Metcalf and Eddy recommended that the City's sewage be transferred from the Barge Canal, screen it, provide settling to

remove solids and then discharge it out in Onondaga Lake. It was felt that by treating the sewage in this manner and then discharging it at a point out in the lake (396 m from shore and 6.1 m deep), that the lake would have sufficient assimilation capacity to prevent nuisance or objectionable conditions for at least 20 years. Besides, the City of Syracuse would save $1,500,000 by not having to improve the quality of effluent more than the minimal amount recommended. Since few fish were thought to be in the lake at the time of this 1920 report and since the lake was not used for pleasure boating or bathing, a lake condition of dubious quality was already implied. In retrospect this action seems to have had an adverse affect on the water quality of the lake.

The concentrations of dissolved oxygen that were measured in April of 1920 were 9.3 mg/l and 7.5 mg/l in the lower waters of the northwest and southwest basins at 19.2 and 13.7 to 21.3 meters respectively.

Metcalf and Eddy gave much discussion to the rate of depletion of oxygen in the lake but there were actually few data from which to make these judgments. In fact, most of the calculations for the comparisons used the few April values of dissolved oxygen. Thus, the relatively high values of spring were used to justify subsurface sewage discharge year-round into Onondaga Lake.

In all fairness to the Metcalf and Eddy (1920) Report, it must be remembered that although the greatly increased present day knowledge allows us to criticize earlier decisions, at that time the combined lake study engineering approach was ahead of its time. The report did recommend municipal primary treatment for Syracuse, whereas most industries discharging to the lake had no treatment whatsoever. Furthermore, most other municipalities around the State had little to no treatment. In addition, the New York State Department of Environmental Conservation approved the plan of Metcalf and Eddy. Therefore, although their data was inadequate from today's standpoint and the lake probably suffered accordingly, the Report was believed to be in the best interest of the community.

The first major hydrographic map of Onondaga Lake was produced by Metcalf and Eddy (1920). Their maximum soundings were from 20.2 to 20.7 meters in the northwest basin and 22.2 to 22.8 meters in the deeper southeastern basin.

Syracuse Intercepting Sewer Reports

Although each of the annual reports of the Syracuse Intercepting Sewer Board described activities of the year, most of these do not consider direct effects of the sewage on the lake nor are data from Onondaga Lake generally included. The sixteenth report (Holmes, 1922) is an exception. Following some recommendations of the 1920 Metcalf and Eddy Report, the concentration of dissolved oxygen was measured at 5 to 6 locations along the longitudinal axis and the percent saturation of those concentrations was plotted and presented by Holmes (1922).

When comparing the oxygen data of 1920, 1921 and 1922, at the time of spring circulation with those of 1968 and 1969, the degradation of oxygen conditions is apparent. Unfortunately, samples acquired for 1920, 1921 and 1922 were only taken at three depths, the surface, mean depth and near the bottom. Therefore, for the six stations, the mean depths are not the same. Just a slight raising or lowering of the sampling bottle at the mean depth could result in a pronounced shift in the positions of the lines drawn. The exact depth of the sampling bottle is also unknown and would influence the results plotted. Nevertheless, the report of Holmes is informative. There is a depletion of dissolved oxygen as the summer season progresses.

New York State Department of Health (1951)

The most complete report summarizing the sources of municipal and industrial pollution to each tributary of Onondaga Lake, as well as the direct discharge of waste to the lake, is that of the NYSDH. Onondaga Lake is listed here as P154, the 154th pond and/or lake in the Oswego River System. Included in this report on the lake are data from the New York State Conservation Department (1947), the Agar-Sanderson Report (1947) and the Syracuse City Engineers Office (1949). The former two reports include information on fish, chemical and coliform conditions. The data from the Agar-Sanderson Report and the Conservation Department indicate poor oxygen conditions in 1946 and 1947 in Onondaga Lake. Summarizing the fish conditions, the latter report states,

> "Pike-perch, catfish, sunfish and suckers are fairly common in late season and an occasional northern perch, northern pike, silver bass and bass are found. This may represent migration into the area from the Canal and Seneca River."

The Conservation Department Report also suggests that nothing is known about fish in the winter when critical conditions may exist owing to suspected low oxygen conditions.

O'Brien & Gere (1952)

In an extensive report by O'Brien & Gere many features concerning the development of sewage treatment facilities for the Syracuse area were described. Topics considered were: Population growth, the sewage system of the City of Syracuse, sewage flows, composition of sewage, the DO, BOD and MPN in Onondaga Lake, the oxygen balance, recreational aspects, consideration of the Seneca River, development along the parkway, existing garbage and rubbish plants, alternative sewage treatment facilities and design and construction of plants. This Report brings together, for the first time, multiple considerations with respect to the sewage treatment and it summarizies some of the data of Onondaga Lake.

Although untreated sewage was discharged into the lake for the first time in 1922 (O'Brien & Gere, 1952) no serious effects were noticed at that time. This assumes that the relative sampling depths, discussed by O'Brien & Gere, were accurate. However, by 1946-47, anaerobic conditions had developed in the lower waters of the lake during summer stratification. It is not clear from page 6-3 of the O'Brien & Gere Report just how the samples of the lower water were obtained, e.g.,

> "All samples taken in deep water sections of the lake were cross sections of the top 30 (9.2 m) feet of water; in the more shallow sections, the samples were taken from top to bottom as the sampling device was being lowered and raised."

Could this sampling device have been merely a flushing sewage sampler which would not have given precise measurements of DO at any particular depth? The data on sulfides described in this Report also indicate that anaerobic conditions in the lower waters were present from 1946 through 1952. O'Brien & Gere also indicate, from fairly meager data, that the sludge deposits were non-existent to slight in the 1920's and 1930's.

Additional Studies (1955-1970)

Unpublished data collected by the Onondaga County Department of Public Works since 1959, represent one of the largest stores of chemical data for the lake. These data, taken at 10 stations on Onondaga Lake at the surface and/or 6.1 m (20 ft.)

depths, cover a period when major developments were affecting the lake. Variations in the BOD data of Onondaga County were analyzed statistically (not shown) in this present (1970) Report to determine statistical variation at several sites on the lake. Although there were some marked year to year differences, the trends for the years represented were somewhat similar and indicated a slight decrease in BOD from 1957 to 1968.

Webber (1960), in an Engineering Study, tried to analyze the factors effecting the concentration of dissolved oxygen in Onondaga Lake. He concluded that,

> "The DO content is theoretically equal to the quotient of the BOD exertion rate divided by the re-aeration coefficient",

and that the re-aeration through the surface of the lake was the most important method of supplying dissolved oxygen to the water. He regarded the thermocline depth in Onondaga Lake as constant. His interpretation is open to question as he determined the thermocline depth indirectly from the plotted data on H_2S from a major soda ash manufacturer. Webber also estimated that theoretical detention time in the lake as 180 days for 1946.

Probably the most widely distributed published work on the unusual chemical composition of Onondaga Lake was that of Berg (1963). When compared to other lakes in New York, the ionic composition of Onondaga Lake was strikingly higher.

In a separate study of Onondaga Lake in 1964 and 1965 (SURC, 1966) several conclusions were drawn. They were as follows:

"1. Present chemical factors have undergone only minor chemical changes since the O'Brien & Gere Report of 1952.

2. Little beneficial effect on the quality and general composition of the south end of Onondaga Lake would be achieved by a force main as proposed originally by O'Brien & Gere. The concentration of inorganic salts would undoubtedly rise if the M.S.T.P. flow were diverted.

3. The inorganic salt concentration of the lake, especially sodium-calcium ratio is approaching that of the effluent of Nine Mile Creek below Route 690 Bridge.

4. Although the algal population of the Lake has shown an increase since 1962, it has not reached troublesome levels.

5. If the M.S.T.P. effluent were diverted from Onondaga Lake, the consequences of increased algal productivity might be more severe downstream than in the lake, particularly since the factors which limit algal bloom in the lake at the present time may not be effective in the downstream system.

6. A yearly study of the chemical composition and algal population should be carried out to serve as a warning indicator of adverse changes in the lake."

Statement No. 3 above and the text of this Report suggests that Onondaga Lake is becoming increasingly saline as a consequence of the soda ash manufacturer's activities. It is noteworthy that this (SURC, 1966) report, after examining one historical reference of Beck (1826), regarded the lake as originally having a dense submerged layer of brine. Schultz (1810) had disspelled this notion earlier but the local belief must have persisted.

The Report also mentions that the oxygen conditions, predicted to be poor by O'Brien & Gere (1952), may indeed have followed predictions. Unfortunately, only surface and bottom samples were taken in 1965 for verification. Complete oxygen profiles need to be made systematically for more meaningful checks.

In addition, the SURC Report also describes some bioassay experiments which indicate inhibition of growth with increasing salinity. This suggests that any possible lessening of algal blooms might be due to the relatively high saline conditions of calcium chloride or sodium chloride. Jackson (1968) also discusses this later in this literature review.

In another unpublished report (Brennan, et.al., 1968), consideration was given to the restoration of Onondaga Lake. Among many aspects discussed, of particular interest were the possibilities of electrolytic treatment (since Onondaga Lake is somewhat saline) and lime precipitation of wastes. Another feature of the Report concerned the benthic deposits (sludge) and what to do with them. The old question was raised, how can the deposits be improved in place or where will they be put if sucked off the bottom?

Brennan et.al., (1968) observed much Enteromorpha, the saltwater form of algae, in Onondaga Lake in 1965 and 1966. In part of the Report, the retention time of the lake was

calculated to be 270 days with a volume of 151,416,472 m^3 (40 X 10^9 gallons). This contrasts with Webber's (1960) calculation of 180 days.

Some of the more interesting data concerning Onondaga Lake are to be found in the unpublished reports of Allied Chemical Corporation (Anonymous, 1968). These data include information on water chemistry, thermal profiles, and some biological measurements. Of primary limnological interest are the data concerning the concentrations of dissolved oxygen and hydrogen sulfide in the lower waters of Onondaga Lake. The O'Brien & Gere Report of 1952 indicated that oxygen conditions were satisfactory in the lower waters back in the early 1920's. However, in a 1945 memorandum from the soda ash manufacturer, it was reported that the hydrogen sulfide was strongly evident in the mill water as far back as 22 August 1910. This unpublished reference questions the possibility that there was dissolved oxygen in the lower waters at that time of the year, even back that far.

The soda ash manufacturer was concerned with the buildup of hydrogen sulfide owing to the costs of treating the lake-water with large amounts of chlorine to prevent scaling of their equipment. The unpublished separate reports of the latter also indicate that the concentrations of hydrogen sulfide appear to be increasing in the lower waters in more recent years. If these reports are true, that is, if the concentrations of H_2S have increased and the concentrations of dissolved oxygen are decreasing, it would seem that the lake is experiencing a worsening condition. Addition items of interest include the large concentration of organic matter, about 40% or higher, from the bottom muds.

Jackson (1968) gives a brief geographical, morphometric, and historical review of Onondaga Lake. Owing to the relative salinity of Onondaga Lake and the high concentrations of chlorides, it is Jackson's opinion that the lake is meromictic. This opinion has since proven to be incorrect but with the early notions about the lower "brine" layer of the lake, it is not difficult to see how it could develop.

In bio-assay tests with 25 algal cultures, Jackson, (1968), found that unfiltered lake water alone would not support the blue-green algal cultures in his experiment. He stated that this was consistent with his observations of three years. Only diluted lake water would support the culture of blue-green algae. Therefore, he felt that the lake should

be worse than it is and that perhaps the "saline and polluted" nature of the lake has kept the algal conditions from worsening.[4]

In another study, Jackson (1969) described attempts to evaluate the rate of primary productivity of phytoplankton in Onondaga Lake. Fourteen respiratory and fourteen photosynthetic measurements were made on each sample collected on six different occasions from the months of May through October. His results indicate that although the same genera of algae were dominant at the southeastern portion of the lake as well as the northwestern portion, the average number of algal cells at the southeastern end of the lake was 96.3 vs 6.5 for the northwest end. The photosynthetic rates (expressed as microliters of oxygen per hour per mg/l ash-free dry weight) always exceeded the respiration rate. He observed no blue-green algae during the 1967 sampling period except for some small coccoid forms. Green algae, Chlamydomonas and Scenedesmus were dominant in May, June and July and Chlorella in August. The diatoms Cyclotella and Stephanodiscus were dominant in September. Jackson questions whether the proposed sewage plant improvement would benefit the lake, i.e., would the improved effluent from the plant decrease the relative salinity with a consequent increase in algal production?

[4] More recent and systematic observations of algal growth in Onondaga Lake have shown that blue-green algae can be prominent during the late summer. Evidence for the latter is discussed further in this Report.

SECTION 7 - SAMPLING & ANALYSES

General

The purpose of this Section is to outline the methods of sampling and analyses for the Onondaga Lake Study. The sampling was carried out in two phases. The preliminary phase, which extended from April 1968 through December 1968, established sampling points and determined the parameters and their frequency of measurement.

During the detailed study, which extended from January 1969 to December 1969, lake water and bottom sediments were sampled and analyzed in those locations and for those parameters which proved to be the most significant during the preliminary phase.

Open Water Sampling

The major open water sampling program, in which variations of chemical and biological concentrations with depth were monitored, was designated as depth synoptic sampling. Depth synoptic stations were located in the two deep pools of Onondaga Lake; namely, Station 1 at the south-deep and Station 2 at the north-deep (Figure 1-2).

Samples were collected at three meter intervals from the surface to the bottom by a two liter PVC VanDorn sampling bottle. Depth synoptics were run on a bi-weekly schedule during the preliminary phase and on a weekly schedule during the detailed phase.

The following is a list of the parameters measured and the equipment used:

TABLE 7-1

Onondaga Lake Analyses

PARAMETER	METHOD OF ANALYSIS
Alkalinity	*Sulfuric Acid Titration Method
BOD	Weston-Stack Oxygen Meter Standardized by Winkler Method
Carbon Dioxide	*Sodium Hydroxide Titration Method
Chlorides	Argentometric

Conductivity	Beckman Conductivity Meter
Dissolved Oxygen	*Winkler Method - Azide Modification
Fluorides	Orion Specific Ion Electrode
E. coli	Millipore Filter Technique
Ammonia Nitrogen	*Direct Nesslerization Method
Organic Nitrogen	*Direct Nesslerization Method
Nitrite Nitrogen	*Direct Nesslerization Method
Nitrate Nitrogen	*Direct Nesslerization Method
Orthophosphorus	*Stannous Chloride Method
Total Phosphorus	*Stannous Chloride Method
pH	*Photovolt pH Meter
Silica Dioxide	Molybdo Silica Method
Total Solids	*Gravimetric
Suspended Solids	*Gravimetric
Sulfides	Orion Specific Ion Electrode - For further details on this procedure see Appendix D
Sulfate	*Gravimetric
Temperature	Atkins or Whitney ($\pm$0.1°C) Thermometer Probe
Transparency	Secchi Disk (20 cm. dia. - all white)
Calcium	Atomic Absorption Spectrophotometer (Perkin-Elmer)
Magnesium	" " "
Potassium	" " "
Sodium	" " "
Copper	" " "
Chromium	" " "
Iron	" " "

Manganeze	Atomic Absorption Spectrophotometer (Perkin-Elmer)
Zinc	" " "
Biological	See Section 11

During the summer months of 1969, duplicate samples were taken at each of the two stations. One sample was filtered using a Millipore filter to remove any suspended particulate matter, and the other was left unfiltered. The filtered sample was then used in a mineral-water equilibria study to determine the mineral stability in the lake.

During the winter months, when the lake was partially covered with ice, no parameters were measured in the field other than temperature and Secchi Disk. During the summer months, the following parameters were measured in the field on a routine basis; temperature, pH, alkalinity, CO_2, sulfides and Secchi Disk. Dissolved oxygen samples were fixed in the field for later determination in the lab.

Overnight Sampling

During the Study three overnight samplings were conducted to determine the variations in those parameters that reflect the respiration of phytoplankton as well as their photosynthetic activity. Parameters were measured at Station 1 at 3 meter intervals, 3 times during the Study, namely, Oct. 10, 1968, June 10, 1969 and July 29, 1969. The following parameters were measured: temperature, pH, alkalinity, CO_2, DO, conductivity and Silicon dioxide (SiO_2).

Waste Discharge Survey

A sampling program of the major tributaries and discharges entering Onondaga Lake was carried out from June 1969 through December 1969. The following were sampled.

* In accordance with Standard Methods

Harbor Brook

East Flume (Soda Ash Manufacturer)

Steel Manufacturer Discharge

Nine Mile Creek

Bloody Brook

Ley Creek

Onondaga Creek

Sanitary Landfill System

*Sawmill Creek

*Seneca River

*Measured November - December 1969

These discharges were sampled on a bi-weekly schedule. Samples were collected with a DO sewage sampler as prescribed by Standard Methods. Due to the shallowness of the creeks, all samples were taken at, or very near, the surface.

All parameters measured for the depth synoptic sampling were also measured for the creek samples with the exception of BOD, total solids, suspended solids, conductivity and CO_2. With the exception of the latter two parameters, these analyses were performed by the Onondaga County Department of Public Works under their lake analysis program. The following parameters were measured in the field; pH, alkalinity and temperature. The dissolved oxygen samples were fixed in the field for later determination in the laboratory.

Tributary Sampling

During June 1969, samples were taken at various upstream points (not shown) on Geddes Brook, Onondaga Creek, Nine Mile Creek and Harbor Brookfor the purpose of assessing the natural contribution of the streams to the waters of the lake.

Grab samples were collected with a bucket and filtered through the Millipore Filter. The analyses run on these samples were the same as those run for the discharge sampling.

Coring

Core samples were taken to enable analysis and observation of the bottom sediments. Three separate types of cores were taken throughout the Lake Study; namely, Alpine, Benthos and Jenkins cores. Benthos cores were taken of the tributaries to assess the "natural" contribution. A Benthos corer is illustrated in Figure 7-1.

Benthos Coring

The Benthos coring apparatus is a "gravity" device which takes a core 6.6 cm - I.D. Cores of up to 2.14 m (7 ft.) in length were taken with this core. Forty cores of this type were taken during the preliminary phase and 21 cores were taken during the detailed phase. Locations of core samples taken in 1969 are illustrated in Figure 1-2.

Once the core sample was obtained and was on board the sampling boat, sediments were extracted from both the top and the bottom of the core sample. These were then placed in a Millipore filter apparatus and the water contained in the sediment (pore water) was forced out with air pressure. Analyses of the pore water performed on board the boat included pH, alkalinity and sulfides. Sufficient water from the sediments was taken back to the laboratory where the analyses shown in Table 7-2 were performed.

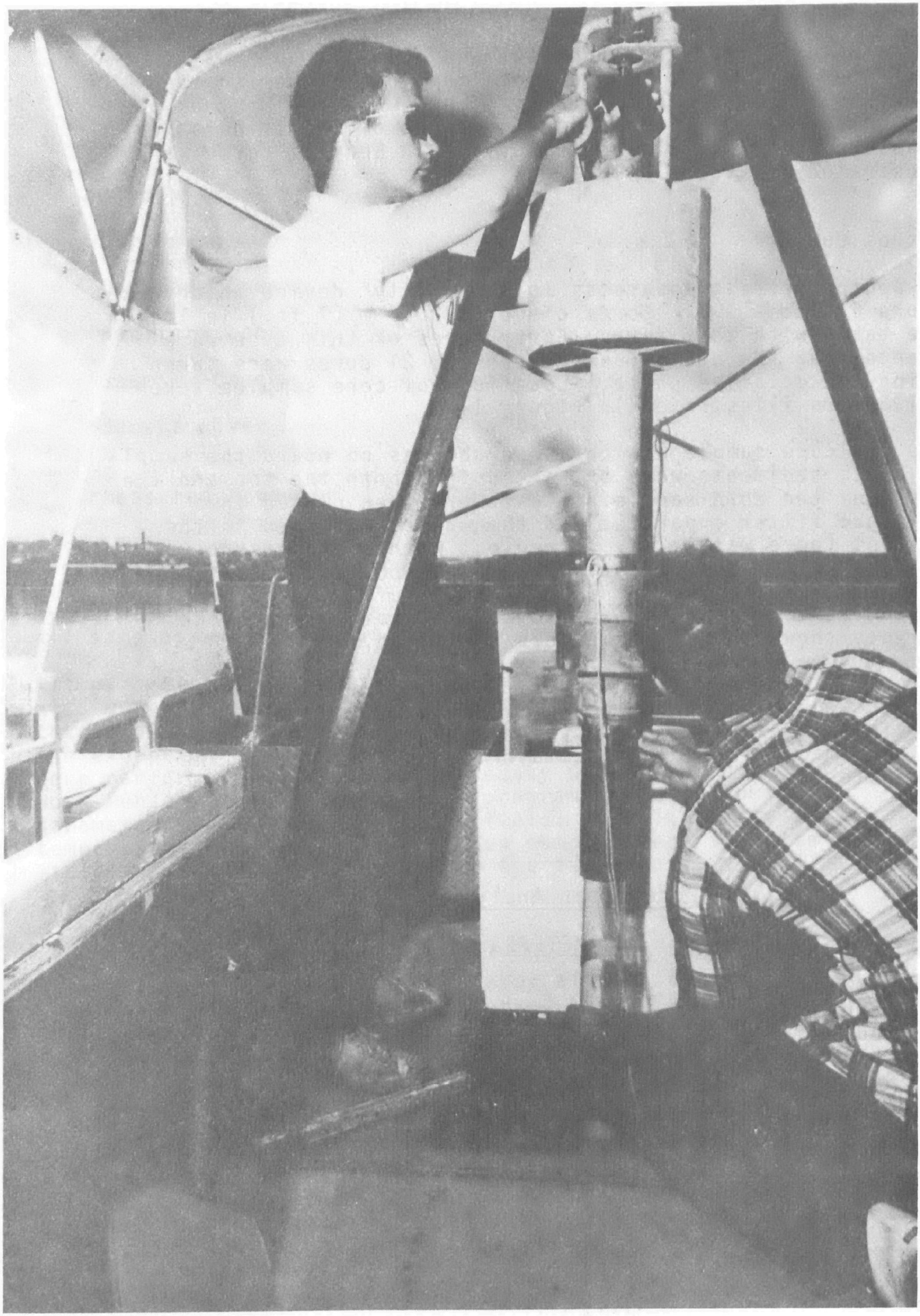
Following the extraction of pore water, cores were extracted from the tubing while on board. Each core was split in half and visually examined. A written description of each core was then made describing the layering and texture of the core material.

TABLE 7-2

Pore Water Analysis

PARAMETERS

Calcium	Potassium
Magnesium	Manganese
Sodium	Iron
Chlorides	pH
Sulfates	Alkalinity
Zinc	Orthophosphorus
Copper	Silicon Dioxide
Chromium	Sulfides



BENTHOS CORER

FIGURE 7-1

Alpine Coring

The Alpine corer is a "piston" type apparatus which takes a core 3.5 cm in diameter. During the sampling of the Lake bottom, cores of up to 12 feet in length were taken with the Alpine corer. During the summer of 1969, eleven cores were taken at various locations as illustrated in Figure 1.2.

Sediment samples were extracted from the bottom and the top of each core. Water was forced from these sediment samples in the same manner as it was with the Benthos corer. Sufficient pore water again was obtained for further laboratory analysis as shown in Table 7-2. The sediments were saved for further observation as study such as carbon dating, pollen analysis and X-ray analyses. Cores were carefully stoppered to prevent air leakage and placed in cold storage for future possible investigation.

Jenkins Coring

The Jenkins corer enabled the gathering of an undisturbed sample of the bottom sediments, enclosed waters, and overlying waters. Core tubing is 7.25 cm in diameter and 51 cm long. Sediments were enclosed to a depth ranging from 10 to 20 cm; the remainder of core length consisted of overlying and undisturbed Lake water. Fifteen cores were taken at various locations in the Lake as illustrated in Figure 1-2. Analyses of the interstitial waters, performed on board, included pH, alkalinity and sulfides. Water was also obtained for other analysis in the laboratory, as shown in Table 7-2.

In each location duplicate cores were taken. One core was preserved in its natural state, while the other core was drained of the Lake water above the sediment, and replaced by deionized water. The analyses shown in Table 7-2 were run on the water samples withdrawn from each core at two week intervals for a period of 2-1/2 months. The deionized water in each of the treated cores was replaced every two weeks. The purpose of the "deionized water" cores was to determine the ultimate effect the bottom sediments would have on the overlying waters.

At the conclusion of the above investigations, the DO content of the overlying waters in the untreated cores was measured. Oxygenated, deionized water was added, when necessary, until the DO concentration stabilized, in order to determine the oxygen demand of the undisturbed sediments.

This procedure was repeated for the same samples following mixing of the upper 2 cm of sediments. The latter was done in an effort to simulate lake turnover conditions. Oxygen demand values were utilized in the Lake Assimilation Capacity Calculation.

Creek Coring

Cores were taken at the mouth of the following tributaries: Nine Mile Creek, Bloody Brook, Ley Creek, Harbor Brook and Saw Mill Creek. These cores were taken by hand using the tubing from the Benthos gravity corer. The purpose of this coring was to determine the sediments accumulated by these tributaries. The analysis run on these cores is shown in Table 7-2.

Gas samples were collected at Station 1 during the months of August and September. Five samples were collected using a sampler fabricated in our laboratory. The gas samples were examined for their composition by gas chromatography.

Temperature Gradients

Temperature gradients were run on the Lake to give an overall temperature picture at any one time within the Lake. Thermal transects were run along the centerline of the Lake extending from the inlet at Onondaga Creek to the outlet at the Seneca River. The number of stations contained in the transect varied from 10 to 15 depending upon wind and wave conditions. At each station the temperature was recorded at half meter intervals from the surface to the bottom using the Atkins or a Whitney (± 0.1° C) probe.

Biological Studies

Biological studies were conducted to determine the significance of: a) algae populations, b) zooplankton populations, and c) fish populations.

TABLE 3

Biological Analysis Stations

LOCATION	SAMPLING METHOD
Ley Creek	Surface; horizontal net
Nine Mile Creek	Surface; horizontal net
Lake Outlet	Surface; horizontal net
Sta. I & II	Horizontal & vertical net; 0, 3, 6, & 12 meter samples & tube samples

For an account of the fish survey and details of the biological studies, see Section 11.

SECTION 8 - GROSS PHYSICAL FEATURES

General

The initial step in a limnological investigation should entail the determination of gross physical features such as, nature and extent of lake bottom strata, lake volume, tributary flows and lake residence times. The origin of the lake bottom has been the source of much discussion and widely varying speculation, particularly in relation to the source of chlorides in the lake. For example, the following exerpt by Spencer, a former Superintendent of the Salt Works (as published by Geddes, 1860).

> "Eminent geologists, who devoted much time in investigating this subject, have I believe, uniformly arrived at the conclusion that the source from which our brine is derived is very deep beneath the mountains or hills south of us, and is conveyed to the points where we find it, by subterrainian currents of water, which have passed through the soliferous material and dissolved it.
>
> I am strongly inclined to the opinion that there is deposited, immediately beneath the Onondaga Lake, a solid mass of salt rock, which is being gradually dissolved, and flows to the points where we find our brine. This salt rock is overlaid by heavy sedimentary basin which forms the bottom of the lake and which prevents the salt from coming in contact with its waters.
>
> All the borings show that the valley is filled with drift and sedimentary matter, and timber is found at various depths down to 134 feet.
>
> The salt water rises in all the tubes, to about the level of the lake, and is strongest when the lake is highest. Does in increased pressure of deep water force the strong brine from its source outward, where the tubes reach it?"

The upward diffusion of chlorides is discussed in Section 12.

Seismic Studies

In an effort to determine the nature of, and the extent to which deposition has taken place in Onondaga Lake, the firms of E G & G, Inc., Mystic Oceanographic Company and Weston-Geophysical Engineers, Inc., were employed to conduct seismic surveys of the lake bottom. Seismic sub-bottom profiling employs acoustic (sound) pulses, electronic signal reception and processing and graphic recording to obtain profile records of the sub-bottom layers indicating their depth and configurations. These surveys can be conducted by employing either the method of reflection or refraction.

In the reflection technique, the seismic signal originates from a boomer transducer which emits repetitive acoustic pulses in the water. The sound pulses are reflected by the various sub-bottom layers and are detected by an acoustic receiving system also under tow. The incoming signals are processed electronically and transmitted to a ship-board strip chart graphic recorder resulting in a profile record displaying the geological findings in their corresponding relationships, depths and geographic conditions. Depending upon the concentration of bottom deposits, various sound sources, ranging from a high frequency pinger probe to a low frequency boomer, can be employed. High frequency systems, with accompanying high resolution are employed for shallow penetration studies, whereas low frequency, low resolution systems are employed for deep penetration studies. Refraction studies rely upon low frequency intermittant signals such as dynamite charges which result in high penetration. The refracted signals, sensed by a trailing cable with sensing probes, are electronically recorded. The primary disadvantage of the latter is its inability to obtain a continuous recording.

Results

In the early spring of 1968, E G & G conducted a survey employing a boomer transducer emitting a sound signal with a frequency of 2 kcs., in an effort to delineate the major geologic strata in the lake. When this system failed to yield results, a 200 kc signal was employed; however, no improved results were obtained. A grid system covering the entire lake was made. During the seismic survey, contours of the lake bottom were recorded, and are illustrated in Figure 1-2. The lack of penetration and sub-bottom definition was attributed to the high gaseous content absorbing acoustical energy. In an effort to minimize the influence of gaseous production, consideration was given to conducting a similar survey during the late fall, just prior to ice cover.

In the fall of 1968, Mystic Oceanographic Company offered to employ their equipment in an effort to obtain positive results. A fish transducer was used, which emitted acoustical sounds ranging from 1 to 10 kcs. A 1-day survey was conducted in the northern basin of the lake where gas production was considered minimal; however, no positive results were obtained. In a final effort to profile sub-bottom layers, consideration was given to the refraction technique. Therefore, in the spring of 1969, shortly after the ice melted, Weston Geophysical Engineers, Inc. offered to conduct a survey, again on a conditional basis. Of the three studies conducted, the results of the latter were the most informative. Charges as high as 9.1 kg (20 lbs.) were set off and a trailing cable was employed at those locations illustrated in Figure 1-2. A summary of the results of this survey follows:

1. "Depths to bedrock were determined both on the shore and opposite these lines in the lake; these vary from 149 feet (45.4 m) on the shore to over 170 feet (51.8 m) in the lake;

2. Where the above measurements were made, the velocities measured were 5,000 ft/sec (1520 m/sec) from the lake bottom to the bedrock surface--these velocities are indicative of water saturated materials or predominantly clayey overburden;

3. No "high" velocity materials were measured between lake bottom and bedrock surface which might indicate a dense glacial till or weathered bedrock existing above hard bedrock;

4. Although seismic measurements were made for the entire length of the lake, bedrock determinations were possible only on the north end due to the existence of gaseous or man-dumped silty materials;

5. The presence of gaseous materials extended for nearly the entire length of the lake and, for the most part, were of considerable thickness (usually greater than 15 to 20 feet or 4.57 m to 6.1 m). This is evidenced by the quality of the seismograms, the material erupted by the seismic shots and release of gases from these materials.

   It has been our experience that gaseous materials such as were encountered have very low seismic velocities (as low as 200 to 600 ft/sec, or 61 m/sec to 183 m/sec), however, they are "masked" by the water velocity of 5,000 ft/sec (1520 m/sec).

Consequently, their thickness could not be determined quantitively. Because of this, the extensiveness of the gaseous materials and the fact that these gaseous materials could not be controlled by bedrock, it was decided to terminante the seismic survey with the results obtained after two days."

Lake Volume and Net Deposition

Bottom contour plots recorded by the E G & G survey were used to determine the volume of the lake. This calculation was based on a water surface of 363.0 USGS datum. The lake elevation is controlled at approximately 362.4 to 363.0 USGS datum, for this section of the Barge Canal System. The lake volume was determined to be 1.405×10^8 cubic meters (37,078 million gallons or 37.078×10^9 gallons).

Water depths recorded in 1913 by the U.S. Army Corps of Engineers were used in order to estimate the net deposition that has taken place in the last 56 years. The water level of the lake at that time, was recorded as 363.0 to 363.5. A total of 8.03×10^6 cubic meters (10.5×10^6 cubic yards) was estimated as the net deposition. This is equivalent to an average deposition over the surface area of the lake of .69 m (2.25 ft.).

Residence Times

Residence times in the lake were calculated for those years in which creek flow data were available. It was assumed that on an annual basis, rainfall and evaporation were equal and opposite in their effect on the lake. Table 8-1 illustrates total annual precipitation, major inflows and corresponding residence times for the years of record. It should be noted that the 1964 residence time reflects a total precipitation of 68.8 cm (27.10 inches), which was the second lowest annual precipitation recorded since 1912, the lowest being 68.5 cm (26.98 inches) in 1939. The 1968 calculation reflects an annual precipitation of 112 cm (44.23 inches), which is the 5th highest precipitation since 1912, the highest being 122 cm (48.17 inches) as recorded in 1922. Thus the calculated residence times are approximately representative of a 56-year return period.

Residence times were calculated for; a) mixing of inflows throughout lake depth (total), and b) confinement of inflows to epilimnion (0-9 m). The plausibility of the latter condition is discussed under Section 10, Chemical Considerations.

TABLE 8-1

ONONDAGA LAKE STUDY

ANNUAL RESIDENCE TIME OF ONONDAGA LAKE

Year	Total Annual Precipitation (inches)	(cm)	Average Daily *Flow (mgd)	(m^3 X 10^6)	Lake Residence Time (days) Total	Epilimnion Only
1963	27.81	70.7	198	0.90	238	154
1964	27.10	68.8	189	0.86	250	161
1965	28.39	72.0	196	0.89	240	154
1966	31.14	79.8	insufficient data			
1967	36.02	91.5	276	1.26	158	102
1968	44.23	112.3	376	1.77	99	64
1969	32.05	81.4	248	1.13	150	98

* Accounts for major inflows namely; Ley Creek, Onondaga Creek, Harbor Brook, Nine Mile Creek and Metropolitan Syracuse Treatment Plant.

Average annual precipitation -- 1912-1968 = 90.4 cm (35.60 inches).

Assumptions: Rainfall - Evaporation = 0
Inflow travels through all lake depths

SECTION 9 - OTHER PHYSICAL CONSIDERATIONS - TEMPERATURE AND TRANSPARENCY

K. M. Stewart

General

One of the most valuable variables for limnological investigations is temperature. Thermal profiles relate directly to physical stratification and indirectly to chemical and biological stratification as well. When temperatures are measured in depth systematically over long periods of time, additional knowledge is gleaned concerning vertical mixing and the circulation of nutrients.

The clarity of a lake is a popular index of a "clean" lake by laymen and scientific investigators as well. Clarity, transparency and opacity are all terms used to describe or discuss the ease with which light penetrates water. The penetration of light is a complex function of scattering and absorption. The turbidity of water, natural discoloration, plankton and bacterial populations and detrital composition all affect how far and which wavelengths of light penetrate the water.

Temperature

For this Study, temperatures were measured systematically (with a thermistor- thermometer) at preselected depth intervals in Onondaga Lake. Two major periods of circulation (overturn) are apparent for each year, (Figure B-34). These two periods represent the vernal and autumnal circulation. Lakes in this category are termed dimictic (Hutchinson, 1957). An expected feature of lakes with similar latitudinal and climatic regimes is the rapid increase of temperatures at most levels following the break-up of ice. Following this there is a continued rise of temperature in the upper waters but the temperatures in the lowest water increase relatively little.

After the summer maxima of temperature and density differences there is a cooling with loss of stability and stratification. The entire lake cools irregularly to some temperature below 4° C after which time, and particularly near or at freezing, an inverse stratification begins. The inverse stratification holds during the winter and, following the loss of ice in the spring, the cycle is repeated with attendant annual modification from solar energy, winds, air temperatures and occasional influential contributions of cold or warm water from tributaries.

The picture for Onondaga Lake is roughly the same and the lake should be termed dimictic also. However, there are some noteworthy discrepancies in Onondaga Lake which affect the normally smooth transition from partial autumnal circulation to complete and uniform mixing. These discrepancies are visualized most easily in the figures for, and in the more detailed discussion of, thermal transects in Appendix A. It is sufficient to state here that chemical contributions to the density structure alter the circulation so that during late fall, Onondaga Lake cools in a pronounced (2 to 5° C difference from top to bottom) inverse (warmest water at the bottom) manner rather than what might be expected (.01 to 0.5° C difference) in less "saline" or more "normal" lakes. Chemical considerations related to the above are discussed in Section 10.

The "saline" nature of Onondaga Lake has led one investigator (Jackson, 1968) to the incorrect opinion that the lake is meromictic. Meromixis implies that some lower area of the lake is effectively and usually permanently sealed off from vertical mixing with the upper waters. Meromictic lakes have lower waters with essentially constant temperature. Such is not the case with Onondaga Lake as the detailed measurements of temperature in Figure B-1 will attest. Nor are the lower waters permanently sealed off from the upper waters.

In 1969 the temperatures in the lower waters rose more rapidly than they did the previous year. Whether this is a function of differential insulation, more heat contributed by industrial or municipal effluents, greater internal turbulence allowing far more heat transfer across the density gradient, or some other combination of effects is not clear at this time.

Thermal Transects

Owing to the relative salinity of Onondaga Lake as compared to other lakes, and following early thermal measurements which indicated that there were unusual lens of warm and cold water in the lake, thermal transects were run along the longitudinal axis of the lake to provide information as to the possible source, or fate of these features.

In addition to studying the distribution of unusual warm and cold temperatures within Onondaga Lake, it was felt that the thermal transects could also provide information on the tilting of the thermocline and some aspects of circulation. Therefore, several thermal transects were undertaken during the course of this Study to make these evaluations.

In addition to the "natural" flow into the lake from the various tributaries such as Nine Mile Creek, Bloody Brook, Harbor Brook, Ley Creek and smaller tributaries, Onondaga Lake

has several unnatural contributions such as the effluent of the Syracuse Metropolitan Sewage Plant, the sewage and industrial discharges from Ley Creek, the thermal discharge from the soda ash manufacturing plant and the relatively dense material coming in from Nine Mile Creek contributed by the overflow from the soda ash waste beds.

Onondaga Lake's inflows and outlet are illustrated in the upper left of Figure A-1. It is well to keep these in mind when examining the thermal transects as they help explain the distribution of some isotherms.

Note that the approximate path of the thermal transects is not directly over the subsurface (6.1 m 20 feet) discharge from the Syracuse Metropolitan Sewage Plant. Furthermore, owing to winds of varying velocity and direction and effects of the earth's rotation, there is little likelihood that any one "parcel" or slug flow of water will travel in a fixed direction for very long. Another consideration is that the largest natural annual inflow is from Onondaga Creek while the flow from Nine Mile Creek (augmented from the drainage off the soda ash waste beds) However, the most significant thermal inflow, observed in several transects, is from the cooling water discharge of the soda ash manufacturing plant. As this latter flow represents water that has been extracted from the lake, heated and then discharged at the surface, its slightly decreased density allows it to flow out over the surface of the lake at the southeast end.

Specific storms can influence one local watershed, draining into Onondaga Lake, more easily than others (Onondaga Lake Drainage Basin, 1951; Sixteenth Annual Report of the Syracuse Intercepting Sewer Board, 1922). Under conditions of relatively low inflow, water from the Seneca River may back in the outlet and further complicate the picture. The latter condition has been observed before (O'Brien & Gere, 1952). Thus, any one of the inflows or the outlet may, on occasion, be responsible for a clear or confusing picture of water movement into the lake.

Cooling water or thermal discharge from the soda ash manufacturer can be observed and measured easily at the site of discharge into the southeastern end of Onondaga Lake. The location can also be observed from a distance under certain atmospheric conditions. For example, when the air is very cold with respect to the water, and the relative humidity is high, a local vapor of "steam" or sea fog appearance can be noted rising over the area of discharge. This "steam" is visible from across the lake on the Thruway and is not uncommon in the late months of the year in the early morning hours.

Water from the Seneca River may back into the outlet of the lake at its northwest end and bring in a tongue of warmer or cooler water.

Both of the above conditions, i.e., the cooling water discharge and the backing of water into the lake from the Seneca River (Figure 9-1), have been recorded by still photography and special Infra-red[5] photographic technique. The infra-red technique senses the true thermal image of the lake, and helps interpret what is measured and observed at the surface of the lake and its part in a more synoptic overview than separate prints provide.

Summary of Transects

The transects discussed one at a time in Appendix A are summarized below. The transects illustrate, with varying degrees of clarity, two main features:

1. The first is the growth and decay of the thermal structure of the lake.

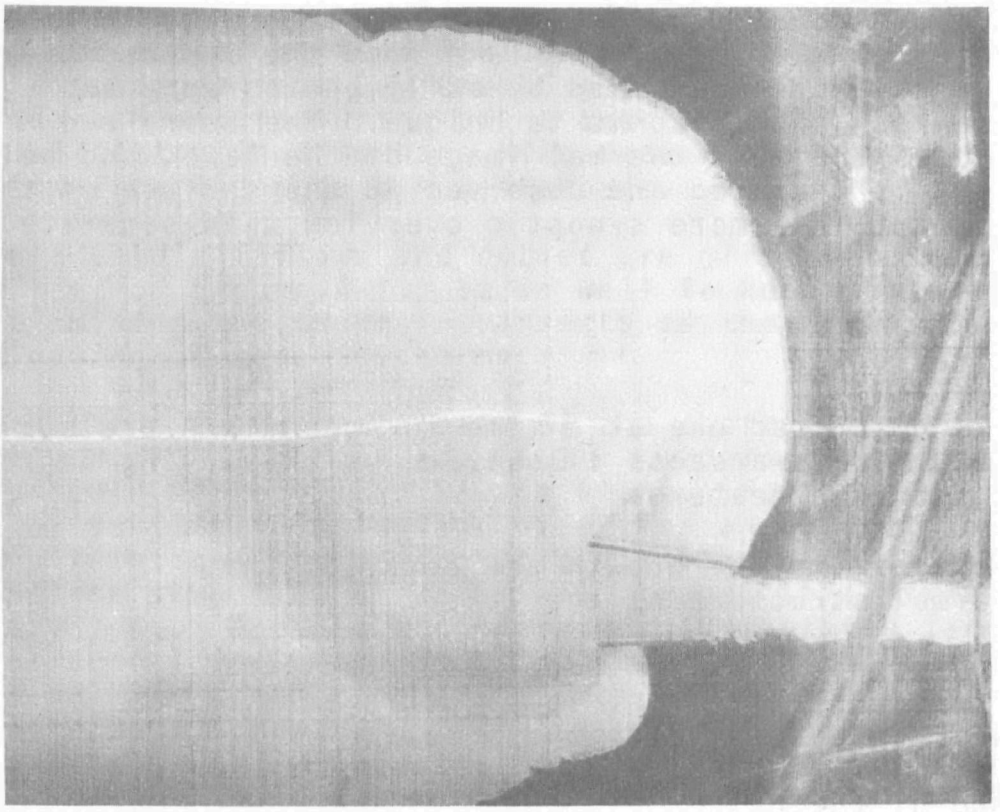
2. The second is the external contributions of water of different temperature and their dispostion within the lake.

The influence of these thermal contributions from industries, creeks and the Metropolitan Treatment Plant may be observed indirectly by taking vertical measurements of temperature across the lake.

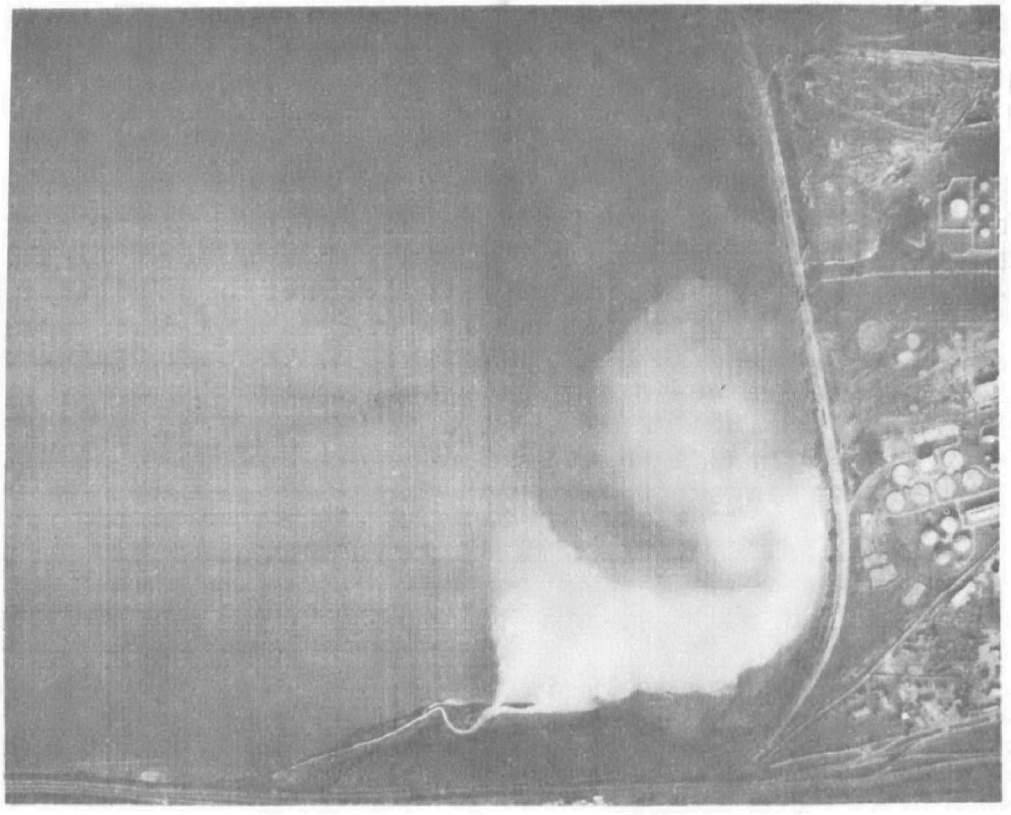
The main thermal discharge is from the soda ash manufacturing plant, where approximately 416 X 10^3 m^3/day (110 mgd) of water from the lake is used for cooling and then discharged at the surface in the southeast end of the lake. Percentagewise, the second most significant thermal discharge is from Nine Mile Creek.

The subsurface discharge from the Metropolitan Plant appears at times to flow down the slopes of the lake into the southeast basin and at other times seems to spread out and form lens of cooler or warmer water at approximately the depth of discharge. It is likely that the oxygen demand of this latter spreading effluent causes an uneven oxygen gradient in Onondaga Lake and accelerates the rate at which any available dissolved oxygen is reduced. Improved treatment of sewage should reduce this influence -- if the gains are not counter-balanced by an increase of population equivalents.

[5] Dr. J. W. Whipple of the USGS in Albany, N. Y., carried out the IR (infra-red) study of Onondaga Lake, 1969.



NORTH END OF ONONDAGA LAKE
INFLUENCE OF SENECA RIVER



NOTE:
DEGREE OF LIGHT CORRESPONDS TO DEGREE OF HEAT

SOUTH END OF ONONDAGA LAKE
"EAST FLUME" THERMAL DISCHARGE

FIGURE 9-1

It is readily apparent from the transects that there are chemical contributions to the density structure which create some abnormalities within the normal thermal profile. This is most striking during late autumn and is considered further in Section 10.

Transparency

Several photometric devices are used to measure the penetration of light. Some are extremely complex and expensive while others are simple and inexpensive. One of the oldest, but most commonly used instruments is a simple flat, white disk (20 cm dia.) called a Secchi Disk. The depth at which this disk just disappears from view is called the Secchi Disk transparency. Such a disk was used during this Study to measure the clarity of Onondaga Lake.

Seasonal and more rapid changes are plotted in Figure B-30. Two gross features are apparent from the graph. The first is that the general clarity of Onondaga Lake is low (mean value of 1.0 meter) when compared (Berg, 1965) to many other lakes in New York. The second feature is the repeatable (1968-1969) sequence of increased clarity (discussed elsewhere in the biological section) in August that appears to result from a collapse of the phytoplankton population. This late summer clearing has been observed frequently by local residents (personal communication with Cy Wilson who has worked periodically on the lake for many years).

The generally low transparency in Onondaga Lake probably reflects the high nutrient content and associated significant quantities of phytoplankton. Water of varying discoloration from the tributaries and industrial and municipal inflows can also induce local differences. However, with some exceptions, the transparency of water at both stations in the lake is quite similar.

SECTION 10 - CHEMICAL CONSIDERATIONS

M. C. Rand, et. al.

General

This Section discusses the major effects certain chemicals have on the structure of lake waters as well as chemical interactions that render it a unique lake with respect to many other fresh-water lakes. Individual chemical species and their distribution within the lake are discussed in Appendix B.

A most important characteristic of Onondaga Lake is the high average chloride concentration (1,690 mg/l), and the source and distribution of these chlorides within the lake. The chloride distribution plays a significant role in the stratification, distribution and mixing of lake waters. Despite stratification in depth, lake waters are well mixed horizontally with respect to most chemical species.

High concentrations of cations such as calcium play a significant role in the buffering capcity and mineral-water equilibria in lake waters. The latter is discussed in greater detail in Section 12.

Lake Stratification vs "Overturn"

Lake overturn is attributable to minimal density differences with the lake with attendant wind and inflow conditions favorable to a mixing of lake waters. Such conditions occur annually during the spring and fall seasons. Chemical gradients can result in differential densities that effectively impede the mixing process.

In 1969 stratification of lake waters began in April, shortly after the ice thaw (Figure B-1). All chemical data for the interim period illustrate only weak, incomplete mixing of lake waters.

Table 10-1 shows water densities and density differentials resulting from temperature and major ion concentrations representative of the 1969 lake "overturn". Ranges for each parameter, with the exception of temperature, represent approximate maximum and minimum values immediately prior to lake "overturn". These values are illustrated in Appendix B Figure B-1, B-4, B-10, B-11, B-16 and B-17. The temperature range is representative of lake waters prior to an iso-thermal condition in the lake. The distinction between temperature and ions was necessary since an iso-thermal condition appeared

to precede briefly the autumnal period of "overturn" in 1968 and 1969.

TABLE 10-1

COMPARATIVE WATER DENSITIES

Parameter	Range Prior to 1969 Overturn	Absolute Density @ 12° C	Density Difference @ 12° C
	mg/l	gm/cm^3	gm/cm^3
Cl	2,300	1.0030	
	1,700	1.0021	.0009
Ca	1,200	1.0023	
	1,100	1.0023	Negligible
Na	1,100	1.0019	
	850	1.0015	.0004
Temp.	10° C	0.9997	--
	12° C	0.9995	0.0002
	16° C	0.9989	0.0006
	24° C	0.9973	0.0016

Prior to iso-thermal conditions observed in 1969, water temperatures ranged from 14° C in the upper waters to 12° C in the lower waters. This temperature differential corresponds to a density change of 0.0002 gm/cm^3. Immediately prior to the period ov overturn in Onondaga Lake a density difference, in the order of 0.0009 gm/cm^3 also can be expected from ion concentrations. Therefore, absolute densities resulting from ion concentrations are approximately 400% higher than those resulting solely from temperature. Since molecular diffusion takes place at a relatively slow rate, the ion concentrations, especially chloride, are significant in modifying the type of overturn.

The moderate response of bottom sediments to density changes and overturn is best illustrated by the contour plots of BOD, ortho-phosphate and DO for Station No. 1, Figures B-35, B-36 and B-37 respectively.

During the periods of overturn, concentrations of DO and BOD tend to increase as the concentrations of ortho-phosphates tend to either remain the same or decrease. Increases in the hypolimnetic waters, with little or no attendant increases in the epilimnetic waters, occurred during the 1968 autumnal overturn (Figure B-35). Lake waters were similarly affected by the spring overturn in 1969. However, the autumnal overturn of 1969 showed no appreciable increases in the hypolimnetic waters. Due to the inability to differentiate the demands on, or contributions of the lower anaerobic waters from the anaerobic sediments, laboratory tests were conducted to determine the maximum BOD and ortho-phosphate concentrations yielded by the sediments.

In the case of the latter, surficial sediments were stored and then shaken in cylinders with ion-free water. Desorption of phosphorus as P was in the order of 0.026 mg/centimeter depth of sediment. Results are further discussed in Section 12. The ultimate oxygen demand of the surficial sediments or benthic deposits was estimated from an undisturbed core sample and found to be 100 lbs. for a bottom surface equivalent to the surface area of the lake. This is further discussed in Section 13. In general, Figures B-35 and B-36, as well as Table B-1, illustrate the tendency of BOD and ortho-phosphate respectively to be confined in the hypolimnetic water of the lake. The "trapping" of materials within the lower waters of the lake is not an uncommon occurrence.

Significance of Chlorides

It is apparent from Table 10-1 that chloride concentrations play a significant role in the stratification of lake waters. Absolute densities as well as density changes attributable to chemical concentrations are primarily the result of calcium and sodium chlorides. Approximately 54% of the chloride input measured under the Waste Discharge Survey is attributable to Nine Mile Creek. Other major sources are the "East Flume" (16.6%) and the Metropolitan Sewage Treatment (10.8%) discharges. Other sources of chloride in the lake are discussed in Section 12.

During the entire sampling period, the mean and geometric mean concentrations of chloride in the hypolimnion exceeded those of the epilimnion by approximately 30%. Higher chloride concentrations in the hypolimnion persisted even at those times when the lake was isothermal and sufficient mixing occurred to carry dissolved oxygen to all depths.

The gradients observed can be explained by considering effects of temperature and solute concentrations in the lake proper as related to inflows throughout an annual cycle.

During the winter months when the temperature difference from the lake surface to the bottom is only a few degrees, the chloride concentrations generally increased with depth; there is no sharp division between the hypolimnion and the epilimnion. Influent discharge water tends to descend to a level determined by its density. The consistency of higher chloride concentrations in the hypolimnion is attributable to chemically concentrated discharges residing in these waters despite temperature fluctuations.

As the Spring thaw takes place, the epilimnetic waters of the lake warm more rapidly than the hypolimnetic waters. At the same time, the warm runoff from streams is relatively dilute with respect to all dissolved species, including chlorides. Therefore, the streams, owing to their relative densities, tend to reside in the epilimnion. Thus, the chloride concentrations in the epilimnetic waters of the lake tend to be reduced by inflows during the early spring months. This is in accordance with observations illustrated by the chloride line plots, Figure B-4. This influence on lake waters tends to diminish through the summer as input volumes and their dilution effect decreases.

Horizontal Mixing

Although lake waters are stratified with respect to depth throughout the major portion of the year, all chemical data indicate good horizontal mixing throughout the year. Table B-1 shows mean and geometic mean values for all parameters measured on the lake and the differences between Stations 1 and 2. Negative differences reflect a higher value in Station 2. With the exception of BOD, nitrite, chromium and Escherichia coli (E. coli), all differences are less than 20% with the majority of differences below 10%. It should be noted that higher BOD, carbon dioxide, E. coli and nitrogen forms at Station No. 1 are attributable to the major pollutional discharges that are along the southeastern end of the lake, and the unstable nature of the constituents.

Observations with respect to chloride, calcium and sodium data illustrate the degree of horizontal mixing within Onondaga Lake. Measurements made under the Waste Discharge Survey (Table 5-4) show that the combined discharges of Nine Mile Creek and the "East Flume" represent 70.6% of the chlorides, 79.4% of the calcium and 61.1% of the sodium. Although Nine Mile Creek discharges into the lake approximately two-thirds the distance up from the southeastern end, differences for these three chemical species in the lake are

in all cases less than 2%. This represents a significant amount of horizontal mixing. Wind data show that the predominant winds originate from the west and west-northwest direction, thus aiding the distribution of waters from Nine Mile Creek to the southern end. It should also be pointed out that there are substantial shifts in wind direction and velocity throughout the day which contribute to the mixing of lake waters. Seiche generated currents probably augment the horizontal distribution of variables, particularly in the hypolimnion.

Calcium and sodium values show variations with depth and relationships with runoff similar to those observed for chloride. As calcium and sodium represent the major cations in Onondaga Lake, such similarities are reasonable. A most interesting observation is the fluctuation of chlorides, calcium and sodium with time, irrespective of depth (Figures B-4, 16, 17). The chloride fluctuations correspond closely to those observed for conductivity (Figure B-20). The above chemical species showed increases beginning in May 1969, with "0-9 meter" waters increasing at a more rapid rate than lower waters. Observations of runoff data for Nine Mile Creek, Figure B-33, show that increases in chemical concentrations correspond with decreases in runoff. The relatively rapid rate of response of the upper waters to runoff variations indicates that the epilimnion is a more dynamic region than the hypolimnion.

Some major parameters showing values higher in the northern end, (Station No. 2) than in the southern end, were dissolved oxygen, total phosphorus, ortho-phosphate and nitrite. Contributions of dissolved oxygen and phosphorus may result from Seneca River waters backing into Onondaga Lake. Figure 9-1 illustrates the influence of Seneca River on Onondaga Lake.

Higher nitrite values at Station 2 presumably result from the greater availability of oxygen for oxidation of nitrogen.

Higher chromium values in the hypolimnion of Station No. 2 may be the result of the "Steel Mill" discharge which discharged approximately 39% of the total chromium measured.

Lake Buffering Capacity

Calcium plays a significant role in the pH-alkalinity relationship, as described under "pH" in Appendix B, through the following reaction:

$$Ca^{++} + HCO_3^- \rightleftharpoons CaCO_3 + H^+$$

The relatively high Ca^{++} concentrations in both the epilimnion and hypolimnion drive the above reaction toward the formation of $CaCO_3$ (calcite). This can best be shown by illustrating the position of equilibrium from a calculation of the solubility product (Ksp).

Since 25° C nearly represents the maximum temperature recorded in Onondaga Lake (28° C) during the sampling phase, the Ksp at that temperature can be used to illustrate the influence of Ca^{++} on the precipitation of $CaCO_3$.

$$\text{Ksp of } CaCO_3 \ (25^\circ \text{ C}) = 4.7 \times 10^{-8} = [Ca^{++}]\ [CO_3^-]$$

Since alkalinity is almost entirely in the form of HCO_3 at a pH less than 8.3, HCO_3 is nearly equal to the alkalinity measured. Values below are for the hypolimnion of Station 1. Values in parentheses () represent minimum concentrations observed.

Parameter	Geometric Mean mg/l	Gram Molecular Weight	[Moles/Liter]
Ca^{++}	827.6 (122.0)	40	20.6×10^{-3} (3.05×10^{-3})
HCO_3	196.2 (84.0)	61	3.22×10^{-3} (1.38×10^{-3})

$$[20.6 \times 10^{-3}]\ [3.22 \times 10^{-3}] = 66.4 \times 10^{-6}$$

$$[(3.05 \times 10^{-3})][(1.38 \times 10^{-3})] = (4.2 \times 10^{-6})$$

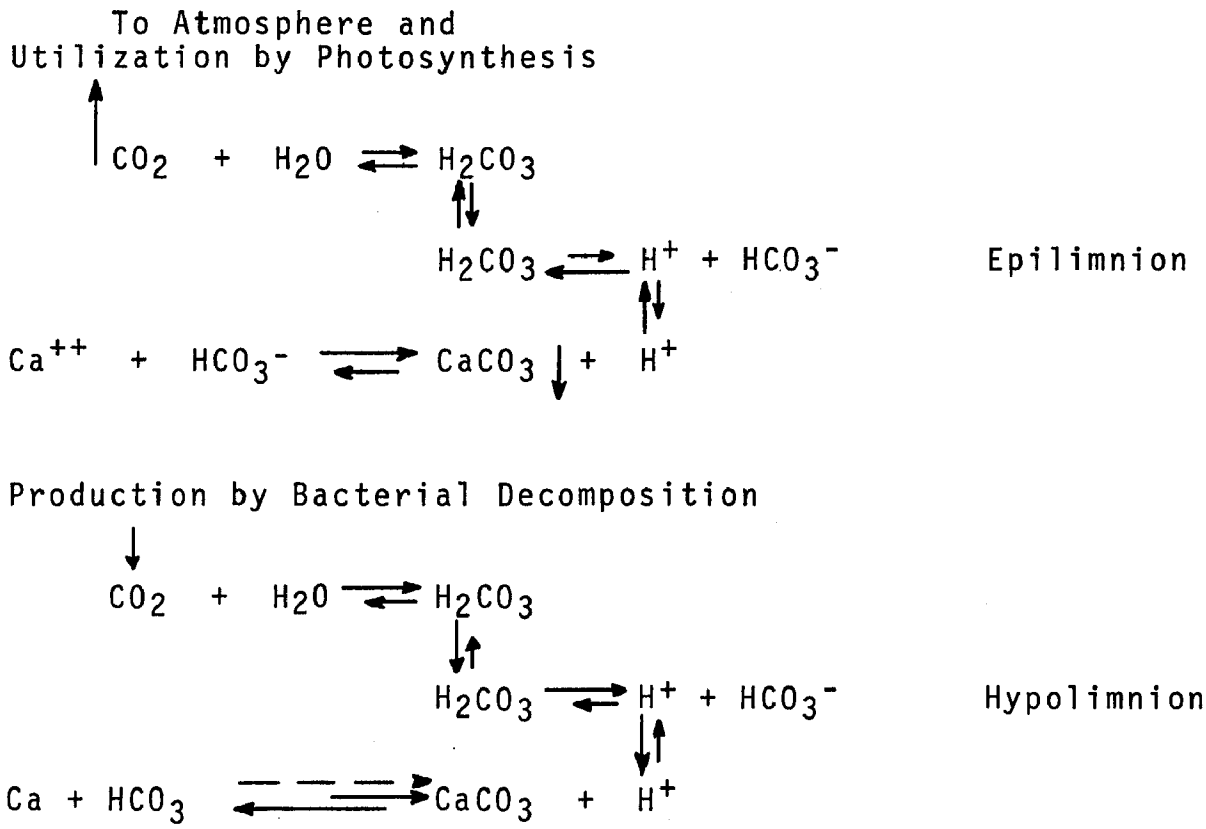
$$66.4 \times 10^{-6} \geqslant 4.7 \times 10^{-8}$$

$$(4.2 \times 10^{-6}) \geqslant 4.7 \times 10^{-8}$$

This precipitation of $CaCO_3$ occurs even in the case of minimum concentrations. The above illustrates the predominant influence of Ca^{++} ions on the precipitation of $CaCO_3$. Its ionic concentration varies from 6.4 to 2.2 times the ionic concentration of alkalinity as HCO_3^-.

The precipitation of $CaCO_3$ occurred throughout the period April 1968 to December 1969 for all zones of the lake

measured. This condition is unique in that many lakes show a precipitation of $CaCO_3$ in the epilimnion, but a dissolution of $CaCO_3$ in the hypolimnion, as illustrated below.



However, consistant precipitation of Ca_3CO_3 occurs in Onondaga Lake as illustrated by the dotted arrows. Increased CO_2 in the hypolimnion reduces the rate at which $CaCO_3$ is formed but does not reverse the reaction.

Overnight Measurements

Results of overnight samples are plotted in Figure B-40 through B-47. Figure B-40 illustrates variations in DO at all depths for Station 1. Surface and 3 meter readings show the greatest variations with time since they are representative of the photic zone of the lake. As expected, DO concentrations at these depths decreased with decreasing daylight reaching an apparent minimal condition at approximately 6:00 a.m. the following day. DO concentrations in the deeper portions of the lake remained relatively constant. Figure B-41 illustrates DO variations on July 29, 1969, when an algae die-off condition was observed in the lake. Even under these conditions there was a decrease in DO concentration with decreasing daylight. A minimal condition for the surface waters was reached at 4:00 a.m. the following day. In

general, DO fluctuations were not as great as was expected from the intense algae production of the lake. Figures B-42 through B-47 represent CO_2, pH, alkalinity, temperature, conductivity and SiO_2. Values of CO_2 were relatively constant with respect to time. Apparently the respiration and photosynthetic activity of phytoplankton was not significant enough to influence the carbonate equilibria in the lake. Other parameters, with the exception of alkalinity, show only slight variations with respect to time. Fluctuations in alkalinity are not explainable from the results of this Study.

Statistical Routines

Depth synoptic data were subjected to three general types of statistical routines, namely; 1) distribution plots, 2) correlation analysis and 3) multiple regression analysis. Statistical routines in conjunction with visual representations provided the basis upon which chemical interrelationships were derived. Results of these routines and an account of the varous interrelationships observed appear in Appendix B.

SECTION 11 - BIOLOGICAL CONSIDERATIONS

J. M. Kingsbury

General

Attention was given to the algae or phytoplankton, the zooplankton, and the fish in Onondaga Lake. Phytoplankton studies began in April of 1968 and extended to December 1969. Zooplankton and fish studies were conducted from January to December 1969. This Section is a summary of the above studies. Details of the phytoplankton, zooplankton and fish studies can be found in that order in Appendix C.

Previous studies of the algae of Onondaga Lake are few (summarized in the Appendix), and the observations on algae reported in them were often obtained incidentally to other purposes. Important parameters such as time or location frequently are not stated in these studies. In no case (except for Hohn's study of diatoms) is determination made to the species level; algae in previous literature are identified only to genus. This is a serious deficiency.

Identifying phytoplankton as "flagellates" instead of by genus and species is similar to identifying "salt" instead of NaCl. Identifying Scenedesmus for Scenedesmus obliquus is like reporting "a chloride" for NaCl.

Nearly concomitantly with this Study, a study of algal productivity, using enrichment of lake water, was conducted in D. F. Jackson's laboratory at Syracuse University. The results became available toward the end of our Study and are discussed in the Appendix. They agree with results reported here or with inferences derivable from the O'Brien & Gere Study in many particulars, although the approaches were different.

Previous published and unpublished studies of Onondaga Lake give, in summary, an impression of a eutrophic lake, rich in numbers of algae, but poor in species, with few or no blue-green algae. This fits the idea put forth by ecologists that given an unusual environment, the few organisms well adapted to its peculiarities will be able to exploit it to the virtual exclusion of other, less well adapted forms.

The purpose of the phytoplankton study was: a) to provide a quantitative account of the species of phytoplankton in the lake through a 12-month period, utilizing enough collecting techniques to ensure a detailed characterization of the lake's

phytoplankton; b) to calçulate the volume of an average individual for each important phytoplankter, and to derive from this and the counts an estimation of the photosynthetic biomass in the lake against time; c) to compare the populations of phytoplankton found in the lake as they changed in time with changes in other measured characteristics of the lake with a view toward discerning limiting or controlling factors; and d) to isolate into unialgal culture a number of the most important species of phytoplankton so that an investigation may be undertaken in the coming year of their individual physiology as it relates to ecologically significant parameters.

Sampling

Methods are discussed in detail in Appendix C. The summer and fall of 1968--Preliminary Phase of Study--were used to test collecting techniques, laboratory techniques and feasibility of collecting under varied conditions, and also to determine the number of stations and frequency of collecting needed to provide an adequate record. The program adopted for collecting employed two principal stations (identical with the two stations employed for the major chemical and physical observations) augmented by collections at 3 other stations. Sampling locations are illustrated in Figure C-1. Collections were made weekly through the growing season. Various techniques involving nets and ultrafiltration were used to concentrate organisms for examination. Collecting was by a combination of water-bottle point samples and horizontally or vertically integrating sampling techniques. All results expressed quantitatively have been derived from water of known volume and location. Identifcations have been by means of standard taxonomic authorities. In comparison with many similar studies, this Study has resulted in an unusually large number of collections for its duration and the size of the body of water involved.

Results

Findings can be discussed under two major headings: 1) organisms and 2) their relationship to the environment.

Both the variety of species and the abundance of certain species of algae in Onondaga Lake is impressive. As listed in the Appendix, approximately 100 species were identified in 1968-9. The dominant phytoplankters show the expected succession for a shallow, nutrient-rich lake: diatoms and flagellates in the spring, green algae of the Chlorococcales in the early summer, blue-green algae later in the summer and an association of flagellates and diatoms in the fall. A seasonal pattern can be described for a number of moderately common species. The lake also supports a surprising number of rare species which appear occasionally in the collections.

The finding of a high diversity of species was unexpected in light of the lake's unusual chemistry and the earlier reported observations.

Phytosynthetic biomass (Figure C-2) follows a seasonal pattern with greatest abundance in June, July and August when the water may be noticeably colored by blooms of green or blue-green algae. Observations from the preliminary phase in 1968 were adequate in retrospect to conclude that in 1969, blooms of algae were less intense than in 1968. During the late summer of 1968, masses of blue-green algae were washed ashore and the bloom persisted through September. Such conditions were absent in 1969. On the basis of previous literature, blooms of blue-green algae were unexpected. The organisms involved, (Polycystis aeruginosa and Aphanizomenon flos-aquae), are among the common troublesome kinds. Both have records of toxicity to animals.

Onondaga Lake is unusually saline, with a salinity approximately one-tenth that of the ocean. Three types of algae typical of marine environment were found in the lake: First, the variety and total number of centric diatoms (Centrales) is intermediate between a typical freshwater environment and an oceanic condition, and dinoflagellates are abundant in the lake. Most of the dinoflagellates and centric diatoms in Onondaga Lake are freshwater species from genera in which the majority of species are marine. Secondly, a rare species of the diatom Chaetoceros was found. This species may have been previously undescribed. All species of Chaetoceros described to date are exclusively marine. Thirdly, the typically intertidal, attached green seaweed Enteromorpha intestinalis, one of the commonest algae along most of the coasts of North America, occurs around the shores of the lake, sometimes abundantly.

The distribution of light is important in the environment of phytoplankton. During the growing season in Onondaga Lake, calculations show that the depth of the euphotic zone (that in which, per 24 hr., light is present in sufficient amounts for photosynthesis to balance or exceed respiration) is significantly less than half the depth of the epilimnion (surface to thermocline). This means that such things as presence or absence of turbulence, degree of turbulence, motility of organisms, and rate of sinking of non-motile organisms will play a significant role in determining whether a given cell will spend sufficient time in the euphotic zone for a successful positive balance between photosynthesis and respiration. Unlike most other algae, typical bloom-forming blue-green algae including those found in Onondaga Lake float at the surface. They thus markedly change the characteristics of light penetration into the water and affect the growth of other phytosynthetic organisms in the water column.

Turbulence tends to destroy surface blooms. The increase of the heavy walled, readily-sinking diatom Melosira granulata in September, for example, appears to be related to the increased turbulence in the epilimnion at that time.

The concentrations of phosphates, nitrates and potassium compounds, in lake water throughout the year, compared with what published minima exist, and the amounts of these compounds used in culture media for algae lead to the conclusion that these principal nutrients are never limiting to algal growth in the lake, nor do any of them appear to be of such great concentration as to be inhibitory to algal growth. Silica (SiO_2) is depleted in proportion to the blooms of diatoms, but may not reach low enough concentrations to become seriously limiting to diatom growth. The concentrations of certain other elements, however, may be limiting or may approach limiting levels for one or more species of phytoplankton. The elevated concentrations of chromium and copper in particular approach levels at which algal inhibition may be expected. In general, conditions in the lake appear to be capable of supporting larger populations of algae than those in 1969. If the level of a metal is acting as a check, its removal or reduction may lead to greater blooms than presently occur.

The level of dissolved oxygen in a natural body of water is critically important to those organisms, fish expecially, which depend on it for respiration. A catastrophic dimunution of dissolved oxygen may occur in lakes as an algal bloom disappears, when oxygen is rapidly removed from the water to meet the demands of decomposition of dead algal cells and of the respiration of those remaining. According to observations of the County (C. Wilson, personal communication) it is usual for Onondaga Lake to "clear" of visible algal growth for a brief period some time during the summer months and for "clearing" to be associated with a marked drop in dissolved oxygen. This phenomenon was not observed in 1968, but in 1969, at the end of July, the phytoplankton disappeared suddenly and almost completely from the lake, and the dissolved oxygen content of the water dropped to approximately 2 ppm at the surface. Chlorella vulgaris was the only common phytoplankter at the time. The sudden death of this species may have occurred as a natural process in the cycle of growth and decay of a population, or it may have been brought about by a change in some, not obvious, environmental parameter.

Zooplankton - Results

Systematic surveys of the zooplankton of Onondaga Lake have not previously been reported. The few observations in earlier reports are scattered, and organisms were not identified to species. Previous literature is summarized in Appendix C.

Sampling for zooplankton was performed at the same times and at the same stations as the sampling for phytoplankton. Collecting was by nets hauled horizontally and vertically, the latter for tows of known length. Organisms were identified as critically as possible (dependant in part on stage of growth), and results expressed quantitatively per unit of water against time for a 12-month period. Details of the methods employed are presented in the Appendix.

Seventeen species in ten genera were identified. The dominant forms include 3 rotifers, 1 copepod, and 3 cladocera. Because the numbers involved were relatively small, they were examined statistically for standard deviation as a measure of their reliability. Variations in counts per unit volume of lake water against time as expressed in line plots were examined to detect possible correlations of peaks and valleys with significant changes in chemical, physical or biological characteristics of the environment.

It was not possible to establish that fluctuations in counts were or were not related to specific chemical parameters, although the shape of some curves individually and collectively suggests the possibility that both limiting events and inhibitory events were sometimes at work in determining the density of populations of zooplankters. Some populations may have been held back from attaining maximum density occasionally by fish predation, but evidence of close control of zooplankton populations by this means, or of any control by changes in food source or levels (algal populations) is lacking, except perhaps in winter when all populations were low. Similarly, although algal cells were often seen within the digestive tracts of some zooplankters, the zooplankton populations seemed to have little or no effect in controlling the density of populations of phytoplankton.

One rotifer and one daphnid identified from Onondaga Lake are normally associated with saline environments.

In general, Onondaga Lake supports a community of zooplankton which is typical for a saline lake at this latitude.

Fish - Results

A survey of the fish in Onondaga Lake was conducted during the summer of 1969 by members of the Department of Conservation, Cornell University, utilizing techniques proven in other lakes of upstate New York. The objectives of the study were to determine the species composition of the fish population and its general condition.

Methods included overnight laying of gillnets to collect adult fishes, collecting of pelagic fish fry by plankton net, collecting of pelagic fish by midwater trawl, collecting of pelagic fry by trawl towed near the surface, and shore seining for small fish. Ekman dredge samples were taken at gillnet stations to sample the benthos at these locations. Location of stations, time of sampling and composition of catches are given in detail in Appendix C.

Onondaga Lake supports a fairly diverse fish fauna, typical of many warm water lakes in Central New York State. Sixteen species were identified in adult or juvenile condition. Except for a large population of white perch, species composition has not changed appreciably from that reported in surveys of the lake in 1927 and 1946. Despite the unusual chemical and physical characteristics of Onondaga Lake, growth of most game and panfish compared favorably with the published growth rates for fish in other waters of the northeast. Reproduction appeared to be very limited in 1969, but the few young taken were of good size and condition.

Distribution of fish in the lake is not uniform. Conditions along the northeast shoreline are favorable to a large and varied fish fauna. Adult fish are scarce in the southernmost part of the lake and young are not found along the northwest shore. These distributions probably reflect the inflow of low quality water at the south end of the lake and from Nine Mile Creek. The level of dissolved oxygen in the hypolimnion is lower than that necessary to sustain populations of fish presently in the lake which must therefore live in the epilimnion at least some of the time to survive. Levels of oxygen in the epilimnion are sometimes marginal. Even though adult fish may be able to survive under these conditions, the reproduction of these species may be limited by them. The reproduction of some fish species may be limited by the quality of the substrate in the littoral area.

Management of the existing fish population, mainly panfish, could provide recreation for area youth and intercity residents were are unable to travel to more distant waters. A comparison of taste and acceptability of fillets from fish taken in Onondaga and Oneida Lakes was conducted with ten participants who were not informed of the source of the fillets. Although some could detect differences in flavor in some species of fish, walleyes especially, none found the Onondaga fish objectionable. If the condition of the southern half of Onondaga Lake can be improved to that currently existing in the northern half, the southern basin should be capable of supporting populations of fish similar to those now present in the northern half. At least this much improvement in the lake would be necessary to support increased fishing pressures than now exist, and further management might be required in the light of changes in the condition of the lake as they occur.

SECTION 12 - GEOLOGICAL CONSIDERATIONS

J. C. Sutherland

General

This Section deals with mineral water equilibria in the open waters of Onondaga Lake as well as the interstitial waters of the lake sediments. Dissolved sulfide and chloride concentrations are discussed with respect to their relationship with concentrations observed in the interstitial waters. The sources of these chemical species are also considered. In particular, chloride data are reviewed to determine the possibility of concentrations emanating from the lake bottom.

Sediment characteristics such as age, consistency, and gases related thereto are also discussed under this Section. Laboratory tests to determine maximum chemical contributions from the sediments are reviewed.

Basis of Mineral Equilibrium Model - Treatment of Chemical Data

Introduction

Chemical analyses from Onondaga Lake are compared to models for saturation (equilibrium) involving common minerals. The treatment may be compared to considerations of dissolved oxygen concentrations (DO). The measured value of DO is compared to a value representing equilibrium with oxygen of the atmosphere. In the mineral equilibrium treatment, solids such as silicates, phosphates, fluorides, carbonates, sulfates, sulfides, etc., rather than oxygen, are "tested" to learn if they have roles as chemical regulators of lake water.

In the DO example given, one asks if water is in equilibrium with the atmosphere. Formally,

$$O_2 \text{ (g., atm.)} \quad O_2 \text{ (aq.)} \; ??$$

A question so formulated about the mineral, calcite, would be,

$$CaCO_3 \rightleftharpoons Ca^{++} \text{ (aq.)} + CO_3^{=} \text{ (aq.)} \; ??$$

That is, "Is the lake in equilibrium with calcite"?

It is desirable to learn about chemical self-regulation in Onondaga Lake because:

1. A lake in equilibrium with minerals tends to resist the imposition of chemical changes (natural or man-made), by dissolving or precipitating of the mineral(s) involved.

2. Change in the concentration of one species tends to promote spontaneous change in other concentrations. For example, if a lake in which the equilibrium reaction prevailed, $CaSO_4.2H_2O \rightleftharpoons Ca^{++}(aq.) + SO_4^{=}$ (aq.) + $2H_2O$, were treated to remove calcium, then the reaction would tend to advance to the right, and perhaps result in undesirably high concentrations of sulfate ion.

3. Changes in the concentration of other chemical species could follow: In the above example, the increased concentration of sulfate could lead to increases in the concentration of dissolved copper, through formation of the ion pair, $CuSO_4°$ (aq.).

4. When oversaturation of a lake with common minerals takes place, the rate of introduction of the involved chemicals is rapid relative to the rate of precipitation of minerals.

Equilibria involving dissolved chemicals, including ion pairs, may be very important. For instance, in a lake containing millimolar quantities of Mg^{++} and $SO_4^{=}$ ions, up to 0.2 millimolar amounts of $MgSO_4°$ (aq.) "molecule" may be present. Typical percentages of dissolved ion pairs in Onondaga Lake are given in Figure D-1 (Appendix D).

TABLE 12-1

Minerals Tested

Carbonates	
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Siderite	$FeCO_3$
Malachite	$Cu_2(OH)_2CO_3$
Rhodochrosite	$MnCO_3$
Sulfates	
Gypsum	$CaSO_4 \cdot 2H_2O$
Phosphates	
Hydroxyapatite	$Ca_{10}(PO_4)_6(OH)_2$
Fluorapatite	$Ca_{10}(PO_4)_6(F)_2$
Octacalcium Phosphate	$Ca_4H(PO_4)_3$
Silicates, aluminosilicates, etc.	
Kaolinite	$Al_2Si_2O_5(OH)_4$
Muscovite	$KAl_3Si_3O_{10}(OH)_2$
K feldspar	$KAlSi_3O_8$
Amorphous silica	$SiO_2 \cdot nH_2O$
Na montmorillonite	$NaAl_7Si_{11}O_{30}(OH)_6$
Ca montmorillonite	$CaAl_{14}Si_{22}O_{60}(OH)_{12}$
Gibbsite	$Al_2(OH)_6$
Oxides	
Cuprite	Cu_2O
Hematite	Fe_2O_3
Pyrolusite	MnO_2
Manganite	Mn_2O_3
Fluorides	
Fluorite	CaF_2
Sulfides	
Pyrite	FeS_2
Covellite	CuS
Chalcocite	Cu_2S
Alabandite	MnS

Basis for Selecting the Minerals for Equilibrium Model Treatment

Silicate minerals, the alkaline earth metal carbonates, gypsum, and fluorite, are minerals common or observed in the rocks of the Onondaga Lake watershed. These minerals react with ground water, with streams that carry them in suspension and with Onondaga Lake in which they may reside as suspended or as settled (bottom sediments) particles.

Minerals of iron, copper and manganese, although ordinarily slow to react with natural waters, might form in the lake (authigenically) by precipitation if the metal ions are sufficiently concentrated. The phosphate minerals also form authigenically if concentrations of dissolved orthophosphates are high enough.

Treatment of Data

All calculations and most tests for equilibrium were performed by computer with programs written expressly for the Onondaga Lake Study.

The thermochemical activities (or, simply, activities) of dissolved chemical species are calculated from lake chemical analyses, from temperature data and from experimental energy data. The chemical activities, related to concentrations, are then tested in models for equilibrium involving the pertinent minerals.

Tests for equilibrium are illustrated in two examples:

A. The reaction of calcite with lake water may be written:

$$CaCO_3 \rightleftharpoons Ca^{++}(aq.) + CO_3^{=}(aq.)$$

At equilibrium, the product of the activities of dissolved species,

$$[Ca^{++}] \times [CO_3^{=}] = Keq.,$$

where Keq. is a temperature-dependent equilibrium constant, and where brackets denote activities.

Should the activity product calculated from a sample of water exceed Keq., then the mineral, calcite, is stable, and would tend to form in the water by precipitation of the chemicals. If the activity product is less than Keq. the water is undersaturated with calcite, calcite is unstable and, if present in suspension, would tend to be dissolved.

B. Equilibria involving reciprocal mineral-water relationships are tested with equations like the following:

$$\underset{\text{kaolinite}}{1/2\ Al_2Si_2O_5(OH)_4} + 5/2\ H_2O = \underset{\text{gibbsite}}{1/2\ Al_2(OH)_6} + \underset{\text{silicate acid}}{H_4SiO_4(aq.)}$$

At equilibrium,

$$[H_4SiO_4] = Keq.,$$

an equilibrium constant for this reaction. If kaolinite and gibbsite are in equilibrium in the lake, removal of silicic acid by processes external to reaction (consumption by siliceous plants, for example) will be accompanied by a tendency for the reaction to proceed to the right, forming gibbsite and silicic acid.

C. Reactions involving oxidation reduction are compared to an oxidation potential calculated from values of pH and DO in the epilimnion, and from dissolved hydrogen sulfide, $SO_4^=$, and pH in the hypolimnion. Comparisons are made in order to determine the stable form of a heavy metal of interest at different levels in the lake. For example, iron could be stable as one of the mineral oxide, sulfide or carbonate forms, or in the aqueous phase, but in general only in one of these forms.

Results

Phosphates

Onondaga Lake is oversaturated with hydroxyapatite and fluorapatite, and is undersaturated with other orthophosphate compounds.

Given existing values of calcium concentration and pH, the phosphate oversaturation factor with respect to hydroxyapatite is approximately 16 (15° C), 10 (0° C), and 100 (25° C). Oversaturation of the lake with fluorapatite is even greater.

Some large lakes with water detention times of two years and longer, Lake Erie for example, remain undersaturated with the apatite minerals except locally where rivers rich in phosphate discharge. But oversaturation in Lake Erie, for example, is uncommon. Data from many analyses suggest that equilibrium is approached from the side of undersaturation and that precipitation of OH-apatite acts to limit concentrations of dissolved orthophosphate.

Into Onondaga Lake, however, streams discharge large amounts of orthophosphate and too rapidly for reactions,

$$10Ca^{++} + 6PO_4^{=} + 2OH^{-} \longrightarrow \text{hydroxyapatite, and}$$

$$\text{"} \quad + \quad \text{"} \quad + 2F^{-} \longrightarrow \text{fluorapatite,}$$

to keep levels of orthophosphate concentration in the low parts-per-billion range.

Related to orthophosphate and apatite minerals is the observation that concentrations of fluoride diminish with depth in the epilimnion (surface to 9 meters). As seen in a plot of data taken June 18 to July 16, (Figure D-4), fluoride concentrations diminish by a factor of four within that depth. Because the waters in the deeper epilimnion have existed for a longer time in the lake than have surface waters, notwithstanding mixing attributable to wind currents, the former have been reacting as lake waters for longer times than have the latter. Being "older", the deeper waters have had longer exposure to conditions of oversaturation with respect to fluoride minerals. The foregoing observations are consistent with the hypothesis that a fluoride mineral is forming in the lake. Fluorapatite, with which the lake is greatly oversaturated, would be the most likely precipitating mineral.

The precipitation of fluorapatite, $Ca_{10}F_2(PO_4)_6$, might remove the equivalent of 4.0 mg/l orthophosphate phosphorus from hypolimnetic waters over a period of time, less than one year. A close estimate of this period would be extremely helpful in determining the rate of P removal.

Carbonates

In most months, the lake is oversaturated with calcite and dolomite. The degree of oversaturation of the lake with respect to calcite is a remarkably uniform function of the pH (Figure D-5):

$$\text{Log}_{10} \text{ SATURATION FACTOR} = \text{pH} - 7$$

Only in middle and late winter, when pH's fall below 7, is Onondaga Lake undersaturated with these minerals.

The reaction,

$$Ca^{++} + CO_3^{=} \longrightarrow CaCO_3 \text{ (calcite)}$$

represents the existing oversaturation of Onondaga Lake with calcite. Differences exist in the degree of oversaturation, surface waters being more oversaturated than deeper waters with a persistent trend. The degree of oversaturation shows stronger relationship to the pH than to temperature, which is somewhat unexpected in view of the significant temperature-dependency of the equilibrium constant.

However, the pH-dependency of oversaturation is consistent with other chemical observations involving the dissolved carbonate species, namely: Concentrations of dissolved carbon dioxide, H^+, and bicarbonate ion, are higher in deeper waters than in overlying waters.

These observations are consistent with results that would be expected from increased, or greater, bacterial oxidation of organic matter in the hypolimnion than in the epilimnion.

The reaction,

$$CO_2 + H_2O \longrightarrow H_2CO_3,$$

leads to higher concentrations of H^+ and HCO_3^- upon dissociation of H_2CO_3,

$$H_2CO_3 \longrightarrow HCO_3^- + H^+.$$

The increased H^+ concentration results in removal of carbonate ion, through the reaction,

$$CO_3^= + H^+ \longrightarrow HCO_3^-,$$

and the decreasing amounts of carbonate ion cause a lowering or diminishing of the degree of oversaturation in the hypolimnion, relative to the epilimnion.

Fluorides

Measurements of the activity of fluoride ion were made for four months in June 1969. During this time, the lake was slightly undersaturated with fluorite, except for an occasional sample of water very near equilibrium with the mineral.

In Figure D-4, data are plotted in a stability diagram for fluorite. Data plot close to the fluorite - lake water equilibrium boundary which suggests that formation of fluorite,

$$Ca^{++} + 2F^- \longrightarrow CaF_2,$$

may limit the concentrations of fluoride ion to values less than 2 mg/l (10^{-4} mol./l.) (see Figure D-6), at present levels of calcium.

Others

With respect to sulfates, Onondaga Lake is undersaturated with gypsum.

Concerning oxides, hematite, and, occasionally, cuprite and pyrolusite are stable in the epilimnion.

With respect to sulfides, pyrite is stable in the hypolimnion. Sulfides of other heavy metals are unstable.

Concerning silicates, kaolinite is stable in nearly all samples of water analyzed (Figures D-7 and D-8). In samples with concentrations of dissolved silica at high levels, equilibrium between kaolinite and Ca montmorillonite is approached, (Figure D-9).

Sources and Magnitude of Chloride Concentrations

High concentrations of major dissolved chemical species, chloride, Na, C, Mg, and K, are present in the enclosed water of lake bottom sediments (Figure D-12). In most sediments taken by piston coring, concentrations of several tens of thousands of mg/l's of sodium and chloride are measured at depths of 4 m. in the sediments. In sediments taken with gravity cores, occasional values exceeding 10,000 mg/l are found at depths of less than one-half m, (Table D-3).

These extraordinary concentrations might be the result of several processes:

1. in situ dissolving of chloride salts.
2. in situ desorption of particle-adsorbed ions accompanying aging in sediments.
3. Entrapment of water from a much saltier Onondaga Lake of the past.
4. Natural ultrafiltration (ion filtering) with upward expulsion of "fresher" water, accompanying compaction of sediments.
5. Ultrafiltration resulting from filter-pressing enclosed water from sediments on board the sampling boat.
6. Changes in ion-exchange properties of sediments with warming, during on-board extraction of water.

7. Introduction of dissolved salts from natural saline ground waters by salt diffusion, by upward displacement of such water during compaction of sediments, and by mass channel flow of subsurface water into shallow sediments.

Discussion

Chloride crystals are not seen in the sediments, nor would such salt crystals, if introduced from surface discharges, survive in the undersaturated waters of the lake. The sediments are prevalently inorganic or crystalline carbonates and silicates. The capacity of such sediments to exchange or adsorb ions is small, at most, amounting to several tens of milli equivalents (meq.) of cations/100 gms sediment, and much smaller amounts of chloride and other simple anions. It is, therefore, unlikely that large amounts of chlorides are removed from lake water by adsorption and ion exchange processes. It is more difficult to imagine large-scale desorption of chloride and sodium under the relatively mild physical and chemical conditions in the sediments. In the historical literature of Onondaga County, there is no suggestion that Onondaga Lake was once a much saltier lake than it is today. The opposite, in fact, is suggested.

Natural compaction of sediments could lead to reverse osmosis in which sediments act as semi-permeable membranes. Where effective, compacting sediments would expel "fresher" water upward, retaining saltier water within them. But in Onondaga Lake, sediment load pressures do not seem adequate to account for the high concentration differences observed between lake water and water at 4 m depth in the sediments, for example. The pressure difference, π , which is also the osmotic pressure, is, at most, one atmosphere. This pressure is adequate to account for total concentrations higher by only 2.0 M, and even at much shallower depths. Controlled studies by others suggest that for significant ultrafiltration to take place during pressure treatment of sediments, pressures of several hundred psi are required. In the present studies, maximum pressures of approximately 90 psi were employed. Recent work (Biscoff, Greer, et al., 1970) confirms that water pressed from marine sediments on board ship or in a warm laboratory is enhanced in concentration of some chemicals and has reduced concentrations in others, relative to values at cold temperature. But the differences are very small relative to differences seen in the Onondaga Lake situation.

Other observations indicate strongly that chemicals in waters of the sediments have been added from salty subsurface waters.

In Figures D-10 and D-11, straight lines of regression are plotted for Na, Ca and Mg against chloride, both for randomly selected data upon the lake waters and for the piston core sediment data.

In Onondaga Lake:

1. Ca is present in nearly exact simple proportion to Cl, with the ion ratio, Ca/Cl = 0.39.

2. Na is present in less perfect proportion with Cl.

3. Mg shows a weak inverse correlation with Cl, decreasing with increasing concentrations of Cl.

These results are expected because of the surface discharges of large quantities of Na, Ca and Cl into the lake, (see Section 5). The negative relationship of Mg, a relatively dilute major ion, with Cl (and, therefore, with Ca) is not inconsistent with the lake's great oversaturation with calcium magnesium carbonate minerals.

The large proportionality constant relating Ca and Cl indicates a source of calcium chloride, specifically. Such proportionality is very rare in natural waters, except ocean water, because of the near absence of calcium chloride minerals. The phenomenon in Onondaga Lake is an artifact of industry.

In the enclosed waters of sediments:

1. Concentrations of all major cations and of chloride are higher than in the lake. Concentrations of Na^+ and Cl^- commonly exceed 10,000 mg/l and, occasionally, Cl exceeds 50,000 mg/l.

2. No persistent relationship of concentration to depth is seen. Even shallow sediments (1 m.) may contain thousands of mg/l of salts.

3. Sodium is present in nearly exact simple proportion with Cl^-. Na/Cl = 1.07.

4. Calcium covariation with Cl is very weak.

5. Magnesium varies in fairly close proportion to Cl.

These observations suggest additions of natural saline underground water derived from natural regional deposits of

rock salt. The high correlations of Na and Mg with Cl are expected because of the presence of Na and Mg chloride in commercial brines around Onondaga Lake. The weak correlation of Ca with chloride is consistent with the absence of $CaCl_2$ crystals in the Syracuse salt formation. The salt could enter the shallow sediments by diffusion, by upward displacement of salty water attending compaction of sediments, and by less uniform processes including random channel flow of saline water into shallow levels of sediments. The last alternative may explain the existence of extremely salty water in sediments less than 1 "m" in depth.

An underground head of pressure very likely exists to apply positive upward pressure of subsurface water, around and beneath the lake. Kantrowitz, 1964, remarking about the saline water in wells and seeps in the region of Onondaga Lake, suggests that subsurface water in the rocks above the Hilderberg escarpment, 15-20 miles south of Onondaga Lake, probably penetrates the Syracuse salt formation (elevation = 320 feet below sea level). The water would then migrate northward through fractures and solution channels in the salt and gypsiferous rocks. The salty Bishop spring and spring-fed salty ponds on the east side of the lake could obtain their pressure by this mechanism.

Static Diffusion Calculations

An estimate of the maximum effect of ionic diffusion from sediments into the lake was made. A calculation made for the chloride ion indicates that the quantity of chloride diffusing from the sediments into the lake is rather small amounting to no more than 45 mg/l into the lower one meter of water during five months time. The calculation is made using the first Fick law of diffusion and a diffusion coefficient equal to 10^{-6} and maximum concentrations of chloride of 63,000 mg/l measured at a depth of 1-2/3 meters in the sediment. Attempts to make empirical estimates of rate of diffusion through the use of Jenkins samples Table D-2 led to large and unrealistic results. Readings indicated a rapid loss of chlorides from the interstices within a short period of time. The "rate" of Cl loss was not discernable from the readings taken of the overlying waters.

Sources and Magnitude of Dissolved Sulfide Concentrations

Sulfide concentrations were measured in the water at stations No. 1 and 2 from the middle of June through the month of October. The content of dissolved sulfide in enclosed waters of sediments was also measured. Sediment depths varied from 0.10 to 4 m. The following are the results.

1. Sulfide in the surface water occasionally exceeded 30 mg/l. Values decreased downward to the thermocline at 9 meters (Figure B-14).

2. Sulfides at depths 6 to 9 meters were negligible.

3. The amount of dissolved sulfide in the enclosed waters of sediments was found to be less than that found in deepest lake waters.

4. The highest contents of dissolved sulfide were measured in the deepest lake water and reached 80 mg/l in early September.

Perhaps the most peculiar observation made was the high sulfide concentrations in the upper epilimnion. This may be attributable to the treatment given water samples before they were analyzed for sulfide. The water samples were made very basic (pH 14). In such a solution, any copper or iron sulfides present as particles in the water would probably dissolve. Introduction of airborne sulfide particles precipitating on the lake could account for the high measured values of sulfide in the surface waters and also for their decreasing concentration with depth in the epilimnion. Also, sulfide released from decaying organisms might produce such values. From the observation of negligible concentrations of dissolved sulfide within the region of 6 to 9 meters, it can be concluded that no significant quantities of sulfide in the form of gases or in the form of turbulent water, are reacting with hypolimnetic waters.

Concentrations of sulfide in sediment enclosed waters were less than those observed in the deepest lake water, suggesting that the high concentrations of sulfide in the hypolimnion are generated therein, i.e., through the action of sulfate reducing bacteria. However, reactions of sulfide minerals at the interface of the sediments and water cannot be discounted as a possible source of high sulfide in the hypolimnion.

Sediment Characteristics

Sediment Shaking Tests

Undesirable chemicals could be added to the lake from bottom sediments in several ways. Upward diffusion through enclosed water and mechanical resuspension are two possible means.

In order to estimate quantities of chemicals that could be added to the lake from the sediments, rinsing tests were conducted in which sediment was shaken (equipoise shaker, Precision Scientific Co.) with water in a tube. The amount

of chemicals released was determined by analysis of the filtered water.

In order to compare the possible effects of sediments separating upon present lake water and upon potentially cleaner water of the future, surface lake water and deionized water were used upon duplicate sediment samples. Sediments from all parts of the lake bottom were tested.

The discussion to follow concerns dissolved phosphate only and is based upon the results listed in Appendix D, Table D-5.

Sediments rinsed with deionized water yielded larger amounts of phosphate than did those shaken with lake water: The average of 34 tests using deionized water is 0.225 ppm orthophosphate (as P) released from one-half gram of sediments into approximately 40 ml of water.

Reasonable values for the porosity of sediments and density of particles being close to 50% and 2.8 gm/cm^3, respectively, then one cm^3 of sediments yielded roughly 0.026 mg of easily removed P.

A cleaner Onondaga Lake will be affected by the existing sediments for an indefinite time. The sediment shaking tests permit some predicitons to be made upon phosphate effects:

Assuming that during a period of five years (approximately 9 detention periods) sediments will yield, at a maximum, easily rinsed phosphate equivalent to that contained in an average 10 cm thick layer of sediments, than 0.26 mg of P/cm^2 of the bottom will have been released by the sediments. If only the hypolimnion (9 m deep) is affected by this addition of P, then a steady state average concentration of P of approximately 0.026 mg/l will occur in the hypolimnion.

These effects appear to be small, and yet are the maximum to be expected. Therefore, phosphate in the present lake sediments is not expected to be an important factor in future lake water.

Gases in Sediments

Four aspects of sediment gases are considered, namely; 1) the inferred presence of gases, 2) observation of gases made directly, 3) collection of gases and 4) the results of gas analyses. The presence of gases in the sediments was strongly inferred by repeated failure to make a map of the sub-bottom profile of the lake using geophysical methods of percussion and explosion seismometry. On summer days during which the water of the lake was calm, bubbles were often seen breaking the water surface. That the sediments are a source of a percentage of the gas bubbles was strongly inferred from observation of bubbles exceeding 3 cm in length in the upper meter or more of collected sediments. The bubbles were clearly visible between the sediments and the transparent butyrate liner used for coring. A second observation of gases in the sediments was afforded by the Jenkins sampler. The Jenkins sampler is used to take an essentially undisturbed portion of sediments from near the sediment water interface. The sampler is transparent and allows observation of the upper most section of sediment together with approximately 30 cm of immediately overlying water. Upon bringing the sampler aboard, bubbles effused from within the sediment into the water immediately overlying them. Although the cause of this strong outgasing is mechanical disturbance and expansion accompanying reduction in pressure upon the sediments, it can be surmized that gas bubbles are present in the lake sediments and that they eventually pass into the above water.

In addition to the above, gases were collected at a level approximately 1 meter above the bottom of the lake in the south and north deeps. A large plastic inverted funnel was suspended one meter above the sediments in order to trap gases bubbling up from below. During the period of sampling (the third week in August until the middle of September) it was found that from 24 to 48 hours time was required to collect sufficient samples for analysis. The most abundant gases found were nitrogen and methane, with trace quantities of hydrogen sulfide present. Carbon dioxide was not detected in any of the samples owing to the solubility of this gas in relation to the technique employed. Values of nitrogen varied from 20 to 53% and values of methane ranged from 47 to 80%. Although it may be assumed that these gases are representative of the sediments, it should be noted that the gases were collected from within the deep waters and one meter above the bottom. Pertinently, on August 29th, a water sampler was taken from a depth near that of the gas sampler and was analyzed for nitrate, nitrite, ammonia, hydrogen sulfide and other relevant chemicals. It is interesting to note that the water and gas are in equilibrium with each other and with respect to nitrogen and hydrogen sulfide. Thus the latter gases measured are representative in part of the deep water environment.

Consistency of Sediments

The sediments of Onondaga Lake have two pronounced and pervasive characteristics:

1. They are very fine grained, clay sized and mostly lacking in grittiness.

2. They are rich in carbonate minerals, primarily calcite, to the extent that violent evolution of carbon dioxide gas results from applying a drop or two of weak hydrochloric acid to a sample of the sediments.

The sediments have three predominant colors, namely black, brown and grayish white. Sediment characteristics and their distribution within the lake are illustrated in Figure D-12. Black sediments were ordinarily the first encountered at the lake bottom and had a greasy feel and an oily odor. From inspection of samples taken with the Jenkins corer, the upper part of these black sediments had a felted coarse and floccy aspect. When suspended rather quickly, the upper few centimeters of sediment settled from suspension leaving the water clear. The porosity of the sediments within this upper felted few centimeters approached 75 to 80%. But at depths of approximately 1/2 meter these black sediments became tacky and rather greasy, and uniformly fine grained.

Brown sediments occurred in three different modes in cores taken within 1,000 feet or so of shore, namely, an occasional thin brown silty layer, brown sediments in an irregular mottling pattern with black sediments, and discrete layers of brown sediments within a column of black sediments. Brown sediments, except for those scarce, thin silty layers described above, were identical to the black sediments in texture and minerology. The brown color suggests that these sediments are somehow oxidized. A possible mechanism for oxidation of sediments at the sediment water interface may be attributable to lake overturn during which time oxygen laden waters are brought into contact with the bottom sediments. The oxidation of only trace amounts of iron, for example, would change the color of black sediments to brown.

Grayish white sediments were frequently encountered in the shallower near shore regions and especially in the north basin of the lake. These same sediments sometimes appeared beneath a thin veneer of black sludgy material, for a thickness of approximately one meter of black material, or as the first sediment encountered on the bottom. In the same regions, black sediments were observed to grade very gradually downward into white sediments below. A common name for the white

sediments is lime mud or marl. These white sediments were composed primarily of the mineral calcite.

The fine grained nature of sediments in general deserves some comment. The scarcity of sandy material in the lake is due to the absence of significant sources of sand in the lower reaches of streams except perhaps in times of infrequent and heavy flooding. The fact that in most months of the year the lake was oversaturated in calcium carbonate is important. The pervasive fine grained nature of the sediments and their richness in calcareous material (marl) suggests that the significant component of these sediments is calcite that is precipitated directly from solution in the lake.

In addition to the carbonate minerals, calcite and dolomite, the black and brown sediments contain silicate minerals. These are quartz, kaolinite, montmorillionite, chlorite, micas and feldspars. Sediments were analyzed for organic composition, which was found to be in the order of 10%.

Very little of the recent history of sedimentation in Onondaga Lake can be inferred from historical accounts. Published reports from the 19th Century indicate that the bottom of the lake at that time was composed mostly of the grayish white marl referred to above. However, there is no account of samples of the lake bottom taken from environments other than near shore. Thus we must assume that the marly bottom of Onondaga Lake as reported in the historical literature, is that bottom seen at and near the shore through whatever thickness of water was transparent at the time of observation. At any rate, the white marl observed in this study is the only sediment in the lake that bears a relationship to the marl reported in the 19th Century.

Presently there are thicknesses of black sediments overlying the marl, ranging from a few centimeters to 4 meters or more. The thicknesses of black sediments were not penetrated in the deeper axial portions of the lake.

Dating of Sediments

Dating of sediments was attempted with techniques utilizing pollen and radio carbon analysis. Dr. M. Faust, previously with Natural Sciences Dept., Syracuse University, N. Y. has studied the pollen contant of several long cores collected during this study. Although for most pollens no definite age determining pattern is apparent, Dr. Faust reports the presence of pollen of the sour gum, or pepperage plant at depths below 180 centimeters in the saddle of the lake and the disappearance of the pollen at the 180 centimeter level.

Dr. William M. Marlowe of Syracuse University[6] informs us that the black tuploe (pepperage) grew in the swamps of Onondaga Lake and that the hollowed stem or trunk of this plant was used to convey salt brine. Mr. Richard Wright of the Onondaga Historical Association,[7] calls our attention to advertisements in Syracuse newspapers of 1875 to 1880 for pepperage. The local supply (swamps of Onondaga Lake) of pepperage may have ceased to be of economic value and from that time pepperage was obtained possibly from the Cicero Swamp near Oneida Lake. Thus from the evidence of pepperage pollen in the lake, it can be surmised that the upper two meters or so of black sediments in the lake have been deposited since 1875 or 1880.

Heavy Metals

Analyses of heavy metals in the enclosed waters of sediments were conducted upon samples taken from gravity and piston cores. In general, concentrations of all metals are several-fold higher than in the lake waters, and there are not persistent relationships of concentration to depth of sediments.

For the metals, manganese, zinc, chromium, copper and iron, the highest observed values are, respectively, 5.6 mg/l, 0.6 mg/l, 0.17 mg/l, 0.35 mg/l and 139 mg/l.

Values measured for Mn, Zn and Cr, indicate that mineral dissolution and/or desorption of ions takes place in the sediments: neither the oxides nor other minerals are stable in the reducing, nearly neutral sediment environment. Cuprous sulfide or chalcocite (Cu_2S) is probably colloidal, perhaps in the form of pyrite.

The low concentrations of metals suggest:

1. That diffusion of heavy metals into overlying waters is slight.

2. That sediments would be only mildly reactive, with respect to these metals, if mixed with, or in contact with typical hypolimnion waters.

[6] Private conversation with Dr. William M. Marlowe, Dept. of Wood Products, N. Y. State College of Forestry, Syracuse, New York.

[7] Private conversation with Mr. Richard Wright, Director, Onondaga Historical Association, Syracuse, New York.

If mixed with, or in contact with oxygenated waters, reaction would result in lower concentrations of Mn and probably copper, due to the formation of oxide minerals. Because of some percentage of the observed concentrations involved metals paired with other ions in solutions, mixing with the present hypolimnion waters, having much lower ionic strength than the sediment enclosed waters, would result in lower concentrations.

SECTION 13 - ENGINEERING CONSIDERATIONS

General

This Section deals with an evaluation of parameters of major significance with respect to lake pollution. Considerations focused on two parameters, namely:

1. Dissolved oxygen, since it is the most widely used and accepted indicator for assessing the condition of receiving waters.

2. Phosphorus, since it has been widely accepted as a readily controllable nutrient in efforts to limit the eutrophication of waters.

A calculation of the assimilation capacity of Onondaga Lake was made to relate the DO content of the lake to Total Oxygen Demand (TOD) of the input loadings. Mineral-water equilibria relationships developed in this Study were used to estimate the mechanisms of phosphorus removal as they are related to phosphorus input loadings.

Lake Assimilation Capacity (LASCAP)

The dissolved oxygen content of water bodies is dependent upon many interrelated physical, chemical and biological factors. The influence of these factors, however, can be encompassed essentially in two variables, namely:

1. The TOD exertion rate.

2. The oxygen reaeration coefficient.

TOD is used herein as the total of carbonaceous and nitrogenous oxygen demand. Twenty-day tests were conducted to determine total oxygen demand exerted in lake waters. These tests indicated that nitrifying bacteria were present in sufficient concentrations within the lake to exert a significant oxygen demand within the first 5-day period of the conventional BOD_5 test, as outlined in "Standard Methods", 12th Edition. For this reason, results of the BOD_5 test for lake waters are herein referred to as TOD_5.

Conversely, however, it was assumed that streams, which were relatively polluted with raw and partially treated wastes and other discharges into the lake did not contain sufficient nitrifying bacteria to exert a significant oxygen demand within the first 5-day period, hence the BOD_5 test results

were essentially a reflection of carbonaceous oxygen demand. In order to account for the nitrogeneous oxygen demand (NOD) of lake discharges, it was assumed that the NOD is equal to 28% of the BOD (anonymous, 1969). The addition of the latter was applied to BOD_5 results, for streams, yielding a TOD_5 value comparable to the lake TOD_5 values measured.

A measurement of these variables provides the basis upon which dissolved oxygen concentrations can be calculated for projected BOD inputs. Factors required to determine these variables are:

1. Lake hydromechanics, e.g., lake structure, turbulence and water currents.

2. Deoxygenation rate, e.g., rate of TOD exerted insitu in the lake.

3. Reaeration rate, e.g., rate of surface aeration at known water conditions.

Lake Hydromechanics

Lake structure and water currents are the two most important factors that determine the distribution of TOD inputs in that they control the limits of the "stabilization zone" of the lake -- that volume effectively stabilizing the major input TOD's. These factors also determine the degree of mixing within this zone and hence the rate at which TOD is distributed throughout.

Chemical data collected throughout this Study show that lake waters are well mixed in the horizontal plane. Whereas line plots and statistical distributions show distinct differences in concentration with respect to depth, very little difference was observed between Stations 1 and 2 for all but a few chemical parameters, Table A-1; exceptions: BOD, E-coli, NO_2 Cr and Cu. Initial observations made on County data, collected since 1959 (not shown) also illustrated good horizontal mixing within the lake waters.

Line plots for conductivity and the major ions, chloride, calcium and sodium, illustrate the tendency of epilimnetic waters (0 - 9 meters) to respond to runoff variations, whereas the hypolimnion tends to be more conservative. This is due to the density difference between influent streams and lake waters as described in Section 10. With the exception of Nine Mile Creek flows, discharges entering the lake are usually less dense chemically than lake waters, and thus would tend to reside in the epilimnion of the lake.

Surface water currents for Onondaga Lake were estimated by Webber, (1960) to be approximately 3.5% of the observed wind speed. A net water current for the epilimnetic depths of Onondaga Lake were estimated by this same author to be 0.6 X the surface water current. On the basis of an 8 mph wind, this would result in a water current in the epilimnetic waters of 0.17 mph, (Webber, 1960). If this water current were aligned with the longitudinal axis of the lake, approximately 7,330 meters (24,000 ft.,) a volume of water could traverse the entire lake in approximately 27 hours. All to often, however, wind directions shift frequently throughout the course of a day. A "critical" condition would arise under conditions of minimum water currents thus causing input BOD's to remain within some limits of the lake. It was on this basis that the assimilation capacity of Onondaga Lake was determined.

Deoxygenation Rate

TOD exertion rates depend upon the specific characteristics of the waste material and the receiving body of water. For the purposes of this calculation, a rate of 0.21 per day at 20° C was used. This is a rate normally applied to domestic sewage, and was found to be the approximate value for Onondaga Lake waters. This rate was adjusted for temperature variation when necessary.

TOD inputs considered for the LASCAP included:

A. Air pollutants

B. Benthic demand

C. The in-lake generated TOD, e.g., algae, zooplankton

D. Waste discharges.

As shown in Section 5.03, air pollutants can contribute as much as 58,500 lbs. (26,700 kilograms) of VSPM or an ultimate BOD of 42,500 lbs. (19,400 kilograms) over a 30-day period. This reduces to a UOD of 1,420 lbs. (650 kilograms) per day.

An approximattion of the oxygen demand of the benthic deposits was made by measuring the total dissolved oxygen depletion from overlying waters of a Jenkins Core sample, (see Section 7). In accordance with Davison, (1969), the upper two centimeters of the sediments were disturbed in order to determine the UOD under simulated "overturn" conditions. The UOD's measured for the undisturbed and disturbed Jenkins Core were 2.4 and 3.4

mg/sq. meter respectively. Corresponding values for the surface area of the lake are 61 and 100 lbs. respectively.

One of the most difficult factors to take into account in determining the assimilation capacity of the lake is the in-lake TOD. Algae can contribute significant quantities of oxygen via photosynthesis and can represent significant TOD, thereby complicating the application of a TOD input-lake DO relationship.

During this Study, a condition occurred in the lake which enabled a minimization of the signficance of algae in the LASAP. On July 30, 1969, a "die-off" condition followed a period of intense photosynthetic activity as illustrated by the contour plot of dissolved oxygen, figure B-37. Following the "die-off", the DO conditions in the epilimnetic waters continued to decrease reaching an apparent minimal condition at the end of September. A period of 10 days following this time was chosen as the critical period, figure B-37, for which the assimilation capacity of the lake was made.

BOD inputs from waste discharges are outlined in Section 5. The major BOD discharges are along the southern shore of the lake. Referring to Table 5-3, the summation of the pounds of average BOD_5 of all major discharges, with the exception of Nine Mile Creek, is equal to 99,230 lbs. (45,000 kilograms).

On the basis of the above figures, the contribution of BOD from air pollution and from the benthic deposits can be considered negligible for the present time.

Calculation of LASCAP

The calculation of a lake assimilation capacity outlined in Appendix E, was made in the following manner:

BOD inputs were determined from the Waste Discharge Survey conducted as part of this Study and from the findings of the Onondaga County Air Pollution Survey.

A "critical" period of 10-days was determined from line plots of bio-mass, Figure C-2, and a DO contour plot for Station No. 1, Figure B-37. This period represented a minimal DO condition and thus a period of minimal photosynthetic activity. An average DO concentration during this period for 0 to 9 meter depths was determined by measuring areas on the contour plot. Similarly, average TOD_5 and temperature were determined for the same period. Using a TOD exertion rate of 0.21 at 20° C adjusted for temperature, the daily TOD_5 input (BOD_5 X 1.28) was integrated to determine the 10-day resident TOD_5 in the lake. This value was then divided by the average 10-day TOD_5

measured in the epilimnion of the lake to determine the volume of epilimnetic waters representing the TOD input. This volume represents the "stabilization zone" of the lake and is shown in Figure E-1. The corresponding surface area was determined and TOD attributable to benthic demand and air pollution were determined; they can be considered negligible for the "critical period" also.

On the basis of a dynamic system whereby reaeration is equal to the oxygen depletion necessary to maintain a zero TOD at the end of any 10-day period, the rate of reaeration (K_2) was calculated as a function of the dissolved oxygen deficit and the first day TOD input demand. The calculation is shown in Appendix E.

Projected DO Concentrations

The stabilization zone, as calculated above, should be relatively independent of changes in TOD inputs, since its limits are determined by the relationship of input flows to the hydromechanics of the lake. Thus the surface area of the lake through which reaeration occurs should also be independent of TOD inputs. Since lake DO concentrations greater than that used in the above calculation would result in larger K_2 rates, 0.0285/day represents a minimum reaeration rate, with which conservative projections of DO concentrations in the lake, on the basis of reduced TOD inputs can be made. Accordingly, various TOD inputs were assumed, results plotted in Figure E-2.

Pertinent Phosphorus Studies

This Section is primarily concerned with the relationship of incoming phosphorus (P) quantities and forms, to the P quantities observed in the lake and the mineral forms which precipitate and/or adsorb phosphorus. Inorganic phosphates can be classified into two very general groups, namely; the orthophosphates and the condensed phosphates. Condensed phosphates cover the pyro, meta, poly and ultra phosphates. The pyro phosphate and tripolyphosphate are the principal condensed phosphates found in the normal sewage and originate primarily from the detergent industry. Schmid (1968) showed that approximately 80% of the total phosphates manufactured are sold in the production of synthetic detergents.

Condensed phosphates hydrolyze to the uncondensed ortho form in aqueous solution. Van Wazer, (1958) listed the major environmental factors in what is believed to be their decreasing order of effectiveness as, temperature, pH, enzymes, colloidal gels, complexing cations, concentration and ionic environment in solution. Approximate effects on rate of

reversion range from 10^6 faster for temperature to "a several fold change" for ionic environment in solution. Solutions of condensed phosphates in the mg/l concentration range will undergo very rapid hydrolysis due to the action of phosphatase liberated by micro organisms, (Karl-Kroph, E., 1957). Sawyer, (1952) conducted a study on reversion of complex phosphates in sewage at 5 and 20° C. After 24 hours, a mixture of sewage and tripolyphosphates ($Na_5P_3O_{10}$) showed a 9% reversion to orthophosphate at 5° C, and 20% reversion at 20° C. A mixture of tetra sodium pyrophosphate ($Na_4P_2O_7$), for this same period, showed 30 and 60% reversion at 5 and 20° C, respectively.

During the more photosynthetically active periods in Onondaga Lake, as illustrated by the DO line plots (Figure B-15), lake temperatures range from 16° to approximately 26° C. The relative abundance of organisms in this lake represents a large source of phosphatase. Based on the above findings, we can conclude that the time required for reversion of condensed phosphates to orthophosphates, during the more active periods in the lake, is in the order of days. It is assumed for the following considerations, that the major difference between total phosphorus and "ortho" phosphorus measured in the lake is "condensed" phosphorus owing to detergent laden domestic discharges. Organic phosphorus will represent a portion of the difference, but also will hydrolyze within a matter of days.

Schmid, (1968) conducted extensive studies to determine the mechanisms for phosphorus removal by lime treatment. He concluded that the most important precipitate formed in the removal of orthophosphates is the apatite, ($Ca_5OH(PO_4)_3$). Although the solubility product reported for this precipitate varies over a wide range, studies by Clark, (1955) showed the solubility product at 25° C to be 10^{-115}. At the pH and ion concentrations encountered in Onondaga Lake, this precipitate is very insoluble. The stability of the apatite in Onondaga Lake, Figure D-2, was determined through geochemical studies reported in Section 12.

Based on investigations on phosphate adsorption phenomena, Schmid found that at a pH of 7.0 and a Ca^{++} concentration of 200 mg/l, a calcium polyphosphate floc adsorbed orthophosphate and some polyphosphate. He does not define the molecular structure of the calcium polyphosphate. He also found, at the same calcium concentrations, that at a pH of 9.5, polyphosphate adsorbs to the orthophosphate floc (hydroxyapatite). At pH 10.0, the polyphosphate adsorbs to calcium carbonate floc.

Phosphorus Interactions in Onondaga Lake

Based on the above findings, the following can be expected to occur in the lake:

a. Hydrolysis of condensed phosphates to the ortho-phosphorus form within a matter of days.

b. The removal of orthophosphates by the precipitation of hydroxyapatite, and fluorapatite.

c. The formation and precipitation of a calcium polyphosphate floc.

d. The adsorption of polyphosphate phosphorus to the calcium polyphosphate floc.

Although pH conditions are less than 9.5, there may be some minor adsorption of polyphosphate onto hydroxyapatite and/or calcium carbonate due to the prevalence of these minerals on the lake.

Phosphorus concentrations for the various zones of the lake are shown in Table B-1. The average (mean) for total phosphorus of all zones in the lake is 2.73 mg/l. Table 5-5, Section 5, shows the Lake Residence Equivalents for major discharges. The total LRE for total phosphorus is 6.8 mg/l. This indicates a removal of approximately 4.1 mg/l throughout the lake by either precipitation within, or passage through the lake. The former possiblity is the most undesirable in that the precipitated phosphorus would represent a storage of this nutritive element within the lake environs. Due to the "backflow" condition observed at the lake outlet and the lack of a control channel at this location that would otherwise enable measurement of outflow volumes, phosphorus discharged from the lake could not be calculated. Consideration is given herein to precipitation within the lake as the major source of removal, since it represents the most undesirable condition with respect to eutrophication.

Mineral equilibrium investigations (Section 12) show that Onondaga Lake is oversaturated with the minerals, hydroxyapatite ($Ca_5OH(PO_4)_3$) and fluorapatite ($Ca_{10}F_2(PO_4)_6$). The lake is also oversaturated with calcite ($CaCO_3$) throughout the year except in the middle and late winter when pH's fall below 7. The lake was found to be undersaturated with other orthophosphate compounds.

On the basis of the above, it can be assumed that the removal of phosphorus within the lake is attributable to precipitation and/or adsorption by the above mentioned minerals. If it is assumed that all incoming phosphorus is removed within the lake, this means the equivalent of 4.1 mg/l throughout the

lake is precipitated and/or adsorbed. Figure B-11, in conjunction with Table B-1, illustrates significantly higher values for the hypolimnion than in the epilimnion, indicating a phosphorus "trap" phenomena.

It is interesting to note the wide range of total phosphorus values, Appendix B, 0.32 - 20.0 mg/l, as compared to the range of orthophosphorus, 0 - 2.8 mg/l. Since hydrolysis of total phosphorus to orthophosphorus likely occurs in a matter of days within Onondaga Lake, the above range differential probably reflects storage of phosphorus during the photosynthetically active period of the lake.

SECTION 14 - ENGINEERING EVALUATIONS

General

This Section deals with the effects of present pollution abatement programs on Onondaga Lake and an evaluation of the significance of other pollutants not presently being abated. Sources of pollution, discussed in Section 5, are considered in terms of parameters of major significance; namely, dissolved oxygen and phosphorus. While other factors are also important, their significance in a lake environment can be related either directly or indirectly to dissolved oxygen or nutrient levels.

It has been stated that organic carbon, in addition to exerting an oxygen demand on receiving waters, may represent the most significant source of carbon as carbon dioxide in eutrophic waters (Kuentzel, 1968). Hence abatement of organic pollution may prove to be a significant factor in limiting the algae growth of Onondaga Lake.

In addition, humic acid, an end product of decomposition, has been shown recently to be a most important factor in the development of blue-green algae (Lange, 1970). Bioassay studies performed by Keenan (1970), strongly indicate increased biological activity as a result of increased organic loading. These studies included laboratory measurements of biomass (nephelometry) and rate of primary production for lake water volumes mixed with various percentages of lake tributary volumes. Results for Ley Creek showed values for biomass and primary productivity consistently higher than for the Metro Sewage Treatment Plant, Onondaga Creek and other tributaries. Whereas most parameters measured (Table 5-4) were higher for the Metro Plant and/or Onondaga Creek than for Ley Creek, the latter represented the highest organic (BOD) input of all discharges. These results indicate the significance of organic carbon as described above.

Phosphorus is treated as a "critical" nutrient insofar as it has been successful in controlling nuisance organisms, (Karanik, J.N., Nemerow, N.L., 1965). This does not preclude the limiting effect on biota of other chemical species not so apparent at this time. This Study, in conjunction with the Onondaga Lake Monitoring Program now in progress, may in fact lend insight to other potentially limiting chemical species. This Section also deals with the concentration of metals in the lake with respect to abatement programs.

Impact of New Metropolitan Sewage Treatment Facilities - Presently Under Design

New facilities are to consist of biological contact stabilization following primary sedimentation, followed by chemical precipitation which will utilize the waste bed overflows from the soda ach manufacturing plant as a source of lime. These facilities will treat wastes emanating from the existing Ley Creek Treatment Plant, the waste bed overflow from the soda ash manufacturing plant, and the sewered areas tributary to the existing Metropolitan Sewage Treatment Plant.

Table 14-1 illustrates BOD_5 and corresponding TOD_5 values for each of the discharges. Predicted future loadings were determined from anticipated reductions due to the new Metropolitan Sewage Treatment Facilities. It should be noted that data taken for Ley Creek after the Ley Creek Treatment Plant discharge was diverted to the Metropolitan Plant, showed a decrease of TOD with time. This can be attributed to stabilization of benthic demand. The predicted values for TOD_5 represent stabilized conditions although higher values could result periodically due to the disturbance of otherwise latent conditions.

Storm Water Overflows

Much of the material discharged to the lake by Harbor Brook and Onondaga Creek is the result of interceptor overflows from the combined sewage system of Syracuse. A study of this system was conducted by the firm of Camp, Dresser & McKee, as part of the Onondaga County Comprehensive Study. On the basis of hydraulic considerations in relation to rainfall and runoff data, the frequency and duration of overflows were determined.

The Report states that the City of Syracuse includes a land area of about 16,000 acres, 13,400 acres of which are served by intercepting sewers which discharge to the Metropolitan Sewage Treatment Plant. An estimated 9,000 acres of sewered areas are tributary to combined sewers. The remainder of the City is served by sewers discharging to the Ley Creek Treatment Plant. It was assumed that there are no significant overflows tributary to the Ley Creek Plant.

The Study enumerated 67 overflows to Onondaga Creek and 27 to Harbor Brook, which discharge to the respective streams by means of intercepting chambers, overflow relief chambers, bypass chambers, and others. It was determined that 7.8 overflow events per month, with a total duration of 21 hours occur for the months of June through November. The average 12-month values are 8.8 per month and 23-1/2 hours respectively. The latter values are equivalent to approximately a 3% time

TABLE 14-1

ONONDAGA LAKE STUDY

	Existing Loadings (Lbs/day)					Predicted Future Loadings (Lbs/day)				
	BOD_5	BOD_{ULT}	NOD	TOD	TOD_5	BOD_5	BOD_{ULT}	NOD	TOD	TOD_5
Metro Plant Effluent	38,503	57,755	16,171	73,926	48,791	2,850	4,275	7,850	12,125	8,100
Ley Creek Plant Effluent	53,576	80,364	22,501	102,865	67,891					
Ley Creek						10,560	15,840	4,435	20,275	13,3818
Onondaga Creek	3,600	5,400	1,512	6,912	4,562	3,600	5,400	1,512	6,912	4,562
Harbor Brook	1,300	1,950	546	2,496	1,647	1,300	1,950	546	2,496	1,647
Storm Water Overflows	8,400	12,600	3,523	16,123	10,750	8,400	12,600	3,523	16,123	10,750
Nine Mile Creek	1,506	2,259	633	2,882	1,902	1,506	2,259	633	2,882	1,902
Steel Mill	746	1,119	313	1,432	945	746	1,119	313	1,432	945
Air Pollution	950	1,420	--	1,420	950	950	1,420	--	1,420	950
Benthic Demand	100	100	--	100	100	100	100	--	100	100
TOTAL	108,681	162,967	45,199	208,156	137,538	30,012	44,963	18,812	63,765	43,337

[8] Reflects recent data subsequent to diversion of Ley Creek Treatment Plant Effluent to the Metro Plant. This does not reflect any decrease due to channel dredging which is scheduled for completion in 1970.

occurrence. All the above values were in close accordance with those reported in the 1961 O'Brien & Gere Report on the main Intercepting Sewer System. The Camp, Dresser & McKee Report refers to studies of other large cities to establish that the liquid portion of sewage overflowing over a given year ranges from 3 to 4% of the annual sewage production. The solids portion of sewage, discharged through combined sewer overflows, is estimated to range from 20 to 30% of the annual production.

Storm water overflows are dependent upon the design and maintenance of the sewer systems through which they flow. Whereas figures related to design derived from other areas are somewhat applicable, the maintenance of systems can be a source of significant variance from one area to another. The 1961 O'Brien & Gere Report concluded that a major cause of overflows was the lack of maintenance of the systems, i.e. cleaning of intercepting chambers.

In an effort to determine what the percentage of overflow to the creeks was as compared with the Metropolitan Plant influent, a comparison was made between rainfall conditions and BOD's discharged to Onondaga Creek and Harbor Brook. These results (not shown) showed that BOD's equivalent to approximately 10% of the BOD's entering the Metro Plant, resulted from a 4-day period of little or no rainfall. Results of 4-day periods showing rainfall varied considerably with a range from 4 to 33%. The latter results were neither sufficient nor consistent enough to warrant any conclusions. For the purposes of this Study, it was assumed that the maximum overflow condition would cause a BOD discharge equal to 30% of the BOD tributary to the Metro Plant. The average BOD_5 of the Metropolitan Treatment Plant from January - October 1969, without the Ley Creek Treatment Plant discharge was 22,755 lbs/day, (10,300 kg/day)[9] - not shown.

Assuming this represents 50% of the influent BOD (in accordance with BOD measurements at the Metro Plant), the average influent BOD_5 is equal to 45,500 lbs/day (20,600 kg/day). Thus the maximum overflow condition could result in as high as 13,300 lbs/day (6,000 kg/day) BOD_5 discharged directly to the creeks. Based on the results of Table 5-3, but replacing values shown for Onondaga Creek and Harbor Brook with 13,300

[9] This figure represents an annual average whereas Table 5-3 is representative of grab samples and includes the Ley Creek Sewage Treatment effluent.

lbs., overflows could increase the "average" condition to a BOD_5 input of 108,681 or a TOD_5 of 137,538 lbs/day (62,400 kg/day). Referring to Figure E-2, this loading corresponds to an approximately zero dissolved oxygen saturation.

Based on reductions as shown on Table 14-1, the corresponding future loading that could occur after the new Metro Facilities are installed is 43,337 lbs/day TOD_5 (19,600 kg/day), which corresponds to a 50% DO saturation value or 4.7 mg/l DO under "critical" lake conditions.

Further significant reductions of BOD discharging to the lake could result from either abating storm water overflows or discharges presently emanating from Ley Creek, exclusive of the Ley Creek Treatment Plant discharge. Table 5-3 shows a discharge of 53,576 lbs/day discharged by Ley Creek, whereas data obtained from Onondaga County showed 32,600 lbs/day (14,800 kg/day) attributable to the Ley Creek Treatment Plant. This is a difference of approximately 21,000 lbs/day (9,500 kg/day) discharging to the lake via Ley Creek. Analyses made on Ley Creek, after the Ley Creek Treatment Plant effluent was pumped to Metro, indicated BOD discharges as high as 51,000 lbs/day (not shown). Such discharges are likely attributable to stabilization of the benthic demand. However, following the first of the year, TOD_5 discharges had averaged 13,381 lbs/day (6,060 kg/day) as of August 1970. Two present sources of pollution in Ley Creek are deposits on the creek bed, and the landfill operation.

Provision is presently being made by Onondaga County to dredge the creek bed. The landfill operation, however, will require further sampling to determine the significance of this source.

Bacterial Concentrations

The New York State Public Health Law Sec. 12.05, states "Organisms of the coliform group or any other organism from from wastes of animal or human origin shall not exceed the following prescribed standards for usage of the classified waters of the State..... Sources of water for bathing, fishing, boating and any other usages except shellfishing for market purposes in tidal salt waters: For such sources, the monthly median coliform value for one hundred ml of sample shall not exceed two thousand four hundred from a minimum of five examinations, and, provided that not more than twenty percent of the samples shall exceed a coliform value of five thousand for one hundred ml of sample, and, provided further that surface waters receiving treated sewage discharges which pass through residential communities where there is a potential exposure of population to the surface waters shall be protected

by the requirement that all effluents from sewage treatment plants shall be adequately disinfected prior to discharge into the surface waters in order that the monthly median coliform value for one hundred ml of sample shall not exceed two thousand four hundred from a minimum of five examinations and provided that not more than twenty percent of the samples shall exceed a coliform value of five thousand for one hundred ml of sample."

Bacterial analysis was performed by the Millipore Filter Technique and measured Escherichia coli, the indicator coliform commonly used to determine bacterial pollution. Table B-1 shows values for the four major lake zones sampled. Appendix B shows the statistical distribution of data for Station 1 which in all cases showed higher concentrations than in Station 2. A level of 5,000 per 100 ml is illustrated on the statistical distributions.

Bacterial data show that the major waters of Onondaga Lake meet State requirements for bathing and other recreational uses. Localized conditions proximate to pollution discharges were not determined.

In accordance with the above State specifications, any discharge carrying wastes of animal or human origin should be adequately disinfected to assure compliance in local or littoral regions as well as the major waters of the lake. This would require that all discharges carrying the above wastes be disinfected, including overflows.

Phosphorus Reductions

Considerations for phosphorus removal are based on total phosphorus for the reasons given in Section 13. Attention is given to the effect of treatment facilities on phosphorus and the mineral stability of the lake. The latter is a factor in determining the availability of phosphates for algae growth.

Table 5-3 shows total phosphorus values which total 10,948 lbs/day (4,960 kg/day). In addition to major discharges from the Metropolitan Sewage Treatment Plant and Ley Creek, Onondaga Creek represents a major discharge. Upon inspection of the individual data it was found that prior to the time that Ley Creek Treatment Plant discharge was pumped to the Metropolitan Plant, 613.3 lbs (278 kg) of P was discharged via Onondaga Creek in lieu of 2,434 lbs shown in Table 5-3. As a result of the current operation of the Metropolitan Sewage Treatment Plant, the additional flows now pumped through this plant from the Ley Creek Sewage Treatment Plant may have resulted in additional overflows along the main trunk to the Metropolitan Plant. These overflows are not expected

to occur after the new Metropolitan facilities are installed. In order to estimate the phosphorus overflow to the creeks following the operation of the new Metropolitan facilities, a percentage (30%) overflow commensurate with that which was assumed for BOD was considered.

If it is assumed that a maximum overflow condition results in a discharge to the creeks of 30% of the phosphorus tributary to the Metropolitan Plant, and if we assume a 10% reduction of phosphorus through the plant, then, (2,570 lbs. ÷ 0.90) (.30) = 850 lbs/day (385 kg/day) represents the maximum phosphorus discharge to the creeks.[10] Upon inspection of the individual data (not shown) comprising the average figures shown in Table 5-3, it was determined that the 850 lbs/day figure more accurately reflects a continuous discharge.

If 850 lbs. for Onondaga Creek and Harbor Brook are used in lieu of the figures shown in Table %-3, the adjusted total is 10,948 - 1,892 lbs/day or 9,056 lbs/day (4,100 kg/day). It is expected that the new treatment facilities will remove 6,280 lbs/day (2,850 kg/day) or approximately 70% of the phosphorus now being discharged under a maximum overflow condition. This is equivalent to an 85-90% removal within the new treatment plant. On the basis of the present surcharge conditions, the above removal represents (6,280/ 10,948) 58% of the total phosphorus discharged to the lake.

Following the operation of the new Metropolitan facilities the remaining phosphorus discharged to the lake, (9,056 - 6,280), 2,776 lbs/day represents a LRE of 1.34 mg/l as compared to the present input LRE of 4.4 mg/l. This concentration will be reduced by any precipitation or adsorption on the minerals formed in the lake. Thus the resultant concentration available to algae and other aquatic organisms will be something less than 1.34 mg/l. Hence the stability of such minerals as fluorapatite, hydroxyapatite and calcite, after the operation of the new Metropolitan facilities, will be significant. The design of the new Metropolitan facilities was investigated and it was concluded that all major chemical species affecting phosphate bearing minerals, with the exception of phosphorus, will be reduced by less than 4% of the total present input. The most significant soft metal is calcium in that it is the constituent common to all of the above minerals and is the single most important factor in

[10] 2,570 lbs. represents Metro Plant discharge shown in Table 5-3 minus Ley Creek T.P. discharge (not shown)

causing precipitation of these minerals through the hypolimnion of the lake. It was determined from the above reductions that the pertinent minerals will continue to precipitate in the lake waters. Presuming that the rate of precipitation of these minerals is dependent upon concentration gradients of the related chemicals, the reduction of phosphorus may significantly decrease the rate of formation of these minerals. Kinetic studies were not conducted to determine the latter effect.

Productivity of a group of 17 Wisconsin lakes suggest a concentration of 0.01 mg/l of inorganic phosphorus as a maximum value permissible without the danger of supporting undesirable growths. In order to reduce the LRE concentration within the lake to less than .01 mg/l, the total phosphorus input would have to be reduced to 16 lbs/day. However, the effect of this phosphorus level on algae growth in Onondaga Lake is not presently known.

Existing knowledge of the physiology of algae is far too inadequate to allow projections with respect to algae growth in Onondaga Lake. This task is further complicated by the unique characteristics of the lake, i.e. chloride concentrations. Reductions in CO_2 concentration and humic acid, both of which are the direct result of organic pollution, may very well be a significant factor in limiting nuisance algae growth.

The Onondaga Lake Monitoring Program now in progress will provide "baseline" data from which future projections for Onondaga Lake, as well as lakes in general, can be made.

SECTION 15 - SUMMARY

The following is a summary of results. Conclusions and Recommendations of this Report can be found in Sections 1 and 2 of this Report respectively.

Physical, chemical, biological and geochemical investigations were conducted to determine the trophic status of Onondaga Lake, as well as to study some basic dynamics of the lake itself. Engineering evaluations were made to determine the effect future pollution abatement facilities will have on the lake.

A Waste Discharge Survey was conducted to determine the major pollutional discharges. Greater than 85% of the total Biochemical Oxygen Demand (BOD), ammonia nitrogen and phosphorus can be accounted for by the discharges of Ley Creek, Onondaga Creek, Harbor Brook and the Metropolitan Sewage Treatment Plant. Nine Mile Creek discharged the major portions of calcium, chloride, sodium, iron and potassium in that order. A major steel manufacturer discharged major portions of chromium and nitrate. Onondaga Creek accounted for significant portions of most chemical species measured reflecting the combined sewer overflows it receives, and to some extent natural drainage.

Seismic studies were conducted to determine the subbottom sediment profile of the lake. Although these were largely unsuccessful, an up-to-date map of lake depths resulted, permitting new determinations of volume and lake residence times. Calculated annual residence times for the period 1963 to 1969 varied from 99 to 250 days. Water depths recorded in 1913 were compared to present data to determine that deposition equivalent to approximately 0.69 m (2.25 ft.) over the surface area of the lake has taken place since that date.

Thermal profiles were taken at preselected intervals over periods of a few hours to determine significant sources of thermal pollution and the degree to which thermal layers are affected by wind and other daily fluctuations. The most significant thermal inflow is from the cooling water of the soda ash manufacturing plant. The second and third most significant thermal discharges are from Nine Mile Creek and the Metropolitan Sewage Treatment Plant respectively. It was readily apparent from the results that chemical contributions to the density structure created abnormalities within the thermal profiles.

Onondaga Lake is an unusual lake with respect to its chemistry, chemical stratification and the stability of minerals in the lake. Statistical analyses performed on chlorides and the

major cations calcium sodium and magnesium, showed high correlation of sodium with chloride in the sediment enclosed waters of the lake and high correlation of calcium with chloride in the open waters of the lake. The latter relationship is primarily the result of the calcium-chloride discharged by a soda ash plant, whereas the former relationship is attributable to invasions of water derived from natural regional deposits of rock salt. Surface discharges account for greater than 90% of the chlorides in the lake. Chloride contributions from the lake bottom, although minor with respect to the stream inflows, do contribute slightly to the lake. The relatively slow rate of diffusion of chlorides from the bottom, under present conditions, suggests that the waters of the lake had a lower mineral content at one time (1810) than the present chemistry indicates.

Chloride concentrations appear to modify the standard thermal picture of density more than any other ion. This feature is most apparent during the autumnal circulation.

Although lake waters are vertically stratified throughout the major portion of the year, chemical data indicate good horizontal mixing throughout the same period. Measurements made under the Waste Discharge Survey show that the combined discharges of Nine Mile Creek and the "East Flume" represent 70.6% of the chlorides, 79.4% of the calcium and 61.1% of the sodium. Although Nine Mile Creek discharges into the lake approximately 2/3 of the distance from the southwest end, spatial differences for these three species are in all cases less than 2%. Predominant winds ranging from the west and northwest directions, encourage the distribution of Nine Mile Creek waters to the southern end. Variations of major ionic species with time, irrespective of depth, indicate that epilimnetic waters of the lake respond to runoff variations whereas hypolimnetic waters are not affected appreciably.

Calcium plays a significant role in the pH-alkalinity relationship. Due to the relatively high calcium concentrations in the lake, dissolution of calcium carbonate in the hypolimnetic waters, as is the case in many other lakes, does not take place. The production of CO_2 in the lower waters, resulting in the release of hydrogen ions through the disassociation of bicarbonate ion, may only slow the rate at which calcium-carbonate is precipitated.

Statistical routines such as multiple regression and correlation analyses were performed on the chemical data.

Biological studies were conducted to determine the genera and species of phytoplankton and zooplankton. These studies included a fish survey of Onondaga Lake. Whereas phytoplankton were monitored for the entire sampling period of the Study, zooplankton and fish studies were confined to 1969.

Approximately 100 species of phytoplankton were identified. The variety of species and the abundance of certain species of algae was impressive. The finding of a high diversity of species was unexpected in light of the lake's chemistry and the earlier reported observations. The dominant phytoplankters showed the expected succession for a shallow nutrient-rich lake: diatoms and flagellates in the spring, green algae, chlorococcales, in the early summer, blue-green algae later in the summer and, in association, flagellates and diatoms in the fall. The lake also supports a surprising number of rare species which appear occasionally in the collections. A rare species of the diatom Chaetoceros was found. Enteromorpha intestinalis, a common alga along most of the coasts of North America, occurs around the shores of the lake, sometimes abundantly. In general, the variation and total number of centric diatoms (Centrales) is intermediate between typical fresh-water environment and an oceanic condition.

Concentrations of principal nutrients such as phosphorus, nitrates and ammonia compounds were neither observed to be limiting nor inhibitory to algae growth in the lake. However, the elevated concentrations of chromium and copper may approach levels at which algal growth is inhibited.

In 1969, an algae "die-off" occurred in the lake waters at which time there was a marked decrease in biomass and a visible clearing of the lake waters. According to previous observations, this is an expected phenomenon for Onondaga Lake. Chlorella vulgaris was the only common phytoplankter at the time of "die-off" in 1969. Although there are some indications that high ammonia nitrogen and accompanying pH conditions might have caused, or contributed to, such a "die-off", the condition may also have reflected either a natural process or some less obvious environmental parameter.

Zooplankton studies suggested the possibility that both limiting and inhibitory events sometimes determined the density of populations of zooplankters. There was some indication that fish predation may have occasionally limited zooplankton densities. Zooplankton populations seem to have little or no effect in controlling the density of phytoplankton populations. In general, the lake supports a community of zooplankton typical for a saline lake at this latitude. Fish studies showed that the lake supports a very diverse fish fauna typical of many warm water lakes in central New York State. Sixteen species were identified and except for a large population of white perch, species' composition has not changed appreciably from that shown in surveys of the lake in 1927 and 1946.

Despite the unusual chemical and physical characteristics of Onondaga Lake, growth of most game and pan fish compared favorably with the published growth for fish in other waters

of the northeast. However, the horizontal and vertical distribution of fish in the lake is not uniform. Most fish were caught from the epilimnetic waters. Adult fish were found to be scarce in the southernmost portion of the lake and young fish were not found along the northwest shore, possibly reflecting the inflow of low quality water in the south end, and flows emanating from Nine Mile Creek respectively. Water quality in the littoral regions may also limit fish life.

Following taste studies conducted on the fish taken from Onondaga Lake, it was concluded that the fish were not objectionable.

Mineral-equilibria investigations determined that several minerals are stable in lake waters throughout the year. Minerals such as hydroxyapatite and fluorapatite, containing orthophosphate, were found to be stable throughout the entire period of sampling. Calcite was found to be stable throughout most of the sampling period with the exception of the middle and late winter periods when pH values were less than 7. The degree of over-saturation with respect to calcite was found to be a remarkably uniform function of pH. Other minerals such as hematite, cuprite and pyrolusite were found to be stable in the epilimnion only. The only sulfide bearing mineral found to be stable was pyrite, and only in the hypolimnion. With respect to silicate, kaolinite was found to be stable in nearly all samples.

Gas analyses performed on samples collected approximately one meter above the bottom of the lake in the south and north deeps showed nitrogen ranging from 23 to 50%, methane ranging from 47 to 80% and hydrogen sulfide in trace quantities. Carbon dioxide was not detected with the technique employed. Sulfide concentrations measured in the sediment enclosed waters were less than those observed in the deepest lake water suggesting that the high concentrations of sulfide in the hypolimnion are generated therein, i.e. through the action of sulfate reducing bacteria. High sulfide concentrations measured in the epilimnetic waters of the lake indicate the possibility of airborne sulfide particles precipitated in the lake. From the observation of negligible concentrations of dissolved sulfide within the reach of 6 to 9 meters, it can be concluded that no significant quantities of sulfide in the form of turbulent water are being transported upward across the thermocline.

Laboratory tests conducted on the sediments of the lake indicate that the expected maximum orthophosphorus contribution of sediments to the hypolimnion is equivalent to approximately 0.026 mg/l. The higher phosphorus concentrations observed in the hypolimnion indicate the sediment source and/or the precipitation of phosphate bearing minerals, and illustrate the confinement of these phosphates to the hypolimnion.

The sediments of Onondaga Lake are rich in carbonate minerals, primarily calcite. Tests conducted to determine the percentage of organic material present in the sediments yielded approximately 10% by weight. The sediments are relatively fine grained and in general contain little or no grit. Sediments appeared in three basic forms; namely, black, brown and grayish white.

Black sediments were ordinarily the first encountered in the lake bottom and had a petroliferous odor, most likely owing to the organic decomposition occurring at the sediment-water interface. Brown sediments occurred as an irregular mottled pattern with black sediments or as discrete layers of brown sediments within the column of black sediments. The brown sediments were identical to the black sediments in texture and mineralogy. This suggests that these sediments are somehow oxidized, possibly as a result of overturn during which time oxygen laden waters are brought into contact with the bottom sediments. Grayish white sediments were encountered frequently in the shallow, near-shore regions, especially in the northern basin of the lake, beneath a layer of black sediments. The thickness of black sediments was not penetrated in the deeper axial portions of the lake. The scarcity of sandy material in the lake was related to the absence of significant sources of sand in the lower reaches of streams, except perhaps in times of infrequent and heavy flooding.

Dating of sediments consisted of pollen and radio carbon analyses. Whereas the latter was largely unsuccessful, some indication of age of sediments was arrived at from pollen analyses in combination with historical accounts of the black tuploe (Pepperage) tree. The latter plant grew in the swamps of Onondaga Lake and its hollowed trunk was used to convey salt brine. Pollen from this plant was observed at the 180 cm level in the south deep sediments of the lake. Newspaper accounts indicate that the supply was depleted in the years 1875 to 1880. The absence of pepperage pollen above 180 cm may be related to the local absence of this plant.

Engineering considerations focused on dissolved oxygen, since it is the most widely used and accepted indicator for assessing the condition of receiving water, and phosphorus, since it has been widely accepted as the most readily controllable nutrient in efforts to limit the eutrophication of waters. This does not preclude the limiting effect on biota of other chemical species not so apparent at this time.

A calculation for the lake's assimilation capacity was developed The sources of BOD input considered in this calculation were: air pollution, benthic demand in lake BOD, i.e. algae, zooplankton, and waste discharges. It was determined from the County Air Pollution Survey that air pollutants can represent

as much as 646 kg/day (1,420 lbs/day) as volatile, settleable particulate matter on the surface of the lake. An approximation of the oxygen demand of the benthic deposits was made by measuring the total dissolved oxygen depleted from overlying waters of an undisturbed core sample. The ultimate oxygen demand that the benthic deposits represent, following simulated overturn conditions, was measured to be 100 lbs. An important factor in determining the BOD input - lake DO relationship is the influence of algae generated within the lake. On July 30, 1969, a "die-off" condition followed a period of intense photosynthetic activity. Following the "die-off", the DO conditions in the epilimnetic waters continued to decrease, reaching an apparent minimal condition at the end of September. A period of 10 days following this time was chosen as the period upon which the assimilation capacity calculation was based. On the basis of known BOD concentrations within the lake, the volume effectively stabilizing BOD inputs was determined. A reaeration rate (K_2) attributable to the related surface area was then calculated. The above K_2 value represents a minimum reaeration rate, with which conservative projections of DO concentrations in the lake, on the basis of reduced BOD inputs, were made.

Assuming a maximum storm water overflow condition, the present TOD_5 input was calculated to be 62,400 kg/day (137,540 lbs/day). This corresponded to a dissolved oxygen saturation approaching 0%. Based on reductions resulting from the new Metropolitan Sewage Treatment Facilities, the future TOD_5 input, assuming the same maximum overflow conditions as above, would be 19,700 kg/day (43,340 lbs/day) which corresponds to a 53% DO saturation value. New facilities will represent a 51% reduction of the total present TOD_5 input to the lake.

Following the installation of the new treatment facilities, significant TOD_5 discharges will result from Ley Creek and the storm water overflows, in that order. Discharges emanating from Ley Creek presently average approximately 6,060 kg/day (13,380 lbs/day) exclusive of the Ley Creek Treatment Plant. These discharges are most likely attributable to deposits in the creek bed and leaching and draining from the sanitary landfill located just east of the mouth of Ley Creek. Storm water overflows can result in TOD_5 discharges as high as 6,020 kg/day (13,300 lbs/day), occurring approximately 3% of the time. The above discharges have been included in the calculation of future DO concentrations in the lake.

On the basis of bacterial concentrations specified in the NYS Public Health Law, Section 12.05, concentrations measured in the deeps of Onondaga Lake fall well below the allowable limits for Class "B" waters. The latter are suitable for swimming and other recreational uses. Bacterial analyses performed by the Millipore Filter Technique showed mean *E. coli*

concentrations of 1200/100 ml in the hypolimnion of Station 1. Corresponding values for Station 2 were less than 50% of the above values.

On the basis of previous studies, it was determined that the majority of condensed phosphorus would convert to ortho-phosphate in a matter of days, owing to such factors as pH, temperature and the existence of phosphatase. Mineral-water equilibria investigations showed that Onondaga Lake is over-saturated with the phosphate minerals, hydroxyapatite and fluorapatite throughout the sampling period, and is over-saturated with calcite, except in the middle and late winter when pH's fall below 7. The lake was found to be under-saturated with respect to other orthophosphate minerals.

Present phosphorus discharges as P total 4,500 kg/day (presently 9,056 lbs/day). This includes a maximum overflow condition resulting in a discharge of 385 kg/day (850 lbs/day). The LRE of the present discharge is 4.4 mg/l as compared to a mean concentration measured in the lake of 2.75 mg/l. The inferred difference is attributable to either precipitation within the lake or mass removal from the lake. Based on reductions resulting from the new Metropolitan Sewage Treatment Plant Facilities, the present phosphorus input will be reduced by approximately 70% resulting in a net input of 2,776 lbs/day equivalent to a LRE of 1.34 mg/l. On the basis of the present relationship of LRE to actual concentrations in the lake, we can assume that the actual concentration in the lake will be something less than 1.35. Upon investigation of the effect of the new facilities on the removal of chemicals effecting the mineral stability of the lake, it was determined that the greatest reduction, with the exception of phosphates, will be for calcium, in the order of 4%. Thus we can conclude that minerals now forming in the lake will continue to form after the new facilities are installed, until phosphate concentrations become limiting.

Since the availability of CO_2 and humic acid within the lake, both of which are end products of organic decomposition, will be reduced substantially by the treatment facilities, they may represent a limiting factor in the growth of nuisance algae growth.

MERCURY

In the Spring of 1970 various State and Federal Authorities discovered substantial discharges of mercury to several lakes throughout the Country emanating from soda ash and chlorine manufacturing plants. The soda ash manufacturing plant, located on the western shore of Onondaga Lake, was found to be discharging in the order of 21 lbs/day. The New York State Department of Environmental Conservation reports that this discharge is presently less than 1 lb/day. However, there remains unanswered questions concerning the quantity of mercury deposited in Onondaga Lake, which is available for incorporation into the aquatic life cycle, and the mercury that is now present in the lake in the form of methyl mercury, e.g. as in fish.

In order to ascertain the concentration of mercury in lake waters, samples of the lake and major discharges to the lake will be collected and analyzed as part of the Onondaga Lake Monitoring Program (January 1970 - December 1970), and presented in the 1970 Report on Lake Monitoring. Core samples, collected during the baseline study (April 1968 to December 1969), will be analyzed during the Monitoring Program in order to determine the mercury quantities in the sediments that are available to the aquatic life cycle. In addition to these analyses, samples of fish as well as other aspects of Onondaga Lake are being analyzed for mercury by the New York State Department of Environmental Conservation.

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N. Y. State Department of Transportion, Waterways Maintenance

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GLOSSARY

assimilation capacity	--	quantity of oxygen available to satisfy oxygen demands
authigenic	--	adj., formed in place
biomass	--	the total amount of organic matter present in a lake per unit area or unit volume
"critical" period	--	as used in this Study - period of time in which minimal DO concentrations were observed following die-off
die-off	--	as used in this Study - sudden clearing of lake owing to disappearance of algae
dimictic	--	adj., pertaining to a lake undergoing two major periods of circulation per year
epilimnion	--	the upper layer of water in a lake being warmer and less dense than the lower waters. Defined as 0-9 m depth for Onondaga Lake
eutrophic	--	ajd., pertaining to waters rich in nutrients, well nourished
hypolimnion	--	lower waters of a lake. Defined as 12 m to bottom for Onondaga Lake
interstitial	--	adj., between or enclosed by

Lake Residence Equivalent (LRE)	--	as used in this Study - an equivalent concentration in the lake resulting from a corresponding input per unit time divided by an assumed detention or residence time of the lake
littoral	--	adj., pertaining to the shoreward region of a lake
meromictic	--	adj., pertaining to a lake having permanent stratification of water masses
mineral	--	a naturally occurring inorganic solid
mottling	--	irregular mixture of colors
oligotrophic	--	adj., pertaining to waters with low concentrations of nutrients
overturn	--	a circulation of mixing of lake waters owing to minimum water densities with attendant wind and inflow conditions; occurring during the spring and fall seasons
"p"	--	negative logarithm to the base 10; i.e. pH = negative logarithm to the base 10 of the activity of hydrogen ion concentration
petroliferous	--	adj., of or pertaining to petroleum
phytoplankton	--	plankton consisting of plant life
seiche	--	free oscillation of water within a lake

thermocline	--	the horizontal zone within a lake throughout which a maximum temperature gradient exists
TOD	--	ultimate carbonaceous and ultimate nitrogenous oxygen demand (as calculated from BOD_5 measurements) = 1.5 BOD_5 + (1.5) (1.28) BOD_5
TOD_5	--	BOD_5 + 1.28 BOD_5
trophic	--	adj., refers to the nutrient status of a lake
zooplankton	--	plankton consisting of animal life

APPENDIX A

DAILY ACCOUNTS OF THERMAL TRANSECTS

by

K. M. Stewart

for

14 May 1968

28 May 1968

12 July 1968

10 October 1968

15 October 1968

22 October 1968

30 October 1968

22 November 1968

3 December 1968

18 February 1969

7 March 1969

18 March 1969

14 May 1969

13 June 1969

22 August 1969

29 August 1969

4 December 1969

ACCOUNT OF THERMAL TRANSECTS

14 May 1968

On this date the isotherms were tilted slightly to the northwest corner of the lake under the influence of winds. There was a concentration of warm water in the southwestern end of the lake with a small bit of warm water in the extreme southeastern end of the lake, the latter probably from the local thermal inputs. In addition, in the deeper southern basin, there were two or three unusual lens of cool and warm water. These were probably thermal contributions from the subsurface Metropolitan sewage discharge.

28 May 1968

One longitudinal and one transverse transect were run on this date. The transverse run was made from the inlet of Nine Mile Creek across the lake to the Marina base. The isotherms of the transverse run indicate a lateral tilting of the thermocline. The temperature of Nine Mile Creek was considerably higher than any in the lake on this date, whereas later on 12 July (although complete transverse measurements were not made) the temperature of the creek was measured and found to be colder than that of the lake surface.

There are two apparent "lens" of water near the path of the transverse transect, the upper of which is cooler than the lower one. It may be speculated that these, in some way, are the results of the warmer but more dense discharge from Nine Mile Creek moving down the slopes of the lake, reaching an equilibrium level, and then moving out where a portion of some cooled entrained water was observed. However, the data for that date are inconclusive at this point.

The warmer upper waters at the northwest end of the lake may be the result of a slight piling up of warmer water from the modest southeast winds at the time of sampling and/or from some warmer water backing in the outlet from the Seneca River.

12 July 1968

The lake has taken on much heat since the previous transects. Many of the isotherms are rather uniform. There seems to be no general tilting of the body of water as noted before. Features of interest in this transect are the relatively warm water that appears to be coming in at the southeastern end

of the lake and the deeper warm and cold lens in the southern basin. As before, these warm and cold lens may reflect some thermal contributions and/or induced turbulence from the Syracuse Metropolitan Sewage Treatment Plant subsurface outfall (which extends out into the lake about 520 m from the southeastern shore). The warmer surface waters in the southeastern corner may reflect some thermal input from the soda ash manufacturing plant cooling water.

10 October 1968

The loss of heat from the lake since the last transect has modified the picture although an item of similarity is the warm water lens at about 10 meters in the southeast end of the lake. Another item of interest is the relatively cold water at the southeastern and northwestern end of the lake at about 6 and 8 meters respectively. The origin of the cooler water in the southeastern end may represent a relatively cool discharge from the Metropolitan Sewage Plant. The source of "cooler" water in the northwestern depths is less clear.

15 October 1968

A lens of relatively cool water extends through most of the lake. The surface waters are only slightly warmer until the northwestern area. Waters from the Seneca River may be backing into the lake to create this difference or there may be some "spilling" from the southeasterly winds.

22 October 1968

The temperature of the surface waters in the southeastern end may reflect a discharge of the soda ash manufacturer and/or Onondaga Creek. One characteristic of this transect is the more rapid cooling of the upper waters than the lower waters. This feature is even more obvious in later transects. On this particular date, the cold water lens of 12 days earlier has essentially disappeared but appears to be replaced, at a slightly lower level, by a relatively warm water lens at depths of about 8 to 11 meters. There was a slight tilting of isotherms at this time also probably associated with modest winds in the direction of the longitudinal axis.

30 October 1968

As evidenced by this transect, the lake has continued to lose heat (as we might expect) during partial autumnal mixing. The surface waters are slightly cooler with the area of warmest

water appearing as a warm water lens in the middle of most of the length of the lake. From these fall transects it is becoming apparent that the lake is not following a "normal" type of autumnal circulation. In the normal situation the lake cools gradually from the surface, erodes away the thermocline and other areas of density differences, and then continues to cool as a body with only minute differences of temperature from top to bottom until shortly before the surface freezes. In the case of Onondaga Lake, however, there is a density difference exceeding that which is normally created by thermal differences. Therefore, there must be some chemical stratification which is influencing the thermal pattern observed

On 30 October 1969, cold water was entering the southeastern end of the lake as indicated by the 9, 10, 11 and 12° C isotherms. This probably reflects cold water from some of the streams more than any other contribution. It would be expected that the streams are cooling more rapidly than the body of the lake owing to their smaller heat budget.

22 November 1968

This particular transect shows, even more clearly than the previous two or three transects, the influence of the chemical gradient on the thermal profile of the lake. The coldest water of about 6° C is at the top of the lake and the warmest water of about 10° C is at the bottom of the lake. Thermally, this situation is hydrostatically unstable. The reason the lake can hold this "apparent" instability is a function of an increased density of the lower waters owing to a slight chemical gradient. Thus, the thermal differences are countered and the lake cools but does so inversely. The slight tilting of the isotherms probably reflects the effects of the resultant winds on the lake.

3 December 1968

The lake is continuing to lose heat at all levels but the thermal inversion remains. There are three areas of relatively cool water in the upper regions of the lake, particularly in the northwestern basin. There are also areas of cooler water at the saddle between the north and south deeps. The origin of the latter cooler water is speculative but may reflect some cool water running down the slopes of the lake. Another item of interest is the pronounced warm water at the surface in the southeastern end of the lake. This most probably is the result of the discharge from the soda ash manufacturer extending out into the lake.

Tributary streams in the southeastern end of the lake would be discharging cold water at this time of the year relative to the heated discharge from the soda ash manufacturer. Furthermore, it is not likely that this warm water is from the Syracuse Metropolitan Sewage Plant because most of the discharge of the latter would exit at about 6.1 meters and there is no evidence, from the distribution of isotherms, that warm water is rising.

18 February 1969

The thermal measurements on this date were incomplete owing to inadequate facilities for sampling from the ice to open water when the transect was run. The transect and others taken during winter when the lake was partially[1] ice covered, were assisted by the use of a "Go Anywhere Vehicle" (GAV), a small six-wheeled vehicle which can travel over ice and snow. The closed body of the vehicle and its six rubber tires provide flotation in the event the vehicle and its occupants break through the ice. The open water was sampled from a boat.

The isotherms in this transect are fairly uniform. There is a slight tendency for the isotherms to "climb the slopes" as the mud usually has a higher temperature than the water immediately over it. The southern basin has two lens of relatively warm water at about four meters of depth. Additional thermal profiles toward the southeastern end of the lake might have provided more clues as to the source of warm water lens.

7 March 1969

The distribution of isotherms in this transect has changed markedly since 18 February 1969, and is more complex. A plot of the isotherms suggests a flow of warm water down the slopes of the southeast end of the lake to about five or six meters

[1] The lake is rarely completely frozen as the thermal discharge of 80 MGD from the soda ash manufacturer creates an open area, the size of which fluctuates with the severity and duration of cold spells. Note, it is also likely that the open water created by this thermal pollution causes the lake ice to break up at an earlier date than otherwise expected.

before spreading out. This suggests water descending until it reaches a level of an equilibrium density, after which it fans out into the lake. The remaining isotherms are complex and illustrate several warm and cool lens or cells of water. The tilting of the isotherms in this case must be assumed to be a function of density differences and not a result of winds, as we might expect when the lake is free of ice. The relatively cool water below the warm thermal input at the southeast end of the lake, and the cool water which is at about the same depth or less in the northwestern basin, represents a departure from a "normal" winter profile for lakes. This may also indicate some slight chemical additions, possibly from both the surface and subsurface discharge of the Metropolitan Sewage Plant.

18 March 1969

The lake still retains a layer of ice which covers a portion of its surface. In the open area of the lake, the warm water at the surface extends close to the ice. In addition, the warm water extends for some distance beneath the ice towards the northwestern end. It is rather surprising that such relatively warm water and ice can co-exist without a rapid disappearance of the ice. The relatively sharp thermal gradients imply little vertical mixing in those portions of the lake.

The ice, immediately at the frozen, open water interface was of poor quality, but upon traveling about 100 meters onto the ice, it was possible to stand in some spots. Further distance from the interface increased the safety.

Immediately below the warm layers of water the temperature drops rapidly, is relatively cool in the middle depths of the lake and gradually increases as the bottom is approached. One exception to this occurs in the south deep. Between 18 and 20 meters there is an unexpected decrease of water temperature above the mud. This feature persists through several stations.

Noteworthy also is the relatively high temperature between the surface anf two meters in the extreme southeast end of the lake. The latter thermal increase is most likely a function of the surface discharge from the soda ash manufacturer.

14 May 1969

Some warm water is entering the southeastern corner of the lake near the surface. This water also appears to be a consequence of the thermal discharge from the soda ash manufacturer. The

overall picture of isotherm distribution presents a fairly stable condition, however, there is some tilting of the isotherms toward the southeast as indicated by upwelling in the northwestern area.

13 June 1969

The distribution of isotherms suggests a rather uniform stratification. As in some of the previous transects, there are some areas of thermal anomalies present in the lake, specifically across the middle area of the lake at about 4 meters in depth. These anomalies may reflect, in part, the subsurface discharge from the Metropolitan Sewage Treatment Plant.

22 August 1969

Another "cell" or lens of water near mid-lake indicates a slight thermal anomaly on this date also. The depth of the "cell" corresponds to the depth of the subsurface discharge of the Metropolitan Sewage Treatment Plant, but the location of the "cell" makes it appear that the discharge from the Nine Mile Creek may have played the role in its formation. The general accumulation of warmer waters in the southeast portion of Onondaga Lake may reflect slight westerly winds and thermal contribution from industrial discharges.

29 August 1969

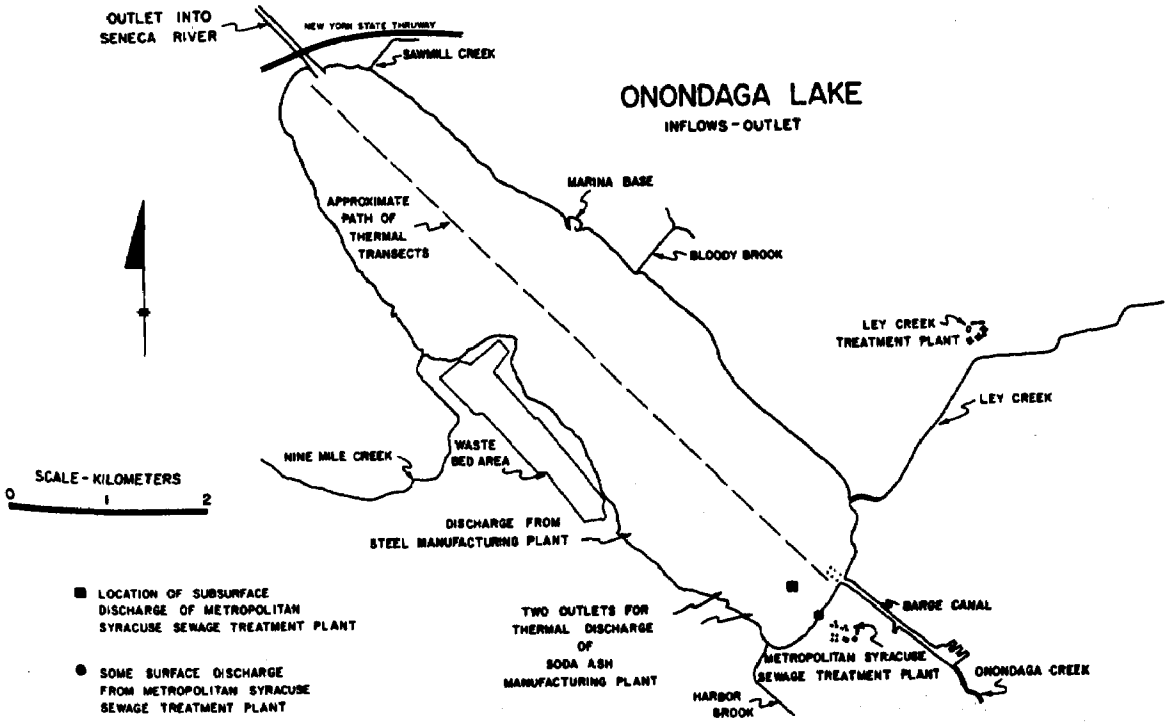
By now the cooler air temperatures, reduced solar radiation of the late summer and winds have caused more mixing of the upper waters than seen in previous transects. In addition, there is a stronger gradient of temperatures at mid-depths, as indicated by close spacing of isotherms. The general impression this transect gives is much more typical of lakes

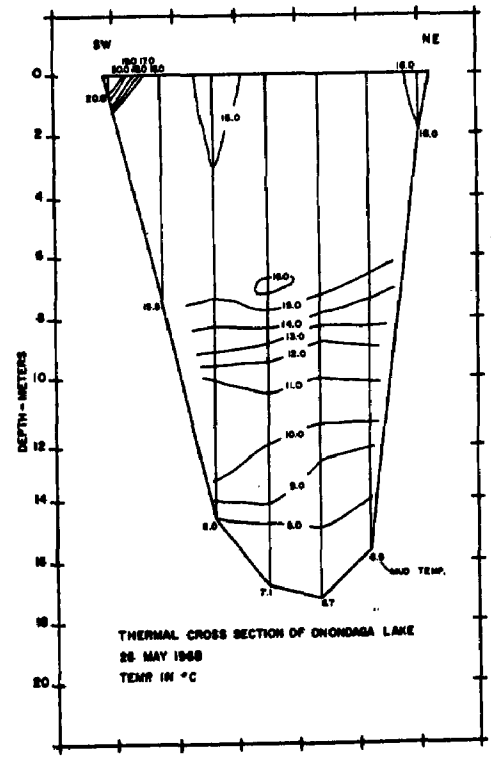
with less salinity. No pronounced thermal discharges are apparent from the temperatures measured on this particular date.

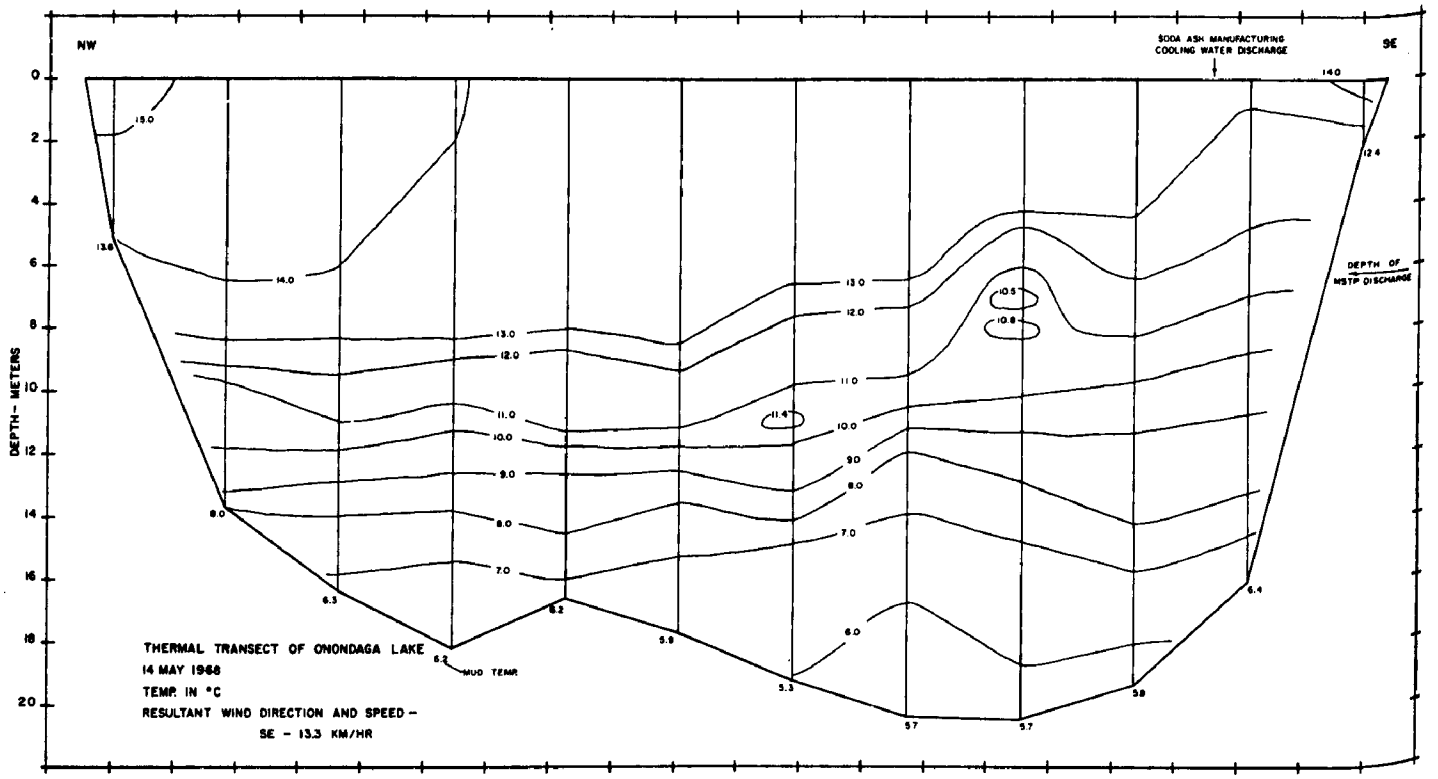
4 December 1969

This transect, run approximately one year after the transect of 3 December 1968, illustrates some of the same features as the latter. The thermal inversion is present again. The isotherms for both years are irregular but this time are extremely uneven owing to the strong winds on the latter date.

There is a cool layer of water coming in at the surface of the southeast end of the lake. This layer, although cooler, is less dense than the lake water and therefore may reflect some discharge from one or all of the three streams in the southeast end of the lake. There is no relatively hot effluent apparent on this date from the cooling water of the soda ash manufacturing plant. One feature difficult to explain is the relatively cold water "pocket" in the northwest basin. Whether this is some reflection of a cooled and more dense discharge from Nine Mile Creek, a possible intrusion of water from the outlet of the lake which has backed in and flowed down the slope, or some other source is only conjecture at this time.


OUTLET INTO SENECA RIVER
NEW YORK STATE THRUWAY
SAWMILL CREEK
ONONDAGA LAKE
INFLOWS - OUTLET
MARINA BASE
APPROXIMATE PATH OF THERMAL TRANSECTS
BLOODY BROOK
LEY CREEK TREATMENT PLANT
LEY CREEK
NINE MILE CREEK
WASTE BED AREA
SCALE - KILOMETERS
0 1 2
DISCHARGE FROM STEEL MANUFACTURING PLANT
LOCATION OF SUBSURFACE DISCHARGE OF METROPOLITAN SYRACUSE SEWAGE TREATMENT PLANT
SOME SURFACE DISCHARGE FROM METROPOLITAN SYRACUSE SEWAGE TREATMENT PLANT
TWO OUTLETS FOR THERMAL DISCHARGE OF SODA ASH MANUFACTURING PLANT
BARGE CANAL
METROPOLITAN SYRACUSE SEWAGE TREATMENT PLANT
ONONDAGA CREEK
HARBOR BROOK


SW
NE
DEPTH - METERS
0
2
4
6
8
10
12
14
16
18
20
THERMAL CROSS SECTION OF ONONDAGA LAKE
26 MAY 1968
TEMP IN °C


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
THERMAL TRANSECT OF ONONDAGA LAKE
14 MAY 1968
TEMP. IN °C
RESULTANT WIND DIRECTION AND SPEED -
SE - 13.3 KM/HR
MUD TEMP

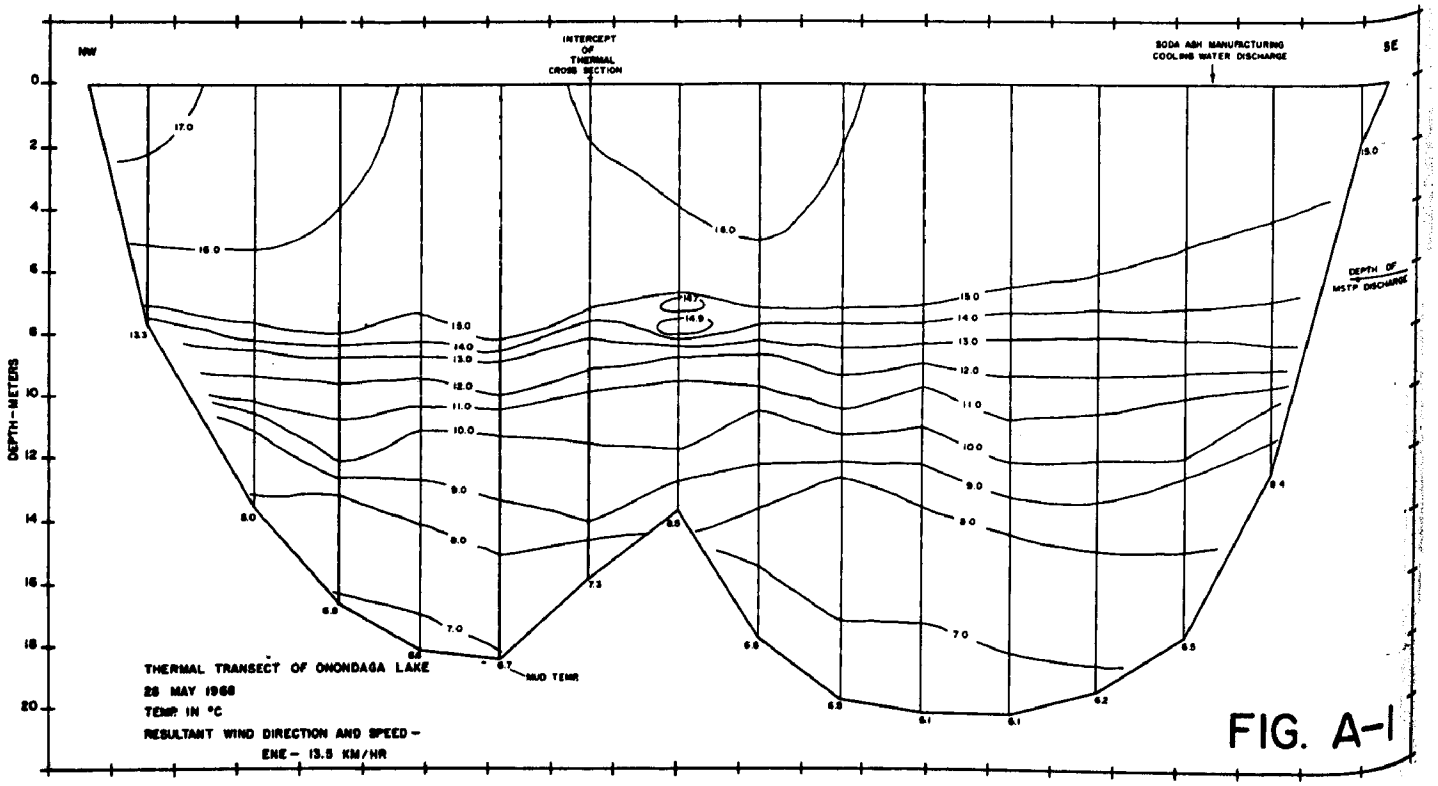
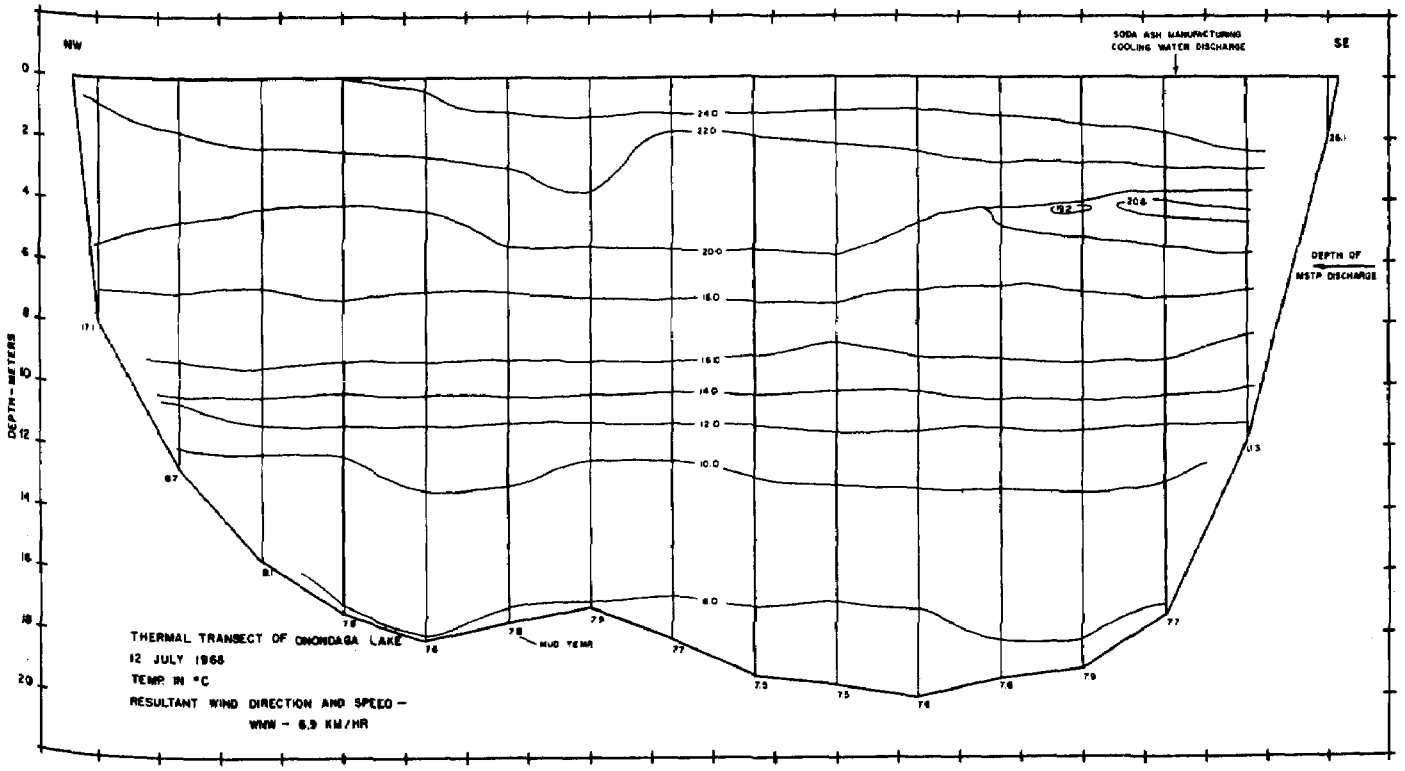
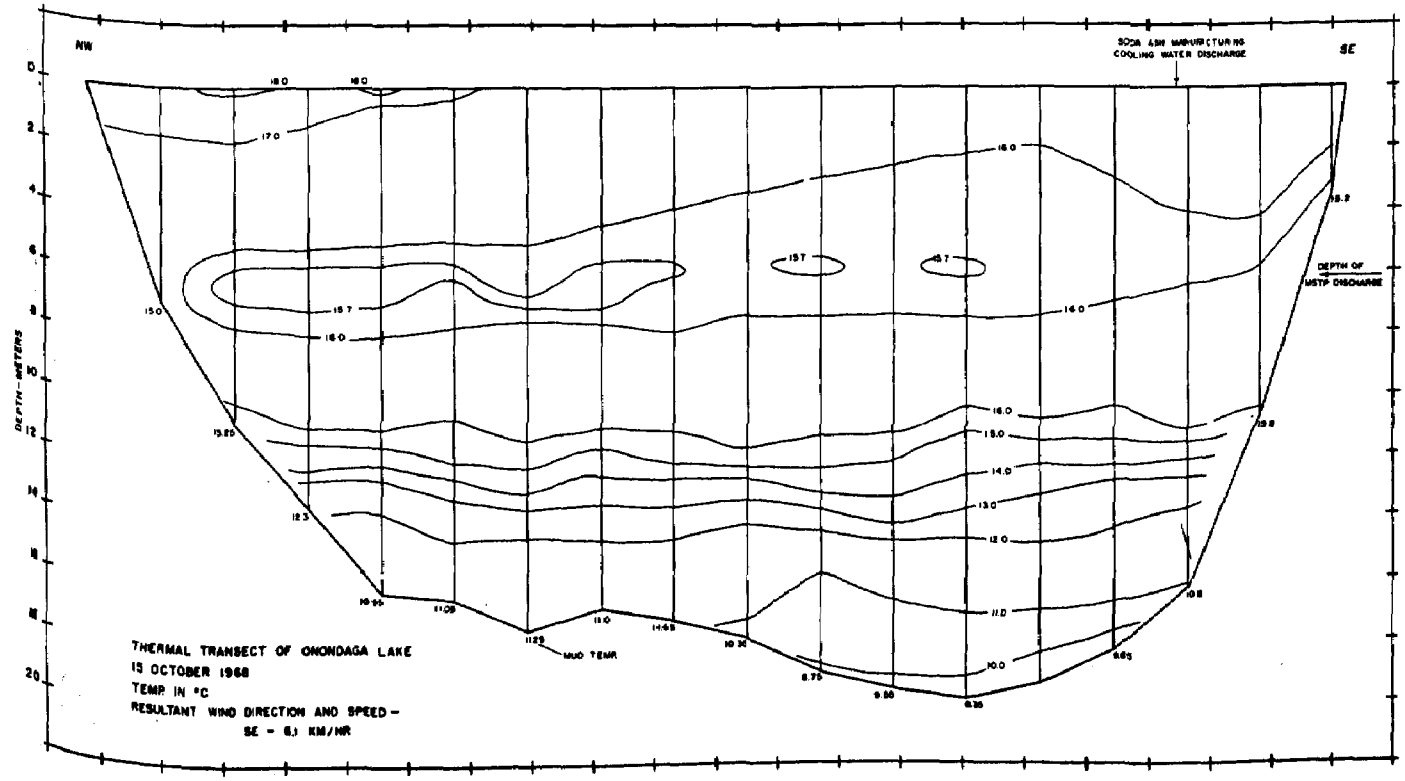
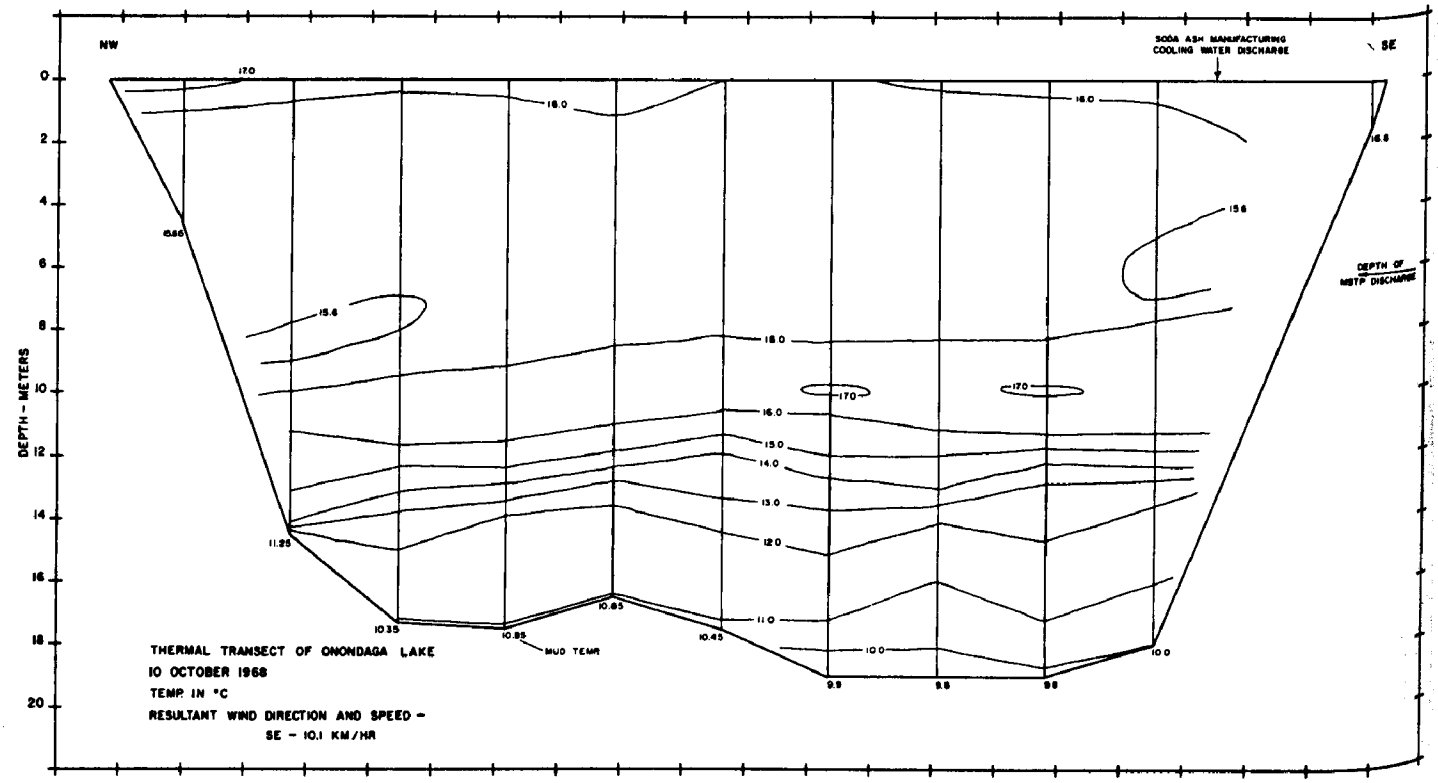

NW
SE
INTERCEPT
OF
THERMAL
CROSS SECTION
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
THERMAL TRANSECT OF ONONDAGA LAKE
28 MAY 1968
TEMP. IN °C
RESULTANT WIND DIRECTION AND SPEED -
ENE - 13.5 KM/HR
MUD TEMP

FIG. A-1


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
MUD TEMP
THERMAL TRANSECT OF ONONDAGA LAKE
12 JULY 1968
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
WNW - 6.9 KM/HR


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
MUD TEMP
THERMAL TRANSECT OF ONONDAGA LAKE
15 OCTOBER 1968
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
SE - 6.1 KM/HR


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
THERMAL TRANSECT OF ONONDAGA LAKE
10 OCTOBER 1968
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
SE - 10.1 KM/HR
MUD TEMP

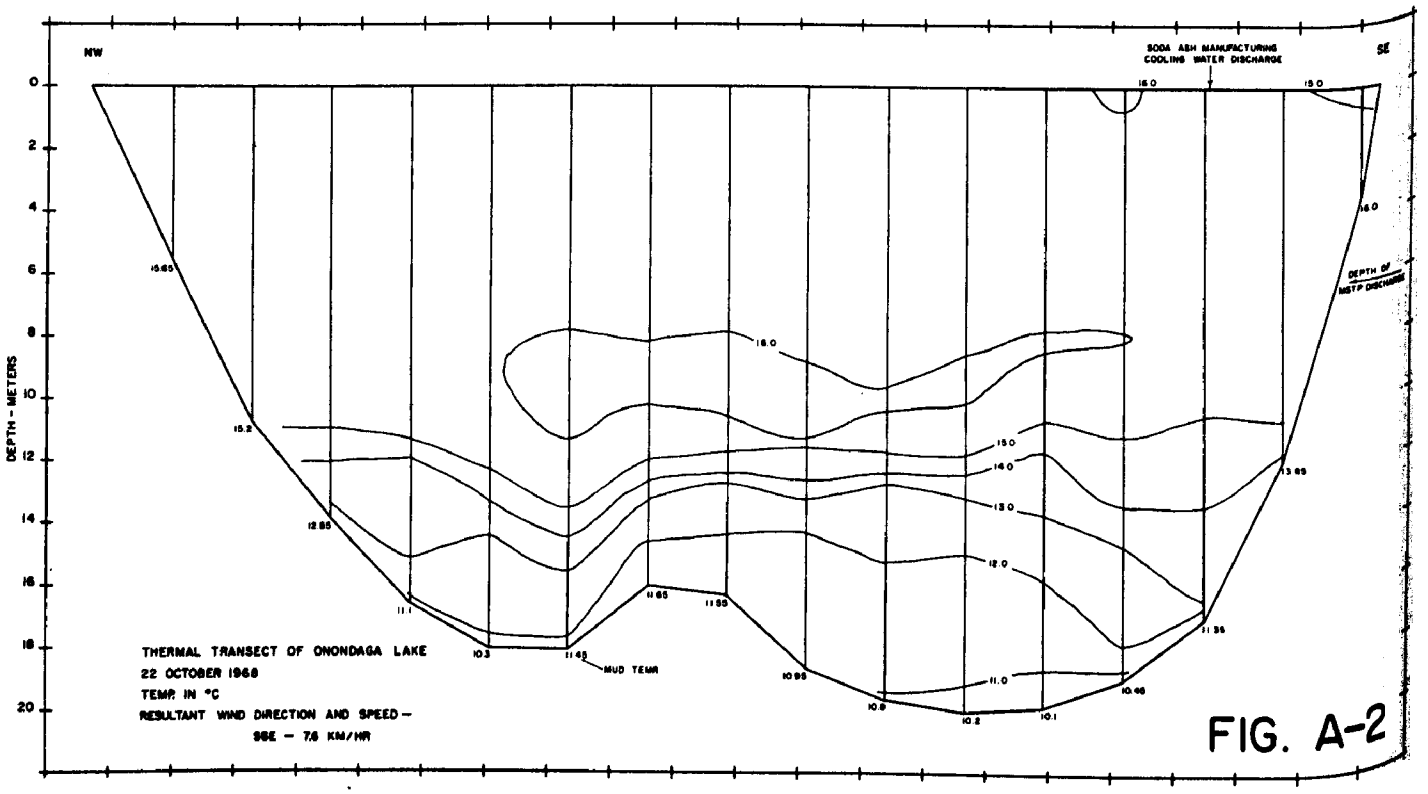
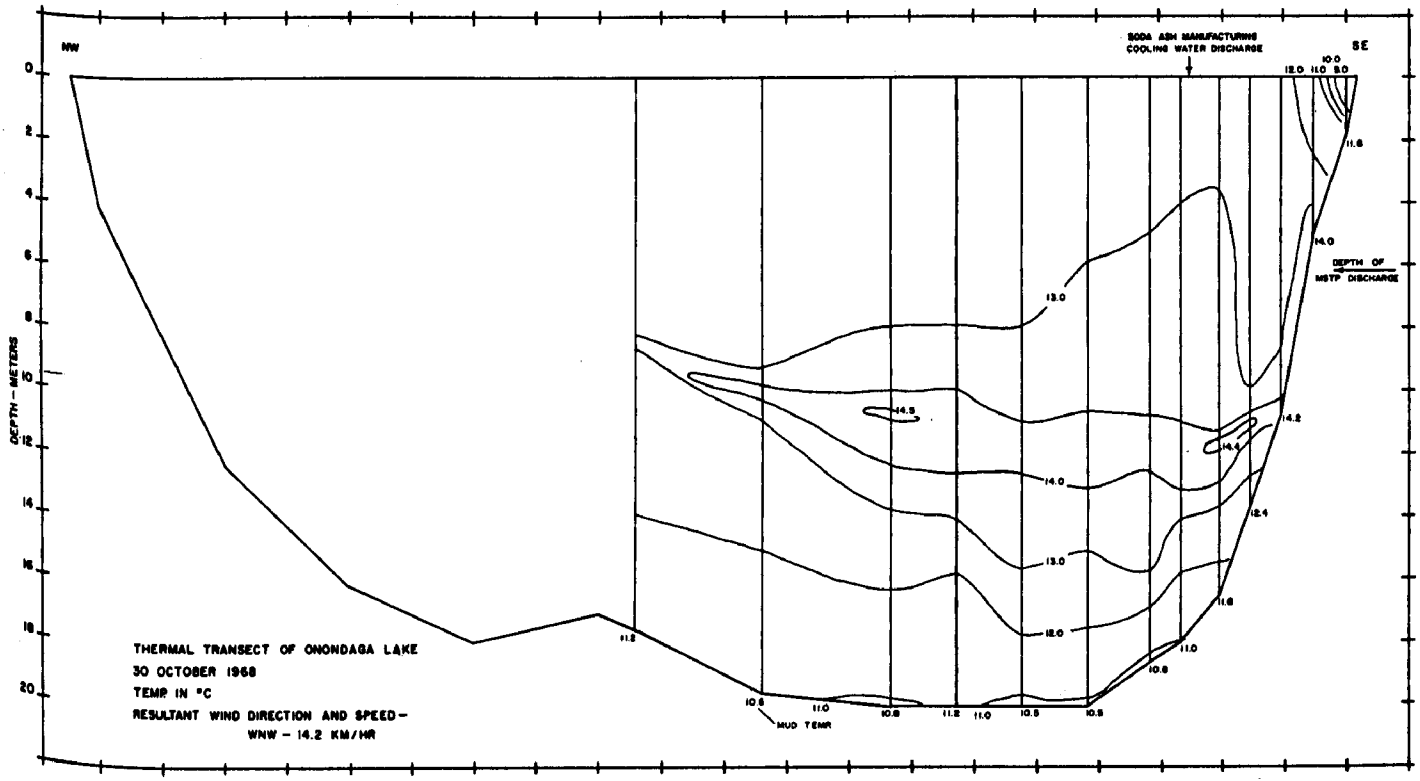
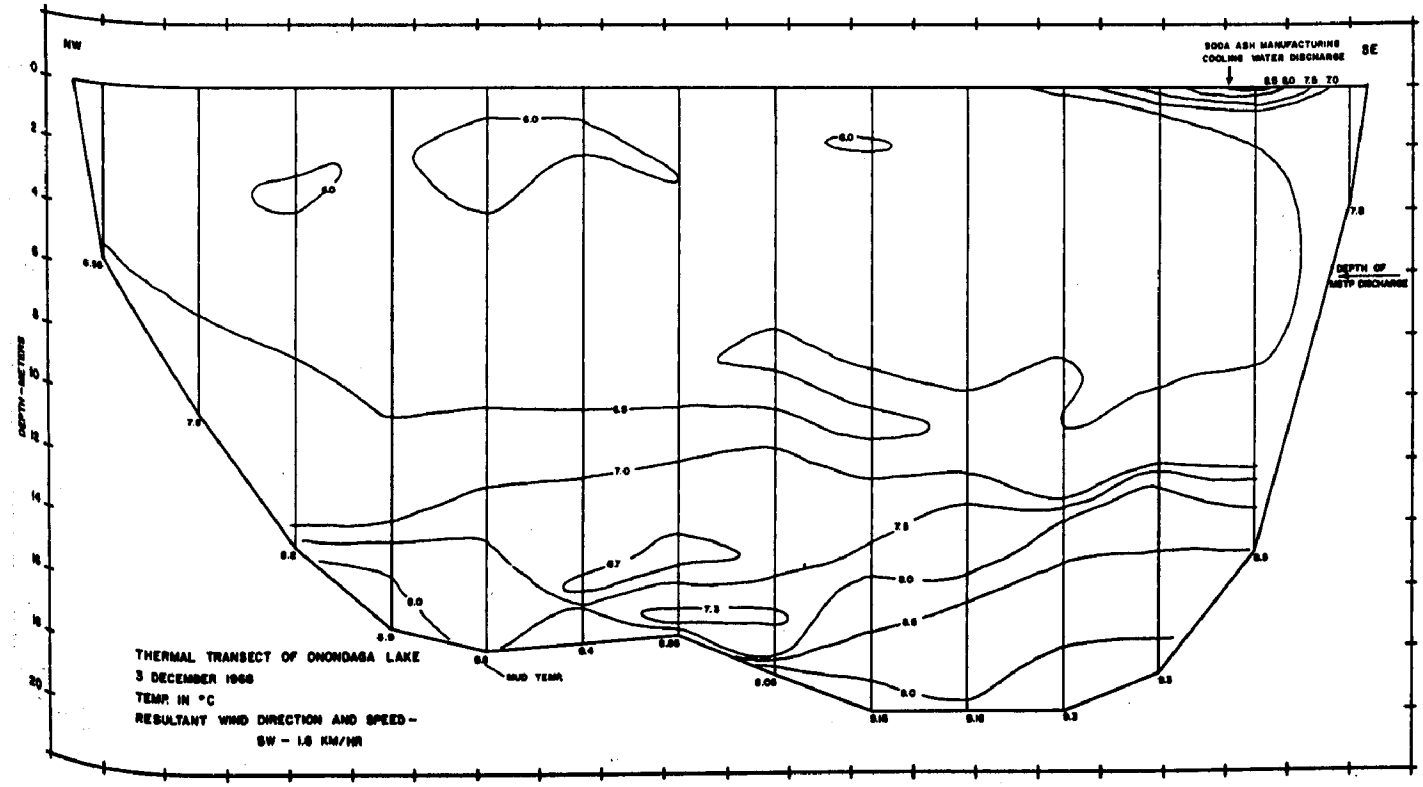
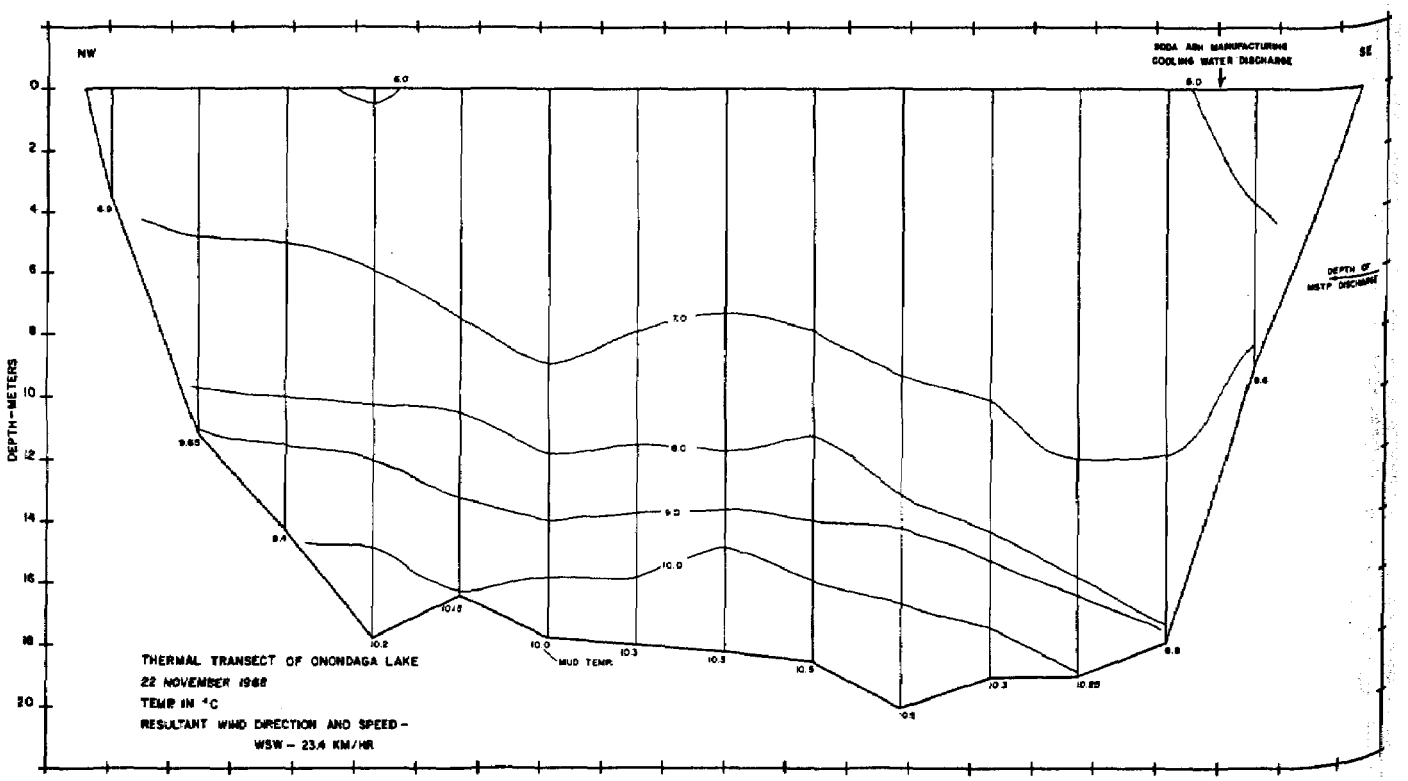

NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
THERMAL TRANSECT OF ONONDAGA LAKE
22 OCTOBER 1968
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
SSE - 7.6 KM/HR
MUD TEMP

FIG. A-2


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
MUD TEMP
THERMAL TRANSECT OF ONONDAGA LAKE
30 OCTOBER 1968
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
WNW - 14.2 KM/HR


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
MUD TEMP
THERMAL TRANSECT OF ONONDAGA LAKE
3 DECEMBER 1968
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
SW - 1.8 KM/HR


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
THERMAL TRANSECT OF ONONDAGA LAKE
22 NOVEMBER 1968
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
WSW - 23.4 KM/HR
MUD TEMP.

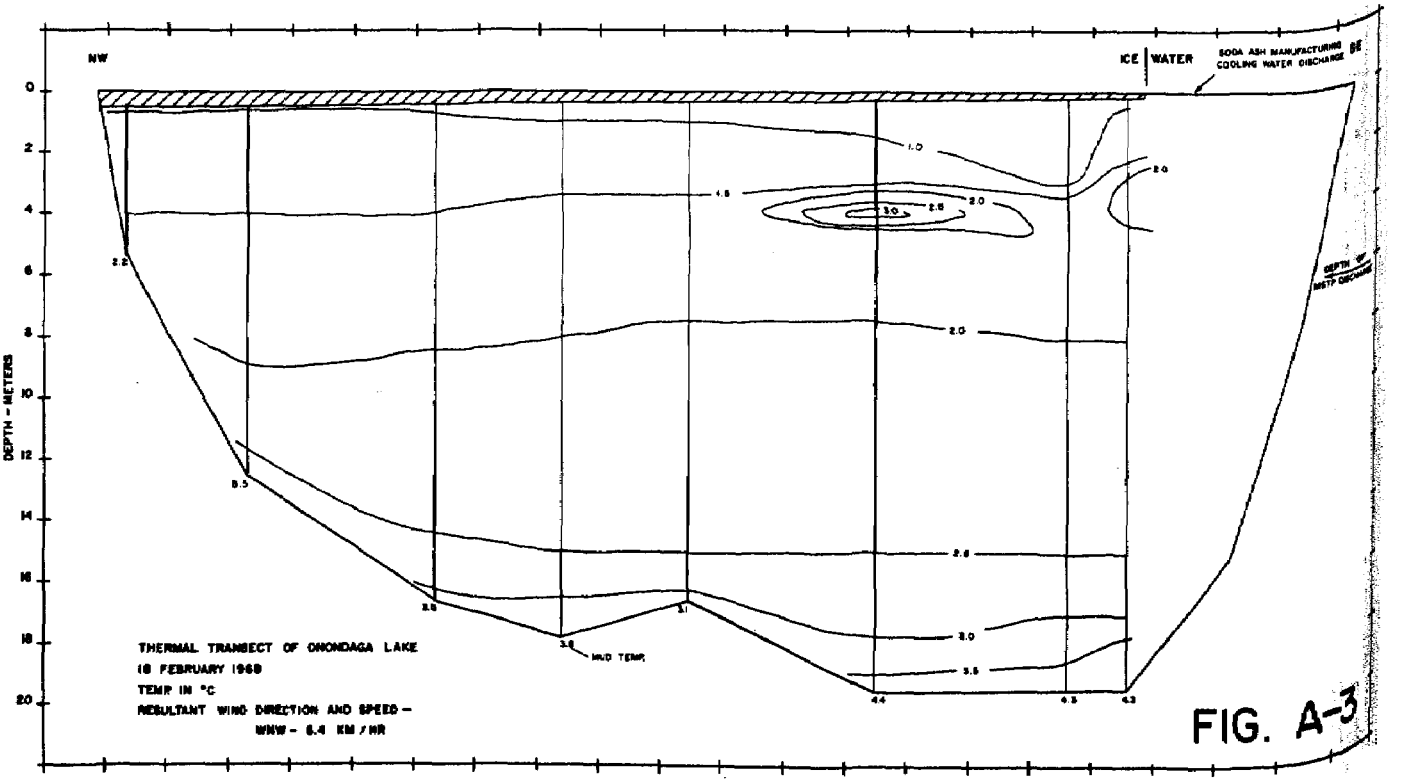
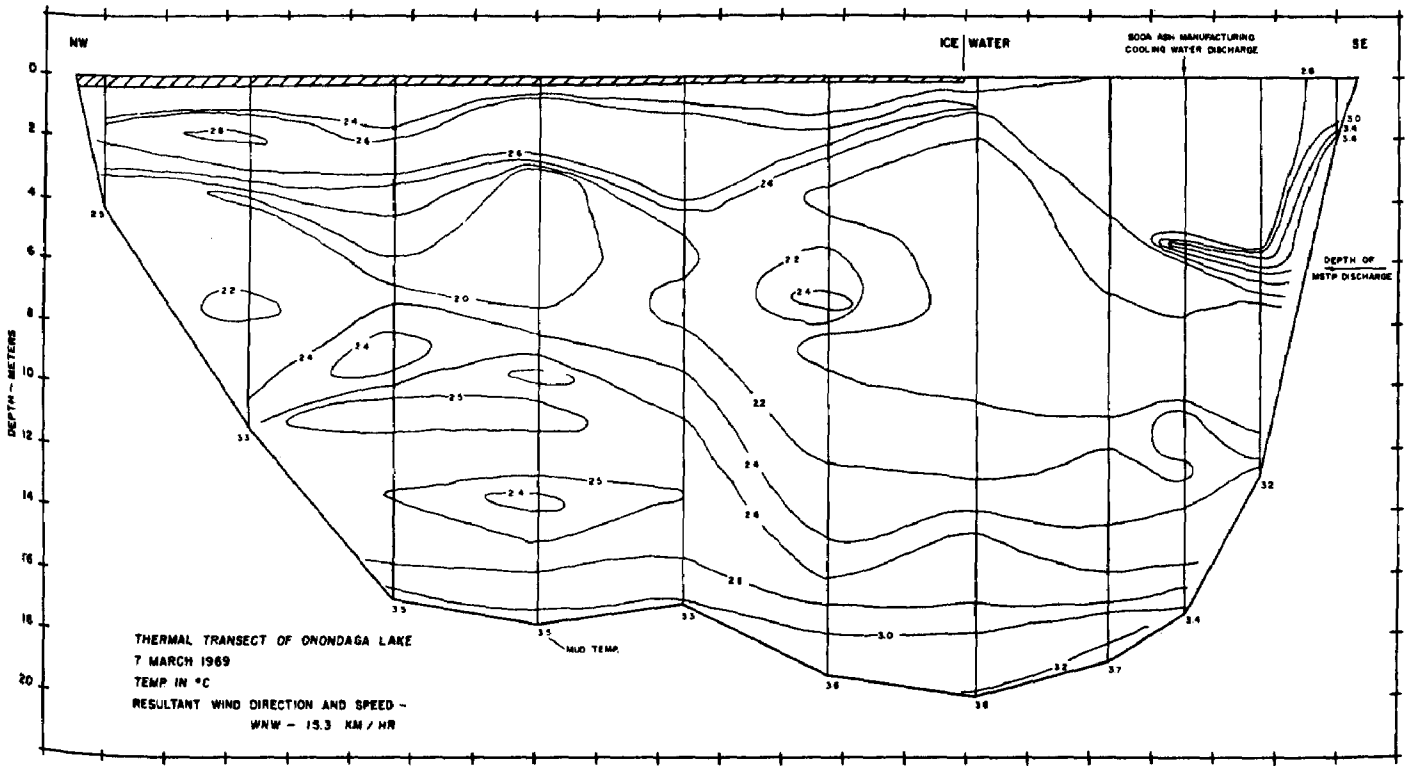
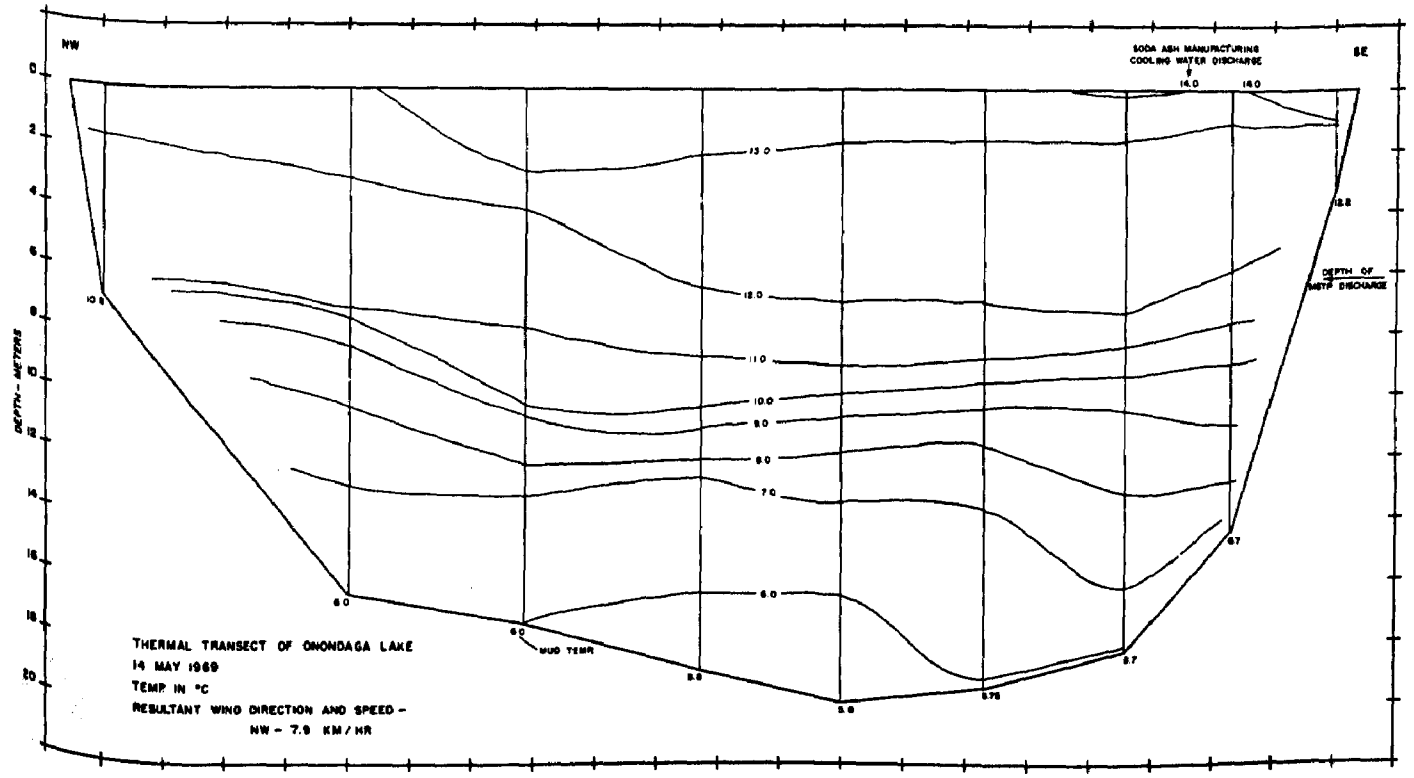
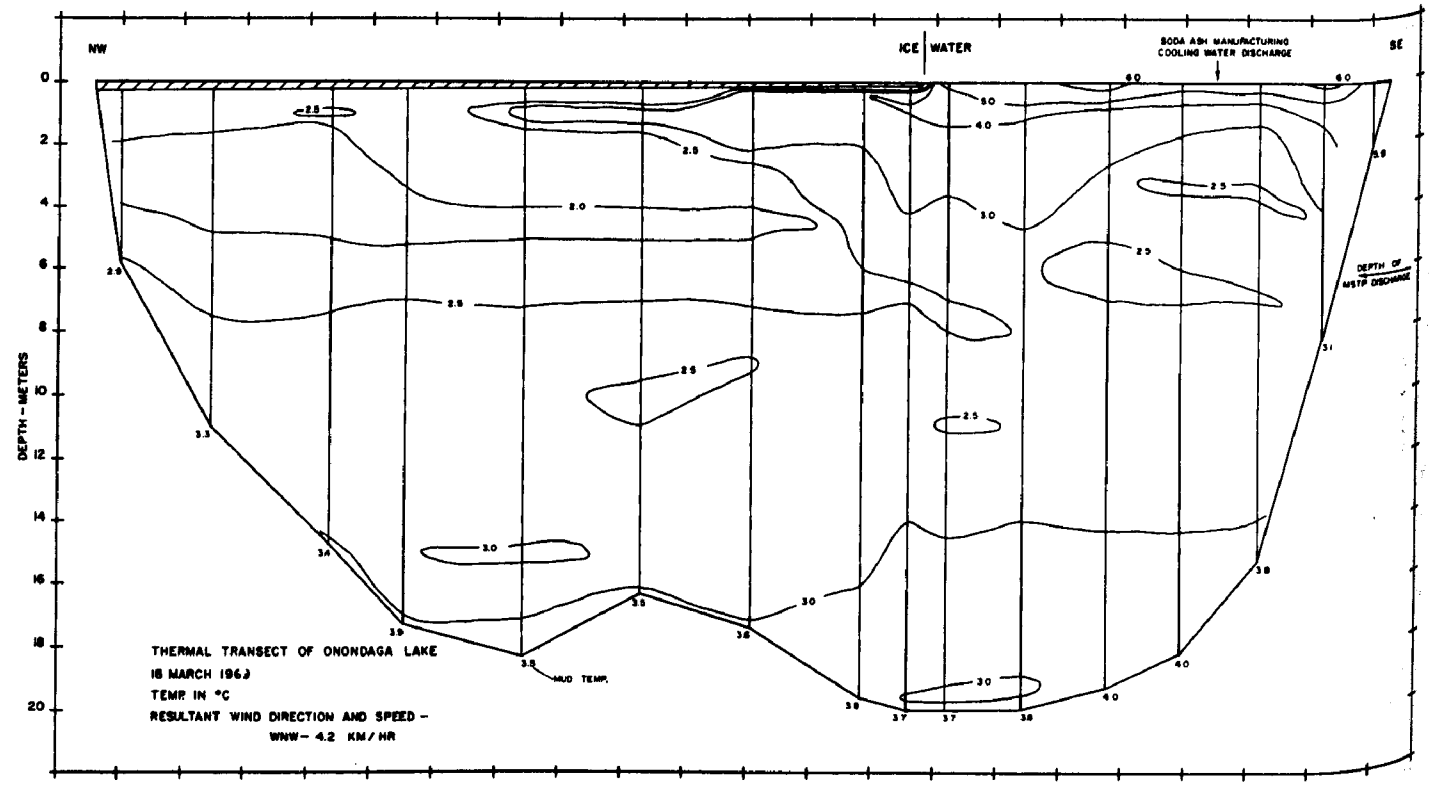

NW
SE
ICE
WATER
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH OF
MSTP DISCHARGE
DEPTH - METERS
THERMAL TRANSECT OF ONONDAGA LAKE
18 FEBRUARY 1969
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
WNW - 8.4 KM / HR
MUD TEMP.

FIG. A-3


NW
ICE | WATER
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
SE
DEPTH - METERS
DEPTH OF MSTP DISCHARGE
MUD TEMP.
THERMAL TRANSECT OF ONONDAGA LAKE
7 MARCH 1969
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
WNW - 15.3 KM / HR


NW
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
SE
DEPTH - METERS
DEPTH OF MSTP DISCHARGE
MUD TEMP.
THERMAL TRANSECT OF ONONDAGA LAKE
14 MAY 1969
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
NW - 7.9 KM / HR


NW
ICE
WATER
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
SE
DEPTH - METERS
DEPTH OF MSTP DISCHARGE
MUD TEMP.
THERMAL TRANSECT OF ONONDAGA LAKE
16 MARCH 1969
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
WNW - 4.2 KM/HR

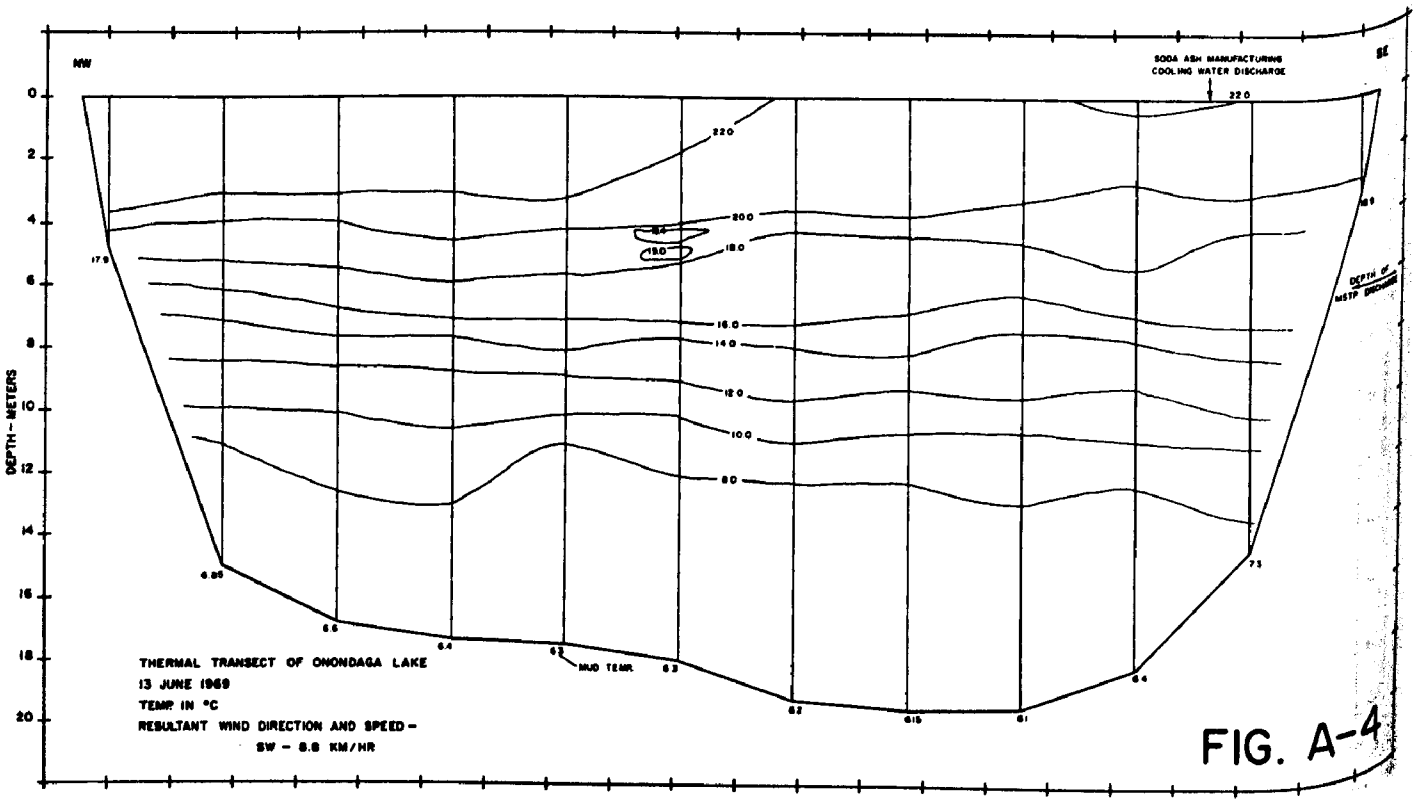
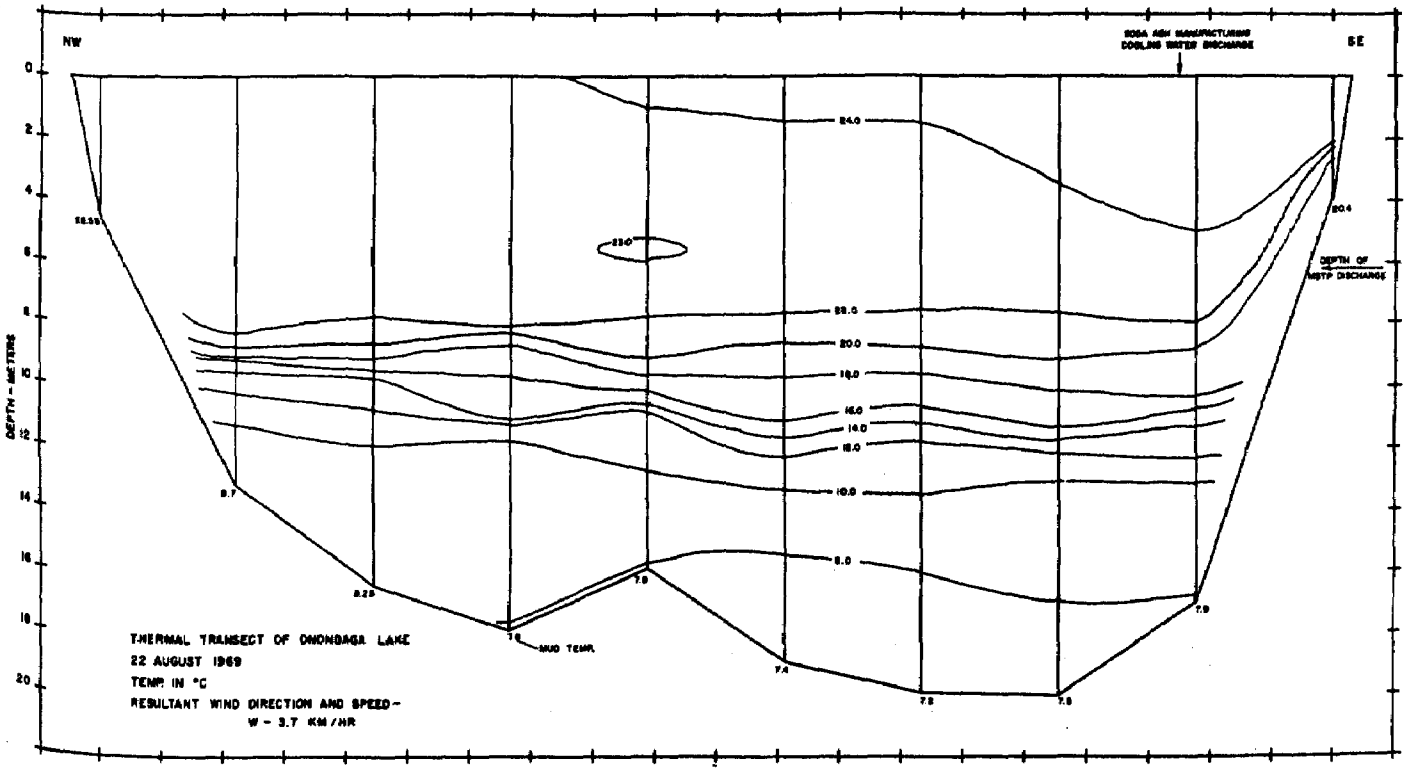
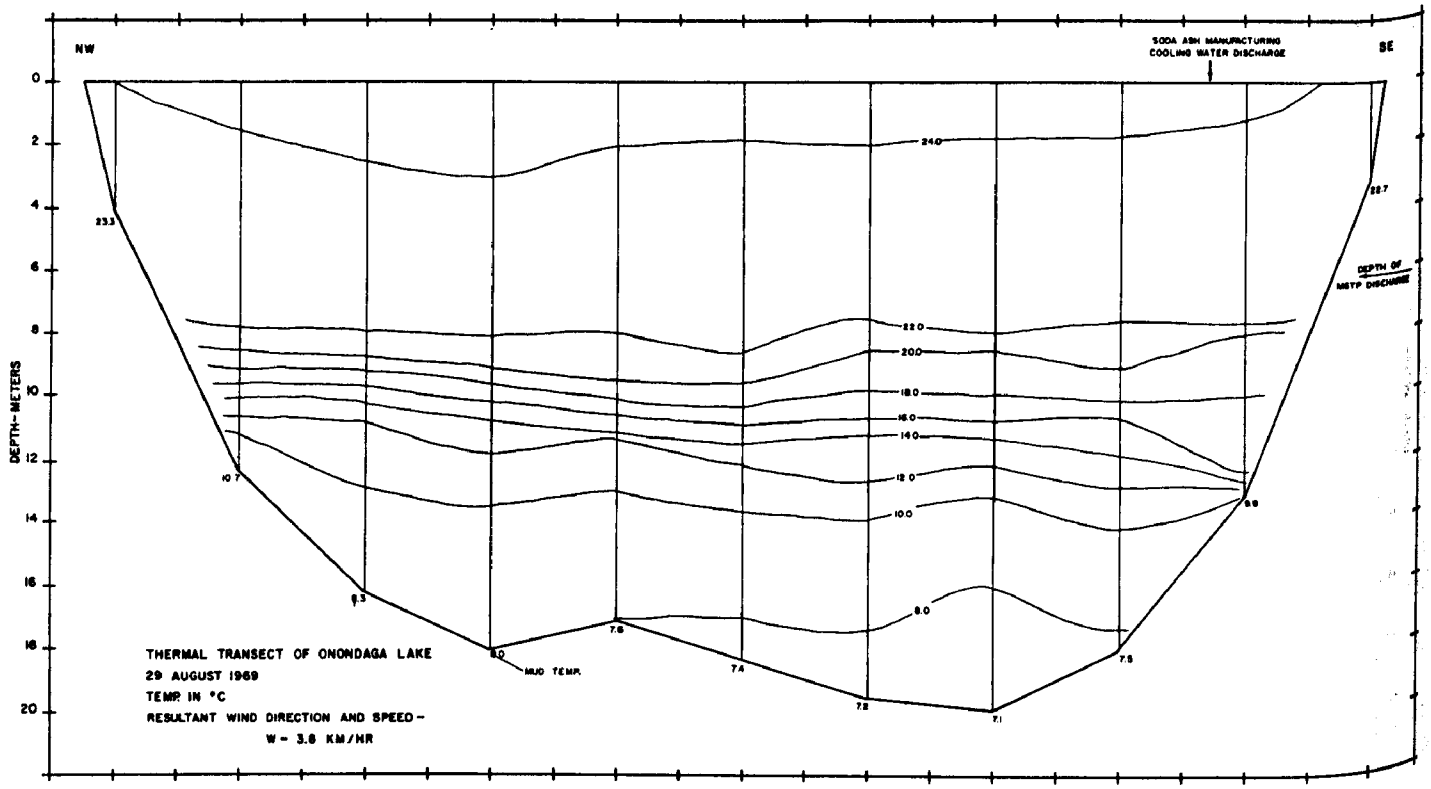

NW
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
SE
DEPTH - METERS
DEPTH OF MSTP DISCHARGE
MUD TEMP.
THERMAL TRANSECT OF ONONDAGA LAKE
13 JUNE 1969
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
SW - 8.8 KM/HR

FIG. A-4


NW
SE
SOLVAY ASH MANUFACTURING COOLING WATER DISCHARGE
DEPTH OF WWTP DISCHARGE
DEPTH - METERS
24.0
23.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
20.4
9.7
8.25
7.9
7.6
MUD TEMP.
7.4
7.8
7.8
7.9
THERMAL TRANSECT OF ONONDAGA LAKE
22 AUGUST 1969
TEMP IN °C
RESULTANT WIND DIRECTION AND SPEED -
W - 3.7 KM/HR


NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH - METERS
DEPTH OF MSTP DISCHARGE
24.0
23.3
22.7
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
10.7
8.3
8.0
MUD TEMP.
7.6
7.4
7.2
7.1
7.8
8.9
THERMAL TRANSECT OF ONONDAGA LAKE
29 AUGUST 1969
TEMP. IN °C
RESULTANT WIND DIRECTION AND SPEED -
W - 3.8 KM/HR

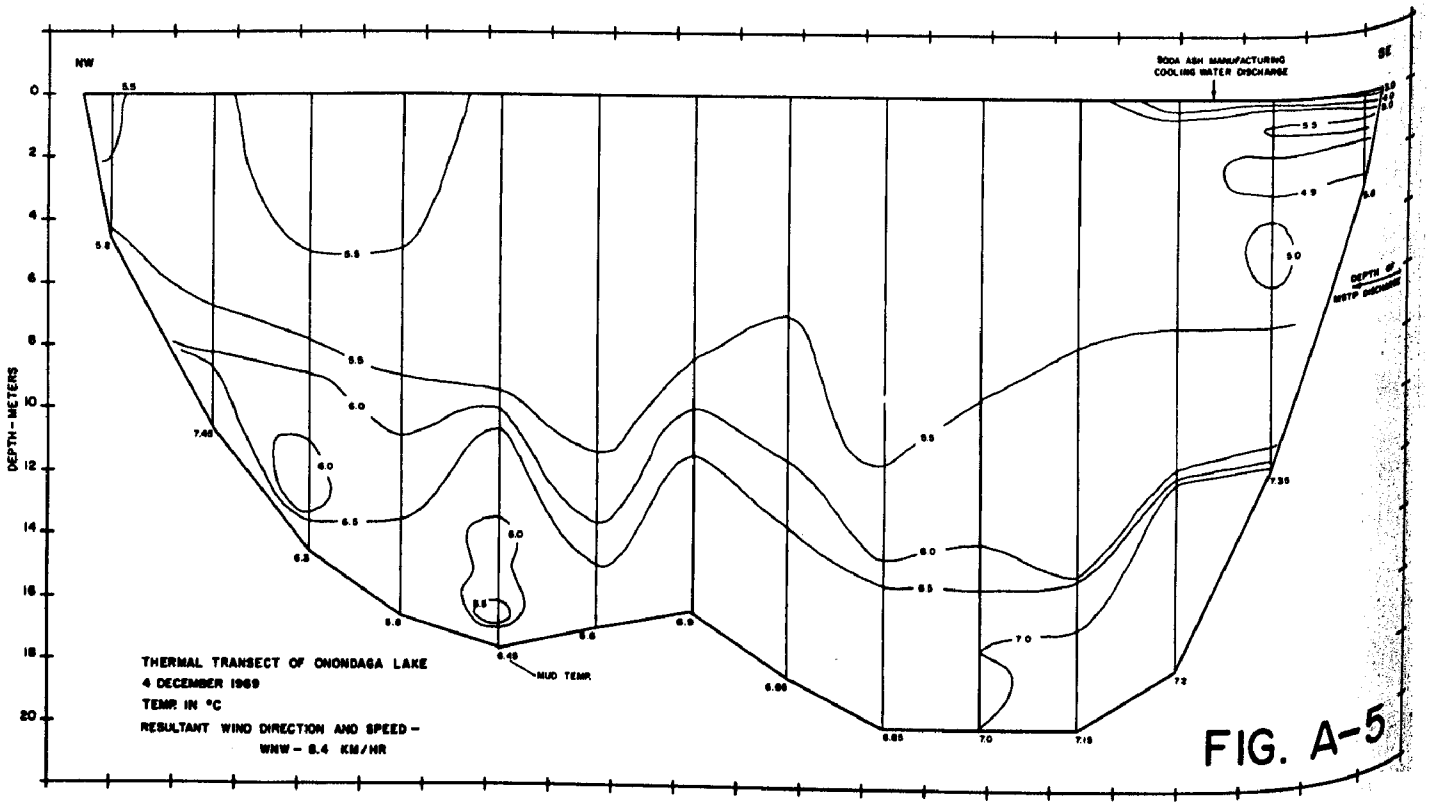

NW
SE
SODA ASH MANUFACTURING
COOLING WATER DISCHARGE
DEPTH - METERS
DEPTH OF MSTP DISCHARGE
5.5
5.8
5.5
5.9
6.0
6.5
6.0
6.5
6.0
6.5
7.0
7.48
6.3
6.48
MUD TEMP.
6.88
7.0
7.18
7.2
7.35
5.5
4.9
5.0
THERMAL TRANSECT OF ONONDAGA LAKE
4 DECEMBER 1969
TEMP. IN °C
RESULTANT WIND DIRECTION AND SPEED -
WNW - 8.4 KM/HR

FIG. A-5

APPENDIX B

CHEMICAL CONSIDERATIONS

This Section includes a detailed review of the chemical parameters measured in the lake waters using three major groups of illustrations, namely:

1. Histograms or statistical distributions of data for each parameter, included with the detailed review. A summary of these results is shown in Table B-1.

2. Depth synoptic line plots, Figures B-1 to B-32.

3. Depth synoptic contour plots, Figures B-34 to B-39.

The results of waste discharge measurements were cited from Section 5 of this Report when considered pertinent.

Data from Stations No. 1 and 2 are illustrated in Table B-1. In those cases where magnitude of values and data distribution for a parameter were nearly equal for both Station No. 1 and Station No. 2, histogram illustrations are shown for Station No. 1 only. However, if there were significant differences between the two Stations, additional comments and histograms were appended.

General considerations for all chemical species are derived primarily from two references; namely, 1) McKee and Wolf, "Water Quality Criteria", State of California, 1963; and 2) Anonymous, "Report of the Committee on Water Quality Criteria", Federal Water Quality Administration, 1968.

Constant reference is made to the epilimnion and hypolimnion under the Section entitled, "Existing Conditions". In all cases, the epilimnion represents depths 0, 3 and 6 meters, whereas the hypolimnion represents depths 12, 15 and 18 meters. The 9 meter depth was not used since this was observed to be the upper limit of the thermocline, and would tend to de-emphasize occurrences in the warmer more active depths of the Lake; conversely it would tend to highlight changes in the colder more inactive depths of the lake.

The statistical parameter most widely used for comparing data was the geometric mean, since it approximates a "most frequent" value. Arithmetic mean values are also compared; however,

this parameter is sometimes significantly affected by extreme values and hence was not used as frequently as the geometric mean.

This geometric mean becomes 0 if any 0 measurements are included. In such cases, 0 readings were not included in the calculation of geometric mean, in order to enable its use as a "most frequent" value.

Other statistical routines such as correlation and regression analysis were performed on the chemical data in an attempt to arrive at a clearer understanding of chemical inter-relationships. These results, in conjunction with visual representations, provide the basis upon which statements in this Appendix are made. Table B-40 summarizes the results of the more pertinent correlation and regression analysis performed.

TABLE B-1

ONONDAGA LAKE STUDY

PARAMETER	SYMBOL	UNITS
Temperature	Temp	°C
Alkalinity	ALK	mg/l as $CaCO_3$
Biochemical Oxygen Demand	BOD	mg/l
Chloride	CL	mg/l
Carbon Dioxide	CO_2	mg/l
Organic Nitrogen	ORG-N	mg/l as N
Ammonia Nitrogen	NH_3-N	mg/l as N
Nitrite	NO_2	mg/l as N
Nitrate	NO_3	mg/l as N
Total Phosphorus	T-P	mg/l as P
Ortho Phosphate	O-PO_4	mg/l as P
pH	pH	$-\log_{10}[H^+]$
Sulfate	SO_4	mg/l
Sulfide	S	$-\log_{10}[S^=]$
Dissolved Oxygen	DO	mg/l
Calcium	CA	mg/l
Sodium	NA	mg/l
Potassium	K	mg/l
Magnesium	MG	mg/l
Conductivity	COND	umhos
Copper	CU	mg/l
Chromium	CR	mg/l
Iron	FE	mg/l
Manganese	MN	mg/l
Zinc	ZN	mg/l
Fluoride	F	$-\log_{10}[F^=]$
Silicon Dioxide	SiO_2	mg/l
Suspended Solids	SS	mg/l
Dissolved Solids	DS	mg/l
Secchi Disk	SECCI	meters
Escherichia coli	ECOLI	Number per 100 ml
Wind	WIND	10-day averages of daily resultant (vector sum) speed 10-day periods-mph
Wind Direction	DIR	Directions corresponding to resultant speeds
Air Temperature	AIR	°C

TABLE B-1

ONONDAGA LAKE STUDY

STATISTICAL PARAMETERS - DEPTH SYNOPTIC DATA

Line Plot Symbol	STATION NO. 1 Epilimnion Mean	STATION NO. 1 Epilimnion Geo. Mean	STATION NO. 1 Hypolimnion Mean	STATION NO. 1 Hypolimnion Geo. Mean	STATION NO. 2 Epilimnion Mean	STATION NO. 2 Epilimnion Geo. Mean	STATION NO. 2 Hypolimnion Mean	STATION NO. 2 Hypolimnion Geo. Mean	MEAN Epilimnion Diff.	MEAN Epilimnion % Diff.	MEAN Hypolimnion Diff.	MEAN Hypolimnion % Diff.
T	13.91	10.27	8.13	7.12	13.78	9.96	7.98	6.77	.13	.9	.15	1.8
ALK	170.39	168.20	198.55	196.23	165.90	164.33	196.37	194.52	449.	2.6	2.68	1.1
BOD	6.21	4.85	12.40	9.02	4.85	3.89	13.44	9.28	1.36	21.9	- 1.04	- 8.4
CL	1458.41	1403.63	1930.23	1914.56	1474.95	1437.03	1886.88	1864.64	- 16.54	- 1.1	43.35	2.0
CO_2	5.16	4.05	10.87	10.03	4.26	3.48	10.26	9.56	.90	17.4	.61	5.6
ORG-N	1.96	1.72	1.48	1.11	1.76	1.50	1.42	1.06	.20	10.2	.06	4.1
NH_3-N	2.14	1.62	4.31	3.79	1.90	1.47	4.08	3.50	.24	11.2	.23	
NO_3	0.39	0.22	0.13	0.04	0.41	0.26	0.13	0.05	- .02	- 5.1	.00	--
NO2	0.06	0.02	0.08	0.00	0.08	0.02	0.14	0.01	- .02	-33.3	- .06	-75.0
T-P	2.34	1.75	3.17	2.51	2.60	1.71	2.80	2.31	- .26	-11.1	.37	11.7
O-P	0.94	0.83	1.57	1.46	0.97	0.80	1.49	1.36	- .03	- 3.2	.08	5.1
pH	7.64	7.63	7.39	7.39	7.69	7.68	7.42	7.42	- .05	- .6	- .03	- .4
SO_4	182.35	180.43	184.41	182.60	177.56	175.09	186.78	184.77	4.79	2.6	- 2.37	- 1.3
S	6.63	5.26	3.50	3.18	6.41	5.61	3.46	3.30	.22	3.3	.04	1.1
DO	4.79	3.79	1.53	1.20	5.78	4.60	1.56	1.22	- .99	- 2.1	- .03	- 2.0
CA	639.37	605.10	849.05	827.57	651.41	618.23	841.00	821.41	- 12.04	1.9	8.05	.9
NA	554.54	528.05	669.75	658.58	558.61	530.74	660.32	650.67	- 4.07	.7	9.43	1.4
K	17.17	15.18	17.79	16.42	16.72	15.03	18.75	16.88	.45	2.6	- .96	5.4
MG	30.38	29.80	30.99	30.51	29.89	29.17	31.48	30.99	.49	1.6	- .49	1.6
COND	4625.83	4533.71	5810.36	5745.89	4715.11	4624.93	5869.31	5808.83	- 89.98	- 3.8	-141.05	2.4
CU	0.05	0.04	0.05	0.04	0.05	0.04	0.04	0.04	.00	--	.01	20.0
CR	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	.00	--	- .01	50.0
FE	0.02	0.17	0.26	0.22	0.20	0.18	0.27	0.24	.00	--	- .01	3.8
MN	0.07	0.06	0.20	0.17	0.08	0.06	0.20	0.17	- .01	14.3	.00	--
ZN	0.07	0.06	0.07	0.06	0.07	0.06		0.07	.00	--	.00	--
F	4.43	4.43	4.56	4.56	4.46	4.46	4.65	4.65	- .03	- .7	- .09	- 2.0
SiO_2	4.89	4.45	8.16	7.92	4.73	4.31	7.60	7.42	.16	3.3	.56	6.9
SS	17.75	13.77	15.90	12.13	16.23	12.10	15.94	11.53	1.52	8.6	- .04	- .2
DS	3200.22	3087.96	3896.25	3818.21	3305.49	3174.52	3910.62	3807.28	-105.27	- 3.3	- 24.37	- .6
SECCI	1.09	0.98	--	--	1.22	1.07	--	--	- .13	-11.8	--	--
ECOLI	1199.61	391.57	250.86	95.65	406.58	88.97	119.92	82.27	793.03	66.1	130.94	5.2

ALKALINITY

General Considerations

"Alkalinity is not a specific polluting substance but rather a combined effect of several substances and conditions. It is caused by the presence of carbonates, bicarbonates, hydroxides and to a lesser extent by borates, silicates, phosphates and organic substances. The major buffering system in natural waters is th carbonate system. This system not only neutralizes acids and bases to reduce the fluctuation in pH, but also forms an indispensible reservoir of carbon for photosynthesis; this is due to a decided limit in the rate at which carbon dioxide can be obtained from the atmosphere to replace that in the water which becomes fixed by the plants. The addition of mineral acids pre-empts the carbonate buffering capacity and the original biological productivity is reduced in proportion to the degree that such capacity is exhausted. It is as necessary, therefore, to maintain the minimum essential buffering capacity as to confine the pH of the water within tolerable limits. In regards to fish and other aquatic life, none of the strong alkalies, such as calcium, potassium and sodium hydroxide has been shown clearly to be lethal to fully developed fish in natural waters when the concentration is insufficient to raise the pH well above 9.0. Interference with normal development and other damage to fish life sometimes may occur, however, at low pH values. When caused almost entirely by bicarbonates, alkalinity does not seem to have any harmful effect upon plankton and other aquatic life," (McKee and Wolf, 1963).

It has been reported that high alkalinity is antagonistic towards the toxicity of copper sulfate to fish. The relative toxicity of 25 mg/l of copper sulfate to brown trout varied inversely with the alkalinity with all fish dying in 2.5 hours when the alkalinity was only 6.0 mg/l; whereas some fish survived after 12.5 hours when the alkalinity was 248 mg/l, (Warrick et al., 1949).

It is generally recognized that the best waters for support of diversified aquatic life are those with pH values between 7 and 8, having a total alkalinity of 100 to 120 mg/l or more. (Huet, M., 1941; Barrett, P.H. 1952). This alkalinity serves as a buffer to help prevent any sudden change in pH deleterious to fish or other aquatic life. Diurnal photosynthetic activity of the aquatic plants in productive waters may result in a conversion of bicarbonate to carbonate, or in extreme cases, the conversion of carbonate to hydroxide. Either of these effects results in a rise of pH. Because these high pH levels

prevail for only a few hours, they do not exert the harmful effects of continuous high levels due to the presence of strong alkalies.

Existing Conditions

Alkalinity values in the epilimnion are distributed in an almost normal distribution with a mean of 170 mg/l and a geometric mean of 168. This distribution (Figure B-2) reflects the relatively constant values of alkalinity for the epilimnion throughout the year. Some of the variation around the central values can be attributed to seasonal trends. However, much of the variation seems to be fairly randon.

The distribution of data for the hypolimnion is skewed considerably toward high values. A comparison of the line plot is helpful. Figure B-2 illustrates similar values of alkalinity from mid-December 1968 to mid-June, 1969, after which time the values increase with depth. Following this period, values in the epilimnion continue to be stable although slightly lower than the previous month, while the values in the hypolimnion become distinctly higher accounting for the skewed distribution.

The distinct change in values of alkalinity between epilimnetic and hypolimnetic waters fades during periods of extensive vertical mixing, particularly during 1968. This would be expected as thermal and other density differences diminish. It can be understood further by examining the breakdown in the stratification of temperature (Figure B-34) and oxygen (Figure B-37).

The higher values of alkalinity in the summer and early fall months were noteworthy. This may be attributable to a high production of CO_2 in these waters and the metastable dissolution of carbonate resulting in a reduction of the rate of removal of bicarbonates through precipitation of carbonate minerals.

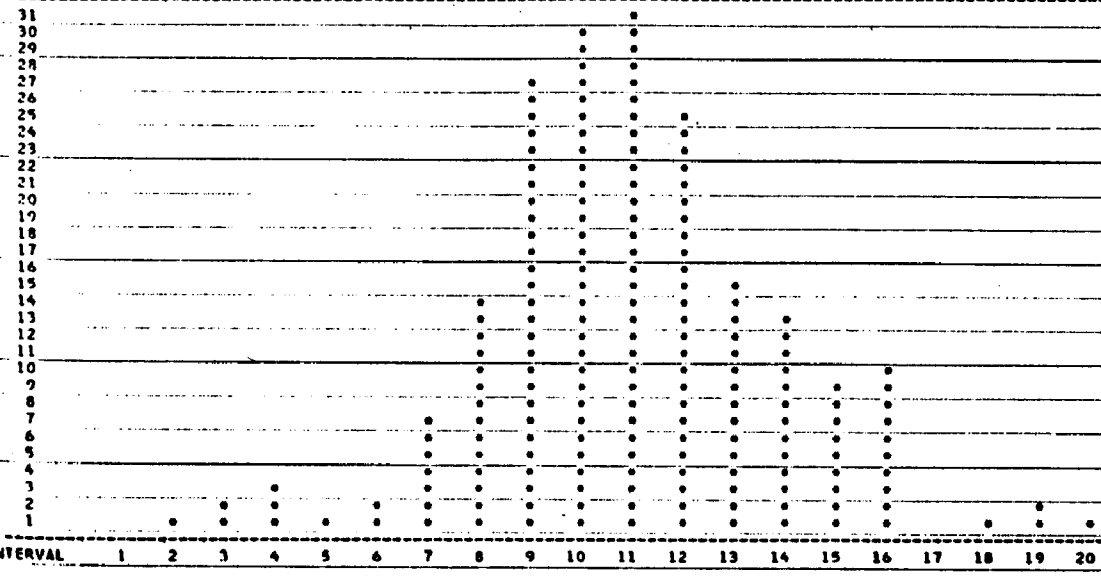
ALK STAT 1 4/17/68 - 12/10/69 EPILIMNION

MIN = 84.00001 MAX = 248.00003 AMEAN = 170.39587 SYDDEV = 26.61707 GMEAN = 168.20672

MOM1 = 0.00000E 00 MOM2 = 0.70846E 03 MOM3 = -0.13983E 03 MOM4 = 0.19577E 07 SKEW = 0.74152E-02 KURT = 0.39003E 01

INTERVAL LENGTH = 9.11111

FREQUENCY	0	1	2	3	1	2	7	14	27	30	31	25	15	13	9	10	0	1	2	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20



ALK STAT 1 4/17/68 - 12/10/69 HYPOLIMNION

MIN = 109.00001 MAX = 284.00006 AMEAN = 198.55960 SYDDEV = 30.01846 GMEAN = 196.23242

MOM1 = 0.00000E 00 MOM2 = 0.90110E 03 MOM3 = 0.33597E 04 MOM4 = 0.26160E 07 SKEW = 0.12420E 00 KURT = 0.32216E 01

INTERVAL LENGTH = 9.72222

FREQUENCY	0	3	0	0	0	1	26	23	16	27	22	17	25	10	9	6		1	1	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

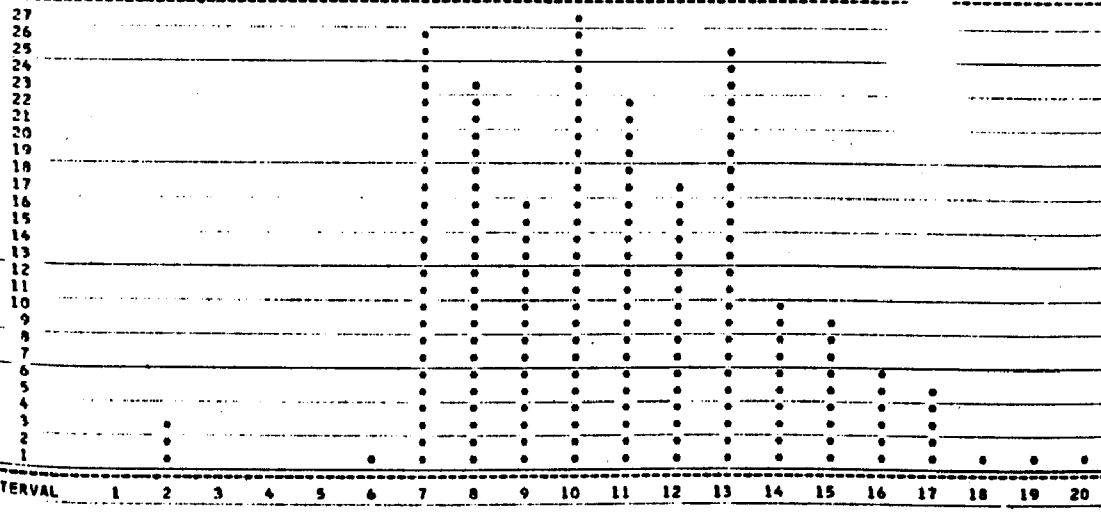


TABLE B-2

BIOCHEMICAL OXYGEN DEMAND

General Considerations

"As in a test for alkalinity, acidity, color, turbidity or specific conductance, the determination of biochemical oxygen demand (BOD) does not reveal the concentration of a specific substance but rather the effect of a combination of substances and conditions," (McKee and Wolf, 1963). BOD is in essence an indirect measure of the amount of oxygen that will be utilized as a result of bio-degradation of material. High BOD's are undesirable in natural waters as their presence depresses the dissolved oxygen content to levels that may be inimical to fish life and other beneficial uses. Furthermore, the exertion of high BOD's can result in septic conditions and cause the development of anaerobic bacteria and saprophytic conditions which inturn degrade the quality of water further.

The ability of water bodies to satisfy the BOD is dependent upon water velocity, surface area with respect to depth, turbulence and sunlight penetration, all of which can be related to the reaeration rate and/or to oxygen production via photosynthesis. Most lakes can be likened to a sluggish, nonturbulent stream with a relatively small surface area with respect to depth. In the case of eutrophic lakes, the oxygen production via phytosynthesis may be offset by the BOD of the algal cells.

Existing Conditions

In both the epilimnion and hypolimnion, the data show a highly skewed distribution, the most frequent values being in the lower end of the range with decreasing frequencies as the BOD values increase. In the epilimnion, the geometric mean is 4.8 mg/l, while in the hypolimnion it is 9.0 mg/l, nearly twice as great. The geometric mean in the epilimnion probably reflects constant organic inputs into the lake rather than algal blooms, which are predominant only approximately 25% of the time, June through September. The period of active production by algae is illustrated most clearly by the DO line plots, Figure B-15. The occasional higher BOD values are reflections of either unusually high input loadings and/or algal blooms. The times at which algal blooms exert a significant demand on the lake can best be illustrated by the dissolved oxygen and BOD contour plots, Figures B-37 and B-35 respectively.

High values in the hypolimnion represent the settleable BOD attributable to inflows, dying phyto and zooplankton, bacteria and

benthal demand. According to laboratory tests outlined in Section 13, the BOD attributable to the latter is only minor. The changes in BOD at all levels, with respect to time, can best be illustrated by the BOD contour plot, Figure B-35.

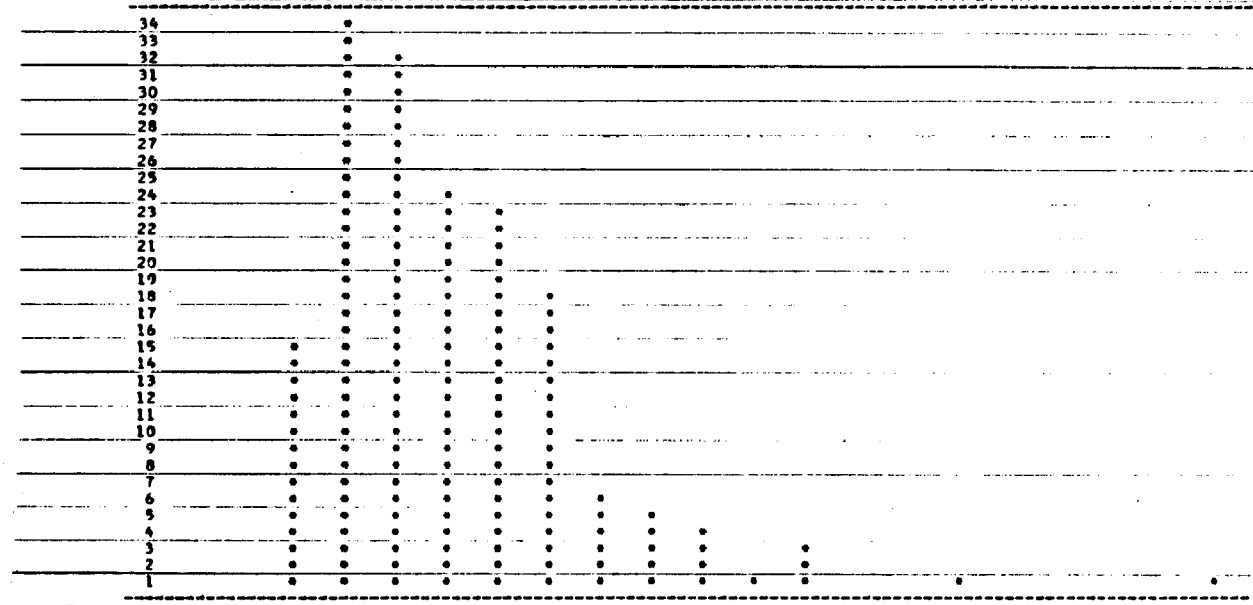
BOD STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00000 MAX = 30.80000 AMEAN = 6.19996 STDDEV = 4.41304 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.19474E 02 MOM3 = 0.15691E 03 MOM4 = 0.33738E 04 SKEW = 0.18257E 01 KURT = 0.88955E 01

INTERVAL LENGTH = 1.71111

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	15	34	32	24	23	18	6	5	4	1	3	0	0	1	0	0	0	0	1



BOD STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 44.40000 AMEAN = 12.39266 STDDEV = 9.26746 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.86257E 02 MOM3 = 0.86686E 03 MOM4 = 0.27869E 05 SKEW = 0.10820E 01 KURT = 0.37457E 01

INTERVAL LENGTH = 2.46666

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	11	34	14	20	21	14	9	5	11	9	4	1	4	1	3	3	0	0	1

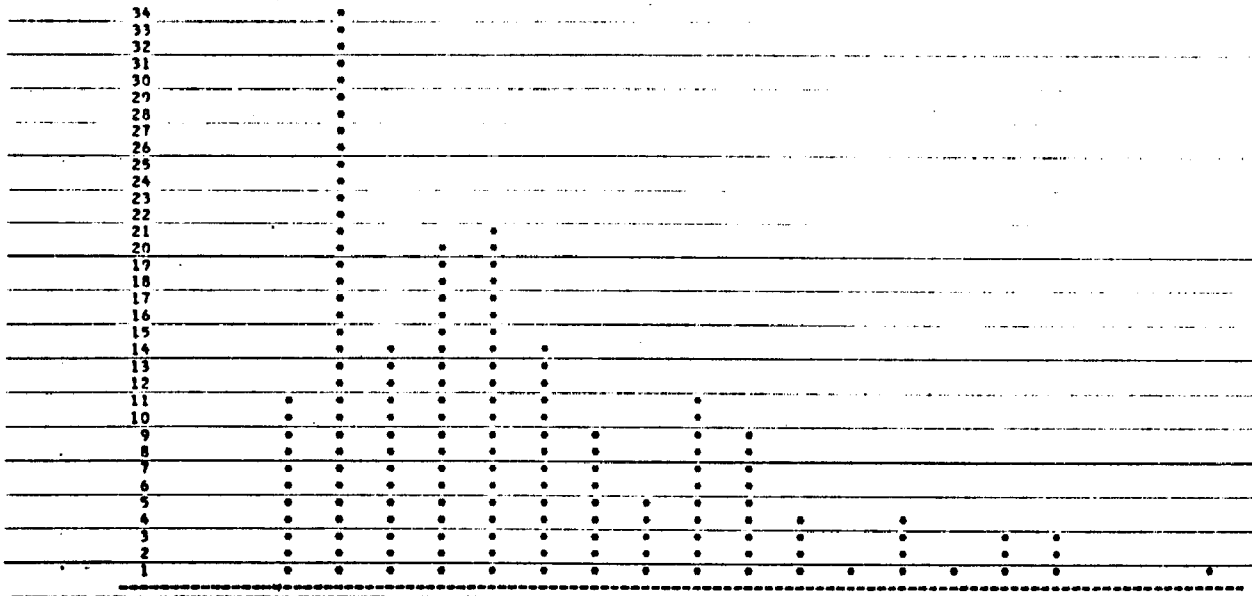


TABLE B-3

CHLORIDES

General Considerations

Chlorides are found in practically all natural waters. They may be of natural mineral origin, or derived (A) from salts spread on fields for agricultural purposes (B) from human or animal sewage (C) from underground springs or (D) from industrial effluents. Chlorides in water may impart a salty taste at concentrations as low as 100 mg/l. (Anonymous, Water Quality and Treatment, 1950; Anonymous, Standards of Water Quality and Factors Affecting Quality, 1947). For average individuals, the taste threshold is about 400 mg/l. Regarding fish and aquatic life, the following concentrations of chloride have been reported, by McKee and Wolf, to be harmful to fish:

Concentration mg/l	Type of Fish
400	trout
4000	bass, pike, perch
4500 - 6000	carp eggs
8100 - 10500	small bluegills

Chlorinity is closely related to the total salinity and its effects on osmosis; hence most fresh water fish cannot tolerate excessive changes in salinity and most salt water fish may be affected adversely by waters of low salinity. "The Aquatic Life Advisory Commission of ORSANCO concluded that it is impossible to generalize on the effects of chloride concentrates on aquatic life, for each mixture of chloride with other salts must be evaluated separately." (McKee and Wolf, 1963)

While Onondaga Lake has often been referred to as a saltwater lake, historical records dating back as far as the late 1700's indicate strongly that the water at that time was fresh water although salt springs existed along the southern and southeastern shores of the lake. This apparently led to the questionable conclusion that the lake itself was salty. Although we cannot define quantitatively for those earlier years, the terms "fresh" or "salty", the lake appears to have increased its "saline" nature and decreased its "fresh" nature as judged by data of this century.

Comparison of present data with those collected by Metcalf and Eddy (1920) show a significant increase in concentrations of

chlorides at both the surface and near bottom waters in the past 50 years. Values ranged from 818 mg/l at the surface to 1009 at the bottom in that portion of the lake designated as the south deep in this Study. Comparable chloride concentrations for approximately the same period, April 1968 and April 1969, and the same temperatures observed by Metcalf and Eddy, 8-9°C., ranged from 1100 to 2200 mg/l.

Existing Conditions

In the epilimnion, chloride values tend towards a normal distribution with a geometric mean of 1404 mg/l with random deviations from that value. Distribution of data for the hypolimnion is considerably different, approaching a bimodal distribution with the modes near 1700 and 2200 mg/l.

The mean and geometric mean concentration of chloride in the hypolimnion exceeded those of the epilimnion by approximately 30%. Referring to the line plots of chloride data (Figure B-4), the chloride concentrations of the upper waters are obviously lower than those in lower waters.

It is rather remarkable that this tendency exists even at those times when the lake is isothermal or nearly so, and when sufficient mixing has occurred to carry dissolved oxygen to all depths. The persistence of this concentration gradient and others, indicates that even when mixing occurs, it is not strong enough to distribute major chemical species as rapidly as they enter.

The gradients observed can be explained further by considering the effects of temperature and solute concentrations upon the water density, both in the Lake proper and from the inflows. During the winter months, when the temperature difference from the lake surface to the bottom is only a few degrees, chloride concentrations generally tend to increase ith depth but there is no sharp divergence between the hypolimnion and the epilimnion. Since the lake maintains a degree of stratification at this time of year, it follows that the density of the lake water increases with depth. Influent discharge water tends to descend to a level determined by its density. The density of most influent water is influenced by its concentration of dissolved matter, and by its temperature. Despite fluctuations in these factors, attributable to weather and other effects, there is a general tendency for the more concentrated inputs to sink deeper in the lake. This reasoning is consistent with the distribution of chloride concentrations found in the lake during the winter months, as illustrated in the line plots, Figure B-4.

As the spring thaw took place, the epilimnetic waters of the lake warm more rapidly than the hypolimnetic waters. Summer

stratification established quickly, the spring isothermal period, (1969 - the only instance covered by the sampling program), was so brief as indicated by the chemical data that only weak, incomplete mixing took place.

Input streams derive from water bodies which are relatively shallow with respect to the lake, and consequently warm quickly. Therefore the discharges, owing to their relative densities tend to reside in the epilimnion. In the spring, the stream runoff is relatively dilute with respect to all dissolved species, including chlorides. Thus the chloride concentrations in the epilimnetic waters of the lake are reduced by inflows during the early spring months. This influence on lake waters tends to diminish through the summer as input volumes and their dilution decreases.

A second observation was made by comparing the distribution of data of the epilimnetic waters with that of the hypolimnetic waters, that the range of values in the upper waters is considerably more narrow. If the epilimnion were more uniformly mixed throughout the year, one would expect a narrower distribution if the chloride input were relatively constant. The highest chloride input into Onondaga Lake was found to be a major soda ash producing industry representing 72% of the chloride input during the sampling period June 1969 to December 1969. The operation of this plant was relatively constant over the sampling period. This indicates an active epilimnetic region as contrasted to a relatively stagnant hypolimnetic region in the lake.

Figures B-38 and B-39, also illustrate a significant increase in chlorides in the epilimnion from the months of June 1969 to October 1969. From data on the stream flow (monitored daily at Dorwin Avenue on Onondaga Creek) it can be seen that beginning in the month of June through the month of October, there was a significant decrease in runoff reflecting the low rainfall during that period. Assuming a constant chloride input, a lower runoff could account for the increased chloride concentration since the flushing action on the lake would be relatively less than under higher runoff conditions. During the summer of 1968 there was little or no consistent increase of chloride concentration. This can again be explained by the stream flows, which were significantly higher than those recorded the following year.

In each calendar year, the chloride concentration in the hypolimnion tended to hold relatively constant. Only at times of fall mixing do progressive changes with time appear. The concentration range maintained in any year could be considered a reflection of the previous years conditions but the data only suggest and do not fully substantiate this concept. The difference between 1968 and 1969 could account for the bimodal distribution seen in the histograms.

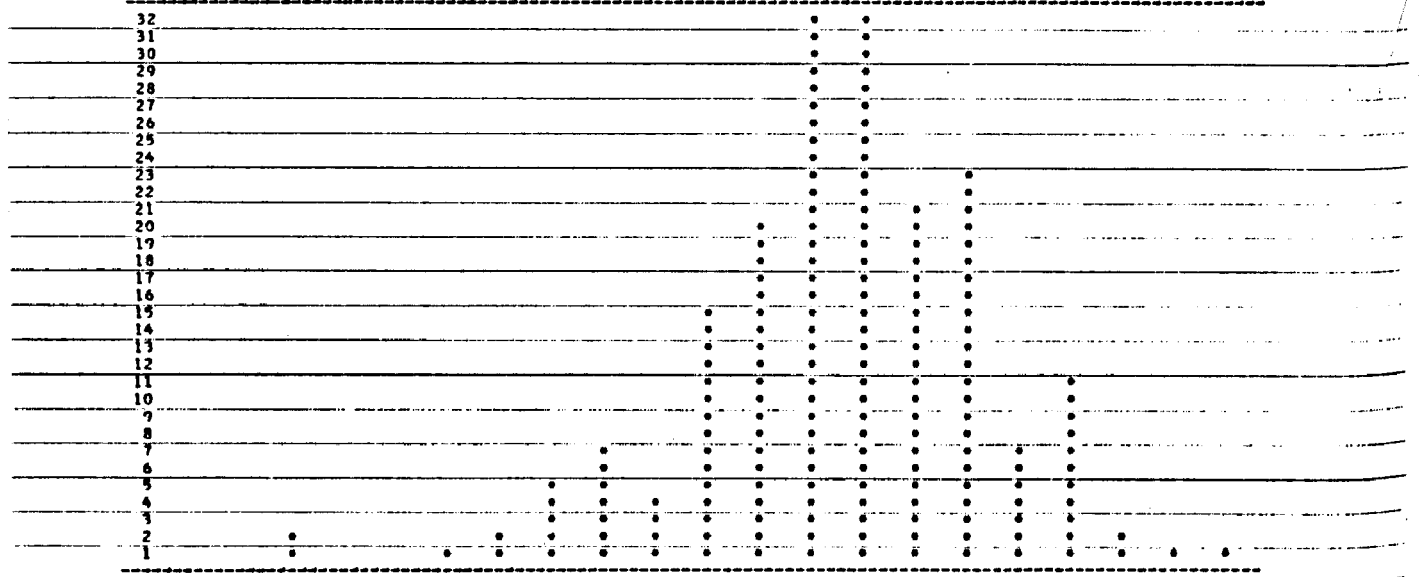
CL STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 137.00003 MAX = 2300.00049 AMEAN = 1458.41943 STDDEV = 339.05102 GMEAN = 1403.63623

MOM1 = 0.00000E 00 MOM2 = 0.11495E 06 MOM3 = -0.24008E 08 MOM4 = 0.58862E 11 SKEW = 0.61599E 00 KURT = 0.44543E 01

INTERVAL LENGTH = 120.16667

FREQUENCY	0	2	0	0	1	2	5	7	4	15	20	32	32	21	23	7	11	2	1	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20



CL STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 1349.00024 MAX = 2615.00049 AMEAN = 1930.23950 STDDEV = 245.85339 GMEAN = 1914.56592

MOM1 = 0.00000E 00 MOM2 = 0.60443E 05 MOM3 = 0.40812E 07 MOM4 = 0.91936E 10 SKEW = 0.27464E 00 KURT = 0.25164E 01

INTERVAL LENGTH = 70.33334

FREQUENCY	0	2	2	4	7	29	12	24	19	10	18	12	21	12	6	4	1	4	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

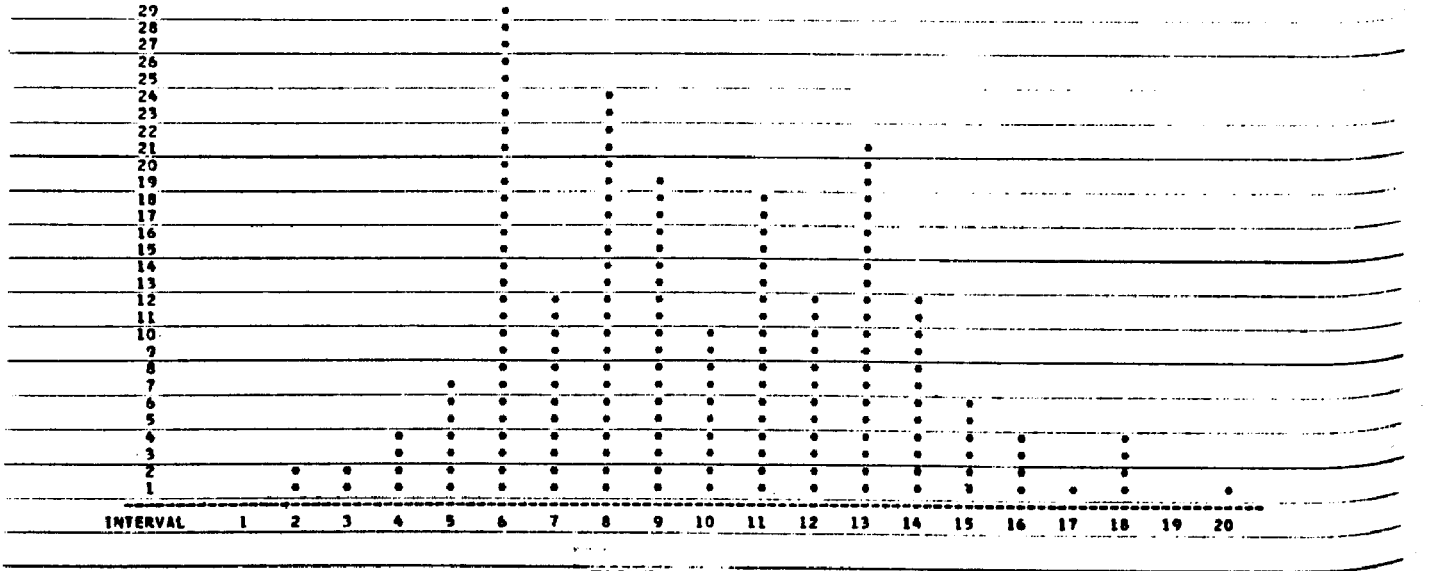


TABLE B-4

CARBON DIOXIDE

General Conditions

Carbon dioxide (CO_2) is a colorless, odorless, noncombustible gas, constituting about .04% of normal air, and highly soluble in water. The source of free CO_2 in water is mostly a product of aerobic or anerobic decomposition of organic matter which is intimately bound in the complex carbonate equilibria.

"An excess of "free" CO_2 (as distinguished from that present as carbonate and bicarbonate) may have adverse effects on aquatic animals. These effects range from avoidance reactions and changes in respiratory movements at low concentrations, to interference with gas exchange at higher concentrations and to narcosis and death if the concentration is increased still further." (Anonymous, Water Quality Criteria, 1968)

Migrating fish tend to respond to slight gradients in CO_2 tension and to avoid concentrations of 1.0 to 6.0 mg/l. It is doubtful that fresh water fish normally survive throughout the year in water with an average CO_2 content as high as 12 mg/l, and concentrations of 20 mg/l will quickly prove fatal to the more sensitive species. When the content of DO drops to 3 to 5 mg/l, the effects of low CO_2 concentrations may be more detrimental. However, the presence of CO_2 may, in some circumstances, have a beneficial effect in so far as fish are concerned. It has been shown by several investigators that CO_2 lowers the pH and consequently the unionized ammonia in certain waters. Thus, it has been reported that 30 mg/l of CO_2 reduced the toxicity of ammonia to trout by lowering the pH value. (McKee and Wolf, 1963)

Existing Conditions

Values for the epilimnion range from 1.0 to 17.6 mg/l in Onondaga Lake. Such a wide range can be attributed primarily to biological production and consumption of CO_2. The most frequent values of CO_2 concentrations range from 1.9 to 7.4 mg/l with a mean and geometric mean of 5.16 and 4.05 mg/l respectively (Figure B-5). These values are approximately 25% higher than those for the corresponding zone at Station 2. The data for Stations 1 and 2 are similar only in that they both show tendencies towards three or more sets of values. The range of values for Station 2 is 1.0 to 9.7 mg/l. The larger values at Station 1 are most likely associated with the proximity of this Station to the inflows with major BOD loadings. Variations and relatively low values for both Stations are related to active photosynthesis. This is illustrated by Figure B-5. The lowest values occur most frequently at the surface and three meters.

In general, values in the hypolimnion run slightly higher than those in the epilimnion at Stations 1 and 2. This may be attributable to the higher degree of biological decomposition in the hypolimnion and the fact that the photosynthetic activity in the epilimnion, which serves as a sink for CO_2, is not present in the hypolimnion.

The data of the hypolimnion are similar for both Stations and show nearly equal values with means and geometric means of approximately 10 mg/l. It can be surmised that the predominant mechanisms controlling CO_2 are biological activity and carbonate precipitation rather than input BOD since the latter might indicate a greater difference between Stations 1 and 2.

CO2 STAT 1 4/17/69 - 12/18/69 EPILIMNION

MIN = 0.00000 MAX = 17.60000 AMEAN = 5.02462 STDDEV = 3.51984 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.12387E 02 MOM3 = 0.41981E 02 MOM4 = 0.79715E 03 SKEW = 0.96285E 00 KURT = 0.51944E 01

INTERVAL LENGTH = 0.97777

FREQUENCY	0	10	3	4	6	11	5	12	7	5	2	1	1	0	0	0	0	0	1	1
12								•												
11						•		•												
10		•				•		•												
9		•				•		•												
8		•				•		•												
7		•				•		•	•											
6		•			•	•		•	•											
5		•			•	•	•	•	•	•										
4		•		•	•	•	•	•	•	•										
3		•	•	•	•	•	•	•	•	•										
2		•	•	•	•	•	•	•	•	•	•									
1		•	•	•	•	•	•	•	•	•	•	•	•						•	•
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CO2 STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 3.96000 MAX = 26.40000 AMEAN = 10.87996 STDDEV = 4.40191 GMEAN = 10.03042

MOM1 = 0.00000E 00 MOM2 = 0.19376E 02 MOM3 = 0.73985E 02 MOM4 = 0.15242E 04 SKEW = 0.86740E 00 KURT = 0.40595E 01

INTERVAL LENGTH = 1.24666

FREQUENCY	0	2	7	11	6	7	7	6	8	6	1	5	0	1	0	1	0	0	0	1
11				•																
10				•																
9				•																
8				•					•											
7			•	•		•	•		•											
6			•	•	•	•	•	•	•	•										
5			•	•	•	•	•	•	•	•		•								
4			•	•	•	•	•	•	•	•		•								
3			•	•	•	•	•	•	•	•		•								
2		•	•	•	•	•	•	•	•	•		•								
1		•	•	•	•	•	•	•	•	•	•	•		•		•				•
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE B-5

NITROGEN

General Considerations

Nitrogen is an essential constituent of protein in all living organisms, and is present in many mineral deposits as nitrate. Nitrogen in organic matter undergoes changes from complex proteins through amino acids to ammonia, nitrites, and nitrates. The inorganic forms are resynthesized into organic compounds by plant and animal forms. The so-called nitrogen cycle in nature is generally dependent upon bacterial action for completion and upon photosynthesis for reconstitution of organic matter.

The total concentration of nitrogen is highly important when considering trophic aspects of the Lake. The specific forms of nitrogen are of importance when considering specific physiological requirements of various primary producers. Organic nitrogen and amino acids may inhibit biological growth whereas ammonia and nitrates often stimulate production by phytoplankton. It has been reported that the critical concentration of inorganic nitrogen below which algal growths were not troublesome was 0.30 mg/l provided that inorganic phosphorous was kept below 0.015 mg/l, (Sawyer, 1957). Sawyer also reported that the optimum N-P ratio appeared to be about 30:1. For other algae, ratios of 15-18:1 were observed.

According to many references shown by McKee and Wolf, 1963, the toxicity of ammonia and ammonium salts to aquatic animals is directly related to the amount of undissociated ammonium hydroxide in the solution, which in turn is a function of pH as explained under the Section entitled pH. Thus a high concentration of ammonium ions in water at a low pH may not be toxic, but if the pH is raised, toxicity will probably increase (Doudoroff, P & Katz, M., 1950). It has been reported by Ellis, 1937 that the toxicity of a given concentration of ammonium compounds toward fish increased by 200% or more between pH 7.4 and 8.0.

Existing Conditions

A cursory examination of the nitrogen and phosphorus concentrations (Figures B-6 and B-10) indicates that neither of these two seem to be limiting if the reported values of Sawyer (1957) apply. In general, the total Kjeldahl, organic and ammonia forms of nitrogen data show wide variation in magnitude with respect to depth and time. Higher values of organic nitrogen were observed in the epilimnion than in the hypolimnion, whereas the opposite was true in the cases of

ammonia and total Kjeldahl nitrogen. The above trends, as well as the tendency of these data toward a normal distribution, can be accounted for by combinations of input discharges, and the complex nitrogen cycle.

Concentrations of nitrite nitrogen are quite low (mean - 0.06 and 0.08 mg/l) and skewed toward low values in both the epilimnion and the hypolimnion. A value of 0.06 mg/l seems to represent a "base" value with higher concentrations occurring irregularly.

Nitrate values in the epilimnion tend to concentrate at the lower end of the scale. The most frequent value was 0.07 mg/l with a decreasing tendency towards higher values. However, the nitrate values in the hypolimnion are distributed in much the same way as the nitrites with skewness toward lower values and a most frequent and "base" value in the vicinity of 0.06 mg/l. A predominance of relatively low values in the hypolimnion is a reflection of the reduction of nitrates throughout much of this zone.

The mean and geometric means of total Kjeldahl nitrogen exceed in all cases, with the exception of the mean value in the hypolimnion, the concentration of 0.6 mg/l which has been reported (McKee and Wolf, 1963) as a "critical" concentration.

In regard to the N:P ratios for algae growth, if we assume a critical P concentration of 0.01 mg/l as P, total Kjeldahl nitrogen values in the epilimnion yield ratios of 382:1 and 410:1. Nitrate nitrogen values yield ratios from 22:1 to 39:1. These ratios are shown in Table B-6A.

TABLE B-6A

	(Nitrogen Concentrations) Geometric Mean	Mean	N:P ratios with P = 0.01 mg/l as P	
ORG-N + NH_3N (TKN)				
Epilimnion	3.82	4.10	382:1	410:1
Hypolimnion	5.44	5.79	544:1	579:1
NO_3				
Epilimnion	0.22	0.39	22:1	39:1
Hypolimnion	0.04	0.13	4:1	13:1

All values in mg/l as N.

Based on the high algal production that now occurs in Onondaga Lake, one can assume that neither nitrate nor total nitrogen is limiting and that the high concentrations of total Kjeldahl

reaffirms that nitrogen is not limiting the growth of phytoplankton.

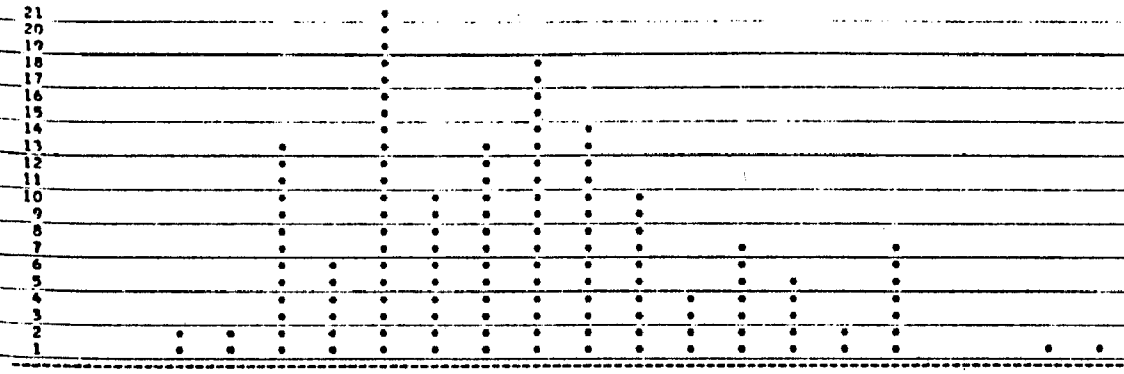
The ammonia form (NH_3) of nitrogen, however, may be inimical to aquatic organisms at high pH conditions as reported above. This may explain the sudden die-off of algae observed on July 30, 1969. Whereas a gradual accumulation of ammonia (NH_3) beginning in early summer, may have contributed to the high growth levels of phytoplankton observed, Figure B-3, the peak concentrations of ammonia nitrogen measured in the 9-15 meter waters, prior to and including July 30th, and the generally high pH conditions (peak = 8.8) observed during this period, Figures B-7 and B-12, may have contributed to the collapse of algae in the lake.

MIN = 1.09030 MAX = 8.61000 AMEAN = 4.10299 STDDEV = 1.51596 GMEAN = 3.82256

MOM1 = 0.00000E 00 MOM2 = 0.22981E 01 MOM3 = 0.20439E 01 MOM4 = 0.19841E 02 SKEW = 0.98667E 00 KURT = 0.29993E 01

INTERVAL LENGTH = 0.41999

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	2	2	13	6	21	10	13	18	14	10	4	7	5	2	7	0	0	1	1



TOT-N STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 1.97000 MAX = 18.72000 AMEAN = 5.79536 STDDEV = 2.32032 GMEAN = 5.44384

MOM1 = 0.00000E 00 MOM2 = 0.53838E 01 MOM3 = 0.29736E 02 MOM4 = 0.34554E 03 SKEW = 0.23803E 01 KURT = 0.11920E 02

INTERVAL LENGTH = 0.93055

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	4	14	33	27	29	11	7	2	4	3	0	0	1	0	0	1	0	0	1

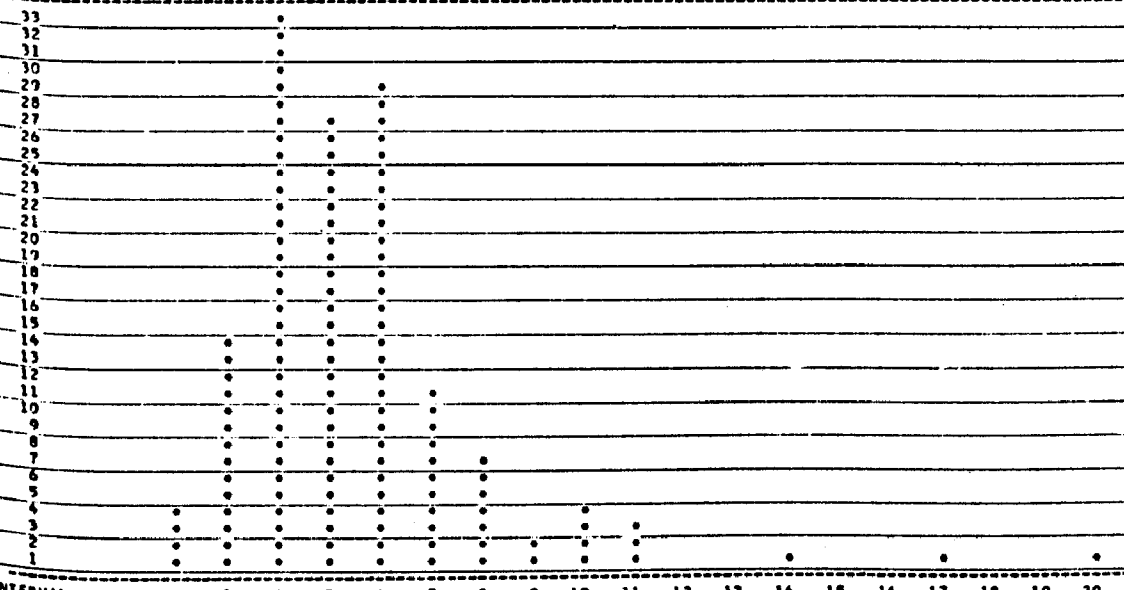


TABLE - 8-6

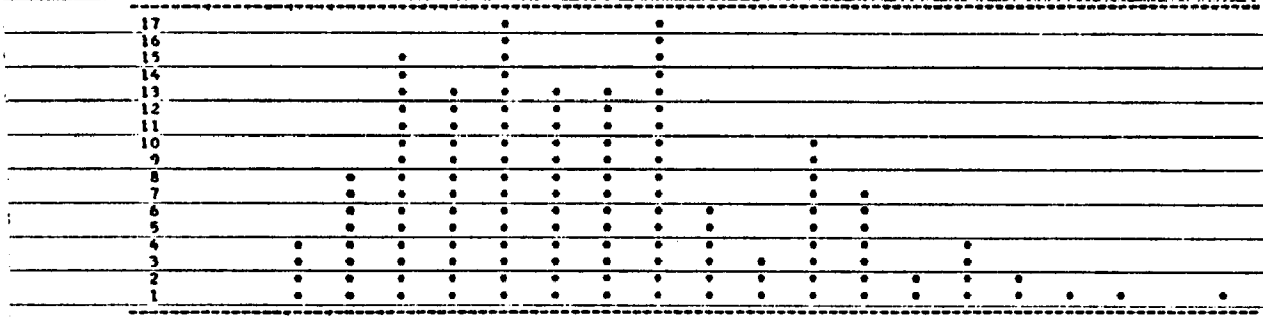
ORG-N STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.31000 MAX = 4.94000 AMEAN = 1.96493 STDDEV = 0.95407 GMEAN = 1.72593

MOM1 = 0.00000E 00 MOM2 = 0.91025E 00 MOM3 = 0.56432E 00 MOM4 = 0.24485E 01 SKEW = 0.64980E 00 KURT = 0.29551E 01

INTERVAL LENGTH = 0.25722

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	4	8	15	13	17	13	13	17	6	3	10	7	2	4	2	1	1	0	1



ORG-N STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.13000 MAX = 7.20000 AMEAN = 1.48269 STDDEV = 1.17943 GMEAN = 1.11115

MOM1 = 0.00000E 00 MOM2 = 0.13910E 01 MOM3 = 0.30022E 01 MOM4 = 0.14363E 02 SKEW = 0.18298E 01 KURT = 0.74224E 01

INTERVAL LENGTH = 0.39277

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	17	37	25	19	9	4	7	10	2	1	3	0	1	0	1	0	0	0	1

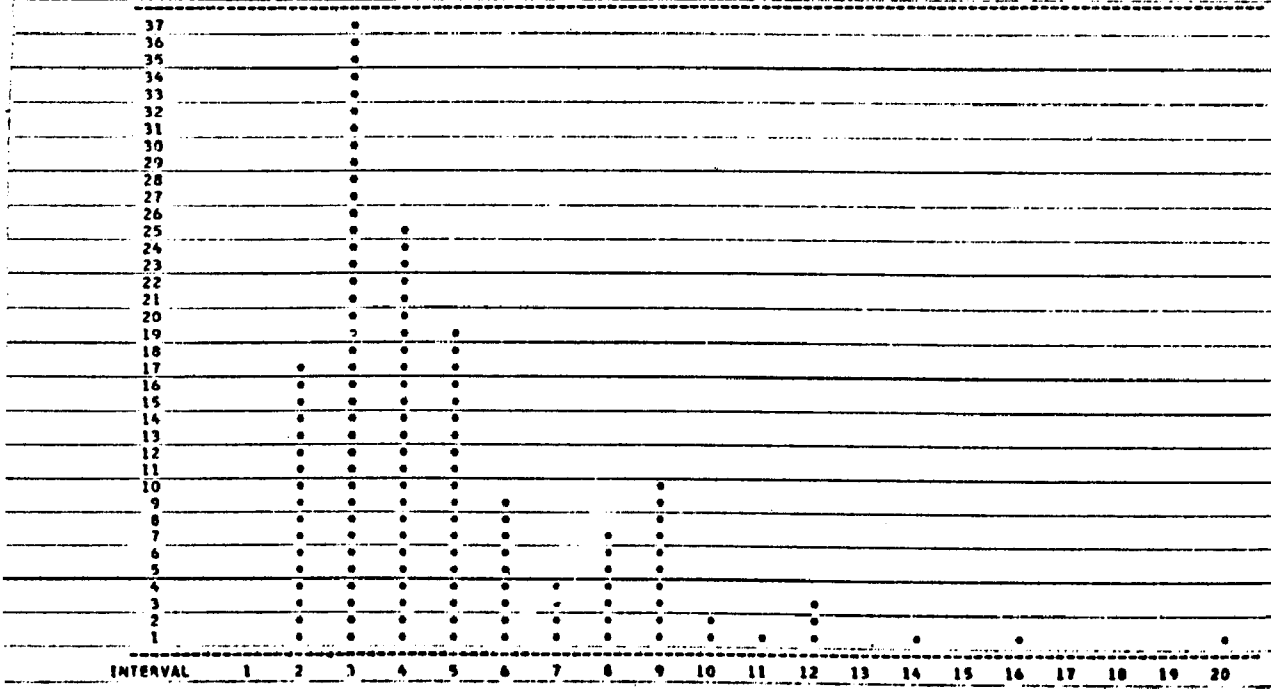


TABLE B-7

NH3-N STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.09000 MAX = 5.53000 AMEAN = 2.14013 STODEV = 1.31682 GMEAN = 1.62478

MOM1 = 0.00000E 00 MOM2 = 0.17340E 01 MOM3 = 0.73667E 00 MOM4 = 0.60920E 01 SKEW = 0.32261E 00 KURT = 0.20260E 01

INTERVAL LENGTH = 0.30222

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	1	7	15	8	19	4	9	12	11	8	6	4	8	10	9	3	0	1	0	1

NH3-N STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.37000 MAX = 12.86000 AMEAN = 4.31267 STODEV = 2.08986 GMEAN = 3.79573

MOM1 = 0.00000E 00 MOM2 = 0.43675E 01 MOM3 = 0.10879E 02 MOM4 = 0.10408E 03 SKEW = 0.11919E 01 KURT = 0.54563E 01

INTERVAL LENGTH = 0.69388

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	4	5	11	20	28	15	14	18	9	3	2	1	3	1	1	0	1	0	1

TABLE B-8

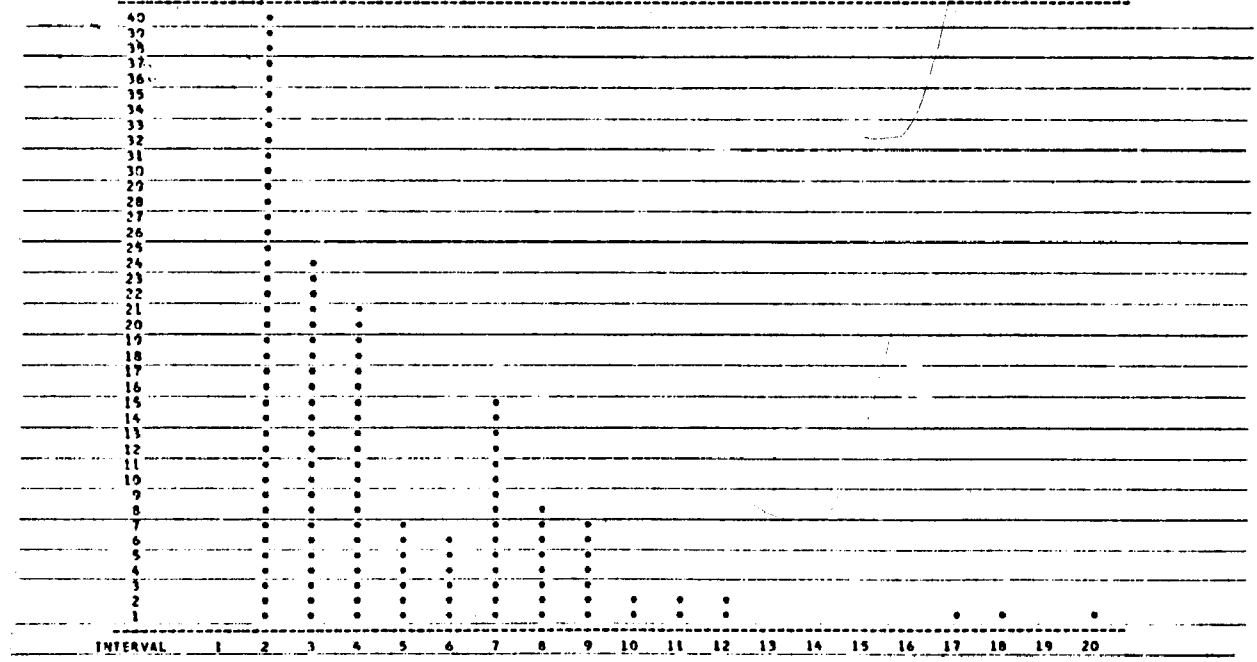
NO2 STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00030 MAX = 0.22500 AMEAN = 0.04054 STDDEV = 0.04078 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.16637E-02 MOM3 = 0.11979E-03 MOM4 = 0.20110E-04 SKEW = 0.17653E 01 KURT = 0.72852E 01

INTERVAL LENGTH = 0.01250

FREQUENCY 0 40 24 21 7 6 15 8 7 2 2 2 0 0 0 0 1 1 0 1



NO2 STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 0.24000 AMEAN = 0.01644 STDDEV = 0.03144 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.98851E-03 MOM3 = 0.12159E-03 MOM4 = 0.22742E-04 SKEW = 0.39124E 01 KURT = 0.23274E 02

INTERVAL LENGTH = 0.01333

FREQUENCY 0 98 14 8 4 3 5 1 2 0 0 0 0 1 0 0 0 0 0 1

EACH • EQUALS 2 POINTS

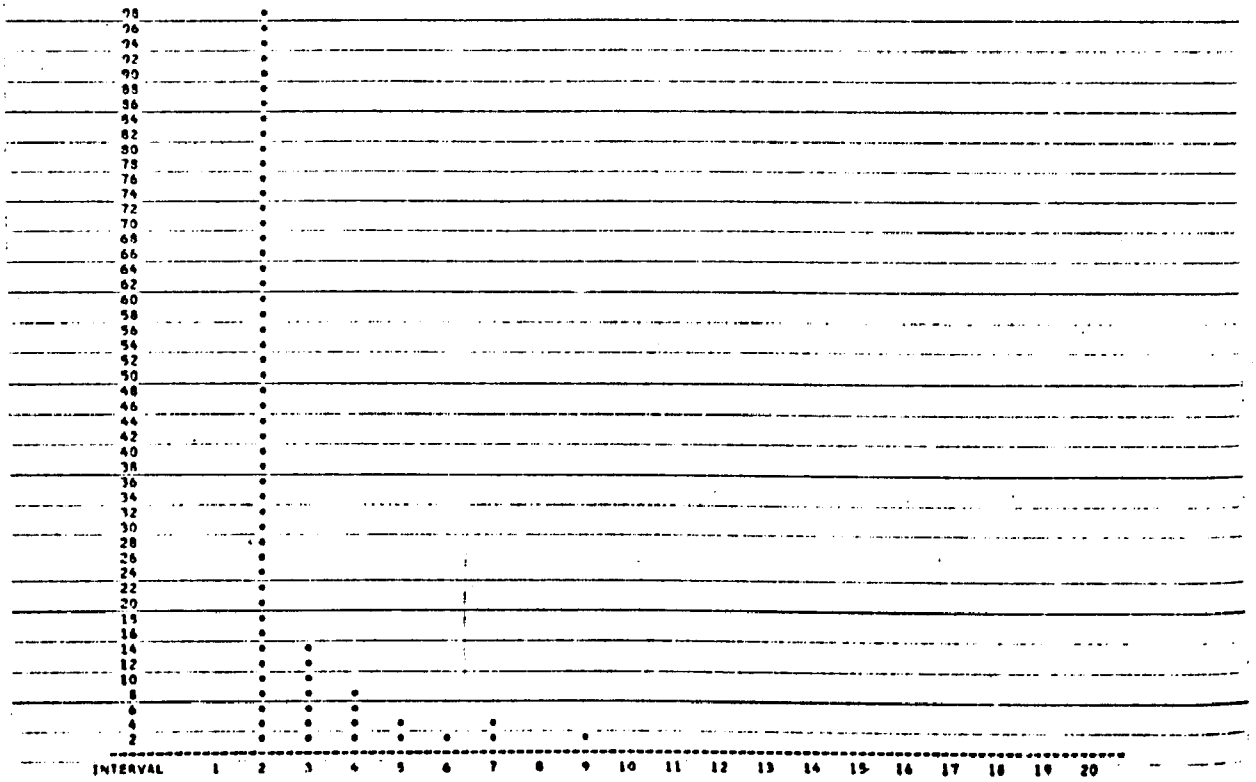


TABLE B-9

NO3 STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00000 MAX = 1.27000 AMEAN = 0.38676 STDDEV = 0.30686 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.94164E-01 MOM3 = 0.11450E-01 MOM4 = 0.18022E-01 SKEW = 0.39628E 00 KURT = 0.20325E 01

INTERVAL LENGTH = 0.07055

FREQUENCY	0	31	17	12	5	3	6	4	15	6	12	12	6	3	2	1	1	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

NO3 STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 0.51000 AMEAN = 0.08963 STDDEV = 0.12494 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.15612E-01 MOM3 = 0.35727E-02 MOM4 = 0.12667E-02 SKEW = 0.18314E 01 KURT = 0.51969E 01

INTERVAL LENGTH = 0.02833

FREQUENCY	0	53	39	8	8	2	2	2	4	1	1	3	0	4	4	2	1	1	1	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

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TABLE B-10

PHOSPHORUS

General Considerations

Phosphorus is an essential element for aquatic life as well as for all forms of life and has been considered an important nutrient to control in efforts to limit eutrophication of water. Evidence indicates that high phosphorus concentrations are associated with eutrophication. There are growth promoting factors which influence the welfare of organisms in lakes and streams. It has been generally acknowledged that although the ortho-phosphate form of phosphorus is directly utilized in most aquatic life, all forms of phosphorus represent a potential source of nutrients as a result of such functions as biodegradation and hydrolysis which readily occur within a lake environment.

Phosphates may occur in surface or ground waters as a result of leaching from minerals or ores and natural processes of degradation or from agricultural drainage, as one of the stabilized products of decomposition of organic matter, as a result of industrial wastes, and as a major element of municipal sewage with its synthetic detergents.

The discharge of excessive amounts of phosphates to streams or lakes may result in an over-abundant growth of algae with concomitant odors and detrimental effects on fish. In themselves, however, phosphates seldom exhibit toxic effects upon fish and other aquatic life and may in fact be beneficial to fish culture under some circumstances, by increasing algae and zooplankton.

In regards to undesirable aquatic growths such as algal blooms, critical phosphorus concentrations will vary with other water quality characteristics. Turbidity, for instance, may inhibit the algal-producing effects of phosphorus in some waters. When waters are detained in a lake, the resultant soluble phosphorus concentration is reduced to some extent over that in the influent streams through uptake by organisms and/or chemical precipitation and adsorption through the formation of stable minerals. In the former case, decomposition and hydrolysis recirculate the phosphates back into lake waters whereas in the latter case, the minerals may deposit themselves on the bottom of the lake until such time that physical forces effectively recirculate and dissolve these minerals in the lake waters (fall or spring overturn).

Studies of the productivity of a group of 17 Wisconsin lakes suggest a concentration of 0.01 mg/l of inorganic phosphorus

as a maximum value permissible without the danger of supporting undesirable growths.

In August of 1969 the State of New York issued a policy announcement regarding phosphorus removals in treatment facilities, especially those related to eutrophication of Lake Erie and Ontario. The major objective was to effect phosphorus removals in treatment plants to the extent that no such discharge shall have a total phosphorus content exceeding the range of 0.5 - 1.0 mg/l as phosphorus at all municipal plants with flows of 1 mgd or greater.

Existing Conditions

In the epilimnion the geometric mean of total phosphorus is 1.7 mg/l with predominant values ranging from 1.4 to 3.6 at decreasing frequencies, followed by a few scattered values of higher concentrations. The data shows a mean value of 2.3 mg/l with higher values, possibly owing to high inputs. The geometric mean of ortho-phosphate in the same region in the lake was found to be 0.8 mg/l with fairly frequent values up to 1.5 mg/l, and only scattered observations of high concentrations. The distribution of these data resembles a normal curve skewed in the direction of lower concentrations. The mean value of ortho-phosphates in the epilimnion was found to be 0.94, approximately 1/2 that of total phosphorus.

In the hypolimnion, the geometric mean for total phosphorus is 2.5 mg/l, substantially higher than that of the epilimnion. The geometric mean of ortho-phosphorus in the hypolimnion is 1.5 mg/l, also substantially higher than the corresponding value in the epilimnion.

Referring to the line plots of total phosphorus and ortho-phosphate, (Figures B-10 and B-11 respectively), concentrations of both parameters tend to be fairly constant with deviant values in the period from July to October 1969. Values range as high as 23 and 4.2 mg/l for total phosphorus and ortho-phosphate respectively. In general, the highest values occurred in waters 9 to 18 meters in depth for both parameters. These values could represent the sedimentation of dying algal masses or the precipitation of phosphate bearing minerals.

T-P STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.32600 MAX = 20.00000 AMEAN = 2.34755 STDDEV = 2.49349 GMEAN = 1.75368

MOM1 = 0.00000E 00 MOM2 = 0.62173E 01 MOM3 = 0.65596E 02 MOM4 = 0.10035E 04 SKEW = 0.42313E 01 KURT = 0.25962E 02

INTERVAL LENGTH = 1.09300

FREQUENCY	0	73	50	31	9	3	0	3	4	0	0	0	1	0	0	0	0	1	0	1

EACH • EQUALS 2 POINTS

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 72          •
 70          •
 68          •
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  6          •  •  •  •
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  2          •  •  •  •  •  •  •
-------------------------------------------------------------------------------
INTERVAL     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
```

T-P STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.81530 MAX = 22.80000 AMEAN = 3.17254 STDDEV = 3.11627 GMEAN = 2.51936

MOM1 = 0.00000E 00 MOM2 = 0.97111E 01 MOM3 = 0.12072E 03 MOM4 = 0.20294E 04 SKEW = 0.398938E 01 KURT = 0.21519E 02

INTERVAL LENGTH = 1.22138

FREQUENCY	0	75	52	25	7	5	5	2	0	0	1	0	0	0	0	1	2	0	0	1

EACH • EQUALS 2 POINTS

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  2          •  •  •  •  •  •  •
-------------------------------------------------------------------------------
INTERVAL     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
```

TABLE B-11

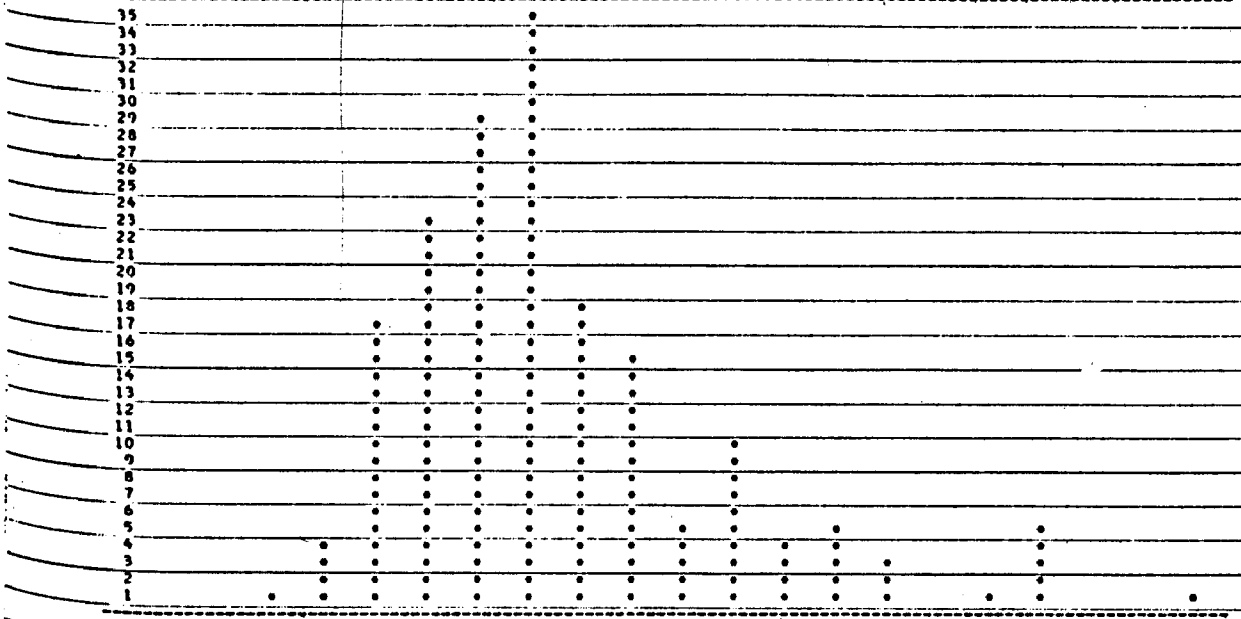
OPO4 STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00000 MAX = 2.80000 AMEAN = 0.93819 STDDEV = 0.48915 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.23927E 00 MOM3 = 0.15360E 00 MOM4 = 0.28062E 00 SKEW = 0.13123E 01 KURT = 0.49014E 01

INTERVAL LENGTH = 0.15555

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	4	17	23	29	35	18	15	5	10	4	5	3	0	1	5	0	0	1



OPO4 STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.60000 MAX = 4.20000 AMEAN = 1.57277 STDDEV = 0.62524 GMEAN = 1.46537

MOM1 = 0.00000E 00 MOM2 = 0.39093E 00 MOM3 = 0.28667E 00 MOM4 = 0.64695E 00 SKEW = 0.11728E 01 KURT = 0.42332E 01

INTERVAL LENGTH = 0.20000

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	5	16	30	31	24	19	13	6	7	5	5	9	3	2	0	0	0	0	1

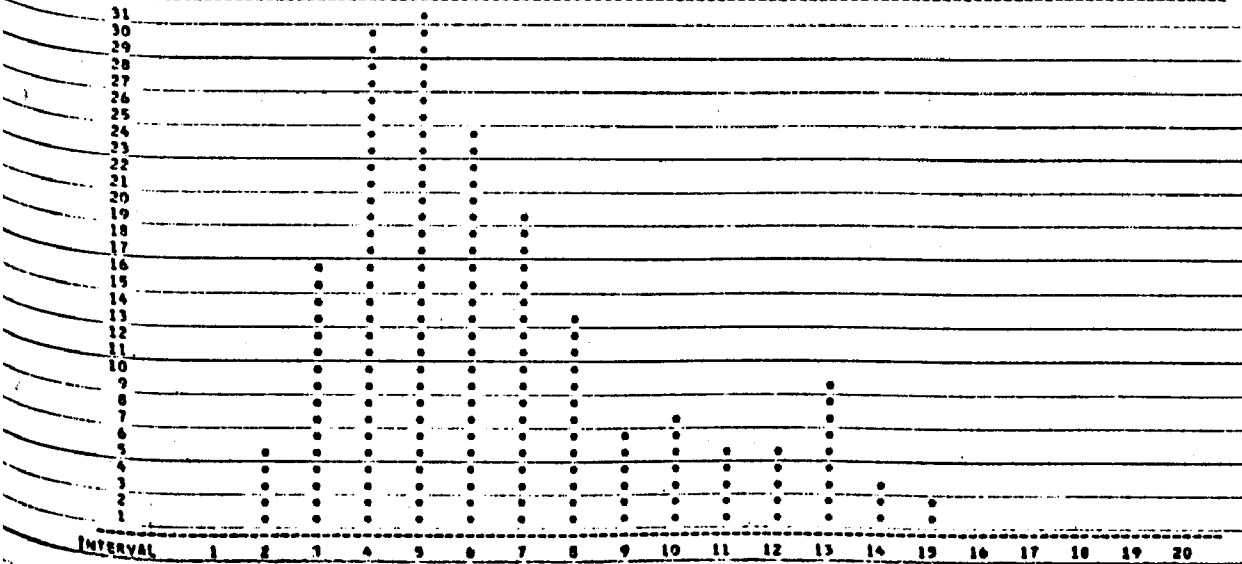


TABLE N-12

General Considerations

The symbol "pH" is used to designate the logarithm (base 10) of the reciprocal of the hydrogen-ion concentration. An excessive concentration of hydrogen ions may affect water adversely in several ways. The pH is related intimately to the concentration of many other substances, in that it reflects the degree of dissociation of the substances. Since the undisassociated compounds are frequently more toxic than the ionic forms, pH may be a significant factor in determining limiting or threshold concentrations. Such is the case, for example, in regard to ammonia, i.e., a high concentration of ammonium ions in water at a low pH may not be toxic, but if the pH is raised, toxicity may result owing to the increase in undissociated ammonium hydroxide (NH_4OH) and ammonia (NH_3) as illustrated below. This reaction proceeds towards the left under high pH or hydroxyl ion (OH^-) concentrations.

$$NH_3 + H_2O \rightleftharpoons NH_4OH \rightleftharpoons NH4^+ + OH^-$$

Owing to their origin in municipal water supplies, most domestic sewages are neutral or slightly alkaline. Many industrial wastes, on the other hand, are so strongly alkaline or acidic that they have a marked effect upon the pH of receiving waters.

The Aquatic Life Advisory Committee of the Ohio River Valley Water and Sanitation Commission (1955) concluded that direct lethal effects of pH on aquatic life are not produced within a range of 5 to 8.5 for most species of importance. However, natural productivity is most easily maintained within the range of about 6.5 to 8.2.

The effects of rapid pH changes on fish have been investigated. A majority of the species tested tolerated rapid changes in pH from 7.2 to 9.6, and from 8.1 to 6.0, (Wiebe, 1959).

Existing Conditions

The pH data in the hypolimnion of Onondaga Lake at Station 1 approximates a normal distribution, but somewhat more skewed toward higher values than are the data in the epilimnion. Mean and geometric mean values range from 7.4 to 7.7 for all zones. The epilimnion of each station shows a maximum value of 8.8 on July 30, 1969, Figure B-12, owing to periods of active photosynthesis as implied in Figures B-35 and B-37.

The slightly lower values in the hypolimnion can be attributed to the production of CO_2 and the inability of this gas to escape to the atmosphere, or be utilized in photosynthesis as occurs in the epilimnion. Thus the accumulation of CO_2 in the lower layers results in a reduced pH and in an increased alkalinity. The increased alkalinity is a partial function of the reduced rate of calcium carbonate ($CaCO_3$) precipitation at lower pH values and lower concentration of dissolved oxygen. The following equations illustrate the cause of increased alkalinity:

1. $CO_2 + H_2O \rightleftharpoons H_2CO_3$
2. $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
3. $Ca^{++} + HCO_3^- \rightleftharpoons CaCO_3 + H^+$

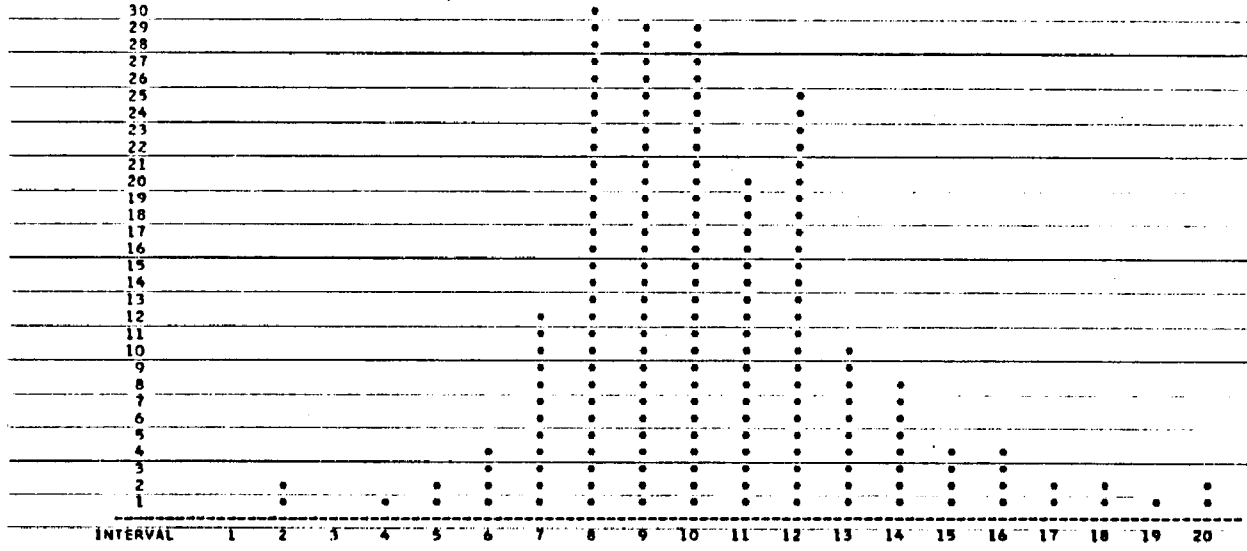
The length of arrows indicate the direction of the predominant reaction. Although there is precipitation of $CaCO_3$, (3), the rate is less than that of the epilimnion.

MIN = 6.55000 MAX = 8.80000 AMEAN = 7.64256 STDDEV = 0.30570 GMEAN = 7.63388

MOM1 = 0.00000E 00 MOM2 = 0.13374E 00 MOM3 = 0.27722E-01 MOM4 = 0.76969E-01 SKEW = 0.56680E 00 KURT = 0.41912E 01

INTERVAL LENGTH = 0.12500

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	2	0	1	2	4	12	30	29	29	20	25	10	8	4	4	2	2	1	2



PH STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 6.45000 MAX = 7.90000 AMEAN = 7.39765 STDDEV = 0.22389 GMEAN = 7.39416

MOM1 = 0.00000E 00 MOM2 = 0.50131E-01 MOM3 = -0.73487E-02 MOM4 = 0.13526E-01 SKEW = 0.65471E 00 KURT = 0.53821E 01

INTERVAL LENGTH = 0.08055

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	2	0	0	0	1	2	3	0	10	28	34	23	19	24	22	6	10	3	1

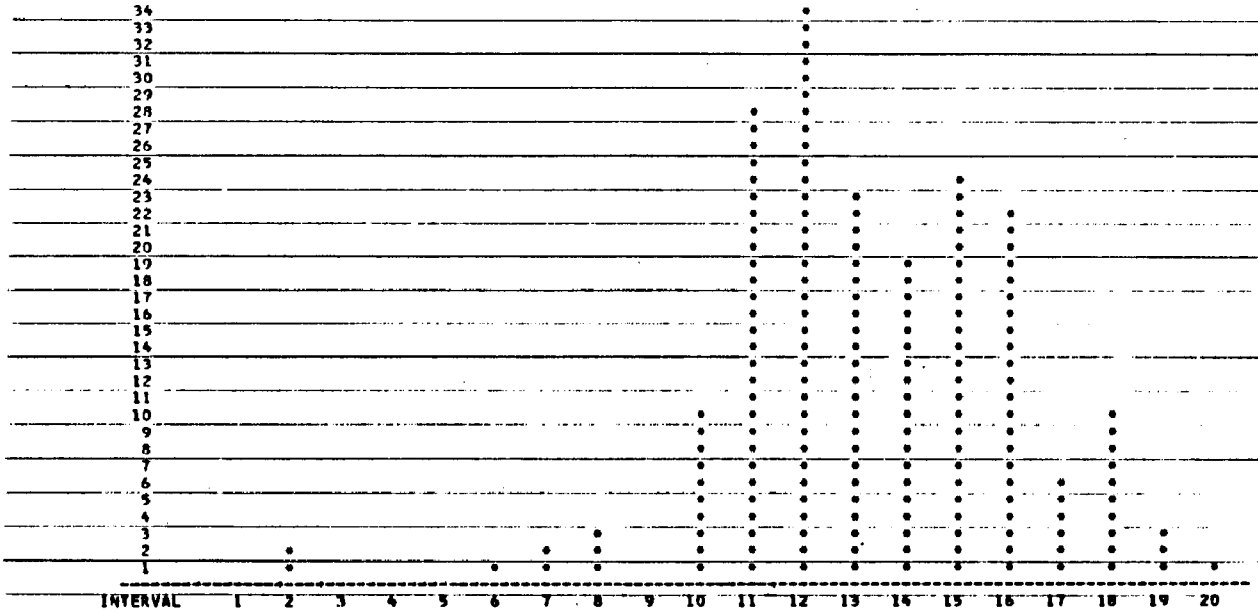


TABLE B-13

General Considerations

Sulfides in water are a result of the natural processes of decomposition, their concentrations being enhanced greatly by anaerobic conditions. Sewage and industrial wastes contribute sulfides, as well as some air pollutants. The presence of sulfides may in some cases be attributable to the action of sulfate-reducing bacteria in the presence of abundant sulfates, whereas sulfates may be the result of sulfide-oxidizing bacteria forms which are restricted to locations where hydrogen sulfide (H_2S) is present and oxygen is available. Hence both sulfides and sulfates are generally found in areas where one body of water with adequate oxygen content borders on another which supplies the H_2S, (McKee and Wolf, 1963).

Sulfate reducing, Desulfovibrio, bacteria are most common and important in flood water systems. They are obligate anaerobic (facultative) autotrophic organisms with an optimum growth pH of 7, but a growth range of 5.5 to 8.5. Optimum temperature range is 24° to 43° C., but they are found to exist at 0° - 100° C. They can grow in fresh water or brines of up to 30% sodium chloride, (McKee and Wolf, 1963). It has been reported that sulfides in the Thames Estuary are believed to be formed mainly by sulfate reducing bacteria rather than by the breakdown of sulfur containing organic compounds by Sulfhydryl splitting bacteria, (Gameson, A.L.H., 1958)

From October 1966 through November 1967 Onondaga County conducted an air pollution study through Syracuse University Research Corporation in which measurements of rates of sulfation were made by lead peroxide sampling. From the stations monitored it was estimated that the monthly deposition of sulfate could be as high as 0.24 mg/cm^2. This is based on a washout of the sulfates covering the surface area of the lake. At a residence time of 150 days estimated for the year 1969, this is equivalent to a concentration of 1.3 ppm throughout the entire Lake.

Existing Conditions

SULFATE

Data in both the epilimnion and hypolimnion tend toward a normal distribution. Geometric mean values were 180 and 182 mg/l for the epilimnion and hypolimnion respectively. The geometric mean of the hypolimnion of Station 2 is 185 mg/l. The epilimnion of Station 2 shows slightly less

values with a geometric mean of 175 mg/l. In general, however, there is little variation of sulfate values with depth except for the period August through October of 1969 in which 12 to 18 meter waters showed somewhat lower values, Figure B-13. Lower values may be due to conversion of sulfate to sulfide via sulfate reducers.

TOTAL DISSOLVED SULFIDES

Histograms, as well as Depth Synoptic (DS) plots of this parameter, portray the negative log to the base 10 of concentration in moles per liter. This was necessary in order to accommodate the wide range of total dissolved sulfide concentrations. Data distribution in the epilimnion tends to be tri-nodal, with a geometric mean of 5.26 or a concentration of 0.18 mg/l. The mean value of the epilimnion is 6.63 or a concentration of 0.007 mg/l.

Referring to the line plot of this parameter, Figure B-14, higher concentrations were observed in the hypolimnion than were observed in the epilimnion. In some cases, however, concentrations decreased from the surface waters to a depth of 6 meters. This could be attributable to sulfate reducers and/or air-borne sulfide particulate matter.

Concentrations in the hypolimnion showed more of a tendency towards normal distribution, with a geometric mean of 3.18 or a concentration of 21 mg/l. The mean of the hypolimnion values was 3.5 or a concentration of 10 mg/l. The higher values in the hypolimnion are due to the greater activity of sulfate reducing bacteria under anaerobic conditions.

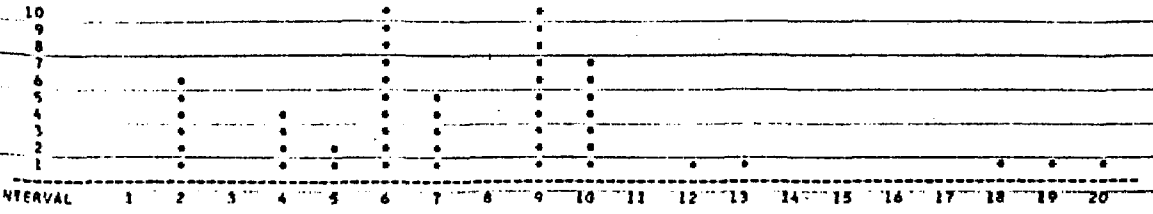
S STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00030 MAX = 14.08800 AMEAN = 6.51711 STDDEV = 4.28456 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.18356E 02 MOM3 = 0.69219E 02 MOM4 = 0.14536E 04 SKEW = 0.88009E 00 KURT = 0.43138E 01

INTERVAL LENGTH = 1.06049

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	6	0	4	2	10	5	0	10	7	0	1	1	0	0	0	0	1	1	1



S STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00030 MAX = 9.42000 AMEAN = 3.39105 STDDEV = 1.63992 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.26893E 01 MOM3 = 0.93643E 00 MOM4 = 0.44617E 02 SKEW = 0.21232E 00 KURT = 0.61689E 01

INTERVAL LENGTH = 0.52333

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	6	0	0	0	1	8	16	11	3	2	1	1	1	0	0	0	0	0	1

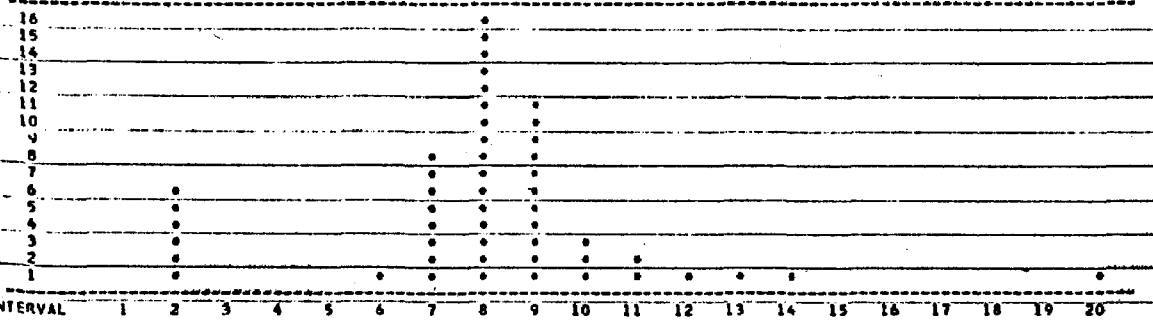


TABLE B-14

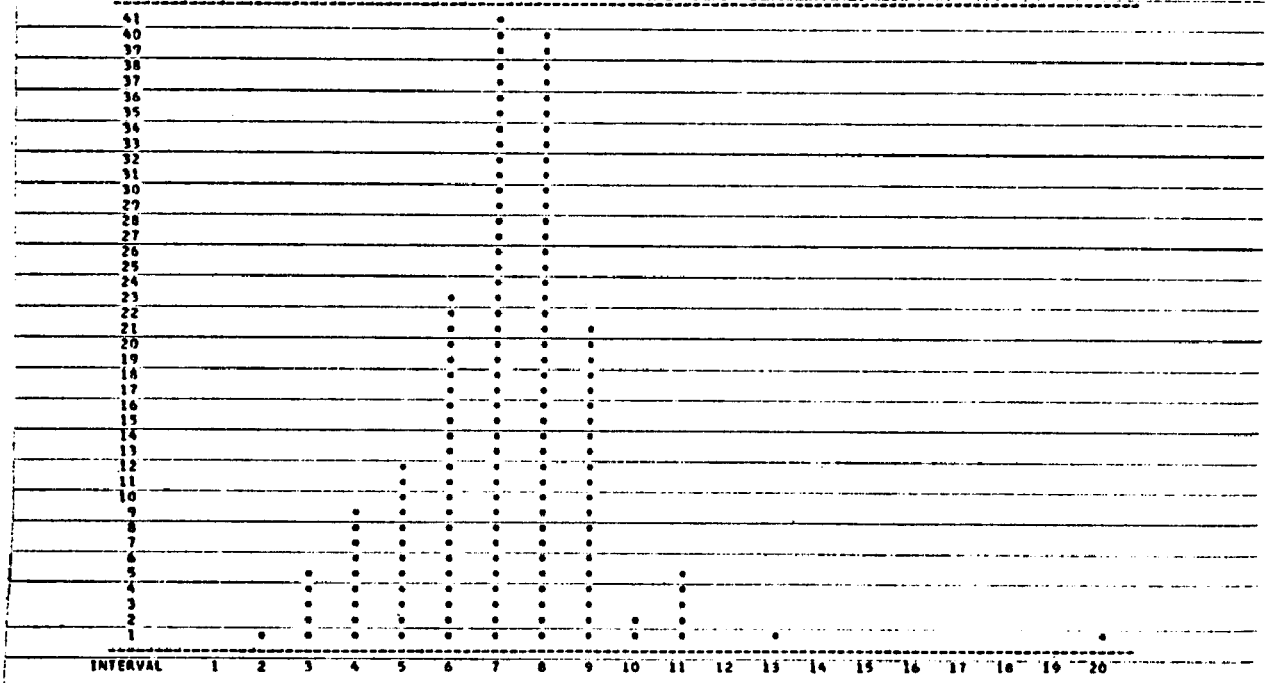
S04 STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 108.00001 MAX = 345.00006 AMEAN = 182.35836 STODEV = 26.97706 GMEAN = 180.43485

MOM1 = 0.00000E 00 MOM2 = 0.72776E 03 MOM3 = 0.23178E 05 MOM4 = 0.55144E 07 SKEW = 0.11806E 01 KURT = 0.10411E 02

INTERVAL LENGTH = 13.16666

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	5	9	12	23	41	40	21	2	5	0	1	0	0	0	0	0	0	1



S04 STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 90.00001 MAX = 265.00006 AMEAN = 184.41540 STODEV = 24.56907 GMEAN = 182.60632

MOM1 = 0.00000E 00 MOM2 = 0.60363E 03 MOM3 = -0.66789E 04 MOM4 = 0.20401E 07 SKEW = 0.46382E 00 KURT = 0.55990E 01

INTERVAL LENGTH = 9.72222

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	2	0	1	2	1	5	7	11	22	45	19	25	12	4	2	1	2	0	1

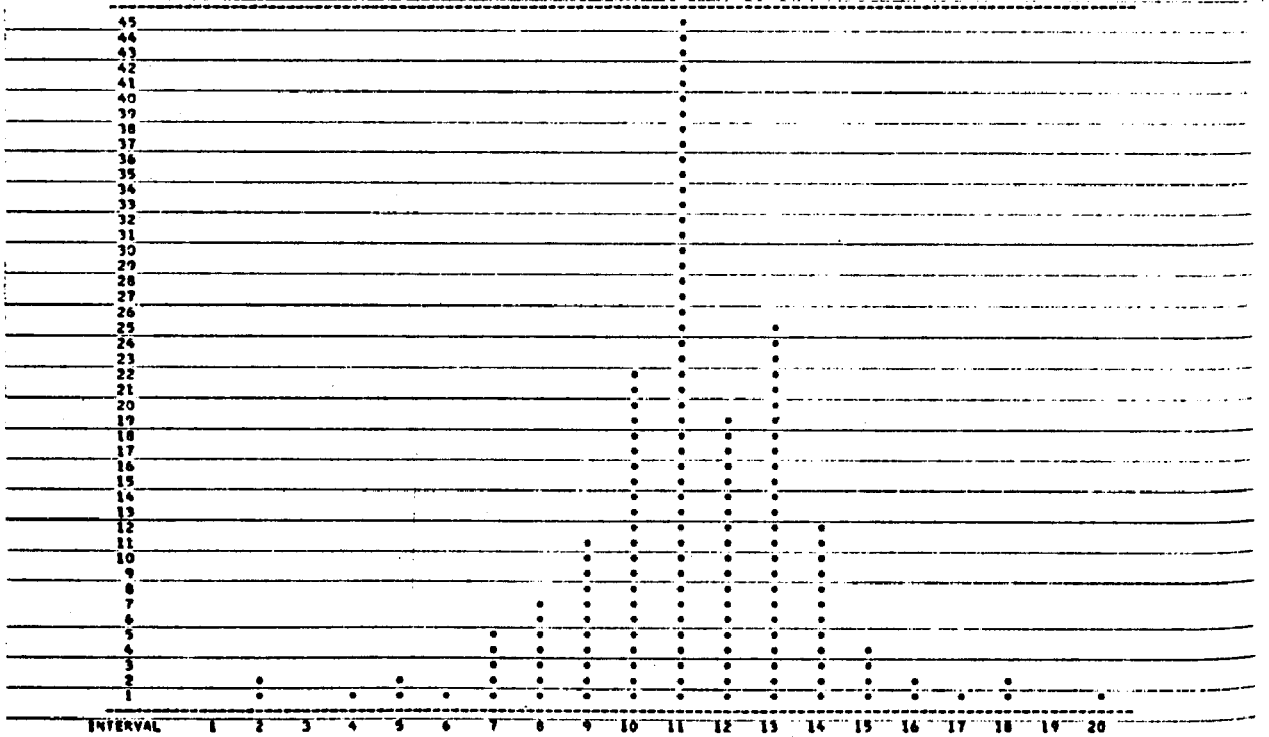


TABLE B-15

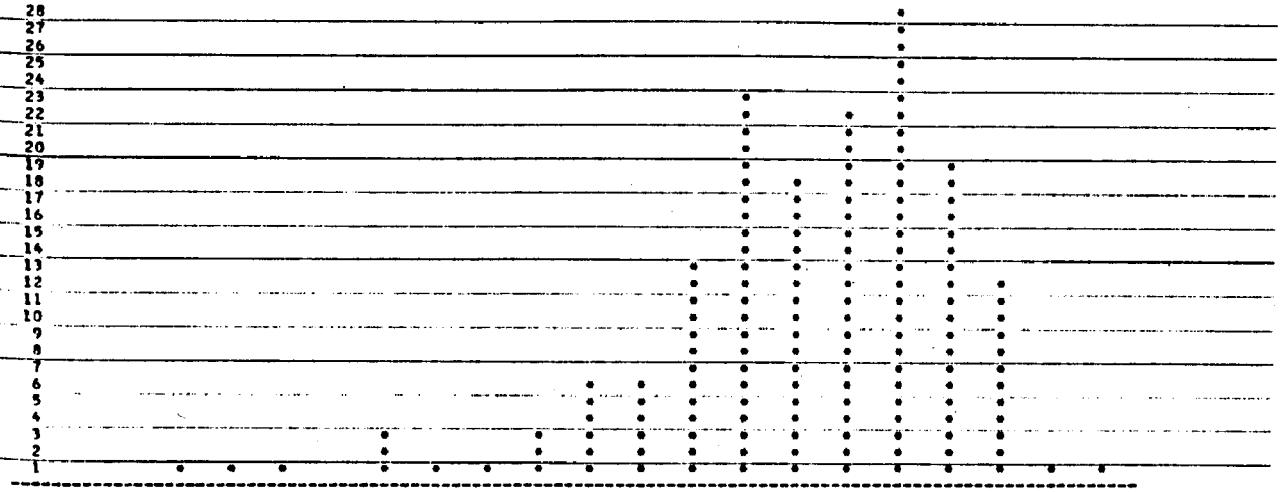
SO4 STAT 2 4/17/68 - 12/18/69 EPILIMNION

MIN = 68.00001 MAX = 224.20001 AMEAN = 177.56185 STODEV = 26.58361 GMEAN = 175.09506

MOM1 = 0.00000E 00 MOM2 = 0.70668E 03 MOM3 = -0.26125E 05 MOM4 = 0.28132E 07 SKEW = -0.13906E 01 KURT = 0.56331E 01

INTERVAL LENGTH = 8.67777

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	1	1	0	3	1	1	3	6	6	13	23	18	22	28	19	12	1	1



SO4 STAT 2 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 104.00001 MAX = 356.00006 AMEAN = 186.78256 STODEV = 28.02901 GMEAN = 184.77099

MOM1 = 0.00000E 00 MOM2 = 0.78562E 03 MOM3 = 0.32845E 05 MOM4 = 0.82677E 07 SKEW = 0.14915E 01 KURT = 0.13395E 02

INTERVAL LENGTH = 13.94444

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	3	0	6	5	25	40	28	22	7	0	0	0	0	1	0	0	0	0	1

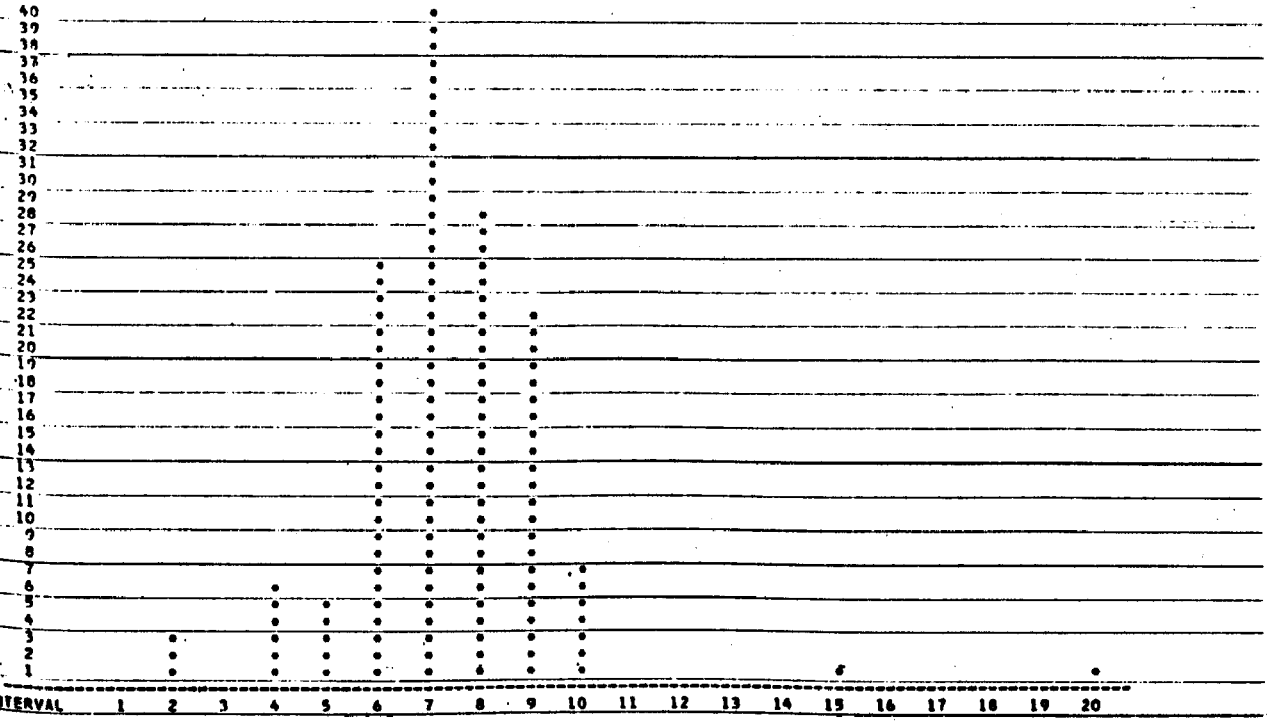


TABLE B-16

DISSOLVED OXYGEN

General Considerations

Perhaps the most widely used chemical parameter for assessing the condition of natural waters is dissolved oxygen (DO). Oxygen enters the water chiefly by diffusion from the air and by the photosynthetic activity of plants. The content of DO in water at equilibrium with a normal atmosphere is a function of the temperature and salinity of the water, the ability of water to hold oxygen decreasing with increases in temperature or dissolved solids. Increases in temperature also increase the respiratory rate of aquatic organisms, thereby decreasing the DO content of the water. Therefore natural waters, being something more than a container of distilled water, are seldom at equilibrium with, or saturated by, dissolved oxygen. Temperatures are changing and physical, chemical and biological activities are utilizing or liberating oxygen. The concentration of DO can also be an indirect indicator of the presence of other substances, i.e., low DO's may be accompanied by the presence of excessive carbon dioxide, ammonia sulfides and in some cases, cyanide, zinc, lead, copper or phenols. The presence of these toxic substances accents the lethal effect of low DO concentrations on aquatic life.

In nature, oxygen often varies with depth of water, especially in lakes and stagnant ponds. For this reason, fish may avoid the deeper cooler waters and be forced to remain in shallow water areas. Concentrations of DO near the bottom muds of the lakes and sluggish rivers, may approach zero. Under such conditions, the hatching of fish eggs has been delayed or prevented. The fish, hatching such eggs, may also be deformed.

In an effort to guarantee desirable fish populations, the New York State Classification System has set standards of not less than 5 mg/l for trout waters, and not less than 4 mg/l for non-trout waters for all classes of water with the exception of "D", the lowest class water, which is specified as not less than 3 mg/l. There is no provision within these classifications to allow for diurnal or seasonal fluctuations at any or all depths of the lake. Presently, Onondaga Lake falls under two classifications, namely, "B" and "C", as shown in Figure 1-2.

Existing Conditions

The geometric mean at Station 1 for the epilimnion is 3.8 mg/l with fairly frequent values down to 3.5 mg/l, and higher values with decreasing frequency. Comparable values were higher for Station 2 owing to the stabilization of input BOD in the

southern basin of the lake. The values above 10 mg/l in the epilimnion at Station 1 occur in the summertime and are attributable to photosynthetic oxygenation.

Except during the winter months (Dec. through Feb.), DO was entirely absent most of the time in considerable parts of the hypolimnion. The geometric mean is 1.1 mg/l. Less frequent values occur below 1 mg/l and scattered values representing higher concentrations range up to a maximum of 7 mg/l. These higher values are relatively infrequent. Even when oxygen did occur in the hypolimnion, values in excess of 1 mg/l were rare, (Figure B-37).

On the basis of laboratory tests conducted during this Study, the depletion of oxygen by the bottom sediments of the lake is negligible. The BOD contour plot (Figure B-35) shows high BOD values in the hypolimnion prior to the 1968 "Period of Overturn". However, during this entire "Period", BOD values decrease at an increasing rate, toward the lake bottom. No increase in BOD in the lower waters is apparent during the vernal and autumnal "Periods" of 1969. In general, the contour plot indicates that little BOD was contributed to the overlying waters during periods of overturn when the maximum effect of benthic demand was expected.

Thus the major portion of BOD observed in the hypolimnion must be due either to materials discharged to the lake or in-lake generated BOD, i.e., algae and zooplankton. However, sulfides exert a significant oxygen demand. BOD tests were calculated so as to reflect true biochemical oxygen demand and not immediate oxygen demand resulting from hydrogen sulfide or other gases emanating from the bottom sediments. Sulfides are discussed further in this Appendix and again under "Gases in Sediments" in Section 12.

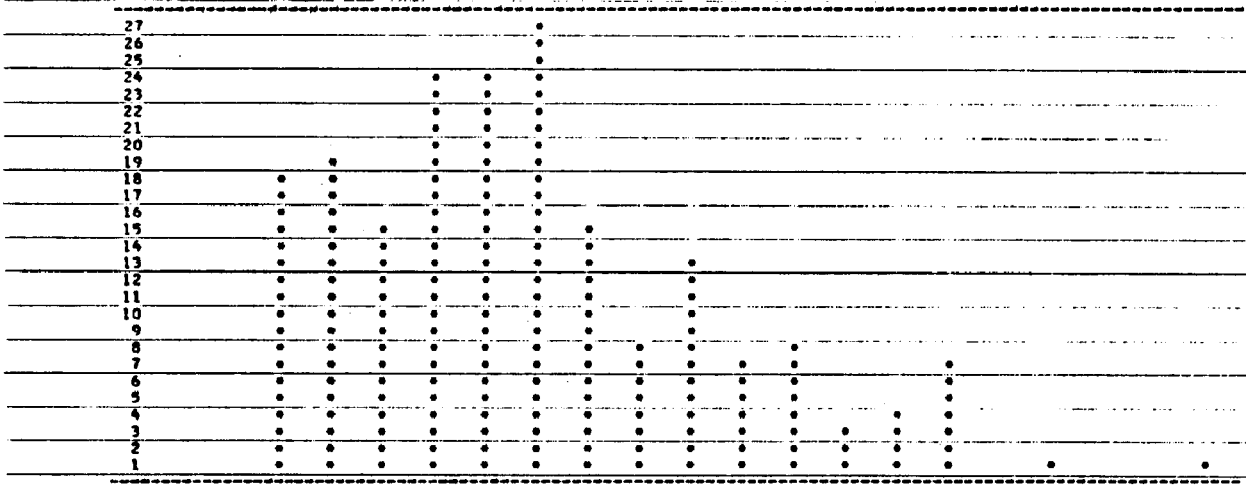
DO STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.40000 MAX = 15.00000 AMEAN = 4.79455 STDDEV = 2.92011 GMEAN = 3.79760

MOM1 = 0.00000E 00 MOM2 = 0.85270E 01 MOM3 = 0.19359E 02 MOM4 = 0.24058E 03 SKEW = 0.77749E 00 KURT = 0.33087E 01

INTERVAL LENGTH = 0.81111

FREQUENCY 0 18 19 15 24 24 27 15 8 13 7 8 3 4 7 0 1 0 0 1



DO STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 7.10000 AMEAN = 0.96461 STDDEV = 1.65113 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.27262E 01 MOM3 = 0.90998E 01 MOM4 = 0.48325E 02 SKEW = 0.20215E 01 KURT = 0.65019E 01

INTERVAL LENGTH = 0.39444

FREQUENCY 0 115 17 14 8 1 6 8 3 3 6 4 1 1 0 0 3 3 1 1

EACH • EQUALS 3 POINTS

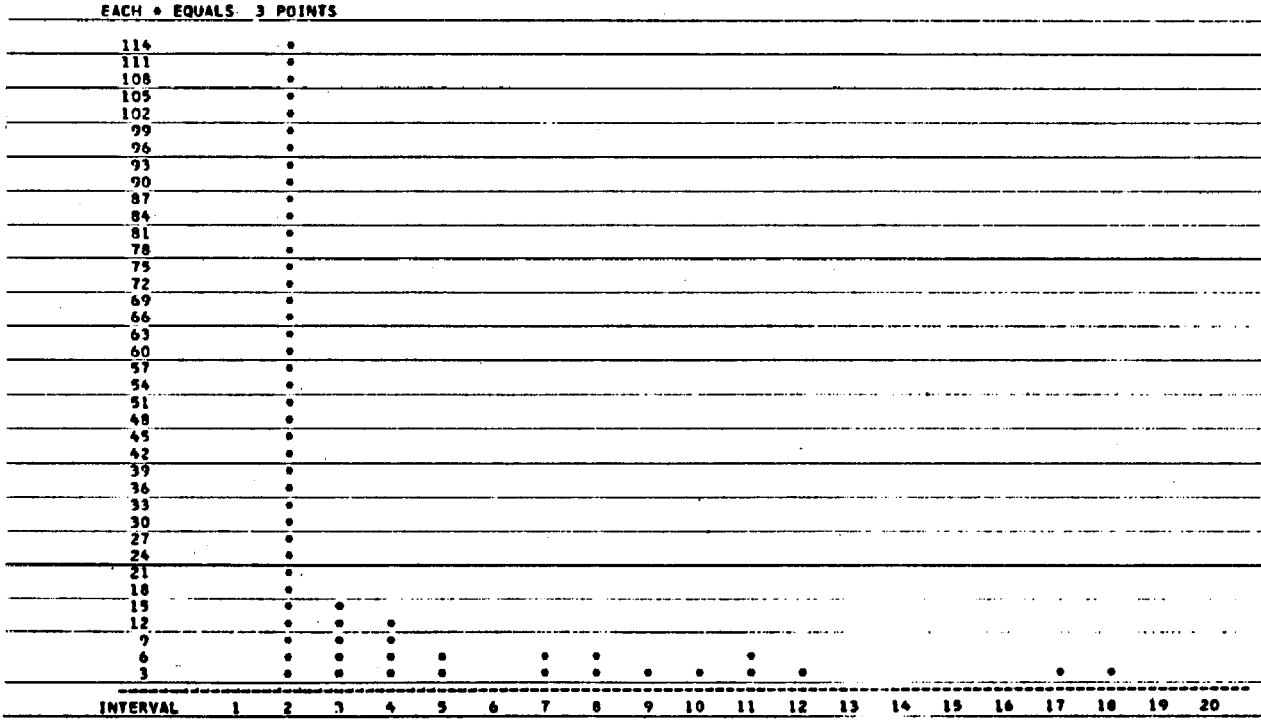


TABLE B-17

CALCIUM

General Considerations

Calcium salts and calcium ions are among the most commonly encountered substances in water. They may result from the leaching of soils and other natural sources or they may be contained in sewage and many types of industrial wastes, (McKee & Wolf, 1963).

Calcium in water reduces the toxicity of many chemical compounds to fish and other aquatic fauna. For example, mature fish have been killed by 0.1 mg/l of lead in water containing only 1 mg/l of calcium but have not been harmed by this amount of lead in water containing 50 mg/l of calcium. A concentration of 50 mg/l of calcium has cancelled the toxic effect upon some fish of 2 mg/l of zinc and 0.7 mg/l of lead, (Jones, J.R.E., 1938). Fish have been reported to survive (calcium chloride) concentrations of 2,500 to 4,000 mg/l of calcium, (Doudoroff & Katz, 1953).

Many calcium compounds precipitate and/or absorb phosphorus compounds. Some of the more significant minerals that do so are hydroxyapatite, calcite and fluorapatite. These minerals are discussed in detail in Section 12.

Existing Conditions

The data for both the epilimnion and the hypolimnion tends towards a normal distribution. The geometric mean for the epilimnion is 605, whereas in the hypolimnion it is 828 mg/l. Concentrations of calcium for the hypolimnion are significantly greater than that of the epilimnion; the mean of the epilimnion being 639, whereas the mean of the hypolimnion is 849. Calcium and sodium represent the major cations in Onondaga Lake and hence one can expect similarities with chlorides, the major anion in the lake. Thus the higher concentrations in the epilimnion and progressively greater concentrations with depth, (Figure B-16) are not reasonable.

The close similarities between Stations 1 & 2 in the epilimnetic any hypolimnetic zones respectively in regards to the distribution of data, mean, and geometric mean values are quite interesting in that the Nine Mile Creek discharge contributed 71% of the Ca measured during the sampling period. Similar observations were made for Cl in which Nine Mile Creek contributed 54% of the Cl measured. Fluctuations of all calcium values with time irrespective of depth, correlate closely with the chloride data. The runoff data are related inversely as well. The significance of Ca in the pH-alkalinity relationship is described in Section 10.

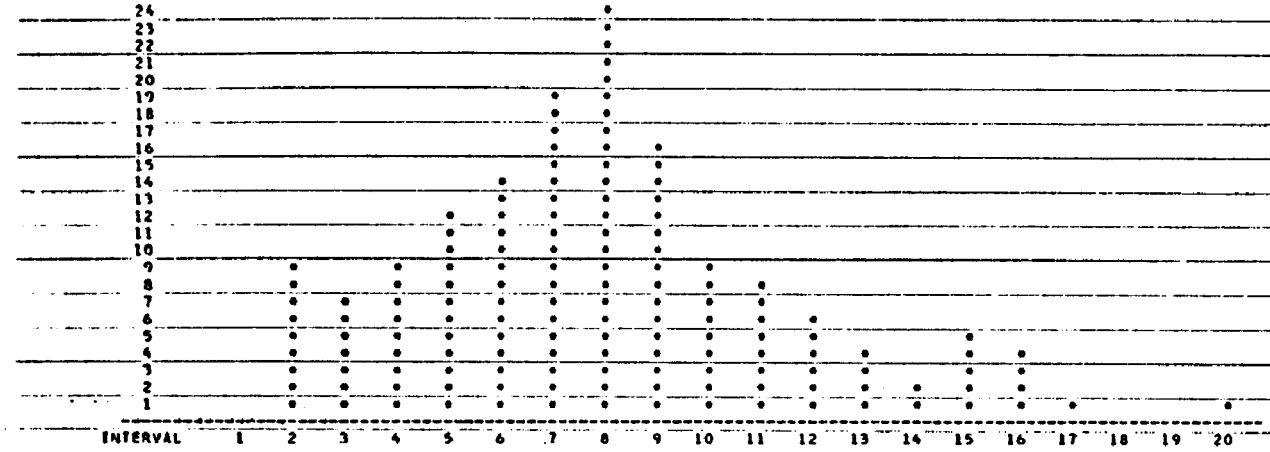
CA STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 260.00006 MAX = 1320.00024 AMEAN = 639.37024 STDDEV = 209.50692 GMEAN = 605.10925

MOM1 = 0.00000E 00 MOM2 = 0.43893E 05 MOM3 = 0.52607E 07 MOM4 = 0.61458E 10 SKEW = 0.57207E 00 KURT = 0.31899E 01

INTERVAL LENGTH = 58.88889

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	9	7	9	12	14	19	24	16	9	8	6	4	2	5	4	1	0	0	1



CA STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 156.80001 MAX = 1340.00024 AMEAN = 849.05578 STDDEV = 182.72424 GMEAN = 827.57458

MOM1 = 0.00000E 00 MOM2 = 0.33388E 05 MOM3 = 0.18695E 07 MOM4 = 0.41409E 10 SKEW = 0.30643E 00 KURT = 0.37146E 01

INTERVAL LENGTH = 69.73333

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	0	0	0	0	0	6	17	26	21	28	9	12	10	6	9	3	1	1

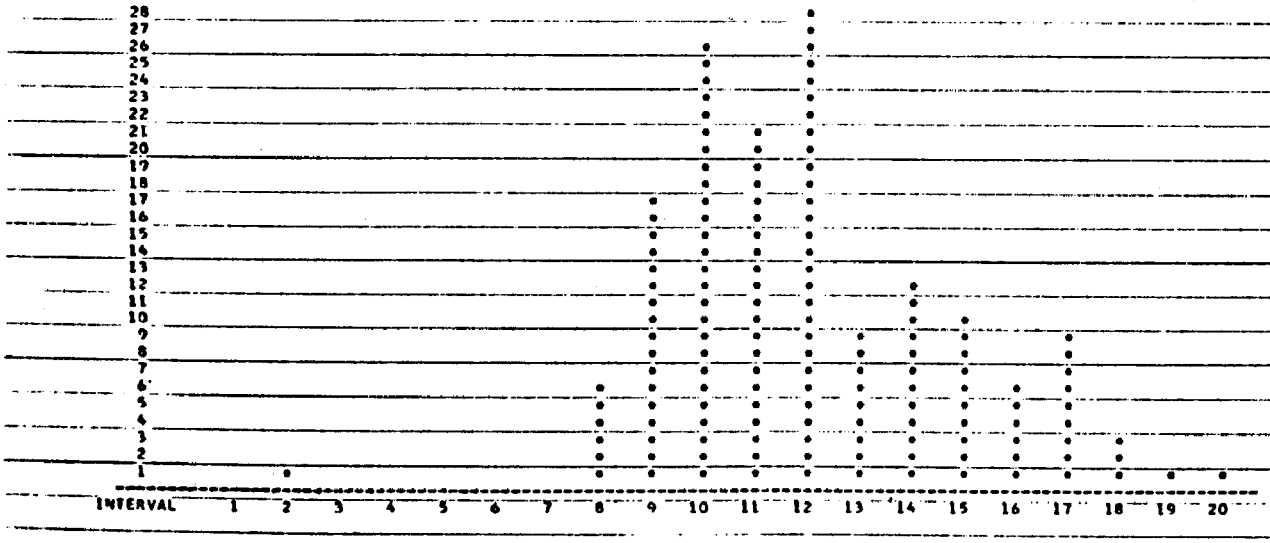


TABLE B-18

SODIUM

General Considerations

This very active metal does not occur free in nature. Owing to the fact that most sodium salts are extremely soluble in water, any sodium that is leached in soil or discharged to streams by industrial wastes will remain in solution, (McKee & Wolf, 1963). Sodium chloride in water may be of natural origin, or may be introduced as a component of sewage, industrial wastes, salt and brine works, oil wells, dairies, or spent irrigation waters. Sodium and chloride ions in natural waters are common but normally they do not dominate there as they do in sea water. Onondaga Lake with its high values of sodium and chloride is pressing that distinction, (McKee & Wolf, 1963).

The threshold concentrations of sodium chloride (NaCl) in natural waters reported for immobilization of some Daphnia and other fish-food organisms range from 2,100 to 6,143 mg/l, (Anderson, B.G., 1946). The resistance of Daphnia magna to NaCl appears to vary with the oxygen tension. At 6.4 mg/l of dissolved oxygen the threshold toxicity level of NaCl was 5,093 mg/l, but at 1.48 mg/l of DO, the threshold for NaCl was only 3,170 mg/l, (Fairchild, E.J., 1955). Many small crustacea and fishfry are immobilized by concentrations above 3,100 mg/l, (Anderson, B.G., 1948). In general concentrations of NaCl that have been found to immobilize or kill fresh-water fish range from a low of 1,270 to a high of 50,000 mg/l.

On the other hand, NaCl has been found to decrease the relative toxicity of some metalic compounds toward fish, (Jones, J.R.E., 1940). NaCl is antagonistic to the toxicity of calcium and potassium chlorides, (Garrey, W.C., 1916). A concentration of 50 mg/l of NaCl has greatly increased the antagonistic effect of sodium nitrate toward copper sulfate poisoning of fish, (Cole, A.E., 1941). The toxicity of NaCl toward fish has been found to be decreased by calcium chloride, (Garrey, W.C., 1916). NaCl is less toxic to fish than the chlorides of potassium, magnesium and calcium.

Existing Conditions

The data for Stations 1 & 2 in both the epilimnion and the hypolimnion tend towards a normal distribution with some skewness toward lower values.

Values in the epilimnion (mean equal to 555 mg/l) are less than those of the hypolimnion (mean equal to 670 mg/l). The chloride distribution in the lake follows a similar pattern. The Nine Mile Creek discharge represents 51% of the total Na measured. All values of sodium, irrespective of depth, also vary much in the same manner as the chloride data, and can be inversely related to runoff.

NA STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 179.00033 MAX = 1170.00024 AMEAN = 554.54687 STDDEV = 179.87377 GMEAN = 528.05493

MOM1 = 0.00000E 00 MOM2 = 0.32354E 05 MOM3 = 0.60639E 07 MOM4 = 0.41622E 10 SKEW = 0.10619E 01 KURT = 0.39760E 01

INTERVAL LENGTH = 55.05555

FREQUENCY	0	1	3	6	14	20	28	22	13	8	7	6	5	5	3	2	1	2	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

NA STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 415.00006 MAX = 1100.00024 AMEAN = 669.75940 STDDEV = 129.39816 GMEAN = 658.58862

MOM1 = 0.00000E 00 MOM2 = 0.16743E 05 MOM3 = 0.28066E 07 MOM4 = 0.13208E 10 SKEW = 0.12954E 01 KURT = 0.47113E 01

INTERVAL LENGTH = 30.05555

FREQUENCY	0	1	2	5	21	25	19	23	16	10	4	4	3	3	2	4	1	1	1	2
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE B-19

POTASSIUM

General Considerations

Potassium (K) is one of the most active metals and reacts vigorously with oxygen in water. For that reason it is not found free in nature but only in the ionized or molecular form. K resembles sodium in many of its properties, and K salts can be substituted for sodium salts in many industrial applications, (McKee & Wolf, 1963). It has been reported that the threshold concentrations of K for fish in different kinds of water are about 400 mg/l when potassium chloride (KCl), nitrate, or sulfate are used, (McKee & Wolf, 1963). Of the chlorides of sodium, calcium, potassium and magnesium, KCl is most toxic to fish, (Brandt, H.J., 1946). While calcium and sodium chlorides tend to nullify the effect of KCl, KCl has no antagonistic affect upon the toxicity of the others, (Garrey, W.C., 1916).

The threshold concentration of KCl for immobilization of Daphnia magna is reported to be 373 to 432 mg/l, (Anderson, B.G., 1944). In Lake Erie water at 20 to 25° C the threshold concentration for Daphnia magna was found to be 430 mg/l, (Anderson, B.G., 1948). Perch have been found to survive concentrations as high as 1,360 mg/l of KCl for an exposure period of three days, (Young, R.T., 1923).

It has been observed that K stimulates plankton growth, (Lackey & Sawyer, 1945). The content of K in lakes in Germany, Austria and Skandanavian countries is reported to vary from 0.4 to 1.5 mg/l in oligotrophic and mesotrophic lakes, and as high as 5-6 mg/l in very eutrophic lakes, (Hoell, K., 1951).

Existing Conditions

The distribution of data on K for both the epilimnion and the hypolimnion tend towards normalcy. The mean and geometric mean for both zones are nearly equal, approximately 17.0 mg/l. This parameter does not appear to be as related to chloride distribution as much as calcium and sodium, in that potassium concentrations in the hypolimnion are not significantly greater than those in the epilimnion and the concentrations of potassium are relatively the same between the epilimnion and the hypolimnion.

Greater than 27% of the K discharged to the lake is from Nine Mile Creek. The fact that the distribution of data is similar from epilimnion to hypolimnion as well as from

Station 1 to Station 2 indicates a mechanism effectively mixing this chemical species.

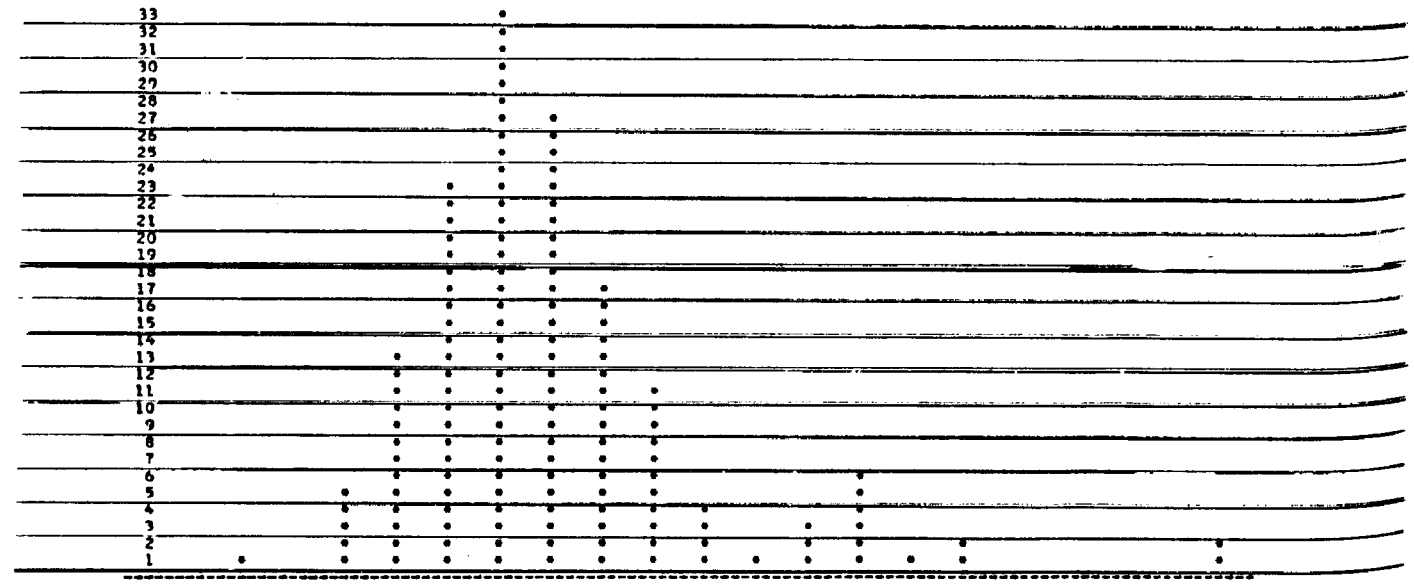
Similarities from epilimnion to hypolimnion may be attributable to mineral stability relationships, whereas horizontal mixing from Stations 1 & 2 is more than likely attributable to the hydromechanics of the lake such as lake currents.

MIN = 0.48200 MAX = 54.64100 AMEAN = 17.17831 STDDEV = 8.67883 GMEAN = 15.18146

MOM1 = 0.00000E 00 MOM2 = 0.75322E 02 MOM3 = 0.10811E 04 MOM4 = 0.39573E 05 SKEW = 0.16538E 01 KURT = 0.69751E 01

INTERVAL LENGTH = 3.00883

FREQUENCY	1	0	5	13	23	33	27	17	11	4	1	3	6	1	2	0	0	0	0	2
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20



K STAT 1 4717/68 - 12718/69 HYPOLIMNION

MIN = 3.45400 MAX = 53.73200 AMEAN = 17.79911 STDDEV = 7.44824 GMEAN = 16.42094

MOM1 = 0.00000E 00 MOM2 = 0.55476E 02 MOM3 = 0.66536E 03 MOM4 = 0.22075E 05 SKEW = 0.16102E 01 KURT = 0.71729E 01

INTERVAL LENGTH = 2.79322

FREQUENCY	0	3	7	9	23	57	17	10	4	5	5	4	2	1	1	1	0	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

EACH • EQUALS 2 POINTS

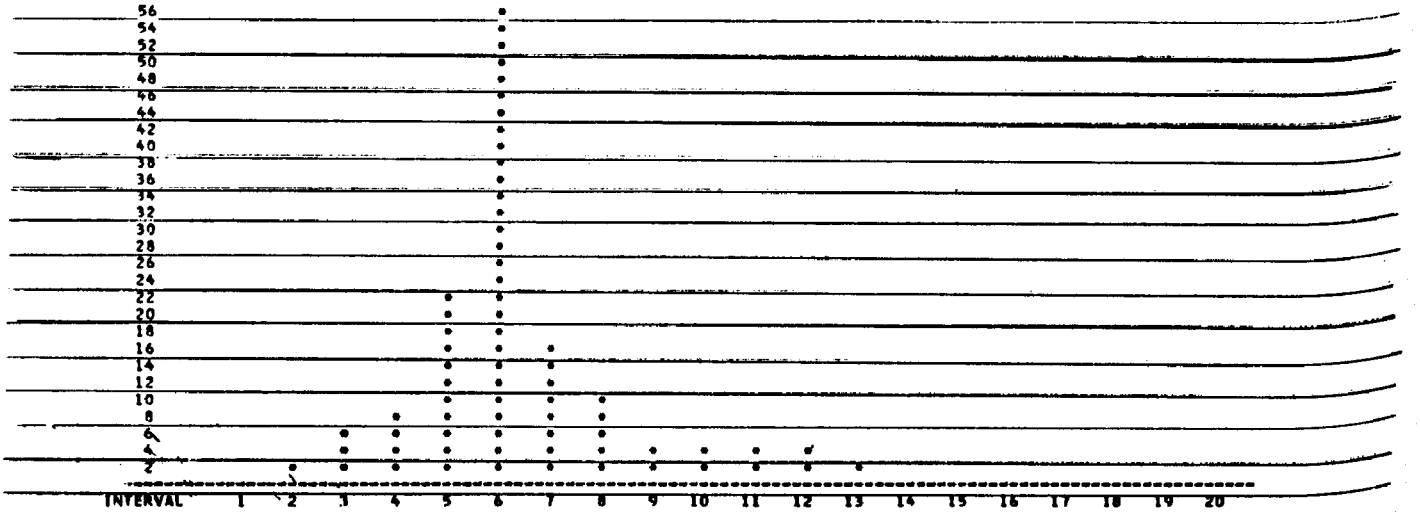


TABLE B-20

MAGNESIUM

General Considerations

Because magnsium (Mg) is very active chemically, it is not found in the elemental state in nature. With the exception of the hydroxide at high pH values, magnesium salts are very soluble. At pH 7, Mg ions theoretically can be present to the extent of 28,800 grams/l, but at pH 10 the maximum possible concentration of Mg ions would be 28.8 mg/l, and at pH 11 only 0.288 mg/l. In general, the pH values in Onondaga Lake have ranged from 6.0 to 9.0. Minerals such as dolomite can significantly affect the presence of Mg in water.

It has been found that magnesium chloride (MgCl) added to water decreased the toxicity of calcium and potassium chlorides toward fresh water fish, and that calcium chloride decreased the toxicity of MgCl, (Garrey, W.C., 1916). Concentrations of MgCl that have been reported to have killed fresh water fish range from 476 to 20,000 mg/l at various exposure times.

Some fish food organisms, such as Daphnia and other cladocerans are less tolerant of MgCl from 740 to 3,500 mg/l, (Anderson, B.G., 1948).

Existing Conditions

The distribution of data from epilimnion to hypolimnion at Station 1 is similar, resembles that of K, and indicates a good distribution of this chemical species with depth.

The mean and geometric mean for both zones are also nearly equal indicating little relationship to chloride distribution.

It is interesting to examine the distribution of Mg data in the light of Onondaga Creek as the major source of Mg (45%). Upon close inspection of the creek data (not shown), it was found that concentrations Mg in Onondaga and Nine Mile Creeks were relatively equal in magnitude with the exception of two measurements in November of 1969, in which Onondaga Creek showed concentrations of 9 to 10 times higher than was otherwise observed. Line plots of Mg, (Figure B-19), show a clear lack of stratification of this species with depth. However, variations in magnitude with time are pronounced. These variations may be inversely related to runoff. Since Onondaga and Nine Mile Creeks represent the two largest sources of Mg discharged to the lake, it follows that this chemical species would be most sensitive to runoff effects.

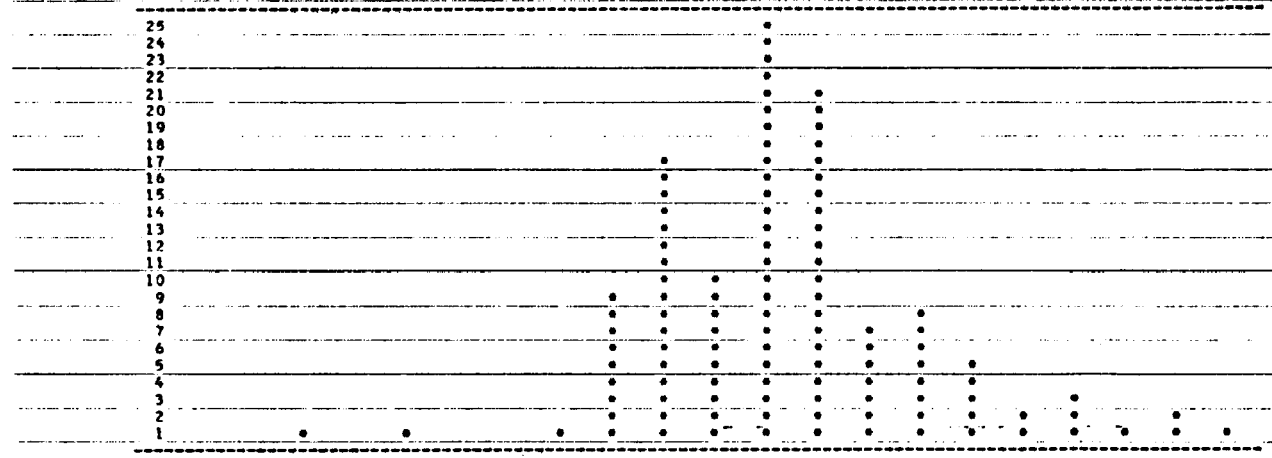
MG STAT 2 4/17/68 - 12/18/69 EPILIMNION

MIN = 7.70000 MAX = 48.20000 AMEAN = 29.89258 STDDEV = 6.23592 GMEAN = 29.17901

MOM1 = 0.00000E 00 MOM2 = 0.38886E 02 MOM3 = 0.65714E 02 MOM4 = 0.70132E 04 SKEW = 0.27099E 00 KURT = 0.46378E 01

INTERVAL LENGTH = 2.25000

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	0	1	0	0	1	9	17	10	25	21	7	8	5	2	3	1	2	1



MG STAT 2 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 22.95000 MAX = 46.50000 AMEAN = 31.48860 STDDEV = 5.76371 GMEAN = 30.99147

MOM1 = 0.00000E 00 MOM2 = 0.33220E 02 MOM3 = 0.15161E 03 MOM4 = 0.36279E 04 SKEW = 0.79184E 00 KURT = 0.32874E 01

INTERVAL LENGTH = 1.30833

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	9	8	4	3	13	15	13	6	4	5	2	3	7	0	0	0	3	3	1

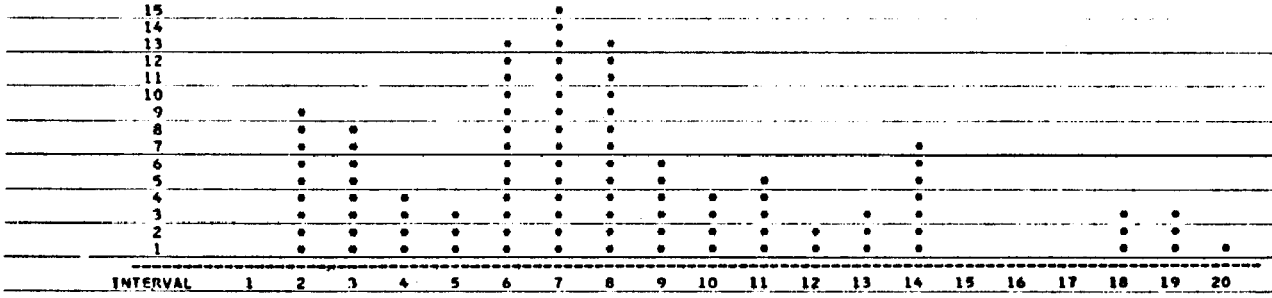


TABLE B-21

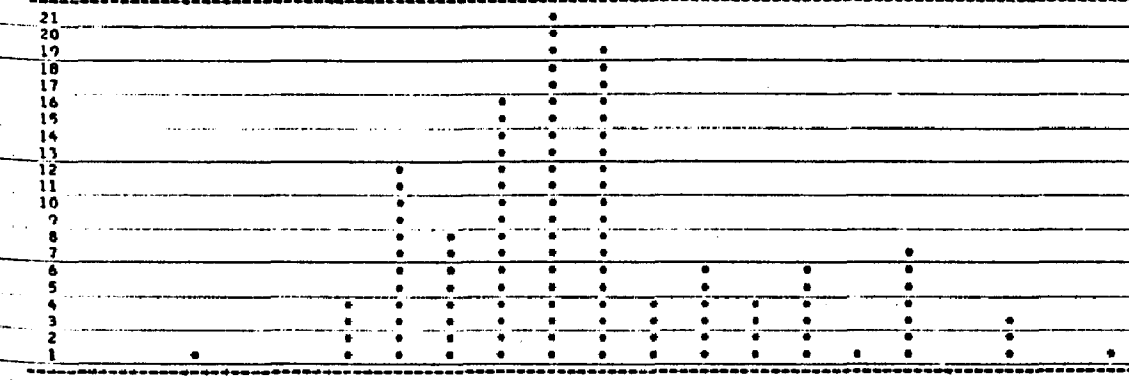
HG STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 15.00000 MAX = 48.40000 AMEAN = 30.38459 STDDEV = 6.12298 GMEAN = 29.80058

MOM1 = 0.00000E 00 MOM2 = 0.37490E 02 MOM3 = 0.18391E 03 MOM4 = 0.49373E 04 SKEW = 0.80118E 00 KURT = 0.35126E 01

INTERVAL LENGTH = 1.85555

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	0	0	4	12	8	16	21	19	4	6	4	6	1	7	0	3	0	1



HG STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 21.90130 MAX = 48.40000 AMEAN = 30.99429 STDDEV = 5.62287 GMEAN = 30.51592

MOM1 = 0.00000E 00 MOM2 = 0.31616E 02 MOM3 = 0.15279E 03 MOM4 = 0.35855E 04 SKEW = 0.85949E 00 KURT = 0.35868E 01

INTERVAL LENGTH = 1.47216

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	9	8	5	4	23	16	17	5	5	2	4	3	6	2	2	0	1	1	1

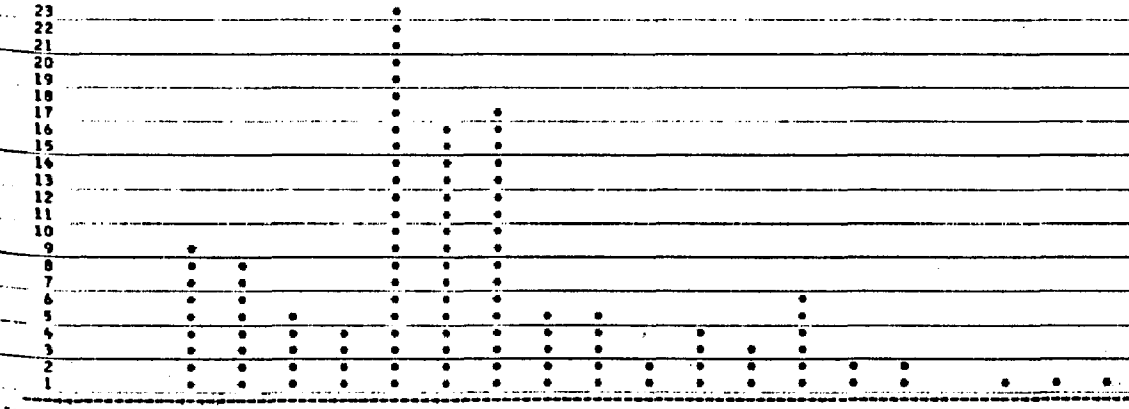


TABLE B-22

CONDUCTIVITY

General Considerations

Natural inland waters usually contain, in solution, relatively small quantities of mineral salts, but in waters exposed to natural brine deposits and/or various chemical wastes, the salt concentration may rise to levels harmful to living organisms because of the increase in osmotic pressure. Conductivity reflects the total ion concentration of water. It is reported as specific electrical conductance, the reciprocal of the resistance in ohms of a column of solution one centimeter, in depth at a specified temperature, (McKee & Wolf, 1963), 24° C in the case of Onondaga Lake

All substances in solution in the water collectively exert osmotic pressure on the organisms living in it, and the aquatic life is adapted to the conditions imposed upon the water by its dissolved constituents. Most species can tolerate some changes in the relative amounts of salt normally present if the total concentration is not exceeded. However, wide variations in the total salinity, or in the concentrations of individual salts, can have far-reaching effects upon stream fauna, (McKee & Wolf, 1963). It has been stated that a specific conductance of 4,000 X 10^{-6} mhos at 25° C is approximately the upper limit of ionizable salts tolerated by fish in mixtures of sodium, magnesium and calcium compounds in gas well waters, (Ellis, M.M., 1943).

Existing Conditions

The distribution of data for the epilimnion of Station 1 is noticeably different than that of the hypolimnion. Whereas the distribution is skewed towards higher values in the epilimnion, the distribution tends more towards normalcy in the hypolimnion, with relatively frequent occurrence of high values. The mean and geometric mean of the epilimnion, 4,625 and 4,533 mg/l respectively are markedly less than the corresponding values in the hypolimnion of 5,810 and 5,746 mg/l. Since the parameters Cl, Ca, and Na represent the major ionic species in the lake, it is not surprising to find that conductivity values are higher in the hypolimnion; and that conductivity increased progressively with increasing depth. The chemical species above act in the same way in these aspects.

In comparison to Station 2, the magnitude of mean and geometric mean for the epilimnetic waters are approximately the same, as well as the corresponding values for the hypolimnetic

waters. However, the distribution of data for the epilimnetic waters is noticeably different from Station 1 to Station 2. The difference in epilimnetic waters may be attributable to direct flow of portions of Nine Mile Creek to the lake outlet, which would influence the values of Station 2 but not that of Station 1. It should be noted however, that a similar distribution was not observed for the Cl data.

The trends of conductivity tend to mimic those of chlorides, except tha the former increased in magnitude at a greater rate in the hypolimnetic waters from June to October of 1969, (Figure B-20). The above are related to runoff as in the Cl data.

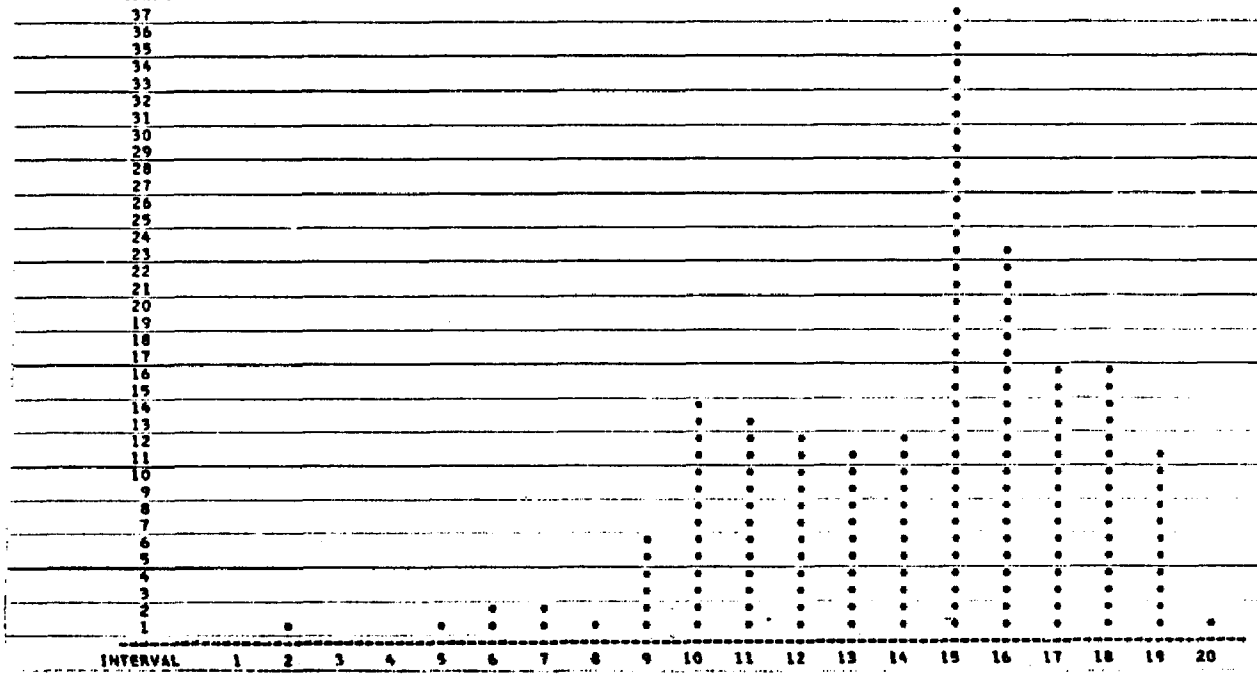
COND STAT 2 4/17/68 - 12/18/69 EPILIMNION

MIN = 1400.00024 MAX = 6100.00098 AMEAN = 4715.11231 STDDEV = 847.16064 GMEAN = 4624.93946

MOM1 = 0.00000E 00 MOM2 = 0.71768E 06 MOM3 = -0.46593E 09 MOM4 = 0.18472E 13 SKEW = 0.76635E 00 KURT = 0.35864E 01

INTERVAL LENGTH = 261.11114

FREQUENCY	0	1	0	0	1	2	2	1	6	14	13	12	11	12	37	29	16	16	11	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20



COND STAT 2 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 4200.00098 MAX = 7600.00098 AMEAN = 5869.31446 STDDEV = 849.10778 GMEAN = 5808.83497

MOM1 = 0.00000E 00 MOM2 = 0.72098E 06 MOM3 = 0.24224E 09 MOM4 = 0.11481E 13 SKEW = 0.39570E 00 KURT = 0.22087E 01

INTERVAL LENGTH = 180.88891

FREQUENCY	0	3	3	3	10	5	20	18	25	5	9	11	3	1	4	9	10	11	2	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

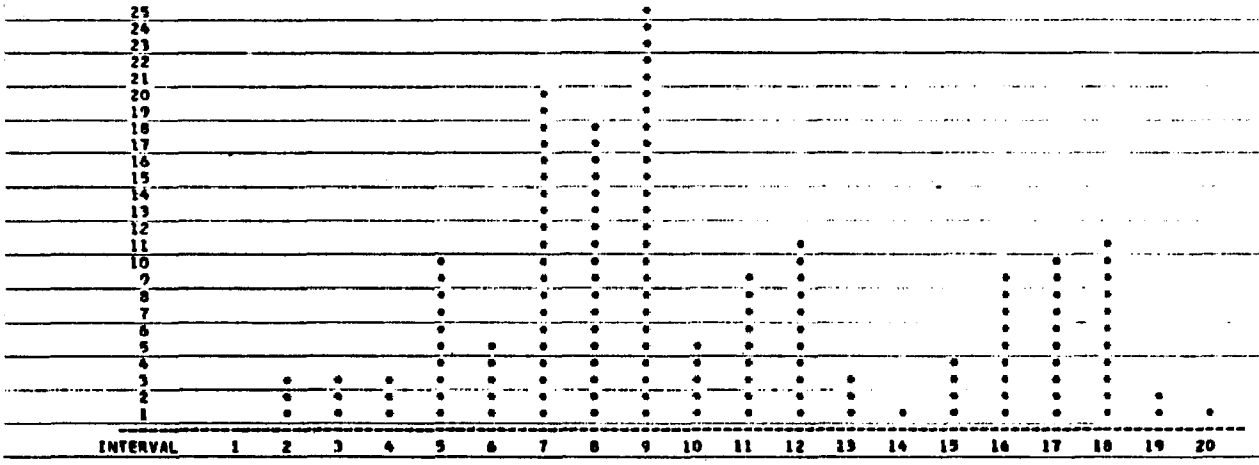


TABLE B-23

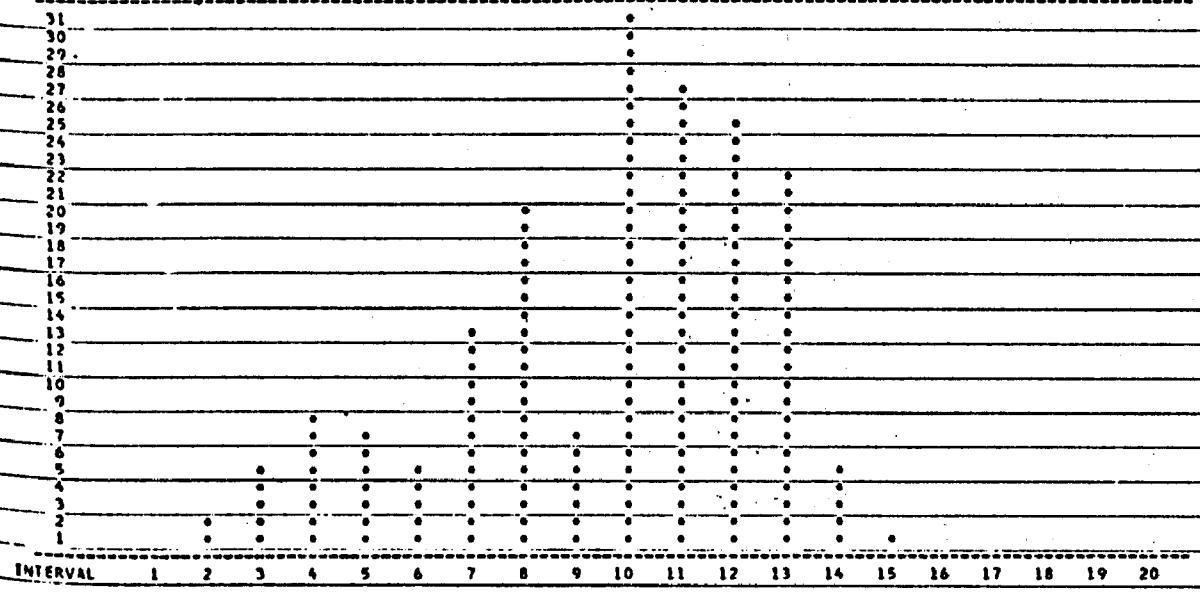
COND STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 2250.00049 MAX = 7500.00098 AMEAN = 4625.83888 STODEV = 871.94104 GMEAN = 4533.71192

MOM1 = 0.00000E 00 MOM2 = 0.76028E 06 MOM3 = -0.30957E 09 MOM4 = 0.18455E 13 SKEW = 0.46698E 00 KURT = 0.31929E 01

INTERVAL LENGTH = 291.66668

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	2	5	8	7	5	13	20	7	31	27	25	22	5	1	0	0	0	0	1



COND STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 4200.00098 MAX = 7650.00098 AMEAN = 5810.36329 STODEV = 871.92773 GMEAN = 5745.89258

MOM1 = 0.00000E 00 MOM2 = 0.76025E 06 MOM3 = 0.26745E 09 MOM4 = 0.13523E 13 SKEW = 0.40346E 00 KURT = 0.23398E 01

INTERVAL LENGTH = 191.66668

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	4	4	5	7	16	17	19	27	10	12	10	3	3	3	12	9	5	8	1	

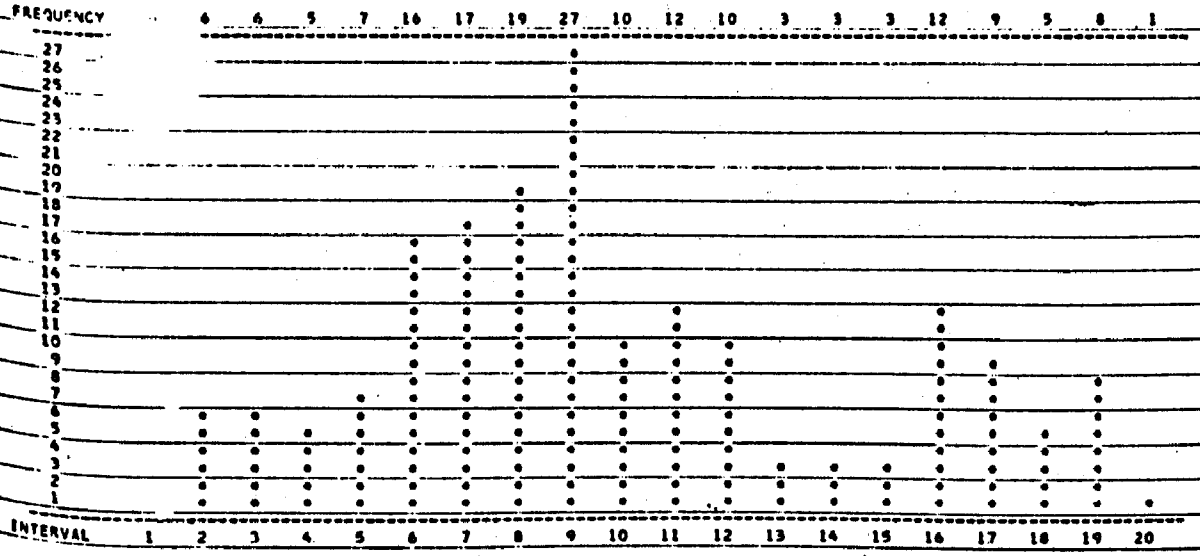


TABLE B—24

TRACE ELEMENTS

Copper and Chromium

General Considerations

COPPER

The effects of copper in water have been reported in terms of copper or copper salts. The chloride, nitrate and sulfate or divalent copper are highly soluble in water, but the carbonate, hydroxide, oxide and sulfide are not. Cupric ions introduced into natural waters at pH 7 or above will quickly precipitate as the hydroxide or as basic copper carbonate, to be removed by adsorption and/or sedimentation, (McKee & Wolf, 1963). Copper in trace amounts may be beneficial or even essential for the growth of living organisms. However, in excessive quantities, copper is toxic to a wide variety of aquatic forms, from bacteria to fish, (Hale, F.E., 1942). Copper may be concentrated by plankton from the surrounding waters by factors of 1,000 to 5,000 or more. The toxicity of copper to aquatic organisms varies significantly, not only with the species, but also with the physical and chemical characteristics of the water, such as its temperature, hardness, turbidity and CO_2 content, (Tarzwell, C.M., 1957). In hard water, the toxicity of copper salts is reduced by the precipitation of copper carbonate or other insoluble compounds, (Hale, F.E., 1942). The toxicity of copper to fish varies greatly with the presence of Mg salts and phosphates, (Ellis & Ladner, 1935). The sulfates of copper and zinc, and of copper and cadmium, have been found to be synergistic in their toxic affect on fish in soft water, (Doudoroff, P., 1952) however, no synergism between copper and zinc has been found to be evident in hard water, (Dept. of Scientific & Ind. Res., 1960).

Because of variable toxicity of copper to living organism, the killing concentrations of copper and copper sulfate reported by independent workers vary over a wide range. Copper concentrations varying from 0.1 to 1.0 mg/l have been noted to be safe for most fish, whereas concentrations of 0.01 to 20 mg/l of copper sulfate have been used to control different aquatic fauna, from insect larvae to snails. The toxicity of copper sulfate to fish varies with the species and exposure, and the physical and chemical characteristics of the water, (McKee & Wolf, 1963). For instance, the fish have been more resistant to copper sulfate in hard, alkaline waters than in soft acid waters.

Hutchinson, (1956), reporting the data of Hale, cites that concentrations as low as .030 mg/l have shown adverse affects on certain algae. Copper sulfate has been used commercially as an algacide in public and private waters since 1904, (Kingsbury, 1968).

Sodium nitrite, sodium nitrate and sodium chloride have been found to be antagonistic to the toxic effect of copper sulfate, (Core, A.E., 1941).

CHROMIUM

Chromium can exist in various ionic forms, i.e. as chromic ion (Cr^{+++}) and dichromate ion ($Cr_2O_7^{--}$). In the chromic form, the chromium is trivalent while in the dichromic form it is hexavalent. All chromous compounds (Cr^{++}) tend strongly to be oxidized to the chromic condition, whereas hexavalent chromium can be reduced to the trivalent form by heat, by organic matter or by reducing agents. Of the trivalent chromic salts, the chloride, nitrate and sulfate are readily soluble in water, but the hydroxide and carbonate are quite insoluble. Of the hexavalent chromate salts, only sodium, potassium and ammonia chromates are soluble. The corresponding dichromates are also quite soluble, (McKee & Wolf, 1963).

Hexavalent chromium salts are used extensively in metal pickling and plating operations, in anodizing aluminum and in the manufacture of many other substances. Trivalent chromium salts, on the other hand, are used much less extensively, being used for instance in photography, (McKee & Wolf, 1963).

There is no evidence that chromium salts are essential or beneficial to human nutrition. When administered orally, chromium salts are not retained in the body but rapidly and completely eliminated, (Browning, E., 1961). The toxicity of chromium salts towards aquatic life varies widely with species, temperature, pH, valence of the chromium and synergistic or antagonistic effects, especially that of hardness. Fish are relatively tolerant of chromium salts, but lower forms of aquatic life are extremely sensitive. There appears to be no evidence to lead to the conclusion that hexavalent chromium is more toxic towards fish than the trivalent form. Hexavalent chromium that have been shown to exhibit some toxic effects towards fish range from 5 (Feller & Newman, 1951) to as high as 520 mg/l, (Doudoroff & Katz, 1953). Hexavalent chromium in concentrations as low as 0.016 mg/l have been reported to be toxic to Daphnia magna, (Metal Finishing Industries Action Committee, 1950). Other similar organisms have been shown to be toxic at concentrations something greater than 0.2 mg/l.

COPPER

Although the concentrations of copper in the epilimnion and hypolimnion of Station No. 1 are quite similar, the distribution of data for the epilimnion of Station No. 2 is considerably different from both zones of Station No. 1 and the hypolimnion of Station No. 2. This difference is not discernable from the line plots, which show only slight variations with respect to time between Stations 1 & 2. Owing to the similarity of the pertinent chemistry between Stations 1 & 2, i.e. nitrates, chlorides, sulfates, alkalinity and sulfides, it does not appear that chemical interactions cause the unique distribution of the epilimnion of Station No. 2. It may be attributable, however, to the differences in biota and biomass observed between Stations 1 & 2 throughout the year, (Figure C-2), owing to the tendency of some plankton to concentrate copper more than others.

The mean and geometric mean are the same for the epilimnion and hypolimnion and are 0.04 and 0.05 mg/l respectively.

CHROMIUM

All values of chromium represent total chromium, and no distinction was made as to form. The distribution of data and the mean and geometric mean values are very similar for all zones except the hypolimnion of Station No. 2. The mean value of this zone is 0.03 mg/l as compared to 0.02 mg/l for all other zones. This represents a significant increase which could be attributable to the influence of a major steel manufacturing discharge. The latter discharge was measured as having an average Cl concentration of 2,318 mg/l and contributing 39% of the total chromium discharged. The Cl concentration results in a liquid density equal to or greater than that which was measured for the hypolimnion of the lake. Therefore, this discharge would tend to reside in this zone. Line plots, (Figure B-22) are quite similar and do not lend clarity to the above discussion. This discharge of the steel plant was analyzed and chromium concentrations of as high as 9.9 mg/l at 6.5 mgd were found. This daily discharge is equivalent to a concentration throughout the lake of 0.0017 mg/l.

CU STAT 2 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00000 MAX = 0.21000 AMEAN = 0.05307 STDDEV = 0.03441 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.11841E-02 MOM3 = 0.62699E-04 MOM4 = 0.61095E-05 SKEW = 0.15587E 01 KURT = 0.57838E 01

INTERVAL LENGTH = 0.01166

FREQUENCY	0	2	15	37	24	28	7	16	4	9	1	2	4	2	1	0	0	0	0	1
37				•																
36				•																
35				•																
34				•																
33				•																
32				•																
31				•																
30				•																
29				•																
28				•		•														
27				•		•														
26				•		•														
25				•		•														
24				•	•	•														
23				•	•	•														
22				•	•	•														
21				•	•	•														
20				•	•	•														
19				•	•	•														
18				•	•	•														
17				•	•	•														
16				•	•	•		•												
15			•	•	•	•		•												
14			•	•	•	•		•												
13			•	•	•	•		•												
12			•	•	•	•		•												
11			•	•	•	•		•												
10			•	•	•	•		•												
9			•	•	•	•		•		•										
8			•	•	•	•		•		•										
7			•	•	•	•	•	•		•										
6			•	•	•	•	•	•		•										
5			•	•	•	•	•	•		•										
4			•	•	•	•	•	•	•	•			•							
3			•	•	•	•	•	•	•	•			•							
2		•	•	•	•	•	•	•	•	•		•	•	•						
1		•	•	•	•	•	•	•	•	•	•	•	•	•	•					•

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CU STAT 2 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.01400 MAX = 0.15000 AMEAN = 0.04729 STDDEV = 0.02537 GMEAN = 0.04134

MOM1 = 0.00000E 00 MOM2 = 0.64379E-03 MOM3 = 0.21822E-04 MOM4 = 0.20362E-05 SKEW = 0.13359E 01 KURT = 0.49129E 01

INTERVAL LENGTH = 0.00755

FREQUENCY	0	14	23	7	25	27	6	4	5	6	3	2	4	1	1	1	0	0	0	1
27						•														
26						•														
25					•	•														
24					•	•														
23			•		•	•														
22			•		•	•														
21			•		•	•														
20			•		•	•														
19			•		•	•														
18			•		•	•														
17			•		•	•														
16			•		•	•														
15			•		•	•														
14		•	•		•	•														
13		•	•		•	•														
12		•	•		•	•														
11		•	•		•	•														
10		•	•		•	•														
9		•	•		•	•														
8		•	•		•	•														
7		•	•	•	•	•														
6		•	•	•	•	•	•			•										
5		•	•	•	•	•	•		•	•										
4		•	•	•	•	•	•	•	•	•			•							
3		•	•	•	•	•	•	•	•	•	•		•							
2		•	•	•	•	•	•	•	•	•	•	•	•							
1		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•				•

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE B-25

CU STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.01030 MAX = 0.18600 AMEAN = 0.05599 STDDEV = 0.03287 GMEAN = 0.04745

MOM1 = 0.00000E 00 MOM2 = 0.10808E-02 MOM3 = 0.39432E-04 MOM4 = 0.47735E-05 SKEW = 0.11097E 01 KURT = 0.40862E 01

INTERVAL LENGTH = 0.00988

FREQUENCY	0	7	33	20	19	19	7	8	14	5	10	3	4	0	1	2	0	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CU STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.01600 MAX = 0.19500 AMEAN = 0.05296 STDDEV = 0.03176 GMEAN = 0.04571

MOM1 = 0.00000E 00 MOM2 = 0.10090E-02 MOM3 = 0.48071E-04 MOM4 = 0.61520E-05 SKEW = 0.14997E 01 KURT = 0.60419E 01

INTERVAL LENGTH = 0.00994

FREQUENCY	0	40	16	18	26	9	9	13	4	11	1	2	0	2	0	0	0	1	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE 8-26

CR STAT 2 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00500 MAX = 0.07300 AMEAN = 0.02519 STDDEV = 0.00969 GMEAN = 0.02364

MOM1 = 0.00000E 00 MOM2 = 0.93920E-04 MOM3 = 0.19698E-05 MOM4 = 0.94316E-07 SKEW = 0.21642E 01 KURT = 0.10692E 02

INTERVAL LENGTH = 0.00377

FREQUENCY	0	1	6	3	26	17	45	12	4	4	1	2	2	0	0	1	0	1	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CR STAT 2 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 0.09600 AMEAN = 0.02769 STDDEV = 0.01533 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.23521E-03 MOM3 = 0.10517E-04 MOM4 = 0.72329E-06 SKEW = 0.29155E 01 KURT = 0.13073E 02

INTERVAL LENGTH = 0.00533

FREQUENCY	0	2	1	5	18	45	17	3	4	2	2	1	0	0	0	0	0	1	2	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE B-27

CR STAT 1 4/17/68 - 12/18/69 EPILIMNION

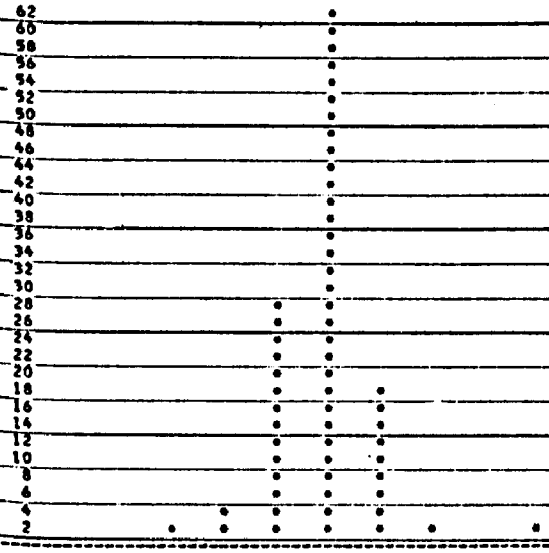
MIN = 0.00500 MAX = 0.09800 AMEAN = 0.02532 STDDEV = 0.01075 GMEAN = 0.02382

MOM1 = 0.00000E 00 MOM2 = 0.11562E-03 MOM3 = 0.44434E-05 MOM4 = 0.27948E-06 SKEW = 0.35738E 01 KURT = 0.20904E 02

INTERVAL LENGTH = 0.00516

FREQUENCY	0	2	5	29	63	18	2	1	2	1	2	0	1	1	0	0	0	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

EACH • EQUALS 2 POINTS



CR STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00400 MAX = 0.10000 AMEAN = 0.02613 STDDEV = 0.01329 GMEAN = 0.02384

MOM1 = 0.00000E 00 MOM2 = 0.17681E-03 MOM3 = 0.75773E-05 MOM4 = 0.51195E-06 SKEW = 0.32227E 01 KURT = 0.16374E 02

INTERVAL LENGTH = 0.00533

FREQUENCY	0	6	2	11	77	19	3	1	1	1	2	1	1	0	1	0	0	0	1	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

EACH • EQUALS 2 POINTS

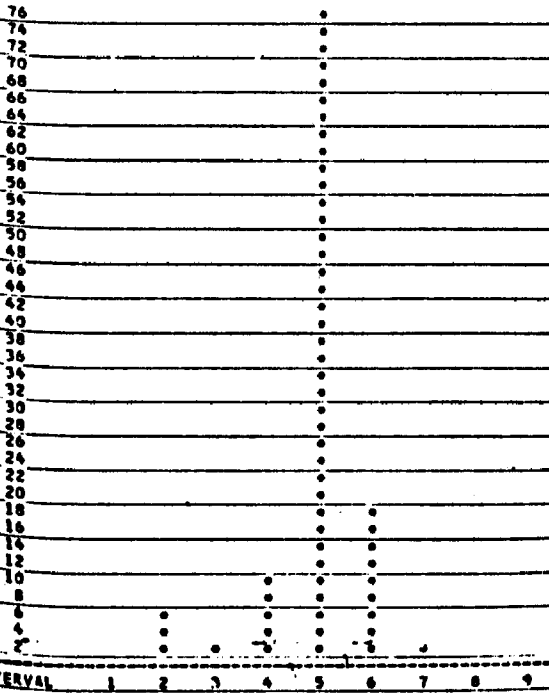


TABLE B-28

TRACE ELEMENTS

Iron, Manganese, Zinc

General Considerations

IRON

Natural waters may be polluted by iron bearing industrial wastes such as those for pickling operations and by the leaching of soluble iron salts from soils and rocks. Although many of the ferric and ferrous salts such as the chlorides, sulfates or nitrates are highly soluble in water, the ferrous ions are readily oxidized in natural surface waters to the ferric condition and form insoluble hydroxides. These precipitates tend to agglomerate, flocculate and settle or be adsorbed on surfaces; hence the concentration of iron in well aerated waters is seldom high, (McKee & Wolf, 1963). Most natural waters have enough buffering capacity to avoid the lowering of pH by additions of iron salts. It has been reported that the decomposition of iron hydroxide on the gills of fish may cause irritation and blocking of the respiratory channels. It is often reported that heavy precipitates of ferric hydroxide may smother fish eggs, (Southgate, B.A., 1948). Iron in the ferrous state apparently does not have the toxic effects that the ferric state has. The buffering capacity of Onondaga Lake is quite strong with pH's ranging from 6.5 to 9.0.

MANGANESE

Manganese, like iron, occurs in the divalent and trivalent form. The chloride, nitrate and sulfate salt of manganese are highly soluble in water; but the oxides, carbonates and hydroxides are only sparingly soluble. For this reason, manganic or manganous ions are seldom present in natural surface waters in concentrations above 1.0 mg/l. Manganese frequently accompanies iron in ground water. The toxicity of manganese toward fish is dependent upon many factors, (McKee & Wolf, 1963). The toxicities of manganous chloride and manganous sulfate have been reported to be slight, being about 2,400 and 1,240 mg/l of manganese respectively, (Oshima, S., 1960 & Iwao, T., 1960). Concentrations of manganese tolerated by fish such as carp and tench have been found to be as high as 15 mg/l for a seven day exposure, (Schweiger, G., 1957).

ZINC

Zinc occurs abundantly in rocks and ores, and is used extensively for galvanizing, in alloys, for electrical purposes, in printing plates and for other industrial purposes. Many of the zinc salts are highly soluble in water, such as zinc chloride and zinc sulfate whereas the zinc carbonate and zinc sulfide are relatively insoluble in water. Zinc is thought to exert its toxic action on fish by forming insoluble compounds with mucous that covers the gills, (Southgate, B., 1955) or possibly as an internal poison, (Dept. of Scientific & Industrial Research, 1958). The sensitivity of fish to zinc varies with species, age and condition of the fish, as well as with the physical and chemical characteristics of the water. Some acclimatization to the presence of zinc is possible and survivors from batches of fish subjected to dissolved zinc have been less susceptible to additional toxic concentrations than fish not previously exposed, (Affleck, A.J., 1952).

It has been found that upon conducting tests in which zinc was precipitated, almost all of the toxicity was attributable to the zinc remaining in solution, (Dept. of Scientific & Industrial Research, 1958). It was also shown that the toxicity of zinc salts to sticklebacks in soft water is reduced by the addition of calcium chloride, (Lloyd, R., 1960). It has been reported that for mature fish the lethal limit for zinc in water containing 1 mg/l of calcium is only 0.3 mg/l but in water with 50 mg/l of calcium, as much as 2.0 mg/l of zinc is not toxic, (Jones, J.R.E., 1938).

Existing Conditions

In the case of iron, values in the hypolimnion were approximately 30% higher than in the epilimnion, whereas values in the hypolimnion were 19% higher in the case of manganese, and equal in the case of zinc. In general, the distributions of data for both iron and zinc were similar from Stations 1 & 2 and for the epilimnion and hypolimnion respectively. Distributions tend towards normalcy with skewness towards lower values.

However, the statistical distribution for manganese values differed from Stations 1 & 2 in that the value of the hypolimnion for Station 1 and Station 2 showed a tendency towards a bimodal distribution, whereas the epilimnion of Station No. 2 showed a narrower range of values. The reasons for this difference in distribution is not readily apparent on the basis of discharge sources and cannot at this time be attributable to mineral stability or biological phenomena. The major contributing discharges for manganese are Onondaga Creek and Ley Creek with 64 and 19%

respectively. In regards to iron, the major contributing discharges are Nine Mile Creek and the Steel Mill representing 27 and 22% of the total respectively. Increased iron concentrations in the hypolimnion may be related to the waters of Nine Mile Creek.

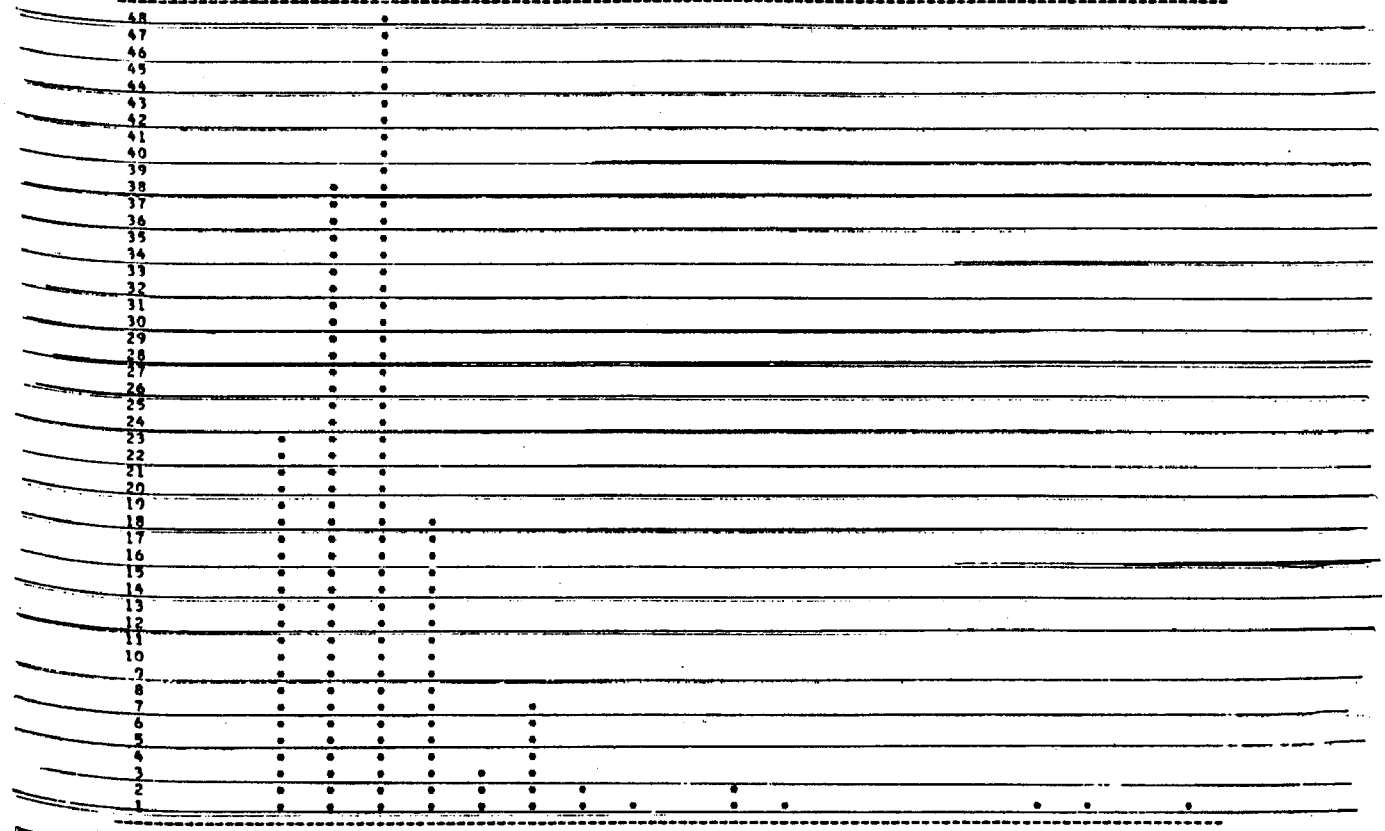
FE STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.06600 MAX = 0.92600 AMEAN = 0.20161 STDDEV = 0.12615 GMEAN = 0.17892

MOM1 = 0.00000E 00 MOM2 = 0.13915E-01 MOM3 = 0.67616E-02 MOM4 = 0.43775E-02 SKEW = 0.33676E 01 KURT = 0.17282E 02

INTERVAL LENGTH = 0.04777

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	23	38	48	18	3	7	2	1	0	2	1	0	0	0	0	1	1	0	1



FE STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.03900 MAX = 1.33000 AMEAN = 0.26014 STDDEV = 0.18229 GMEAN = 0.22799

MOM1 = 0.00000E 00 MOM2 = 0.33231E-01 MOM3 = 0.23766E-01 MOM4 = 0.22933E-01 SKEW = 0.39231E 01 KURT = 0.20766E 02

INTERVAL LENGTH = 0.07172

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	8	26	65	29	5	7	0	2	0	0	0	0	2	0	1	0	0	1	1

EACH • EQUALS 2 POINTS

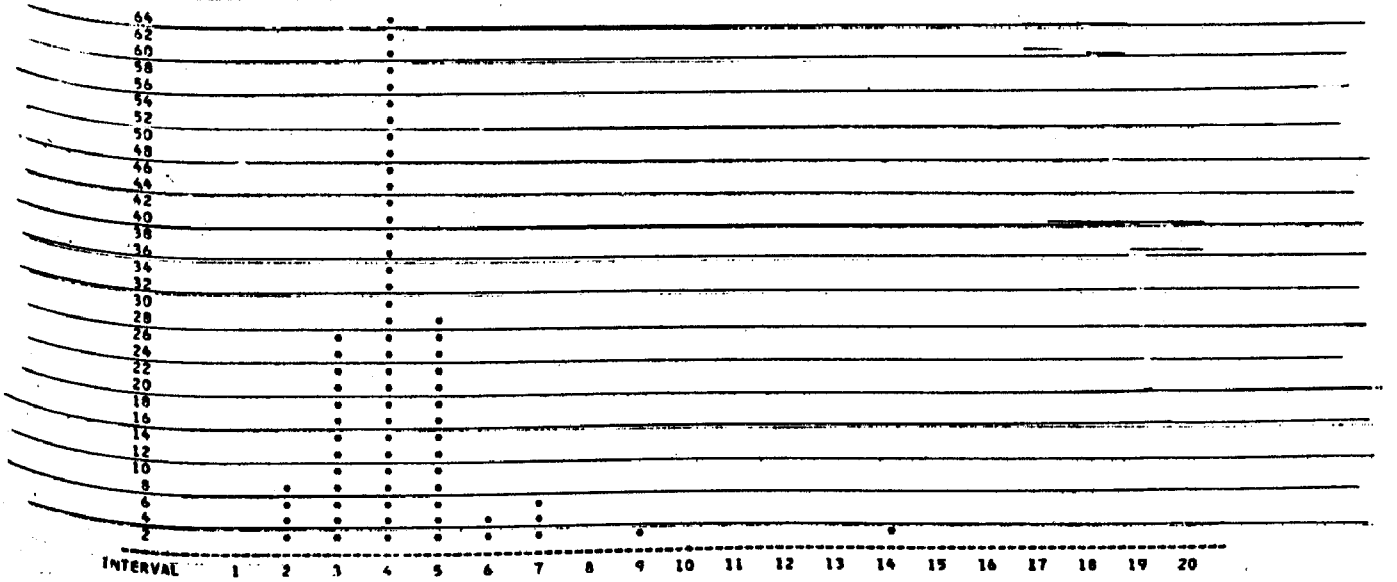


TABLE B-29

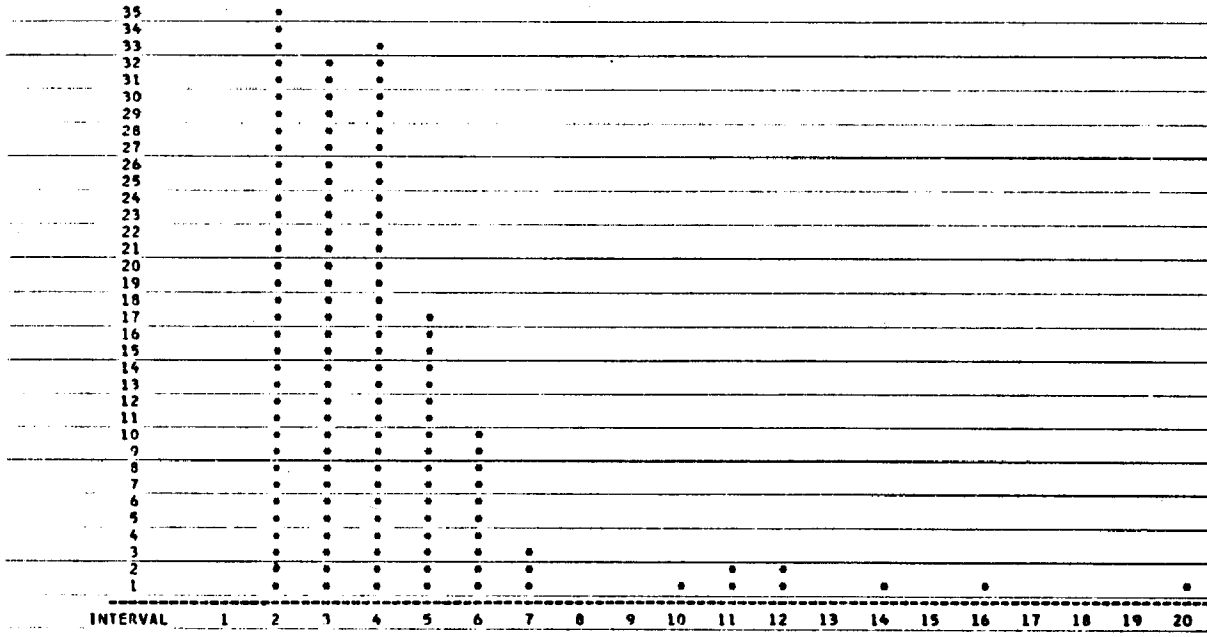
MN STAT 2 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.01400 MAX = 0.47500 AMEAN = 0.08142 STDDEV = 0.06776 GMEAN = 0.06449

MOM1 = 0.00000E 00 MOM2 = 0.45924E-02 MOM3 = 0.92715E-03 MOM4 = 0.30336E-03 SKEW = 0.29791E 01 KURT = 0.14383E 02

INTERVAL LENGTH = 0.02561

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	35	32	33	17	10	3	0	0	1	2	2	0	1	0	1	0	0	0	1



MN STAT 2 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.01400 MAX = 0.40000 AMEAN = 0.20028 STDDEV = 0.09602 GMEAN = 0.17356

MOM1 = 0.00000E 00 MOM2 = 0.92216E-02 MOM3 = 0.23800E-03 MOM4 = 0.15860E-03 SKEW = 0.26876E 00 KURT = 0.18650E 01

INTERVAL LENGTH = 0.02144

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	2	1	3	12	14	11	12	7	6	3	4	4	9	12	6	7	3	1	1

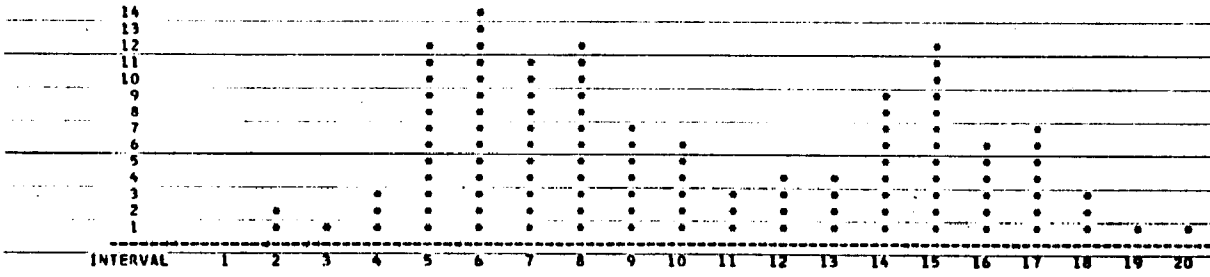


TABLE B-30

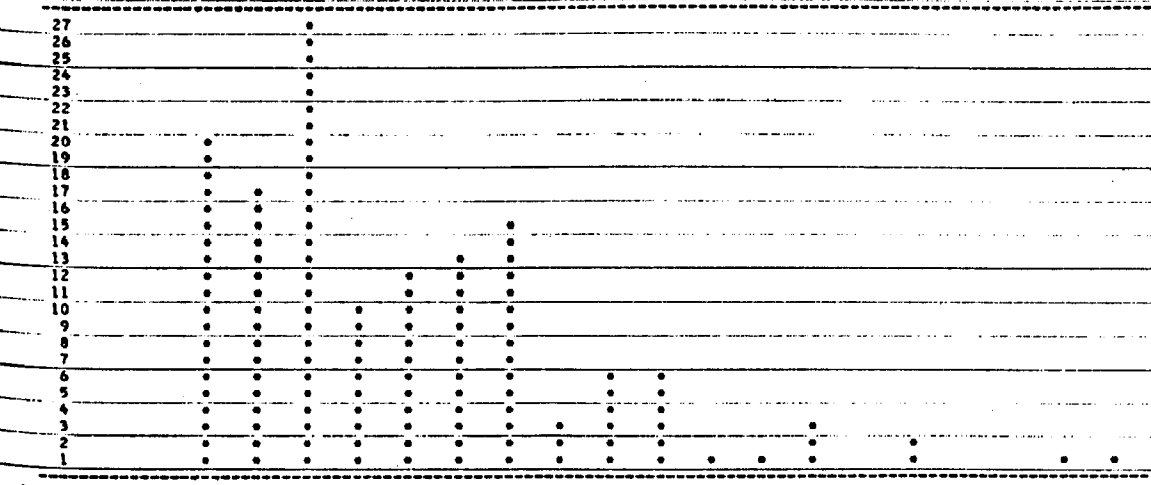
MN STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.01400 MAX = 0.25000 AMEAN = 0.07257 STDDEV = 0.04559 GMEAN = 0.06042

MOM1 = 0.00000E 00 MOM2 = 0.20792E-02 MOM3 = 0.13029E-03 MOM4 = 0.22168E-04 SKEW = 0.13742E 01 KURT = 0.51277E 01

INTERVAL LENGTH = 0.01311

FREQUENCY	0	20	17	27	10	12	13	15	3	6	6	1	1	3	0	2	0	0	1	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20



MN STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.01400 MAX = 0.90000 AMEAN = 0.20508 STDDEV = 0.10385 GMEAN = 0.17794

MOM1 = 0.00000E 00 MOM2 = 0.10789E-01 MOM3 = 0.68761E-03 MOM4 = 0.30558E-03 SKEW = 0.61388E 00 KURT = 0.26269E 01

INTERVAL LENGTH = 0.02700

FREQUENCY	0	1	4	8	25	15	13	10	7	10	11	7	8	5	8	0	0	1	2	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

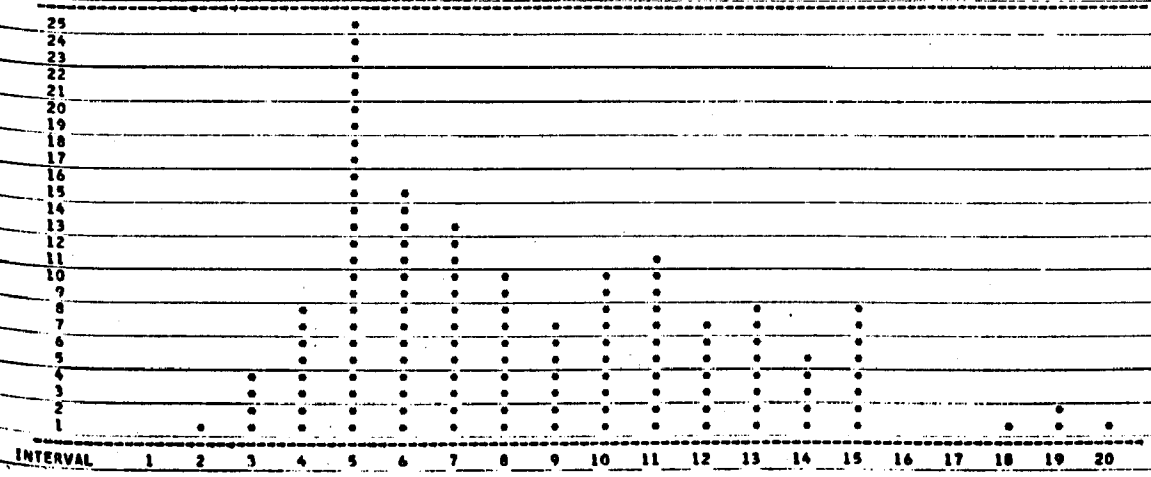


TABLE B-31

ZN STAT 1 4/17/68 - 12/18/69 EPILIMNION

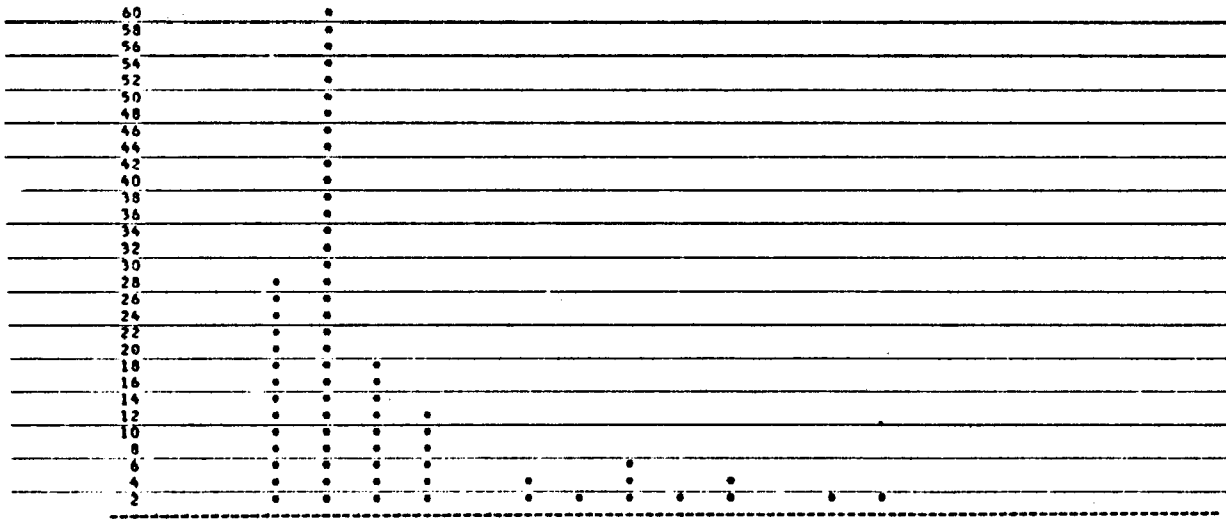
MIN = 0.01830 MAX = 0.39500 AMEAN = 0.07982 STDDEV = 0.06717 GMEAN = 0.06253

MOM1 = 0.00000E 00 MOM2 = 0.45119E-02 MOM3 = 0.63240E-03 MOM4 = 0.15029E-03 SKEW = 0.20866E 01 KURT = 0.73829E 01

INTERVAL LENGTH = 0.02083

FREQUENCY	0	28	61	19	13	1	5	3	6	3	4	1	2	2	0	0	1	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

EACH • EQUALS 2 POINTS



ZN STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.02000 MAX = 0.36000 AMEAN = 0.07656 STDDEV = 0.06177 GMEAN = 0.06163

MOM1 = 0.00000E 00 MOM2 = 0.38166E-02 MOM3 = 0.53829E-03 MOM4 = 0.12010E-03 SKEW = 0.22829E 01 KURT = 0.82430E 01

INTERVAL LENGTH = 0.01888

FREQUENCY	0	29	50	21	17	12	3	2	1	2	2	1	3	1	1	3	0	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

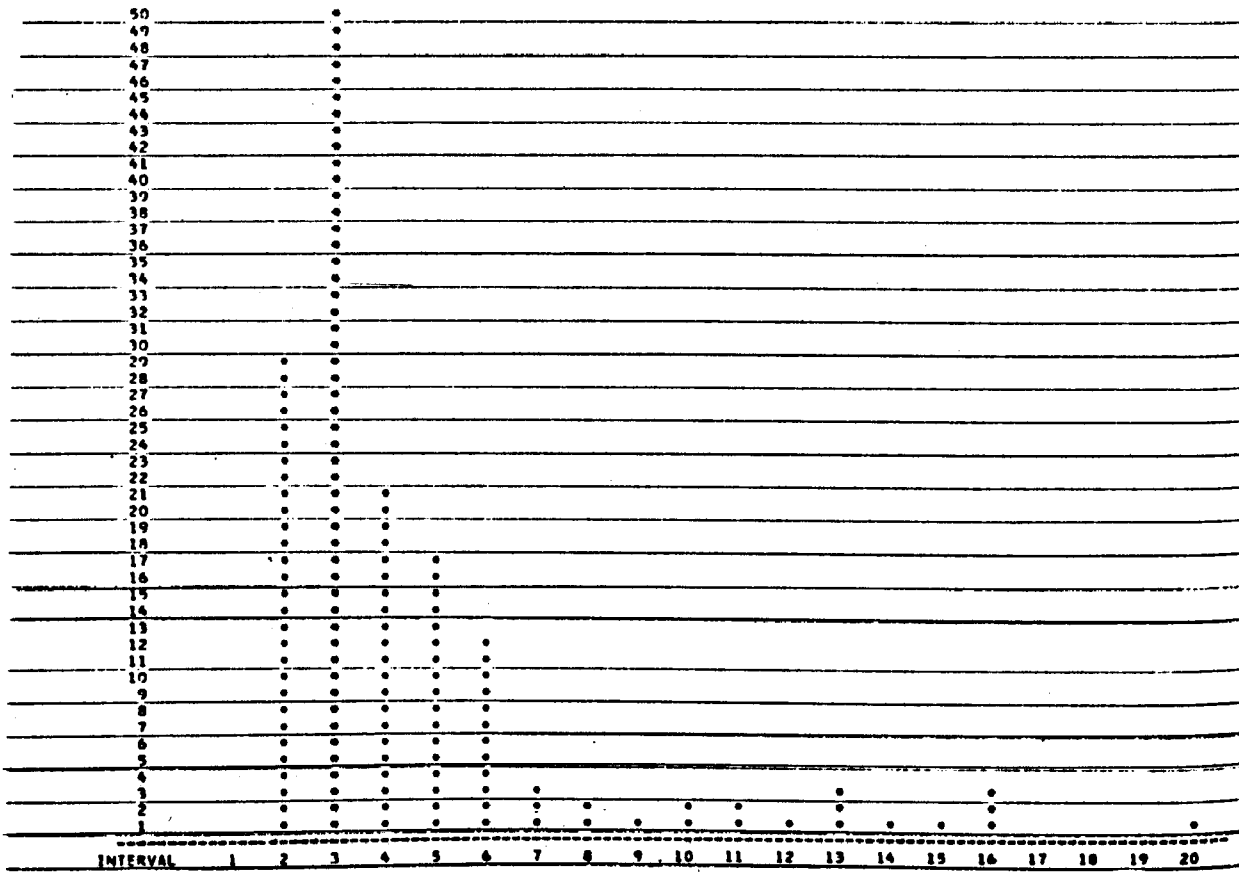


TABLE B-32

FLUORIDE

General Considerations

Fluorine is the most reactive nonmetal and is never found free in nature. It is a constituent of fluorite or fluorspar, (calcium fluoride in sedimentary rocks) and also of cryolite (sodium alumninum fluoride in igneous rocks), (McKee & Wolf, 1963). Fluorapatite is sometimes present in natural waters and can be significant in precipitating phosphates.

There have been numerous articles describing the effects of fluoride-bearing waters on dental enamel of children and a few papers pertaining to skeletal damage. Many repots generalize that the effects of water containing less than 0.9 to 1.0 mg/l of fluoride will seldom cause mottled enamel in children. For adults, concentrations of fluorides less than 3 or 4 mg/l are not likely to cause cumulative fluorosis and skeletal effects. It has been stated that the presence of about 1.0 mg/l of fluoride ions in natural waters may be more beneficial than detrimental, (McKee & Wolf, 1963).

There is evidence to support the contention that fluorides in excess of the threshold for mottling of teeth and up to 5 mg/l produce no harmful effects other than mottling, (Worker, H., 1949).

Existing Conditions

Data tend to be distributed normally for the epilimnion of Station 1 whereas data for the hypolimnion as well as both zones of Station 2 show a bimodal and sometimes a tri-nodal distribution. All values represent the negative log to the base 10 of the concentration in moles per liter. In all cases, mean and geometric mean values fall within the range of 0.4 to 0.7 mg/l. The minimum and maximum values of the epilimnion of Station No. 1 represent the widest range of 3.95 to 5.05 or corresponding concentrations of 2.13 and 0.17 mg/l.

Line plots show some tendency toward lower values or higher concentrations in the epilimnetic waters, especially during the late summer and eary fall months, (Figure B-26).

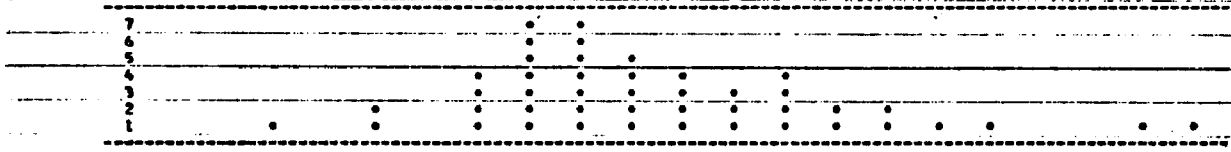
F STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 3.95000 MAX = 5.05000 AMEAN = 4.43865 STDDEV = 0.22031 GMEAN = 4.43328

MOM1 = 0.00000E 00 MOM2 = 0.48540E-01 MOM3 = 0.72656E-02 MOM4 = 0.86372E-02 SKEW = 0.67939E 00 KURT = 0.36658E 01

INTERVAL LENGTH = 0.06111

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	0	2	0	4	7	7	5	4	3	4	2	2	1	1	0	0	1	1



F STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 3.95000 MAX = 4.96000 AMEAN = 4.56865 STDDEV = 0.18820 GMEAN = 4.56470

MOM1 = 0.00000E 00 MOM2 = 0.35420E-01 MOM3 = -0.34159E-02 MOM4 = 0.50382E-02 SKEW = -0.51243E 00 KURT = 0.40157E 01

INTERVAL LENGTH = 0.05611

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	0	0	0	0	1	1	3	8	5	2	5	8	2	2	4	2	0	1

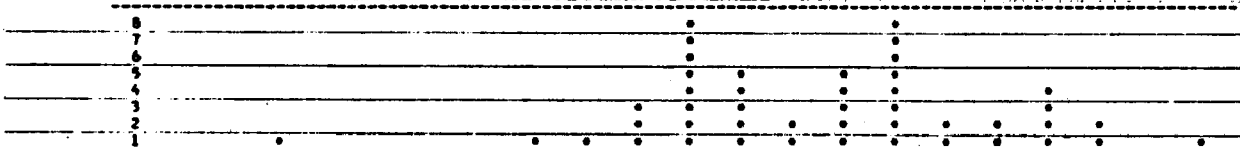


TABLE B-33

SILICON DIOXIDE

General Considerations

"The element silicon is not found free in nature but it occurs as silica in sand or quartz and as silicates in feldspar, kaolinite and other minerals", (McKee & Wolf, 1963). Silicon dioxide may occur in natural waters as finely divided or colloidal suspended matter in concentrations of 1 to 40 mg/l, (Love, S.K., 1960). An abundance of silica in water along with other necessary nutrients, favors the growth of diatoms. The diatom Asterionella, and possibly other algae, require silica concentrations above 0.5 mg/l for growth in ponds and cannot utilize silica when present at lower concentrations, (Lund, J.W.G., 1951).

Existing Conditions

The distribution of data for the epilimnion of Station No. 1 tends to be bimodal with a mean and geometric mean of 4.9 and 4.5 mg/l respectively, whereas the distribution for the hypolimnion tends more toward normalcy with corresponding values of 8.2 and 7.9 mg/l. Mean and geometric mean values for Station No. 2 are very similar to corresponding values for Station No. 1, with only slight differences noted in the distribution of data.

Line plots of this parameter show stratification from June through October with higher values predominant in the 12 to 18 meter waters. Of interest are the relatively low values observed in the surface waters on June 4th and September 18, 1969. On these same dates, relatively high numbers of diatoms were observed in the surface waters, as described in Appendix C. This can be explained on the basis of incorporation of a silica into the walls of the diatoms.

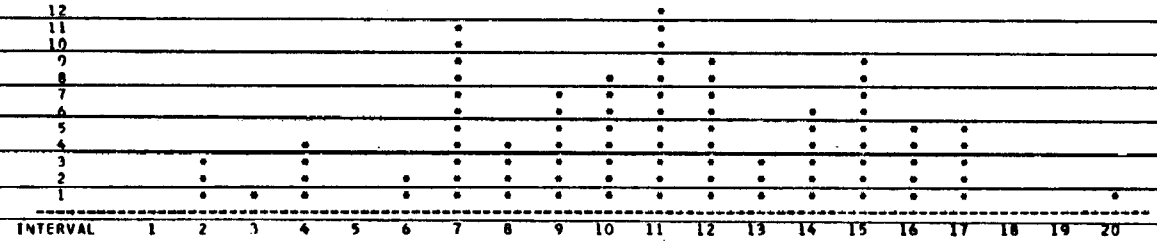
SIO2 STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.75000 MAX = 8.85000 AMEAN = 4.89999 STDDEV = 1.78877 GMEAN = 4.45426

MOM1 = 0.00000E 00 MOM2 = 0.31997E 01 MOM3 = -0.15954E 01 MOM4 = 0.26211E 02 SKEW = 0.27874E 00 KURT = 0.25601E 01

INTERVAL LENGTH = 0.44999

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	3	1	4	0	2	11	4	7	8	12	9	3	6	9	5	5	0	0	1



SIO2 STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 4.00000 MAX = 15.20000 AMEAN = 8.16776 STDDEV = 2.02177 GMEAN = 7.92713

MOM1 = 0.00000E 00 MOM2 = 0.40875E 01 MOM3 = 0.62805E 01 MOM4 = 0.70815E 02 SKEW = 0.75997E 00 KURT = 0.42383E 01

INTERVAL LENGTH = 0.62222

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	1	14	4	6	15	11	11	8	7	5	2	2	0	1	0	1	0	1

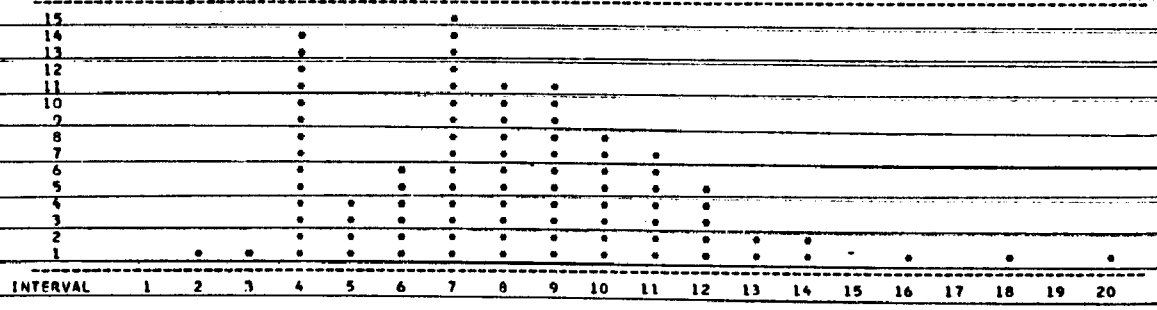


TABLE B-34

General Considerations

In natural waters, suspended solids consist normally of erosion silt, organic detritus and plankton. Development by man, however, can add suspended solids in the form of liquid wastes from domestic and industrial discharges, street washings and in the form of settleable air pollutants. The physical charactertistics of suspended solids can be injurious to aquatic life by clogging the gills and respiratory passages of various aquatic fauna; by causing abrasive injuries; and by blanketing the stream bottom, killing eggs, young fish and food organisms, and destroying spawning beds. Indirectly, suspended solids are inimnical to aquatic life because they impede light penetration and, by carrying down and trapping bacteria and decomposing organic wastes on the bottom, they promote and maintain the development of noxious conditions and oxygen depletion, (McKee and Wolf, 1963).

Dissolved solids (DS) were determined by subtracting suspended solids (SS) from total suspended matter (TSM). Thus, DS represents the sum total of ions, molecules and colloidal solids. Thus, based on the relative portion of ions with respect to colloidal and molecular solids in the water, DS can be analogous to conductivity. Irrespective of the chemical nature of dissolved solids, DS can adversely affect fish and aquatic life by their exertion of osmotic pressure in a liquid media. "In natural waters the dissolved solids consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates and possibly nitrates of calcium, magnesium, sodium and potassium, with traces of iron, manganese and other substances. The mineral content of natural waters may be lowered artificially by dilution or raised by the addition of chemical wastes, dissolved salts, acids, alkalies, gas and oil-well brines, or drainage waters from irrigated lands. All salts in solution change the physical and chemical nature of the water and exert osmotic pressure", (McKee & Wolf, 1963).

The blood of fresh water fish has an osmotic pressure approximately equal to 6 atmospheres, or about 7,000 mg/l as sodium chloride, and fresh water fish have been able to live well in sea water diluted to this level, (Ellis, M.M., 1937). Limiting concentrations of dissolved solids for fresh water fish are not definitely known, but may range from 5,000 to 10,000 mg/l, according to species and prior acclimating (Mace, H.H., 1953). Some fish are adapted to living in more saline waters, and a few species of fresh water forms have been found in natural waters with a salt concentration of 15,000 to 20,000 mg/l, (Rawson, D.S. and Moore, J.E., 1944).

"Dissolved solids influence the toxicity of heavy metals and organic compounds to fish and other aquatic life, primarily because of the antagonistic effect of hardness metals. Chromates, copper, cyanides, detergents, phenolic compounds, zinc and several other substances are generally more toxic in distilled water than in hard water with high dissolved solids", (McKee & Wolf, 1963).

Existing Conditions

- Suspended Solids (SS)

The distribution of data for the epilimnion and hypolimnion of Station No. 1 show a tendency towards normalcy with skewness towards lower values. Station No. 2 shows similar distributions. Mean and geometric mean values for the epilimnion of Station No. 1 are slightly higher (8%) than the corresponding values for Station No. 2., whereas values for the hypolimnion of Station No. 1 are almost equal to those of Station No. 2. Relationships of magnitude with depth are not apparent from the line plots, (Figure B-28). This is most likely due to the effects of wind on plankton distribution in the upper waters, decomposition of plankton in the lower waters and input variations.

- Dissolved Solids (DS)

Distributions for the epilimnion and hypolimnion of Station No. 1 tend towards normalcy with skewness towards higher values. Mean and geometric mean values of the epilimnion of Station No. 2, equal to 3,305 and 3,174 mg/l respectively, are slightly higher (3.3%) than the corresponding values of Station No. 1. Hypolimnion values of Station No. 2 are almost equal to those of Station No. 1. Slightly higher values in the epilimnion of Station No. 2 may be attributable to the influence of the Nine Mile Creek Discharge.

Referring to Figure B-29, it can be seen that in general DS values in the epilimnetic waters are less than DS values in the hypolimnetic waters and that the relationship of DS values to time, irrespective of depth is very similar to that which is observed for conductivity, (Figure B-20), as well as the major anion and cation species, calcium, sodium and chlorides, (Figures B-16, B-17 & B-4). This is attributed to the fact that DS measures ionic species to a great extent.

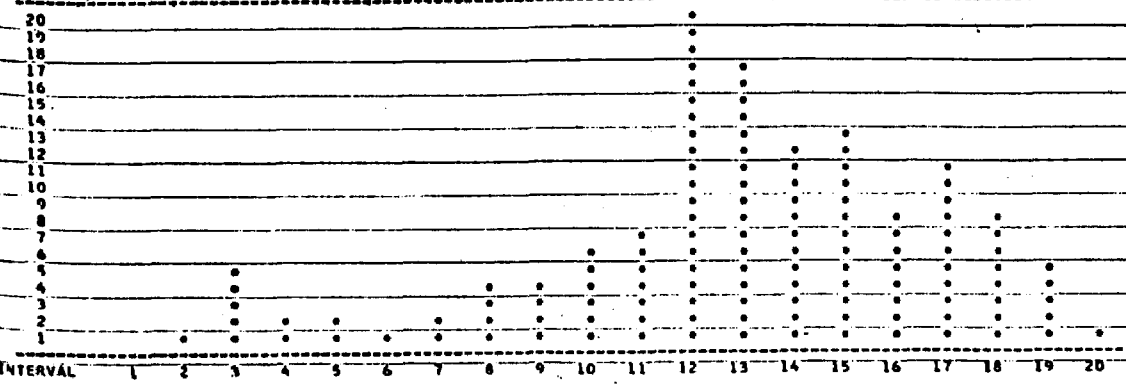
TS STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 1240.00024 MAX = 4402.00098 AMEAN = 3237.07764 STDDEV = 695.48010 GMEAN = 3145.83594

MOM1 = 0.00000E 00 MOM2 = 0.48369E 06 MOM3 = -0.26467E 09 MOM4 = 0.79372E 12 SKEW = 0.78679E 00 KURT = 0.33925E 01

INTERVAL LENGTH = 179.66668

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	1	5	2	2	1	2	4	4	6	7	20	17	12	13	8	11	8	5	1



TS STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 1755.00024 MAX = 5596.00098 AMEAN = 4066.78174 STDDEV = 707.20263 GMEAN = 3990.16504

MOM1 = 0.00000E 00 MOM2 = 0.50013E 06 MOM3 = -0.37884E 09 MOM4 = 0.13237E 13 SKEW = 0.10710E 01 KURT = 0.52923E 01

INTERVAL LENGTH = 213.38891

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	4	3	1	0	0	0	0	6	11	28	14	13	19	8	12	8	0	1	1

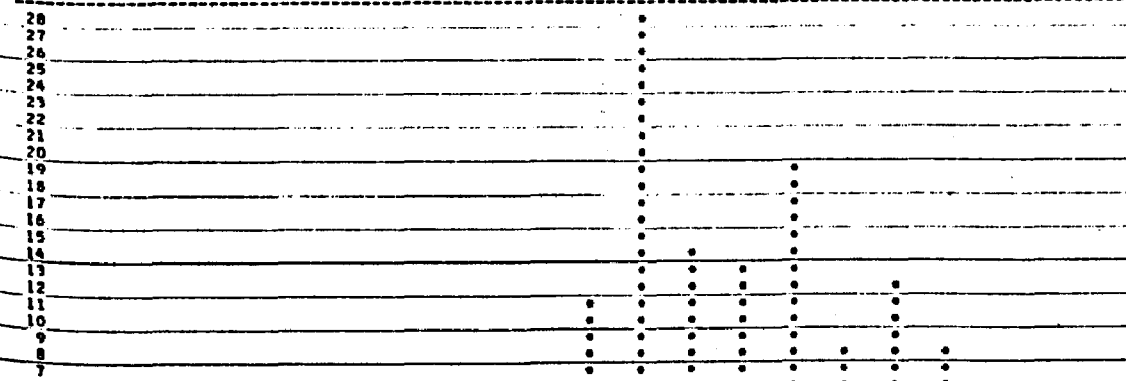


TABLE B-35

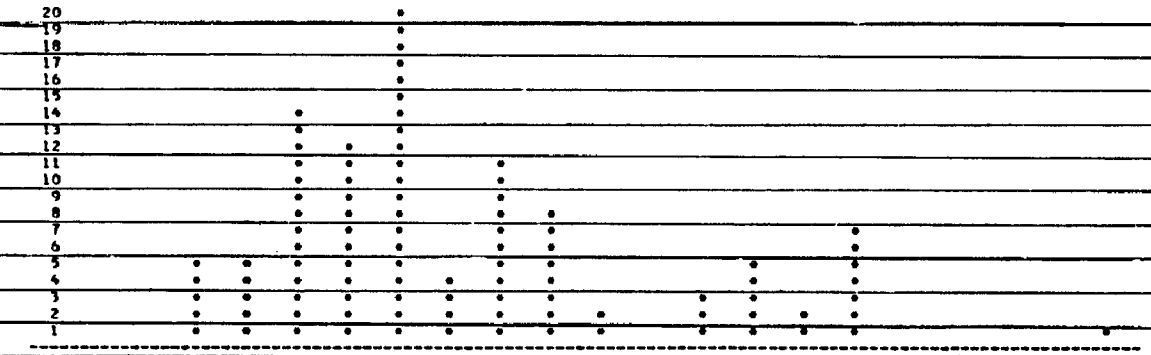
SS STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 0.00000 MAX = 55.00000 AMEAN = 17.72121 STDDEV = 11.55834 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.13359E 03 MOM3 = 0.14010E 04 MOM4 = 0.57803E 05 SKEW = 0.90735E 00 KURT = 0.32387E 01

INTERVAL LENGTH = 3.05555

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	5	5	14	12	20	4	11	8	2	0	3	5	2	7	0	0	0	0	1



SS STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 59.00000 AMEAN = 15.85353 STDDEV = 11.09307 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.12305E 03 MOM3 = 0.18959E 04 MOM4 = 0.79365E 05 SKEW = 0.13889E 01 KURT = 0.52410E 01

INTERVAL LENGTH = 3.27777

INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FREQUENCY	0	6	9	11	22	14	9	11	4	4	0	1	0	5	2	0	0	0	0	1

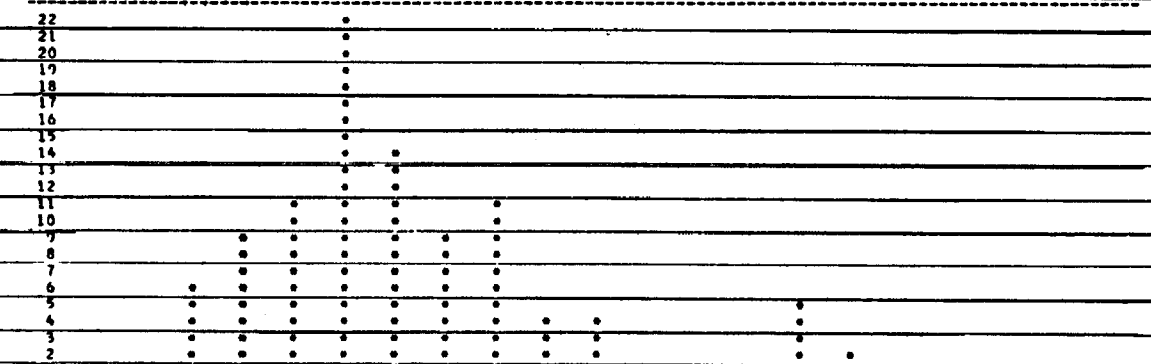


TABLE B-36

DS STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 1204.00024 MAX = 4350.00098 AMEAN = 3200.22803 STDDEV = 765.92431 GMEAN = 3087.96289

MOM1 = 0.00000E 00 MOM2 = 0.58664E 06 MOM3 = -0.32656E 09 MOM4 = 0.97970E 12 SKEW = 0.72680E 00 KURT = 0.28467E 01

INTERVAL LENGTH = 174.77780

FREQUENCY	0	1	3	4	1	2	2	4	3	2	7	13	8	7	7	10	13	5	6	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

DS STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 1749.00024 MAX = 5128.50098 AMEAN = 3896.25293 STDDEV = 693.51648 GMEAN = 3818.21240

MOM1 = 0.00000E 00 MOM2 = 0.48096E 06 MOM3 = -0.38875E 09 MOM4 = 0.12340E 13 SKEW = 0.11654E 01 KURT = 0.53347E 01

INTERVAL LENGTH = 187.97222

FREQUENCY	0	4	3	1	0	0	0	0	0	4	9	21	19	6	13	8	3	3	5	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE B—37

ESCHERICHIA COLI

General Considerations

The coliform bacteria are members of the family Entero-bacteriaceae. They include the genera Escherichia and Aerobacter. As far as can be determined, Escherichia coli is entirely of fecal origin. Although this organism is not pathogenic, it is used as an indicator of pollution, and by association, to the potential presence of pathogens.

The Millipore Filter Technique was employed in order to determine positive numbers of Escherichia coli (E-coli,) in lieu of the MPN tests which yields a most probable number of E-coli upon a "completed test".

Existing Conditions

The data are distributed similarly at Station No. 1 for both the epilimnion and hypolimnion with concentrations centered around a very narrow range. Skewness tends towards lower values, and is somewhat more prominant for values of the hypolimnion. The mean value for the epilimnion, 1,200/100 ml, is nearly five times the mean of the hypolimnion, 252/100 ml. Thus, it would appear that influent domestic discharges distribute predominantly in the epilimnion, with lower numbers in the hypolimnion representing cell dieoff and/or portions of input domestic wastes. The distribution of data for the epilimnion of Station No. 2 also shows a very narrow range of values with a mean, 407/100 ml., considerably less than that of the corresponding zone at Station No. 1. Data for the hypolimnion of Station No. 2, however, shows a distribution markedly different from the three previously mentioned zones. This zone shows a much broader distributon of values.

Line plots of E-coli show a greater tendency of bacteria at Station No. 1 to stratify with depth with concentrations decreasing with increasing depths. The opposite trend at Station 2 could be the result of die-off in the surface waters along with some sustaining of bacteria on decaying algae in the hypolimnion (Figure B-31).

ECOLI STAT 2 4/17/68 - 12/18/69 EPILIMNION

MIN = 2.00000 MAX = 10000.00197 AMEAN = 405.58337 STDDEV = 1377.60888 GMEAN = 88.97528

MOM1 = 0.00000E 00 MOM2 = 0.18978E 07 MOM3 = 0.13770E 11 MOM4 = 0.14552E 15 SKEW = 0.60320E 01 KURT = 0.40404E 02

INTERVAL LENGTH = 555.44445

FREQUENCY	0	55	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
EACH • EQUALS 2 POINTS																				
54		•																		
52		•																		
50		•																		
48		•																		
46		•																		
44		•																		
42		•																		
40		•																		
38		•																		
36		•																		
34		•																		
32		•																		
30		•																		
28		•																		
26		•																		
24		•																		
22		•																		
20		•																		
18		•																		
16		•																		
14		•																		
12		•																		
10		•																		
8		•																		
6		•																		
4		•																		
2		•	•																	
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

5000 PER 100 ML

ECOLI STAT 2 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 387.00006 AMEAN = 119.90245 STDDEV = 84.36433 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.71173E 04 MOM3 = 0.72499E 06 MOM4 = 0.25499E 09 SKEW = 0.12074E 01 KURT = 0.50387E 01

INTERVAL LENGTH = 21.50000

FREQUENCY	0	4	4	1	8	4	2	4	6	3	2	0	1	0	0	0	0	0	1	1
8					•															
7					•															
6					•				•											
5					•				•											
4		•	•		•	•		•	•											
3		•	•		•	•		•	•	•										
2		•	•		•	•	•	•	•	•	•		•							
1		•	•	•	•	•	•	•	•	•	•		•						•	•
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

LESS THAN
5000 PER 100 ML

TABLE B-38

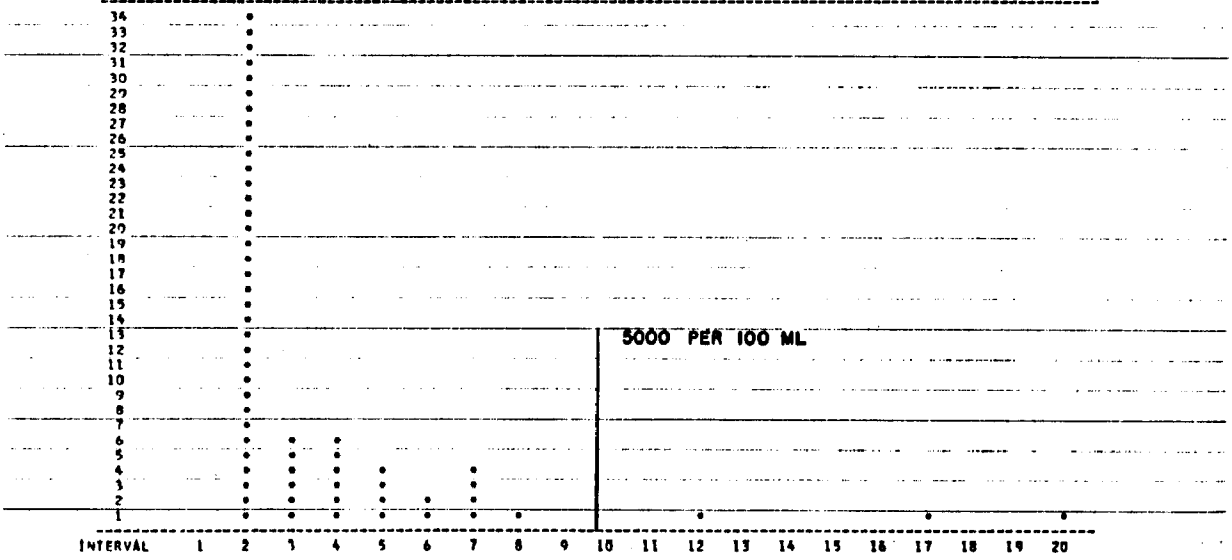
ECOLI STAT 1 4/17/68 - 12/18/69 EPILIMNION

MIN = 2.00000 MAX = 10000.00197 AMEAN = 1199.61670 STDDEV = 1891.84546 GMEAN = 391.57861

MOM1 = 0.00000E 00 MOM2 = 0.35790E 07 MOM3 = 0.20310E 11 MOM4 = 0.16453E 15 SKEW = 0.29995E 01 KURT = 0.12844E 02

INTERVAL LENGTH = 555.44445

FREQUENCY	0	34	6	6	4	2	4	1	0	0	0	1	0	0	0	0	1	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20



ECOLI STAT 1 4/17/68 - 12/18/69 HYPOLIMNION

MIN = 0.00000 MAX = 4256.00098 AMEAN = 250.83053 STDDEV = 565.43029 GMEAN = 0.00000

MOM1 = 0.00000E 00 MOM2 = 0.31971E 06 MOM3 = 0.10973E 10 MOM4 = 0.43706E 13 SKEW = 0.60703E 01 KURT = 0.42759E 02

INTERVAL LENGTH = 236.44445

FREQUENCY	0	45	7	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
INTERVAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

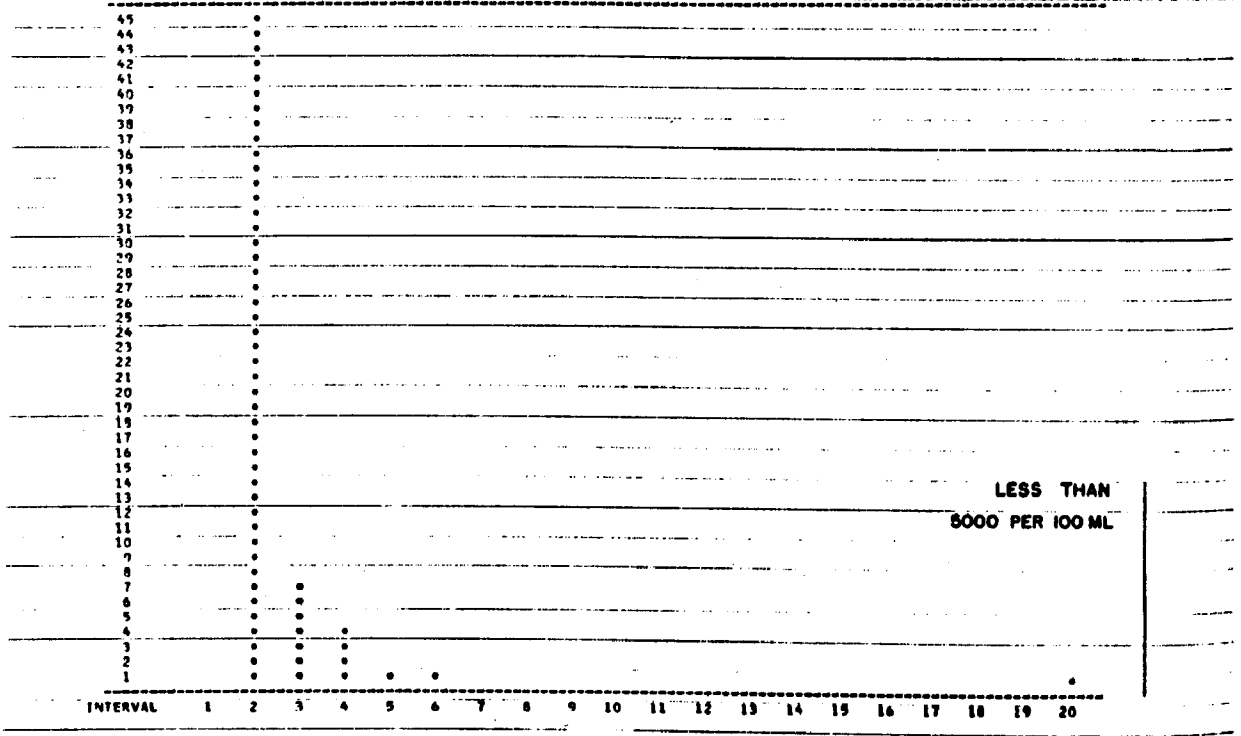


TABLE B—39

STATISTICAL ANALYSIS

The main types of statistical methods used were basic statistics, correlation analysis, histograms and regression analysis. The purpose of these methods was to gain insight into the various relationships between the parameters measured. As such, the results of these methods were never an end in themselves but were used in conjunction with visual displays, reports and the experience of the Advisors and staff. Only those statistical analyses were run that, in the opinion of the Advisors and staff, had the highest probability of being fruitful.

Table B-2 shows some of the results of regression analyses. Such conclusions as the following may be inferred from this table.

The relationship between dissolved oxygen and pH is especially strong in the epilimnion and either is non-existent in the lower waters or is masked by the influence of other parameters. Possibly, this relationship does not hold for dissolved oxygen less than a certain threshold point which is not obtained in the lower waters. Relatively large percentages of dissolved oxygen (epilimnion), chloride (epilimnion) and alkalinity (hypolimnion) are "explicable" through the combined effects of other variables, while only in the case of dissolved oxygen can a simple variable (pH) be considered as more influential than others.

Care must be taken in interpreting some of the measures. For example, if the number of variables is close to the number of observations, one is no longer gaining a measure of a "trend" but "fitting to errors" as in the case of run number 7. This forces a higher correlation coefficient (R) than would be obtained if more observations were available.

Regression analysis was not used to develop a predictive model of any measurable parameter. Such an undertaking would be beyond the scope of this Study.

TABLE B-40

ONONDAGA LAKE STUDY

CORRELATION & REGRESSION ANALYSIS

DEPTH SYNOPTIC DATA

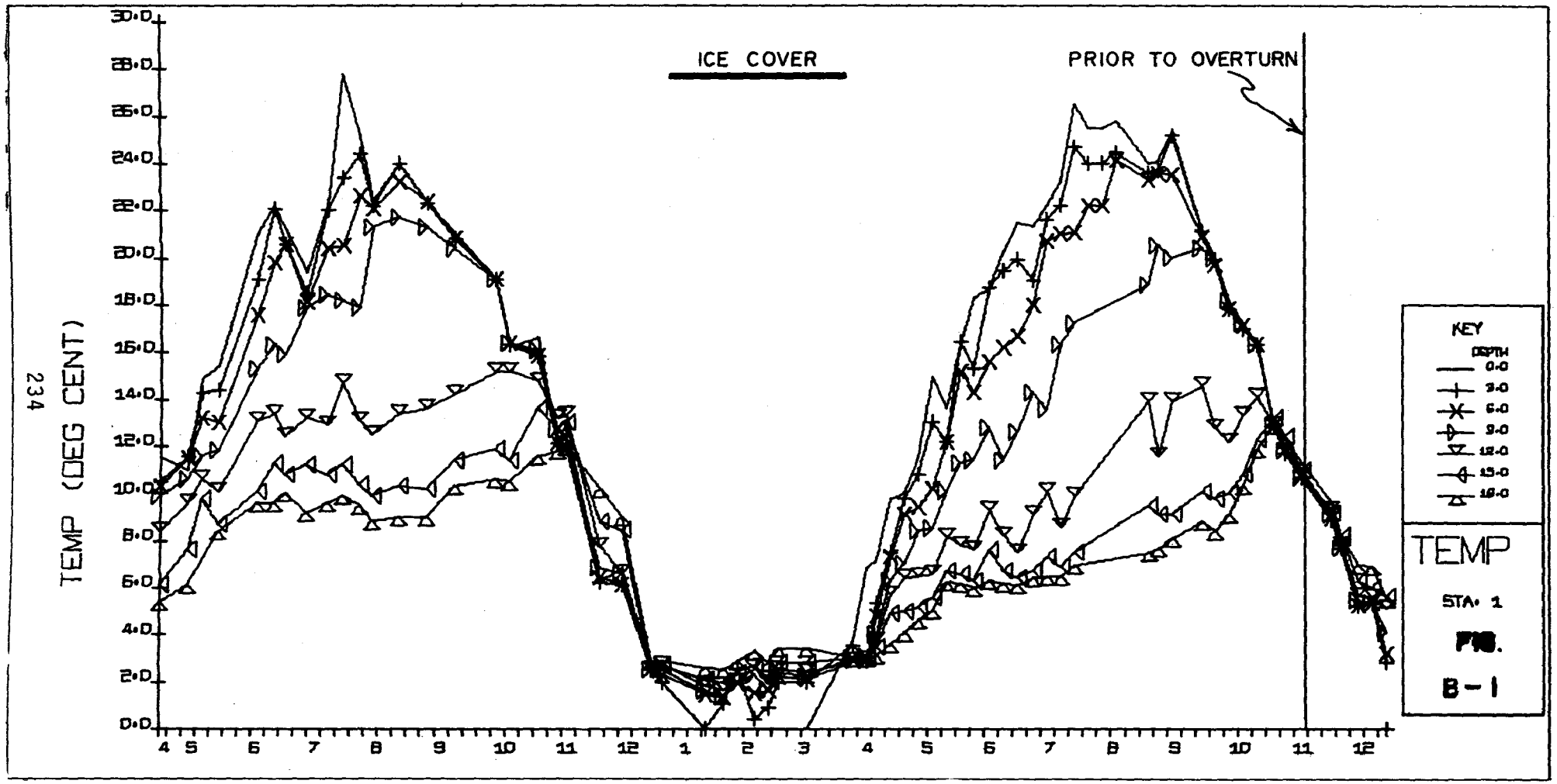
Symbol	Explanation
R	Multiple correlation coefficient
S^2	The square of the multiple correlation coefficient. A measure of the amount of variation in the dependent variable that is accounted for or explained by variations of the independent variables
Sres	The standard deviation of the residuals, i.e. the standard deviation of the differences between the predicted and actual values of the dependent variables.
Mean of dependent variable	The average value of the dependent variable
Sres/Mean	A comparative measure of the variation in the residuals, i.e. a comparative measure of "predictability"
Sm	The standard error (deviation) of the mean, i.e. the constant term in the predictive equasion
Regression - (at a risk Significant level of 5%)	- Y - could not happen by chance - N - could happen by chance
Largest Gr	Value of the highest correlation coefficient of the independent variables with the dependent variable after correcting for interdependence of the independent variables
Variable of Gr	Name of variable of largest Gr

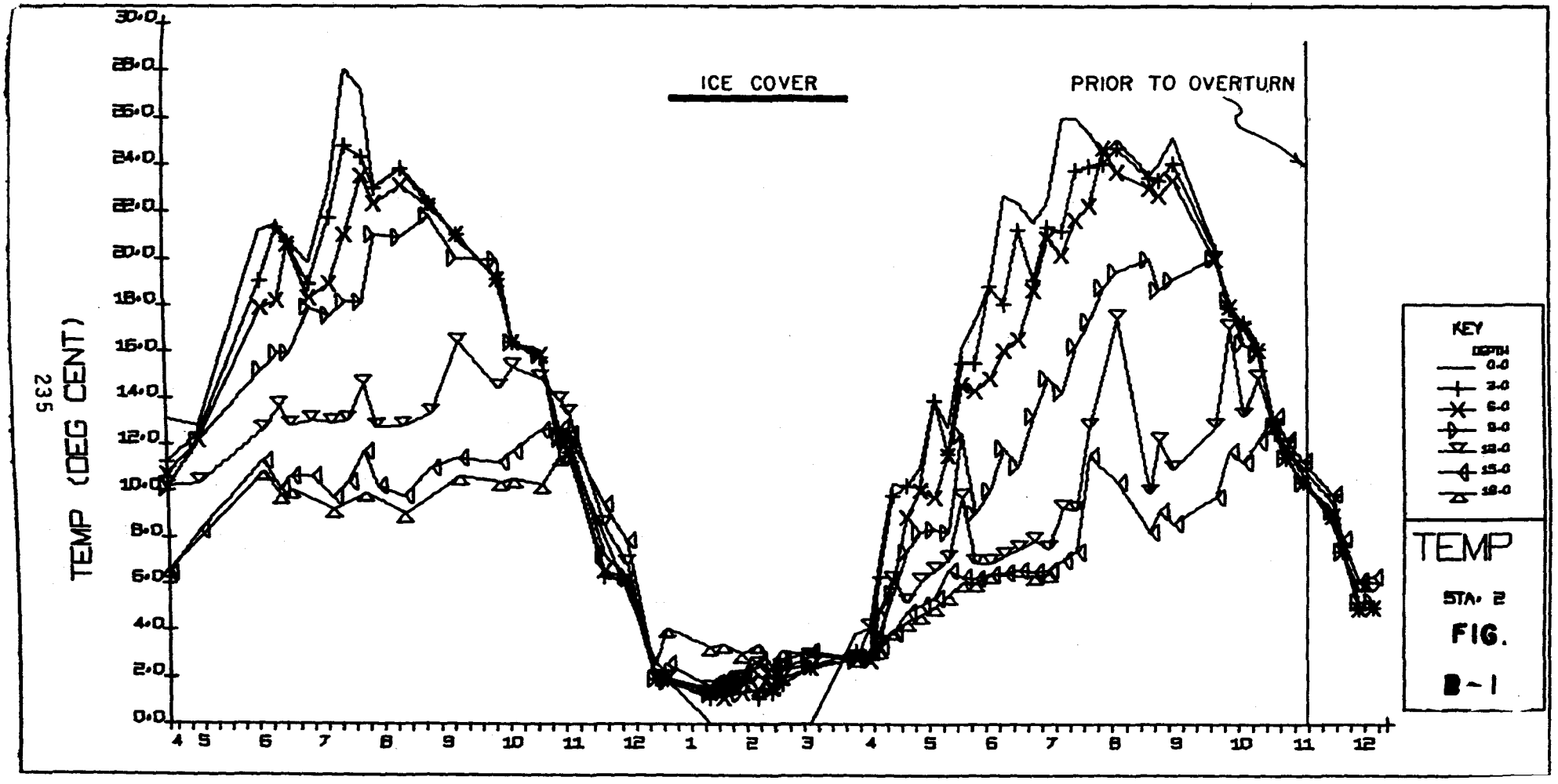
TABLE B-40

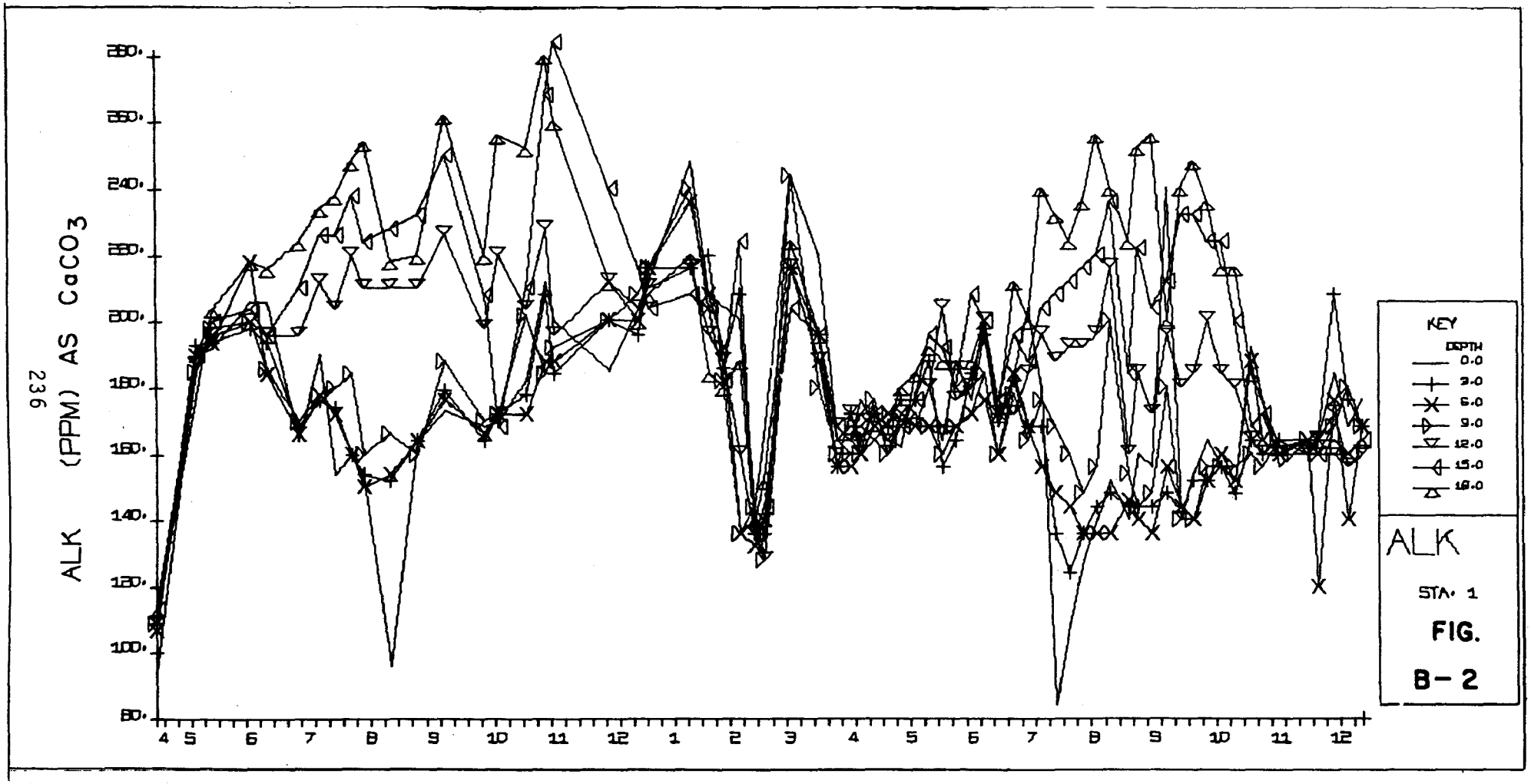
ONONDAGA LAKE STUDY

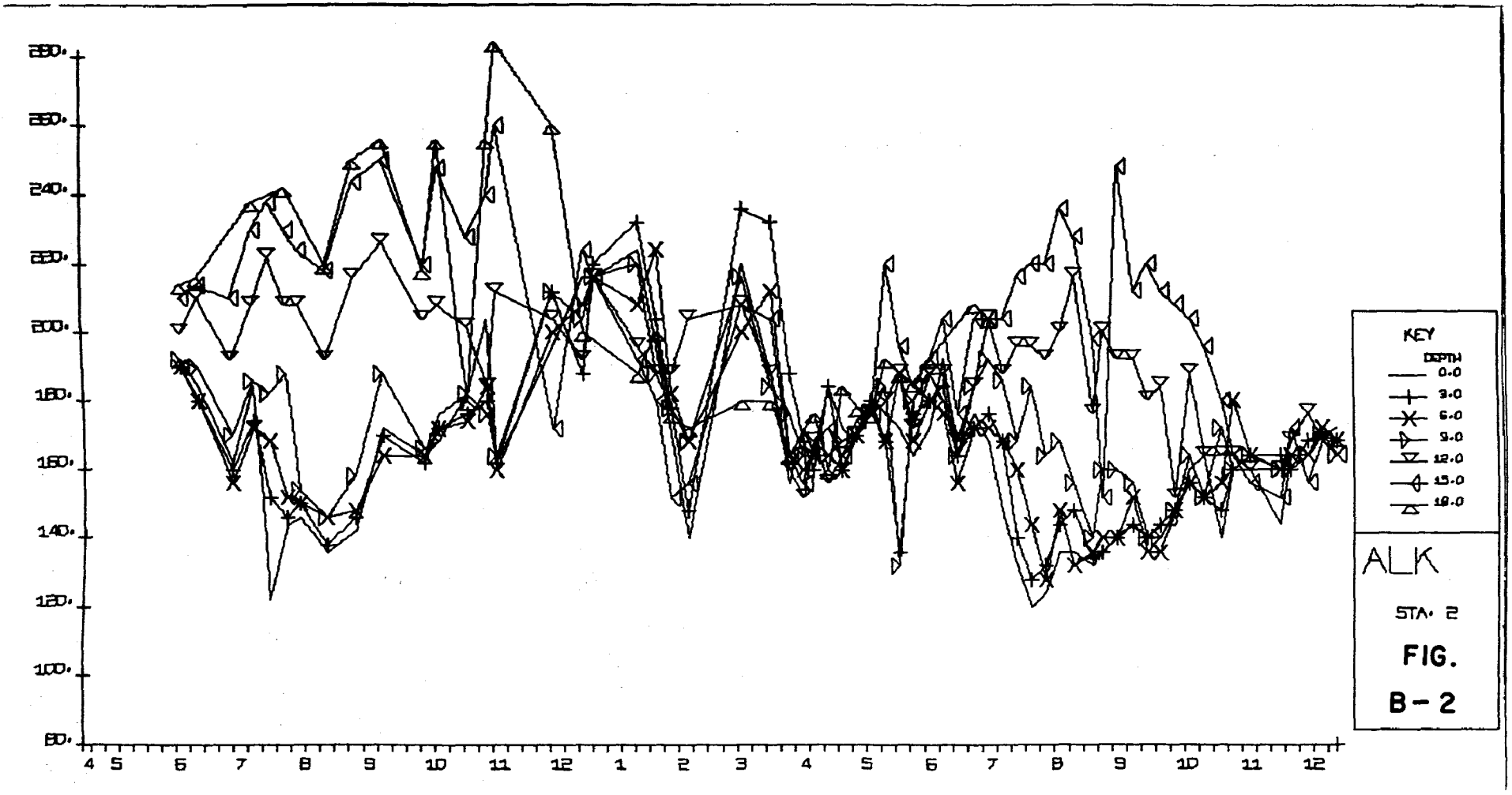
CORRELATION & REGRESSION ANALYSIS - DEPTH SYNOPTIC DATA

Run	Depen Vari-able	Identi-fication	Num-ber of OBS.	R	R^2	Mean of Depen Variable	Sres Mean	Sm	Regress Signif?	Lar-gest Gr	Vari-able of Largest Gr	Variables by Decreasing Gr	Comments
7	Diatoma Tenue	Surface Only	40	.81	.66	652.4	.28	368.5	N	-.45	SIØ2	SIØ2, K, ATEM, SØ4, WTEM, NORG, WVEL, ALK	Insuff. Data
9	DO	All Depths	432	.81	.66	3.27	.73	.11	Y	.58	PH	PH, DPTH, COND, OPO4, ALK K, CL, BOD	High Relat'sp to PH
15	DO	Epilimnion	170	.84	.71	5.51	.48	.18	Y	.69	PH	PH, DPTH, TEMP, NUH3, CL, ØPØ4, ALK, K	
16	DO	Hypolimnion	170	.69	.48	0.91	1.22	.08	Y	-.31	DPTH	DPTH, NA, TEMP, PH, NNH3, TIME, CL, ALK	
10	BOD	All Depths	432	.63	.40	9.52	.73	.33	Y	.31	ALK	ALK, TEMP, DPTH, K, CØND, SOY, TIME, NNH3	
17	BOD	Epilimnion	198	.58	.34	5.93	.63	.26	Y	.26	CL	CL, ALK, OPO4, TEMP, DPTH NORG, PH, NNB	
18	BOD	Hypolimnion											No test D O
11	ALK	All Depths	432	.76	.58	175.6	.12	.86	Y	.32	BOD	BOD, K, NA, PH, SO4, DPTH ØPO4, TEMP	
19	ALK	Epilimnion											No test D O
20	ALK	Hypolimnion	170	.83	.69	187.3	.09	1.30	Y	.34	BOD	BOD, K, DPTH, CL, TEMP, PH, UNH3, SO4	
8	OPO4	All Depths	432	.72	.52	1.31	.43	.03	Y	.27	NNH3	NNH3, TEMP, CL, TIME, PH COND, K, SO4	
13	OPO4	Epilimnion	198	.70	.49	1.06	.52	.04	Y	.34	CL	CL, NNH3, TIME, TEMP, K, BOD, PH, DO	
14	OPO4	Hypolimnion	170	.75	.57	1.67	.33	.04	Y	.27	TEMP	TEMP, PH, K, SO4, COND, BOD, TIME, NNH3	
24	CL	All Depths	432	.83	.69	1625.0	.12	9.70	Y	.26	COND	COND, DPTH, NA, OPO4, BOD SO4, K, TIME	
23	CL	Epilimnion	198	.85	.72	1422.3	.14	14.30	Y	.34	OPO4	ØPO4, BOD, COND, K, DO, NA, TEMP, SO4	
22	CL	Hypolimnion	170	.70	.49	1834.3	.09	13.20	Y	.35	DPTH	DPTH, TEMP, TIEM, ALK, PH NA, DØ, NORG	


ICE COVER
PRIOR TO OVERTURN
TEMP (DEG CENT)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
TEMP
STA. 1
FIG.
B-1


ICE COVER
PRIOR TO OVERTURN
TEMP (DEG CENT)
235
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
TEMP
STA. 2
FIG.
B-1


ALK (PPM) AS CaCO3
280
260
240
220
200
180
160
140
120
100
80
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ALK
STA. 1
FIG.
B-2


280.
260.
240.
220.
200.
180.
160.
140.
120.
100.
80.
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ALK
STA. 2
FIG.
B-2

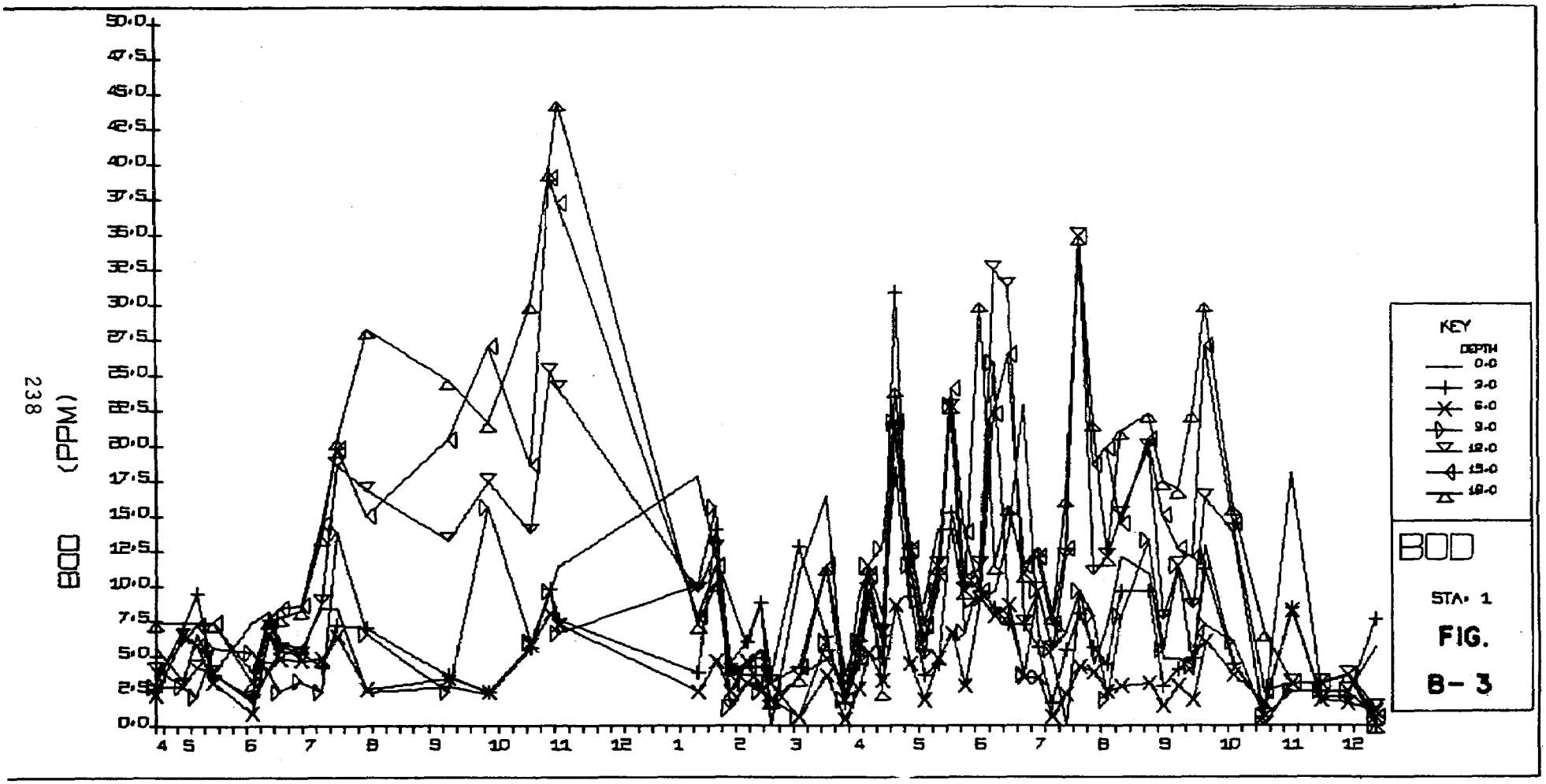

BOD (PPM)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
BOD
STA. 1

FIG. B-3

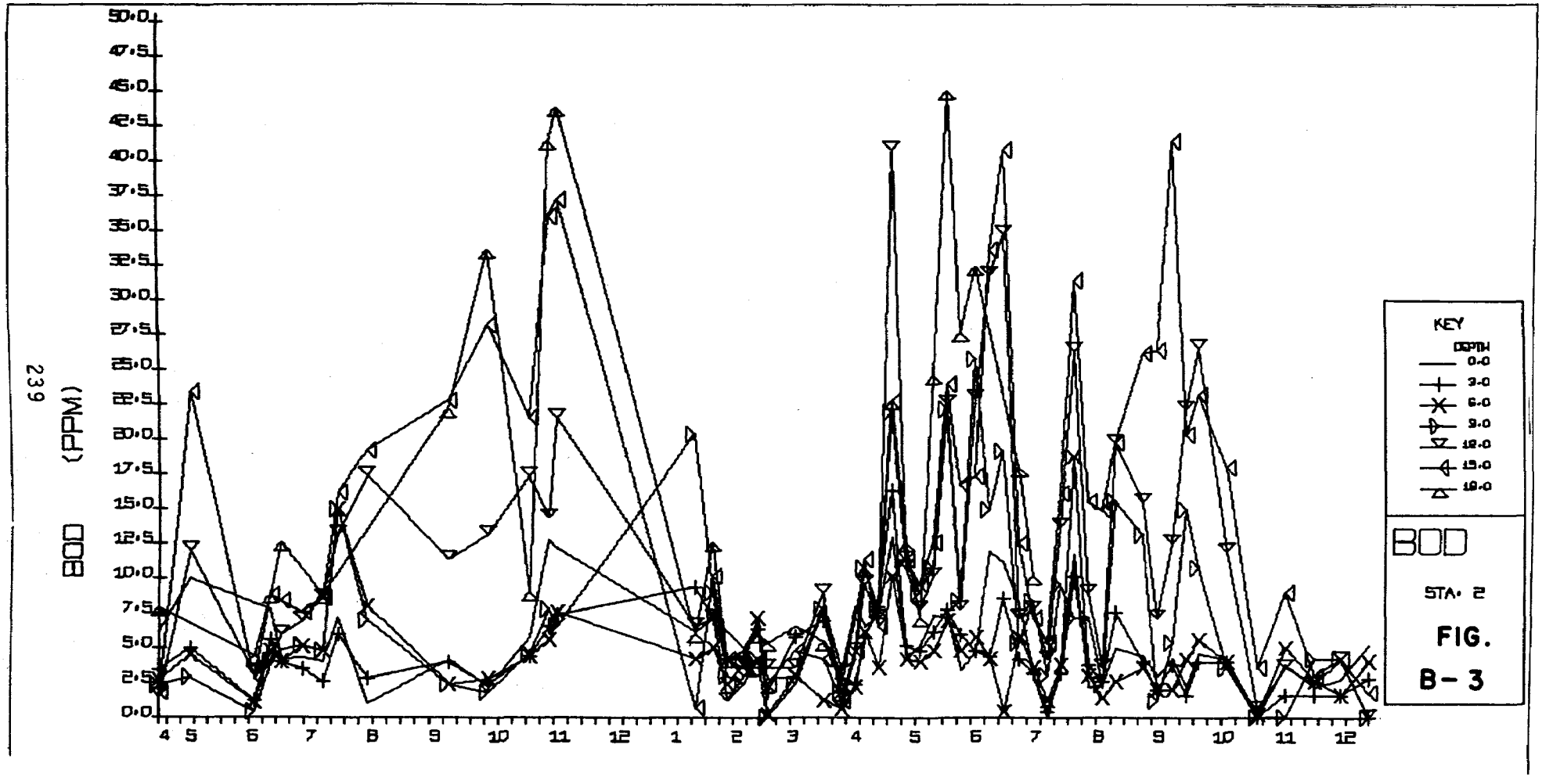

BOD (PPM)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
BOD
STA. 2

FIG. B-3

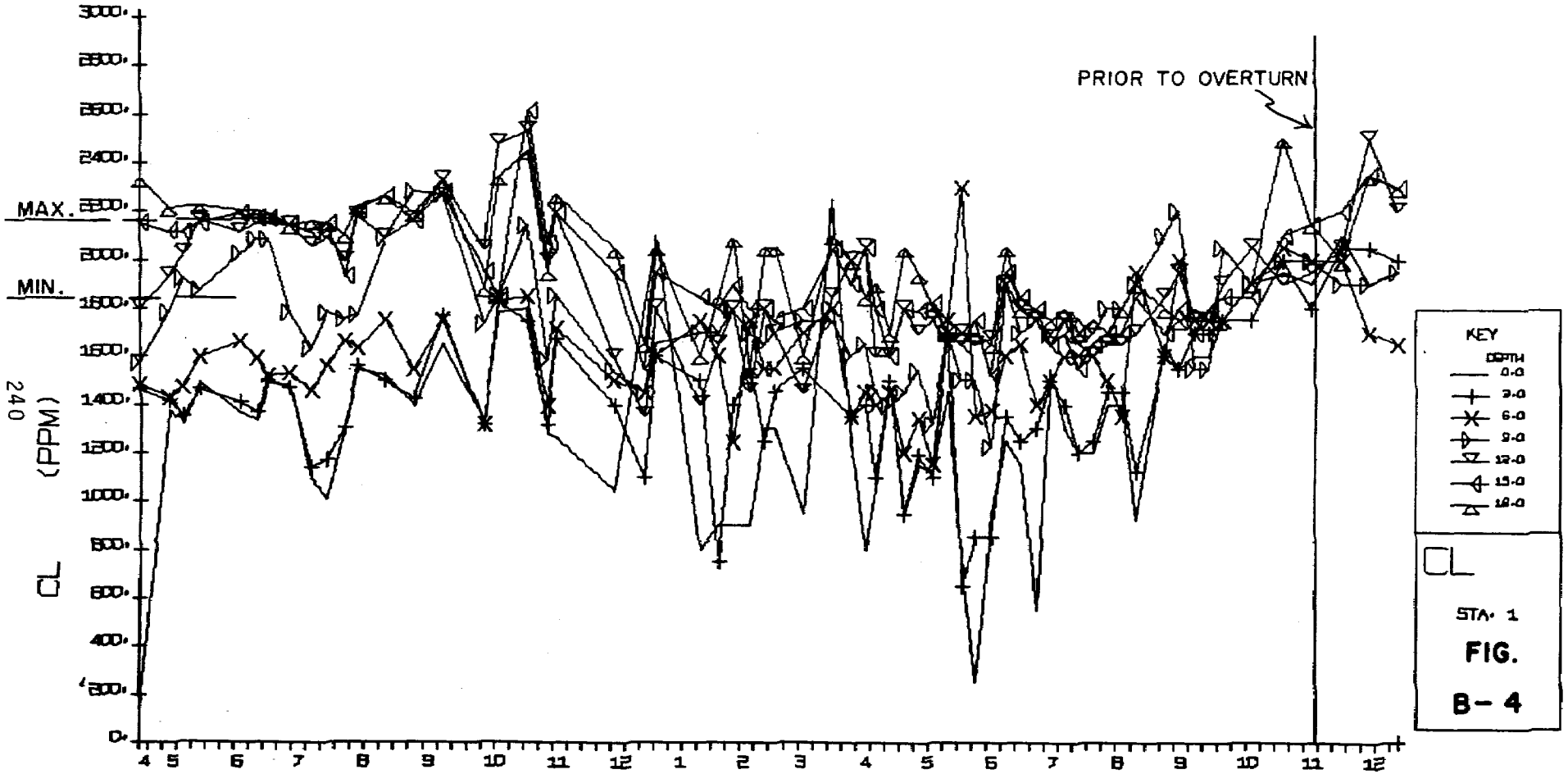

PRIOR TO OVERTURN
MAX.
MIN.
CL (PPM)
240
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CL
STA. 1

FIG.

B-4

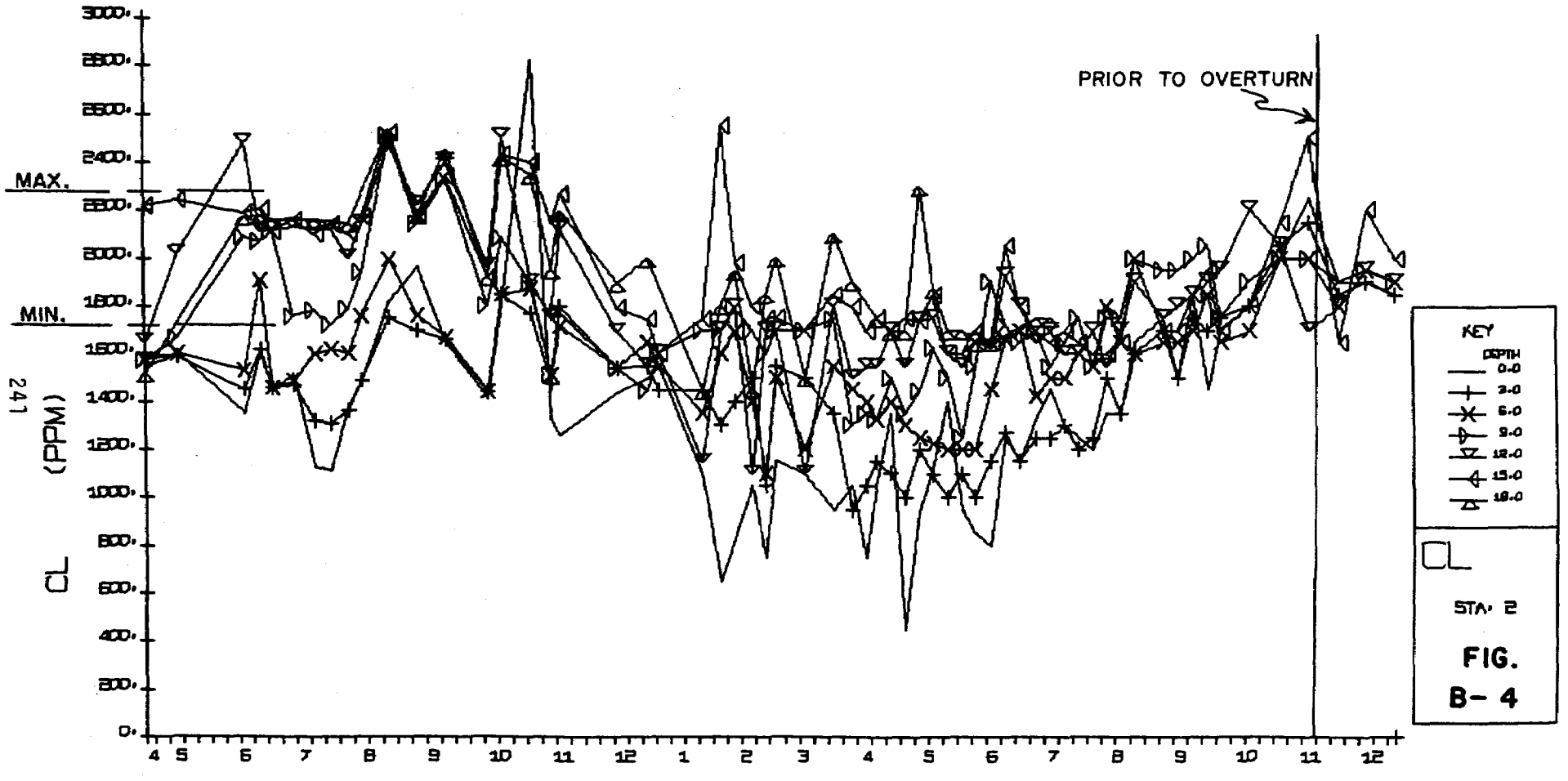

PRIOR TO OVERTURN
MAX.
MIN.
CL (PPM)
241
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CL
STA. 2

FIG. B-4

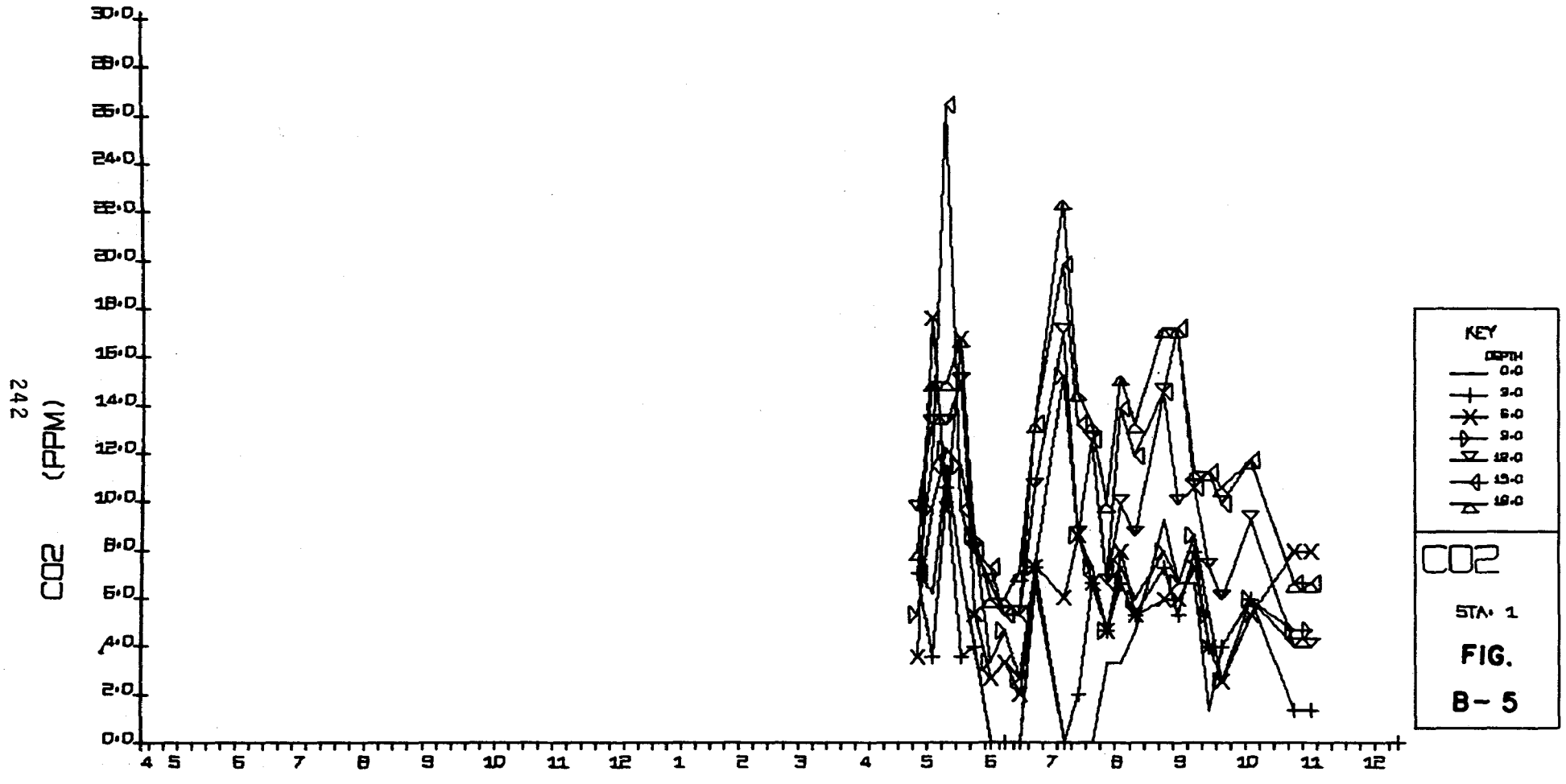
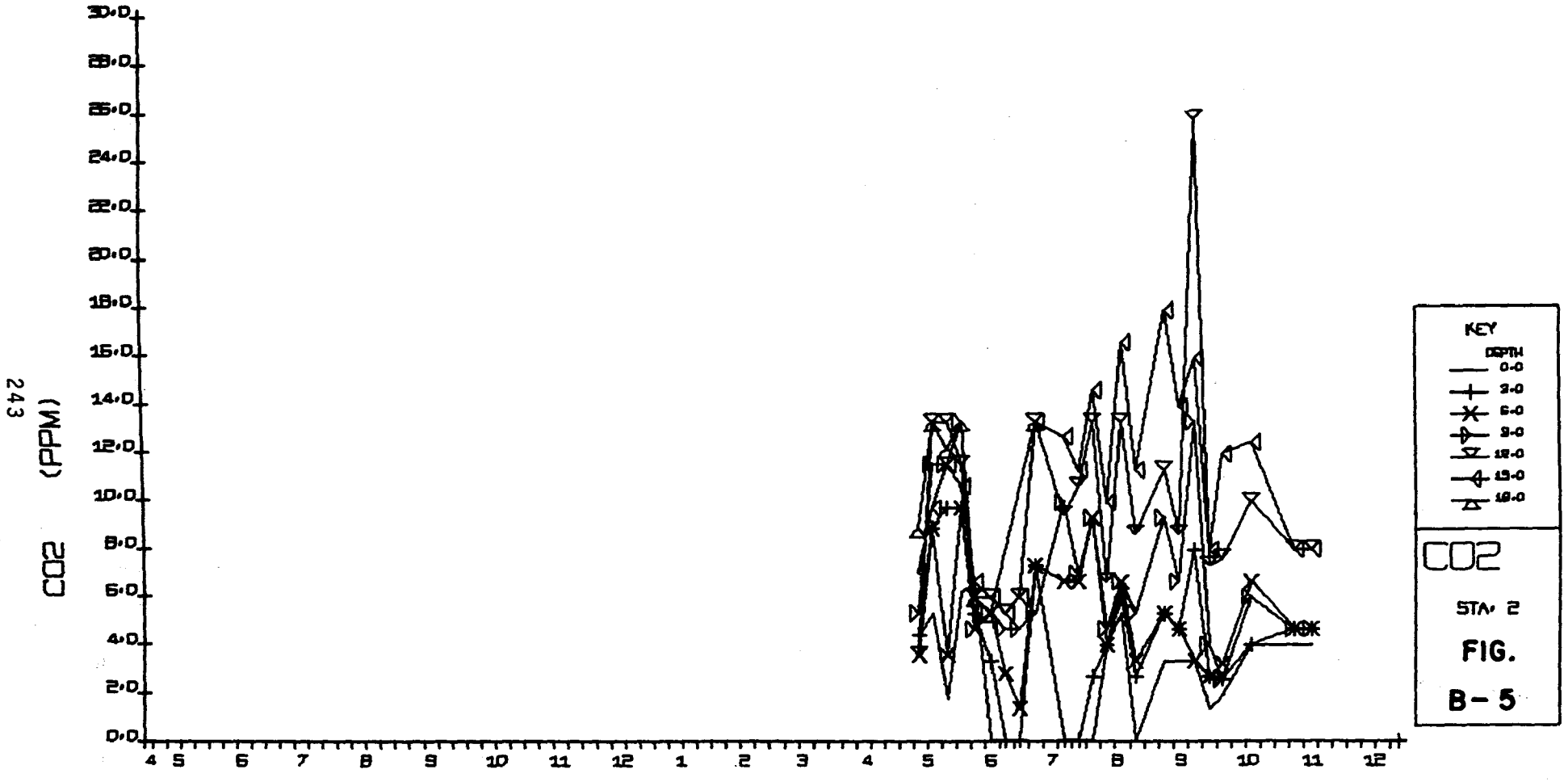

CO2 (PPM)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CO2
STA. 1

FIG. B-5


30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
CO2 (PPM)
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CO2
STA. 2
FIG.
B-5

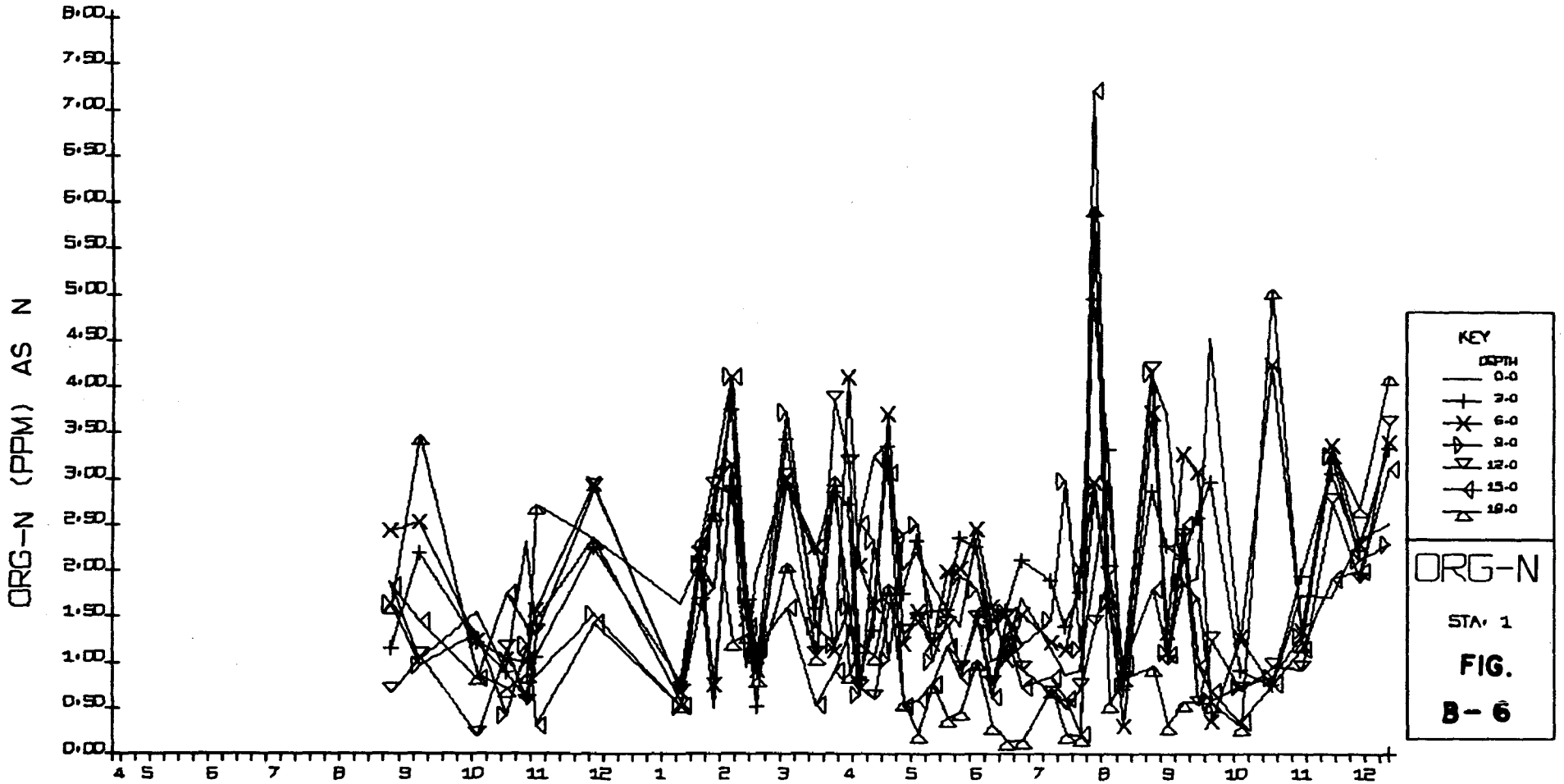
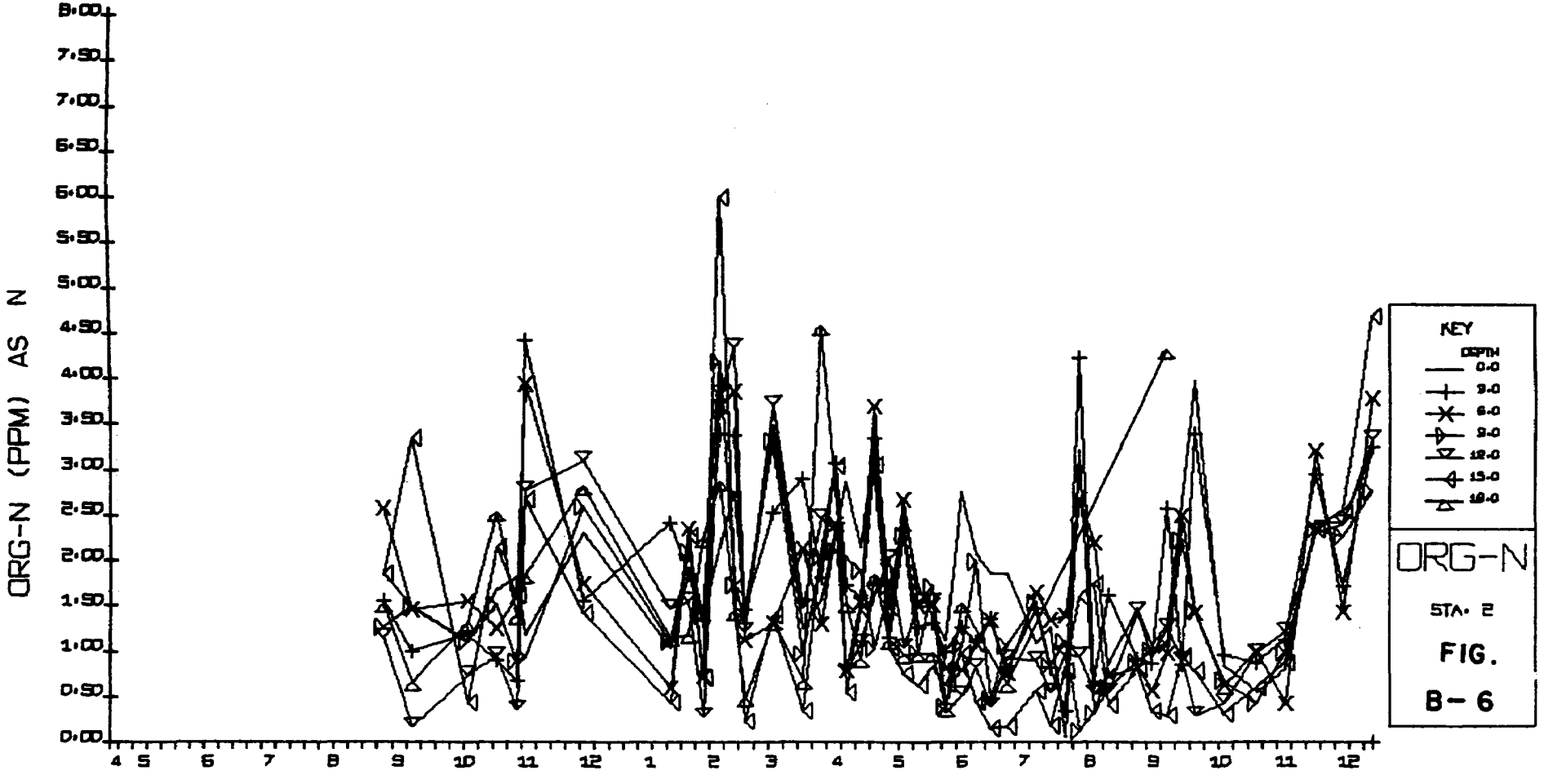

ORG-N (PPM) AS N
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ORG-N
STA. 1

FIG. B-6


ORG-N (PPM) AS N
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ORG-N
STA. 2
FIG.
B-6

NH3-N (PPM) AS N
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
NH3-N
STA. 1

FIG.

B-7

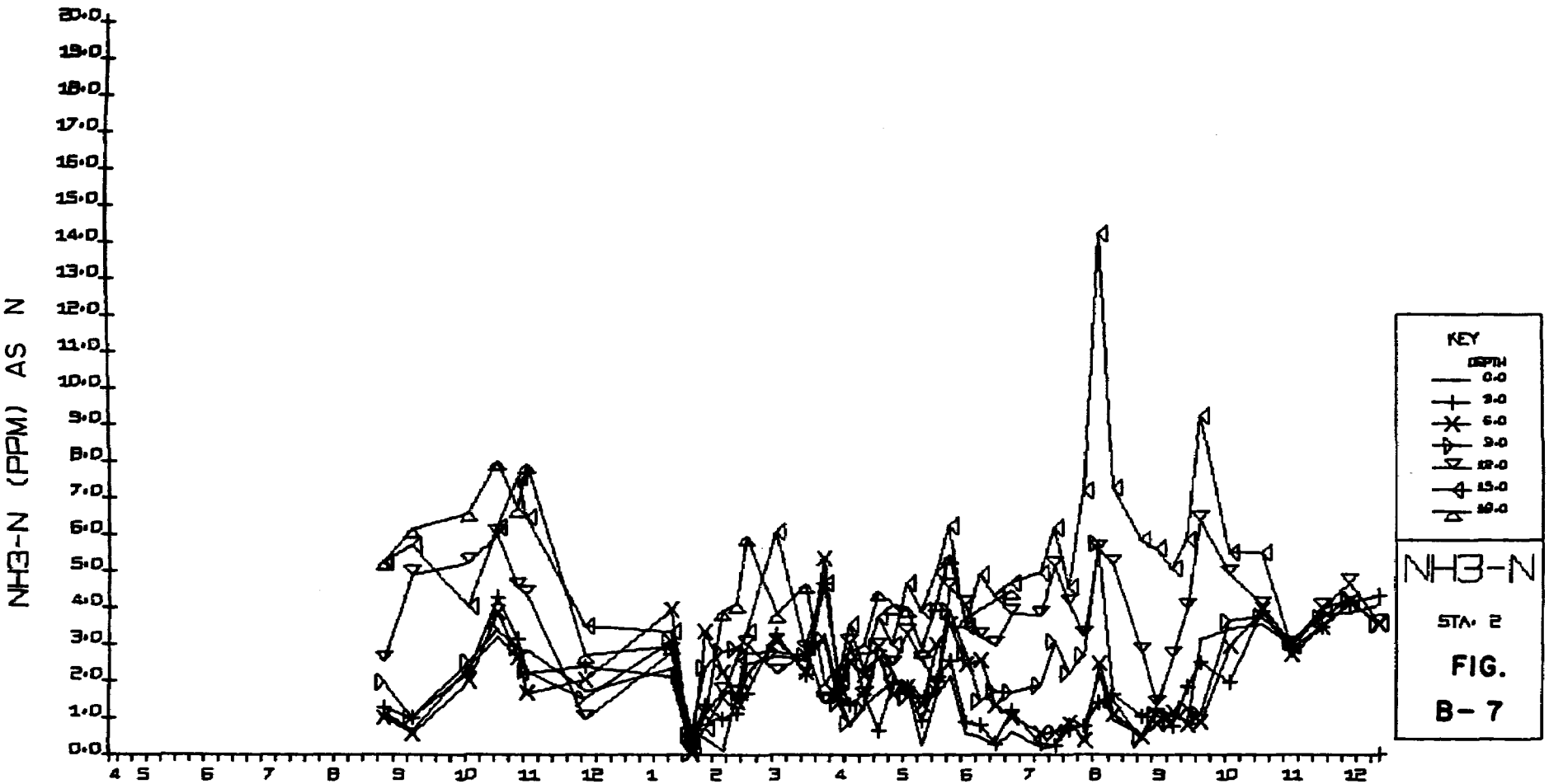

NH3-N (PPM) AS N
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
NH3-N
STA. 2

FIG.
B-7

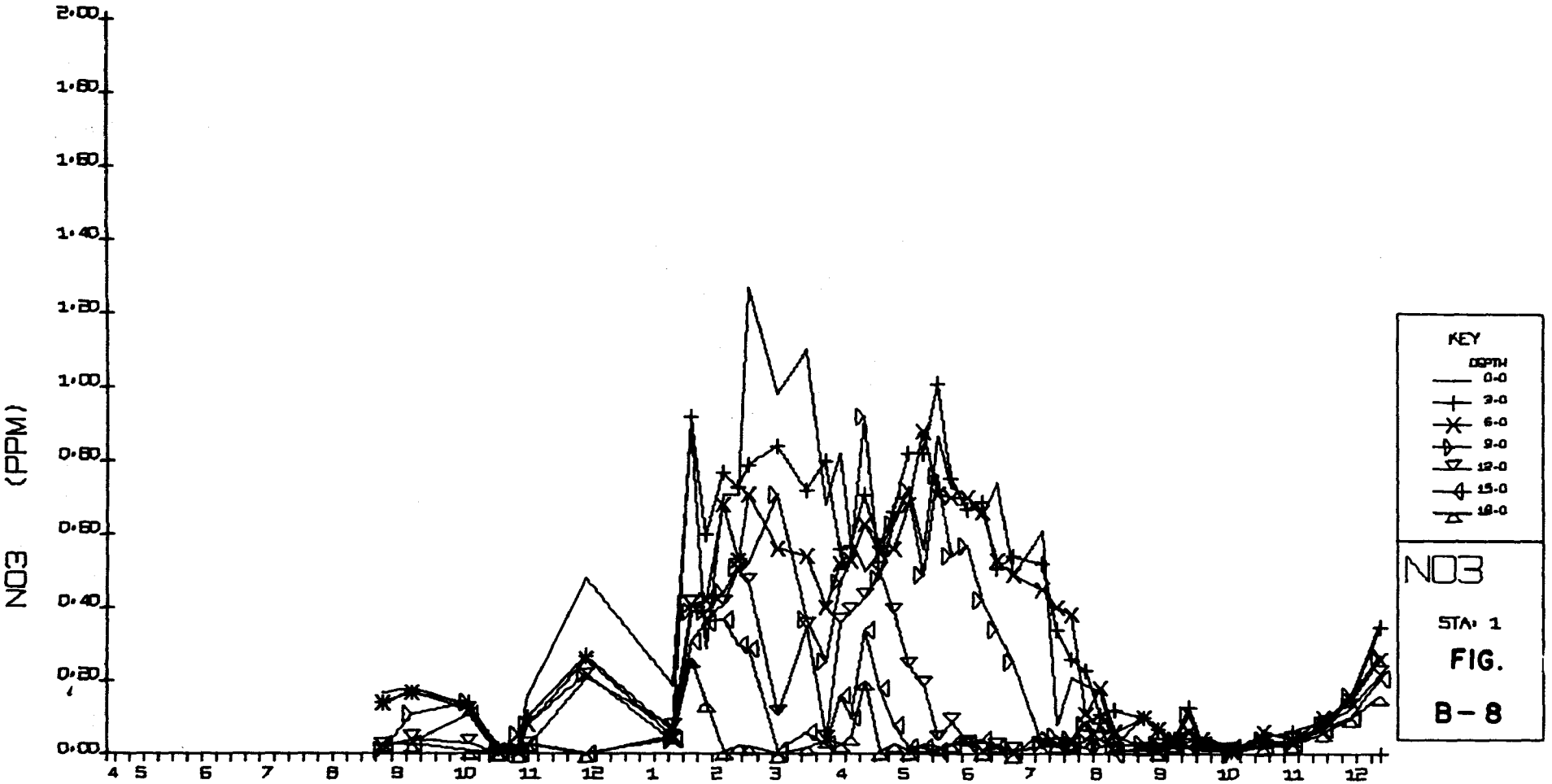

NO3 (PPM)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
NO3
STA: 1

FIG.

B-8

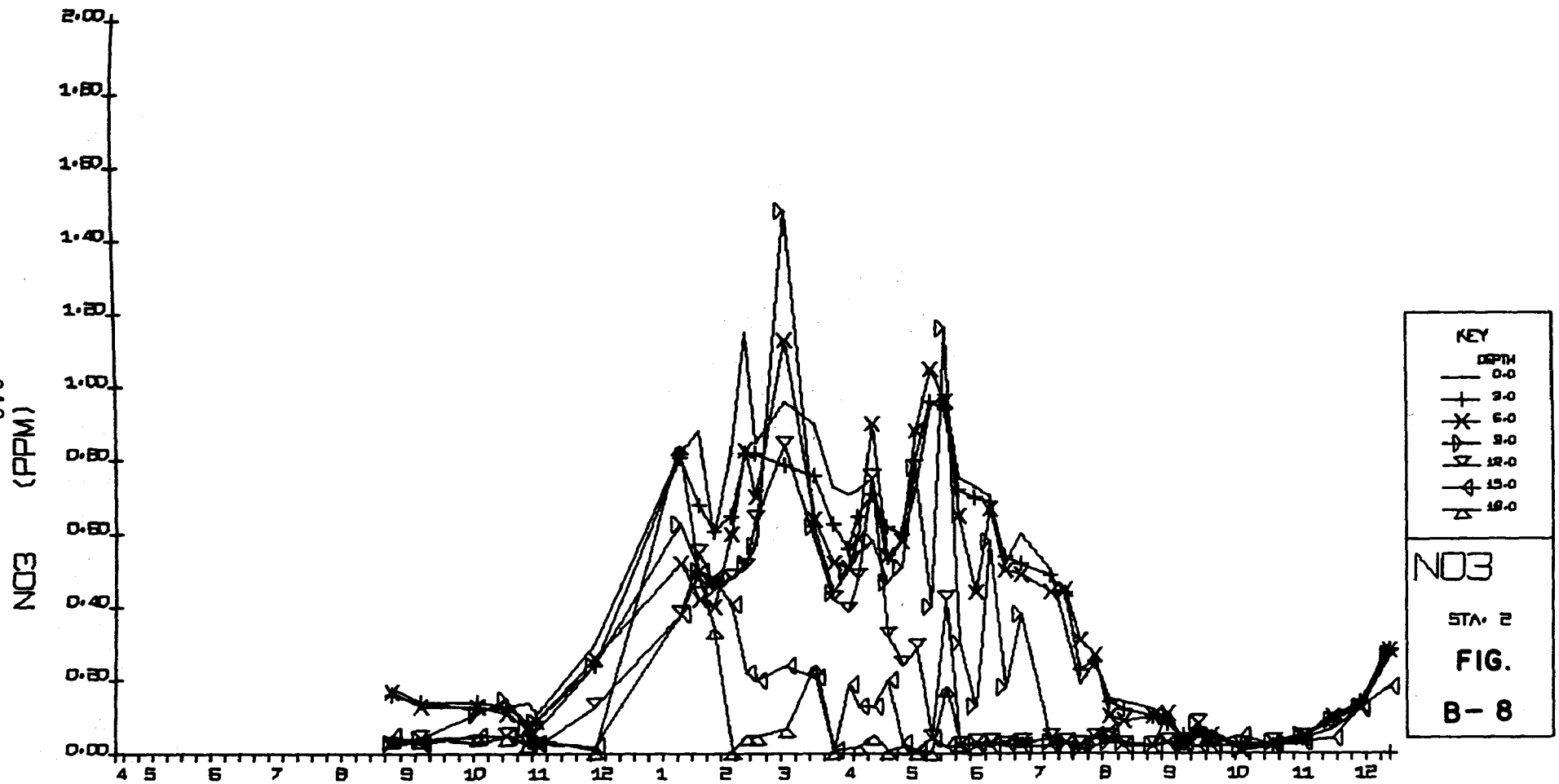

NO3 (PPM)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
NO3
STA. 2

FIG. B-8

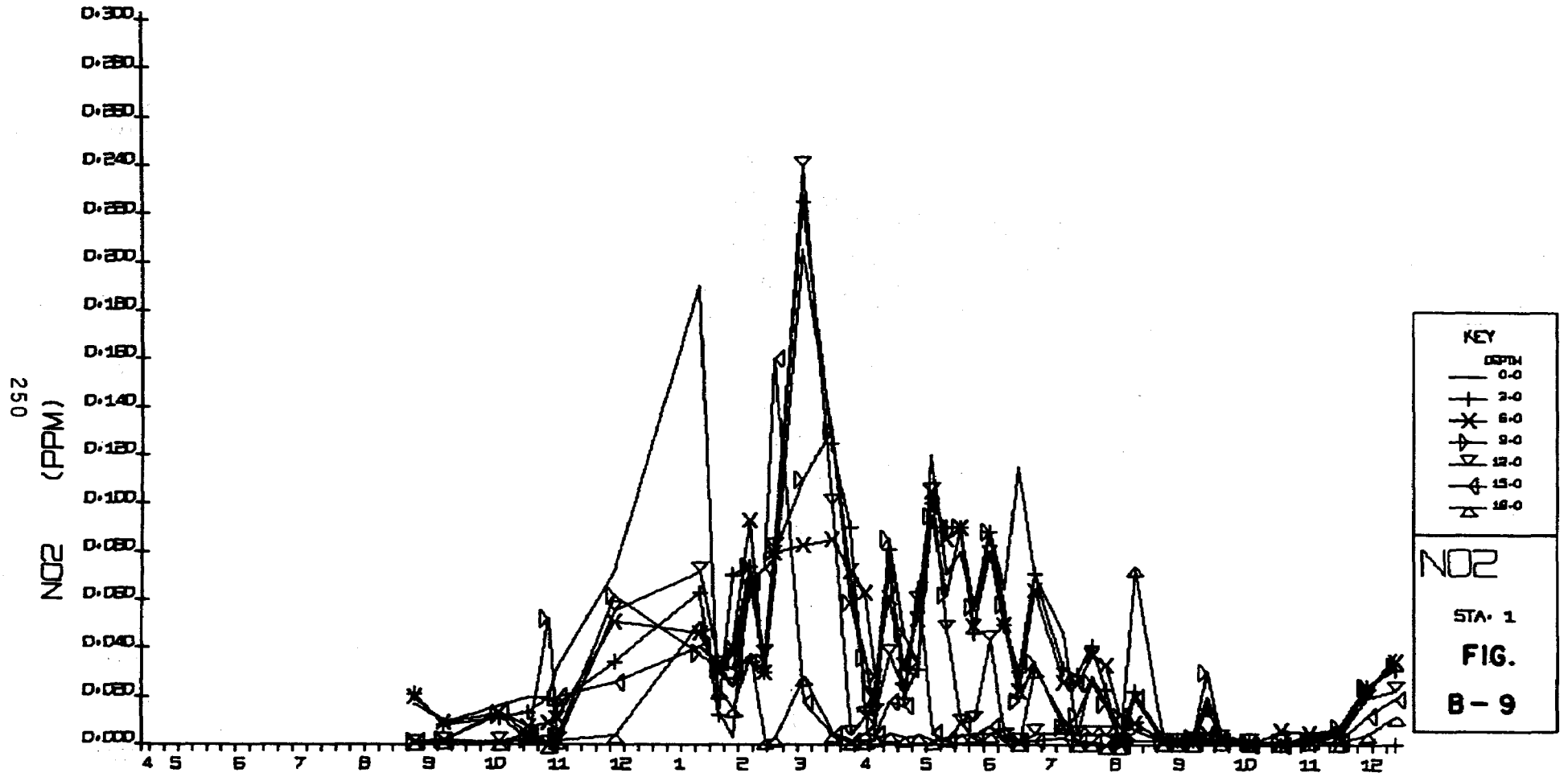

NO2 (PPM)
250
0.300
0.280
0.260
0.240
0.220
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
2.0
6.0
9.0
12.0
15.0
16.0
NO2
STA. 1

FIG.

B - 9

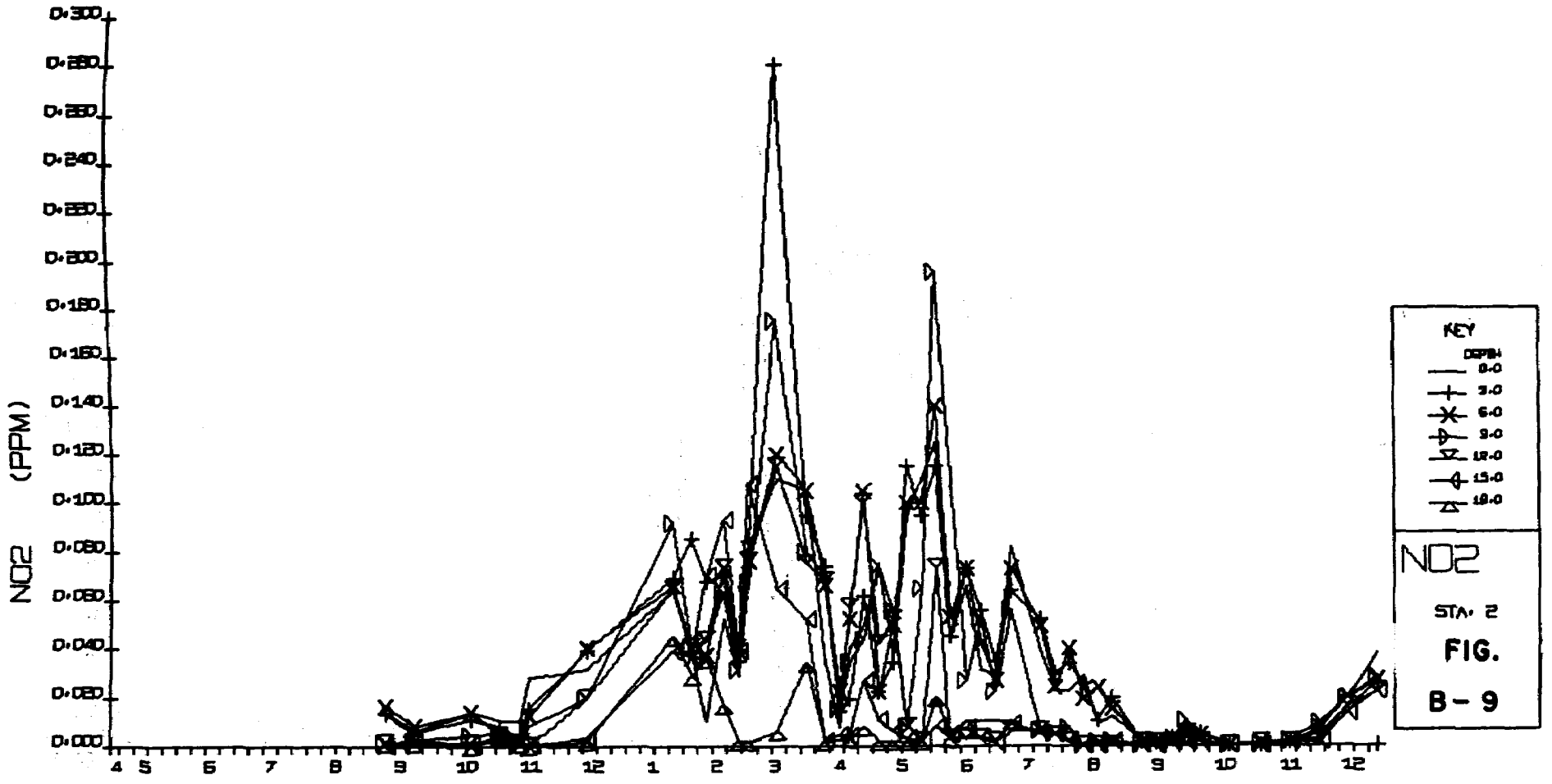
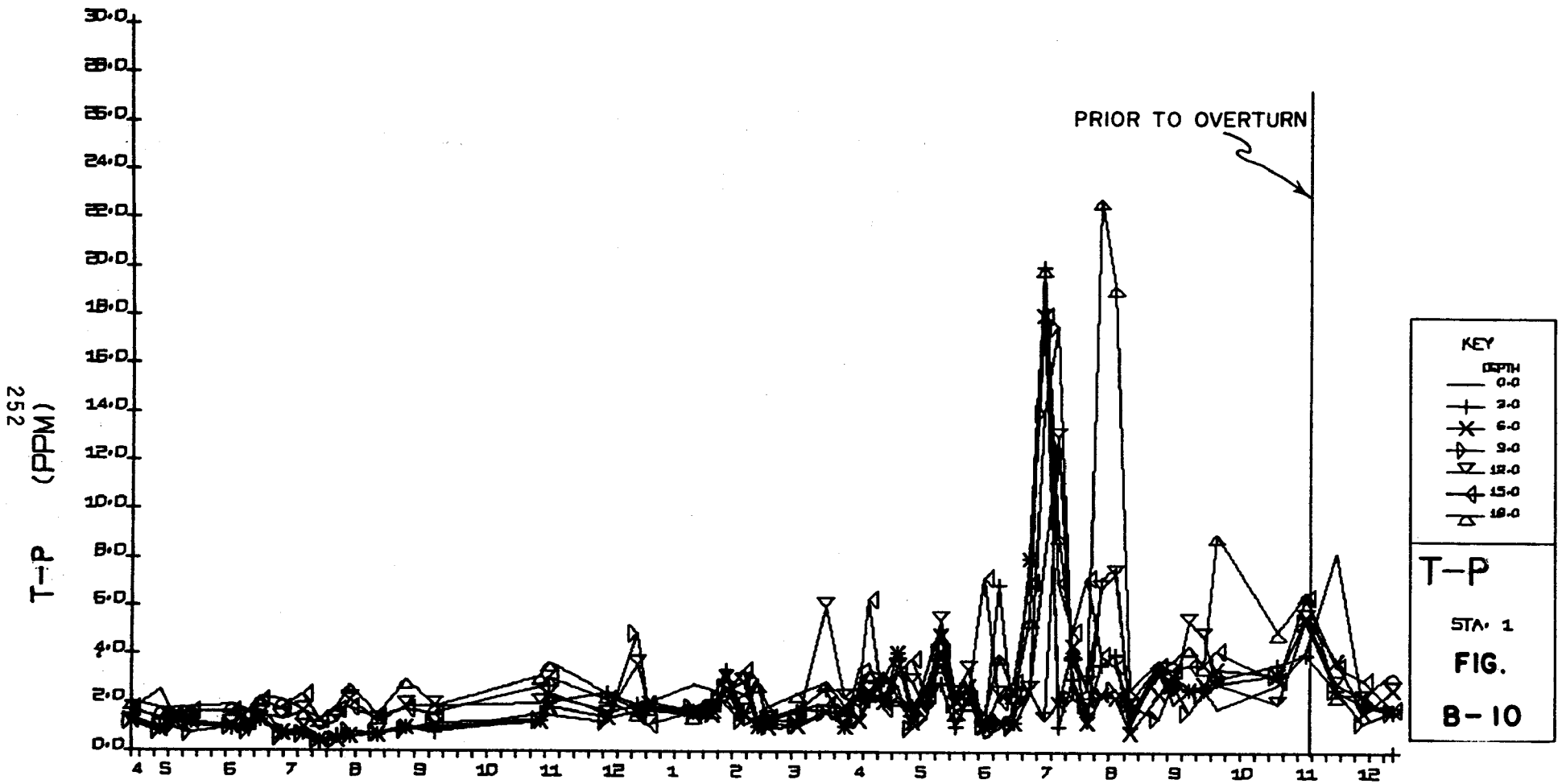

NO2 (PPM)
0.300
0.280
0.260
0.240
0.220
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
NO2
STA. 2

FIG. B - 9


T-P (PPM)
252
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
PRIOR TO OVERTURN
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
T-P
STA. 1
FIG.
B-10

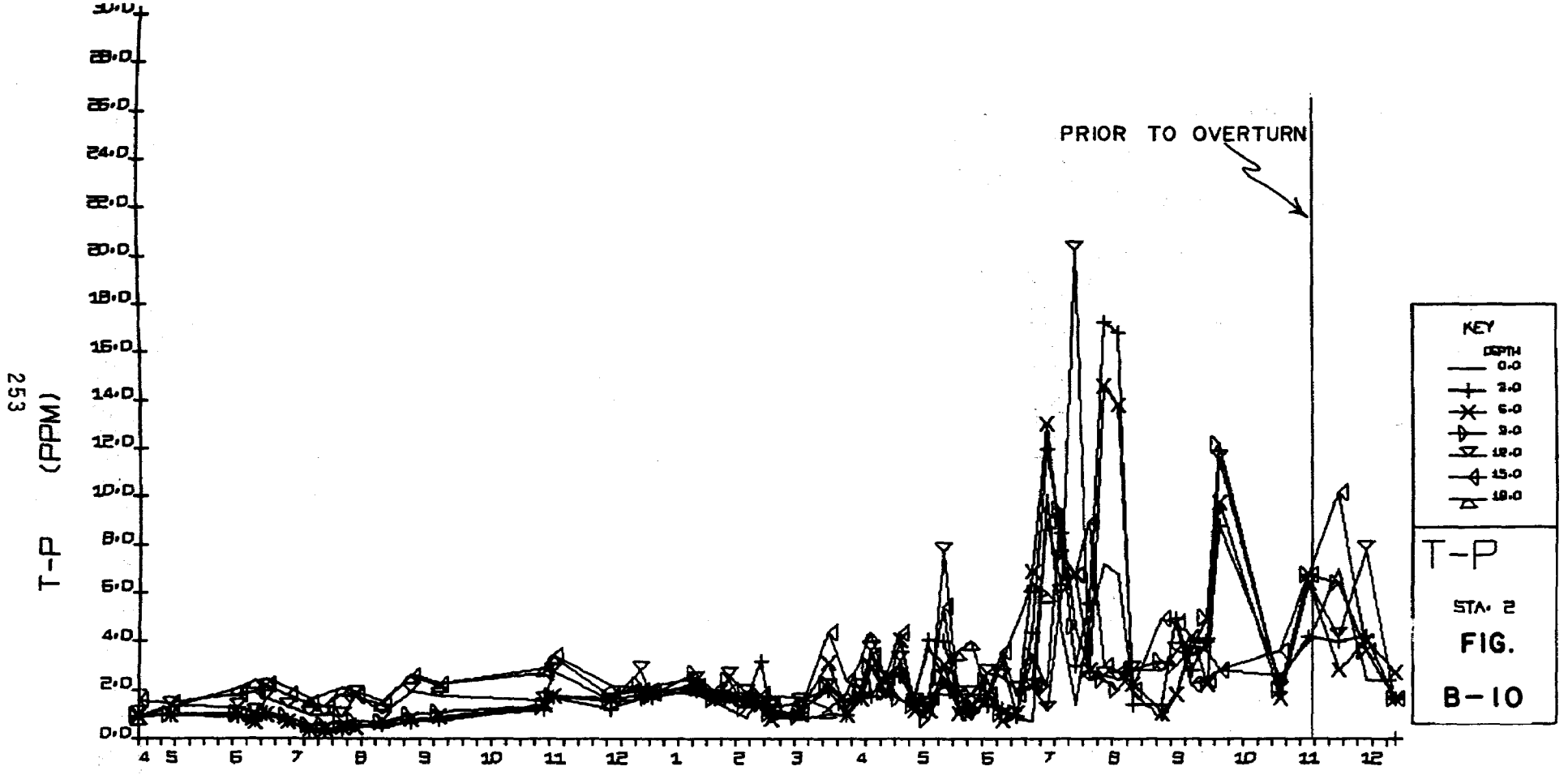

T-P (PPM)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
PRIOR TO OVERTURN
KEY
DEPTH
0.0
2.0
6.0
9.0
12.0
15.0
18.0
T-P
STA. 2

FIG. B-10

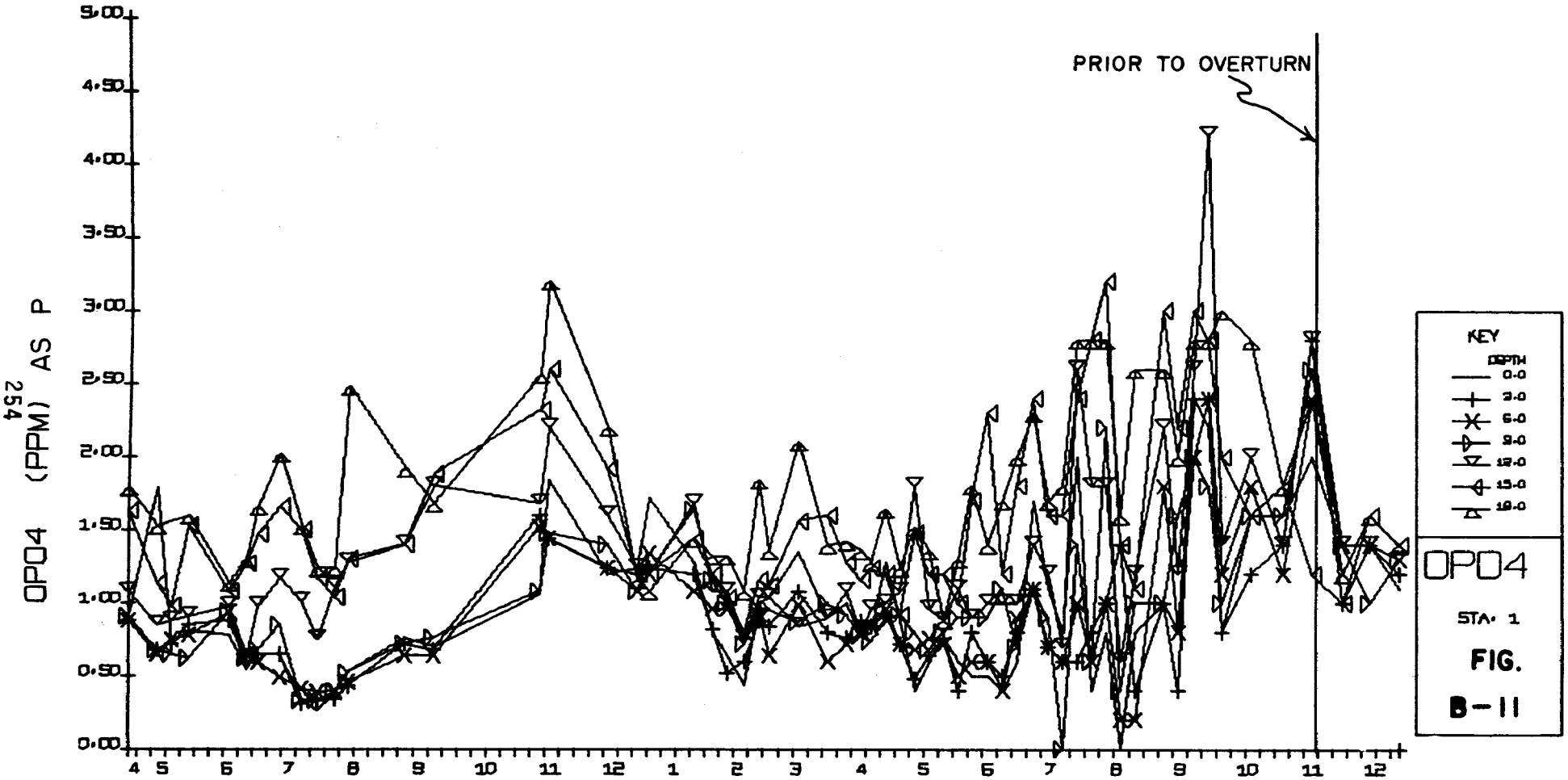
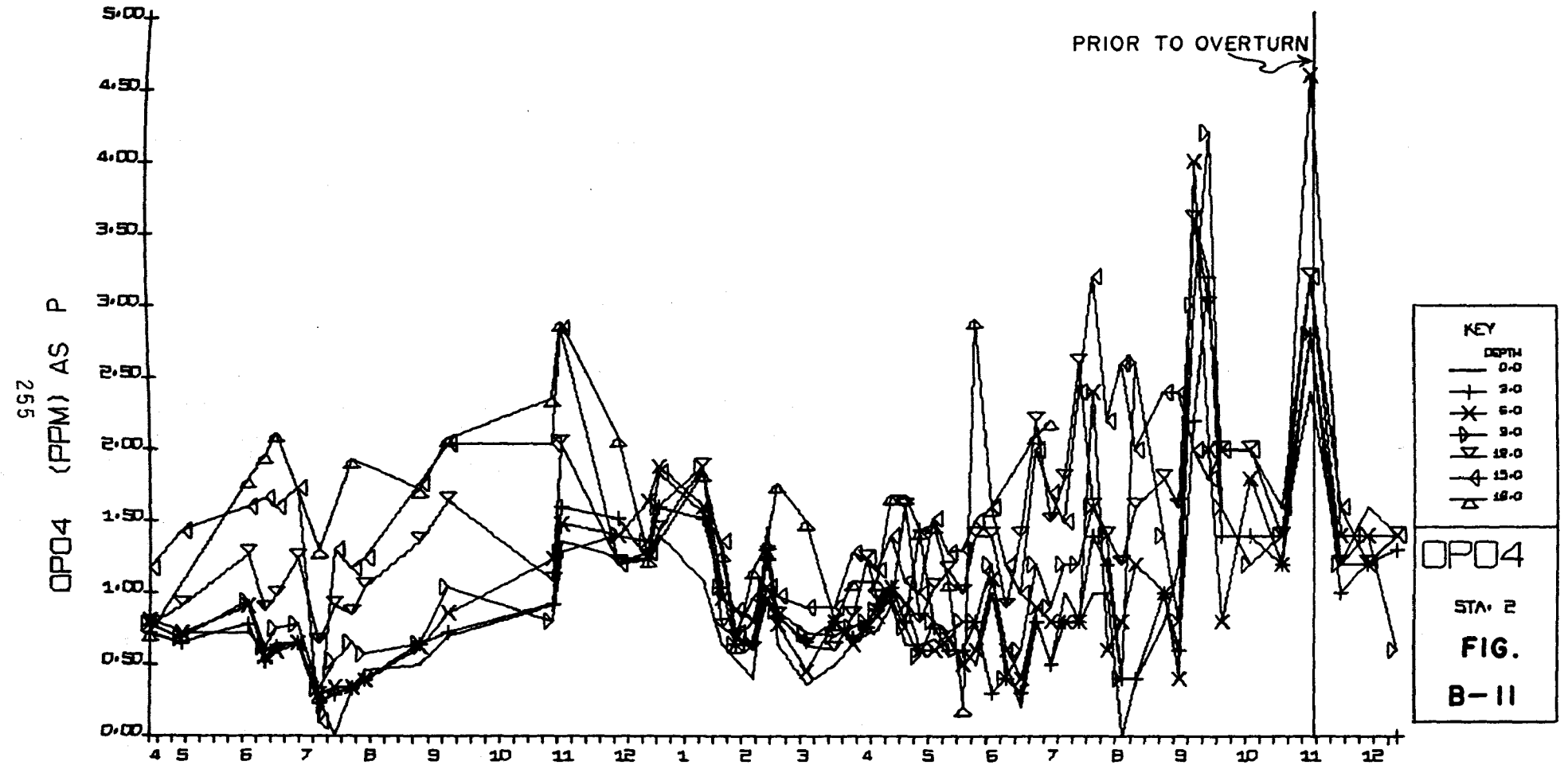

PRIOR TO OVERTURN
OPO4 (PPM) AS P
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
OPO4
STA. 1

FIG. B-11


PRIOR TO OVERTURN
OP04 (PPM) AS P
255
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
OP04
STA. 2
FIG.
B-11

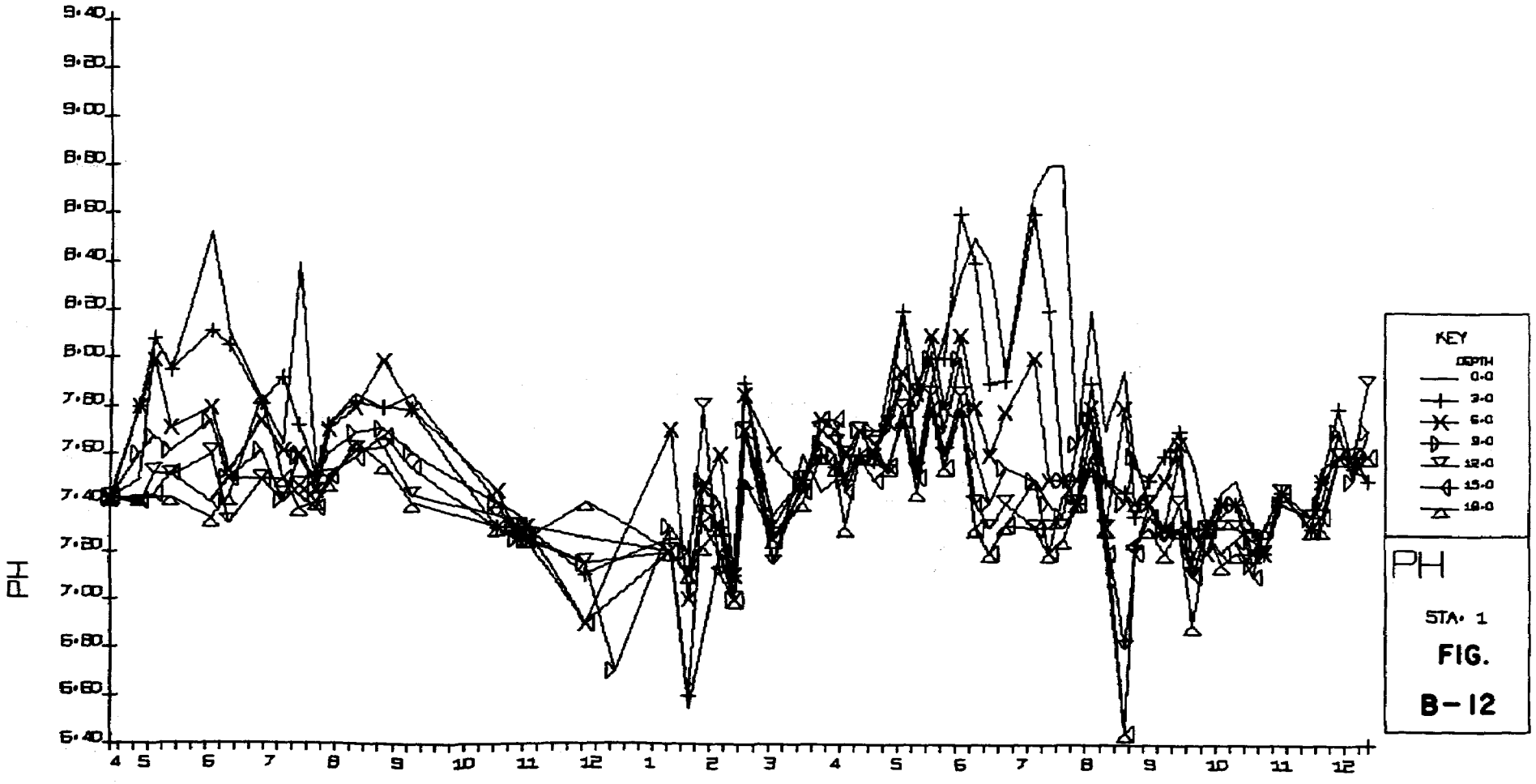
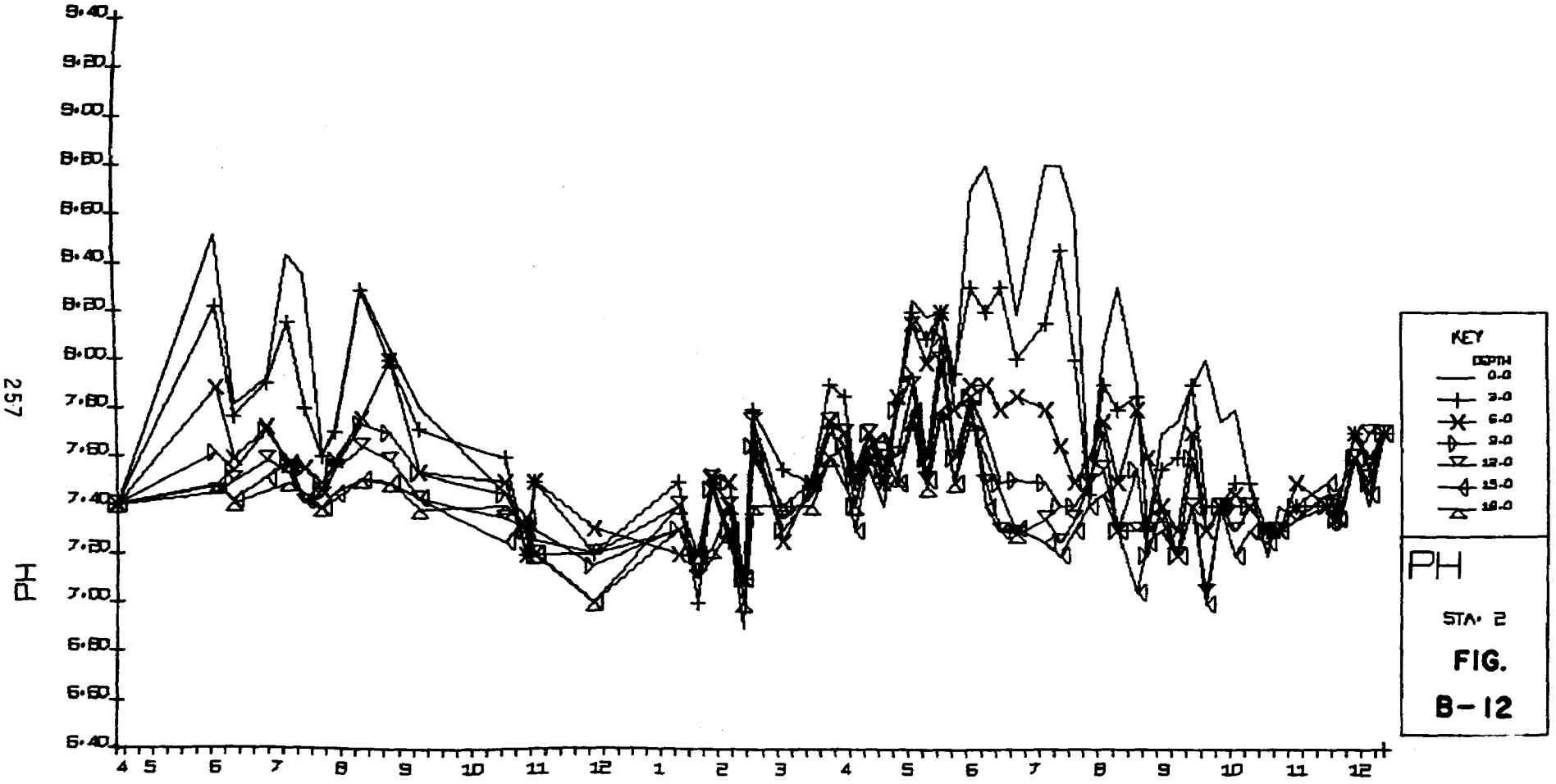

9.40
9.20
9.00
8.80
8.60
8.40
8.20
8.00
7.80
7.60
7.40
7.20
7.00
6.80
6.60
6.40
PH
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
PH
STA. 1

FIG.

B-12


9.40
9.20
9.00
8.80
8.60
8.40
8.20
8.00
7.80
7.60
7.40
7.20
7.00
6.80
6.60
6.40
PH
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
PH
STA. 2
FIG.
B-12

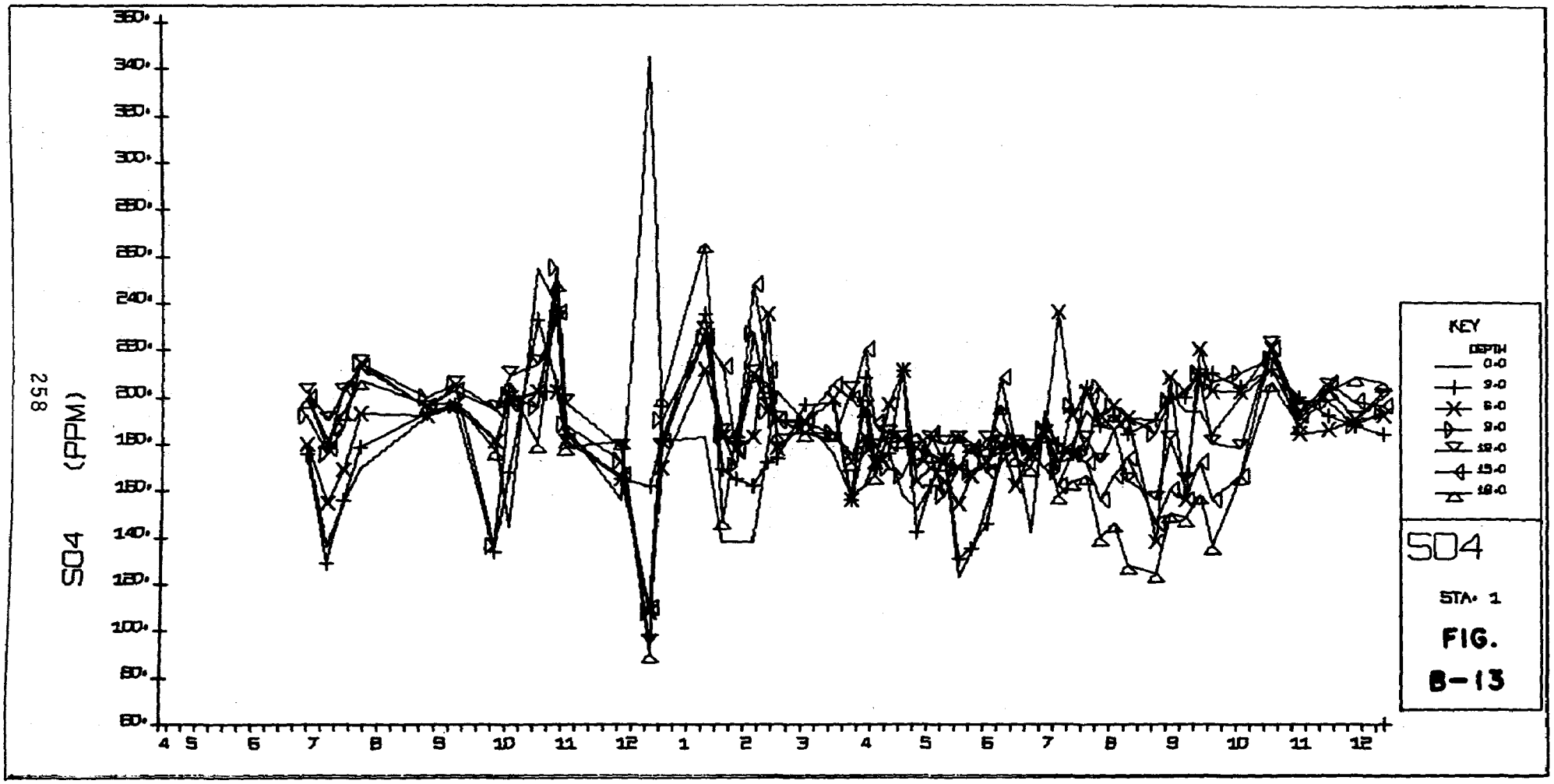
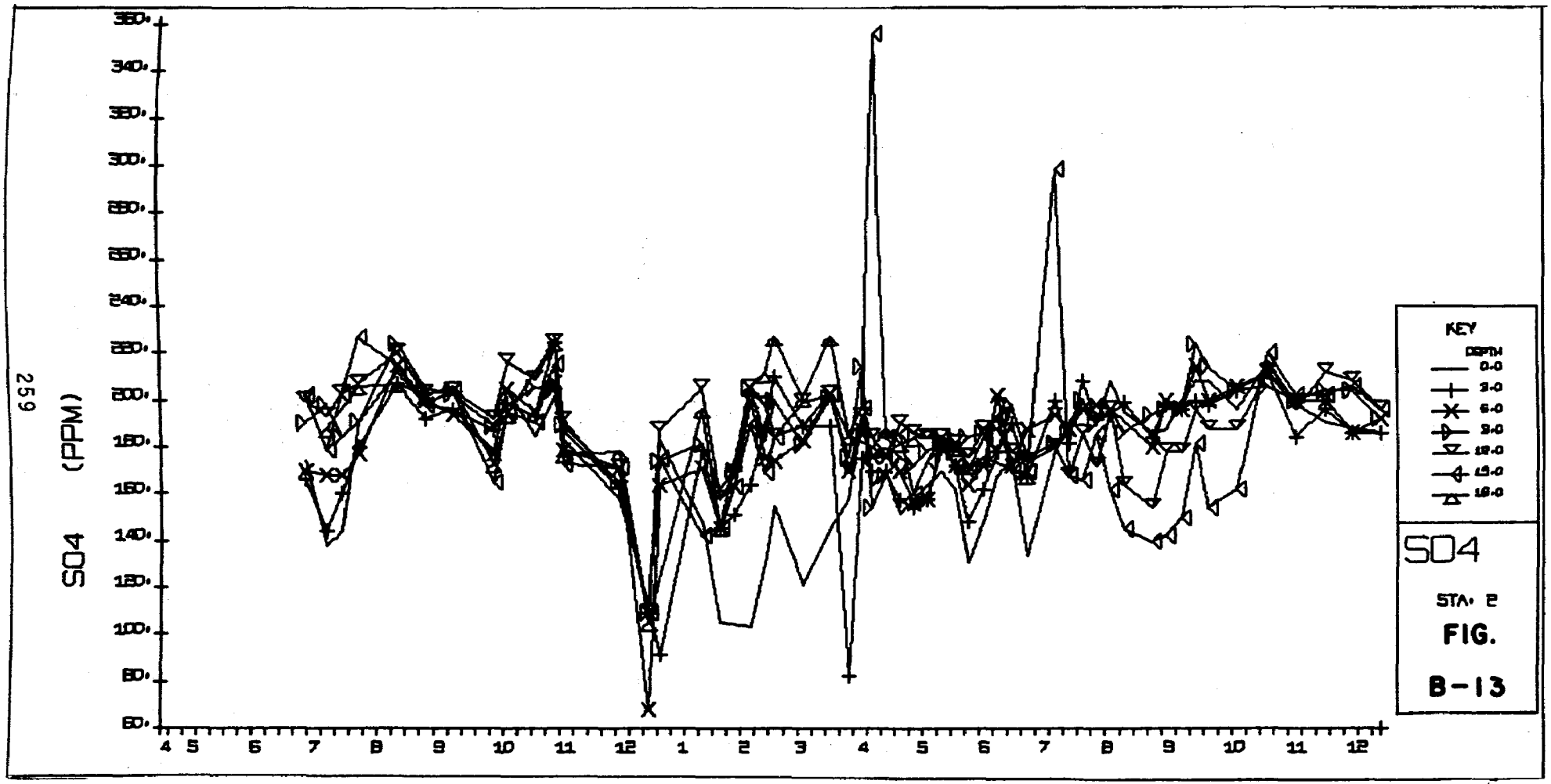

SO4 (PPM)
258
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SO4
STA. 1

FIG.
B-13


SO4 (PPM)
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SO4
STA. 2
FIG.
B-13

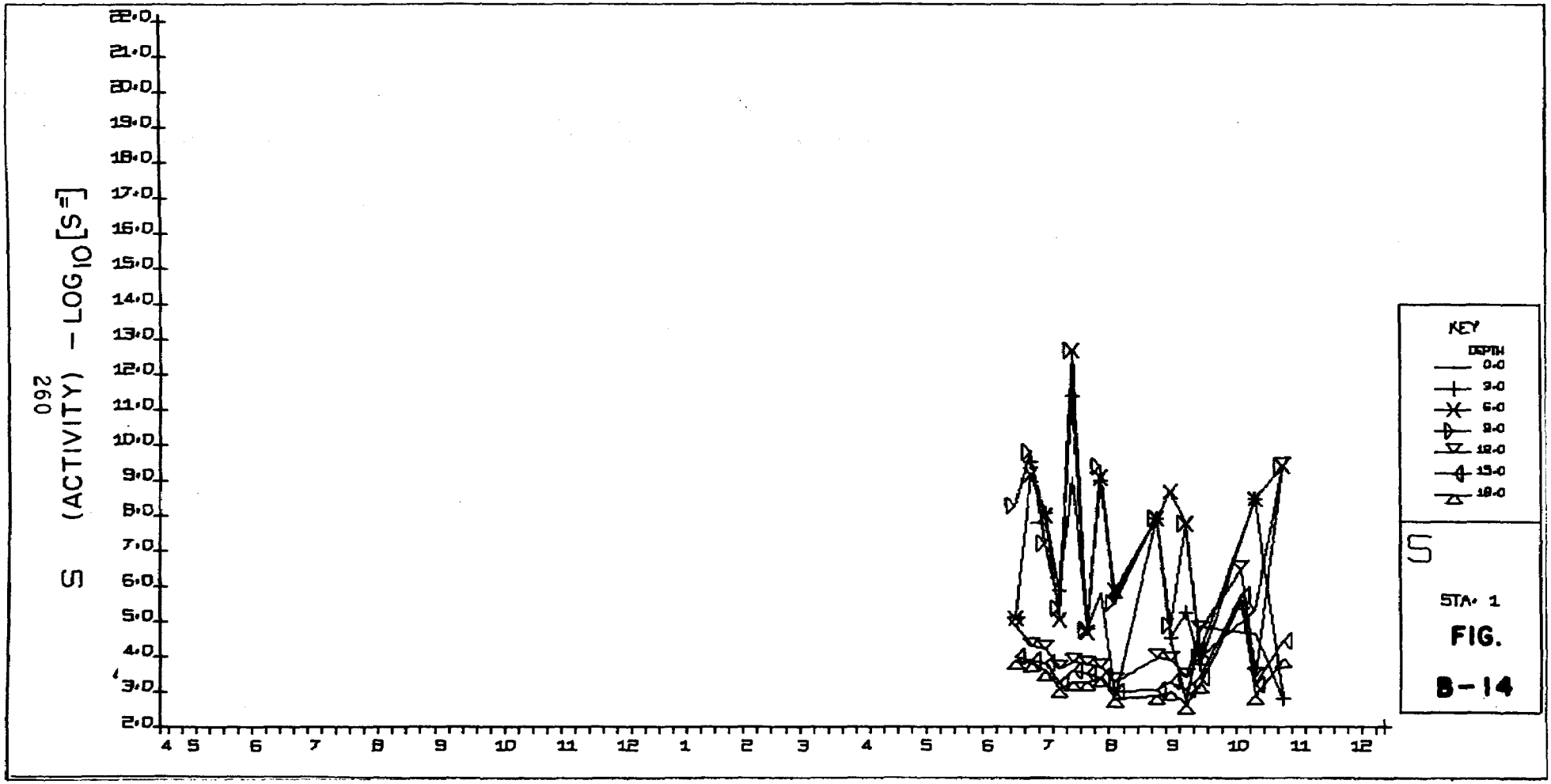
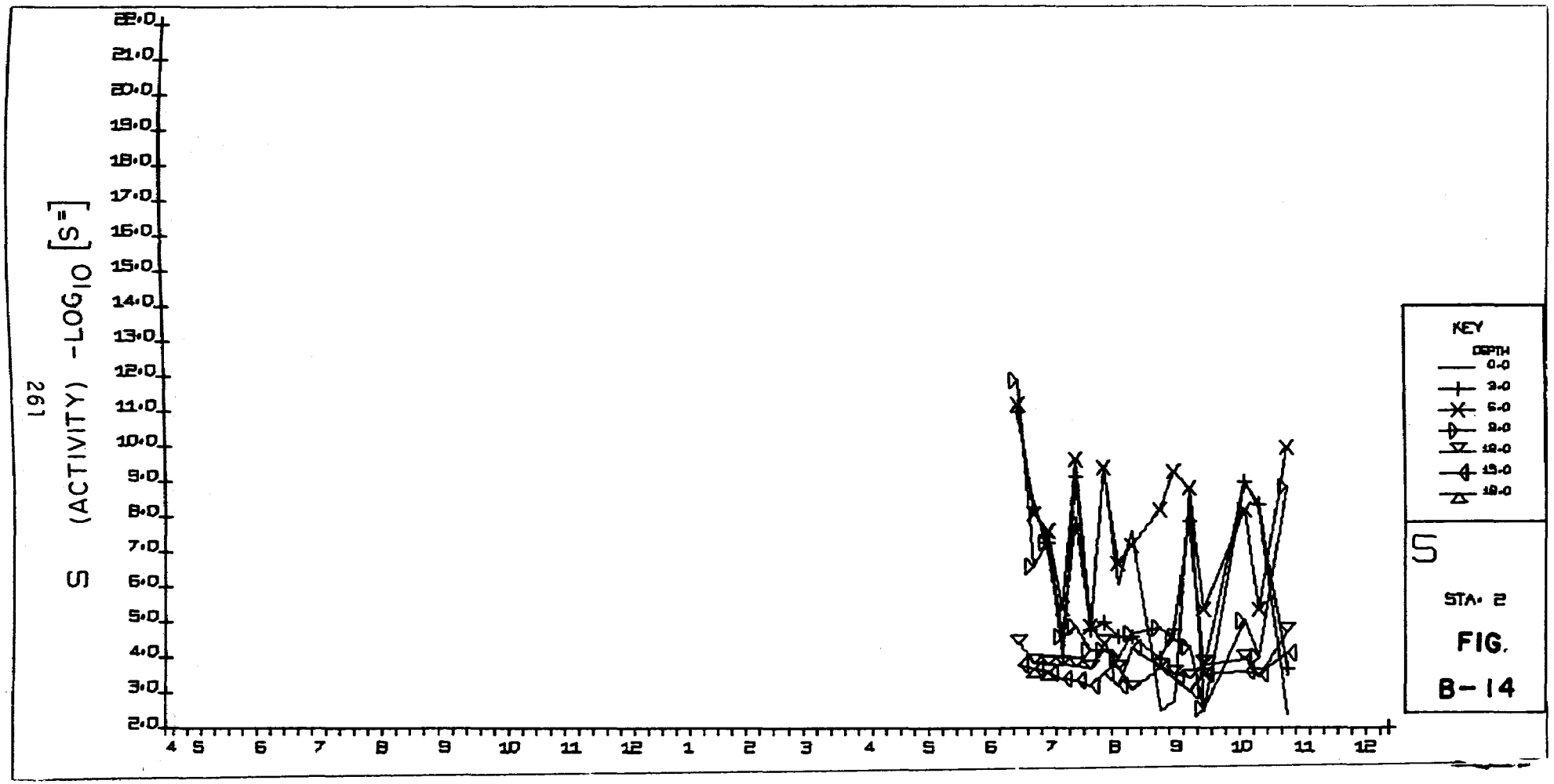

S (ACTIVITY) − LOG10[S=]
260
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
S
STA. 1

FIG.

B-14


S (ACTIVITY) -LOG10 [S=]
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
2.0
5.0
8.0
10.0
15.0
18.0
S
STA. 2
FIG.
B-14

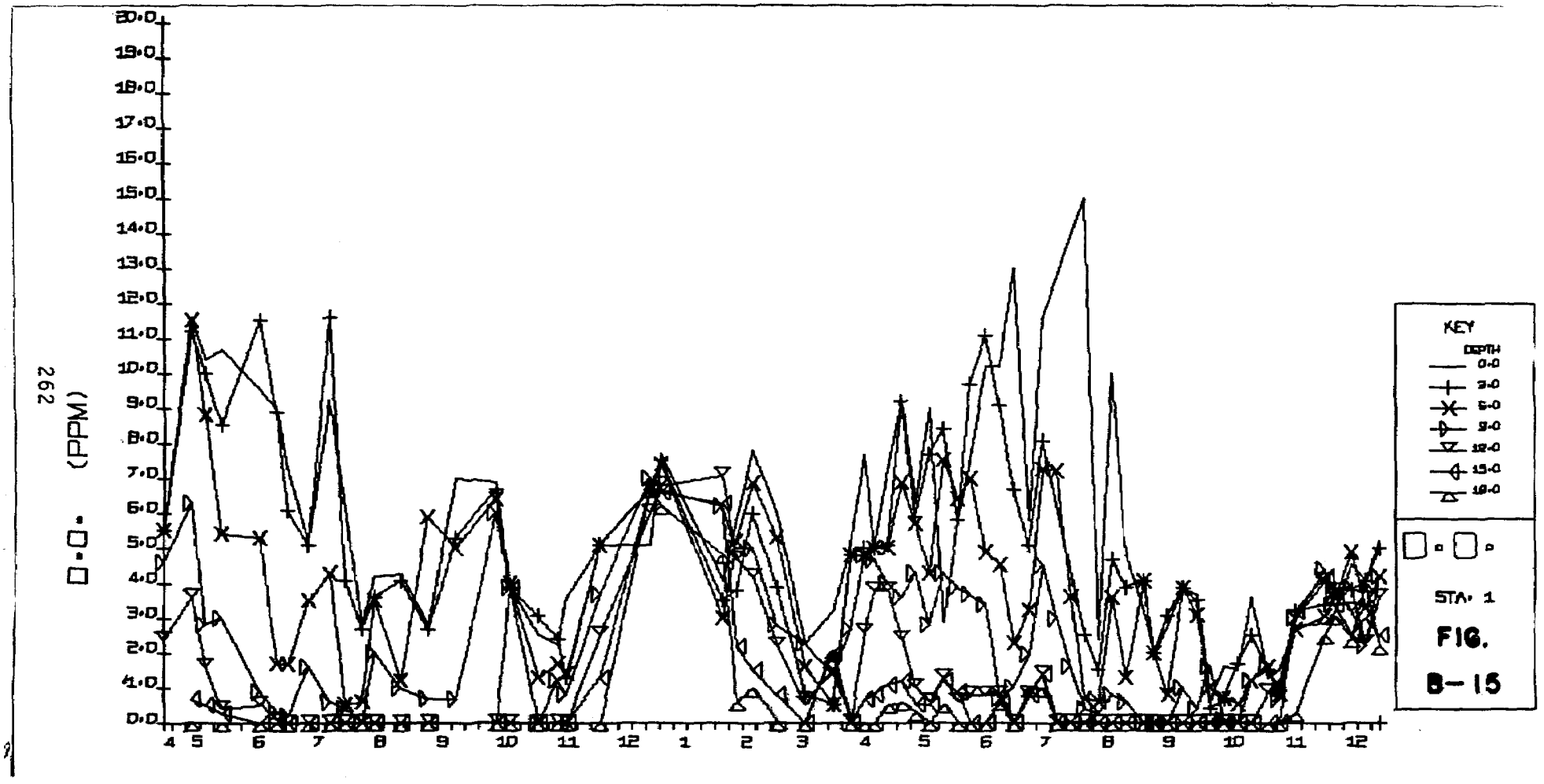


FIG. B-15

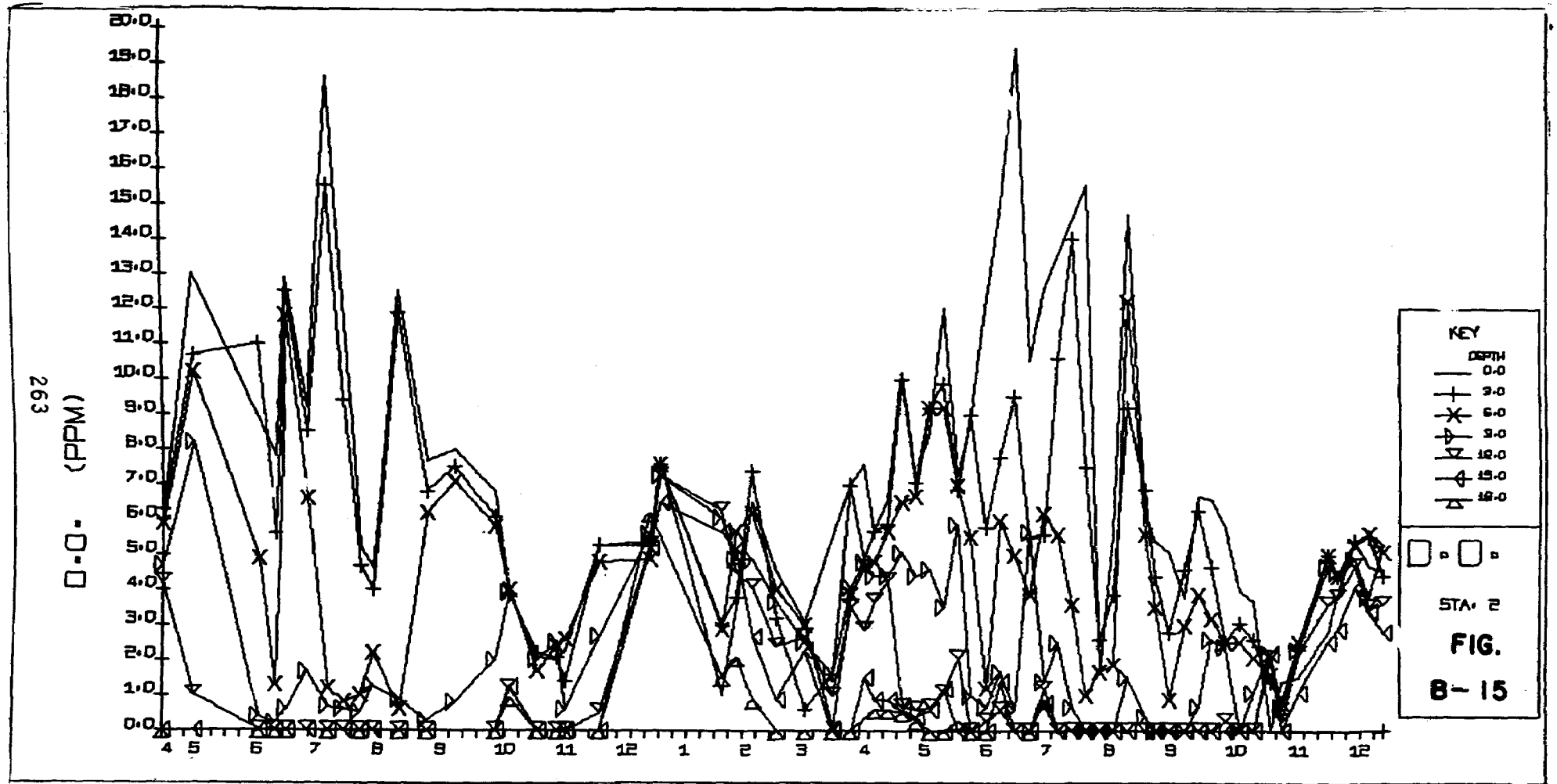

D.O. (PPM)
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
STA. 2

FIG. B-15

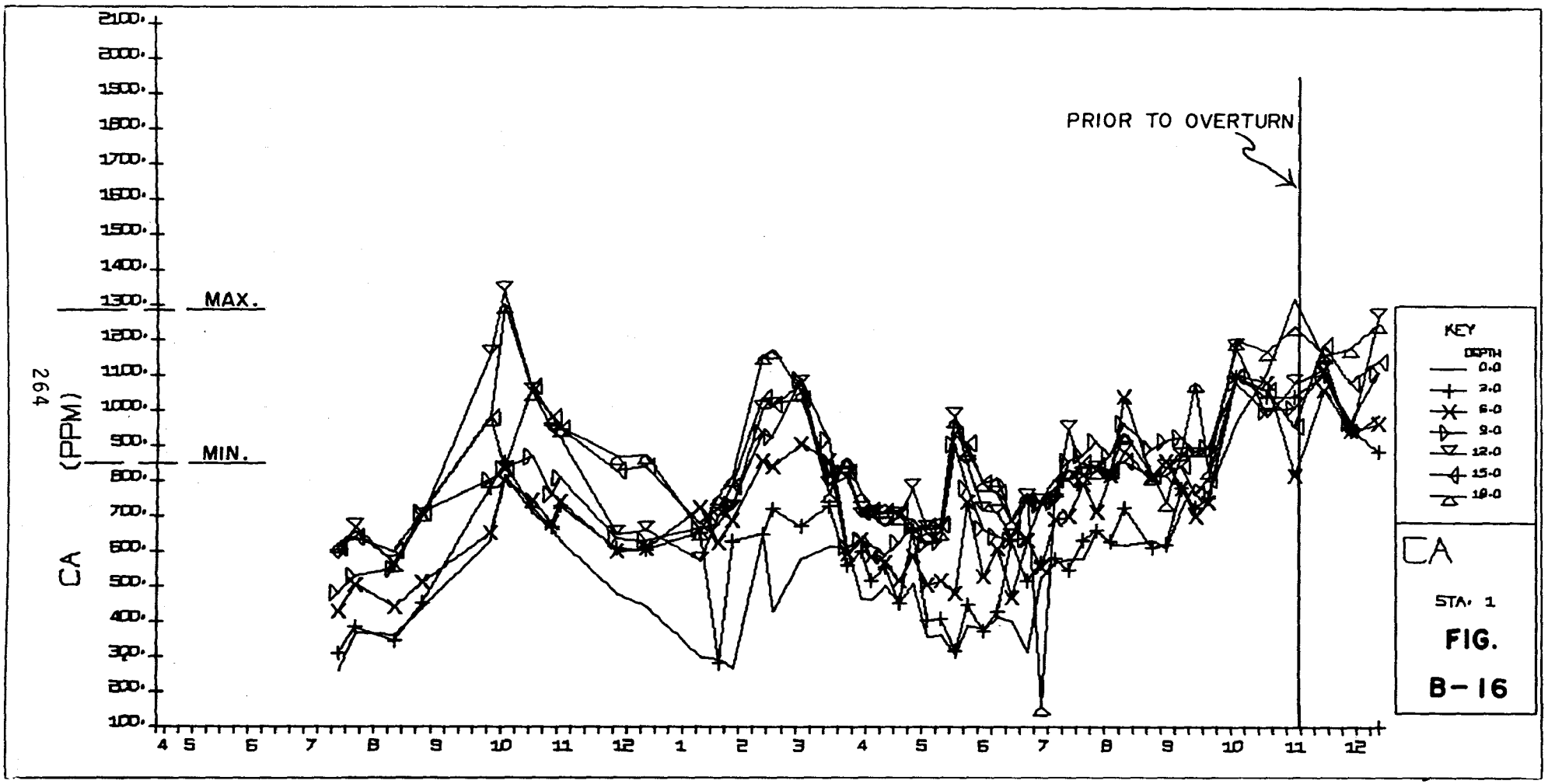
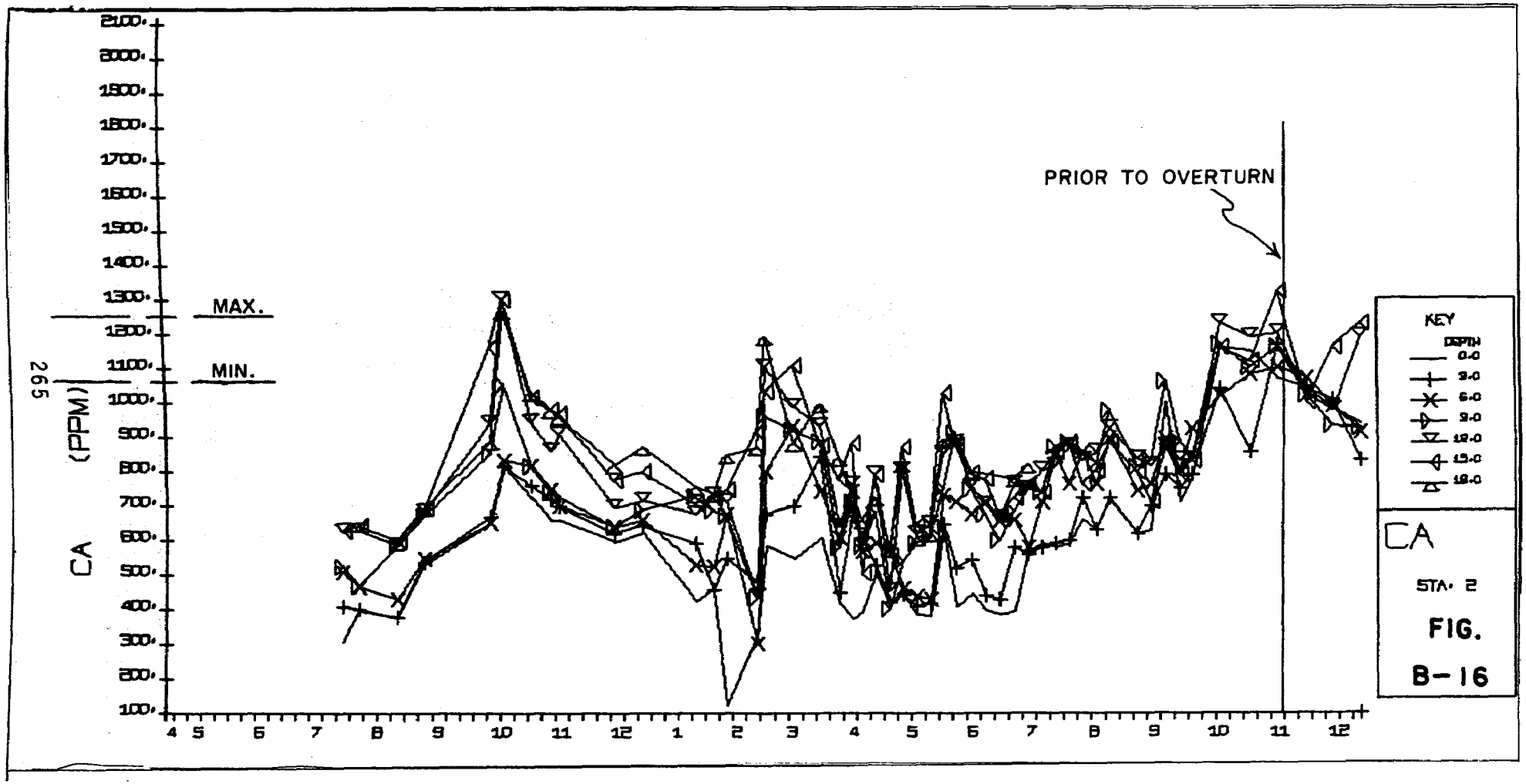
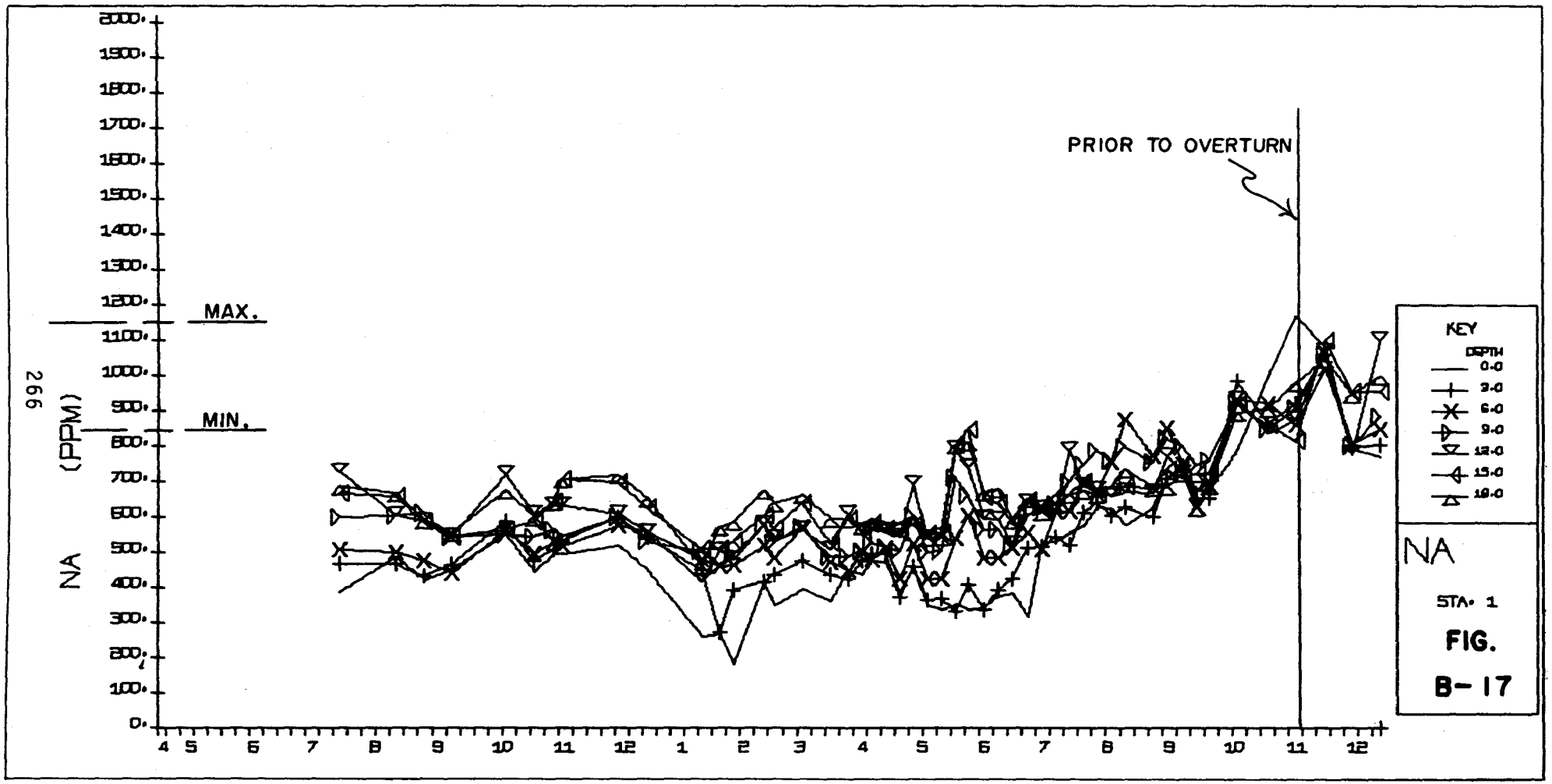
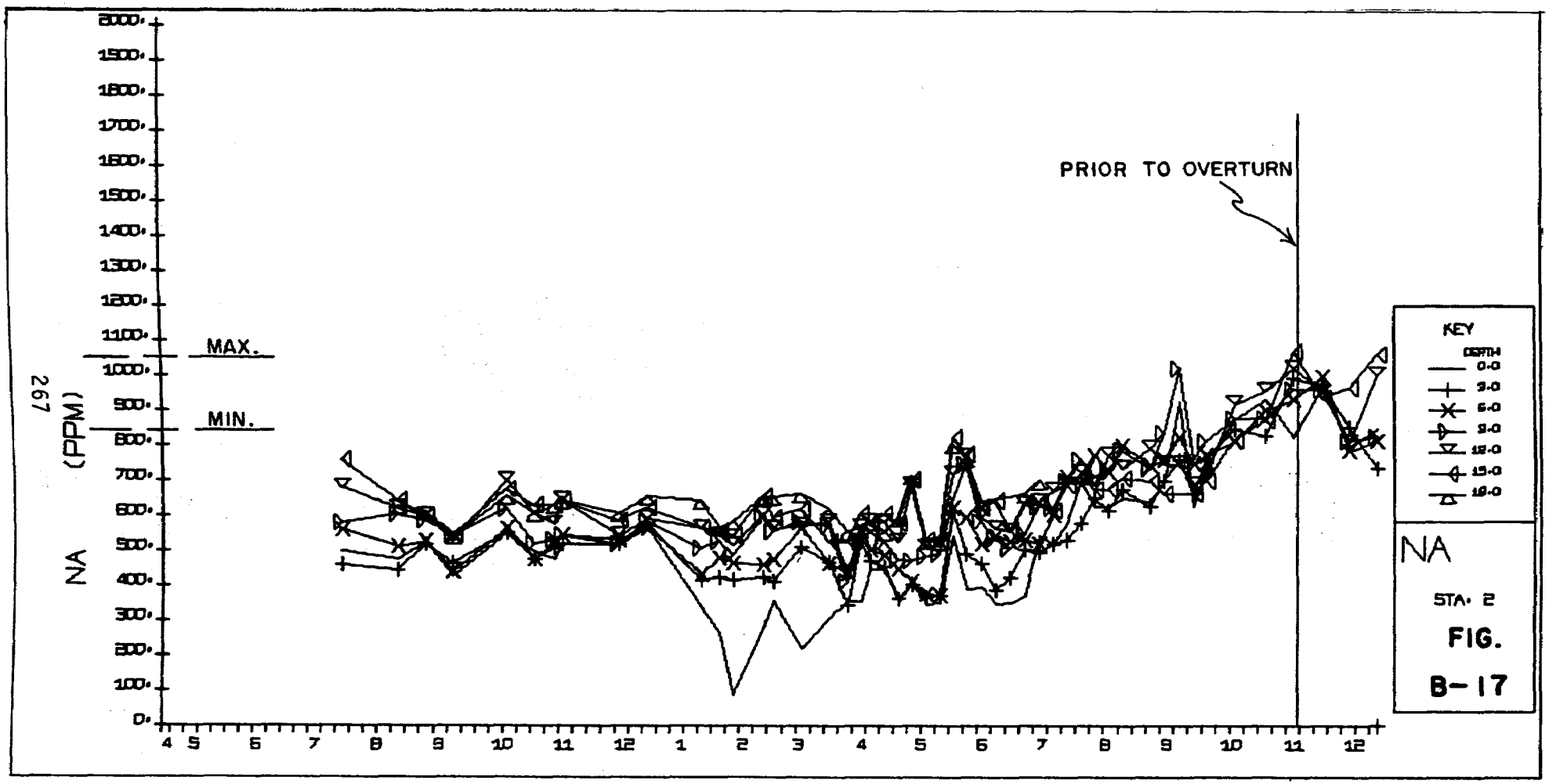

PRIOR TO OVERTURN
MAX.
MIN.
CA (PPM)
2644
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CA
STA. 1

FIG. B-16


PRIOR TO OVERTURN
MAX.
MIN.
CA (PPM)
265
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CA
STA. 2
FIG.
B-16


PRIOR TO OVERTURN
MAX.
MIN.
NA (PPM)
266
2000.
1900.
1800.
1700.
1600.
1500.
1400.
1300.
1200.
1100.
1000.
900.
800.
700.
600.
500.
400.
300.
200.
100.
0.
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
NA
STA. 1
FIG.
B-17


PRIOR TO OVERTURN
MAX.
MIN.
NA (PPM)
267
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
NA
STA. 2
FIG.
B-17

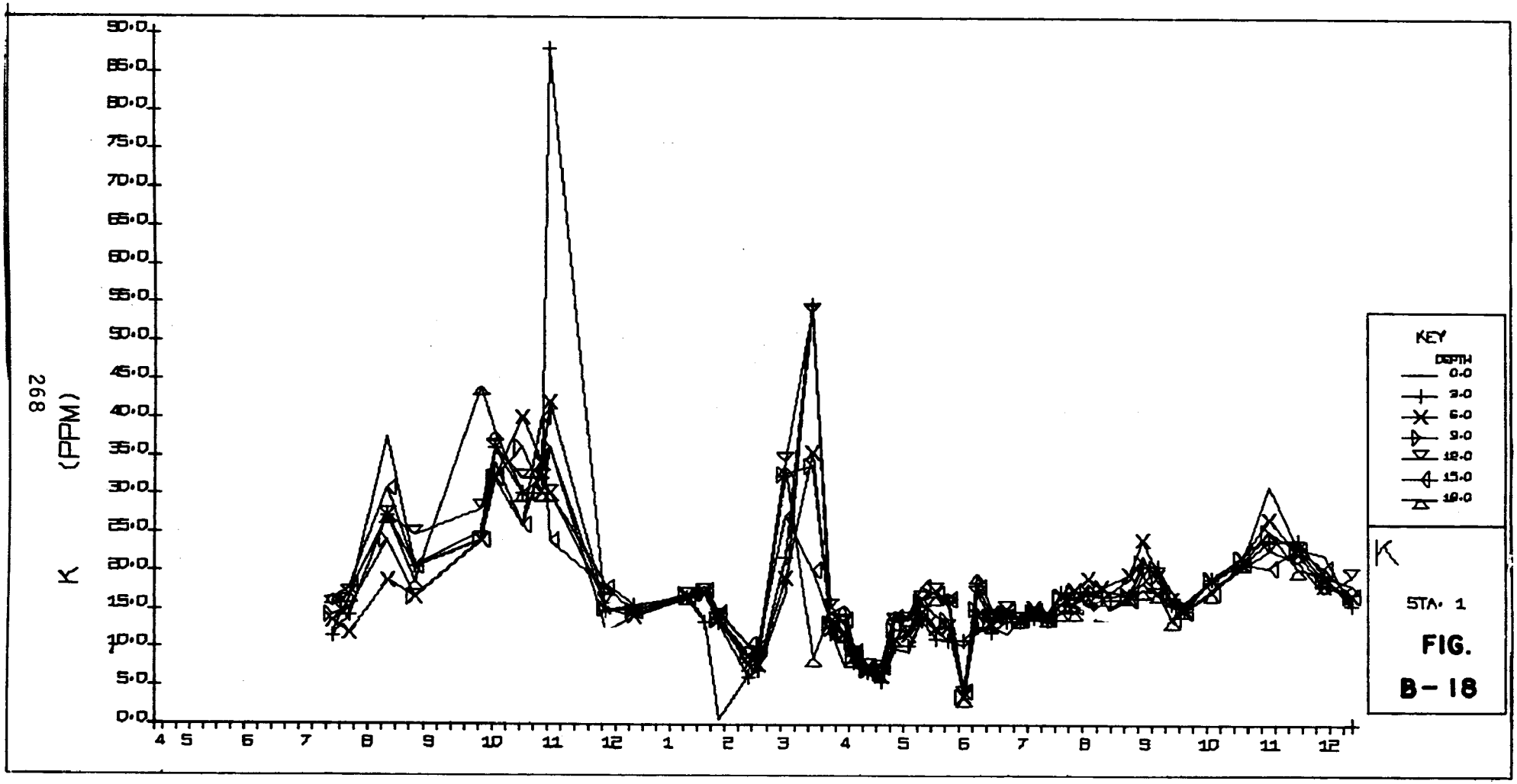

K (PPM)
268
50.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
K
STA. 1

FIG.
B-18

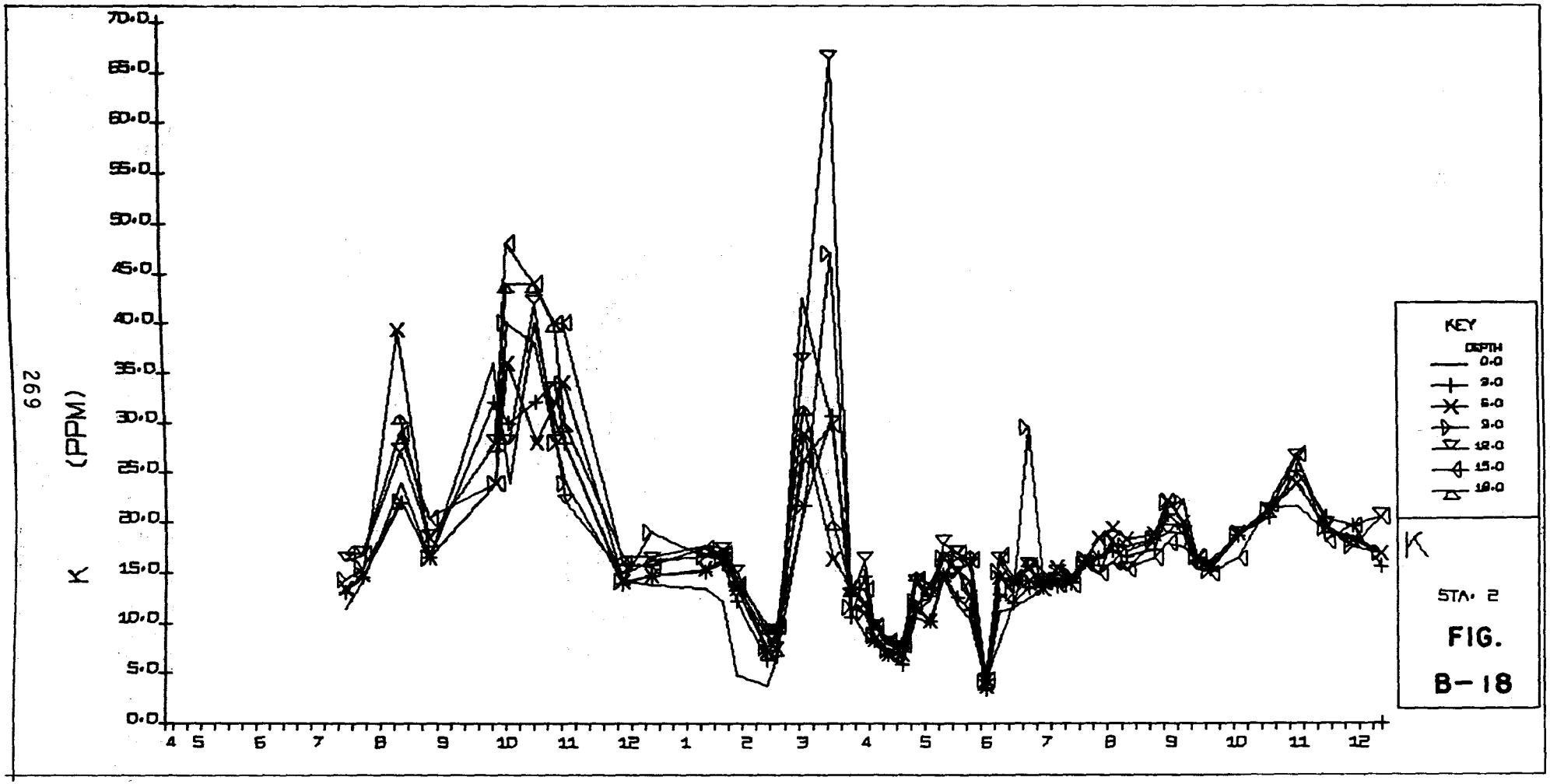

K (PPM)
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
2.0
6.0
9.0
12.0
15.0
18.0
K
STA. 2

FIG. B-18

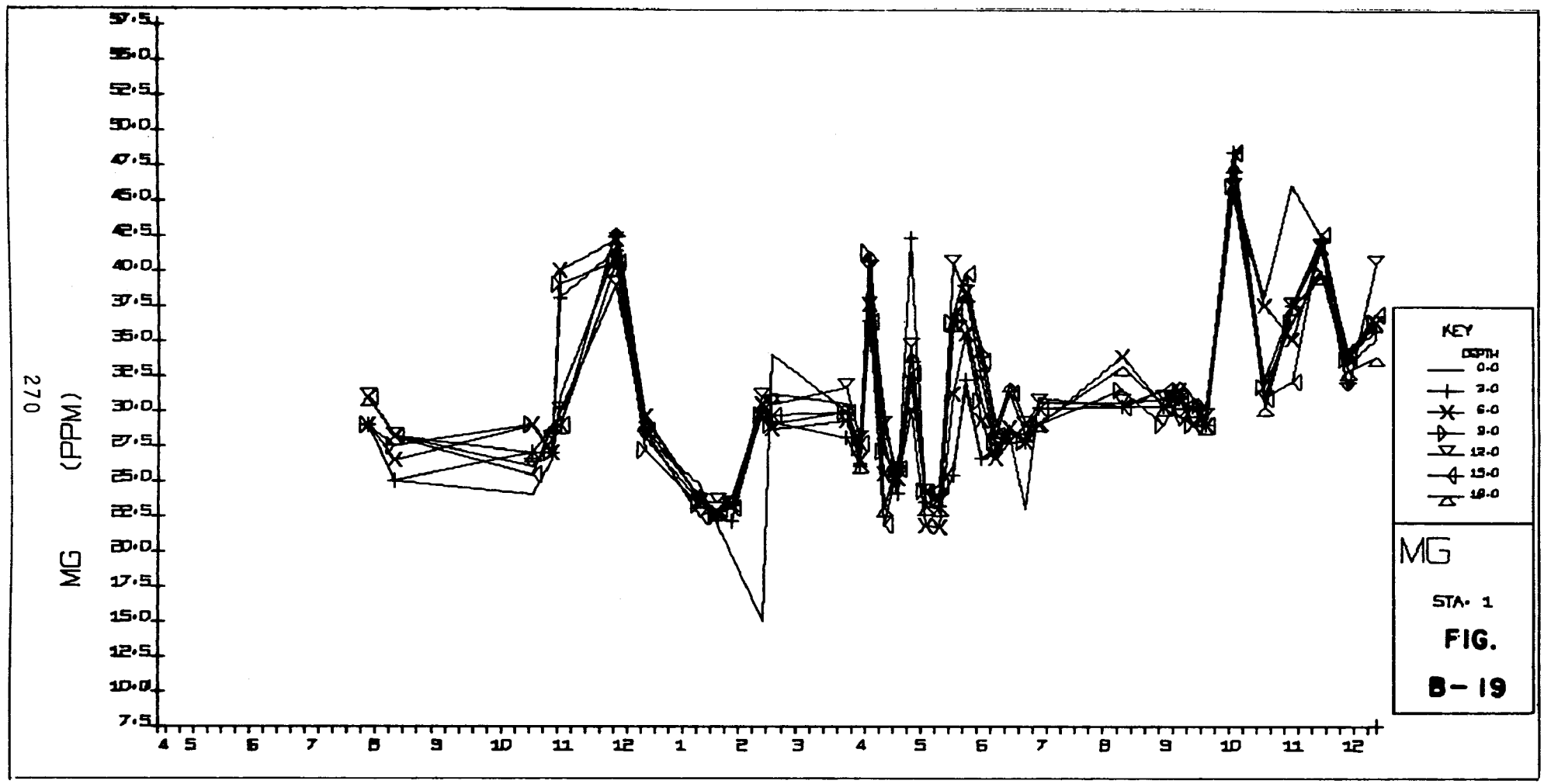
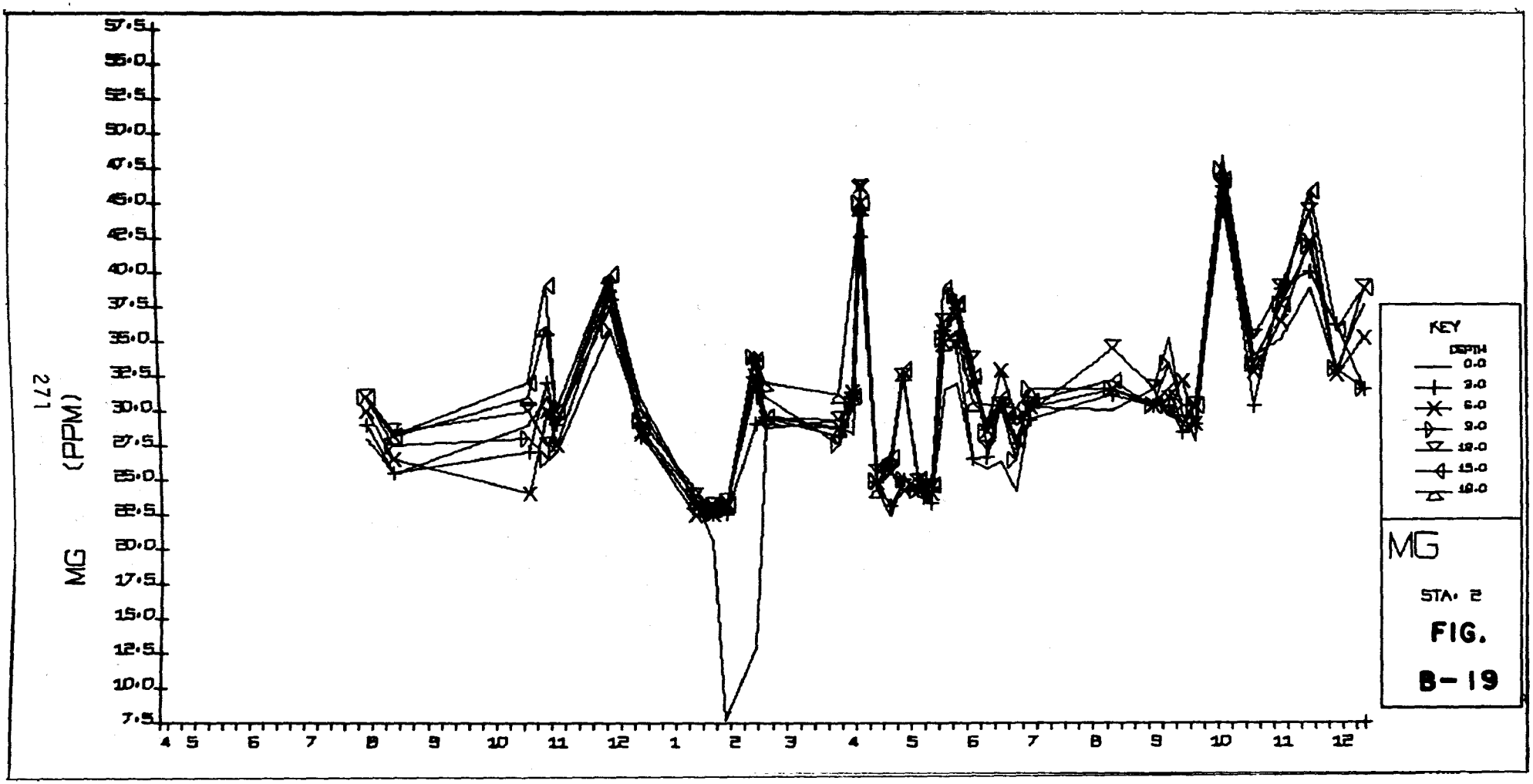
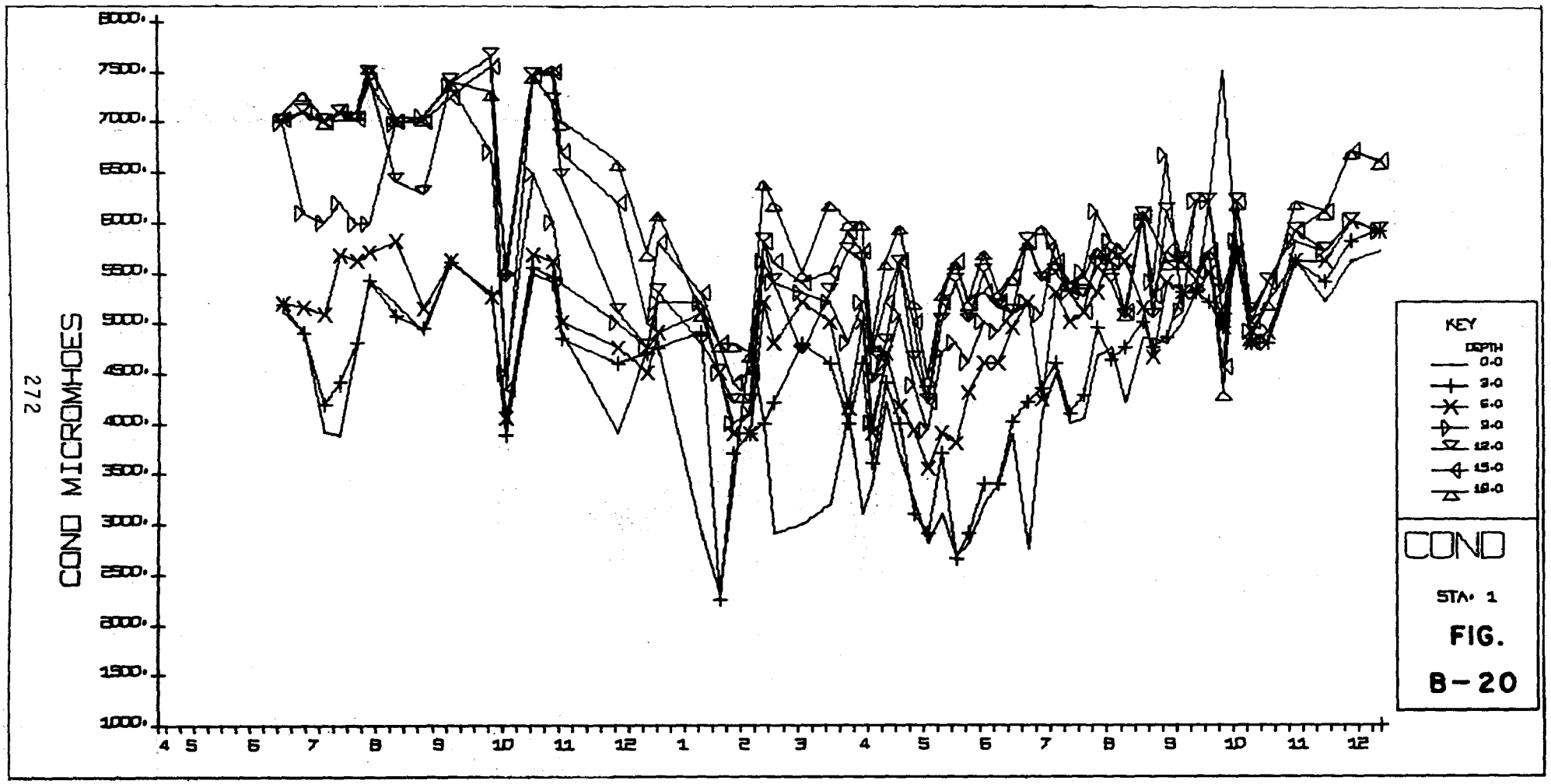

MG (PPM)
270
57.5
55.0
52.5
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
MG
STA. 1

FIG.

B-19


MG (PPM)
271
57.5
55.0
52.5
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
MG
STA. 2
FIG.
B-19


COND MICROMHOES
8000.
7500.
7000.
6500.
6000.
5500.
5000.
4500.
4000.
3500.
3000.
2500.
2000.
1500.
1000.
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
COND
STA. 1
FIG.
B-20

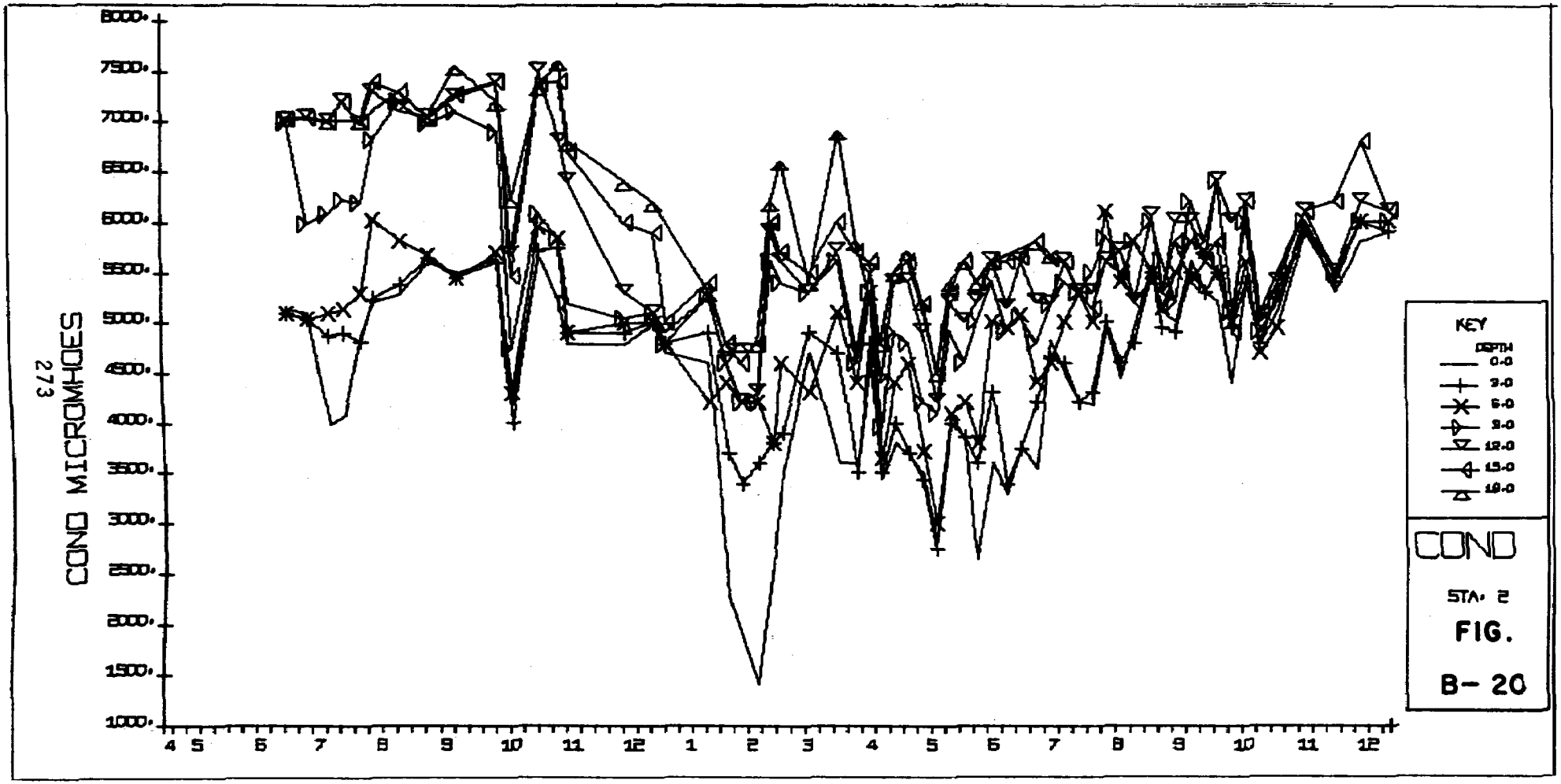
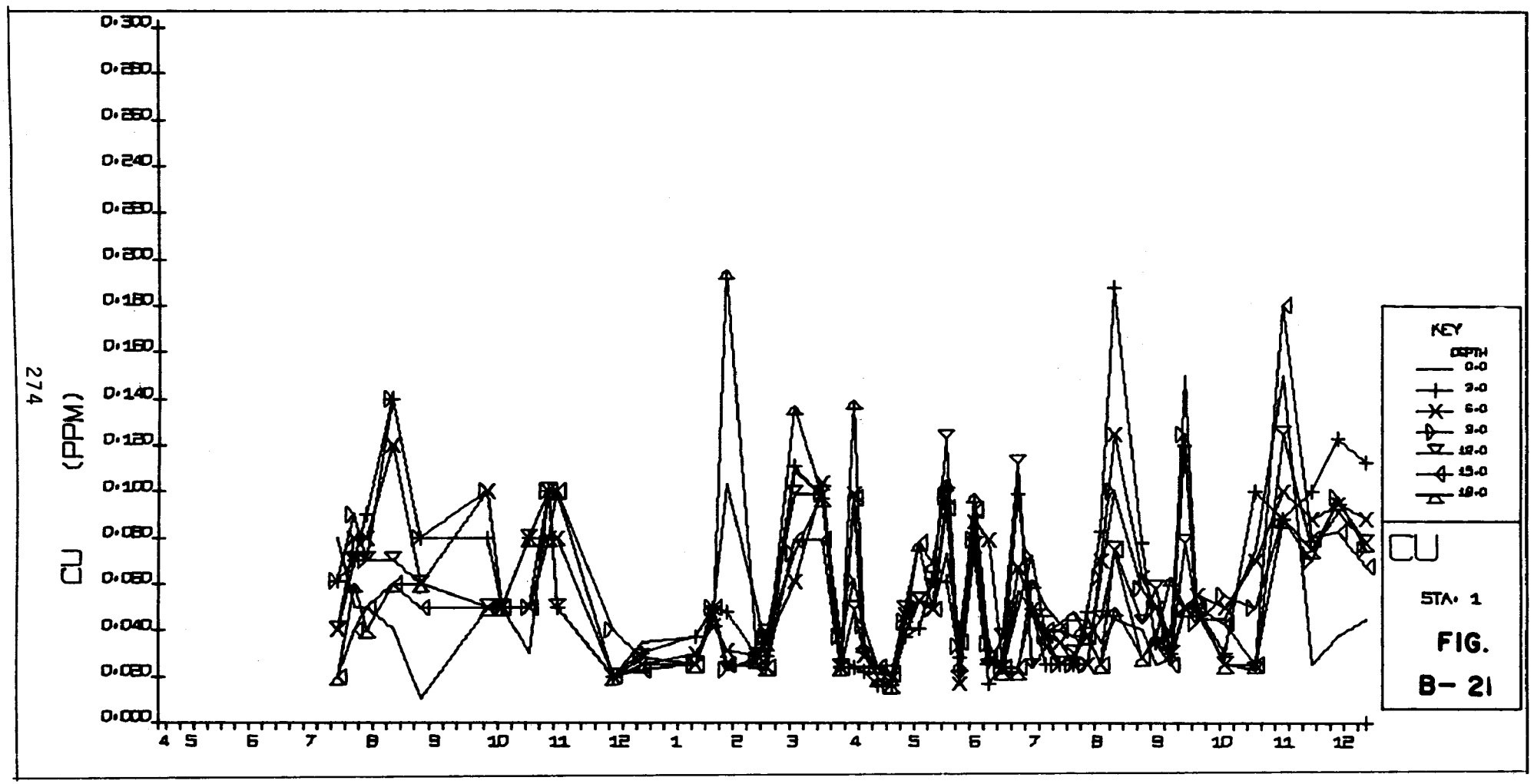
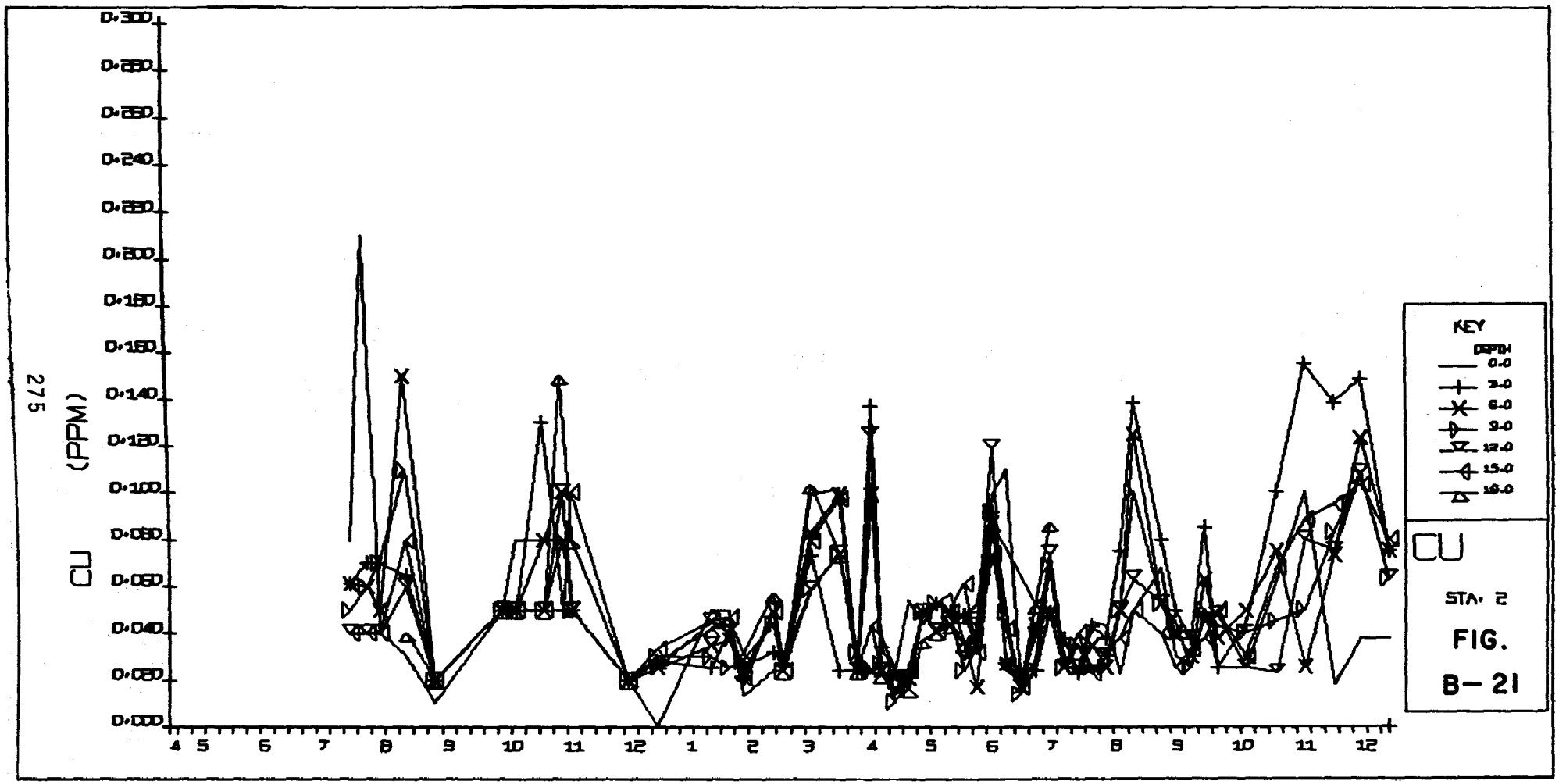
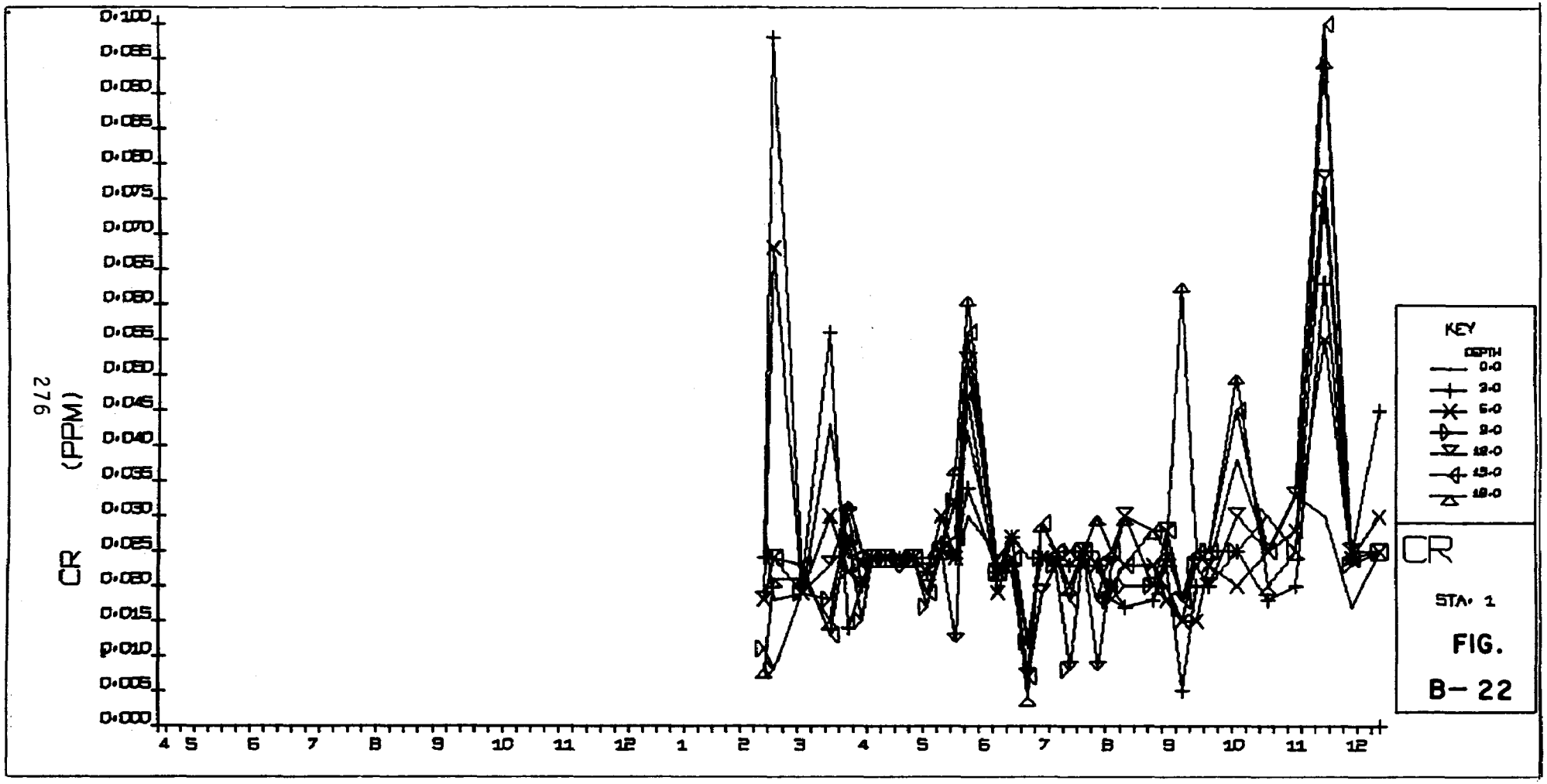

COND MICROMHOES
273
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
COND
STA. 2

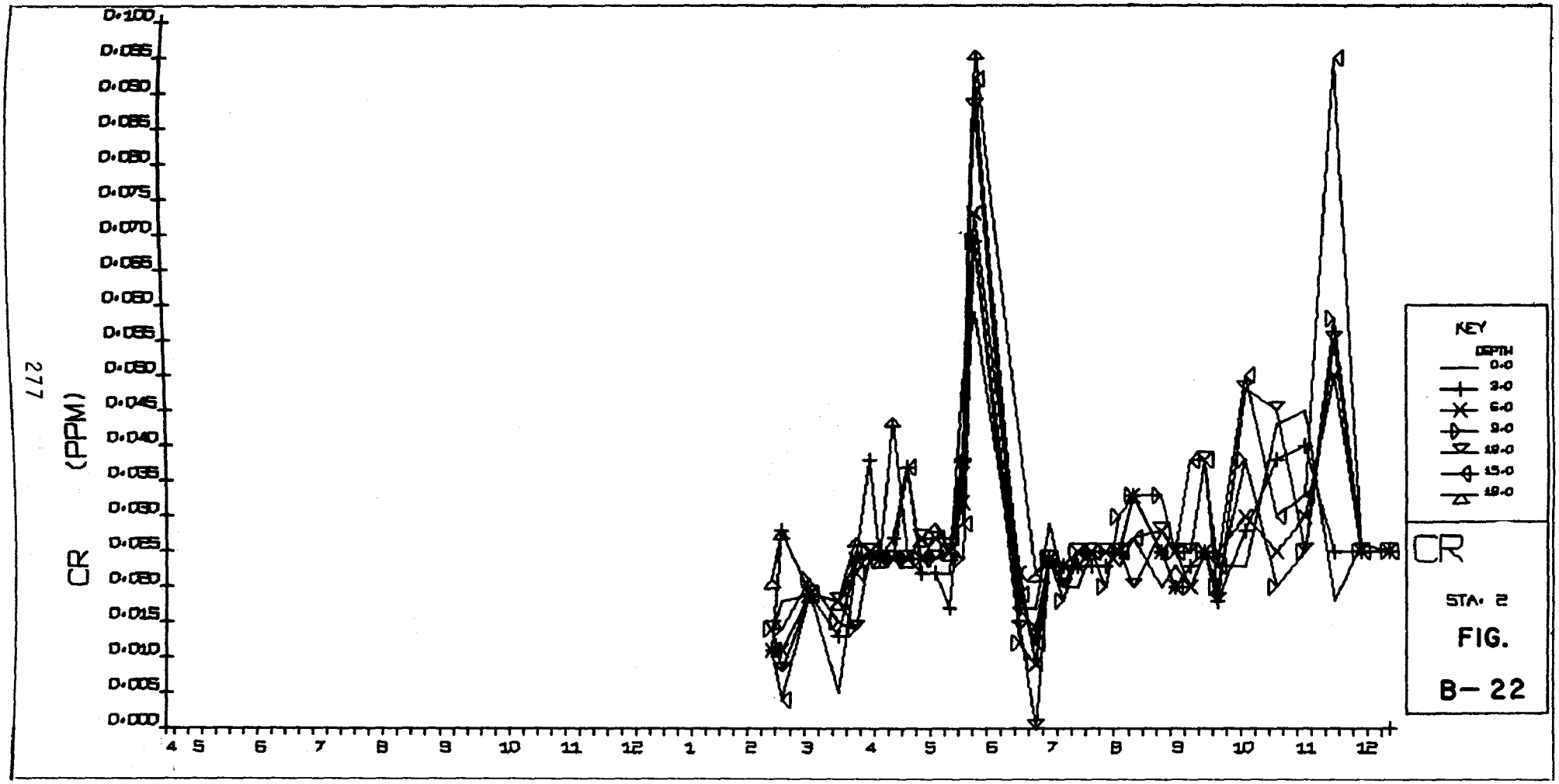
FIG.

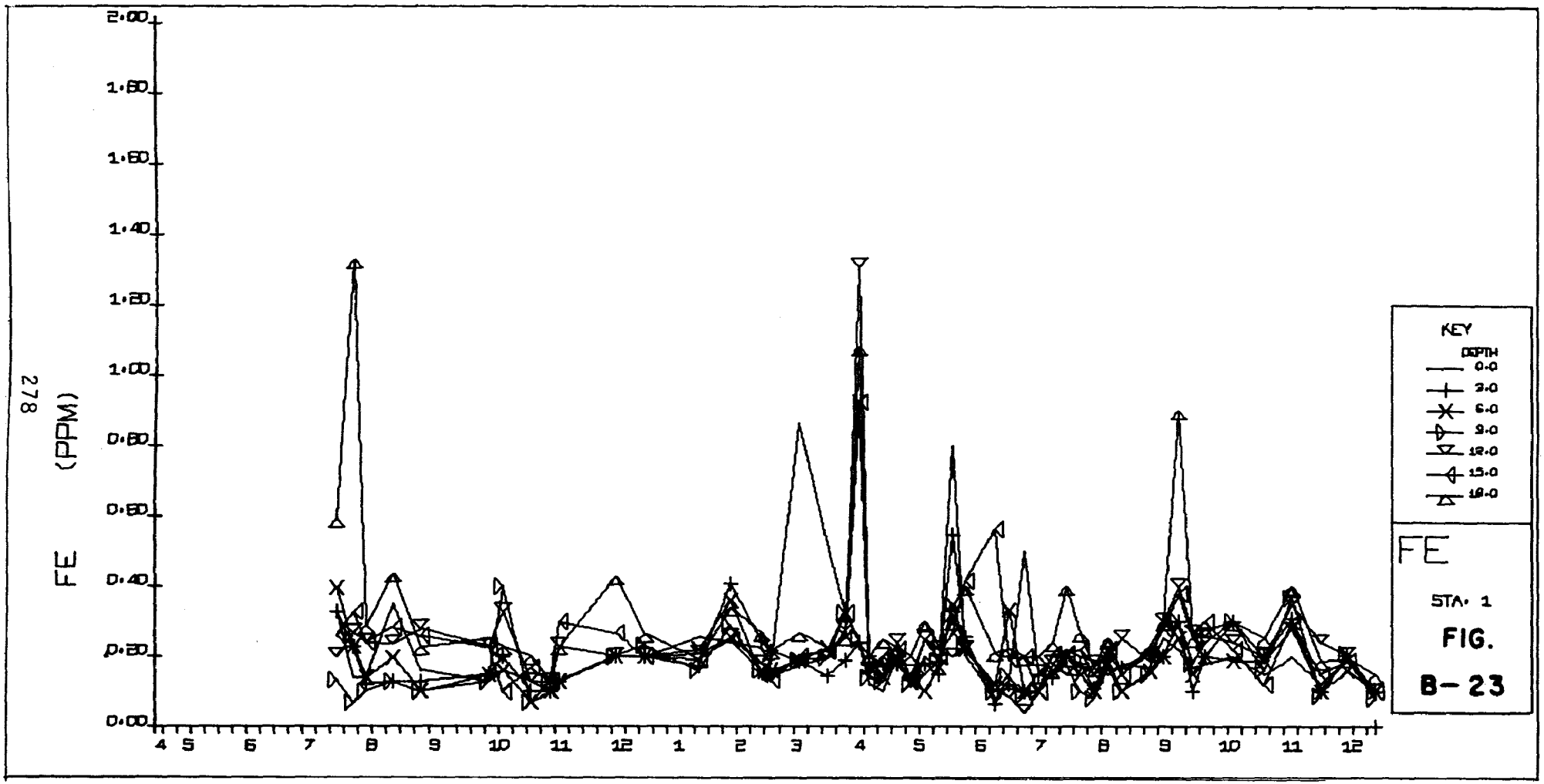
B- 20

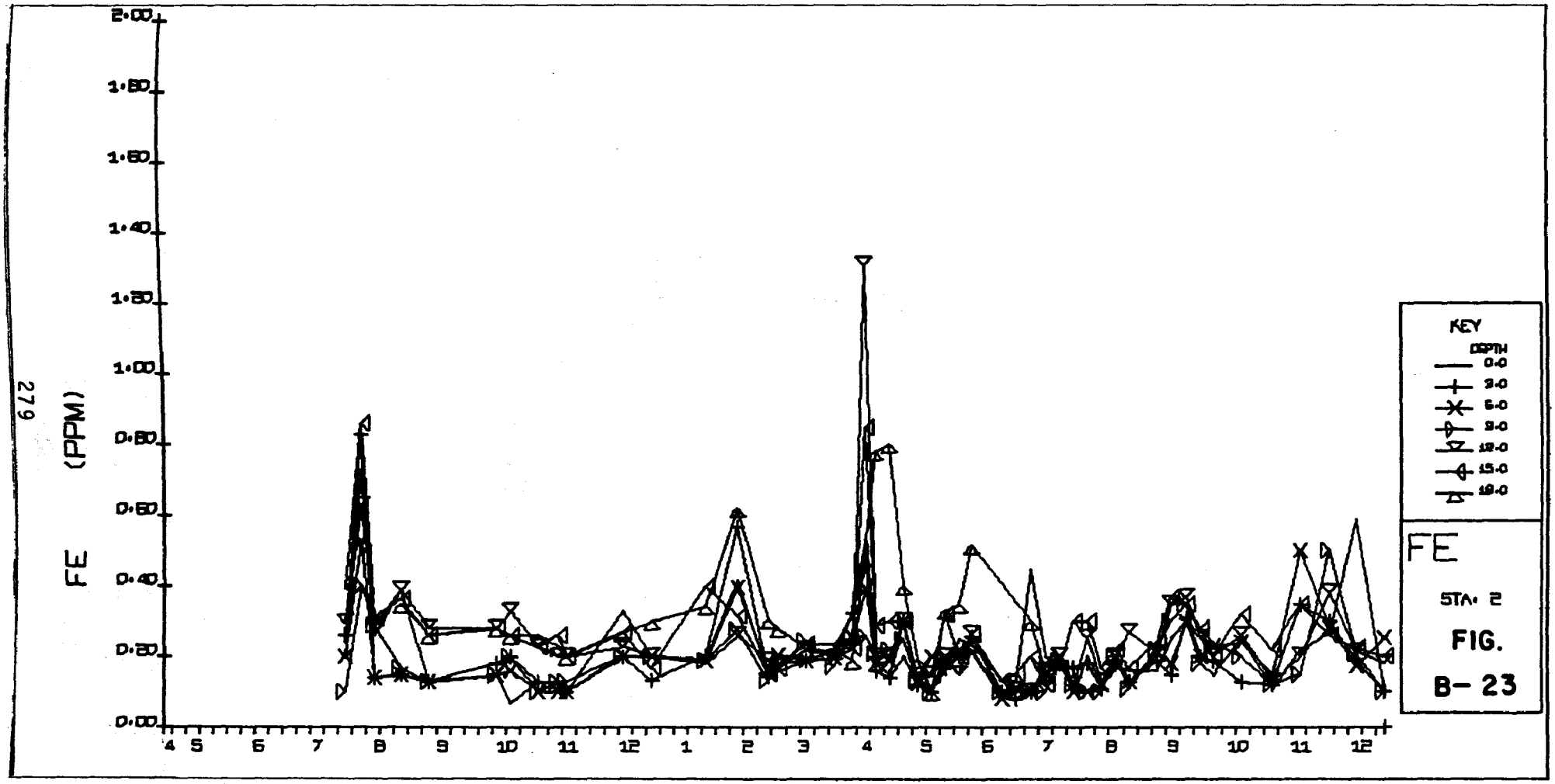

0.300
0.280
0.260
0.240
0.220
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
CU (PPM)
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CU
STA. 1
FIG.
B- 21

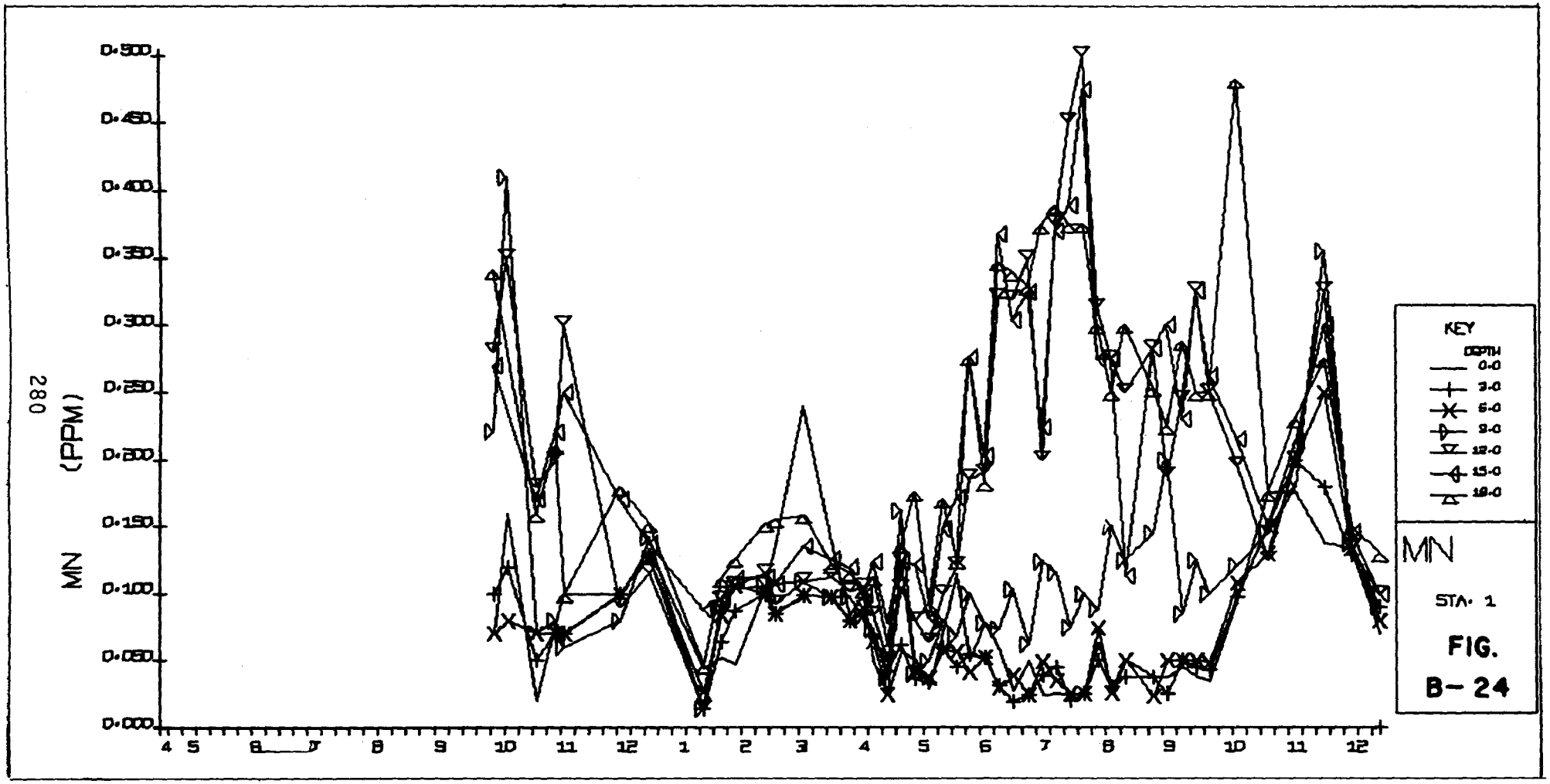

0.300
0.280
0.260
0.240
0.220
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
CU (PPM)
275
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CU
STA. 2
FIG.
B-21

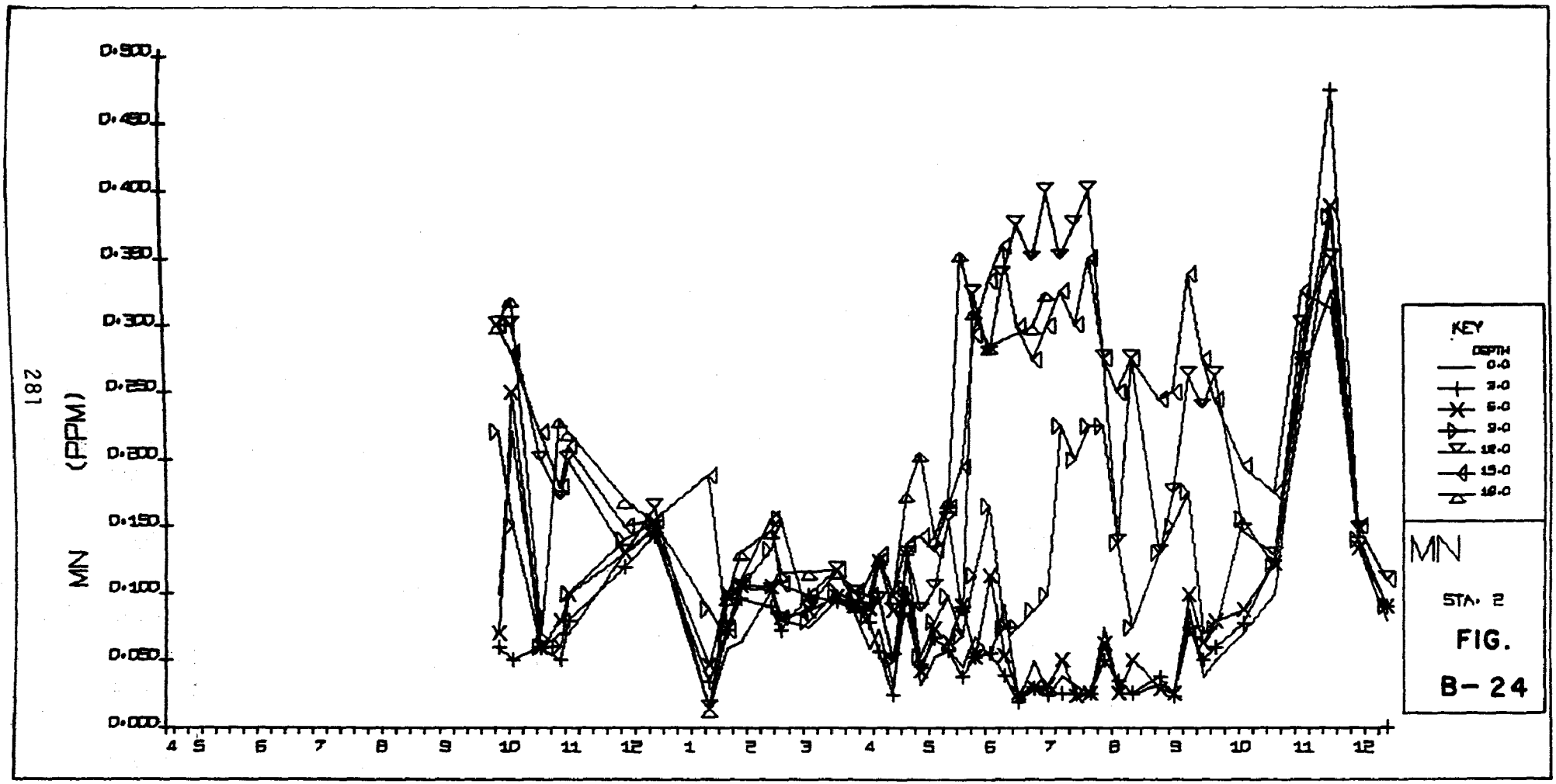

0.100
0.095
0.090
0.085
0.080
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
CR (PPM)
276
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
2.0
5.0
9.0
12.0
15.0
18.0
CR
STA. 1
FIG.
B-22

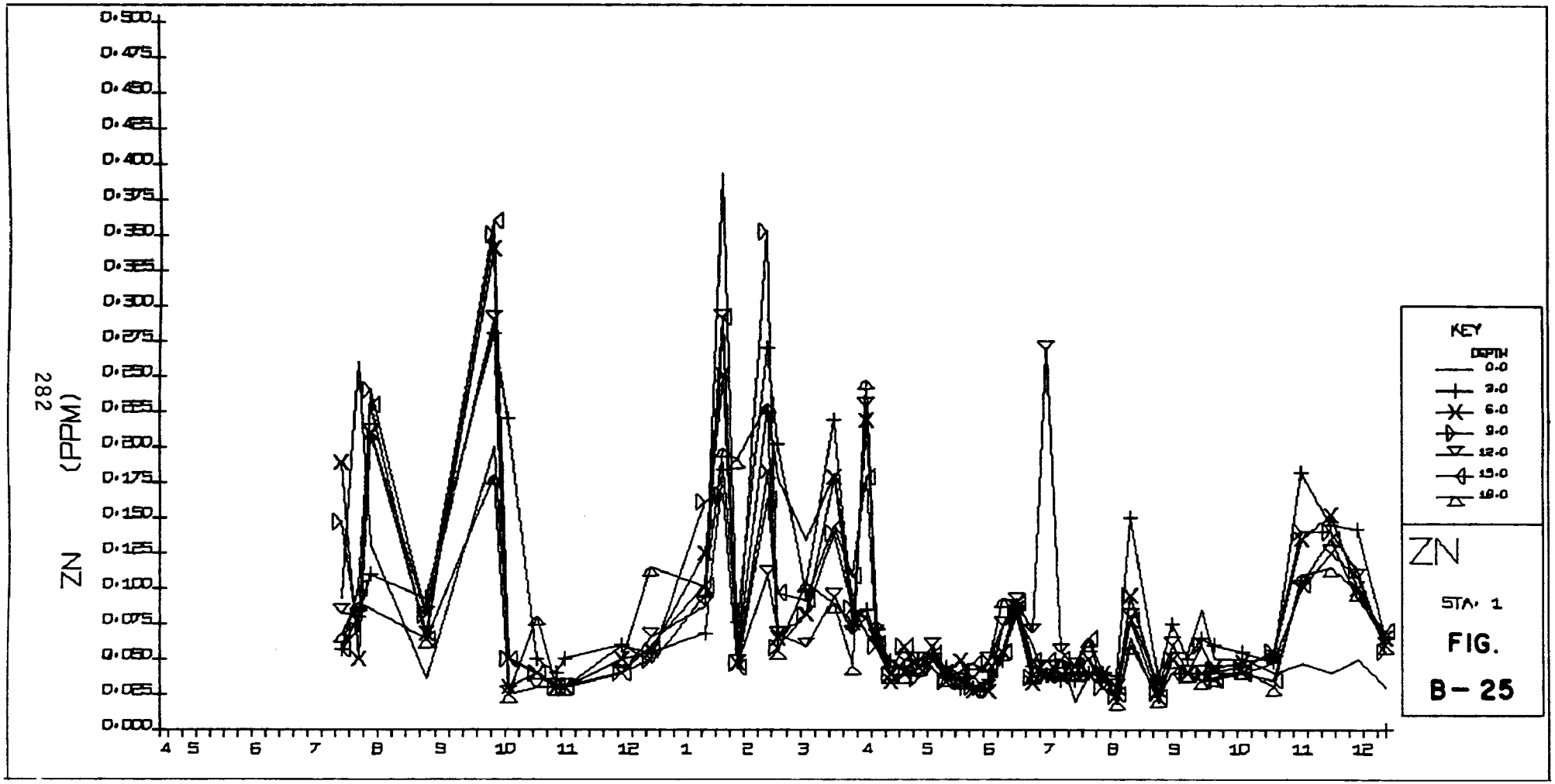

0.100
0.095
0.090
0.085
0.080
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
CR (PPM)
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CR
STA. 2
FIG.
B-22

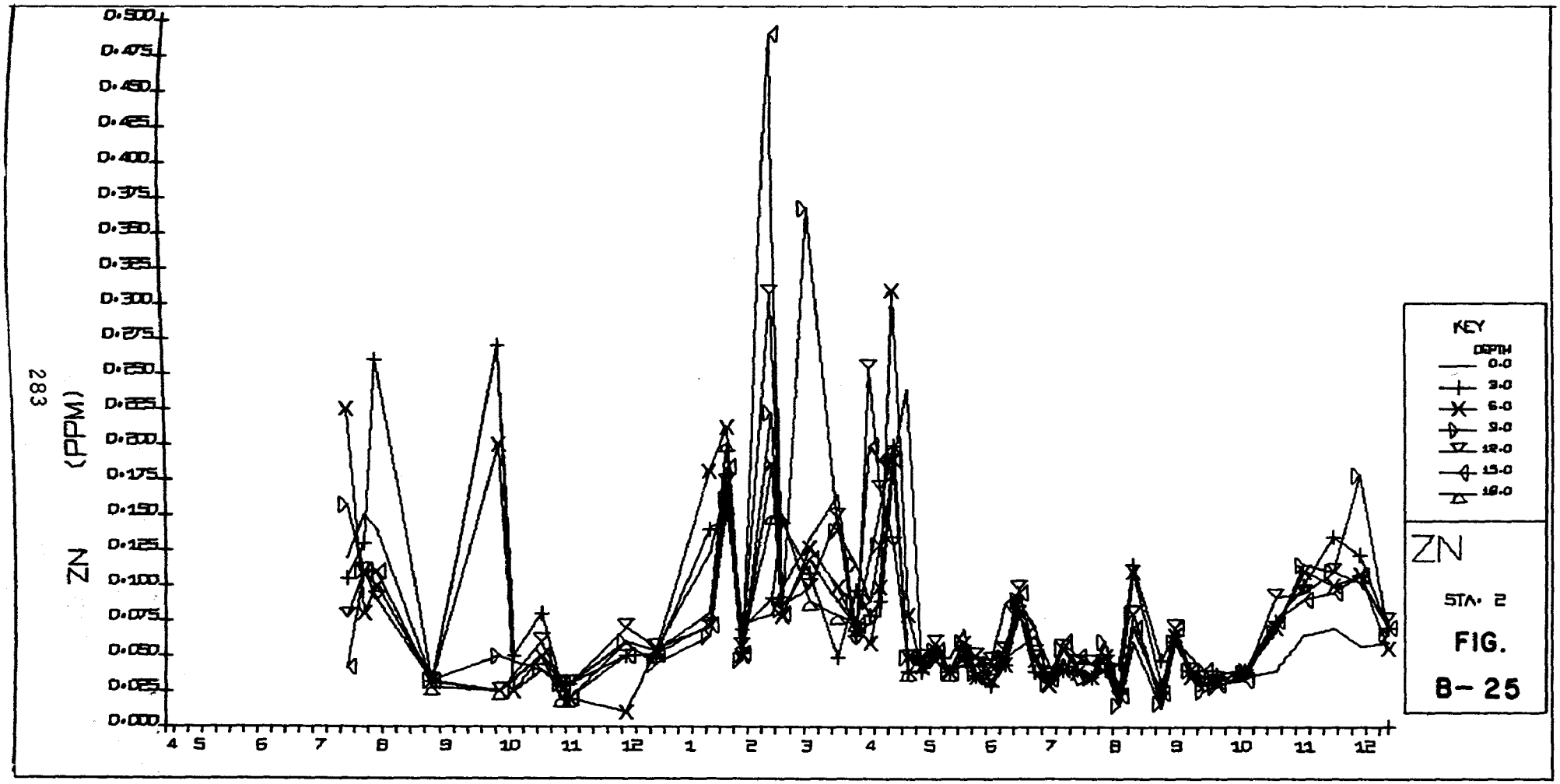

2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
FE (PPM)
278
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
FE
STA. 1
FIG.
B-23


FE (PPM)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
FE
STA. 2
FIG.
B-23


MN (PPM)
280
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
MN
STA. 1
FIG.
B-24


MN (PPM)
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
MN
STA. 2
FIG.
B-24


0.500
0.475
0.450
0.425
0.400
0.375
0.350
0.325
0.300
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
ZN (PPM)
282
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ZN
STA. 1
FIG.
B-25


0.500
0.475
0.450
0.425
0.400
0.375
0.350
0.325
0.300
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
ZN (PPM)
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ZN
STA. 2
FIG.
8-25

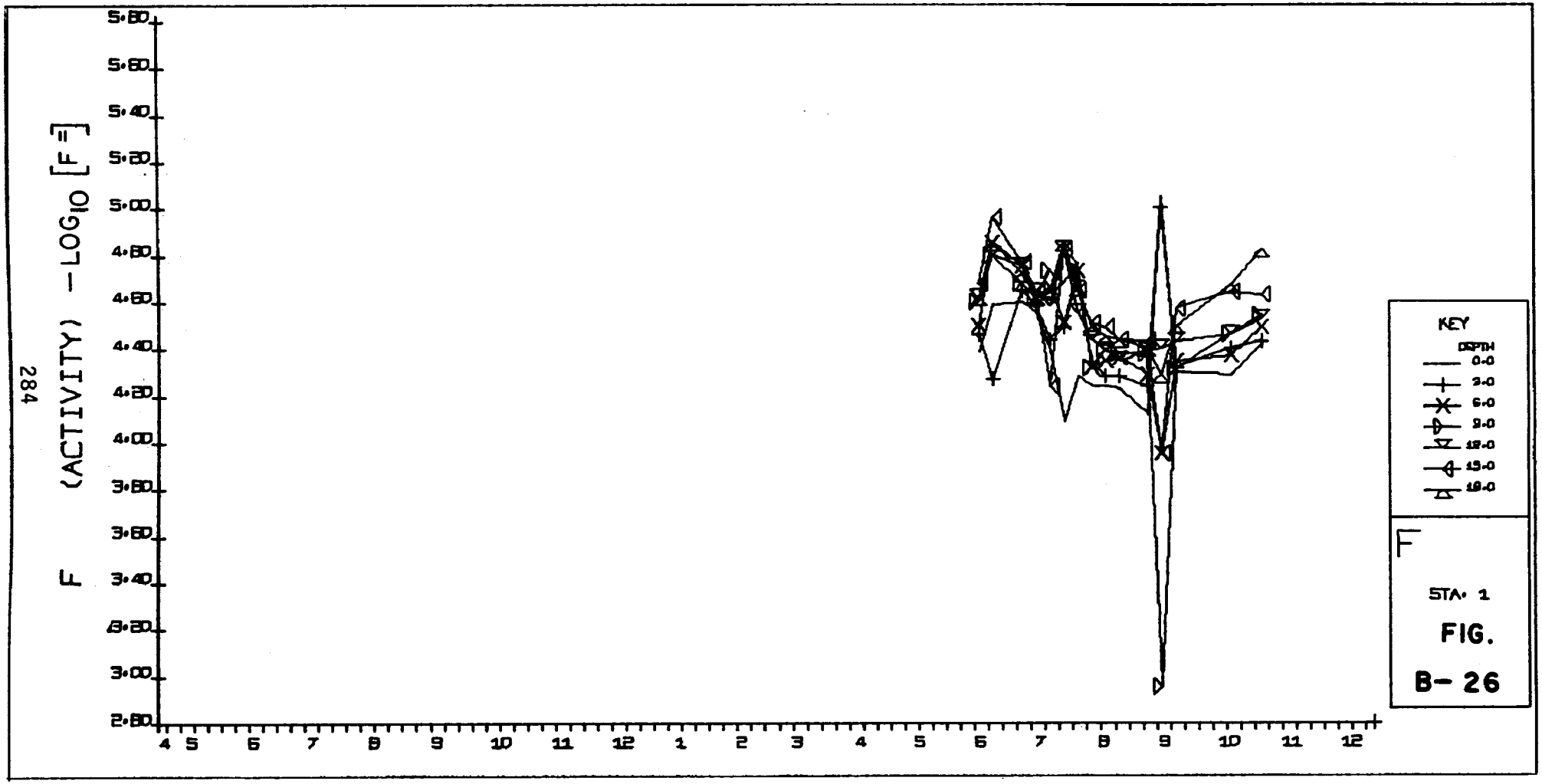

F (ACTIVITY) $-LOG_{10}$ [F=]
5.80
5.60
5.40
5.20
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
2.80
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
F
STA. 1

FIG.

B-26

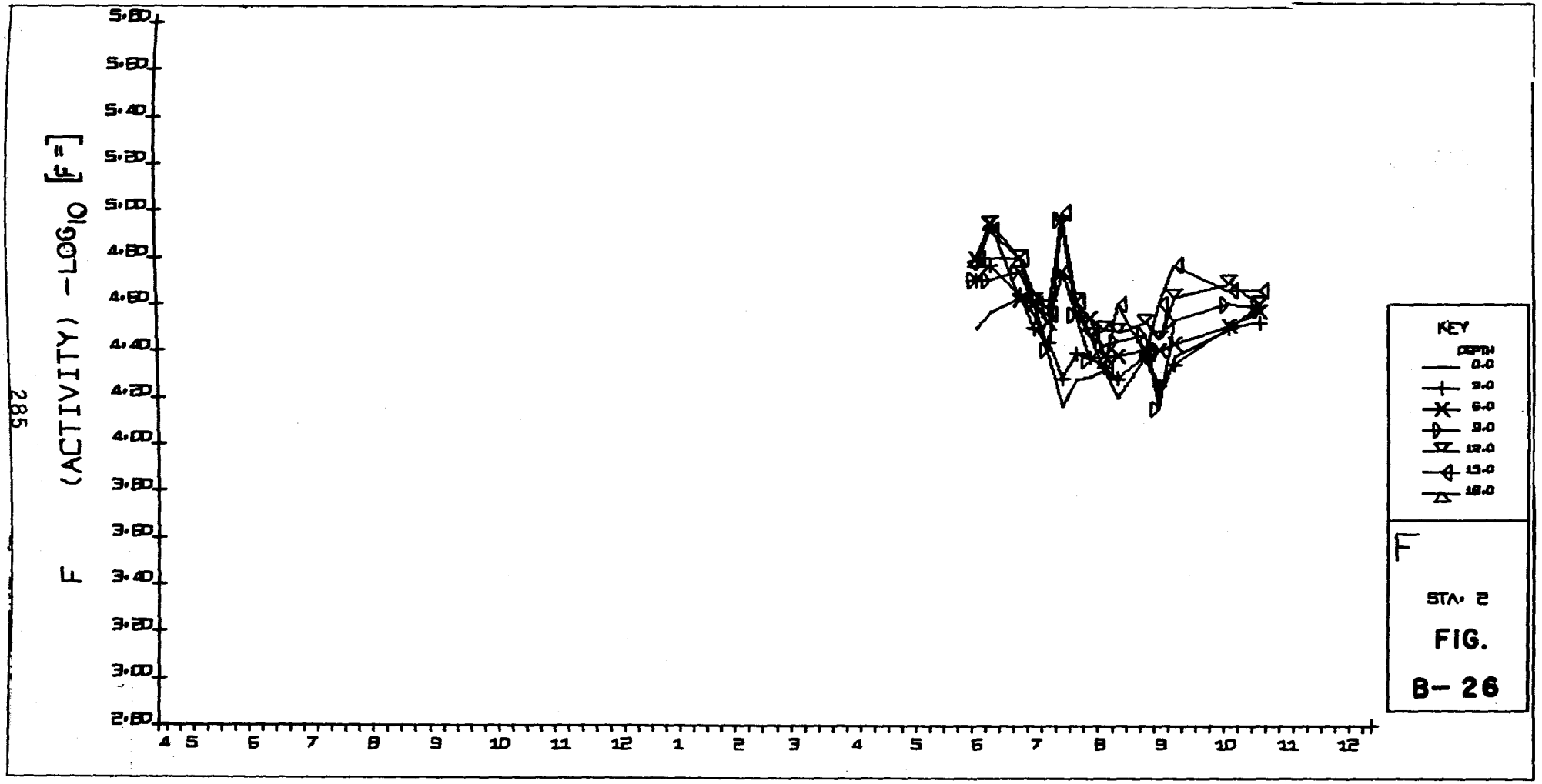
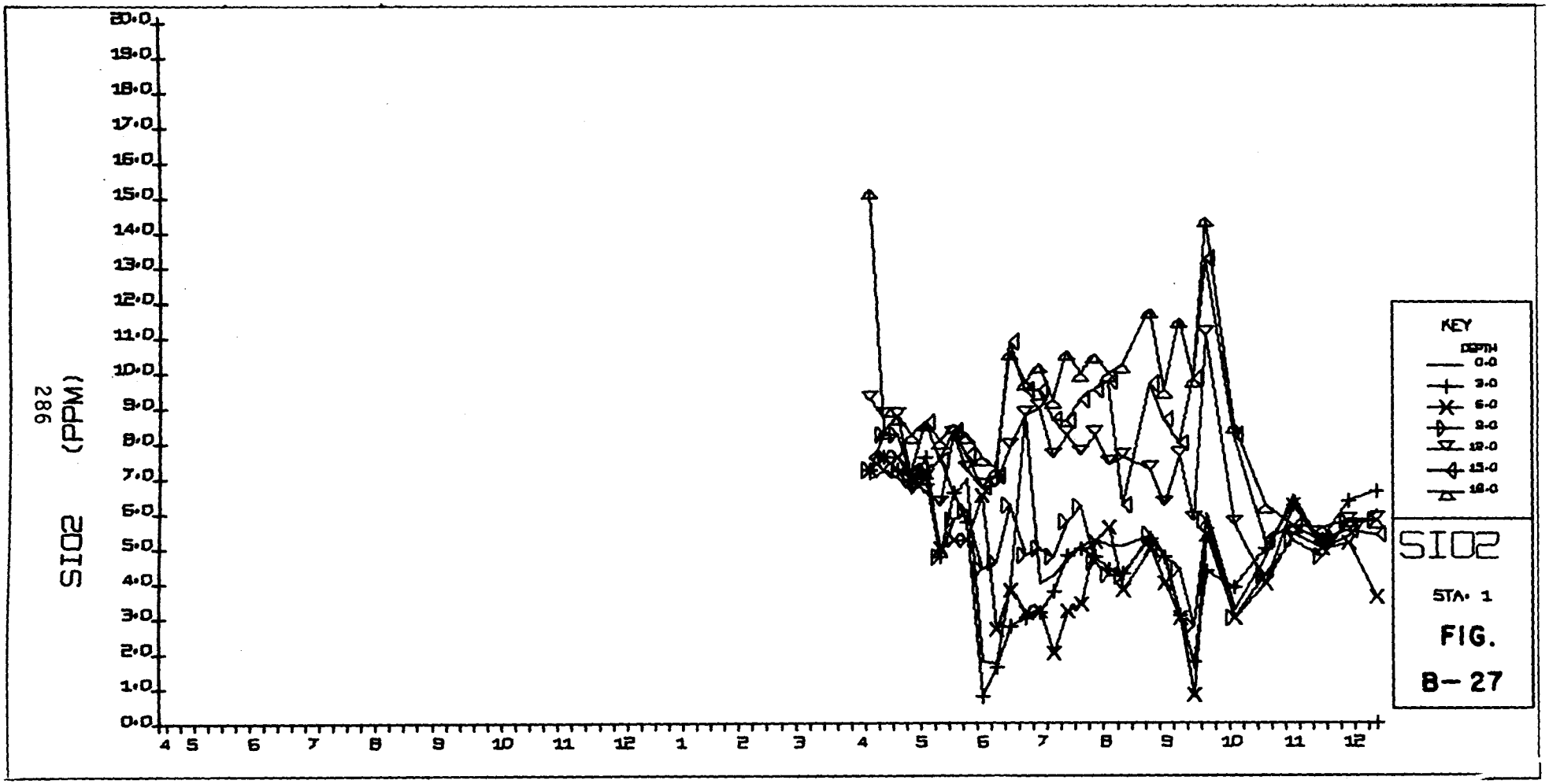
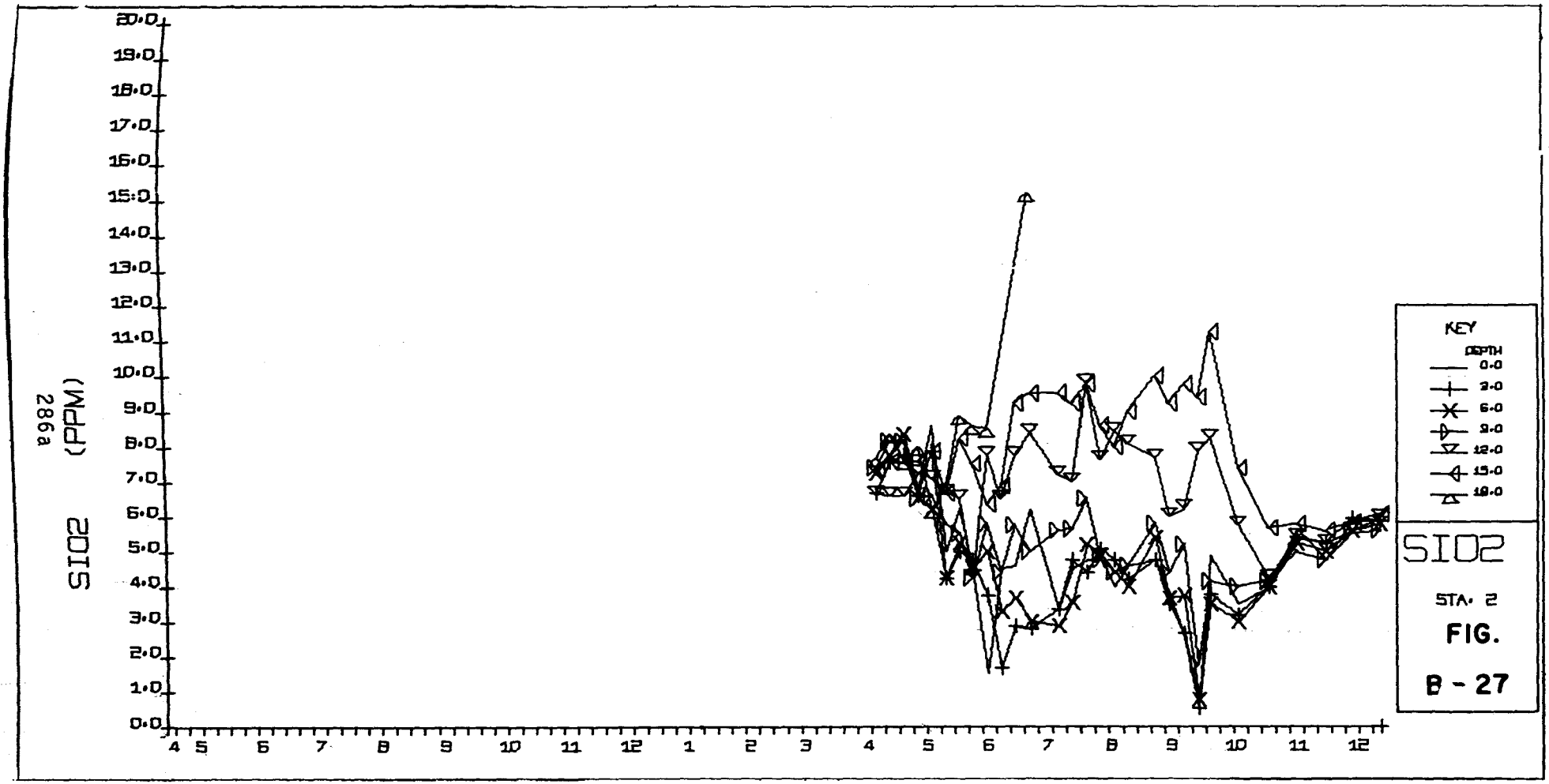

F (ACTIVITY) $-LOG_{10}$ [F=]
5.80
5.60
5.40
5.20
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
2.80
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
F
STA. 2

FIG.

B-26


SIO2 (PPM)
286
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SIO2
STA. 1
FIG.
B-27


SIO2 (PPM)
286a
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SIO2
STA. 2
FIG.
B - 27

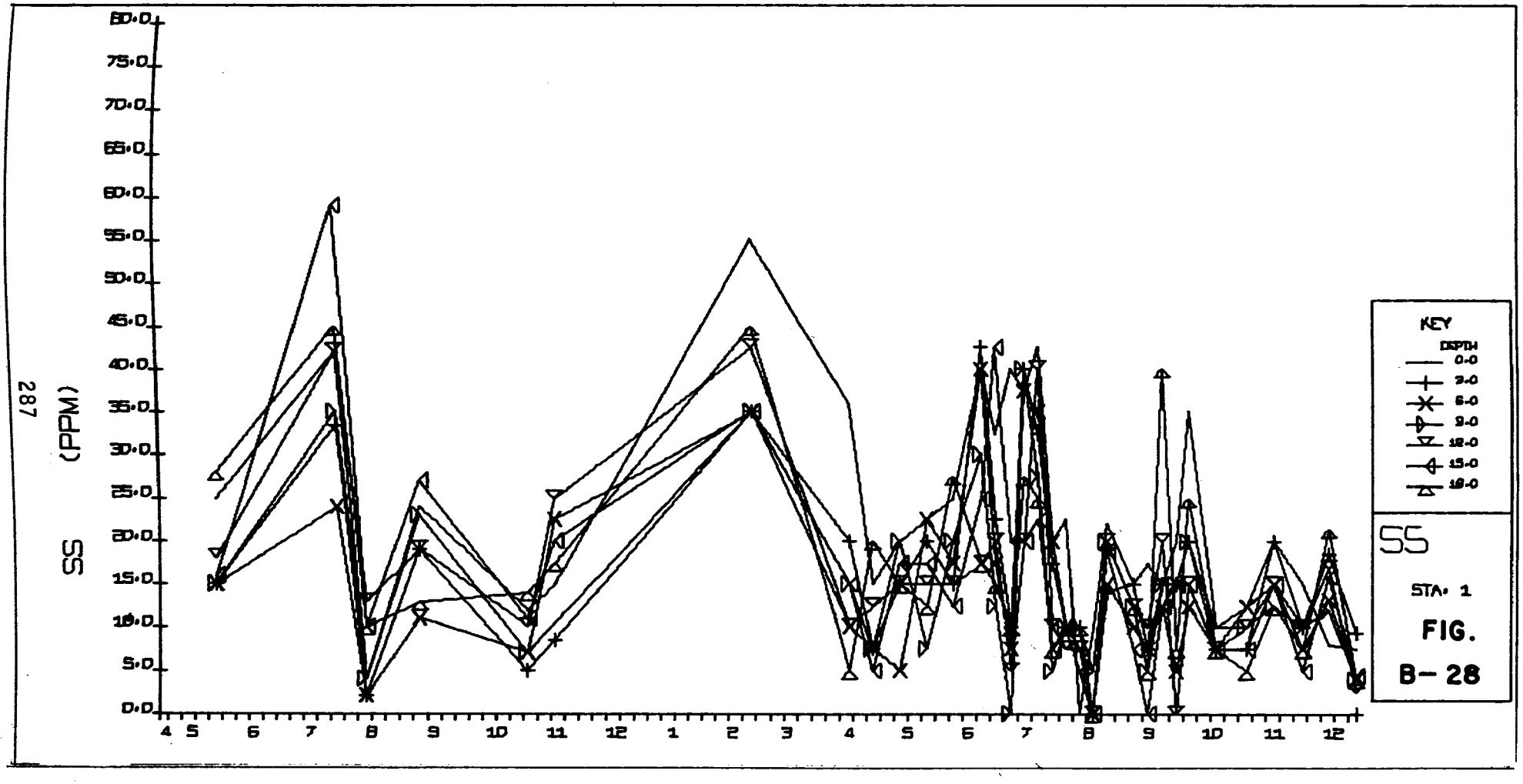
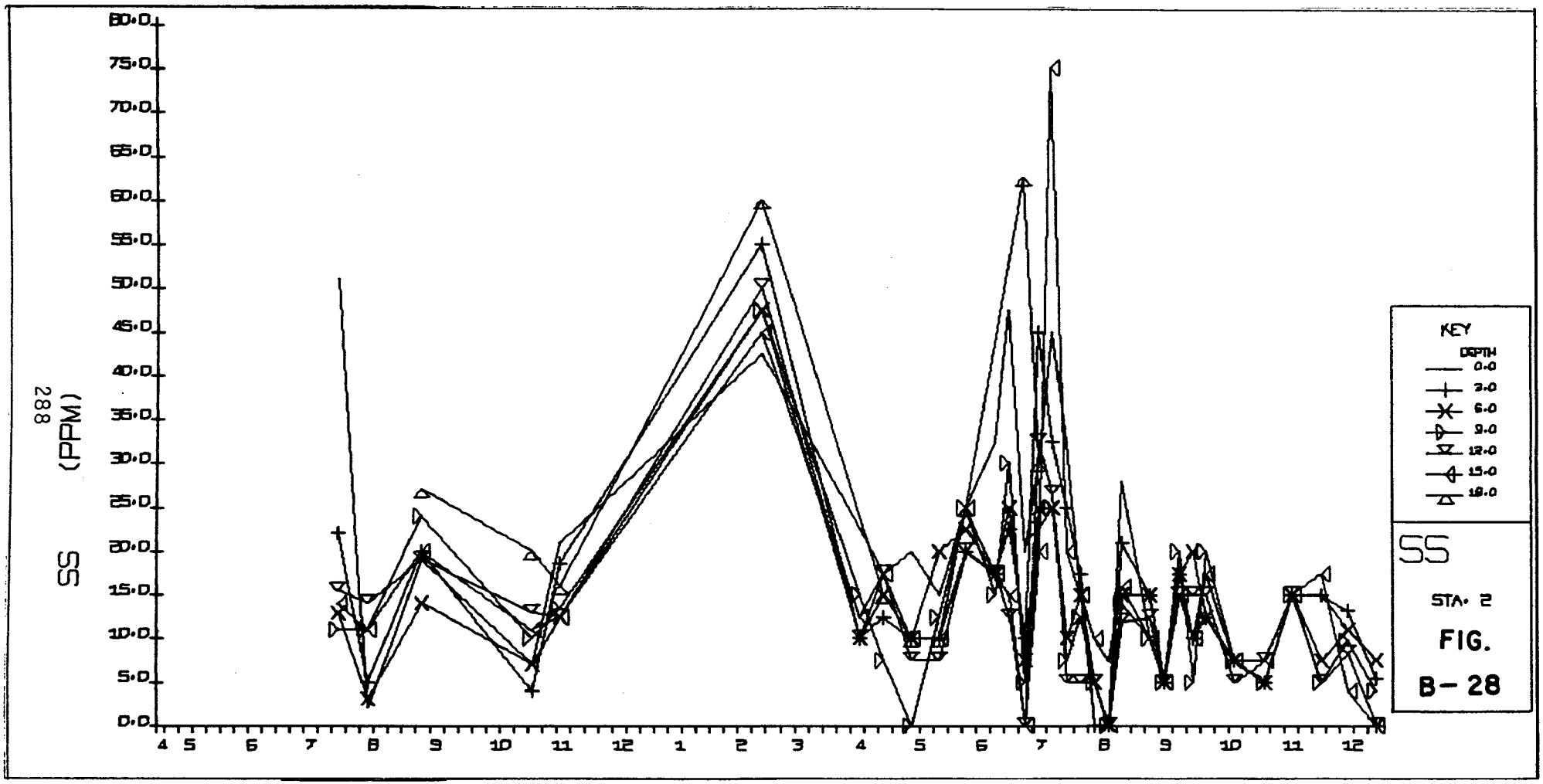

SS (PPM)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SS
STA. 1

FIG. B-28


SS (PPM)
288
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SS
STA. 2
FIG.
B-28

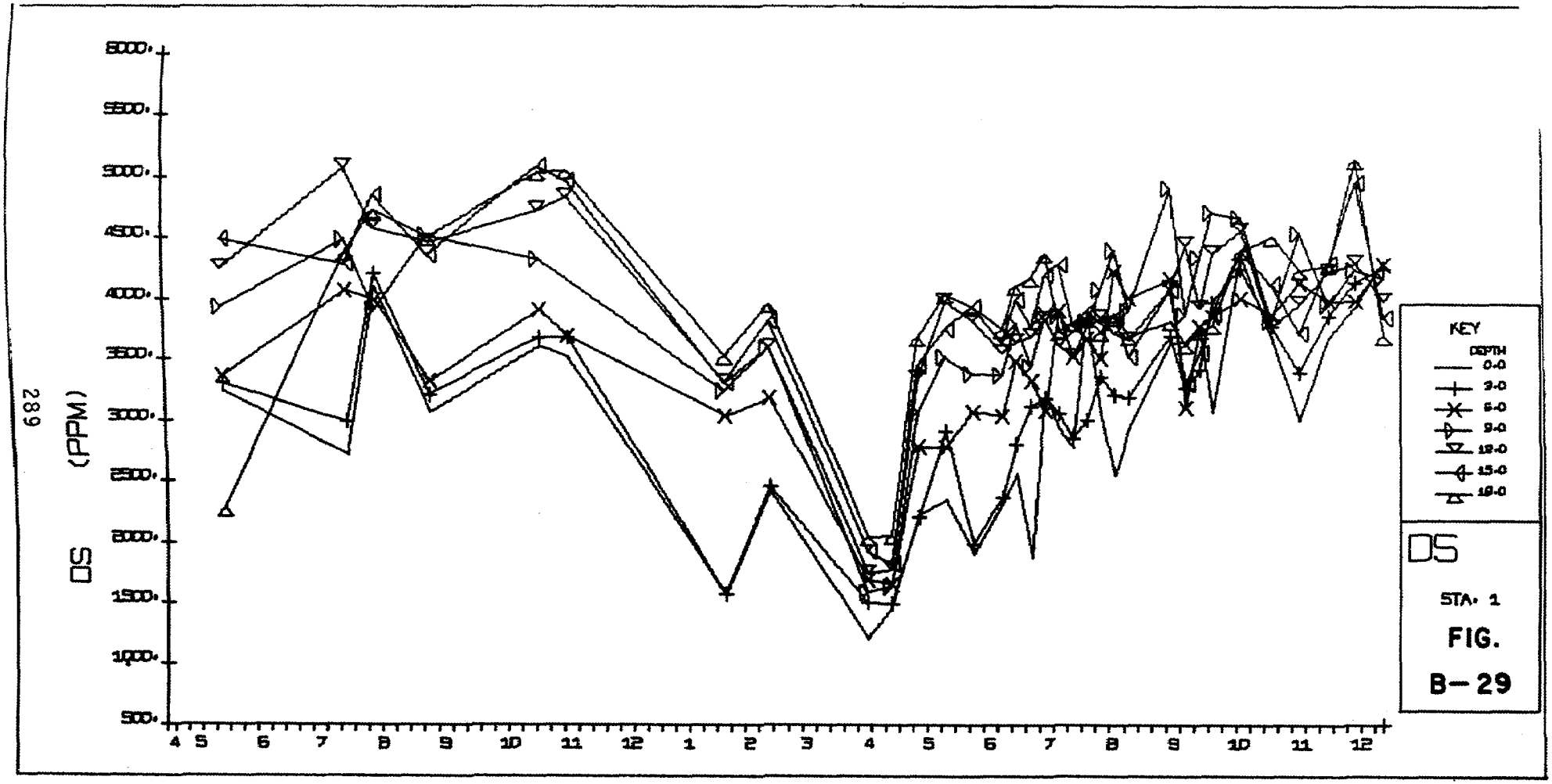

DS (PPM)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
DS
STA. 1

FIG.

B-29

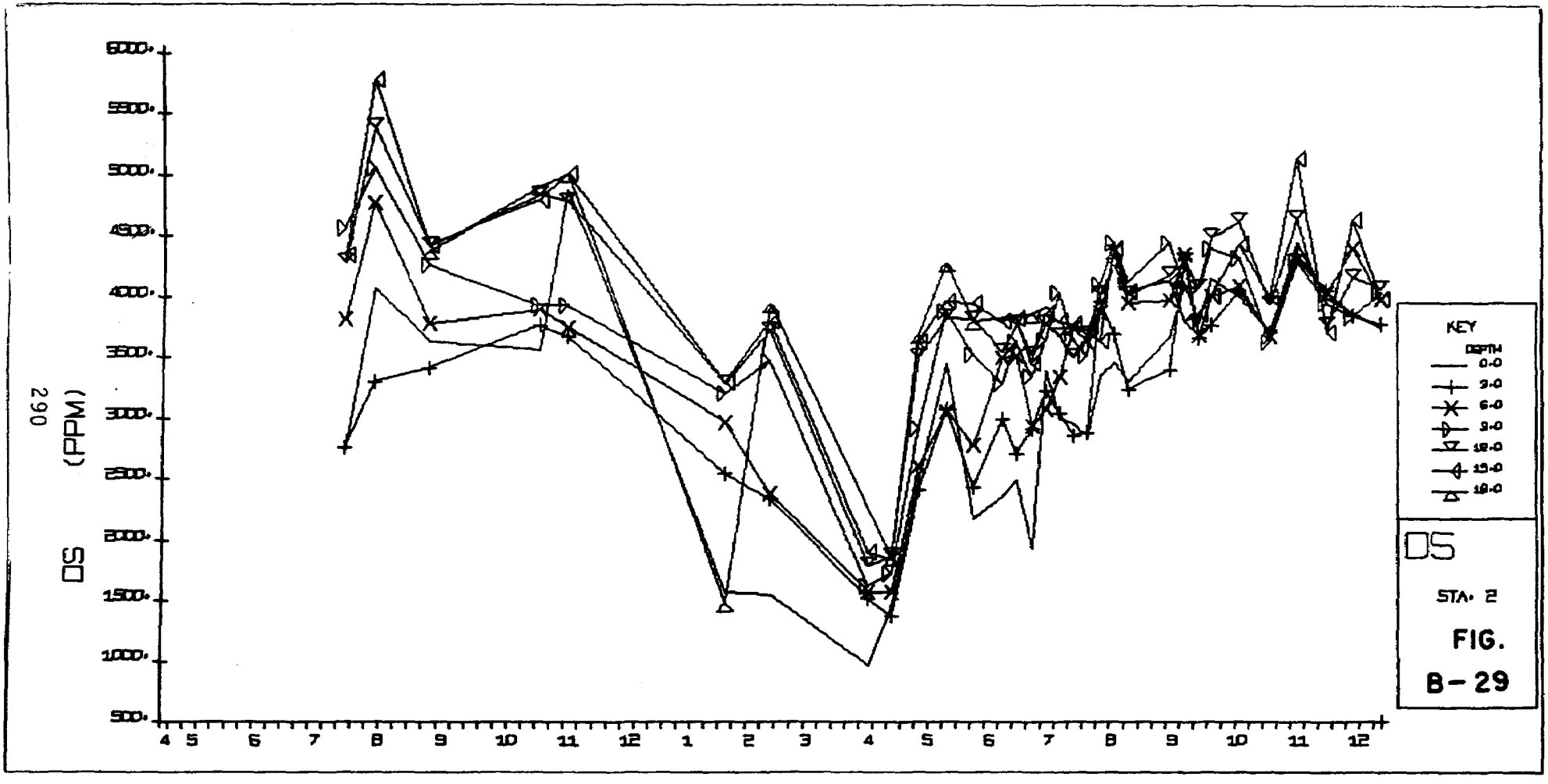

6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
DS (PPM)
290
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
DS
STA. 2

FIG. B-29

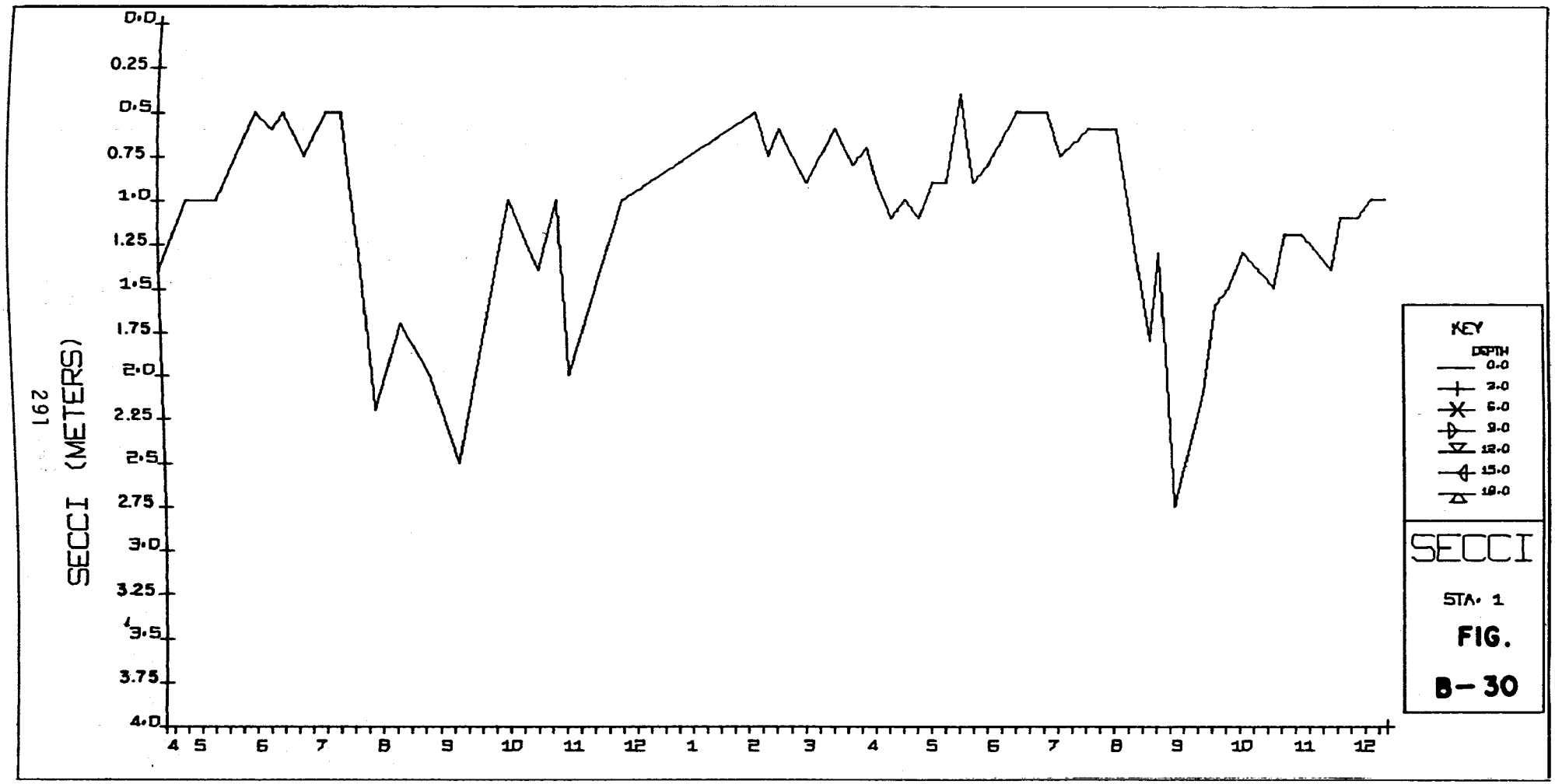
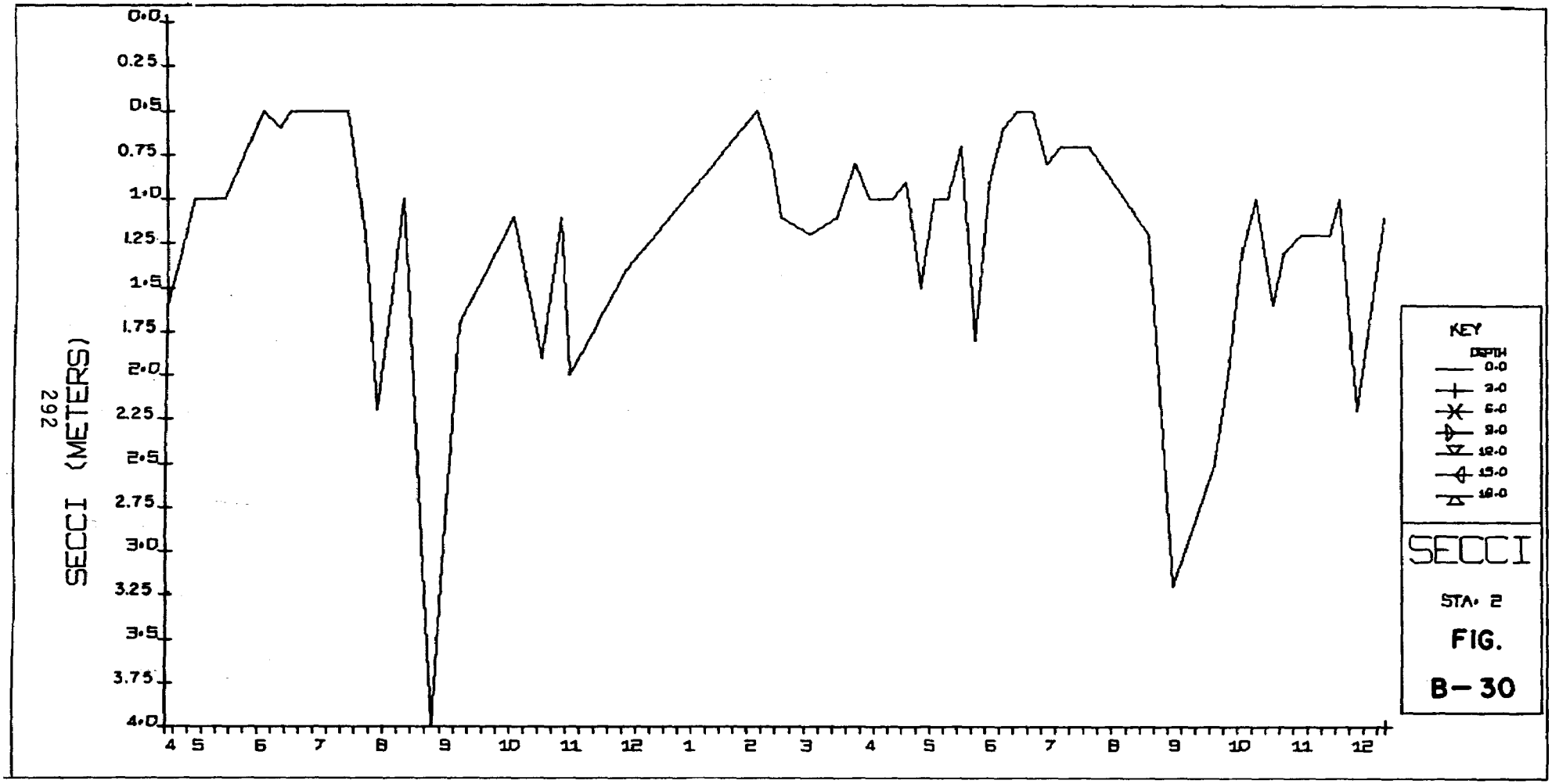
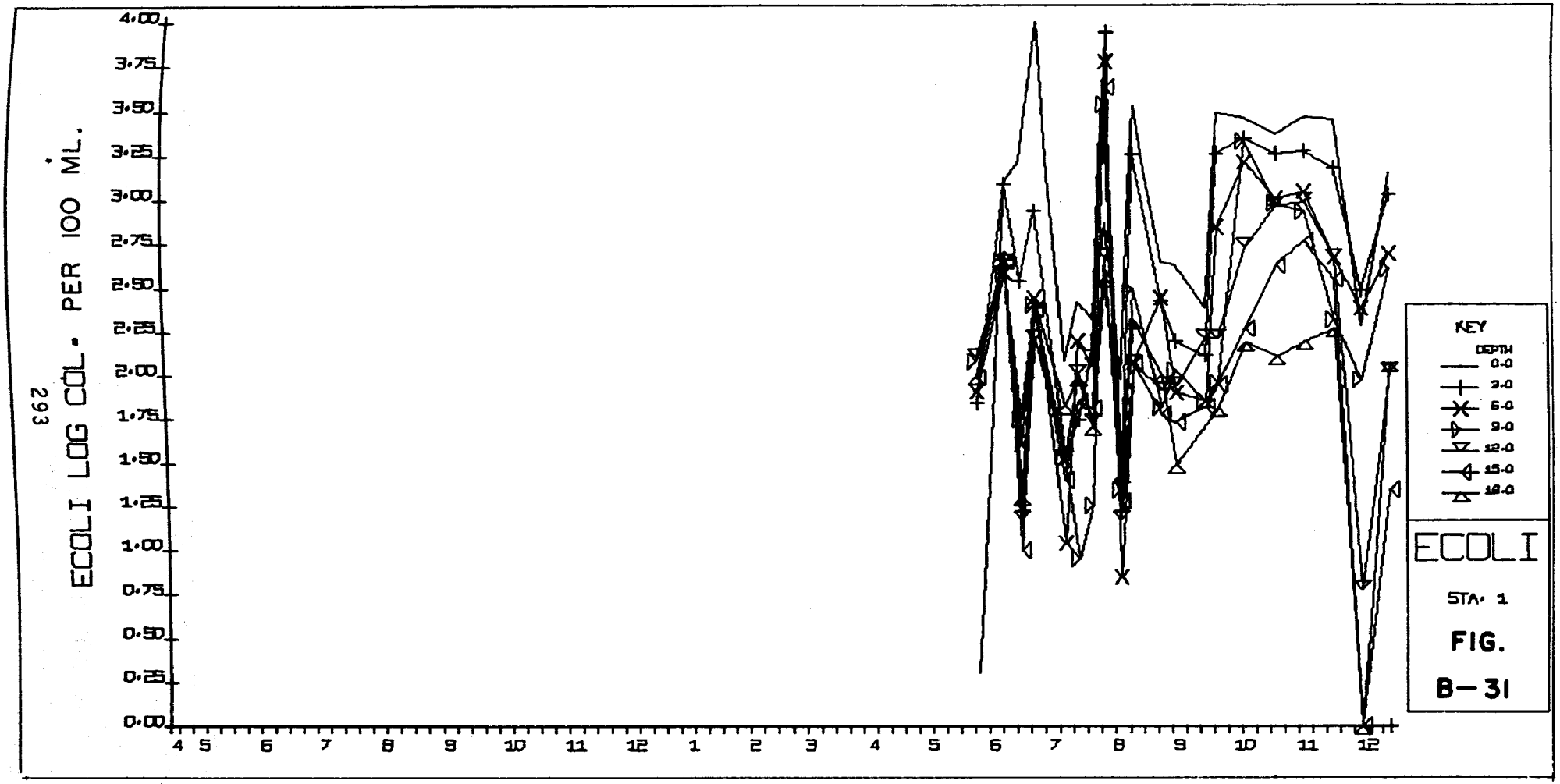

SECCI (METERS)
0.0
0.25
0.5
0.75
1.0
1.25
1.5
1.75
2.0
2.25
2.5
2.75
3.0
3.25
3.5
3.75
4.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SECCI
STA. 1

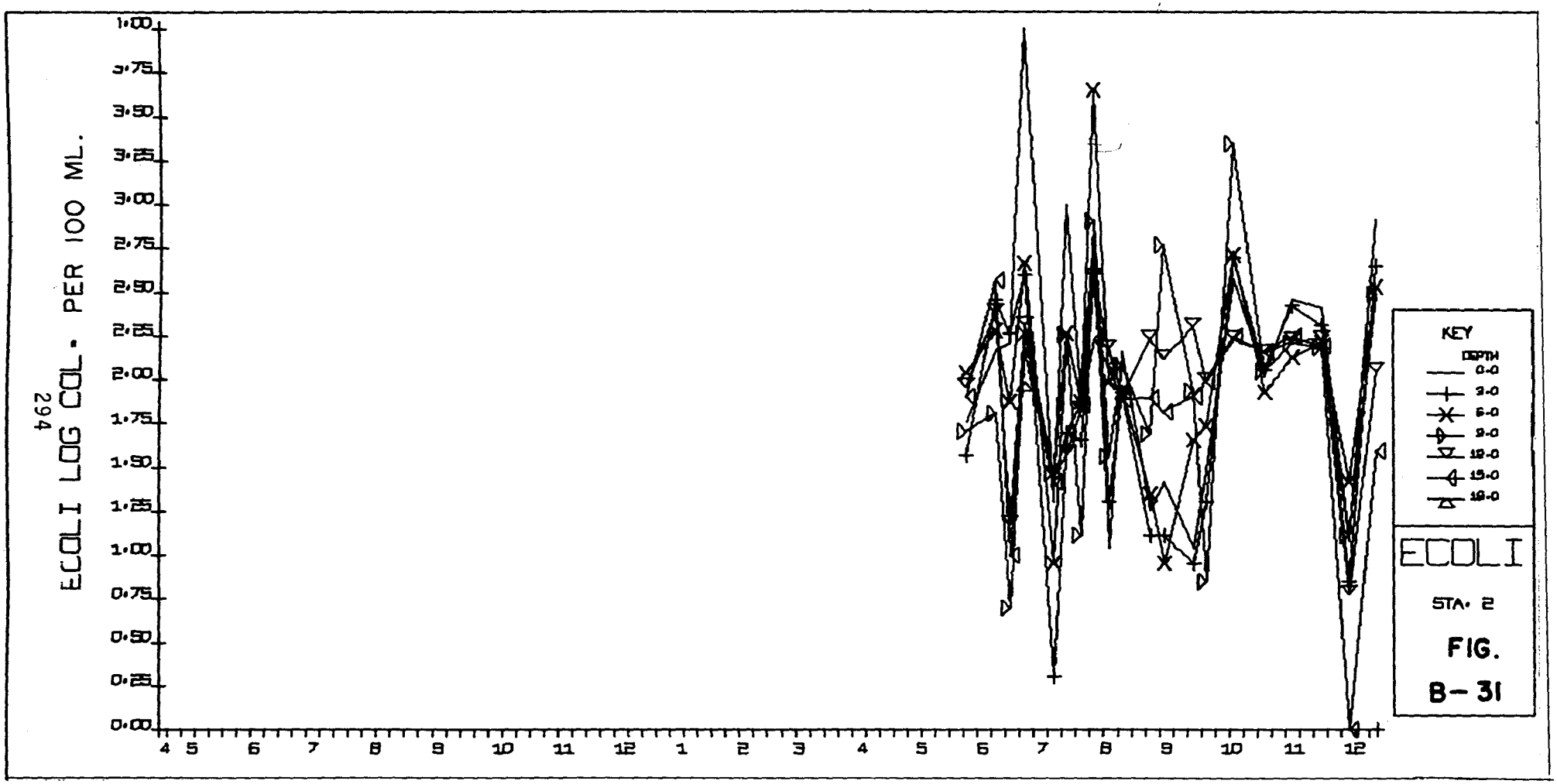
FIG.

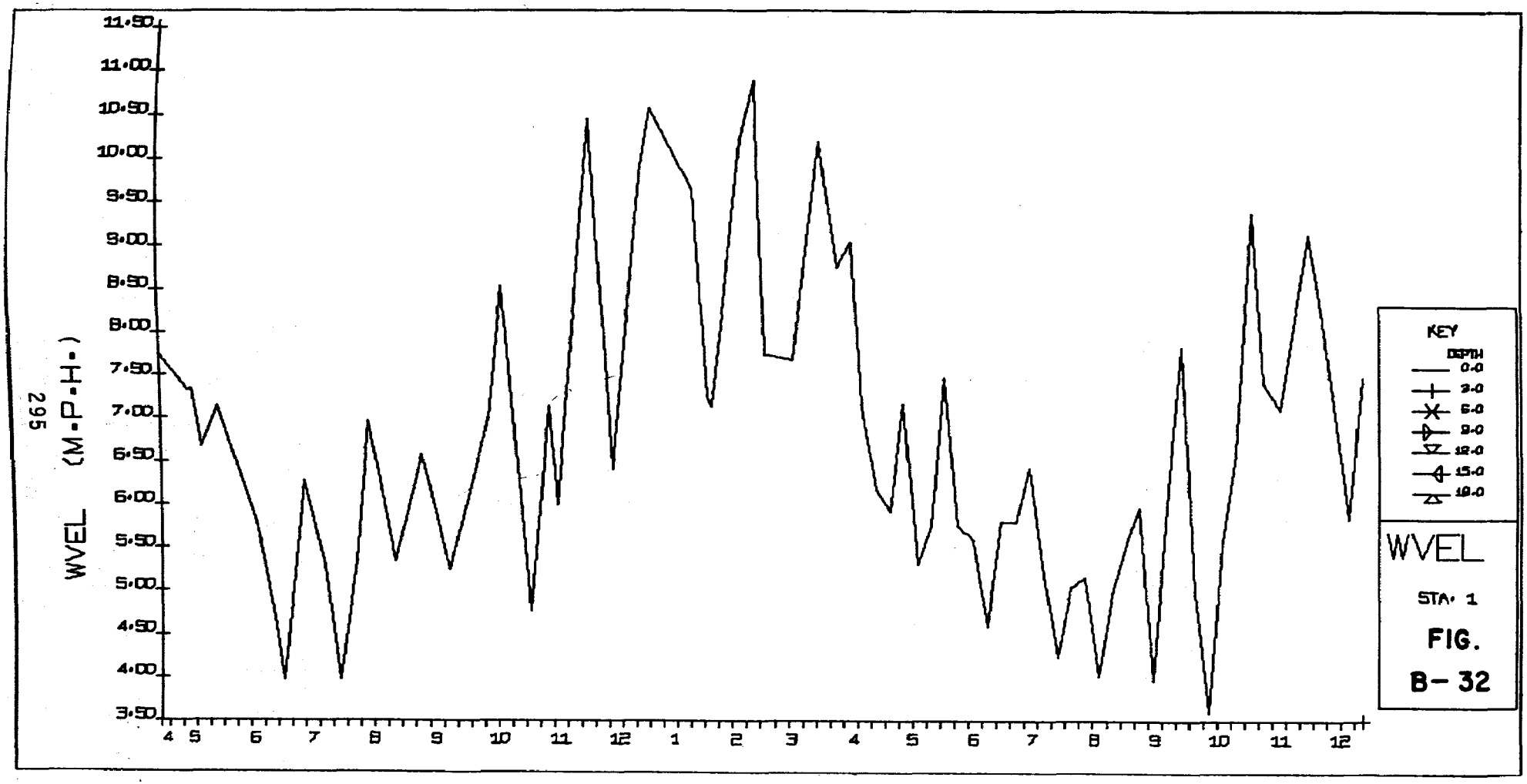
B-30

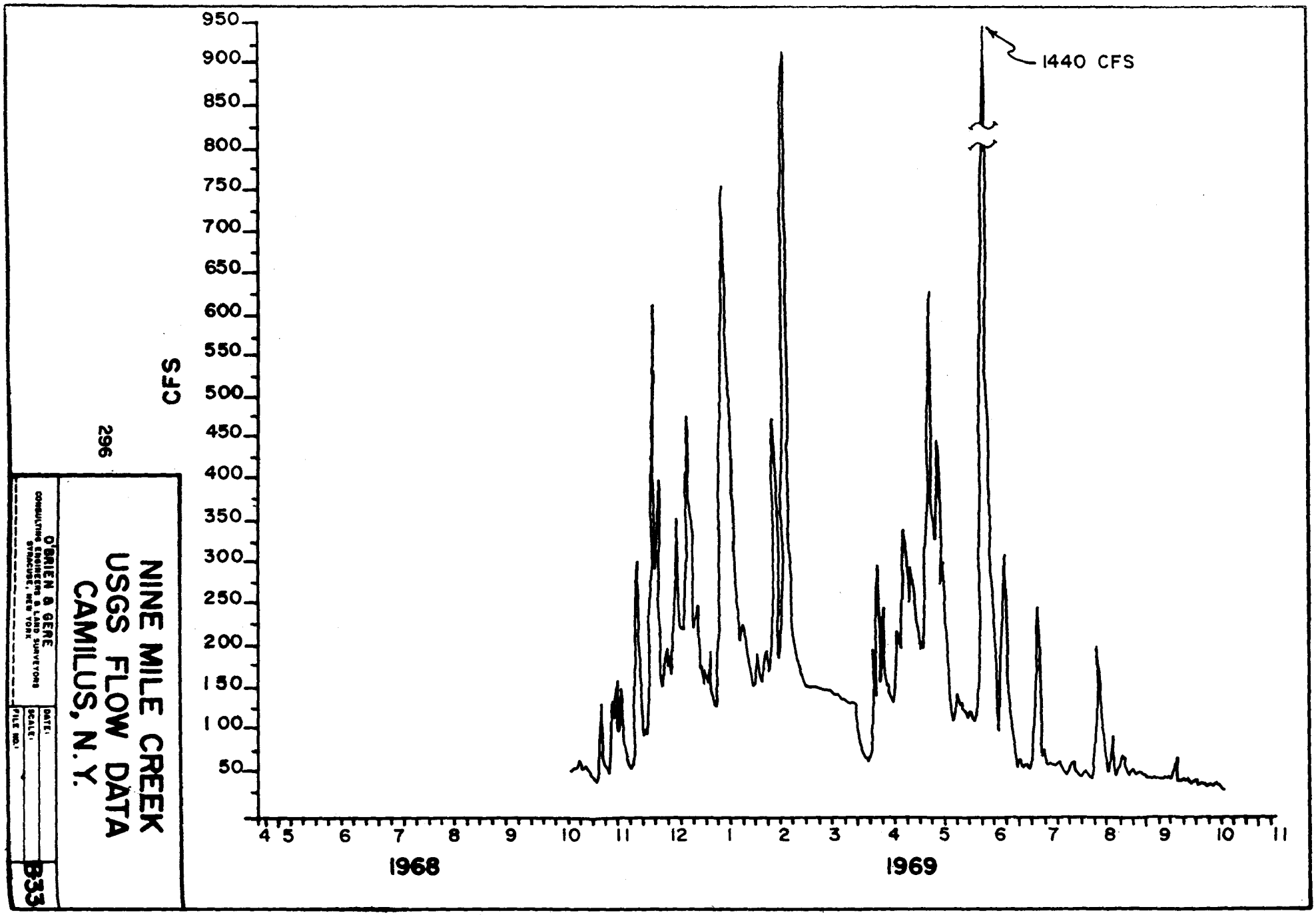
291

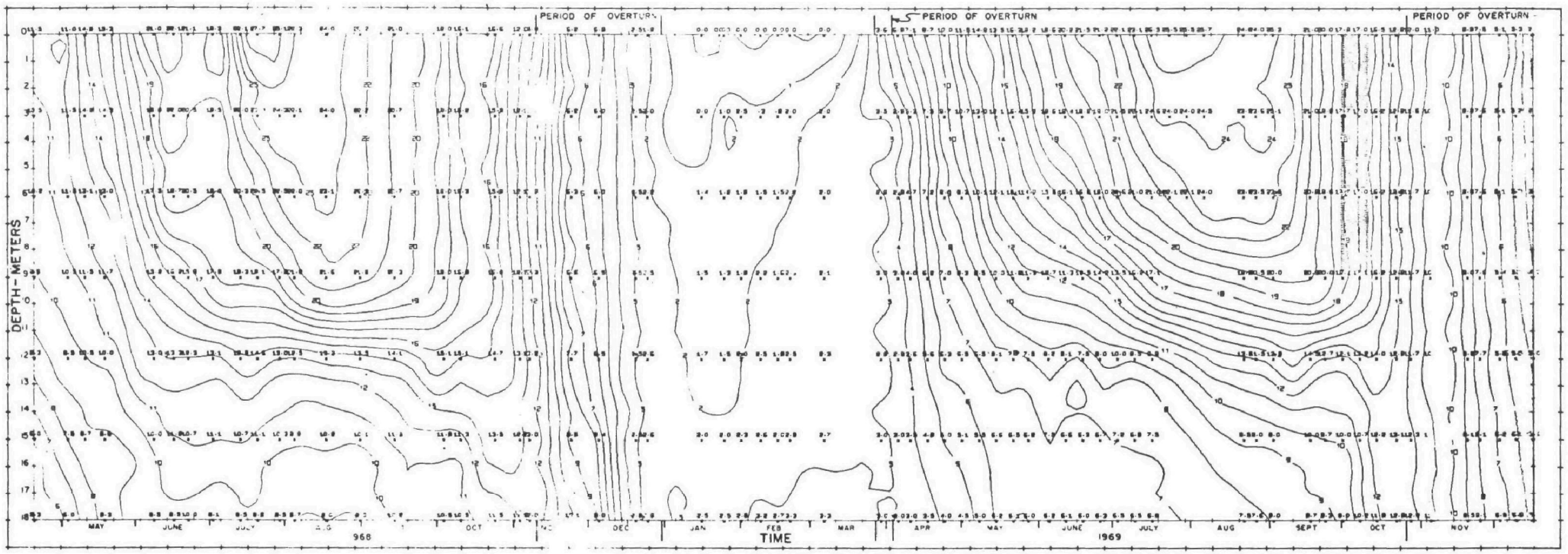

SECCI (METERS)
292
0.0
0.25
0.5
0.75
1.0
1.25
1.5
1.75
2.0
2.25
2.5
2.75
3.0
3.25
3.5
3.75
4.0
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SECCI
STA. 2
FIG.
B-30


ECOLI LOG COL. PER 100 ML.
293
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ECOLI
STA. 1
FIG.
B-31


ECOLI LOG COL. PER 100 ML.
294
1.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ECOLI
STA. 2
FIG.
B-31


WVEL (M-P-H-)
295
11.50
11.00
10.50
10.00
9.50
9.00
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
WVEL
STA. 1
FIG.
B-32


NINE MILE CREEK
USGS FLOW DATA
CAMILUS, N.Y.
O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK
DATE:
SCALE:
FILE NO.:
B33
296
CFS
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
1440 CFS
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11
1968
1969

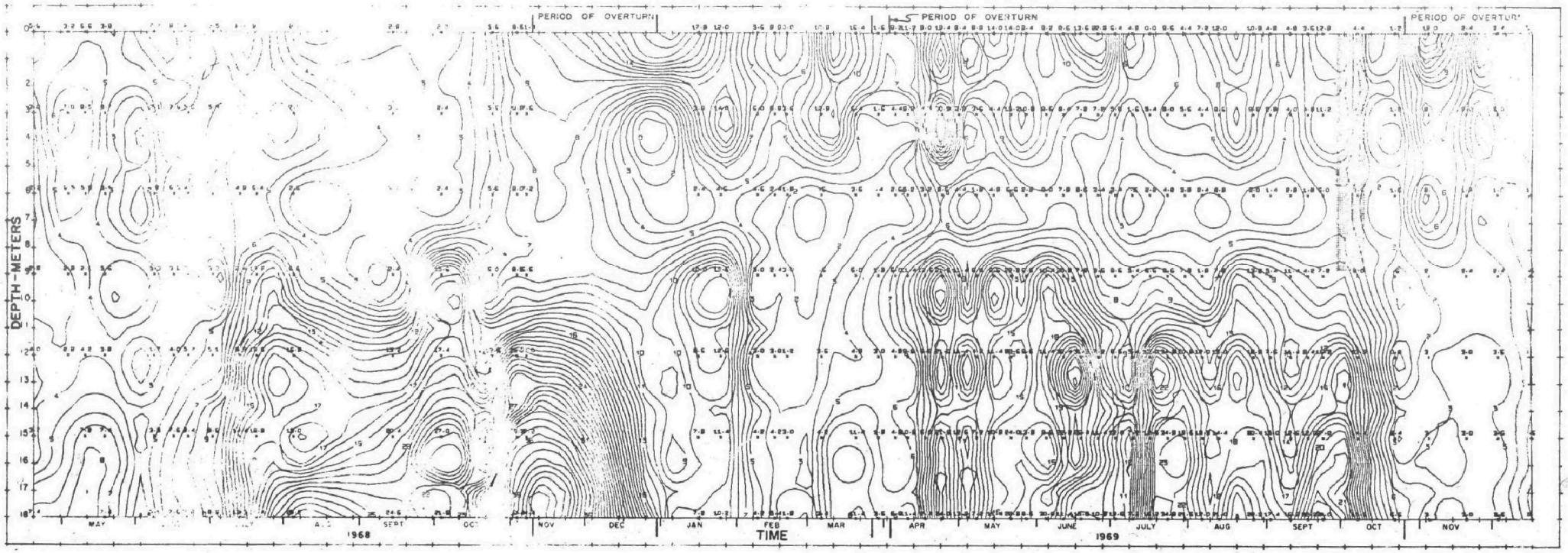


WATER TEMPERATURE 4/17/68 TO 12/18/69 STATION 1

CRITICAL PERIOD

FIGURE B-34

FIGURE B-34

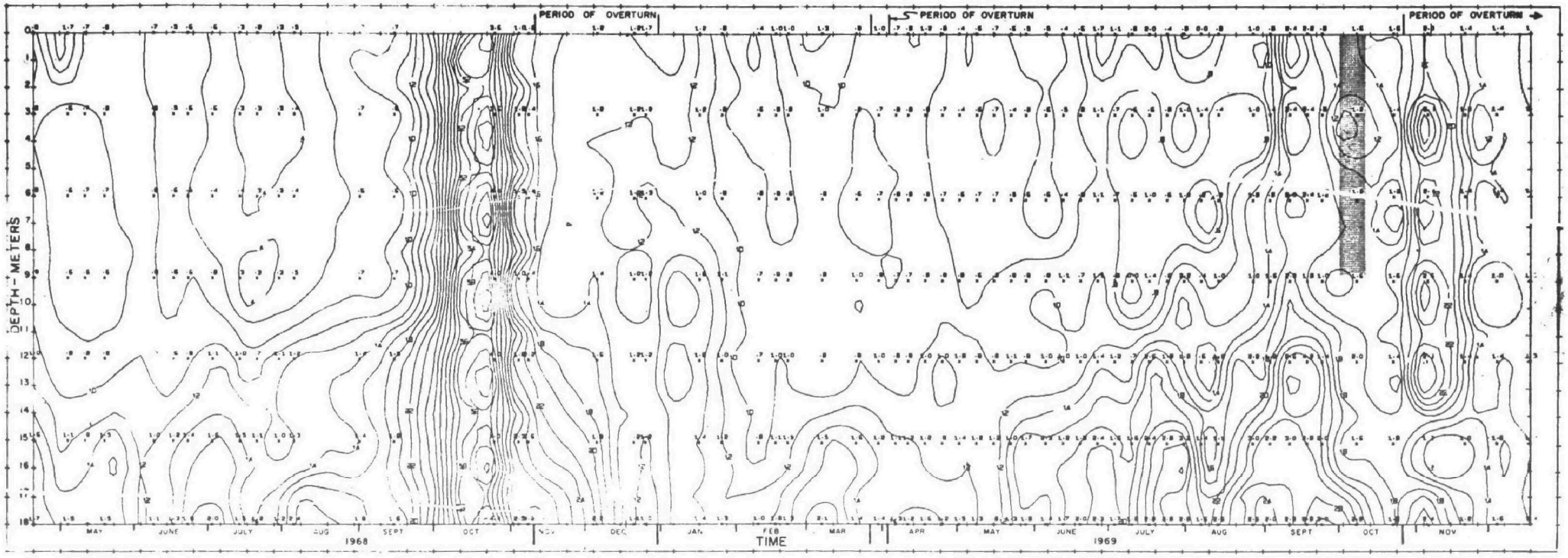


BIOCHEMICAL OXYGEN DEMAND 4/17/68 TO 12/18/69 STATION

CRITICAL PERIOD

FIGURE B-35

FIGURE B-35



ORTHO - PHOSPHATE 4/17/68 TO 12/18/69 STATION

CRITICAL PERIOD

FIGURE B-36

FIGURE B-36

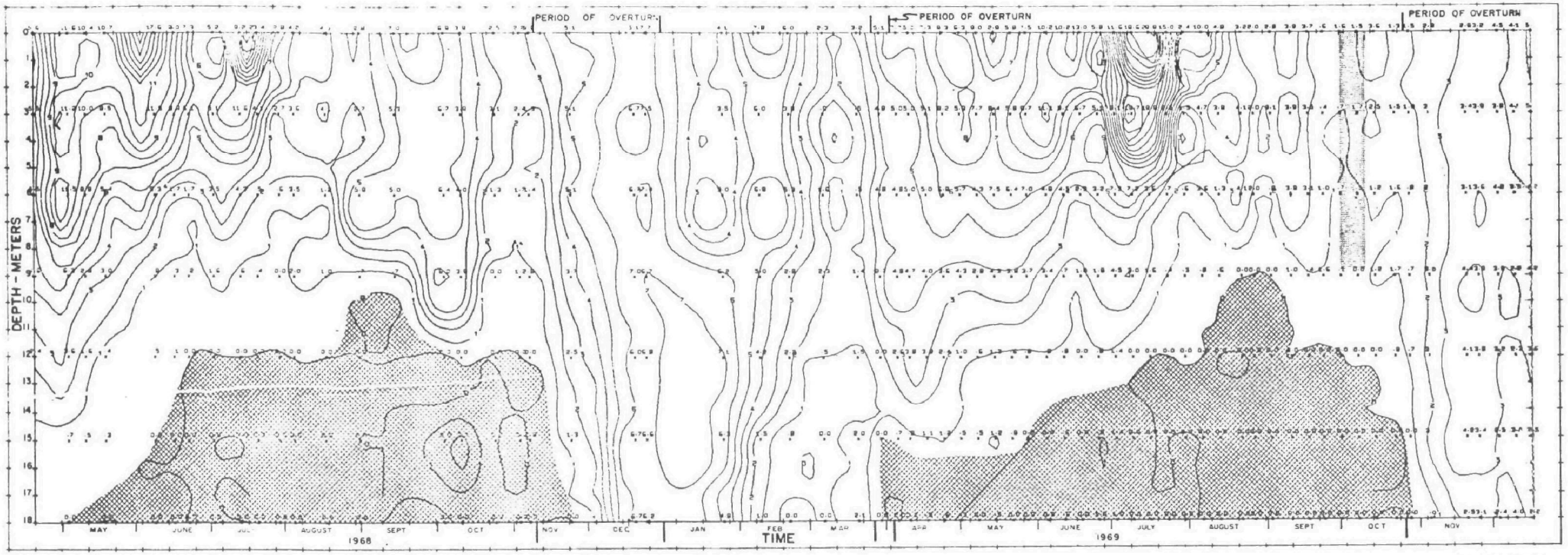


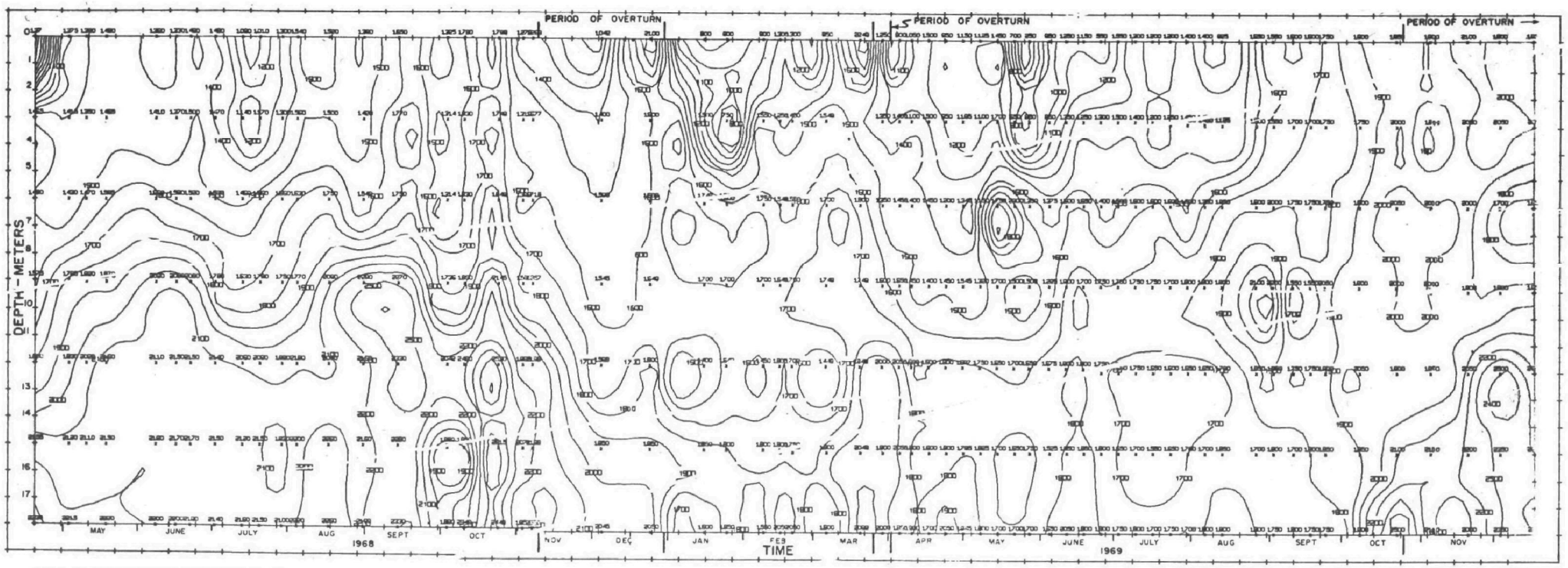
FIGURE B-37

DISSOLVED OXYGEN 4/17/68 TO 12/18/69 STATION 1

CRITICAL PERIOD

AREA OF 0.0 DISSOLVED OXYGEN

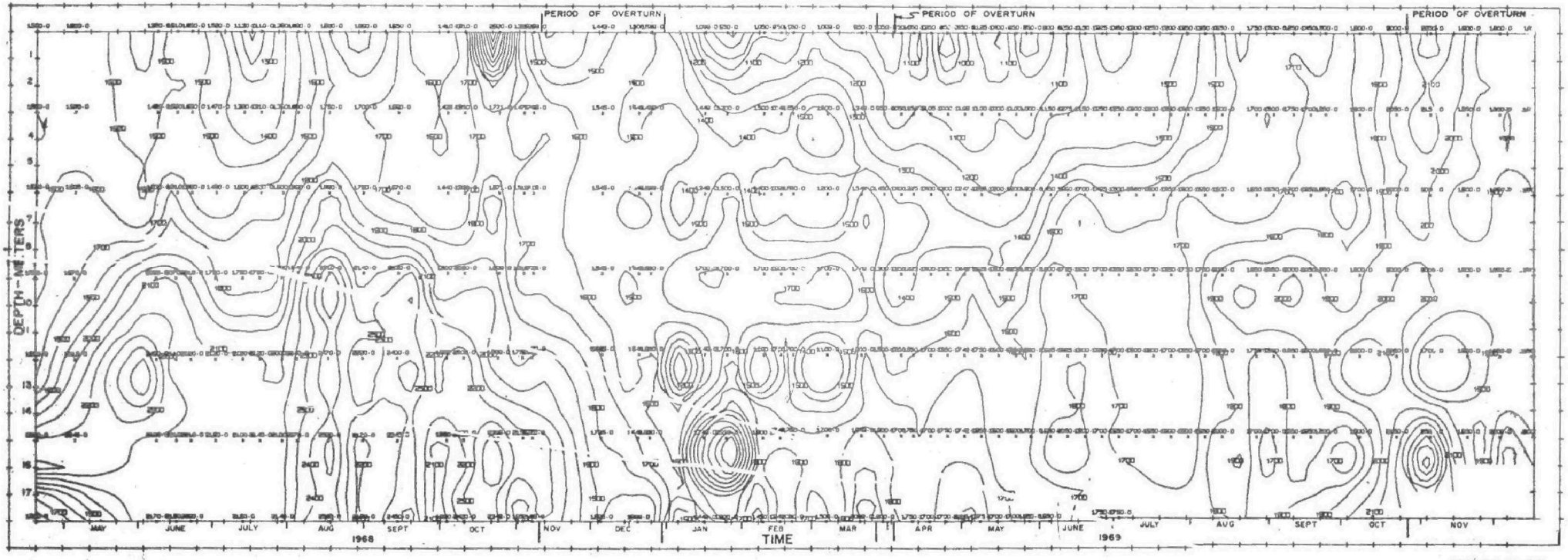
FIGURE B-37



CHLORIDE CONCENTRATION 4/17/68 TO 12/18/68 STA- 1

FIGURE B-38

FIGURE B-38



CHLORIDE CONCENTRATION 4/17/68 TO 12/18/69 STA- 2

FIGURE B-39

FIGURE B-39

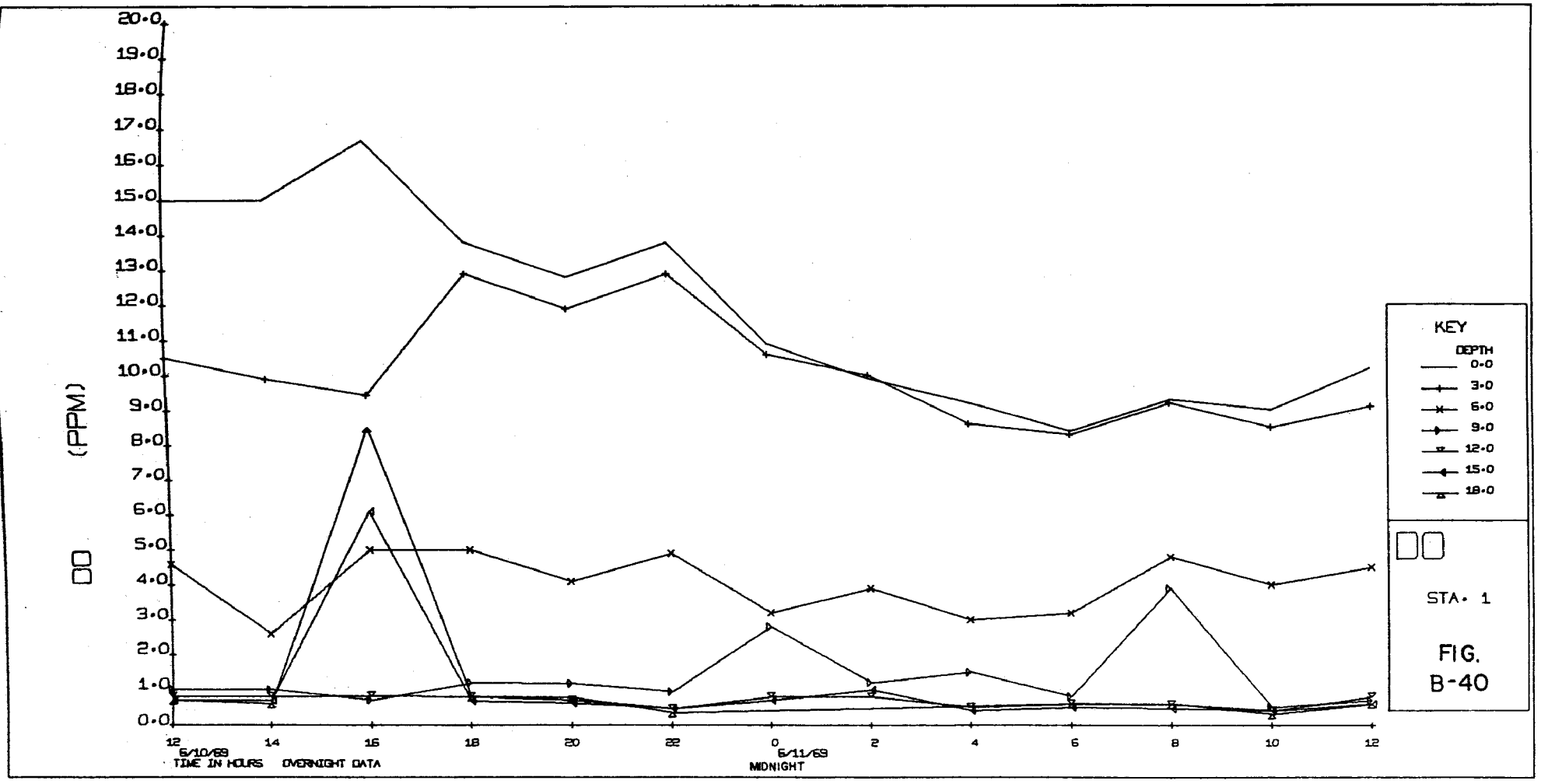
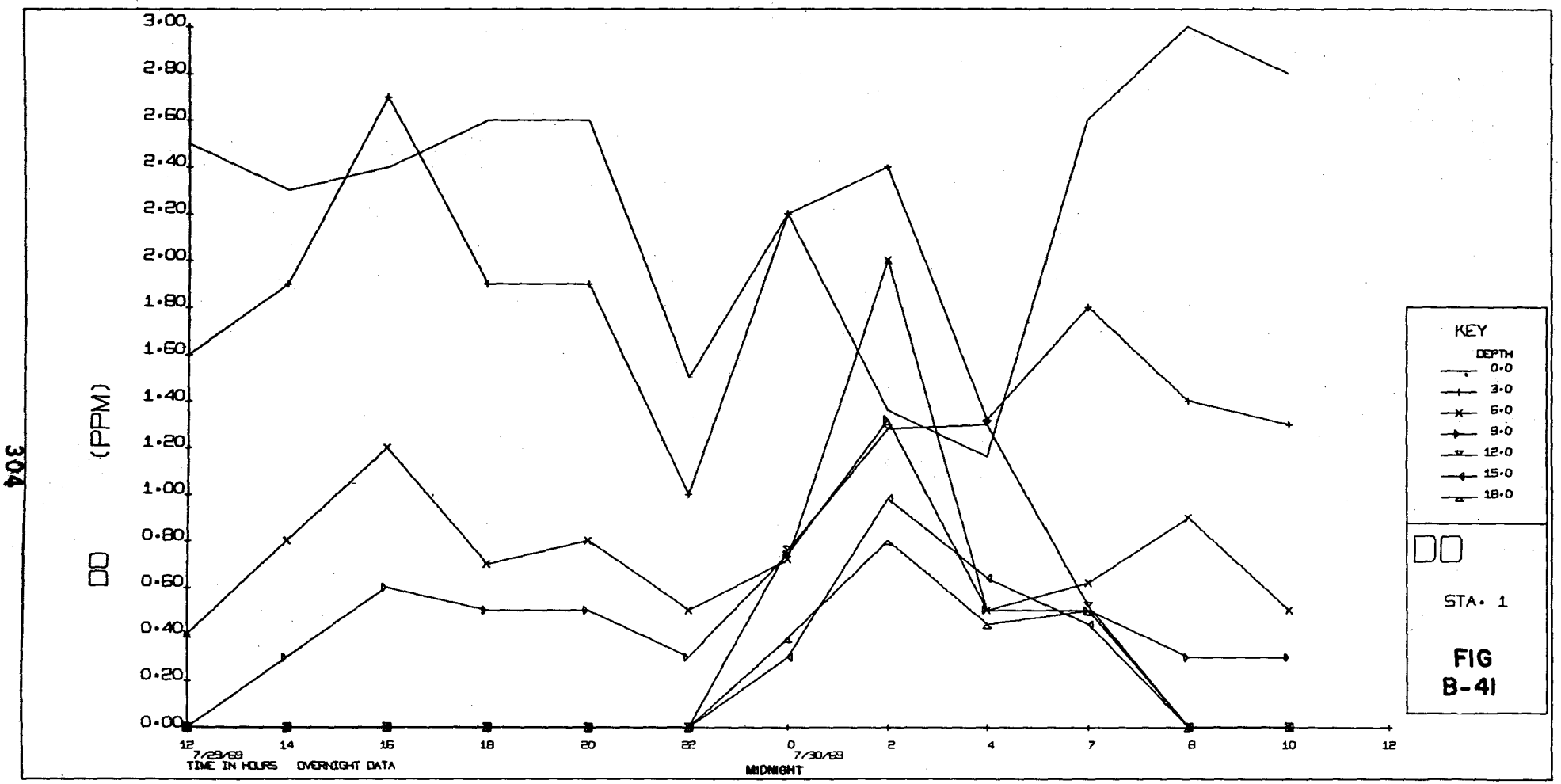
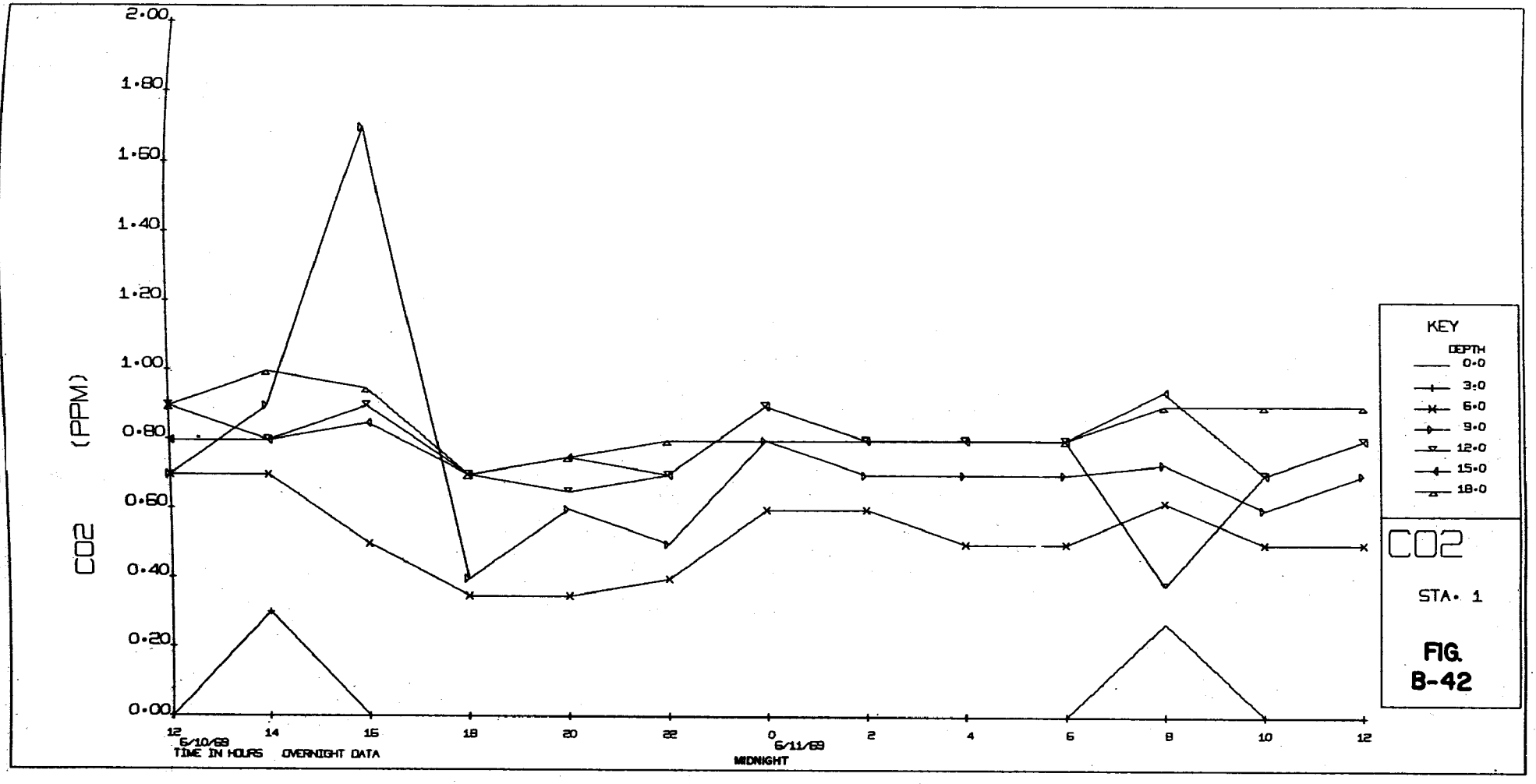

20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
DO (PPM)
12
14
16
18
20
22
0
2
4
6
8
10
12
5/10/69
5/11/69
TIME IN HOURS OVERNIGHT DATA
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
DO
STA. 1

FIG. B-40


3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
DO (PPM)
12
7/29/69
14
16
18
20
22
0
7/30/69
2
4
7
8
10
12
TIME IN HOURS OVERNIGHT DATA
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
DO
STA. 1
FIG
B-41


2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
CO2 (PPM)
12
14
16
18
20
22
0
2
4
6
8
10
12
6/10/69
TIME IN HOURS OVERNIGHT DATA
6/11/69
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
CO2
STA. 1
FIG.
B-42

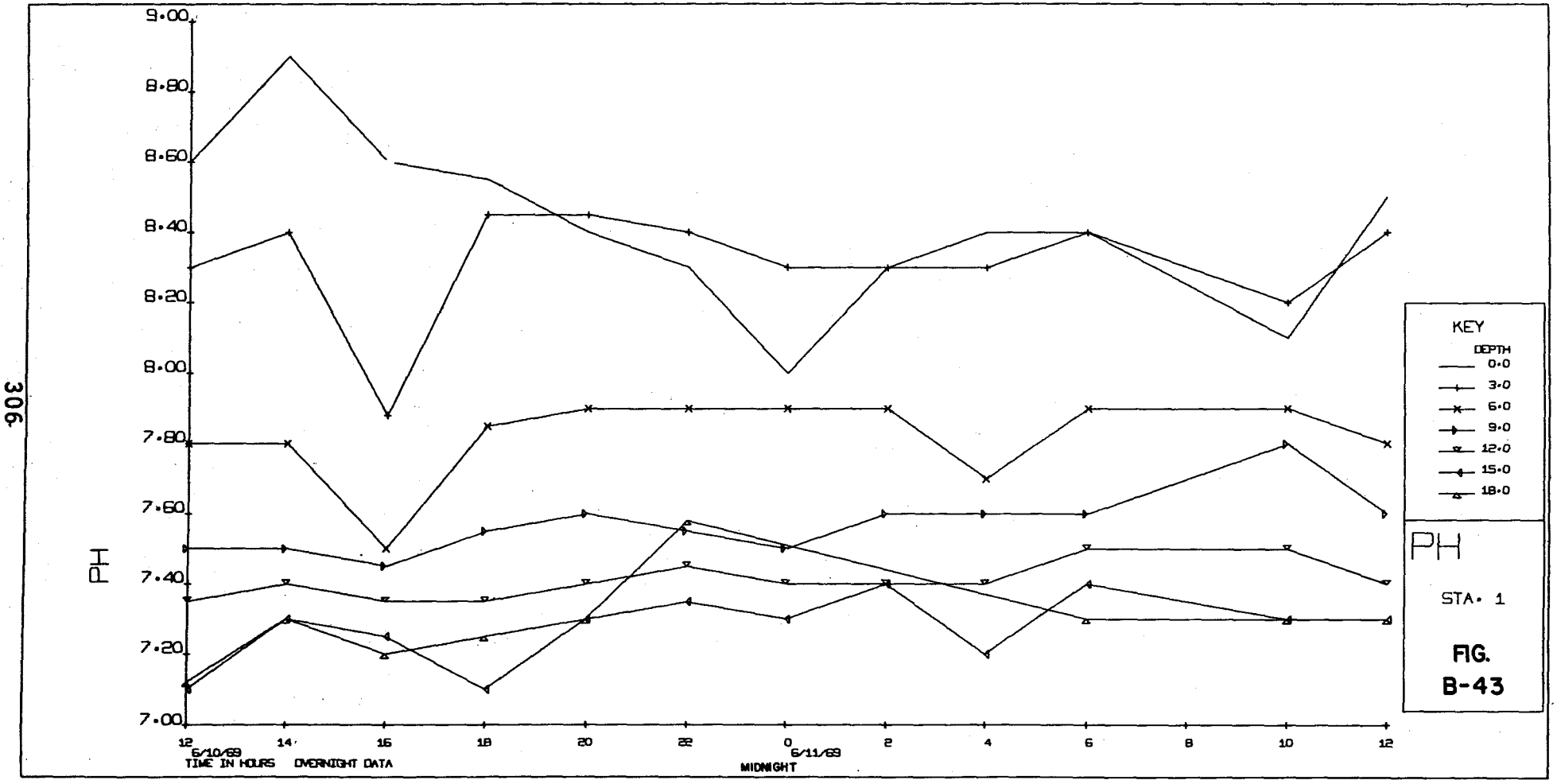
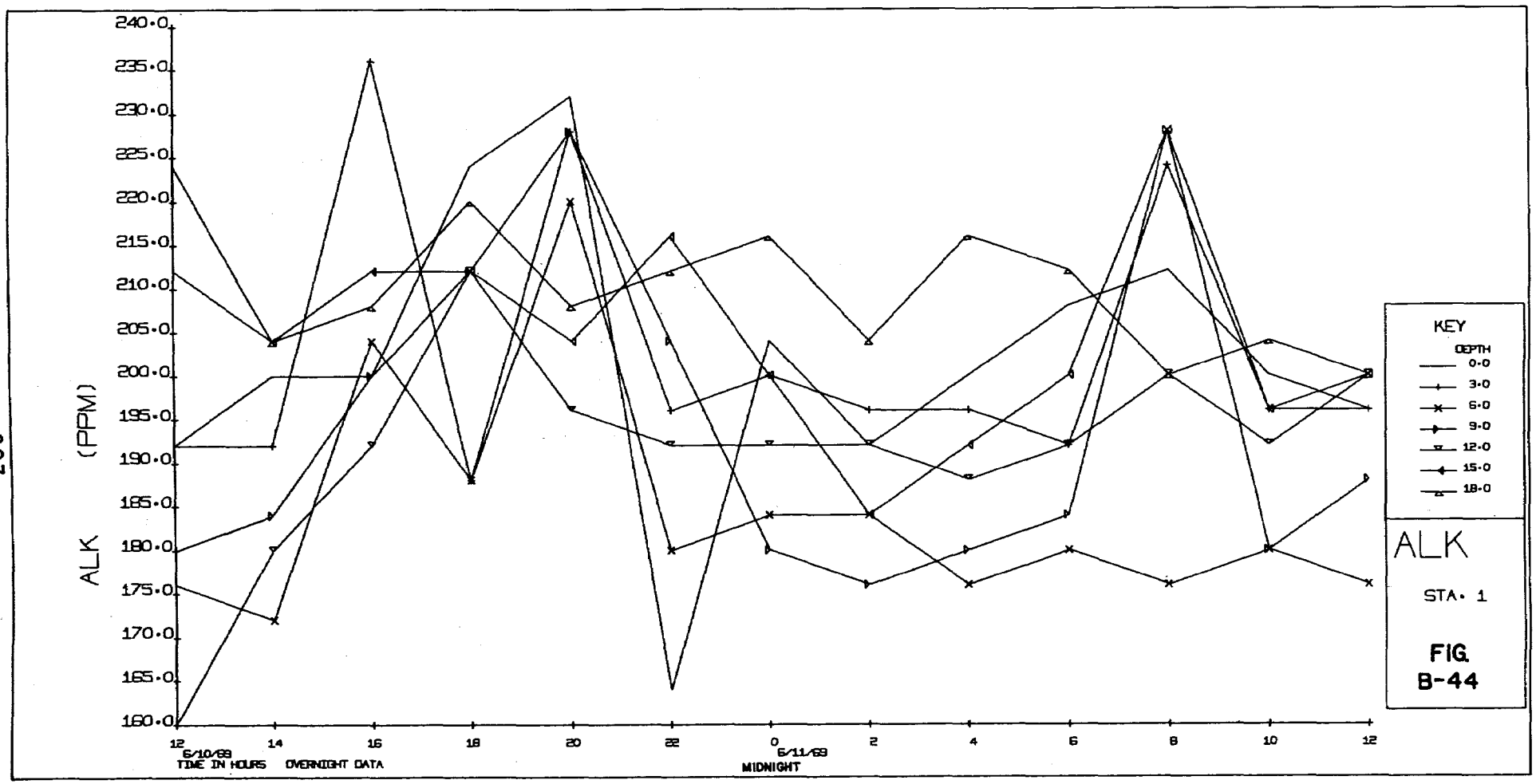
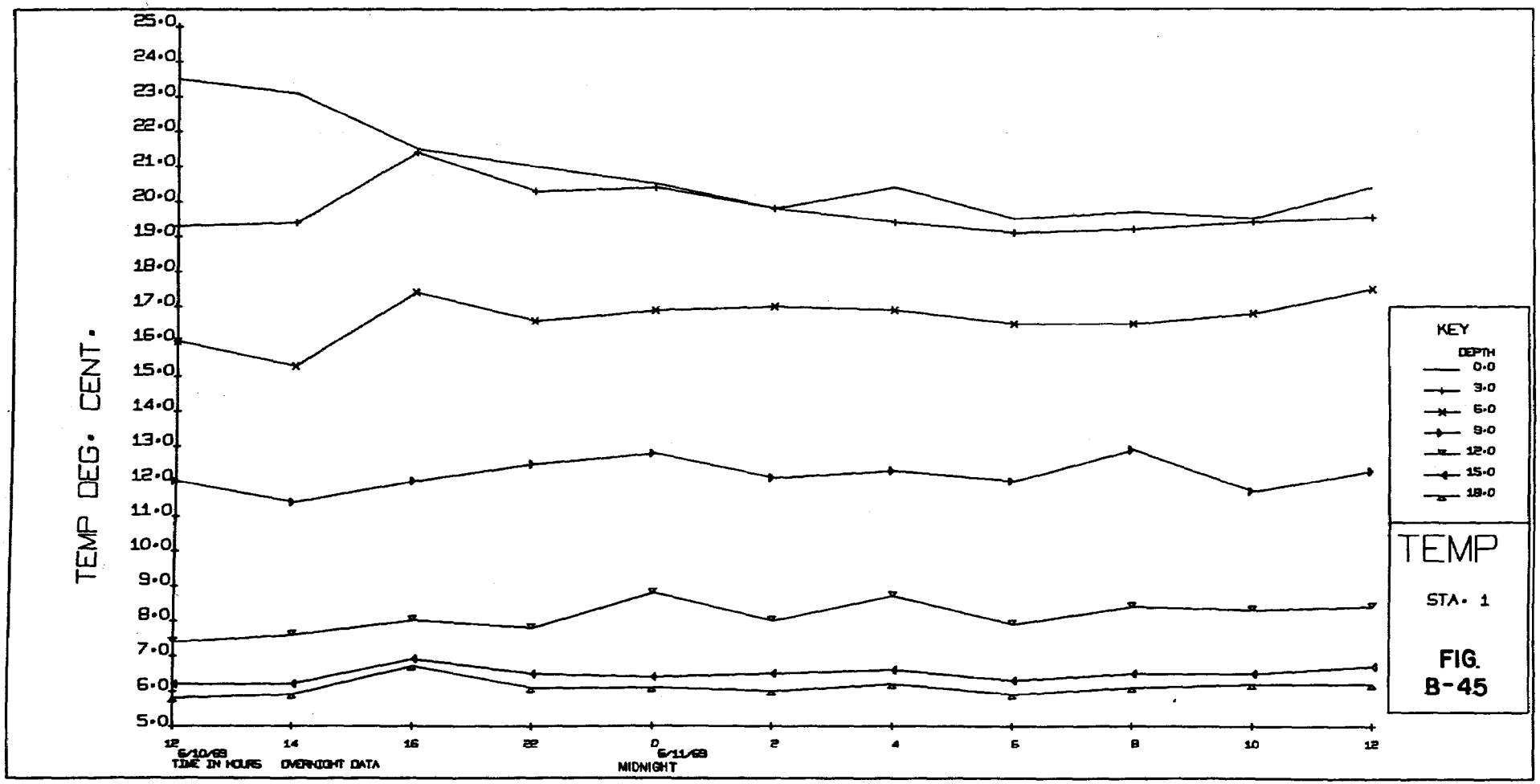

9.00
8.80
8.60
8.40
8.20
8.00
7.80
7.60
7.40
7.20
7.00
PH
12
14
16
18
20
22
0
2
4
6
8
10
12
6/10/69
TIME IN HOURS OVERNIGHT DATA
6/11/69
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
PH
STA. 1

FIG.
B-43


240.0
235.0
230.0
225.0
220.0
215.0
210.0
205.0
200.0
195.0
190.0
185.0
180.0
175.0
170.0
165.0
160.0
ALK (PPM)
12
14
16
18
20
22
0
2
4
6
8
10
12
6/10/69
6/11/69
TIME IN HOURS OVERNIGHT DATA
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
ALK
STA. 1
FIG. B-44


TEMP DEG. CENT.
25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
12
14
16
22
0
2
4
6
8
10
12
5/10/68
TIME IN HOURS OVERNIGHT DATA
5/11/68
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
TEMP
STA. 1
FIG.
B-45

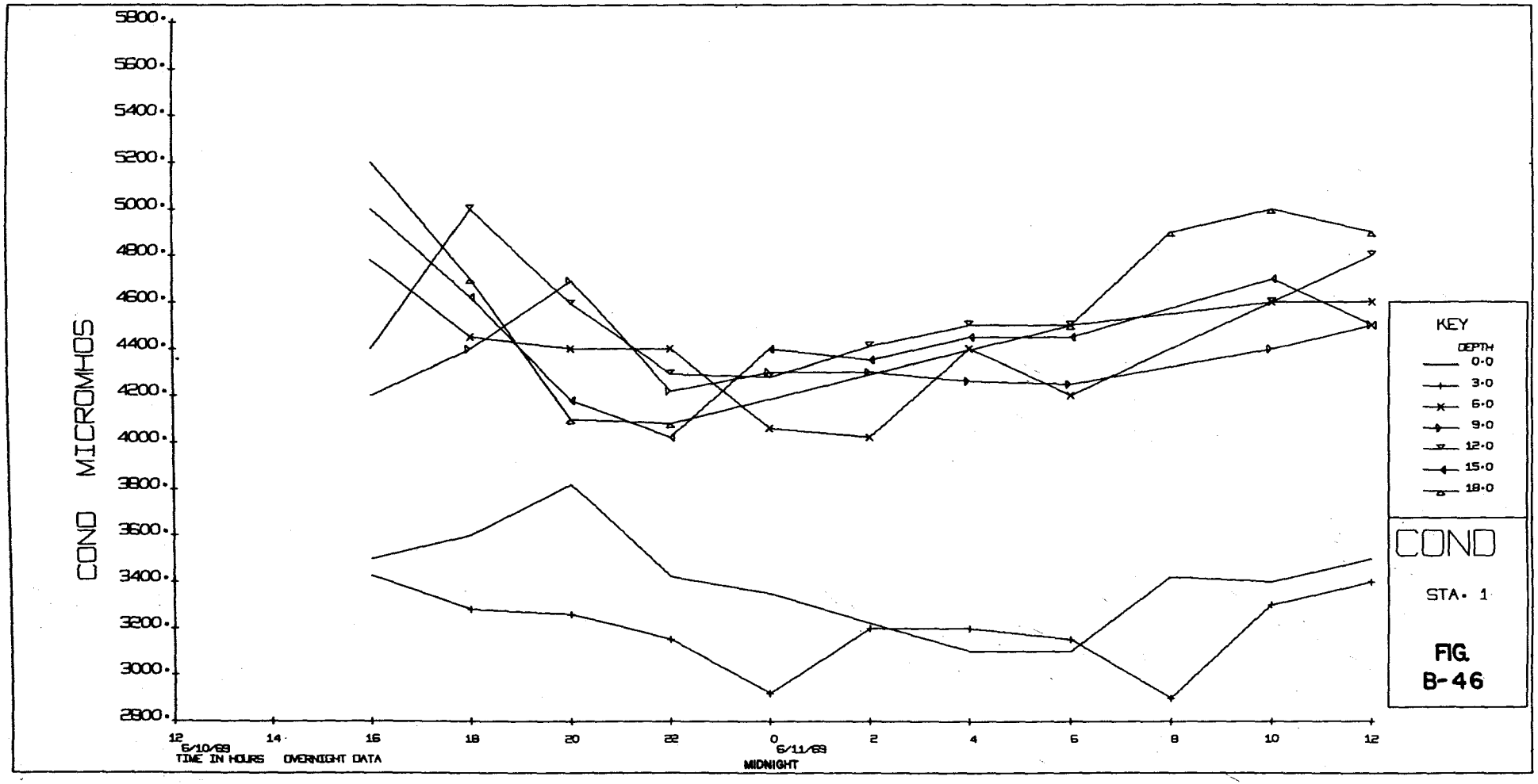
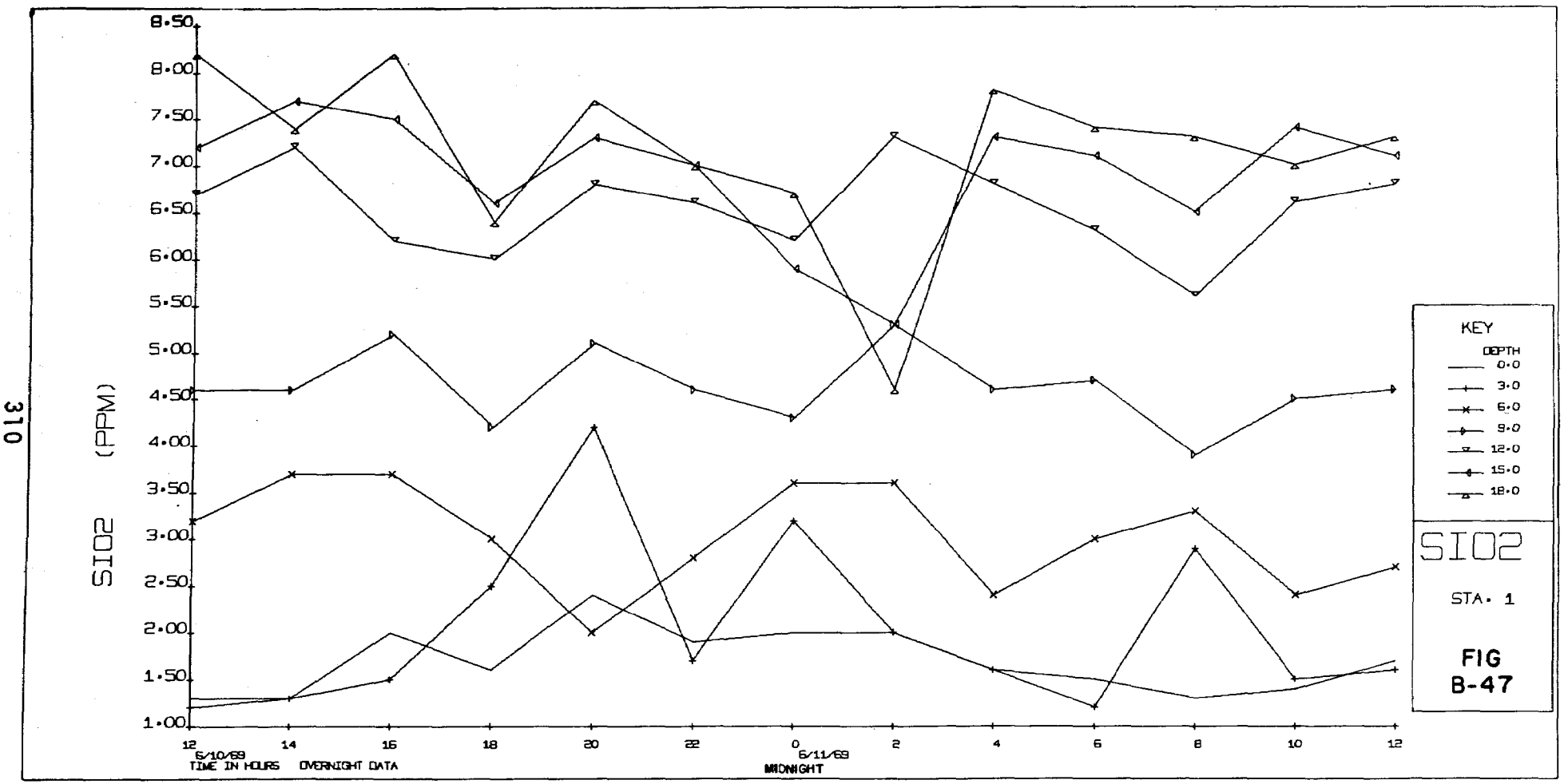

COND MICROMHOS
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
12
14
16
18
20
22
0
2
4
6
8
10
12
6/10/69
TIME IN HOURS OVERNIGHT DATA
6/11/69
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
COND
STA. 1

FIG. B-46


8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
SIO2 (PPM)
12
14
16
18
20
22
0
2
4
6
8
10
12
6/10/69
6/11/69
TIME IN HOURS OVERNIGHT DATA
MIDNIGHT
KEY
DEPTH
0.0
3.0
6.0
9.0
12.0
15.0
18.0
SIO2
STA. 1
FIG
B-47

APPENDIX C

BIOLOGICAL CONSIDERATIONS

by

J. M. Kingsbury & P. Sze

This Section deals with the details of phytoplankton, zooplankton and ichthyological investigations of Onondaga Lake. Methods and results are included in their respective Sections.

Figure numbers for the Section on phytoplankton investigations refer to figures prefaced by a C under this Appendix.

INTRODUCTION

Previous Studies

Prior to 1968 when this Study was initiated, published and unpublished observations on the phytoplankton of Onondaga Lake were scattered and often obtained incidentally to other studies. In nearly all cases, identity of organisms was recorded only in general terms. Thus, for example, Jackson (1968) noted that blooms of green algae (Chlorophyta) and euglenoids (Euglenophyta) have occurred during late June and early July in the Lake since 1962. Miscellaneous observations during the summer (June to early October) of 1963 by Onondaga County (unpublished) indicated that members of the Chlorococcales were common, particularly Chlorella and Scenedesmus. The diatom Melosira is mentioned as predominant at times. During 1964-65, the Syracuse University Research Corporation (SURC) studied the Lake for the Onondaga County Department of Public Works (results unpublished; final report, 1966). Flagellates (Lepocinclis, Chlorogonium and Chlamydomonas) were common from May through early July, with the maximum concentration of algae for the year occurring in June. Pennate diatoms (Pennales) and coccoid greens (Chlorococcales) were present from July through September, being then followed by centric diatoms (Centrales). Little else was known of the seasonal succession of algae in the Lake.

The most recent observations were made from May through October 1967 by Jackson (1969). He sampled the lake on six dates at two locations and measured the following: (a) "Productivity rates." Photosynthesis and respiration were measured using a Warburg Apparatus. (b) "Quality of the standing crop." Cell counts were made of dominant genera using a Sedgwick-Rafter counting chamber and a Whipple Disc. Unfortunately, no species were identified. The results are summarized in Table C-1. (c) "Quantity of standing crop." Dry weight was used as a measure of the standing crop of phytoplankton, but it is not clear how zooplankton and detritus were separated from the algae for the determination.

TABLE C-1

Dominant Genera in 1967 (Jackson, 1969)

May 15th	-- Chlamydomonas, Lepocinclis, Chlorogonium
June 12th	-- Chlamydomonas, Scenedesmus, Chlorella
July 17th	-- Scenedesmus, Chlorella
August 15th	-- Chlorella, Cyclotella, Scenedesmus
September 11th	-- Cyclotella, Stephanodiscus, Chlorella
October 16th	-- Cyclotella, Stephanodiscus

In his survey of the diatoms of Western New York State, Hohn (1951) included diatoms from Onondaga Lake, but his data consist of no more than a list of species. As an outgrowth of this survey, Hohn (1952) described a new variety (var. radiatus) of Coscinodiscus subtilis from the Lake.

In the laboratory, Jackson (1968) attempted to determine the potential for algal growth in Onondaga Lake. He used several concentrations of filtered Lake water as culture medium for various test algae obtained from the Indiana University Culture Collection.

Most notable in light of the results presented in our Study is the apparent absence of colonial and filamentous blue-green algae (Myxophyceae) in earlier reports.

Although Anabaena was occasionally found in the Onondaga County collections, nothing is said about either Polycystis (Microcystis) or Aphanizomenon. Absence of blue-green blooms was noted by Jackson (1968) who speculated why members of the Myxophyceae were unsuccessful in Onondaga Lake on the basis of his results with filtered lake water. Similarly, SURC was concerned with the paucity of blue-green algae in Onondaga Lake and concluded: "It seems evident from our studies that the major elements are not limiting for algal growth in Onondaga Lake but rather that the saline elements in the lake combine to create conditions which are inhibitory to the growth of those types of algae which contribute to troublesome blooms in eutrophic lakes."

METHODS

1. 1968 Phytoplankton Observations.

During the preliminary phase of the Onondaga Lake Study (1968), various locations on the Lake were sampled using a No. 20 net. The purpose of work in the preliminary phase was to select sampling stations, to compare various sampling techniques and to get a general picture of the phytoplankton. When appropriate, these observations have been combined with detailed data for 1969. No quantitative data from 1968 were used, as cell counts were made for the purpose of developing facility with the filtering technique and cannot be translated to an equivalent basis for comparison.

2. Collection of Samples.

During 1969, Onondaga Lake was sampled regularly at five stations. The two main stations, designated North-Deep and South-Deep, were at the deepest points in the north and south basins respectively. Samples for quantitative analysis were taken at the surface and selected depths. Supplementary stations for surface samples were placed near the mouths of Ley Creek and Nine Mile Creek and at the Lake Outlet to the Seneca River (Figure 1). All stations were located by sighting on landmarks. During January, February, March and December, the deep-water stations were sampled twice a month; no sampling was done at the other stations except in December. During the remainder of the year, sampling was weekly at all five stations. Bad weather in October and November caused modification of the sampling program.

At the North- and South-Deep Stations, samples were taken at depths of 0, 3, 6 and 12 meters. A surface sample was collected in a plastic pitcher from which 50 ml of lake water was carefully measured into a graduated cylinder and preserved with Acid Lugol's.[11] (Prescott, 1964). Subsurface samples were collected by means of a VanDorn Bottle or Kammerer Bottle and 50 ml of each was preserved. An integrated sample of the top 0.6 meter was taken by lowering vertically a plastic tube to the desired depth -- the lower end at 0.6 m. and the other

[11] Some samples were preserved with 3% formulin.

end sticking above the surface -- and then closing the ends with rubber stoppers. After mixing the contents of the tube, 50 ml of water was measured off and preserved. Often duplicate samples were collected.

The three inshore stations were sampled using a pitcher to collect surface water, as already described for the deep-water stations.

During 24-hour periods on June 10/11 and July 29/30, samples at 0, 3, 6 and 12 meters were collected every 4 hours at the South-Deep Station.

3. Net Samples and Qualitative Observations.

At the same time that unconcentrated 50 ml samples were collected, as described above, vertical and horizontal net hauls were made with a No. 20 net. These samples were either preserved with formulin or returned to the laboratory unpreserved. The samples concentrated by the net were used for identifying algae and for initiating unialgal cultures. Identifications were made of recently preserved or living cells, and a list of organisms present in each net haul was prepared without any attempt at quantification.

4. Filtering and Quantitative Observations.

Quantitative observations on the phytoplankton were made using a modified version of the procedure of DeNoyelles (1968) for staining, filtering and counting cells. Upon return to laboratory, the 50 ml samples of Lake water (with a known volume of preservative) were stained with 0.5 ml of 1.0-1.5% Aniline Blue solution. After allowing approximately 24 hours for viable cells to stain, an aliquot (0.6, 1.0, 2.0 or 4.0 ml) was withdrawn from each sample with a syringe and filtered through a 0.8 micro Millipore Filter (AAWP 013, 0.8 micro, white, plain, 13mm). The volume filtered depended upon the amount of matter (detritus and plankton) in a given sample. Filters were mounted in Einschlussmittel W15 (Carl Zeiss), which made them semitransparent and permanent. Later cells of major species present were enumerated by superimposing a Whipple Disk Micrometer over a filter. The area of the filter counted for each species depended on the abundance, size and arrangement (colonial; filamentous, etc.) of the cells. Cell counts, along with volume of Lake water filtered and area of filter used for counting, were recorded directly on a coding form, and an IBM 1130 Computer was programmed to transcribe the raw data into cells per milliliter.

Note On Taxonomy and Nomenclature.

Identifications of genera were based on G. M. Smith's The Fresh-water Algae of the United States, (1950). Algae of the Western Great Lakes Area by G.W. Prescott (1962) was the principal reference for determining species, excluding diatoms and desmids. For diatoms, The Diatoms of the United States, Vol. 1, by R. Patrick and C.W. Reimer (1966) or Das Phytoplankton des Susswassers, Diatomeen (1962) by Huber-Pestalozzi was used. Desmids were identified with Fr. Irenee-Marie's Flore Desmidiale de la Region de Montreal (1938).

Nomenclature throughout this Report consistantly follows the authorities used for identification. Confusion may result in the case of the colonial blue-green alga commonly called "Microcystis". We are using the designation "Polycystis aeruginosa".

For convenience, members of the classes Chlorophyceae, Bacillariophyceae, Dinophyceae and Myxophyceae are referred to as the greens, diatoms, dinoflagellates and blue-greens respectively.

The word "pulse" is used in a general sense to mean any distinct peak on a graph.

January 14, 30; February 14, 19; March 5, 19.

During the first two months of 1969, the lake was covered with 15 to 30 centimeters of ice, except at places along shore near warm discharges. Snow or rain collected at times on the frozen surface. In March the ice broke up, beginning at the southern end, so that by the second half of the month the southern basin was free. Few phytoplankters were collected during this three-month period. Water temperatures ranged from 0 to 3° C. There was no reason to believe major nutrients (PO_4, NO_3, NH_4) were limiting.

April 4, 9.

Although there was no detectable change in the phytoplankton counts, net hauls revealed an increase in pennate diatoms and Chlamydomonas sp. The lake at this time was free of ice at the deep-water stations.

April 16, 23.

Chlamydomonas sp. dominated the phytoplankton, being more abundant in the northern basin (Figures 4 and 5). Common diatoms included Navicula sp., Amphiprora alata and Nitzschia sp.

April 30.

Chlamydomonas sp. (Figures 4 and 5) and the diatoms were considerably reduced from the levels of the previous two weeks.

May 7.

Dominant species were Synura uvella (Table 5) and Cyclotella glomerata, with Chlamydomonas sp. and Diatoma tenue also common.

May 14.

Synura uvella was drastically reduced while Cyclotella glomerata had increased over the previous week's level. The diatom was more abundant in the 3 and 7 m samples than in

surface samples, and appeared in greater numbers at the northern stations. Diatoma tenue (Figures 7 and 8) had increased over its level of May 7, and displayed a distribution similar to Cyclotella. Chlamydomonas sp. (Figures 4 and 5) was very reduced. Other diatoms of moderate importance were Synedra ulna, Nitzschia sp. and Amphiprora alata. Chlorella vulgaris and Scenedesmus sp. were also present, particularly at the North-Deep.

May 21.

All species were greatly reduced. Cyclotella glomerata was practically gone. Diatoma tenue was common in surface samples from the northern basin, (Figures 7 & 8). On this date and May 27, Chaetoceros sp. was collected in the northern basin.

May 27.

Synura uvella reappeared in surface and 3 m samples. Diatoma tenue continued its increase. As before, this diatom was commoner at the northern stations. Cryptomonas ovata, collected in small numbers throughout the lake on May 21, was now common. Also present was Carteria sp.

June 4.

On this date the diversity of phytoplankton was high, particularly at the outlet. The presence of a few cells of a number of species was seen more clearly in net samples than filtered samples. Diatoma tenue and Cyclotella bodanica were dominant. Diatoma reached its maximum abundance at the surface but was noticeably reduced at Ley Creek and Nine Mile Creek (Figures 7 and 8). Similarly Cyclotella bodanica was abundant at surface with a higher count at the South-Deep than North-Deep. Cells of Cyclotella glomerata, Nitzschia sp. and Melosira virans were common, but in lesser numbers. Also present were greens of the Order Chlorococcales, and at the outlet, colonial and filamentous blue-greens appeared. Associated with the high level of diatoms was a drop in silicate. Some diatoms had fungal cells attached to their frustules. The parasites were not identified but probably were chytrids (Chytridiales).

June 10/11.

Diatoma tenue was greatly reduced from its peak abundance of the previous week (Figures 7 and 8). Cells appeared unhealthy,

sometimes with epiphytic fungi. Chlamydomonas sp. dominated the phytoplankton with greater than 10 cells/ml at the North-Deep (Figures 4 and 5). Chlorella vulgaris was common at the North-Deep. Also present were Nitzschia sp., Cryptomonas ovata and Scenedesmus sp.

June 18.

Chlamydomonas sp. continued to dominate (Figures 4 and 5). Chlorella vulgaris (Figures 10 and 11), Scenedesmus obliquus (Figures 13 and 14), Scenedesmus quadricauda (Figures 16 and 17) and Cyclotella glomerata were also abundant. Oocystis Borgei was present but less common. Diatoma tenue was practically gone.

June 25.

Common species were Chlamydomonas sp., Scenedesmus obliquus, S. quadricauda and Chlorella vulgaris; none was dominant. Vertically, the phytoplankton were common in the 3 m samples. In general, these species were more abundant at Nine Mile and the outlet than at other stations.

July 2.

Chlorella vulgaris (Figures 10 and 11), Scenedesmus quadricauda (Figures 16 and 17) S. obliquus (Figures 13 and 14) were dominant at the deep-water stations and Nine Mile, but an unusually large number of other species were also found, particularly at the outlet. Chlamydomonas sp. was very reduced (Figures 4 and 5). The level of phytoplankton at the Ley Creek Station was very low compared to the rest of the lake. Aphanizomenon flos-aquae was common at Nine Mile; Pediastrum Boryanum, Melosira granulata and Coscinodiscus subtilis at the outlet. Oocystis Borgei was found throughout the lake. During the summer rotifers and copepods did not appear to ingest algae, but Daphnia often had its gut filled with cells of Chlorella.

July 9.

Chlorella vulgaris and Scenedesmus obliquus were dominant, with Scenedesmus quadricauda common, but reduced from its level of July 2 (Figures 16 and 17).

July 16.

Scenedesmus obliquus had declined (Figures 13 and 14), particularly at the North-Deep, while Chlorella vulgaris continued dominant (Figures 10 and 11). Cells of Chlorella from 12 m had a "wrinkled" appearance. This characteristic was observed generally in deep samples during most of the period of occurrence of the species.

July 23.

Chlorella vulgaris dominated the lake plankton (Figures 10 and 11), but Polycystis aeruginosa was abundant at the outlet (Figure 22). Also common at this station was Coscinodiscus subtilis.

July 30.

The algae were noticeably reduced, particularly Chlorella vulgaris (Figures 10 and 11). Unhealthy looking cells were found at 6 and 12 m but were largely absent from the surface waters.

August 6.

Chlamydomonas sp. was dominant at all stations except the outlet (Figures 4 and 5). This flagellate was particularly abundant in the southern basin. Blue-greens, Aphanizomenon flos-aquae (Figures 19 and 20) and Polycystis aeruginosa (Figure 22), were the major species at the outlet. For the first time, Aphanizomenon was collected at all stations. Chlorella vulgaris was abundant at the deep-water stations (Figure 10). Coscinodiscus subtilis was common at the outlet.

August 13.

Chlamydomonas sp. was reduced but still common in the southern basin and at Nine Mile (Figures 4 and 5). Once again, Chlorella vulgaris dominated (5×10^4 cells/ml) except at the outlet (Figures 10 and 11). Polycystis aeruginosa dominated at the outlet (3×10^4 cells/ml) and Aphanizomenon flos-aquae was common at the outlet and North-Deep (Figures 19, 20 and 22).

August 22.

The level of algae was reduced from that of August 6 and 13. The greens were predominant in the southern basin while the

blue-greens dominated in the northern suggesting a transition was occurring in the lake. Chlamydomonas sp. was common at Ley Creek (Figure 5), and Chlorella vulgaris at both southern stations (Figures 10 and 11). At the outlet and Nine Mile, Polycystis aeruginosa was common (Figure 22), along with Aphanizomenon flos-aquae (Figure 20) and Anabaena circinalis (Figure 23) at the outlet.

August 27.

The blue-greens dominated the lake phytoplankton, having replaced the greens. Chlorella vulgaris continued its decline while Aphanizomenon flos-aquae was the dominant form (Figures 19 and 20). Also common were Polycystis aeruginosa, which was very abundant at the outlet (10^5 cells/ml), and Anabaena circinalis confined to the northern basin.

September 3.

Aphanizomenon flos-aquae continued its increase, with filaments primarily in the surface and 3 m samples (Figures 19, 20 and 21g). Chlamydomonas sp. was abundant at Ley Creek, where the blue-green was unimportant (Figure 5). Polycystis was abundant at Nine Mile and the outlet (Figure 22), with Pediastrum duplex and Pediastrum simplex common at the latter. Melosira granulata was fairly common at the North-Deep and Nine Mile (Figures 24 and 25).

September 10/11.

Melosira granulata, a diatom, replaced the blue-greens as the dominant form (Figures 24 and 25). Cells collected at the South-Deep on September 10, were most abundant vertically at the surface while the collections of September 11, at the North-Deep had the highest level of cells at 3 m (Figure 26 b). Aphanizomenon flos-aquae followed in abundance, being concentrated vertically at 3 m (Figure 21 h). Windy weather may have been responsible for the increase in Melosira and decline of Aphanizomenon. It is likely (see below and Lund, 1954, 1955) that the former depends on turbulence to remain afloat while the latter, which normally floats on the surface due to the buoyant effect of pseudovacuoles (gas vacuoles), was partially blown ashore and partially mixed in the epilimnetic waters. Polycystis aerugionsa, also possessing pseudovacuoles, was common at the South-Deep but scattered throughout the water column.

September 18.

Though still abundant, Melosira granulata was reduced (Figures 24 and 25) and Aphanizomenon flos-aquae was again dominated (Figures 19 and 20). The diatom was unimportant at Ley Creek and the outlet. At the deep-water stations filaments were more abundant in subsurface samples than at the surface (Figure 26c).

Cells generally had fungi (chytrids) attached to the walls. Aphanizomenon returned to its level of September 3. At the outlet, Pediastrum duplex, P. simplex and Fragilaria crotonensis were common. Polycystis was abundant at the South-Deep. This was the first time in either 1968 or 1969 that a desmid, Staurastrum paradoxum, was found in the lake at a station other than the outlet.

September 25.

Aphanizomenon flos-aquae was dominant (Figures 19 and 20). Other common species in the lake were Cryptomonas ovata, Chroomonas Nordstetii, Polycystis aeruginosa and Melosira granulata. M. granulata was abundant in 6 m samples from the deep-water stations (Figure 26d). At the outlet, Pediastrum duplex, P. simplex, Coscinodiscus subtilis, Fragilaria crotonensis and Glendinium pulvisculus were also common.

October 2.

Cryptomonas ovata dominated together with Aphanizomenon flos-aquae. Melosira granulata and Chroomonas Nordstetii continued to be moderately common throughout the lake and Pediastrum duplex, Coscinodiscus subtilis, Fragilaria crotonsis and Glenodinium pulvisculus at the outlet.

October 8.

Cryptomonas ovata was dominant, while Aphanizomenon flos-aquae had declined. Melosira granulata continued to decline.

October 15.

Chlamydomonas sp. was dominant at Ley Creek (Figure 5) and common at the other stations, where Cryptomonas ovata was dominant. At the deep-water stations, Cryptomonas was concentrated at the surface, with 8 X 10^2 cells/ml at the South-Deep and 2 X 10^3 cells/ml at the North-Deep. At the

outlet, Coscinodiscus subtilis, Pediastrum duplex, Pediastrum Boryanum, Fragilaria crotonensis were also common. Melosira granulata was practically gone.

October 23, 29.

The phytoplankton were reduced throughout the lake. Cryptomonas ovata was the most common species with 300 cells/ml. Other less abundant species were Aphanizomenon flos-aquae and Cyclotella glomerata.

November 5/6.

The most common species were Cryptomonas ovata and Aphanizomenon flos-aquae.

November 13.

Cryptomonas ovata was dominant, with 200 cells/ml. Coscinodiscus subtilis, Fragilaria crotonensis (Figure 23) and Asterionella formosa were relatively common at the outlet.

November 20, December 4.

The phytoplankton were further reduced. Cryptomonas ovata was the commonest species with 100 cells/ml. Chlamydomonas sp., Neidium sp., Melosira granulata, Cyclotella glomerata, Cyclotella comta, Fragilaria crotonensis, Coscinodiscus subtilis, Stephanodiscus astraea and Nitzschia sp. were also present. At the outlet, Euglena gracilis and Asterionella formosa were moderately common.

December 18

Thin ice covered the outlet station (no sample). Surface temperatures at the North- and South-Deeps were 2.6° and 2.8° C respectively. No algae were present at the North-Deep. Cryptomonas ovata was the most common species at the South-Deep, Ley Creek and Nine Mile Stations. Also found at these stations were Cyclotella comta, Asterionella formosa and Nitzschia sp.

Summary.

The annual succession of phytoplankton observed in Onondaga Lake during 1969 was generally typical for a eutrophic lake.

The finding of a high diversity of species was not entirely expected in light of the lake's unusual chemistry and earlier observations. With respect to the phytoplankton, the year may be divided roughly into five periods.

The Winter Period lasted from December through March and was characterized by an almost complete absence of algae.

The Spring Period was from April into June. The characteristic species during this time was the diatom Diatoma tenue, but other species showed pulses. Synura uvella and Cyclotella glomerata reached peaks in May while Cyclotella bodanica showed one in early June. Chlamdomonas sp. reached maxima in April and in June, following the peak of Diatoma on June 4.

Chlorella vulgaris, Scenedesmus obliquus and Scenedesmus quadricauda characterized the Early Summer Period, lasting from June to early August. Initially, in June all three species were dominant but S. quadricauda and S. obliquus declined during the first half of July leaving Chlorella vulgaris to reach a maximum in the July 16 and 23, samples. On July 29/30 all samples showed an unexpected paucity of phytoplankton but the following week Chlorella returned. Chlamydomonas sp. had a peak in early August.

The Late Summer Period lasted from August into October. The blue-green algae and Melosira granulata were dominant, with Aphanizomenon flos-aquae important over most of the period. During mid-August a transition was obvious between the Early and Late Summer forms. The former persisted in the southern basin while the latter developed in the northern. Polycystis aeruginosa (Microcystis) showed a sporadic abundance and Melosira granulata a pulse in early September. In 1969, there was no distinct autumn flora. The Late Summer species declined leaving Cryptomonas ovata, present during most of the summer, as the dominant form. Cryptomonas increased slightly to a maximum in mid-October. Chlamydomonas displayed a brief pulse at the same time.

In 1968, a warm period in late September stimulated the reappearance of Chlorella vulgaris and the Autumn Period consisted of a mixture of Early and Late Summer species, with the overall level of phytoplankton declining as the water cooled. There was no distinct diatom flora associated with an overturn either year.

Biomass

Biomass is one of several accepted indices of production in natural bodies of water. In this Study biomass of phytoplankton has been estimated using cellular volume, excluding the wall and sheath. For the 10 major species, cellular

dimensions were measured, and the volume of an "average cell" was determined for each species. The species used were Chlamydomonas sp., Chlorella vulgaris, Scenedesmus obliquus, Scenedesmus quadricauda, Melosira granulata, Cyclotella bodanica, Cyclotella glomerata, Diatoma tenue, Polycystis aeruginosa and Aphanizomenon flos-aquae. For Chlamydomonas, separate calculations were made for spring and summer forms. The total cellular volume per unit volume of water was determined for each date from phytoplankton concentrations in the 0.6 tube samples taken at the deep-water stations. The validity of estimating production by determining biomass hinges on the following assumptions:

a. An average volume for the cells of a given species is applicable over the entire period of abundance. If the average cell size of a species changed greatly during the period, the average volume would not be valid for all dates.

b. The species employed represented the great bulk of biomass present on any given date. The ten species represented nearly all the biomass at the deep-water stations, although the shallow-water stations, particularly the outlet, often had significant counts for a number of species in addition to the ten of overall importance in the lake.

c. Cellular contents are relatively uniform. Inclusions within cells vary in importance from species to species. For example, the centric diatoms have a large vacuole while the vacuole of the green algae is inconspicuous. The greens, therefore, have a greater concentration of protoplasm per unit volume than the diatoms.

d. The physiological condition of cells is representative of a healthy, reproducing population. Active cells of a species tend to divide rapidly and be smaller than quiescent cells (see Stewart, 1968), yet the former are the significant producers. Calculations of protoplasmic volume may give undue emphasis to the latter.

Despite such obvious shortcomings of our method of estimating productivity, we feel the procedure is superior to other standard techniques and reflected best the general situation observed in our samples and in the lake. Estimated

production was high when particular species showed maxima and, in many cases, was associated with noticeable coloring of the lake water.

Maximum production occurred during June, July and part of August (Figure 2). The earlier peak in April was associated with an abundance of Chlamydomonas and the one in May with Cyclotella glomerata. The minimum in late June marked the transition from Spring forms, represented by Diatoma tenue and Chlamydomonas sp., to Early Summer forms, consisting of Chlorella vulgaris, Scenedesmus quadricauda and Scenedesmus obliquus. The precipitous drop on July 30, resulted from a major reduction of algae in all samples and general clearing of the lake. In August and September, estimated production was consistantly higher at the southern station. At other times, both stations were similar. The difference could indicate either actual lesser production at the North-Deep, or the presence at the North-Deep of species not included in the estimate but contributing significantl to production. We believe the former applies, that is, the difference in production was real. Chlamydomonas and Chlorella were responsible for the peak at both stations in early August. Both species were more numerous in the southern basin. The peak in September was associated with Melosira granulata. The final peak resulted initially from a pulse of Chlamydomonas sp. in mid-October and then a combined effect of Chlamydomonas and Cyclotella glomerata during the remainder of the month.

Diversity Index.

During the preliminary phase of the project, we were impressed by the large number of species of phytoplankton in Onondaga Lake. The unusual chemistry of the water suggested an environment which would be inhabited by only a few well-adapted species. This was not the case. The lake showed an obvious seasonal succession marked by a rich flora. We hoped with Margalef's diversity index (Margalef, 1968) to achieve some measure of the variety of phytoplankton in the lake. This index has been derived from information theory and is a theoretical measure of the organization of an ecosystem. The form of the expression used was

$$D = -\sum_{i} Pi \ln Pi$$

where Pi is the number of individuals of species i divided by the total of all individuals. According to Margalef (1968), high diversity reflects high organization, and maximum diversity is also associated with a high degree of stability. For valid application of the diversity index certain criteria are implied:

a. Diversity of organisms is a measure of organization of the entire ecosystem and is not strictly applicable to a component community, such as phytoplankton alone. However, Margalef states that the diversity at the ecosystem level will probably be reflected at the level of major components. This reservation suggests that use of the index to measure diversity in a phytoplankton community should be accompanied by special caution in the interpretation of results.

b. In theory, the diversity index operates in a closet system where the total number of individuals is constant. The distribution of the individuals among the categories is variable. This situation obviously does not exist in Onondaga Lake. Here a succession of forms occurs with the species present on one date not necessarily extant at all on another. In addition, the total of individuals is highly variable.[12]

Plotted values of the diversity index, based on observations from the South-Deep and North-Deep Stations are shown in Figure 3. Maxima occurred in late May-early, July, early August, late August, and late September-early October, at both stations, though not always simultaneously. In all cases, the peaks can be interpreted in terms of effects of specific species on the index. Similar line plots could be presented for the inshore stations. However, the latter probably reflect the flow into or out of the lake in addition to the actual measure of community organization. For example, if the Seneca River was mixing with the lake water at the outlet when a sample was taken, high diversity would not indicate stability. Similarly, rain would tend to increase the flow of the creeks and thus increase the likelihood of attached algae being torn from their substrate and washed into the lake. Thus it does not seem possible to draw useful conclusions from the rise or fall of the diversity index for either the deep or inshore stations.

[12] Wilhm and Dorris (1968) discussed the use of diversity indices to measure water quality.

Chlamydomonas spp.

The species of Chlamydomonas were not distinguished one from another in this Study (except C. epiphytica), because of the complex and highly technical taxonomy of the several hundred known species. It is doubtful whether "forcing" an identification out of one of the available keys would have had any merit. Isolations of Chlamydomonas from the lake have been made and cultures are available for further systematic study. The rather specialized Chlamydomonas epiphytica attaches to the sheath of Polycystis aeruginosa, and its distribution generally follows that of the blue-green. The following discussion does not include data for this species which is treated separately in Appendix B.

Since sampling in 1968 was done primarily with nets, few observations were made of Chlamydomonas, which is normally too small to be retained. The more detailed data for 1969 show pulses of Chlamydomonas spp. in April, June, August and October (Figures 4 and 5). Chlamydomonas acted as an opportunist, with brief maxima between the more sustained developments of the other major species. Chlamydomonas was the first genus to develop in the spring, and it declined during the pulses of Cyclotella glomerata and Synura uvella which followed Its second pulse followed the peak of Diatoma tenue in early June and gave way to Chlorella vulgaris, Scenedesmus obliquus and Scenedesmus quadricauda. When Chlorella temporarily declined at the end of July, Chlamydomonas again displayed a brief pulse, before the coccoid green redeveloped. The final pulse of the flagellate occurred during the decline of Melosira granulata in October. The opportunistic nature of Chlamydomonas is a result of its ability to develop rapidly and, in some instance, to its ability to live heterotrophically.[13] The pulses in August and October were greater in the southern basin, particularly at Ley Creek, and suggest a correlation with domestic waste discharged there.

[13] Heterotrophic nutrition among species of Chlamydomonas is variable, see Danforth (1962).

Following the break-up of the ice at the end of March, Chlamydomonas was the first major species to develop. During the first half of April, many cells were dividing, with daughter cells inside the parent wall. Maxima were reached in April 16-23 at all five lake stations. Cell numbers were greatest at the outlet (Figure 5). At the deep-water stations, cells were concentrated at the surface on April 16 (Figure 6a), but on April 23 (Figure 6b) reached their greatest abundance in the water column at 3 m. The reduction in Chlamydomonas on April 30 was followed by a brief increase on May 7 before the complete decline of the April-May pulse. Chlamydomonas was absent May 21 and 27 when the closely related Carteria sp. was collected in the lake.

The June pulse of Chlamydomonas presented a maximum on June 10/11-18 at all five stations; numbers were considerably lower at Ley Creek than elsewhere (Figures 4, 5 and 6c). The North-Deep appeared to be slightly ahead of the South-Deep both in development and decline of the bloom. At the time of greatest abundance, the lake water was distinctly green, with bright yellow-green bubbles forming wherever the water had been stirred up.

The flagellate was, apparently, held by the surface tension of the bubble. This phenomenon was not observed during the bloom of Chlorella vulgaris and, therefore, proved to be a way of recognizing the presence of large numbers of Chlamydomonas.

After being absent in July, Chlamydomonas pulsed again in early August, reaching a maximum on August 6, (Figures 4, 5, 6d and e). The greatest number of cells (10^5 cells/ml) was at Ley Creek. The development at the outlet was less than at the other stations. Chlamydomonas declined over the remainder of the month, but on September 3, increased at Ley Creek to 4 X 10^5 cells/ml. During August and early September, cell counts were generally greater at the South-Deep than at the North-Deep and this is, in part, responsible for the difference in biomass between these stations (Figure 2).

From September 10 through October 8, Chlamydomonas was found occasionally, but numbers were never significant. Chlamydomonas developed a final pulse around October 15, and declined through November (Figures 4 and 5).

Diatoma tenue

Diatoma tenue was previously reported from Onondaga Lake by Hohn (1951). During the Spring Period of 1969, this diatom was a major species in the lake (Figures 7, 8 and 9). In April, cells were collected in net hauls at the three stations in the northern basin. Cells were not numberous enough to appear in filtered samples until May 7, when cells were present at all 5 stations. The greatest number was at the North-Deep and least number at Ley Creek. No cells were collected from 12 m at either deep-water station, (Figure 9a). In the May 14, samples, D. tenue generally showed a slight increase with cells at the deep-water stations reaching their highest concentrations at 3 m, (Figure 6b). No cells were found at Ley Creek. As was generally the case during the period of occurrence, levels at the North-Deep were higher than at the South-Deep (Figure 7). In the May 21, samples, D. tenue was reduced or showed no increase compared to its levels of May 14, except at the outlet. Overall, the phytoplankton were reduced on this date and the concomitant appearance of Chaetoceros sp. is suggestive of a change in the environmental character of the lake. On May 27, D. tenue again had increased at every station. Cells showed their greatest vertical concentrations at the 6 m level in the South-Deep and at 3 m in the North-Deep (Figure 6d). No cells occurred at 12 m in either location. The diatom reached its maximum for the year on June 4, with 1.8×10^4 cells/ml at the North-Deep. At both deep-water stations, maximum abundance was at the surface on this date (Figure 6e).

Fungal cells were seen attached to frustules on June 4. No positive identification of the parasite was made, but it is likely that it was a chytrid (Chytridiales) and possibly Rhizophidium. Other diatoms also were attacked by fungal cells. Whether the fungus caused the ensuing decline of D. tenue or appeared as a result of the already unhealthy condition of cells is unknown. In the English Lake District, Canter and Lund (1948, 1951) have shown that Rhizophidium planktonicum, a parasite on Asterionella formosa and other diatoms, can delay the occurrence and reduce the level of maxima. On the other hand, Steward (1968) has found that active angiosperm cells resist infection better than inactive cells. Therefore, the fungus may at the start be taking advantage of "weakened" cells of D tenue.

On June 11, D. tenue was noticeably reduced, except at the outlet where it continued to increase (Figures 7 and 8). At the deep-water stations, more cells were found at 3 or 6 m than at the surface, (Figure 6f). During the remainder of June, cells were mainly at 12 m at the deep-water stations and absent at the other stations. This appears to indicate that

cells were sinking following the maximum of June 4. After July 2, when a few scattered cells were collected, the diatom was entirely absent, except for several cells in a vertical net haul at the South-Deep on October 15.

Overall, the spring development of Diatoma tenue was similar at the five stations in the lake (Figures 7 and 8). The levels at Ley Creek tended to be lower than at the other stations, and the maximum at the outlet was delayed a week compared to the rest. Levels at the North-Deep were generally a little higher than at the South-Deep.

The possibility that senescent cells of Diatoma tenue sink deserves further comment. Sinking is not the only possible explanation for the observed distribution. The cells could merely be persisting longer at 12 m than in the upper waters, where competition is greater. However, the low levels of light at 12 m make it unlikely that the large population observed at that depth actually developed there. Secchi disk readings of less than one meter on June 4 and 11, at both stations, suggest a relatively shallow euphotic zone (see Figure 27). If pronounced sinking commenced after the diatom population reached a maximum, this could have resulted from a change in the buoyancy of the cells associated with a changed physiological state, or from a change in external conditions, such as turbulence. Lund (1959) felt that diatoms with silicate frustrules were always heavier than water and, therefore, always tended to sink. He showed (1954, 1955) that the filamentous diatom Melosira italica subsp. subarctica required turbulence to remain suspended in the euphotic zone. With respect to Diatoma tenue in Onondaga Lake, there was no marked change in the wind during the first half of June. The possibility that D. tenue was physiologically unhealthy during the decline is suggested by the presence of the parasitic fungus. Changes in the composition of stored metablolites, especially lipids, or in the contents of the vacuoles are obvious ways in which buoyancy might change.

Chlorella vulgaris

Chlorella vulgaris dominated the phytoplankton populations from the end of June until the middle of August in 1969 (Figures 10, 11 and 12). This coincided with the period of maximum organic production in the lake (Figure 2). Chlorella appeared in the northern basin in early May but was found in the southern basin only after the middle of June, following the decline of Chlamydomonas sp. (Figures 4 and 5), and became clearly dominant in the first samples in July. Chlorella increased to a maximum abundance (10^5 cells/ml) on July 16, at all five stations. It continued at this level of

abundance at the deep-water stations through July 23, but declined earlier at the shallow stations (Figures 10 and 11). During the period of abundance, cells were concentrated at or near the surface (Figures 12 f, g). On July 30, Chlorella was absent from the surface waters at all locations (Figures 10 and 11) and was only found in appreciable numbers at 6 or 12 m at the deep-water stations, (Figure 12h), where cells were in the "wrinkled" condition (discussed below). The August 6 samples showed Chlorella again increasing, though Chlamydomonas temporarily dominated in numbers. By the next week (August 13), Chlorella dominated the phytoplankton populations for a second time and then declined during the remainder of the month. For most of August, concentrations of cells were greater at the South-Deep than the North-Deep (Figure 10); this difference is reflected in the plots of biomass (Figure 2). During September and October, Chlorella was collected but never in large numbers.

The overall pattern of occurrence of Chlorella vulgaris was similar at all 5 stations, though initial development was earliest at the North-Deep (Figures 10 and 11). In July, the increase at the outlet and Ley Creek lagged behind that of the other stations, and, following the maxima in July, the three shallow-water stations declined sooner than the deep-water stations. In 1968, Chlorella presented an additional pulse at the end of September, which lasted into October; this did not occur in 1969.

The vertical distribution of Chlorella at the North- and South-Deeps are interesting. As shown in Figures 12 a, b, for the North-Deep on June 11 and 18, the initial increase of Chlorella developed at the surface. Few cells were at 6 m, just at the top of the thermocline, or 12 m, just below it. On June 25, cells were mostly absent from the surface and concentrated at 3 m (Figure 12 c). Figures 12 a, b, and c show that development in June at the South-Deep was delayed a week compared to the North-Deep and that cells reached their greatest concentration at 3 m. At both stations for most of July, cells were generally most abundant at the surface and distinctly less numerous at 12 m (Figures 12 d, e, f and g). On July 30, cells at the South-Deep were concentrated at 12 m and at the North-Deep at 6 m (Figure 12 h). At the South-Deep on the following week (August 6), the pattern was similar with no cells at 6 m and a large number at 12 m. However, additional cells occurred at the surface (Figure 12) and suggest that a new growth of Chlorella was starting at the surface while cells of the previous cycle were gradually sinking. The pattern at the North-Deep on August 6, shows vertical maxima at 3 and 12 m (Figure 12i) and can be interpreted in similar fashion as the pattern at the South-Deep, with an overlap between the declining and increasing groups of cells.

On August 13, cells reached high concentrations at the surface and at 6 m at the South-Deep (Figure 12j). The vertical pattern at the South-Deep was similar the following week (August 22, Figure 12k). At the North-Deep on August 13 and 22, there was only one distinct vertical maximum (at 3 m, Figure 12j, k). From August 27, through November, Chlorella remained in the Lake at low concentrations.

Cell counts do not readily distinguish the condition of cells as long as they appear alive. However, gross anomalies are sometimes observed. In this investigation, some Chlorella cells were slightly flattened on several sides giving the appearance of a ball which had been squashed by pressing at various points on the surface.

Generally, these cells did not give a positive reaction for starch with iodine (I-KI) solution. Filtering and counting was done within a few days of collection, and it is doubtful that the preservative was responsible for this condition. During July, "wrinkled" cells generally occurred in 12 m samples and not in other samples taken on the same day. On July 30, all cells of Chlorella were "wrinkled". "Wrinkled" cells were observed in deeper samples (6, 12 m) on August 6, but not at the surface, where cells were actively dividing. On August 13, "wrinkled" cells were collected at 6 and 12 m. For the remainder of the year, most cells were "wrinkled".

The abrupt disappearance of Chlorella vulgaris together with general absence of phytoplankton from the surface waters on July 30, was unexpected, since no such clearing was observed in 1968. It is unlikely that either temperature or light was responsible. The lake continued relatively undisturbed by winds. Measured inorganic nutrients showed no change that would be associated with clearing. Reduction in dissolved oxygen on July 30, resulted from the low amount of phytosynthesis by algae and uptake of oxygen by increased bacterial activity. The increase in bacteria, shown by a rise in the coliform counts, may have resulted from the breakup of cells of the previous algal bloom. Predation will be discussed later, but there is no evidence to suggest that grazing by zooplankton reduced the phytoplankton. Aside from effects of unmeasured inorganic or organic nutrients, three explanations exist for the absence of Chlorella which was the only species of consequence at the time:

1. Competition with another species of phytoplankton: Chlorella returned to a dominant position after the decline of July 30. Thus it was not displaced by another species, although Chlamydomonas sp. showed a brief pulse of the flagellate was probably due to

its ability to develop faster than Chlorella and this development may have been favored by an ability to live heterotrophically on the products of bacterial activity. Since no successful competitor appeared, the decrease in population of Chlorella cannot be explained immediately on this basis.

2. Extra-cellular products: Assays were not made for organic compounds secreted or released by the metabolic activities or decomposition of organisms. Thus, the possibility that the water became "conditioned" by such activities cannot be ruled out. The abrupt decline in populations of Chlorella could have been caused either by its own activities in forming autoinhibitory substances or by compounds released by other organisms. According to Pratt (1940) and Pratt and Fong (1940), Chlorella vulgaris, in culture, secretes a substance (later called chlorellin) which retards its further development, and old cells release higher concentrations than actively dividing ones. However, no satisfactory evidence is available to demonstrate growth-inhibition in natural populations of Chlorella, and it is questionable whether the concentration of an inhibitor could reach an effective level in a lake. In the case of inhibitory substances from sources other than Chlorella, the possibilities are almost limitless and the source need not be within the lake. The Bristol Pharmaceutical Plant, for example, is known to discharge antibiotics occassionally into Ley Creek.

3. Processes inherent to the cells: The possibility should not be overlooked that clearing may have been associated with normal functioning of the cells. In studies with synchronous cultures of Chlorella ellipsoidea (review articles by Hase, 1962, Tamiya, 1963), it has been shown that the length of time between divisions is independent of light intensity but varies with temperature. At constant intensity, cells divide more quickly at higher temperature, (within 9-25° C range studied). This shortening of the period of the life cycle implies that cells have less time to build up photosynthetic reserves of starch, which are produced and stored during the "growth phase" and utilized as the cells prepare to divide. Conditions in the lake in

July were perhaps optimal for the turnover of cells. Temperatures at the surface were above 25° C on July 16 and 23, and light probably was saturating. In this situation, cells will be drawing more and more on reserves to make up for the energy they did not have time to store during the growth phase. Eventually, they will "use themselves up" and the whole population will collapse.

The effect of grazing by zooplankton on algae is difficult to determine because ingestion (or intake) must be distinguished from digestion of algal cells. Of the genera of zooplankton in Onondaga Lake, only Daphnia was seen with ingested algae. In the case of other zooplankters, intake of algal cells was not observed, though the possibility cannot be overlooked in light of their known feeding habits. Daphnia ingested green algae, and cells of Chlorella vulgaris appeared either macerated or intact within the guts (during July and August). The maceration of cells need not imply that they are being digested; it may merely be a physical effect of passing through the gut. No other species of algae were recognized in gut contents.

Of interest in connection with grazing on Chlorella vulgaris by zooplankton is a study by Ryther (1954), involving cultures of this algae and Daphnia magna. He found that secretions of Chlorella inhibited the activities of Daphnia and that actively dividing algal cells had a smaller inhibitory effect than did senescent ones. Ryther suggested that the inhibitory substance was chlorellin, known from the work of Pratt to be a self-inhibiting secretion of Chlorella (see above). He further observed that cells could pass through the animals' guts and remain viable. No firm conclusion can be drawn regarding the importance of predation on Chlorella in Onondaga Lake without further experiments.

Scenedesmus obliquus and Scenedesmus quadricauda

Six species of Scenedesmus were found in Onondaga Lake during 1968-1969, but only S obliquus and S. quadricauda were abundant at any time. Both species were associated with Chlorella vulgaris, although reaching maxima slightly earlier in July.

Scenedesmus obliquus was first collected on April 20, at the North-Deep. Its occurence in the lake until June 11, was irregular, and cells were relatively uncommon. On June 11, there was a noticeable increase of S. obliquus at the stations in the northern basin, while a similar increase at the South-Deep occurred the following week (Figures 13 and 14).

For the remainder of June and the first half of July, this alga was common at all stations except Ley Creek and, at the deep-water stations, tended to be concentrated in the water column at 3 or 6m (Figure 15). S. obliquus was declining on July 23, and practically gone on July 30, (Figures 13 and 14). From August through October, cells were relatively uncommon. In contrast to the other stations, S. obliquus never became common at Ley Creek, except for a minor pulse on July 23. The overall patterns at stations other than Ley Creek were similar. The drop at the Outlet on July 2, was probably due to inflow of water from the Seneca River. This "reversal" of flow was indicated by the presence in the sample of a number of species not found elsewhere in the lake, and a temporary reduction in the levels of lake species at the outlet (see Chlorella vulgaris, Figure 11).

Scenedesmus quadricauda was collected from mid-April through October (Figures 16 and 17). It became common in June at all stations except Ley Creek and reached maxima at the four stations in late June or early July. Cell numbers declined through July, but, in early August, there was a second, short pulse, after which S. quadricauda was uncommon. Its vertical distribution at the deep-water stations during the period of abundance was variable (Figure 18) but the small number of cells involved makes it difficult to separate statistical variability from actual fluctuations in populations. It appears that cells were concentrated at the surface on June 18, (Figure 18a) and at 3 m on June 25, (Figure 18b). During the maximum (July 2), cells were most abundant at the surface at the South-Deep but at 6 m at the North-Deep (Figure 18c). On July 9, cell numbers had declined, and cells were concentrated at the surface (Figure 18d). On subsequent dates, cells were scattered throughout the water column (Figure 18 e and f).

Blue-green Algae: Polycystis, aeruginosa, Aphanizomenon flos-aquae, Anabaena flos-aquae and Anabaena circinalis

Polycystis (Microcystis) aeruginosa, Aphanizomenon flos-aquae and Anabaena spp. are generally considered among the seriously troublesome algae. Blooms of these forms have aroused concern in many lakes because they are obvious to the casual observer, often diminishing the recreational appeal of a lake, and because they have been implicated in the deaths of animals, such as fish and cattle. At times, blue-greens increase to such an extent that the water is colored bright green and parts of the shore, where they accumulate, have the appearance of green paint. The increase may be quite sudden.

All three types mentioned above form extensive aggregations of cells. Gas vacuoles (pseudovacuoles, discussed below) contained within the individual cells give them buoyancy, and the aggregations accumulate at or near the surface of the water. Thus they become noticeable when an equivalent bloom of a non-floating algae might not.

Blue-green algae may be responsible for the deaths of vertebrate animals in three ways (Fogg, 1962a; Prescott, 1968):

1. Toxins released by the algae: Laboratory studies by Gorham (1962) have shown that Polycystis (Microcystis) aeruginosa and Anabaena flos-aquae form substances toxic to mammals, (Schwimmer and Schwimmer, 1968).

2. Products of algal decay: Following a bloom of blue-green algae, their cells break down in the water. The products of decomposition are in some cases toxic, particularly protein derivatives.

3. Depletion of oxygen by the algae: Blue-green algae produce oxygen by photosynthesis only during the day. At night, they utilize oxygen dissolved in the water to meet their respiratory requirements. A massive bloom thus may reduce the level of dissolved oxygen at night to the point that fish are killed.

Four species of planktonic blue-greens are discussed in this Section. Aphanizomenon flos-aquae, Anabaena circinalis and Anabaena flos-aquae are filamentous, while Polycystis (Microcystis) aeruginosa is an aggregation of spherical cells held together in mucilage. Other blue-greens were found in the lake but only these four were ever common in the plankton.

Blue-greens appeared in July but were found in significant numbers only after the greens declined. They dominated the phytoplankton during August and September then declined through November. This pattern held for both 1968 and 1969, but the overall numbers were greater in 1968, when Polycystis aeruginosa, Aphanizomenon flos-aquae and Anabaena flos-aquae were the major species. In 1969, Aphanizomenon was again abundant but Polycystis was less common than in 1968. Anabaena flos-aquae was uncommon in 1969, having been found in lesser abundance than a fourth blue-green, Anabaena circinalis, which itself was never present in great amount.

In 1969, Aphanizomenon flos-aquae developed earlier at the outlet than at the other stations (Figure 20). Here, although filaments were collected on June 4 and July 2, (also at Nine Mile), an obvious increase did not begin until July 16. Than Aphanizomenon built up steadily to a maximum (10^4 cells/ml) on September 3. The decline during the next week may be attributable to stormy weather. On September 11, 10^3 cells/ml were present at the outlet. A new increase, more gradual than the first, commenced but was halted in October, possibly by cooling of the water.

At the two deep-water stations, Aphanizomenon displayed a short pulse from August 6 to 13, (Figures 10 and 21). After declining temporarily, it held to a relatively stable level of 10^3 cells/ml at the North-Deep from August 27, through September 25. During October it declined. Cells of Aphanizomenon were, generally, less numerous at the South-Deep, where a maximum occurred on September 3, and then declined gradually.

The pattern at Nine Mile Creek was similar to the North-Deep (Figure 20). At Ley Creek, Aphanizomenon displayed a brief pulse August 22-27 but was uncommon the rest of the time (Figure 20).

Polycystis (Microcystis) aeruginosa was less abundant than Aphanizomenon in 1969. this colonial blue-green displayed a gradient in number from a maximum at the outlet lessening towards the southern end of the lake (Table 2). Polycystis was initially found at the outlet on June 4, and was continuously collected there through November. On July 23, it began increasing (Figure 22). After a temporary drop on July 30, associated with the overall clearing of the lake, this blue-green increased again, reaching a maximum on August 27 - September 3, of 10^5 cells/ml. On September 11, it had begun to decline. At the intermediate station in the northern basin (North-Deep), Polycystis was found from July 2 through October. In addition to a short pulse August 6, the alga was abundant during September, with a maximum of 6×10^3 cells/ml on September 18, (Figure 22). At the South-Deep, Polycystis was collected from the middle of July until the middle of October and was abundant during the first half of September, with a maximum of 4×10^4 cells/ml on September 18, (Figure 22). Overall in September, the counts at the North-Deep tended to be higher than those at the South-Deep. Only a few colonies were collected at Ley Creek, the southern most station, during the entire summer. It is interesting to note that the period of abundance at the deep-water stations came slightly later than at the outlet (Figure 22). The stormy weather on September 10, and 11 seems to be the dividing point, marking the end of the maximum at the outlet and followed by the maximum at the North- and South-Deeps (September 18). One explanation could be that

TABLE C-2

OCCURRENCE IN POLYCYSTIS AERUGINOSA IN 1969

STATION	PRESENT	COMMON*	MAXIMUM
Outlet	June 4 - Nov. 13	July 23 - Sept. 25	Sept. 3
North-Deep	July 2 - Oct. 29	Aug. 27 - Oct. 2	Sept. 18
South-Deep	July 16 - Oct. 15	Aug. 27 - Oct. 2	Sept. 18
Ley Creek	irregular July 23 - Sept. 2	never	never
Nine Mile	July 23 - Oct. 29	irregular	Sept. 3

* Count greater than 100 cells/ml; isolated values ignored.

cells were blown down the lake by wind. But it is also as likely that development was first triggered at the outlet by proper conditions and then spread through the lake.

Anabaena flos-aquae was collected from August into October in 1968 and was common during the second half of August and first half of September. In 1969, filaments were collected from July until October but in nothing like the numbers or regularity of 1968.

Anabaena circinalis was rare in 1968 but, in 1969, was more abundant than A. flos-aquae. Filaments were collected from July 23, through September 25, in the orthern basin (Figure 23). Only on September 3, were they found at the South-Deep.

Pseudovacuoles or gas vacuoles are present in all four species of planktonic blue-greens discussed. Their function is unknown, but it has been suggested that they contain metabolic wastes, are used to shade the cell from solar radiation, or are of primary use for flotation (Fogg, 1941; Fritsch, 1945). Generally, cells with pseudovacuoles float on the surface of the water, although there are instances of layering at an intermediate depth (Lund, 1959). If an algae tends to float on the surface, it is very susceptible to winds. During August, Onondaga Lake was relatively calm, and Aphanizomenon was concentrated at the surface (Figure 21). In September, the winds increased and reduced the population of the blue-green by blowing filaments ashore. Figures 21 for September 10/11, and 18, show that turbulence of the water mixed the remaining cells throughout the epilimnion.

Much has been written about the environmental conditions under which blue-green algae are observed, and it is not our intention to present a review here (see Pearsall, 1932); (Hutchinson, 1967). However, the sodium requirement of certain species deserved comment because of the salinity of Onondaga Lake. In attempting to culture various blue-green algae, Allen (1952) found that some species had requirement for sodium, which was not replaceable by potassium. Further studies demonstrated that Anabaena cylindrica had an absolute need for at least 5 ppm sodium (Allen, 1955). None of the planktonic species of Onondaga Lake show evidence of a sodium requirement, but we have isolated Aphanizomenon flos-aquae from the lake for further experimentation along these lines.

Nitrogen fixation by blue-green algae is reviewed by Fogg (1962) and Fogg and Stewart (1965). Generally, fixation of nitrogen occurs in the absence of other nitrogen sources. It requires an energy source, hydrogen donors and carbon skeletons. Molybdenum is a component of the enzyme systems involved. Of the species

found in Onondaga Lake, only Anabaena flos-aquae had been shown to fix nitrogen (Billard, 1967). Anabaena circinalis may (Hutchinson, 1944, 1967), but there is no evidence that Aphanizomenon flos-aquae or Polycystis aeruginosa can carry out the process. The high levels of soluble nitrogen compounds in the lake create an unfavorable condition for fixing atmospheric nitrogen. The relatively low numbers of Anabaena spp. in 1969 make it doubtful that fixation, if it occurred, contributed significantly to the nitrogen in the lake. It can be concluded that nitrogen-fixation under the present conditions is unlikely. However, if nitrogenous discharges into the lake are reduced, Anabaena flos-aquae already present could increase to the point that its nitrogen fixation would be important in the general fertility of the lake.

Melosira granulata

Melosira granulata is a centric diatom, generally found with its cells arranged in a filament. Hohn (1951), who described other diatoms in Onondaga Lake, did not record its presence. In 1968-69, filaments were collected during most of the year, but the diatom was present in relatively large numbers only in the Late Summer Period, in association with the blue-greens. In 1969, M. granulata displayed a sharp peak of 10^4 cells/ml on September 10/11 (Figures 24 and 25). Except for a slight increase at the end of September, the diatom declined steadily following the maximum. The pattern was similar at all stations, except Ley Creek where an increase did not occur.

With observations from the deep-water stations, it is possible to follow the distribution of Melosira granulata in the water column during September and early October. Cells were present in the epilimnion on September 3, (Figure 26a), but an increase was not observed until September 10/11, following stormy conditions (Figure 26b). At the South-Deep (September 10), the greatest number of cells was found at the surface, while at the North-Deep (September 11) cells were slightly more numerous at 3 m than at the surface. On September 18, M. granulata had declined in numbers, with the greatest concentration of cells at 3 and 6 m (Figure 26c). A week later (September 25) cells were further concentrated at 6 m, except that a new growth of cells was occurring at the surface at the North-Deep (Figure 26d; absence of cells in the count for 3 m at the North-Deep was rechecked). By October 2, there was a similar secondary development at the South-Deep, while they were concentrated at 3 m at the North-Deep (Figure 26f). Cells were not common on succeeding dates.

Lund (1954, 1955) studies the occurrence of Melosira italica subsp. subartica, a winter species in the English Lake District.

He showed that the diatom had a relatively high sinking rate and depended on turbulence to remain in the euphotic zone. He found an inverse correlation between its occurence in the plankton and its abundance on the bottoms of the lakes studied. The vertical distribution of M. granulata during September and early October (1969) in Onondaga Lake suggests that, following their maximum at the surface, cells began to sink. The initial appearance of cells is not explained by the effect of turbulence. On September 3, before the stormy weather, cells were already increasing in the epilimnion (Figure 26a). Possibly, turbulence made the September 10/11 maximum greater than it would have been otherwise, but it is questionable what effect winds could have on the hypolimnetic waters (below 12m). Cells may have been suspended in shallow water. Finally, the general occurrence of Melosira granulata from the latter need not be expected to apply to the former. M. granulata tends to occur in more eutrophic lakes during the summer, often associated with blue-green algae (Pearsall, 1932; Lund, 1954). This is in contrast to M. italica as stated above.

From September 18, through October, M. granulata was parasitized by a fungus, and an argument similar to the one for Diatoma tenue could be made concerning the condition of cells (see discussion for Diatoma).

OTHER SPECIES

Certain species require additional comment for the following reasons:

1. They were moderately abundant for an extended period of time, or
2. They were very common for a brief time, or
3. They were uncommon but their presence in the lake is of special interest.

This Section deals with such species.

Enteromorpha intestinalis

Enteromorpha is generally considered to be a marine "seaweed". Its "normal" habitate is in tidepools and in the intertidal zone along the coast, but it is also found in brackish water away from the ocean. The presence of *Enteromorpha* in Onondaga Lake and its tributaries was known before the present survey (Jackson, 1968; Kingsbury, personal communication). During the summer of 1969, the alga was collected in shallow water on the Solvay waste beds.

Pediastrum spp. (Table 3)

Three species of the planktonic genus *Pediastrum* were collected for relatively long periods of time in Onondaga Lake but were never abundant.

Pediastrum Boryanum was the least common of the three species. It was present at the outlet from June through October, with a maximum of 843 cells/ml on July 2. *P. Boryanum* was collected during June at the North-Deep and irregularly at the other stations.

Pediastrum duplex was collected from June into November at the outlet and North-Deep. At the outlet, maxima of greater than 700 cells/ml occurred on August 27 and September 25. The alga had a scattered pattern at the other stations.

Pediastrum simplex appeared later than the other two species. At the outlet, it was found from July into November, with a maximum on September 18, of 734 cells/ml. It occurred at the North-Deep from August through November and at the South-Deep

from August through November and at the South-Deep from late August through November. It was collected irregularly at Nine Mile and was never found at Ley Creek.

Desmids: Closterium gracile and Staurastrum paradoxum (Table 3)

Desmids have often proved to be valuable as indicator organisms because the presence of certain distinctive species can be related to particular environmental conditions. Desmids tend to be found in waters low in calcium and with acid pH's (Hutchinson, 1967; Prescott, 1968). Prescott (1968) gave their optimal pH range as 5.4 to 6.8. Considering the high levels of calcium and a pH near 8 in Onondaga Lake, the presence of two desmids, Closterium gracile, Staurastrum paradoxum is of particular interest. Although little information is available in the literature on Closterium gracile, Staurastrum paradoxum is reported to occur over a wide range of calcium concentrations (Pearsall, 1932). Closterium gracile was not collected in 1968 and Staurastrum paradoxum only irregularly at the outlet from August through October.

In 1969, Closterium appeared at the outlet in mid-September. It spread to the deep-water stations in early October and was found at Nine Mile the end of October. The desmid was never collected at Ley Creek. Closterium was collected at the outlet, North- and South-Deep Stations until the end of October and at Nine Mile until the middle of November.

Staurastrum paradoxum appeared the end of August (1969) at the outlet. It was found at the North-Deep in mid-September. Only on Oct. 2, was it collected at the South-Deep and was never found in samples from Nine Mile or Ley Creek. Staurastrum declined at the North-Deep at the end of October and at the outlet in mid-November.

Reynolds (1940) has shown that the biradiate and triradiate forms of S. paradoxum occur at different times of the year and that the latter is found in late summer. All cells of Staurastrum collected in 1969 were triradiate.

Although the number of cells never reached a measurable level, both desmids were consistantly found during the periods given for their occurrence in 1969, in contrast to their irregular appearance of 1968.

Synura uvella (Table 4)

During its two pulses in May (1969), Synura uvella dominated

the phytoplankton. The first pulse was on May 7, with the greatest number of cells found at the outlet. The second pulse occurred on May 27, when the greatest number of cells was at the South-Deep.

Cyclotella spp. (Table 3)

Cyclotella glomerata, part of the nannoplankton (not retained by nets) occurred in both spring and fall. In spring, the diatom had two pulses, May 7-14 and June 18-25. During October, November and December, C. glomerata was found in relatively small numbers. This pattern of occurrence leads to two conclusions. First, in both spring and fall, cells developed at the same time at all stations. This suggests that there is a reserve of cells existing all the time in the lake which gives rise to the observed growths under favorable conditions. Second, the occurrence of C. glomerata in both spring and fall suggests that temperature or light is the critical factor for initiation of growth.

Cyclotella bodanica occurred only in spring. It developed a major pulse in early June and a minor pulse in early July.

Cyclotella comta was collected in the fall, when it held a relatively constant level during October, November and December. It was never abundant.

Coscinodiscus subtilis (Table 3)

The type locality for the variety radiatus of Coscinodiscus subtilis is Onondaga Lake (Hohn, 1952). During the summer of 1968 and 1969, cells of Coscinodiscus subtilis were collected which matched the descriptions of Hohn (1951, 1952) for the variety. No comparisons were made with type specimens.

In 1969, Coscinodiscus was collected in the northern basin from the beginning of July into December. Maxima of greater than 500 cells/ml occurred on July 2, July 23, and October 2, at the outlet. The diatom was collected in the southern basin in early July and October (once in November).

Chaetoceros sp.

The genus Chaetoceros is generally considered to be marine, but collections of C. Elmorei have been made in several lakes in North America. In The Fresh-water Algae of the United States (1950), G.M. Smith cites references on the occurrence of the species in Devil's Lake, North Dakota. Rawson and Moore (1944)

collected C. Elmorei in the saline lakes of Saskatchewan. Anderson, Comita and Engestrom-Heg (1955) and Anderson (1958) have described the occurrence of the same species in Lake Lenore and Soap Lake, saline lakes in Washington. Huber-Pestalozzi (1962) summarizes the occurrence of C. Elmorei in Europe.

In Onondaga Lake, a few cells of Chaetoceros were collected in 1969. They were found May 21, 27, and June 4 at the stations in the northern basin. A sample of the Onondaga Chaetoceros, which appears to be a very rare or as yet undescribed species, was sent to Dr. R. Patrick for identification.

Fragilaria crotonensis (Table 4)

In Linsley Pond, Fragilaria crotonensis competes with Anabaena circinalis for phosphate (Hutchinson, 1944). When nitrate is low, the blue-green is favored; when nitrate is high, the diatom is likely to be dominant. A similar interaction may be occurring in Onondaga Lake between the same two species, although neither is as abundant as in Linsley Pond. Figure 23 shows that Fragilaria increased at the outlet when A. circinalis declined after September 3. Although competition for nutrients is dependent on the direction of flow between the lake and Seneca River a reversal of flow could have been responsible for Fragilaria replacing A. circinalis. Further, the stormy weather on September 11, may have reduced the blue-green population (see discussion for Aphanizomenon flos-aquae) and created the turbulence necessary to suspend the diatom (see discussion for Melosira granulata). Neither species was common enough at the other stations to allow a comparison with the outlet.

Fragilaria crotonensis was collected at the stations in the northern basin from August 27, through December 4. It was commonest at the outlet, reaching a maximum there of 700 cells/ml on October 15. The diatom occurred at the South-Deep from September 25, to November 13; it was never observed at Ley Creek.

Dinoflagellates: Glenodinium pulvisculus and Ceratium hirundinella (Table 3)

Although two species of dinoflagellates were collected with some regularity in Onondaga Lake during the summer, neither Glenodinium pulvisculus nor Ceratium hirundinella was ever abundant.

Glenodinium pulvisculus, generally part of the nanno-plankton, was not found in 1968. In 1969, it was collected

at the outlet from the end of July until October. A maximum of slightly less than 200 cells/ml occurred on September 25, through October 2. Scattered collections of Glenodinium were made at the North-Deep and one collection (October 8) at the South-Deep. Cells were never found in samples from Nine Mile or Ley Creek.

Ceratium hirundinella displayed two pulses in 1968. The first pulse occurred during August when the dinoflagellate was observed spreading throughout the lake on successive weeks. On August 8, Ceratium was collected only at the outlet. The next week (August 14) it was found at the other two stations in the northern basin (North-Deep and Nine Mile), as well as at the outlet. A week later (August 20), it was also found at the South-Deep. It was never collected at Ley Creek. The second pulse occurred at the end of September and in early October, only at the North-Deep and outlet.

In 1969, Ceratium hirundinella was not collected as often as in 1968. It never spread to the southern basin in 1969, and its occurrence at the North-Deep and Nine Mile was irregular. Two pulses were recognized at the outlet, the first in late July and early August and the second during the second half of September.

Cyclomorphosis (seasonal polymorphism) of Ceratium has been reviewed at length by Hutchinson (1967). Among the characteristics of the dinoflagellate which show seasonal change, the presence or absence of the fourth horn is most readily determined. Its presence seems to be related to high temperature. During the first pulse in 1969, all individuals possessed a fourth horn. Most of the members of the second pulse had a fourth horn but a few did not.

Cryptomonads: Chroomonas Nordstetii and Cryptomonas ovata (Table 3)

Chroomonas Nordstetii and Cryptomonas ovata are both members of the nannoplankton. They were collected over relatively long periods of time in 1969.

Chroomonas was collected regularly from July into October at the South-Deep, North-Deep and Nine Mile Stations. Concentrations were of the order of 10^3 cells/ml. At the deep-water stations, cells generally were concentrated at the surface and 3 m. At Ley Creek and the outlet, the flagellate was less common and its occurrence irregular.

Except at Ley Creek, Cryptomonas was collected from late May into December. A maximum occurred on October 15, when there were 8×10^2 cells/ml at the South-Deep and 2×10^3 cells/ml at the North-Deep. Cryptomonas occurred irregularly at Ley Creek.

TABLE C-3

PERIODS OF OCCURRENCE OF 14 SPECIES OF PHYTOPLANKTON IN ONONDAGA LAKE DURING 1969 (FOR COMPARISON OBSERVATIONS FOR 1968 ARE INCLUDED FOR 4 SPECIES)

SPECIES	YEAR	OUTLET	STATION			
			NORTH-DEEP	SOUTH-DEEP	NINE MILE	LEY CREEK
Pediastrum Boryanum	1969	6/4-10/29	5/27-7/2	(June 25)	(7/2-9/18)	never
Pediastrum duplex	1969	6/4-11/13	6/11-11/20	(6/4-10/8)	(6/11-9/18)	(7/23)
Pediastrum simplex	1969	7/2-11/13	8/6-11/20	8/27-11/20	(8/27-10/29)	never
Closterium gracile	1968	never	never	never	never	never
	1969	9/18-10/29	10/2-10/29	10/8-11/5	10/29-11/13	never
Staurastrum paradoxum	1968	(8/8-11/14)	never	never	never	never
	1969	8/27-11/13	9/18-10/29	10/2	never	never
Cyclotella bodanica	1969	6/4-11, 7/9	5/27-6/11 (7/2-16)	5/27-6/11 (7/2-16)	5/27-6/18	(6/4-11) (7/16)
Cyclotella comta	1969	(9/25-12/4)	10/2-11/20	9/25-12/18	10/25	9/25-11/20
Cyclotella glomerata	1969	5/7-7/2	5/7-6/25	5/7-7/2	5/7-6/25	5/7-6/18
		10/15*-12/4	10/8-12/4	10/8-12/18	10/25*-11/20	11/13-20**

* No samples at Outlet and Nine Mile on Oct. 3.

** No samples at Ley Creek on Oct. 23, 29, Nov. 5.

TABLE C-3 - Cont'd

SPECIES	YEAR	OUTLET	STATION NORTH-DEEP	SOUTH-DEEP	NINE MILE	LEY CREEK
Coscinodiscus subtilis	1969	7/2-12/4	6/25-11/13	(7/2-9, 10/2-11/20)	(7/2-11/20)	(7/2-10/8)
Fragilaria crotonensis	1969	8/27-12/4	7/28-11/20	9/25-11/13	9/25-12/4	never
Glenodinium pulvisculus	1968	never	never	never	never	never
	1969	7/23-10/2	8/6-9/18-10/8	10/8	never	never
Ceratium hirundinella	1968	8/8-27 9/30-10/7	8/14-27 9/30	8/20	8/14-27	never
	1969	7/23-8/13 9/18-25	8/22 9/18-25	never	8/27	never
Chroomonas Nordstetii	1969	99/11-10/2	7/2-10/15	7/2-10/15	7/2-10/15	(7/2-8/27)
Cryptomonas ovata	1969	5/21-12/14	5/21-12/18	5/21-12/18	5/27-12/18	5/27-12/18

TABLE C-4

CONCENTRATIONS OF SYNURA UVELLA IN SURFACE SAMPLES (X 10^3 CELLS/ML)

DATE	STATIONS				
	SOUTH-DEEP	NORTH-DEEP	LEY CREEK	NINE MILE	OUTLET
April 30	0	0	0	0	0
May 7	3	5	9	6	18
May 14	0	0.5	0	0	0
May 21	0	0	0	0	0
May 27	12	3	0	3	0
June 4	0	0	0	0	0

Light, Temperature and Turbulence

Light, temperature and turbulence in the water column are essentially independent of phytoplankton concentration, although "self-shading" may be critical during a bloom. Light not only is the source of energy for photosynthesis, but its diurnal and seasonal rhythms are used by organisms to time their activities. The concept of critical day length has played an important role in explaining the development of higher plants. However, this idea has been largely overlooked in dealing with algae. Temperature determines the rate of metabolic processes and thus sets the range over which a species can function efficiently. Temperature also determines the stability of the water column. Turbulence suspends relatively heavy cells of diatoms, which would otherwise settle to the bottom (as already discussed). Mixing of the waters also keeps the distribution of cells and nutrients relatively uniform in the epilimnion.

The effect of light is confined to a layer at the surface of a lake, called the euphotic zone. In the euphotic zone, there is more than enough light to allow algae to meet their respiratory needs by photosynthesis. A rough approximation of the depth to which the euphotic zone extends can be made using the Secchi disk. Three assumptions are involved:

1. At the depth the Secchi disk appears, the light intensity has been reduced to 5% of the surface intensity (Hutchinson, 1957).

2. The bottom of the euphotic zone occurs at the depth where the surface intensity has been reduced to 1% (Yentsch, 1962).

3. In penetrating through water, light is reduced in intensity logarithmically (Yentsch, 1962).

Based on these assumptions, Figure C-27 has been constructed, from which the depth of the euphotic zone can easily be determined. For example, if the Secchi disk disappears at a depth of 2 m, the euphotic zone ends at 3.1 m. By this method of approximation, it has been determined that the euphotic zone rarely exceeds 3 m in depth in Onondaga Lake.

The remainder of this Section will be devoted to the interaction of light, temperature and turbulence to create conditions favorable for photosynthesis and algal growth.

Certain generalizations are made about the conditions favorable for the different groups of algae. The greens of the Order Chlorococcales and the blue-greens are assumed to grow best at relatively high light intensities, at high temperatures (20°-25° C) and in relatively calm water. The diatoms are favored by moderate to low light, moderate temperatures and moderate mixing. Four situations will be discussed below:

1. Mixing throughout the water column. In the absence of thermal stratification, mixing by the winds can occur from top to bottom in a relatively shallow lake. The euphotic zone extends only to a limited depth, while mixing occurs to the bottom. If the phytoplankton are being mixed throughout the water column, individual cells spend relatively less time in the euphotic zone and more time at depths where there is insufficient light for photosynthesis. A slight increase in algae was observed with the disappearance of the ice cover. Illumination continued to increase, but this favorable effect was offset by the mixing of winds. In Onondaga Lake, the euphotic zone is relatively shallow (less than 3 m as shown by the Secchi disk). This means a cell may spend a large proportion of its time at intensities too low for net production. With the formation of the thermocline and thus reduction of the depth of mixing in late April, the algae increased noticeably. A similar condition applies in late fall but in reverse -- as the thermocline weakens, the depth of vertical mixing becomes greater. At both times of the year, the unfavorable mixing of algae seems to be more important than the accompanying resuspension of nutrients, which might otherwide be expected to favor algal growth. To say this another way, establishment of a thermocline does not reduce algal growth in the epilimnion, as in oceans and many lakes, because in Onondaga Lake the epilimnion is always nutrient rich. The absence of a phytoplankton increase associated with the times of "overturn" may largely be due to the adverse effect of increased turbulence. Low temperatures may also contribute to holding back growth in the spring.

2. Relative stability in the epilimnion. When the epilimnetic waters are calm, phytoplankton can maintain a relatively constant position in the water column. While diatoms are at a disadvantage because of their heavy walls, lighter genera, such as Chlorella and Scenedesmus, are favored. Layering of algal cells can occur with "sun cells" at the surface and "shade cells" lower in the euphotic zone (Yentsch, 1962). The former are more efficient at photosynthesizing at high light intensities while the latter are adapted to lower intensities. This condition may exist in Onondaga Lake in June and July, when single-celled and small colonial forms predominate. In August, the blue-green algae dominate. Although the cells are aggregated in large masses or filaments, the gas vacuoles concentrate the cells at the surface by their buoyant effect. The existence of a layer of blue-green algae on the surface requires almost total calm. The shading by the blue-greens during a bloom considerably reduces light penetration into the water and creates a shallow euphotic zone. Diatoms, more efficient at the low light intensities than green algae, thus occur below the blue-greens if they can compensate for the absence of turbulence. The single-celled centric diatoms such as Coscinodiscus, have a large vacuole which helps to offset the weight of the wall.

3. Thermal stratification with mixing in the epilimnion. With moderate turbulence in the epilimnion, local depletions of nutrients are prevented and the heavier cells of diatoms can remain suspended. In Onondaga Lake, the epilimnion extends deeper than the euphotic zone. Because of the mixing in the epilimnion, a cell may spend part of the time at low intensities of light, even though the lake is stratified. Species adapted to photosynthesize efficiently at higher intensities will be at a disadvantage relative to species able to photosynthesize with less light. Diatoms will generally be favored under these conditions, as shown by the growths of Diatoma tenue and Melosira granulata.

4. Winter. Under ice, little mixing occurs, temperatures and light are low. Snow or water

may collect on the ice further reducing illumination in the water. Diatoms are the species most likely to develop at reduced levels of light and at low temperatures, but ice cover protects the water from disturbence by the winds, which aids in suspending cells. Therefore, it is not surprising that algae were not found under the ice in Onondaga Lake.

Relationship of Phytoplankton to Water Chemistry

Two approaches have been taken to relate the algae to the chemical environment of Onondaga Lake:

1. Comparison of the phytoplankton with the line plots for different nutrients shows no obvious correlation between changes in the level of any nutrient and algal activity, except silica.

2. The chemical environment of the lake has been compared to the conditions for algal growth in culture, as described in various literature. Culture techniques vary with the investigator and results obtained by one method are not strictly equivalent to results from another or to natural conditions. Generally, algal requirements for a particular chemical species are lower in nature than in culture.

1. Phosphate

Phosphorylated compounds are intermediates in most reactions in cells. On the average, algae contain 10^{-7} µgm of phosphorous/cell (Kuhl, 1962). Cells are able to store phosphorus when it is available, and draw on this store in times of depletion in the environment (Chu, 1943). In culture, good growth is obtained with 0.1 to 2.0 ppm phosphate-phorphorus ($P\text{-}PO_4$); growth is limited by concentrations below 0.05 ppm and inhibited by concentrations greater than 20 ppm (Kuhl, 1962, using the data of Chu, 1942). Chu (1943) observed that the upper phosphate limit for growth was lower with NH_4 as the nitrogen source (2.0 ppm $P\text{-}PO_4$) than with nitrate (8-20 ppm). Rhode (1948) divided algae into three categories in terms of their phosphate requirements for optimum growth:

	$P-PO_4$	
	Lower Limit	Upper Limit
Low P requirement	< 0.02 ppm	< 0.02 ppm
Medium P requirement	<0.02 ppm	> 0.02 ppm
High P requirement	>0.02 ppm	> 0.02 ppm

According to Rhode (1948) Uroglena americana and Dinobryon divergens belong to the group with low phosphorus requirement -- they are inhibited by the addition of 0.005-0.010 ppm $P-PO_4$ to a sample of lake water. Asterionella formosa belongs to the intermediate group, and Scenedesmus quadricauda has a high phosphorus requirement.

The mean concentrations (arithmetic mean) of phosphate-phosphorus in the epilimnion of Onondaga Lake during 1968-69 were 0.94 ppm at the South-Deep and 0.97 ppm at the North-Deep. These values are within the range for optimum growth given by Kuhl (1962). Therefore, it appears that the phosphate concentrations in the lake are sufficient to meet the needs of phytoplankton.

2. Nitrogen

Nitrogen is a necessary component of proteins. Algae utilize both ammonia (NH_4) and nitrate (NO_3) as sources of nitrogen. Chu (1943) found that cultures of various species of algae generally grew in concentrations of nitrogen (nitrate or ammonia) from 0.3 to 13 ppm, with optimum growth between 1.3 and 6.5 ppm. Above 13 ppm, increasing concentrations caused increasing inhibition. Rhode (1948) observed that Scenedesmus quadricauda grew well in cultures with 5 ppm nitrate-nitrogen and poorly with 0.05 ppm. Neither of these investigators used species of blue-green algae which are known to grow well at low nitrogen levels (Pearsall, 1932, Hutchinson, 1967).

In Onondaga Lake, the mean concentrations of ammonia-nitrogen in the epilimnion in 1968-69 were 2.14 ppm at the South-Deep and 1.90 ppm at the North-Deep. Nitrate-nitrogen means were 0.39 ppm and 0.41 ppm for the South-Deep and North-Deep respectively. Nitrite means of 0.06 ppm and 0.08 ppm were observed for the same stations.

The concentrations of ammonia-nitrogen appear to be sufficient to support algal growth throughout the year. Low levels in the epilimnion were observed in July, late August and early

September. Probably, the phytoplankton were responsible for this reduction in concentrations. High values in the hypolimnion probably resulted from the sinking and decomposition of cells. During July, the high pH (8.7) indicated the existence of undissociated NH_4OH, thought to be toxic to organisms (Hutchinson, 1957). However, the bloom of Chlorella vulgaris through most of July showed no signs of being affected by NH_4OH.

Nitrate alone appears to be sufficient to support algal growth from January through July. It was depleted in mid-July and remained at a low level through November. During this period of low nitrate, the nitrogen requirements of the phytoplankton were undoubtedly met with ammonia. Blue-green algae were common during late August and early September when ammonia (and nitrate) were at minimum concentration.

As in the case of phosphate, nitrogen does not appear to be limiting the growth of the phytoplankton.

3. Potassium concentration in the lake fell within within the range for optimal algal growth as determined by Chu (1942).

4. Silica (SiO_2)

The walls of diatoms are composed of "hydrated amorphous silica" Lewin, (1962). Silica dioxide (SiO_2) constitutes 96.5% of the wall which may represent up to 50% of the dry weight of the cell (Lewin, 1962). The silica content depends on environmental conditions and the physiology of the cell. Orthosilicic acid, $Si(OH)_4$, is the probable form taken up by the cell; uptake is an active process requiring the expenditure of energy (Lewin, 1962).

Chu (1942) determined the concentrations of SiO_2 for optimum growth of several diatoms in cultures: Nitzschia palea 9.8-39 ppm, Fragilaria crotonensis 19.6-39 ppm, Asterionella gracillima 9.8-19.6 ppm, and Tabellaria flocculosa 2-19.6 ppm. These concentrations are considerably higher than the concentrations occurring in many lakes where diatoms are known to thrive (Hutchinson, 1957, 1967). In the English Lake District, Lund (1954) estimated that the lower limit for the growth of Melosira italica subsp. subarctica to be 0.6 ppm and that Asterionella and Tabellaria could grow at even lower concentrations.

The mean values for the concentration of SiO_2 in the epilimnion of Onondaga Lake during 1969 were 4.89 ppm at the South-Deep and 4.73 ppm at the North-Deep. In April and May, concentrations in the epilimnion were greater than 7 ppm. The bloom of

Diatoma tenue reduced the levels to 1.8 and 1.5 ppm at the South-Deep and North-Deep respectively (surface values for June 4). During June, July and August, concentrations of SiO_2 gradually increased to approximately 5 ppm, but the bloom of Melosira granulata again reduced the concentrations to 0.8 ppm at the South-Deep and 0.5 ppm at the North-Deep (surface values for September 18). Silica returned to a level of 5 ppm for the remainder of the year. Thus silica (SiO_2) appears to be depleted by blooms of diatoms to a level that it may be limiting to further growth.

5. Metals (Cu, Cr, Zn, Mg, Mn).

In low concentrations, metals are activators of enzyme systems, but at higher concentrations they become inhibitory. Most common species of algae are inhibited by 1-2 ppm $CuSO_4$ (Krauss, 1962). Some algae are sensitive to concentrations as low as 0.03-0.05 ppm Cu (Hutchinson, 1957, using data of Hale). Greenfield (1942) found that phytosynthesis by Chlorella vulgaris was inhibited by 10^{-7} M $CuSO_4$ (0.0064 ppm Cu). However, mutants of Ankistrodesmus braunii are able to withstand 5 X 10^{-5} M (3 ppm Cu) (Kellner, 1955). The mean concentration of copper in the epilimnion of Onondaga Lake was 0.05 ppm in 1969. Thus copper approaches concentrations that may be inhibitory to the growth of some algae.

Hervey (1949) reported that the susceptibility of algae to chromium varied with culture conditions and species. Growth of members of the Chlorococcales was completely inhibited by 3.2-6.4 ppm Cr, euglenoids by 0.32-1.6 ppm and diatoms by 0.032-0.32 ppm. In the epilimnion of Onondaga Lake, the mean concentration of chromium is 0.02 ppm, and at some of the higher levels occasionally observed in the lake, this metal is probably inhibitory to algal growth.

Greenfield (1942) reported that at least 10^{-2} M $ZnSO_4$ (654 ppm) was needed to inhibit photosynthesis by Chlorella vulgaris. Thus zinc is probably not inhibitory in Onondaga Lake where the average concentration in the epilimnion was 0.07 ppm.

Greenfield (1942) observed no inhibitory effect with $MgSO_4$ or $MnSO_4$ on Chlorella vulgaris.

The relatively high levels in the lake of certain metals may be inhibitory to algal growth. Other conditions appear to be favorable for larger populations of algae than those found in the lake. If the level of a metal is acting as a check, its removal or reduction may lead to greater blooms than presently occur.

Grazing

Grazing by herbivorous zooplankters has often been thought to be a significant factor in controlling the abundance of phytoplankton. The effect of grazing on the phytoplankton community of Onondaga Lake should have been most apparent in June, July and August, when the plants reached their maximum abundance and biomass for the year (1969). A comparison of the time plots for the zooplankters with the time plots for dominant species of phytoplankton and with the plots for overall biomass of phytoplankton should give an indication of the extent of feeding by zooplankton on phytoplankton. If grazing is a significant factor in controlling algae, a maximum in phytoplankton should be followed within a week by a maximum in one or more species of zooplankton followed by a drop in the abundance of phytoplankton. In Onondaga Lake, the communities of algae and zooplankton, to the degree they were related, presented peaks and valleys simultaneously. In the absence of a lag a drop in the abundance of phytoplankton cannot be casually associated with an increase in zooplankton. This suggests that interaction between the phytoplankton and zooplankton is less important in determining the abundance of either group than are other environmental conditions acting simultaneously but independently on both communities.

Bioassays

The major objective of the present study was to describe the seasonal succession of phytoplankton. Absence of any prior studies of the phytoplankton through one entire annual cycle indicated that this was the most urgent need. Bioassays, in which algae are grown in lake water enriched in various ways, may provide useful information relating the algae found in the lake with particular factors of the environment. Dr. D.F. Jackson's laboratory at Syracuse University has been conducting bioassay investigations related to Onondaga Lake for an extended period, but results have not yet appeared in a form available for our use.

Current State of Onondaga Lake with Respect to the Phytoplankton

Onondaga Lake undergoes a seasonal succession of phytoplankton typical of a eutrophic lake (see Rawson, 1956). Both the variety of species and the abundance of certain species is impressive. Approximately 100 species have been identified in 1968-69. The dominant phytoplankters show the expected succession for a shallow, nutrient-rich lake: diatoms and

flagellates in the spring, green algae of the Chlorococcales in the early summer, blue-green algae later in the summer, and an association of flagellates and diatoms in the fall. A seasonal pattern can be described for a number of moderately common species. Finally, numerous rare species occassionally appear in the lake.

Biomass is greatest in the lake during June, July and August, when the water is noticeably colored by blooms of greens and blue-greens. In 1969, the blooms were less intense than in the previous year. During the late summer of 1968, masses of blue-green algae were washed ashore, and the bloom persisted through September. The difference between the two years is probably due more to random variation in the algal populations than to changes in environmental conditions.

A "catastrophic oxygen deficiency" occurs in many highly productive lakes at the end of algal blooms (Hutchinson, 1957). In relatively calm water, respiration and decomposition of the cells at the termination of a bloom may greatly reduce the dissolved oxygen (DO) in the water. Prior to the present study, Onondaga Lake usually "cleared" for a brief time each summer. This clearing was associated with a marked drop in DO (C. Wilson, personal communication). The phenomenon disappeared and the DO content of the water dropped to approximately 2 ppm at the surface. It is uncertain whether this clearing can be attributed to the effect of a single population (Chlorella vulgaris) or to the total phytoplankton community. Chlorella vulgaris was the only common phytoplankter at the time.

Jackson's (1969) observations from May through October 1967 agree, in general, with our observations in 1968-69, except that he did not report blue-green algae. The presence of noticeable blooms of blue-greens during the summers of 1968 and 1969 make it surprising that blue-greens were not found in 1967.

We were unable to confirm the observations of Jackson (1969) that Cladophora replaces Enteromorpha near the discharge of the Metropolitan Treatment Plant and thus is associated with high pollution. During July 1969, Cladophora was collected near the marina in Liverpool, (little pollution) while Enteromorpha was found on the waste beds (southern basin). Cladophora seems to require a solid substrate for attachment, while Enteromorpha can grow in the semi-solid substance of the waste beds. The distribution of neither alga appears to be related to pollution.

Onondaga Lake also has unique characteristics. It is more saline than the other lakes in central New York (Berg, 1963).

Although the seasonal succession of dominant phytoplankters suggests a typical eutrophic lake, the composition of the less abundant species shows a trend toward a marine flora. The variety and total number of centric diatoms is intermediate between a typical fresh-water environment and an oceanic condition. The presence of dinoflagellates further supports this tendency. Both groups are considerably more important in the oceans than in fresh water. Most of the centric diatoms and dinoflagellates in Onondaga Lake are fresh water species from genera in which most of the species are marine. Two characteristically marine species of algae were found in the lake: Enteromorpha intestinalis; which seems to thrive, and an unidentified and perhaps previously unknown species of Chaetoceros. Chaetoceros is a genus lacking clearly fresh water species.

ZOOPLANKTON OF ONONDAGA LAKE, NEW YORK

by

G. Waterman

INTRODUCTION

Zooplankton comprise the second trophic level of open water in lakes. As such they reflect some environmental conditions much as the algae. They feed upon algae and bacteria, and in turn are consumed by fish as well as aquatic insects and a few predatory crustaceans. It is difficult to establish their role as a population regulator to the algae, though they undoubtedly have a moderating influence on the extent of algae blooms. However, it is clear that their own population size and relative abundance can be controlled through extensive grazing by fish. It is thus reasonable to expect a lake study to include a general survey of the species composition and abundance of zooplankton, though no previous study has done so.

METHODS

The sampling program as well as processing methods have been designed to reveal approximate density of the abundant forms and presence of rarer species, but gives no information on extremely rare organisms which would require intensive sampling to reveal (cf. Hairston and Byers, 1954).

Weekly samples were taken (less often in colder months) with a 9-inch #20 mesh net, from the same stations as employed in the algal study (Figure C-1). Vertical hauls with known length of tow were made only at stations 1 and 2 (North and South Deeps) and used for counting. Mean sample volume was 115 liters (minimum 76 liters). Horizontal tows from all five stations were evaluated qualitatively.

All organisms were identified from slide-mounted material at a compound microscope, using keys in Edmondson (1959) and J. L. Brooks (1957) as well as careful comparison with material from other lakes, mostly in New York State. One rare rotifer (designated Rotifer B) was not identified owing to its amorphous features and consequent taxonomic problems. The other rotifers (*Brachionus sp.*, *Polyarthra sp.*, and *Asplanchna sp.*) are ambiguous at the species level, hence identified to family only.

Counting was done at a dissecting microscope, using whole samples for sparce organisms, aliquots for abundant ones, in which case single replicate aliquots were always counted, as were replicate samples when available (all but three dates, one station each; cf. Table C-6).

RESULTS

The resultant data are summarized in Table C-5, from which C-28 is extracted to show graphically the behavior of abundant forms. Greater detail, including separate station data is appended in Tables C-6 and C-7 and Figure C-28. The reader is reminded that these data are biological in nature and hence may deviate from statistical reality.

Results for the three rotifers (Keretella hiemalis, Brachionus sp. and Polyarthra sp.) show trend only, because absolute concentrations of such small organisms are not adequately reflected by towed net samples owing to losses through the mesh (Likens and Gilbert, in process, Hall and Copper, in press). Density figures for nauplii and small copepodids are similarly affected, but since in this lake they are almost 100% Cyclops vernalis (see below), we can establish the reliability of their trends by comparison with adults of that species (Figure C-28). It seems reasonable to assume that trends in the density of the three rotifers mentioned are equally unaffected by net sampling losses.

TABLE C-5

ONONDAGA LAKE STUDY

ZOOPLANKTON: MEAN NUMBER PER 100 LITERS*

			Jan		Feb	March	
			14	30	14	5	19
	Cladocera:						
1.	Daphnia similis:	total	1				
2.		with eggs	1				
3.		ripe ovaries					
4.	Daphnia pulex:	total	8	2	1	tr	
5.		with eggs	1	1			
6.		ripe ovaries					
7.	Ceriodaphnia quadrangula						
	Copedoda:						
8.	all copepod nauplii		1	tr			
9.	cyclopoid copepodids		2	5	1	tr	1
10.	Cyclops Vernalis		1	1			
	Rotifera:						
11.	Keratella hiemalis				1		
12.	Brachionus sp.						
13.	Polyarthra sp.						
	Rare spp:						
14	Asplanchna sp.						
15.	Keratella cochlearis						
16.	Filinia longiseta						
17.	Rotifer B						
18.	Chydorus spaericus						
19.	Bosmina longirostris						
20.	Cyclops bicuspidatus thomasi						tr
21.	Mesocylops edax						
22.	Diaptomid copepodids						
23.	Diaptomus sicilis						

* Arithmetic mean of two station means (North & South basin near center), rounded to integers.
Blank space means none present in aliquots counted,
tr = trace

TABLE C-5 - (Cont'd)

	April					May			
	4	9	16	23	30	7	14	21	27
1.									
2.									
3.									
4.				tr	tr			1	tr
5.								tr	
6.									
7.					tr	tr			
8.				1	2	1	1	134	45
9.				tr	1	2	1	2	75
10.	tr			tr			1	3	7
11.						tr		159	
12.				tr	1	36	1,355	32,693	910
13.				tr					
14.				tr	tr	1			
15.									
16.									
17.				2	4				abundant
18.									
19.									
20.						tr			
21.									
22.						tr	tr		
23.				tr	tr			tr	

TABLE C-5 - (Cont'd)

	June				July		
	4	11	18	25	2	9	16
1.		tr	tr	4	20	134	1,708
2.		tr	tr	1	4	12	134
3.			tr	1	4	10	32
4.	2	6	73	98	86	94	52
5.	1	2	1	10	10	4	16
6.				4	10	8	6
7.	129	356	1,180	3,012	3,606	1,488	3,061
8.	1,446	10,262	6,125	5,476	4,402	2,992	4,196
9.	295	1,605	4,749	2,659	616	408	1,404
10.	51	400	949	690	418	517	835
11.	92	71					368
12.	62		34				
13.			tr	220	1,392	540	386
14.							
15.							
16.	416						
17.							
18.							
19.							
20.							
21.							13
22.							
23.							

TABLE C-5 - (Cont'd)

	July		August			
	23	30	6	13	22	27
1.	1,844	1,954	396	3,096	1,608	1,696
2.	31	150	42	30	123	89
3.	56	3	6	33	30	28
4.	54	60	3	89	54	46
5.		10		4	5	2
6.		3			3	
7.	1,912	844	656	1,380	1,649	617
8.	5,364	2,726	440	3,270	2,018	1,044
9.	1,423	268	634	1,072	1,192	294
10.	730	132	134	512	336	114
11.	499	233	126	44	207	451
12.						
13.		14	620	1,781		12
14.						
15.						
16.						
17.						
18.						12
19.						
20.						
21.						
22.						2
23.						

TABLE C-5 - (Cont'd)

	September			October			Nov	Dec
	3	18	25	3	15	29	20	18
1.	666	526	120	3	224	7	88	35
2.	18	16	5	tr	22		21	
3.		38	2	tr	30	3		
4.	84	152	242	3	164	8	848	975
5.		4	81	1	36		252	138
6.			11	tr	18			22
7.	303	2,112	926	8	166		9	
8.	935	1,778	1,694	45	1,641	49	63	44
9.	223	557	413	53	1,604	42	182	45
10.	98	117	110	2	234	1	13	4
11.	724	592	306	33	204	57	1,998	426
12.				7				
13.	2,044	1,649	782	16	3,564	344	97	2
14.		14						
15.							29	
16.								
17.								
18.	18	6						
19.	2							
20.								
21.								
22.			6					
23.								

TABLE C-6

ONONDAGA LAKE STUDY

ZOOPLANKTON: MEAN NUMBER PER 100 LITERS @ EACH STATION*

		Jan				Feb	
		14		30		19	
		S	N	S	N	S	N
	Cladocera:						
1.	Daphnia similis: total	1					
2.	with eggs	1					
3.	ripe ovaries						
4.	Daphnia pulex: total	11	6	4	1	1	
5.	with eggs	1	1	1			
6.	ripe ovaries						
7.	Ceriodaphnia quadrangula						
	Copedoda:						
8.	all copepod nauplii	1		tr			
9.	cyclopoid copepodids	3	2	8	1	1	
10.	Cyclops Vernalis	1	1	1	tr		
	Rotifera:						
11.	Keratella hiemalis					1	
12.	Brachionus sp.						
13.	Polyarthra sp.						
	Rare spp:						
14.	Asplanchna sp.						
15.	Keratella cochlearis						
16.	Filinia longiseta						
17.	Rotifer B						
18.	Chydorus spaericus						
19.	Bosmina longirostris						
20.	Cyclops bicuspidatus thomasi						
21.	Mesocylops edax						
22.	Diaptomid copepodids						
23.	Diaptomus sicilis						

* Arithmetic mean of two samples rounded to integer; total counts or aliquot(s) used from each sample.
Blank space means none present in aliquots counted, tr = trace

TABLE C-6 - (Cont'd)

	March				April											
	5		19		4		9		16		23		30	
	S	N	S	N	S	N	S	N	S	N	S	N	S	N
1.														
2.														
3.														
4.	tr										tr			tr
5.														
6.														
7.														tr
8.											1	tr	2	1
9.	tr		1	tr							tr	tr	1	tr
10.					tr						tr	tr		
11.														
12.												tr	tr	1
13.											tr	tr		
14.												tr	tr	tr
15.														
16.														
17.											2	3	3	4
18.														
19.														
20.			tr	tr										
21.														
22.											tr		tr	tr
23.														

TABLE C-6 - (Cont'd)

	May							
	7		14		21		27	
	S	N	S	N	S	N	S	N
1.								
2.								
3.								
4.					tr	1	tr	tr
5.					tr			
6.								
7.		tr					tr	tr
8.	tr	2		1	268		17	72
9.	1	3	1	1	1	2	126	23
10.			1	1	1	5	8	5
11.		tr			268	50	10	
12.	21	52	224	2,486	44,593	20,793	1,397	422
13.								
14.	1	tr						
15.								
16.								
17.							abundant	
18.								
19.								
20.	tr	tr						
21.								
22.		tr		tr				
23.					tr			

TABLE C-6 - (Cont'd)

	June							
	4		11		18		25	
	S	N	S	N	S	N	S	N
1.			tr	tr	tr	tr	7	tr
2.			tr		tr	tr	1	tr
3.						tr	1	
4.	1	2	3	8	94	52	75	122
5.	1	1	1	3		1	20	
6.								8
7.	204	54	340	371	1,199	1,160	4,321	1,703
8.	1,424	1,469	7,204	13,319	8,677	3,573	6,473	4,480
9.	267	323	503	2,707	3,255	6,243	3,936	1,382
10.	75	27	262	548	980	918	793	587
11.	110	74	54	88				
12.	74	79			67			
13.					tr	tr	152	287
14.								
15.								
16.	87	745						
17.								
18.								
19.								
20.								
21.								
22.								
23.								

TABLE C-6 - (Cont'd)

	July							
	2		9		16		23	
	S	N	S	N	S	N	S	N
1.	35	6	160	109	2,854	561	2,097	1,590
2.	5	4	20	4	155	112	31	31
3.	5	2	17	4	52	13	57	54
4.	41	131	171	16	70	33	103	5
5.	4	16	6	3	23	8		
6.		21	16	1	9	4		
7.	3,790	3,422	1,935	1,040	3,412	2,710	2,055	1,768
8.	2,506	6,298	4,240	1,744	5,739	2,652	5,501	5,227
9.	617	615	555	262	2,301	507	1,598	1,248
10.	167	669	500	534	1,448	220	674	787
11.					619	118	356	642
12.								
13.	1,433	1,351	935	144	540	231		
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.					26			
22.								
23.								

TABLE C-6 - (Cont'd)

	July 30		August 6		August 13		August 22	
	S	N	S	N	S	N	S	N
1.	1,332	2,575	212	579	639	5,553	1,685	1,531
2.		301		85	25	35	217	29
3.	5		5		30	36		59
4.	86	33	5		89	89	59	48
5.	20				9			10
6.	5							5
7.	742	945	123	1,189	1,455	1,304	2,120	1,178
8.	2,749	2,073	350	529	2,438	4,103	2,447	1,589
9.	343	193	1,084	183	560	1,583	2,120	265
10.	96	168	139	128	564	460	435	236
11.	198	268	129	122	88		326	88
12.								
13.	28		863	376	824	2,738		
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								

TABLE C-6 - (Cont'd)

	August		September					
	27		3		18		25	
	S	N	S	N	S	N	S	N
1.	2,884	509	1,084	248	929	122	167	72
2.	144	34	25	12	26	5	4	5
3.	46	9			76		4	
4.	73	18	18	150	189	116	347	137
5.	4				8		140	22
6.							22	
7.	833	401	320	286	1,523	2,700	888	265
8.	1,555	532	1,626	244	1,798	1,758	2,195	1,193
9.	369	219	386	60	738	376	417	409
10.	147	82	151	46	133	101	73	147
11.	674	228	960	489	824	360	157	456
12.								
13.		25	3,104	984	1,357	1,941	695	868
14.						28		
15.								
16.								
17.								
18.		23	9	27		11		
19.				5				
20.								
21.								
22.		4						11
23.								

TABLE C-6 - (Cont'd)

	October				November		December
	2	15		29	20		18
	S	S	N	S	S	N	S
1.	3	345	104	7	29	146	35
2.	tr	43				42	
3.	tr	33	26	3		21	
4.	3	172	156	8	1,350	345	975
5.	1	42	31		368	136	138
6.	tr	4	31			21	22
7.	8	164	167		10	8	
8.	45	1,024	2,258	49	68	58	44
9.	53	1,442	1,766	42	324	39	45
10.	2	234	233	1	2	24	4
11.	33	235	175	57	1,264	2,733	426
12.	7						
13.	16	1,827	5,301	344	136	58	2
14.							
15.						58	
16.							
17.							
18.							
19.							
20.							
21.							
22.							
23.							

TABLE C-7

ONONDAGA LAKE STUDY

COEFFICIENTS OF VARIATION*, MAJOR SPECIES

		Jan		Feb	March	
		14	30	19	5	19
	Cladocera:					
1.	Daphnia similis	141				
2.	Daphnia pulex	42	85	81	141	
3.	Chydorus spahaericus					
	Copepoda:					
4.	all copepod nauplii	141	141			
5.	cyclopoid copepodids	28	110		141	141
6	Cyclops vernalis		141			
	Rotifera:					
7.	Keratella hiemalis			141		
8.	Brachionus sp.					
9.	Polyarthra sp.					

* $\frac{100\ s}{-K}$

Blank space means none present in aliquots counted.
- means no replication

TABLE C-7 - (Cont'd)

	April					May			
	4	9	16	23	30	7	14	21	29
1.									
2.				141	141			141	141
3.					141	141			
4.				141	47	141	141	141	87
5.				141	141	71		47	74
6.	141			141				94	33
7.						141		97	
8.				141	141	60	118	51	76
9.				141					

TABLE C-7 - (Cont'd)

	June				July				
	4	11	18	25	2	9	16	23	30
1.		141	141	141	100	27	95	19	45
2.	47	64	41	34	74	117	51	128	63
3.	82	6	2	61	7	42	16	11	17
4.	2	42	59	26	61	59	52	4	1
5.	13	97	44	68	1	51	90	17	40
6.	67	52	5	21	95	5	104	11	38
7.	28	34					96	40	21
8.	29		141						
9.			141	43	4	104	57		141

TABLE C-7 - (Cont'd)

	August				September			October		
	6	13	22	27	3	18	25	2	15	29
1.	66	112	7	99	89	108	56	28	76	--
2.	141		14	85	111	34	61	34	7	--
3.	115	8	40	50	8	39	6	16	1	--
4.	29	36	30	69	104	2	42	9	57	--
5.	100	67	110	36	103	46	1	75	14	--
6.	6	14	42	40	75	19	48	34	1	--
7.	4	141	81	70	46	55	69	39	21	--
8.								29		
9.	56	76		141	73	25	16	64	69	--

TABLE C-7 - (Cont'd)

	November 20	December 18
1.	95	10
2.	84	19
3.	16	
4.	11	89
5.	111	15
6.	120	141
7.	52	51
8.		
9.	57	141

INTERPRETATION

The extremely low densities of zooplankton from December through April probably reflect the depressing effect of low temperature, and ice cover on algal food. The first major growth of each form appears to be exponental, suggesting that it is growth without active inhibition from environmental deficiencies. Though unexplained, the marked fluctuations which follow suggest that a relatively high density of each abundant organism is ordinarily possible but is being interrupted; high sections of each curve are often somewhat flattened compared to the low sections, which are relatively momentary. This suggests the action of an inhibitor (causing the troughs) as well as a limiting factor (leveling the tops). Such a conjecture gains some support from the following observations: a) Each trough appears for almost all plankters at the same date and with adjacent similar motion, yet in each case at least one plankter is not thus affected. This mitigates against explaining the troughs by artifact. (The exception, October 2nd, may indeed result from a sampling anomaly). b) Some similar behavior is seen in the algae, as follows:

DATE	ZOOPLANKTON	PHYTOPLANKTON EVENT
mid July	depression	no depression of phytoplankton biomass but Chlorella unhealthy and Scenedesmus density decreased
beg. Aug.	marked depression	marked depression, particularly Chlorella; generally unhealthy cells
beg. Sept.	depression	depression, blue-greens have just attained dominance
beg. Oct.	depression	depression at South-Deep only
beg. Nov.	depression	no depression

Particularly striking is the trough of all plankton at the beginning of August, and it is tempting to explain this on the basis of chemical inhibitor (a combination of high NH_3 with high pH (8.8) perhaps). However, too little is known about the

tolerance of zooplankters to high ion concentrations to permit decisive equation with the chemical data (see discussion in Hutchinson, 1967). Zooplankton densities after November 1, are likely to be temperature linked.

The high densities of zooplankton are mostly confined to the period of warm water temperatures, thus suggesting that controlling factors may also be influenced by temperature. The upper limits of these densities may not be a function of food supply; brood sizes for all crustaceans are large throughout the summer and fall, averaging for daphnids better than 6 eggs per gravid female, which is possible but unlikely in the presence of food shortage (Hall 1964). Moreover, dissolved oxygen, N, PO_4 and K levels as well as algal densities are generally high throughout the period (see Appendix B for nutrients).

Predation by fish is occuring and may be affecting densities of cladocera; in June (and to some extent in August) white perch were seen to select large daphnia. However, throughout July and August there was an abundance of large D. similis, an improbable situation in the presence of heavy grazing (Brooks 1966; Brooks and Dodson, 1965; Hall and Cooper, in press; Hall and Waterman, in process).

Sudden decreases in plankton density could conceivably follow from disease, but there was no visible signs of parasites, degenerate eggs, or anomalous growth.

The spatial distribution of Onondaga zooplankton seems rather homogeneous. Abundance of principal plankters seldom shows marked divergence between North and South-Deeps (Figure C-28, Table C-6). Moreover, remarkably similar species compositions are found at the peripheral stations, there being little or no observable divergence (from deep stations) on 24 out of 32 dates -- except at the outlet station, where backflow from the Seneca River is apparent. Physical information on the backflow (Section 9) is supported by the following:

NUMBER OF OCCURRENCES

Species	Deep Stations	Outlet Stations
Diaptomus sicilis	3	4
Diaptomid copepodids	4	7
Chydorus spahaericus	3	3
Bosmina longirostris	1	6
Asplanchna sp.	4	7

Chydorus, though not more frequent at the outlet, appeared much more abundant there, as did Bosmina and Asplanchna. Other peripheral divergences are trivial by comparison.

Vertical distribution was not studied, but a striking lack of observable differences in species composition or density between surface and vertical hauls at the deep stations suggests that stratification of zooplankters was not extreme within the epilimnion.

The species composition of Onondaga Lake is highlighted by two plankters which are often associated with saline waters. Daphnia similis (subgenus Ctenodaphnia), a very large species not previously known from this region, is normally observed in lakes with very high salinities, perhaps above 5000 ppm (Brooks 1957). Brachionus sp. is formally found in hard water and some species are marine (Edmondson, in Edmondson, 1959; and Ahlstrom, 1940).

Daphnia similis appears to have experienced only limited success in the lake in June (conceivably because of fish grazing) but it multiplied exponentially in early July, leveling off (with the notable exception of the August 6 crash) until the beginning of September. The subsequent decline may be a function of temperature.

The two daphnia may also be in competition. Daphnia pulex shows only low densities in the summer when D. similis is high. After some parallel densities in October, D. pulex becomes the dominant daphnid as though it were the more successful form at lower temperatures. However, competition with Ceriodaphnia (see Figure C-28) or selective fish predation, (decreasing with temperature) may have occurred, while temperature and even change in food species might have had some effect. Interaction of several (or all) of these factors and others is likely.

The Ceriodaphnia curves are notably similar to those of the copepods nearly all of which are Cyclops vernalis, the other species (Mesocyclops edax and Diaptomus sicilis) being rare and sporadic. The first peak of nauplii is about a week ahead of the copepodids and adults, presumably showing normal ontogenetic sequence of the first abundant generation. Thereafter they and (Ceriodaphnia) all change density in approximate parallel. The greater amplitude of the curves for juvenile forms probably reflects natural mortality prior to maturity. The general shapes of these curves is discussed above. This lake is perhaps unique in having but one relatively abundant copepod.

The ragged rotifer curves no doubt reflect the tremendous fecundity and shortgeneration time of these small organisms,

but they also result from a sampling routine which, as discussed above, is less suitable than for the crustaceans, and a correspondingly less fastidious counting result. The Brachionus explosion (in May), probably occurring in the absence of competition of predation, appears to exhibit natural exponential growth (to the point of crowding) and decline. The subsequent explosion of Cyclopoda suggests that Brachionus may have been a food source for them, at least in late May. Cyclomorphs of Keretella hiemalis were seen throughout the year, but were not studied.

In general the Onondaga Lake zooplankton populations conform to what might be expected in a saline lake at this latitude. Explanation of the fluctuations neither requires nor excludes the possibility of relationship with specific chemical parameters.

FISH SURVEY OF ONONDAGA LAKE - SUMMER, 1969

by

R. L. Noble and J. L. Forney

INTRODUCTION

Under contract with O'Brien & Gere Engineers, Inc., Syracuse, New York, a fish survey of Onondaga Lake was conducted during the summer of 1969 by the Department of Conservation, Cornell University. The objectives of the study were to determine the species composition of the fish population and its general condition.

METHODS

Fishery investigations were conducted in Onondaga Lake on May 12-13, June 18-19 and August 7-8, 1969. To ensure that the greatest variety of fish would be taken, a number of different sampling techniques were utilized (Table C-8).

TABLE C-8

Summary of Fishery Research Activities

Conducted on Onondaga Lake, 1969

Date	Activity	Objective
May 13-14	Mid-water Trawling	Adult pelagic fish
	Half-meter plankton netting	Pelagic fry
	Gill netting	Adult inshore fish
June 18-19	Half-meter plankton netting	As above
	Gill netting	As above
August 7-8	Mid-water Trawling	Adult pelagic fish reproduction
	Gill netting	As above
	Seining	Reproduction, small littoral fish
	Ekman dredge sampling	Benthos

Gillnetting was done during each sampling period to collect adult fish. Four nets, each 125 feet long by 6 feet high and mesh sizes of 1-1/2 to 4 inches (stretch), were set overnight during each month at stations throughout the shallow portions of the lake (Stations 3-8, Fig. 1).

A half-meter plankton net, equipped with #0 mesh (aperture size .5 mm) was towed near the surface at Stations 1-6 in May and at Stations 1-3, 5, 7 and 8 in June to collect pelagic fry. Approximately 34 m^3 were strained per haul.

An 8 x 8 foot mid-water trawl with 1 inch mesh wings and 1/4 inch cod-end liner was towed in May and August in search of pelagic fish, either adult or young. A single tow was made across the lake at Station 1 in May and two tows near Station 3 in August.

A 6 foot mid-water trawl with 1 inch mesh and 1/8 inch cod-end liner and 1/16 inch mesh catch bucket was towed near the surface in August in search of pelagic fry. Tows were made from the Liverpool launching area (Station 9) to Station 2, and from Station 2 to Station 11.

A 75 foot bag seine with 1/4 inch mesh was used in August to collect small fish along the shoreline. Hauls were made from a depth of 3 to 4 feet to the shore at Stations 8-11.

In addition to the fish survey, benthos samples were taken with an Ekman dredge at the gill net sites in August. Two 100 cm^2 samples were taken at each station, one at the shallow and one at the deep end of the gill net.

SPECIES COMPOSITION

The following species were collected in the course of the 1969 Onondaga Lake investigation:

Cyprinus carpio - Carp - 55 adults
Notropis atherinoides - Emerald shiner - 4 adults
Catostomus commersoni - White sucker - 2 adults, 5 young
Moxostoma macrolepidotum - Northern redhorse - 6 adults
Moxostoma sp. - Redhorse sucker - 1 adult
Ictalurus punctatus - Channel catfish - 20 adults
Ictalurus nebulosus - Brown bullhead - 3 adults, 3 young
Culaea inconstans - Brook stickleback - 1 adult
Roccus americanus - White perch - 607 adults, 10 young
Micropterus dolomieui - Smallmouth bass - 5 adults
Lepomis macrochirus - Bluegill - 1 adult
Lepomis gibbosus - Pumpkinseed (Common sunfish) - 3 adults
Lepomis sp. - Bluegill or Pumpkinseed - 3 young
Perca flavescens - Yellow perch - 22 adults
Stizostedion v. vitreum - Walleye - 5 adults
Aplodinotus grunniens - Fresh water drum - 6 adults

This list is probably incomplete, however, it is unlikely that any species common in Onondaga Lake is not represented.

Carp - Carp appear to be common in Onondaga Lake. Adults were taken in gill nets and by seining, and a single adult captured in a mid-water trawl when towed on bottom in approximately six feet of water. Carp were also frequently observed jumping from the water when setting nets in the evening. Adults ranged from 255 mm to 668 mm and were all age II and older. The absence of young carp in the seine hauls and yearlings in all samples indicates that the population may not be reproducing well in the lake.

Emerald shiner - Four adult emerald shiners were seined just each of the outlet of Onondaga Lake.

White sucker - Two adult suckers were taken in gill nets at Station 3 in May. Four young and one yearling were taken in seine hauls at Stations 9 and 10. Reproduction may occur in the lake.

Redhorse suckers - Six adult northern redhorse suckers were taken in gill nets at Station 3. In addition, a single specimen of another species of redhorse was caught. The taxonomy of this genus is presently under revision and therefore the species was not determined.

Channel catfish - Catfish were taken in gill nets at three sites in August (Stations 3, 5 and 8). Sizes ranged from

260-512 mm total length. These fish appeared to be in good condition, and were feeding on zooplankton chironomids, and filamentous algae.

Brown bullhead - Three adult bullheads were taken in gill nets in August at three separate sites, and three young of the year were taken in August at Station 9 in the seine. Bullheads probably are reproducing in Onondaga Lake.

Brook stickleback - A single adult stickleback was seined at Station 9 in August. This species is not typically a lake inhabitant.

White perch - A white perch population appears to be well established in Onondaga Lake. Adults were taken in large numbers in gill nets, particularly at Stations 3 and 5. Size of adults range up to 263 mm, with most fish between 170 and 230 mm total length. Examination of scales revealed that this size range was composed of fish mainly age 3 to 5. All year classes of white perch were well-represented in the adult population; indicating that the population should be fairly stable. Although much individual variation in growth was apparent, growth of white perch in Onondaga Lake can be considered average (Table C-9). Scales indicated that exceptionally rapid growth occurred in 1968, but little growth had occurred prior to August 7, 1969 judging from scale markings.

Food habits of white perch were determined on each sampling date. White perch fed primarily on chiromids and zooplankton and most stomachs were nearly full on all sampling dates.

On May 13, chironomids and zooplankton were utilized to a large extent, one or both occurring in over 80 percent of the stomachs. In the later samples, chironomids played a lesser role. In June, chironomids occurred in only 12 percent of the stomachs, compared to a 74 percent occurrence of zooplankton, and in August they occurred in 20 percent of the stomachs compared to 66 percent for zooplankton. On June 19, it was noted that the larger zooplankton (D. pulex) were often selected. On the August sampling date, some zooplankton selection occurred, but the smaller cladocerans were being utilized to a greater extent than previously. The white perch population of Onondaga Lake depends substantially on the zooplankton for food, however, the composition of the zooplankton as well as the amount of benthos may have considerable influence on the growth rate.

White perch apparently spawned between mid-May and mid-June. Large numbers of adult white perch in spawning condition were collected at Stations 3 and 5 in May but most of those caught on June 18-10 were spent. Only 10 young were collected by

TABLE C-9

AGE AND GROWTH OF WHITE PERCH IN ONONDAGA LAKE, 1969

Age	May 13 - 14		June 18 - 19		August 7 - 8	
	No. Aged	Mean Length (mm)	No. Aged	Mean Length (mm)	No. Aged	Mean Length (mm)
I	0	--	1	114	0	--
II	1	168	3	144	3	182
III	23	204	30	185	16	210
IV	39	211	31	204	36	213
V	18	216	20	222	6	224
VI	9	229	6	239	2	234
Older	1	235	6	251	0	--
Total	91		97		63	

seining in August, and none by fry sampling. The occurrence of so few young indicates that reproductive success was not substantial in 1969. Large numbers of young may not be necessary to maintain the population since mortality from angling is probably negligible and predators do not appear abundant.

The white perch is an exotic species, which until recently was found principally in brackish water along the east coast. It invaded New York around 1950 and became established in some of the natural waters. It evidently found a favorable niche in Onondaga Lake and has become firmly established.

Smallmouth bass - Five smallmouth bass were taken in gill nets at Stations 3 and 5. These fish ranged from 191 to 279 mm and from age 2 to 5. Growth rate is within the range observed in other New York waters. The magnitude of the smallmouth population is difficult to assess from these samples since smallmouths are not very vulnerable to gill nets.

Sunfish - One adult bluegill and three adult pumpkinseeds were taken. In addition, three young sunfish were seined in August at Station 10. Reproduction probably occurred in Onondaga Lake. Sunfish were likely more abundant in Onondaga Lake than it appeared from these samples, since they are not particularly vulnerable to gillnetting.

Yellow perch - Adult yellow perch were taken in gill nets on all sampling dates, but in small numbers. Examination of scales of the 22 perch revealed that growth in Onondaga Lake was average for this species. At Station 6, ripe females were taken in May, which is unusually lake in the season to find females with eggs. In nine New York lake studies during the spring of 1969, yellow perch spawned in late April. Possibly the eggs were retained because of adverse spawning conditions. No young yellow perch were taken by tow nets or by seining, indicating the reproduction probably was poor.

Walleye - In August, five adult walleyes were taken by gill nets at Stations 3 and 8. These walleyes ranged from 468 to 550 mm in length and appeared to be in good condition, although the stomachs were empty.

Freshwater drum - Six freshwater drum were taken with gill nets in August at Stations 3 and 8. These fish ranged from 268 to 307 mm in length and were age 3 and 4.

DISTRIBUTION

Gill net sites were selected to give a general indication of distribution of fish. Station 3 and 5, along the east shore produced good catches in May, so these sites were retained for each sampling period (Table C-10). Station 6, near the mouth of Ley Creek, produced only five yellow perch and one carp in May and no fish in August. Station 7, at the southwest end of the lake, was sampled in June and yielded no fish. Stations around the mouth of Nine Mile Creek (Stations 4 and 8) were not productive in May and June, however a wide variety of fish were caught in August. The bottom at these stations (Stations 6-8) was soft and foul-smelling.

Only the northern basin was seined for reproduction, (Stations 8-11), and only at Stations 9 and 10 were young fish found. The bottom of these stations on the east shore was noticeably more clean and firm than at the two stations on the west side.

BENTHOS

Benthos samples were taken with an Ekman dredge at Stations 3, 5, 6 and 8 on August 8, 1969. A shallow and deep sample were taken at each station. Only at Station 8, near the mouth of Nine Mile Creek, were large numbers of benthic organisms taken.

Station	Depth in Feet	Organisms
3	5	Bottom calcareous, no sample
	20	None
5	5	1 chironomid larva
	12	None
6	8	None
	15	None
8	6	Chironomid larvae, ostracods
	10	Chironomid larvae

Benthos samples were deposited with the Department of Ecology and Systematics (G. Waterman under Contract with O'Brien & Gere Engineers, Inc.) for further classification.

TABLE C-10

GILL NET CATCHES, ONONDAGA LAKE, 1969

	Station	Depth in Feet	White Perch	Carp	Yellow Perch	Channel Catfish	Bullhead	Redhorse Sucker	White Sucker	Walleye	Smallmouth Bass	Freshwater Drum	Pumpkinseed	Bluegill
May 13 - 14	3	5-15	71		2									
	4	20-35	2											
	5	6-7	21	1	5									
	6	8-15		1	5									
June 18 - 19	3	5-15	202	9				2			1			
	5	7-17	173	10	5						1			
	7	14-30	N											
	8	12-25	N											
August 7 - 8	3	5-20	103	8		17	1	5	2	4	2	4	2	1
	4	5-12	21	12		2	1				1			
	6	8-15	N											
	8	6-10	14	4	5	1	1			1		2		
		TOTAL	607	45	22	20	3	7	2	5	5	6	2	1

N -- None

SUMMARY AND RECOMMENDATIONS

Onondaga Lake supports a fairly diverse fish fauna, typical of many warm water lakes in Central New York State. Except for the large population of white perch, species composition has not changed appreciably from that reported in the surveys of 1927 and 1946. Despite the unusual chemical and physical characteristics of Onondaga Lake, growth of most game and pan fish compared favorably with published growth rates of fish in other waters of the northeast. Reproduction appeared to be very limited in 1969, however, those young taken were of good size and condition.

The general distribution of fish in Onondaga Lake indicates that the population may be restricted to areas where conditions are favorable. It is obvious that conditions along the northeast shoreline of the lake are favorable to a large and varied fish fauna, and it is unlikely that limnological conditions in the remainder of the lake are much worse than marginal. The apparent paucity of adult fish in the southernmost part of the lake and lack of young along the northwest shore probably reflect the inflow of low quality water at the south end of the lake and from Nine Mile Creek.

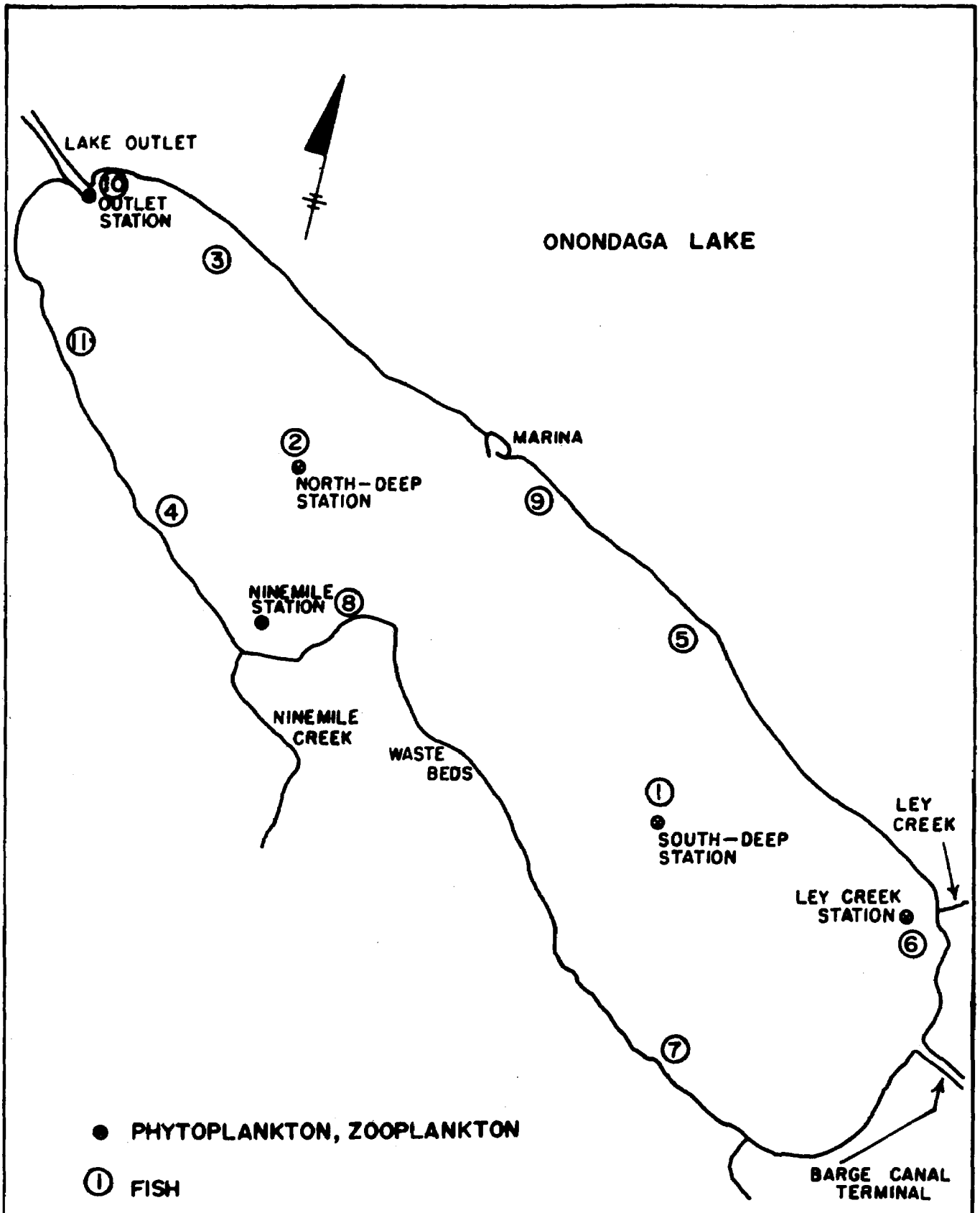
Anoxic conditions in the hypolimnion have not prevented development of a substantial pan fish population since the habitat of white perch, yellow perch and sunfish does not necessarily include the hypolimnion. Epilimnetic oxygen conditions, although marginal at times, are evidently not critical for the present fish species. These conditions may, however, limit fish production. In addition, the quality of the substrate in littoral areas may limit reproductive success.

Nevertheless, Onondaga Lake, located within a metropolitan area, can provide angling opportunities for many urban dwellers. Management of the existing fish population, consisting principally of pan fish, could assure recreation for youth of the area and for inter-city residents who are unable to travel to more distant waters. Utilization of this resource is presently limited by aesthetic considerations and uncertainty about the quality of the fish.

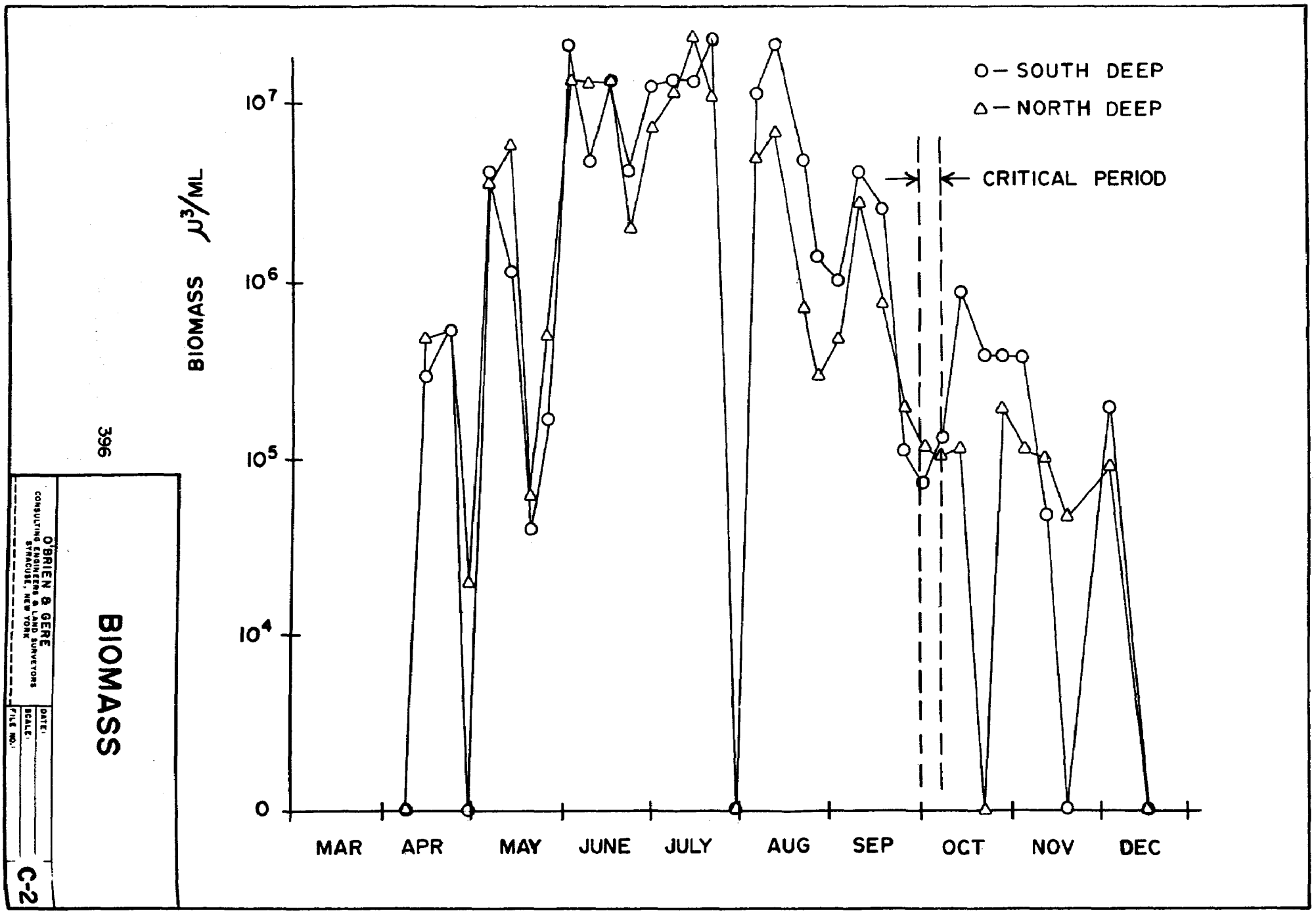
In response to complaints that the flavor of Onondaga fish is tainted and that they are undesirable for consumption, a taste test was conducted using walleyes and white perch from Onondaga and Oneida Lakes. Without knowledge of the source of each fish, ten participants tasted fillets of fish from each lake. White perch from the two sources, although distinguishable by four persons, did not have an objectionable taste. The taste of Onondaga Lake walleyes, however, was considered less desirable than that of Oneida Lake walleyes by seven person, but few

few people actually considered them objectionable. In contrast, one participant regarded the taste of Onondaga Lake walleyes superior to that of the Oneida Lake counterpart. It appears from this test that tainting of the flavor of Onondaga Lake fish should be little deterrent to the development of an active sport fishery on Onondaga Lake.

If current efforts to improve water quality are successful and the results of these improvements made evident to the public, fishing pressure will increase. Whether the present population could sustain an intensive fishery, however, is uncertain. When the entire basin can be improved to the existing conditions of the northeast area of the lake, the lake as a whole should be able to produce and maintain populations of pan fish similar to those at Stations 3 and 5. Management of the population under greater fishing pressure and improved habitat will require further study when such changes occur.



BIOLOGICAL SAMPLING LOCATIONS



396

O'BRIEN & GERE
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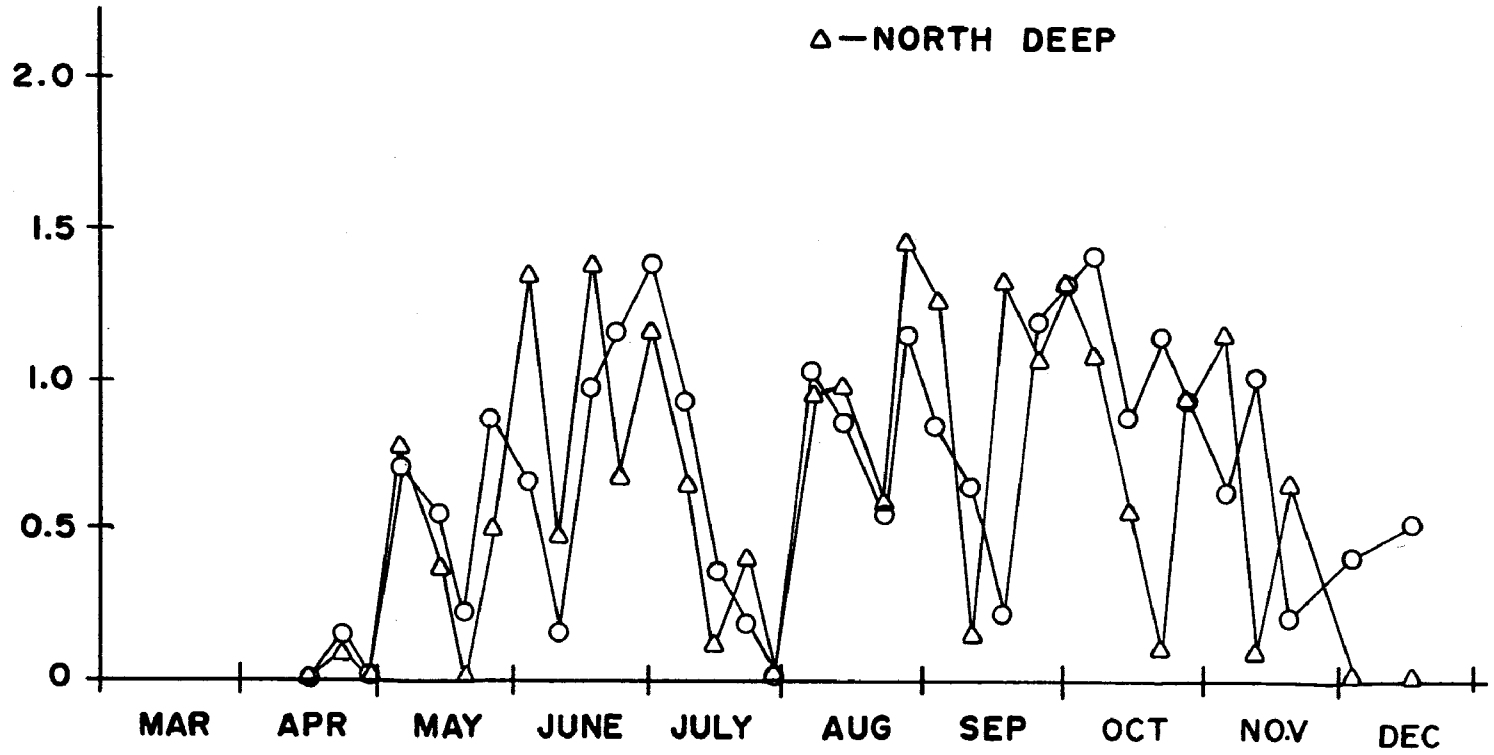
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

BIOMASS

C-2



397

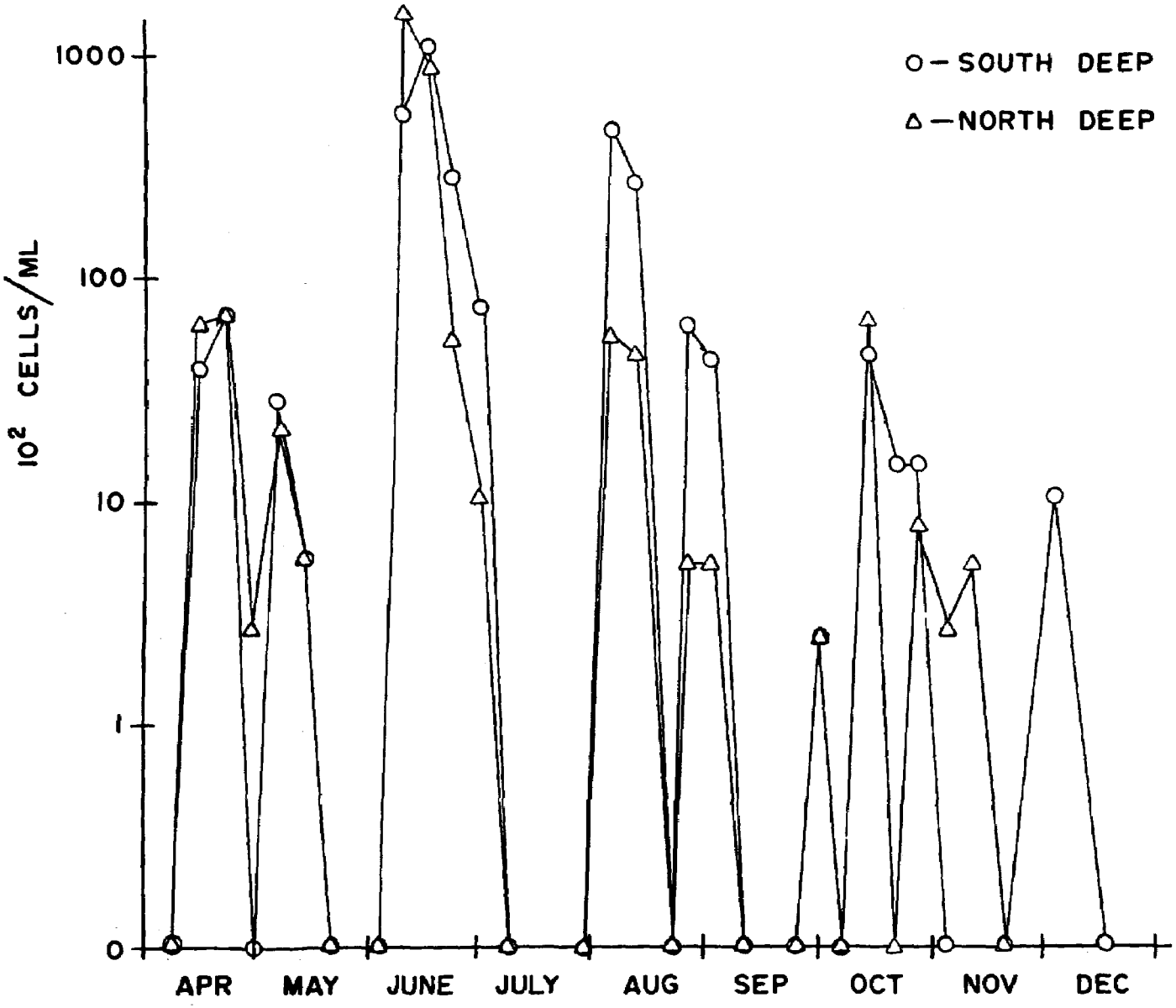
PHYTOPLANKTON DIVERSITY INDEX

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-3

CHLAMYDOMONAS
(TUBE SAMPLES)



O'BRIEN & GERE
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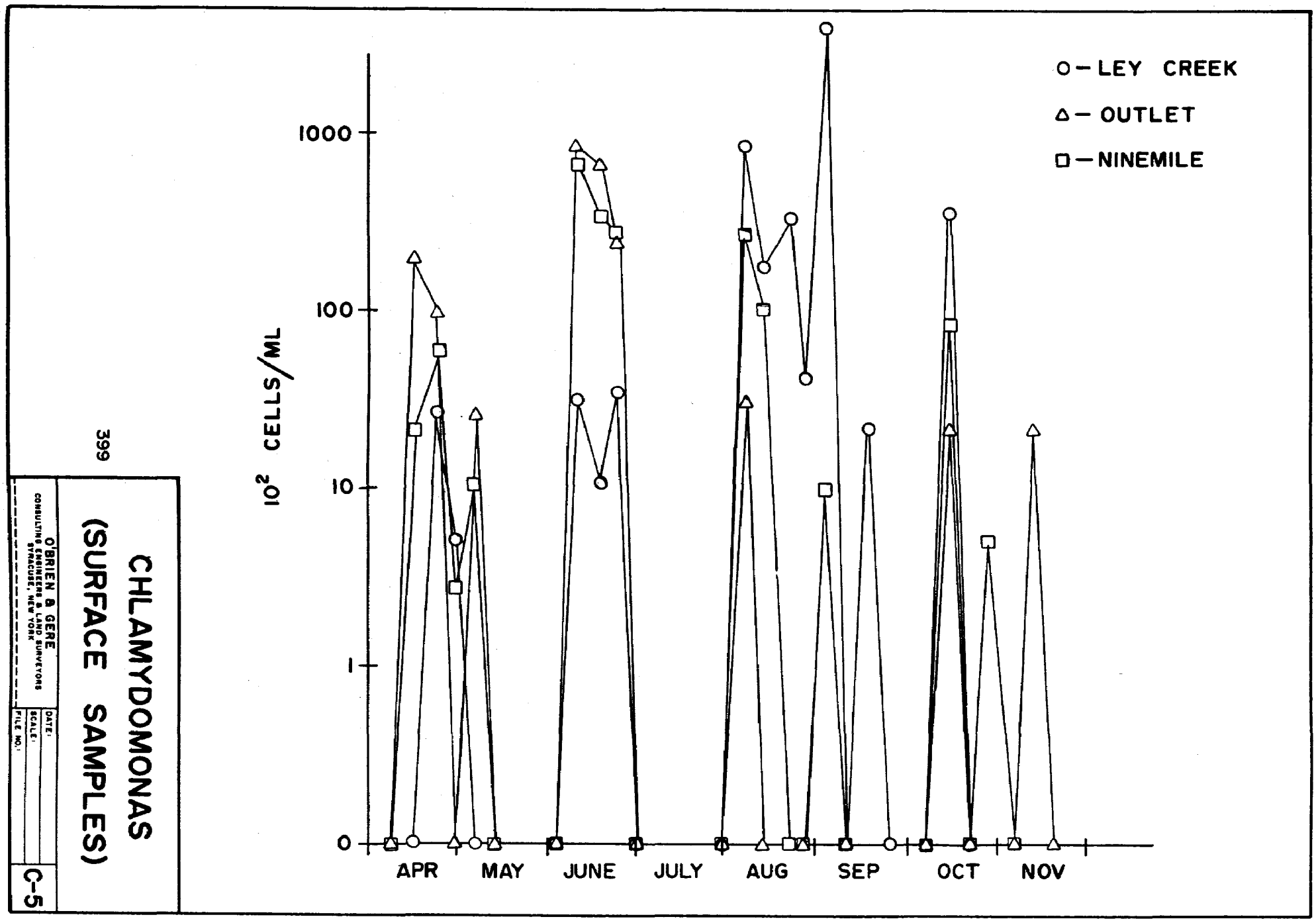
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-4



399

CHLAMYDOMONAS (SURFACE SAMPLES)

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CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

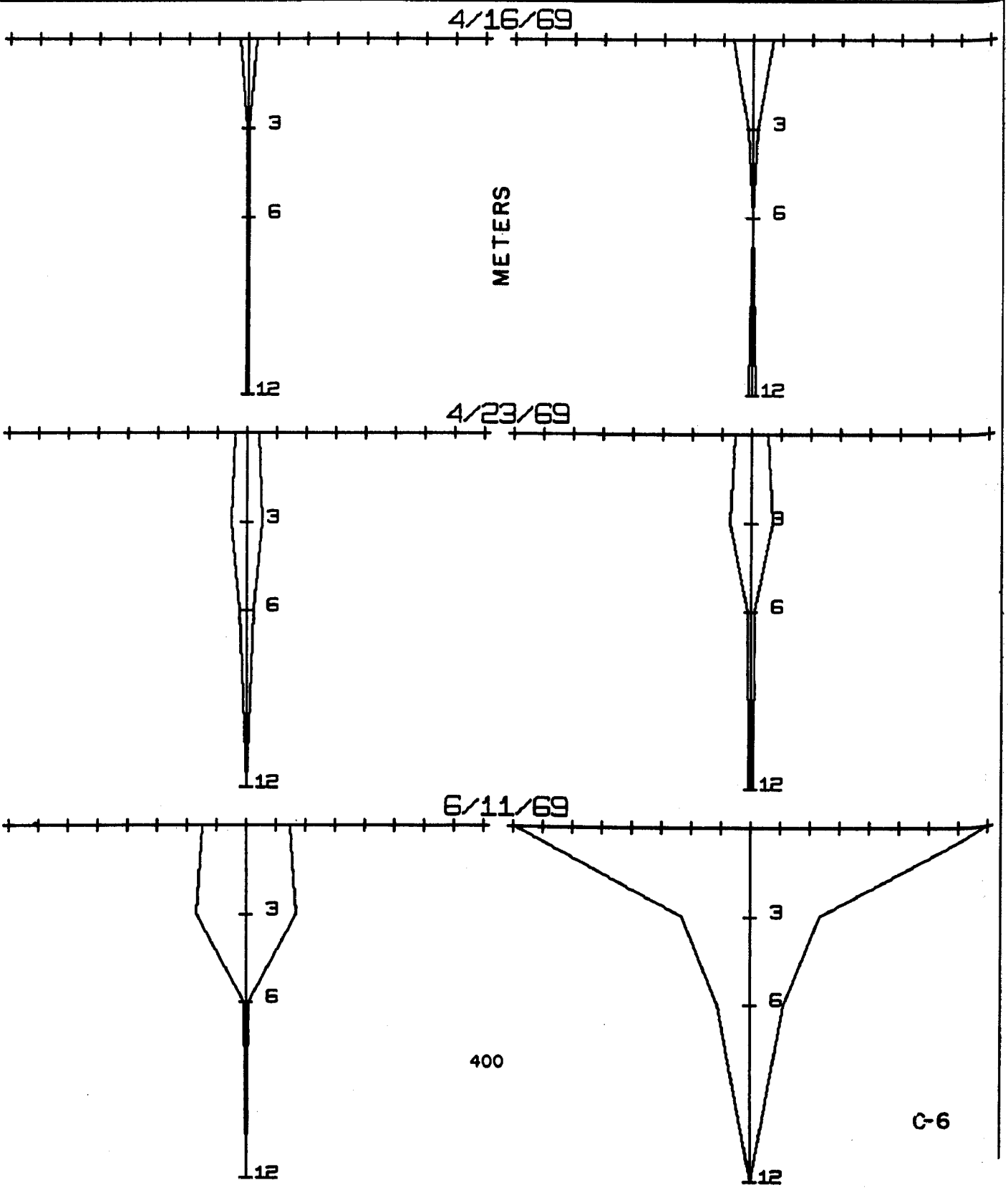
DATE:
SCALE:
FILE NO.:

C-5

CHLAMYDOMONAS SP.

PHY18

STATION 1 1/4 IN = 14300 CELLS/ML STATION 2



C-6

CHLAMYDOMONAS SP.

PHY19

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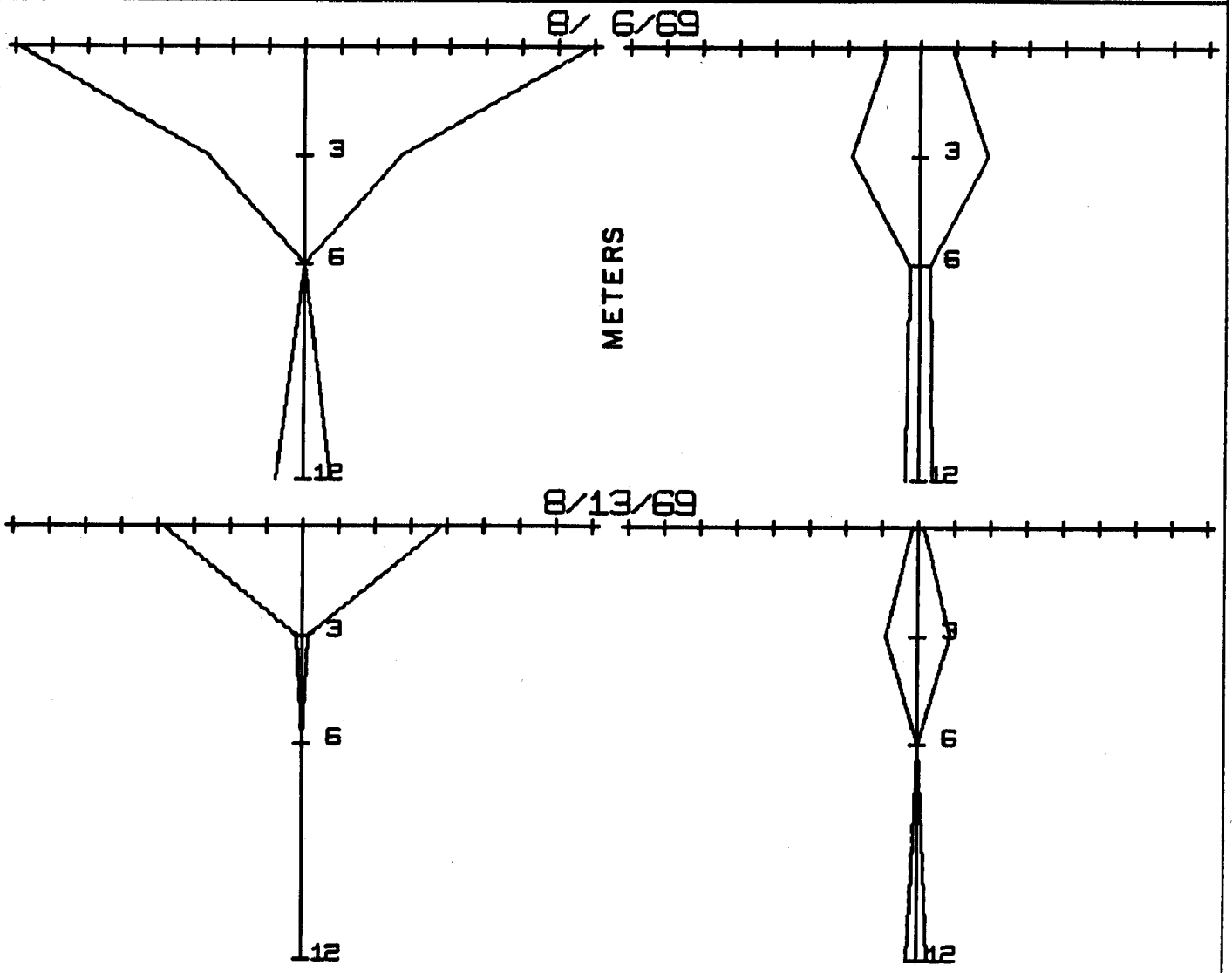
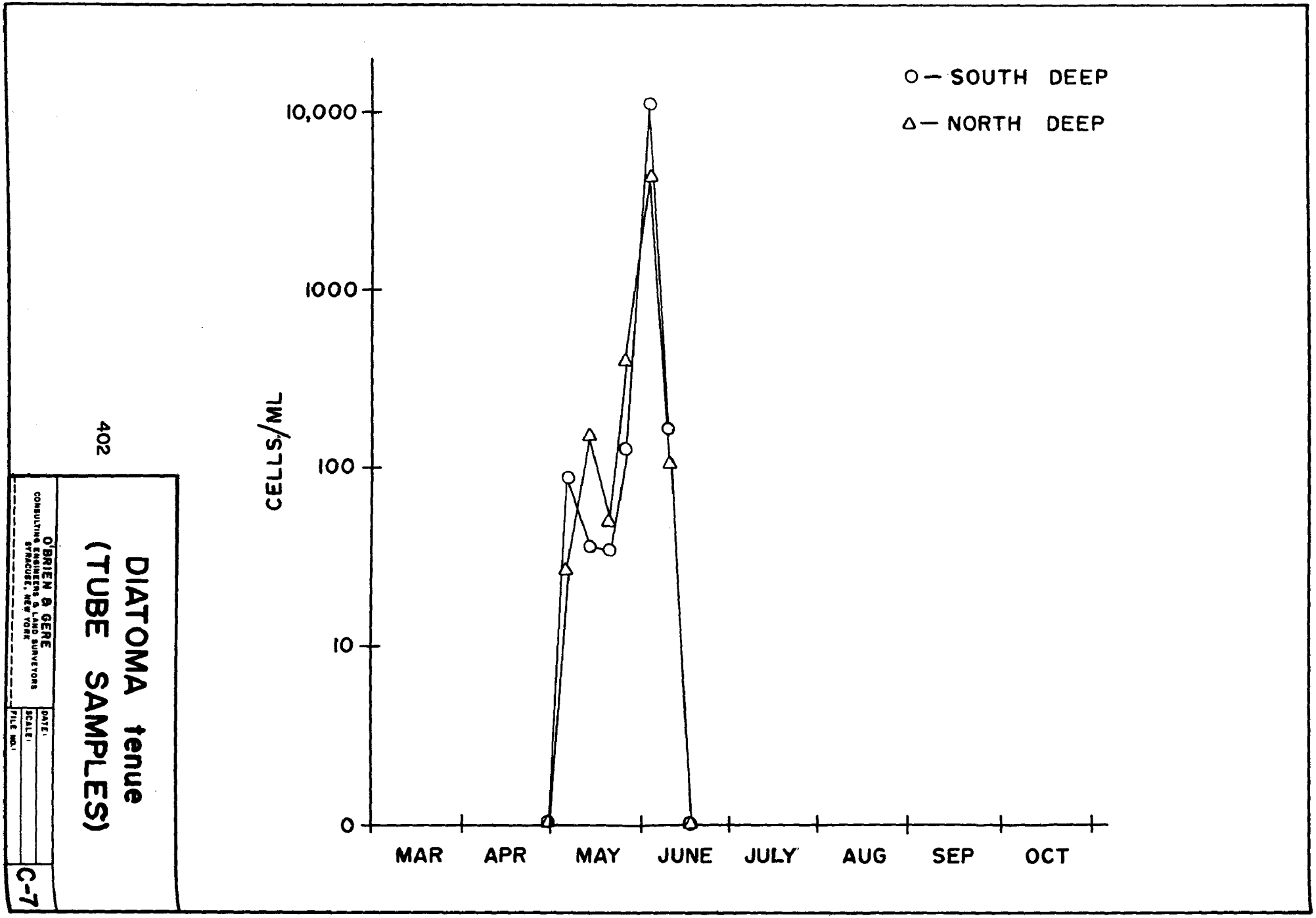




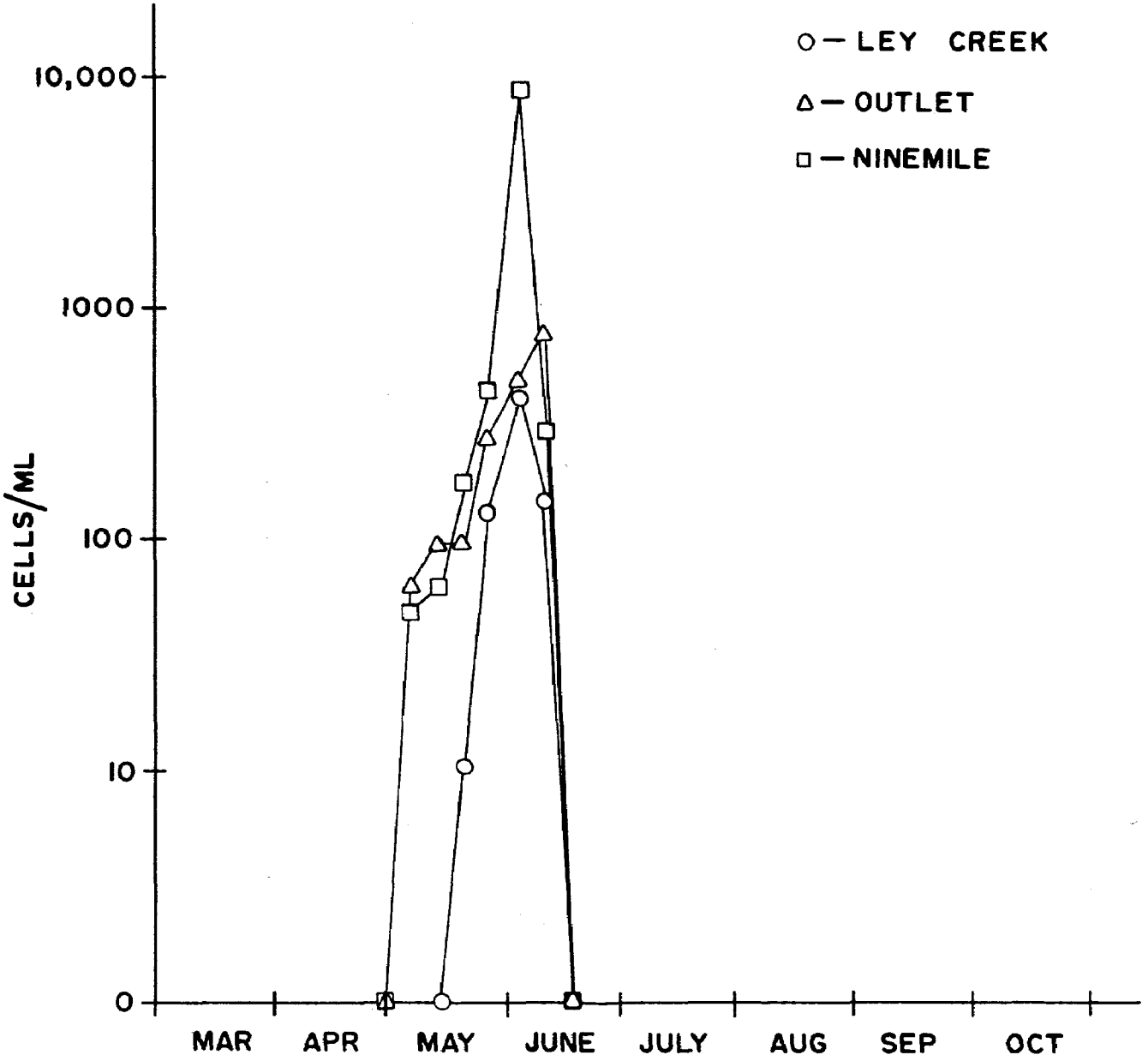
402

DIATOMA tenue (TUBE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-7



403

DIATOMA tenue
(SURFACE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

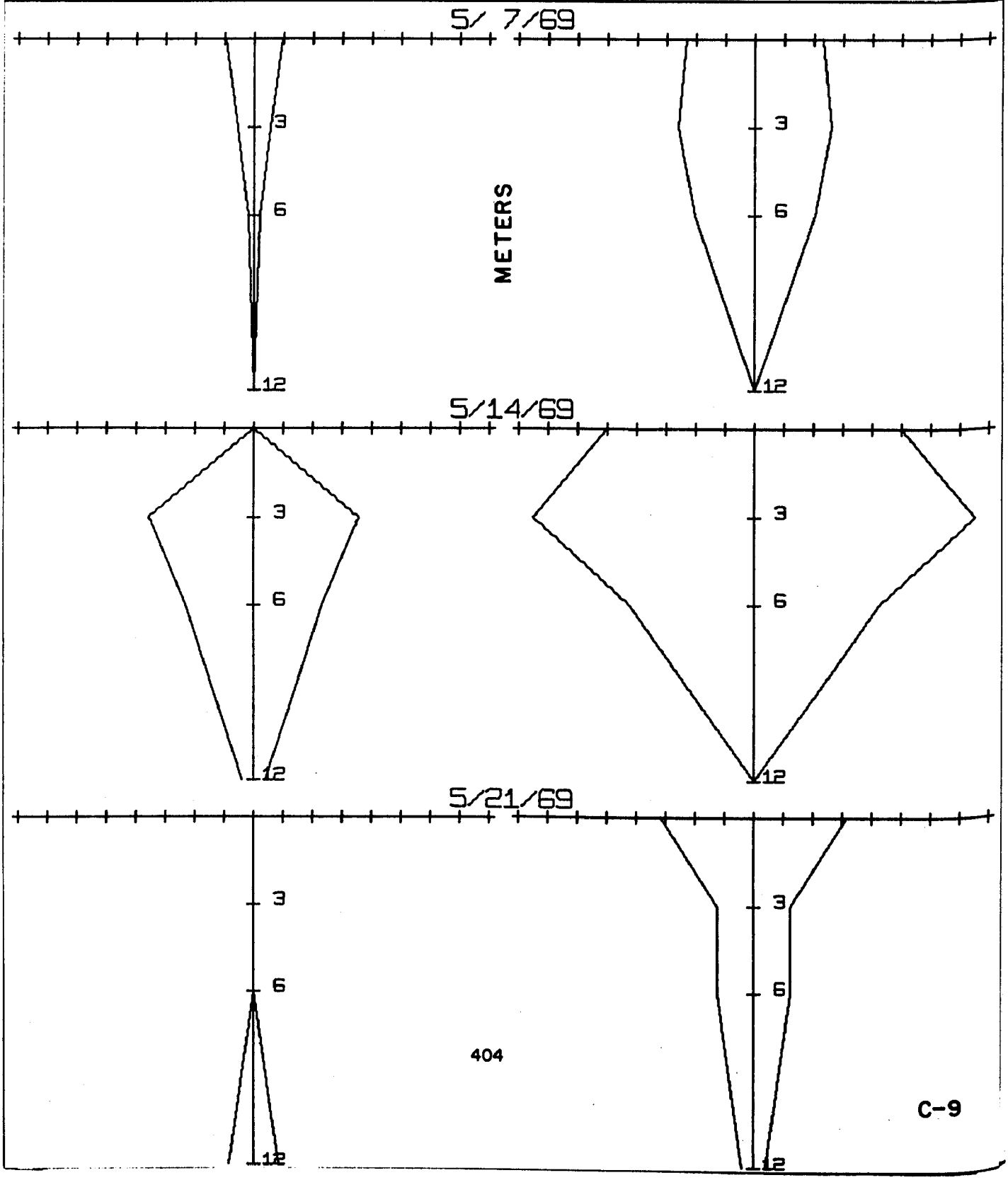
DATE:
SCALE:
FILE NO.:

C-8

DIATOMA TENUE

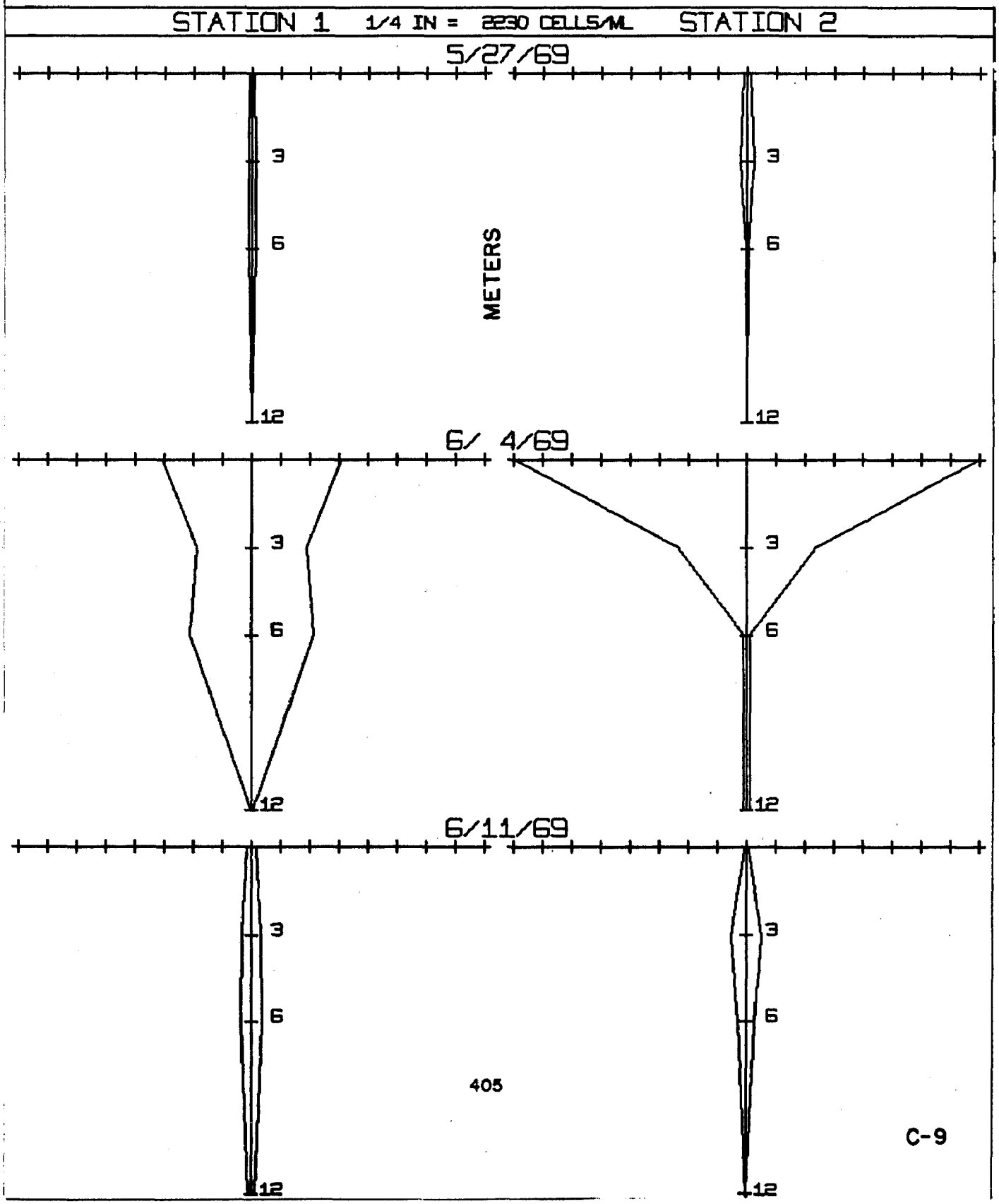
PHY 1

STATION 1 1/4 IN = 40 CELLS/ML STATION 2



DIATOMA TENUE

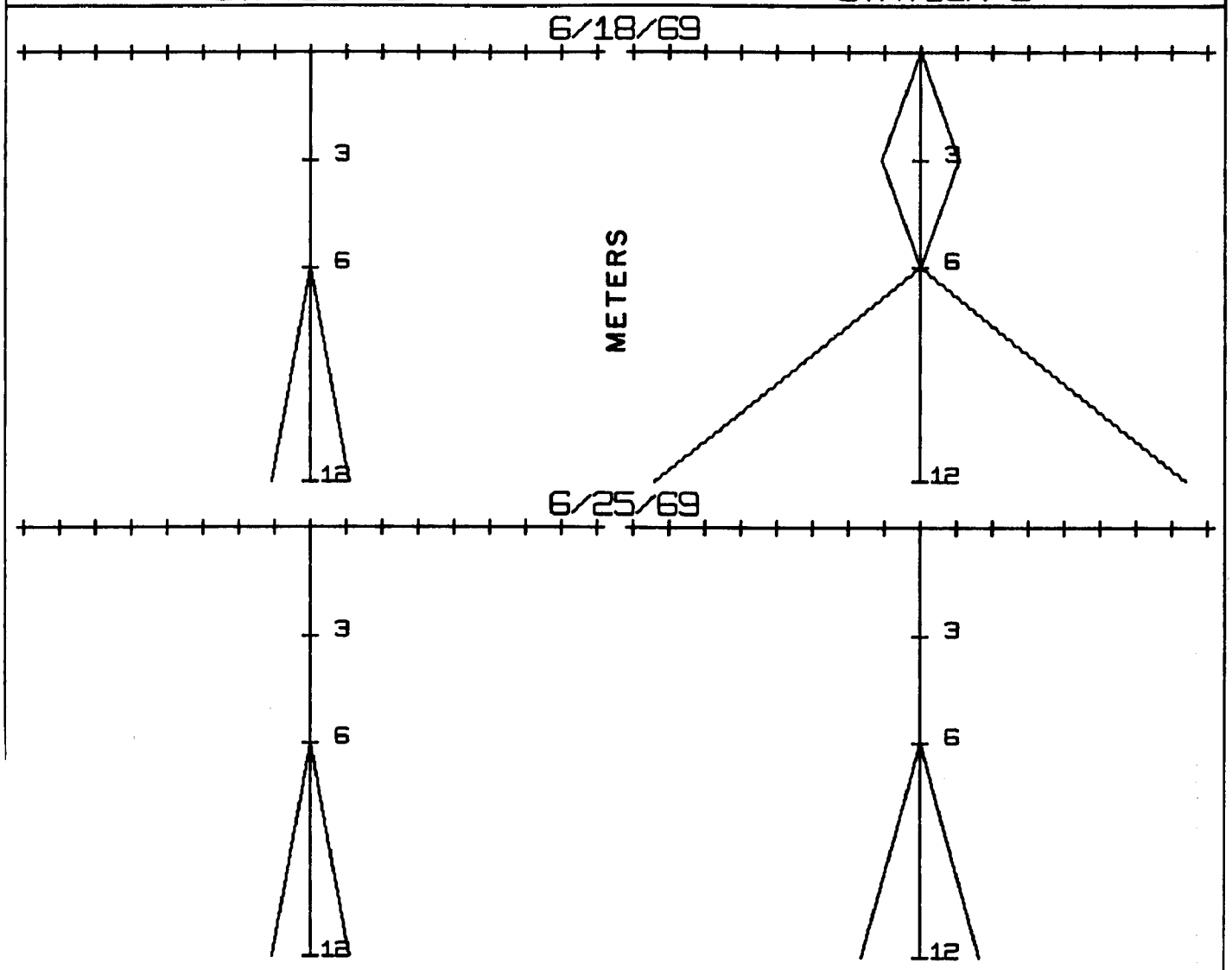
PHY 2

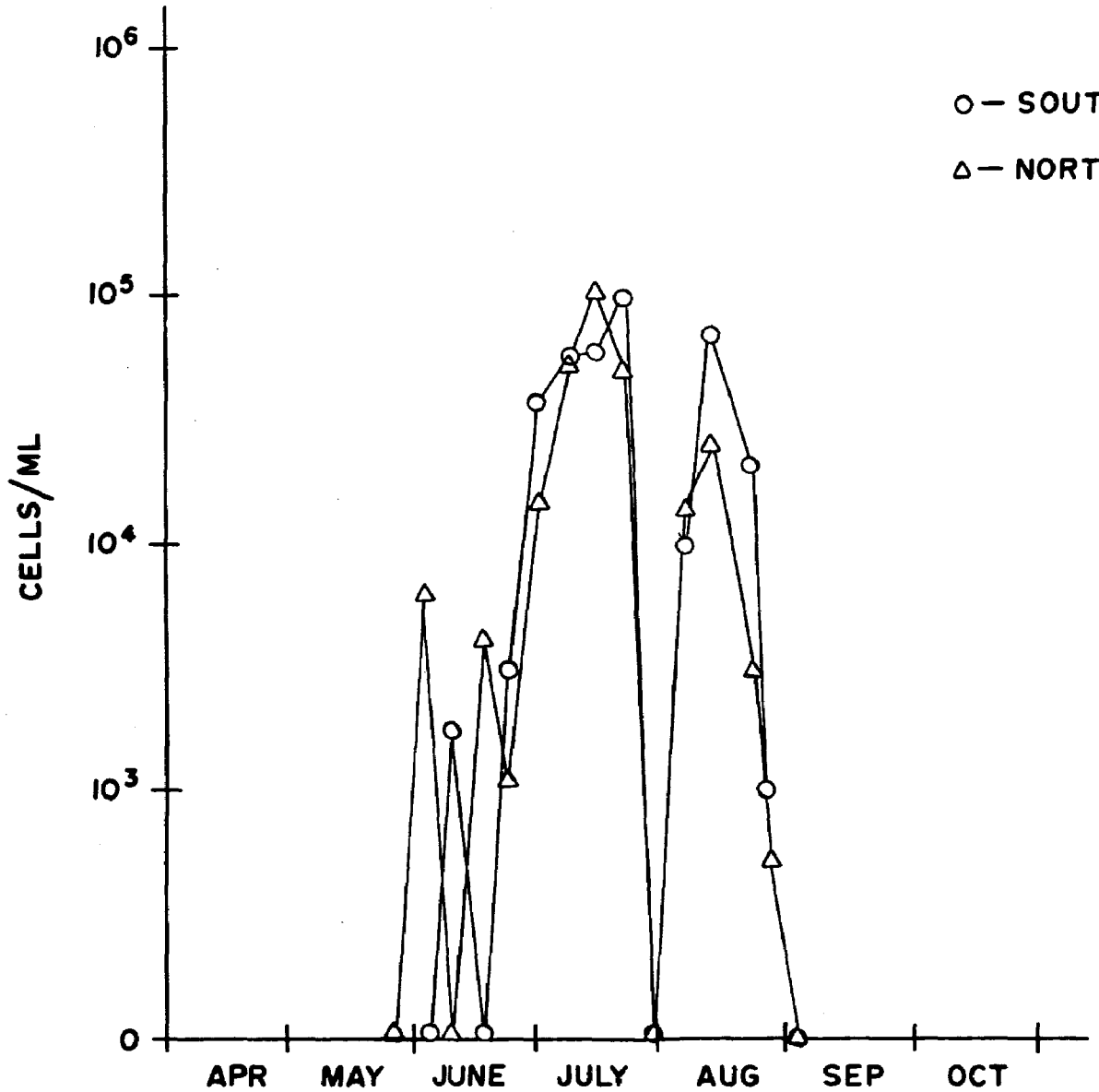


DIATOMA TENUE

PHY 3

STATION 1 1/4 IN = 40 CELLS/ML STATION 2





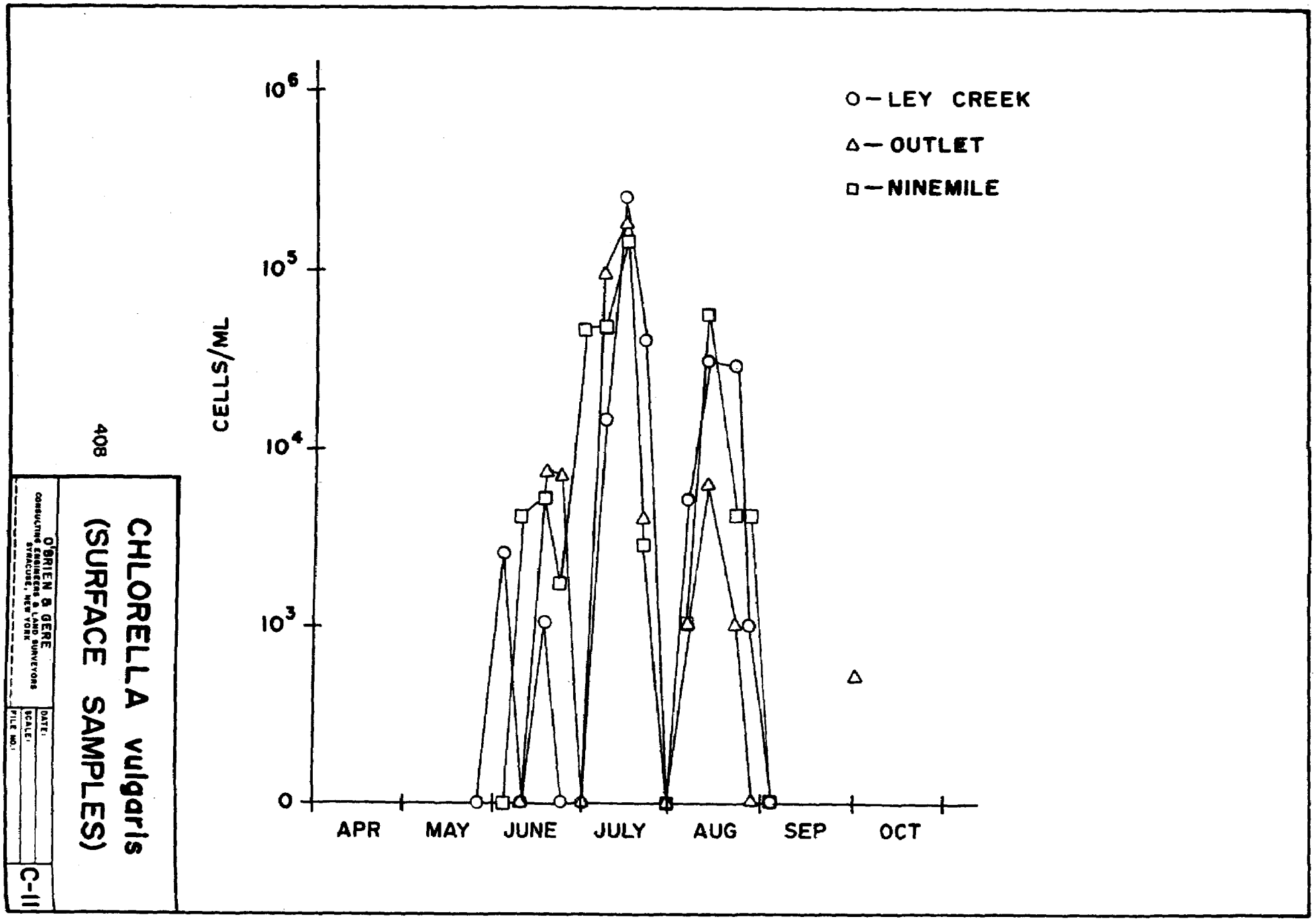
407

CHLORELLA vulgaris (TUBE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

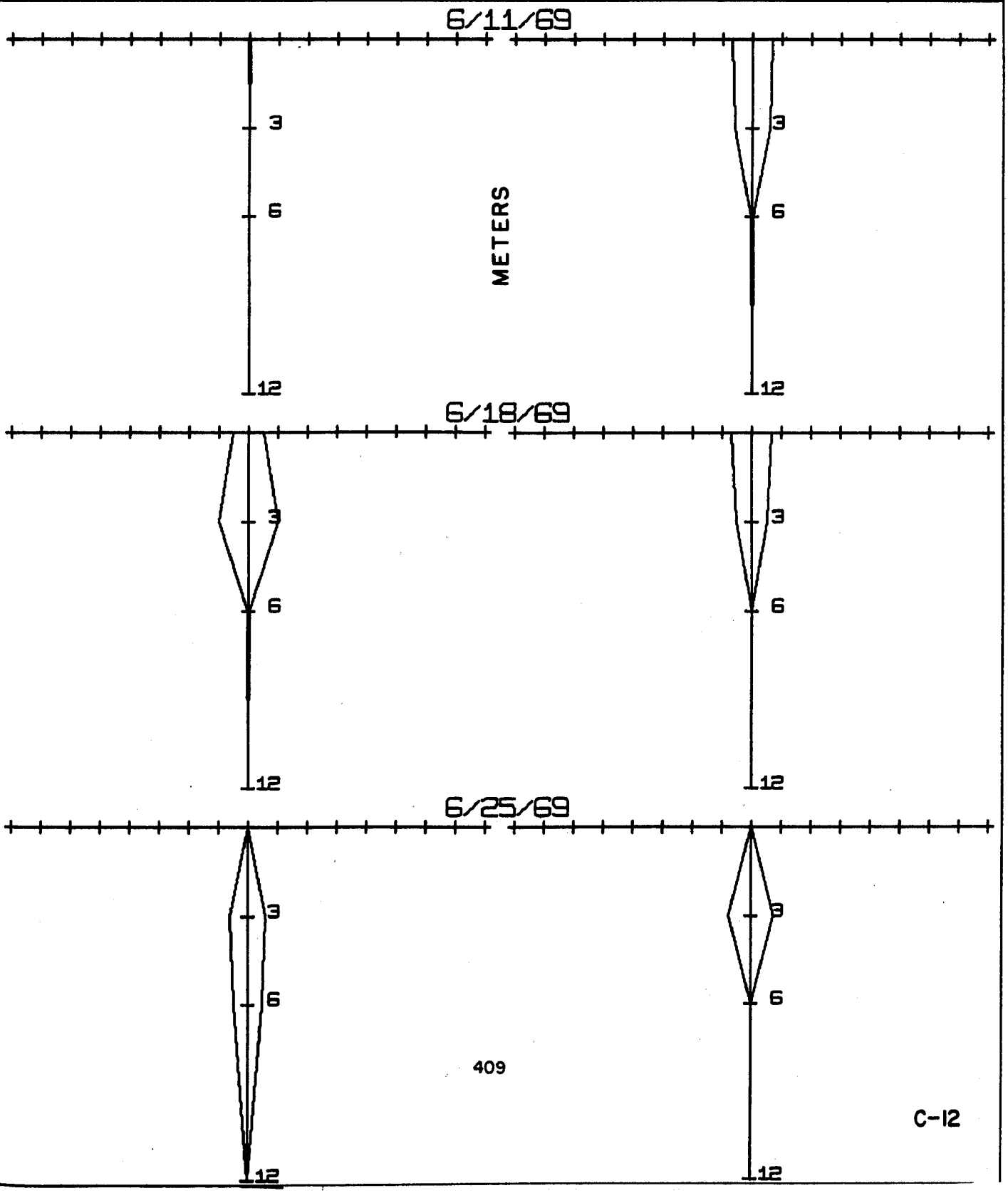
C-10


CHLORELLA vulgaris
(SURFACE SAMPLES)
408
O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK
DATE:
SCALE:
FILE NO.:
C-11
CELLS/ML
10^6
10^5
10^4
10^3
0
APR
MAY
JUNE
JULY
AUG
SEP
OCT
O — LEY CREEK
△ — OUTLET
□ — NINEMILE

CHLORELLA VULGARIS

PHY 4

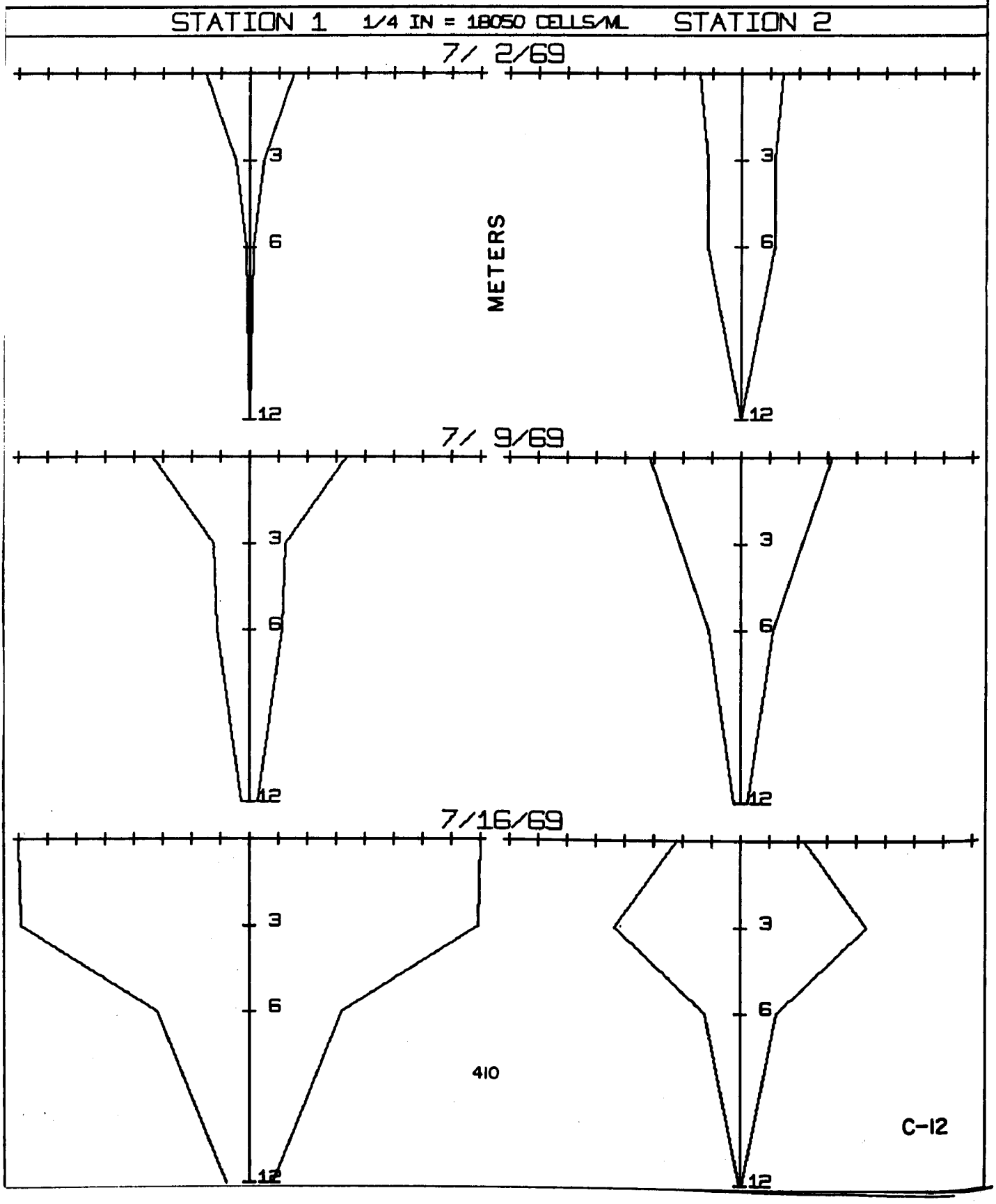
STATION 1 1/4 IN = 18050 CELLS/ML STATION 2



C-12

CHLORELLA VULGARIS

PHY 5

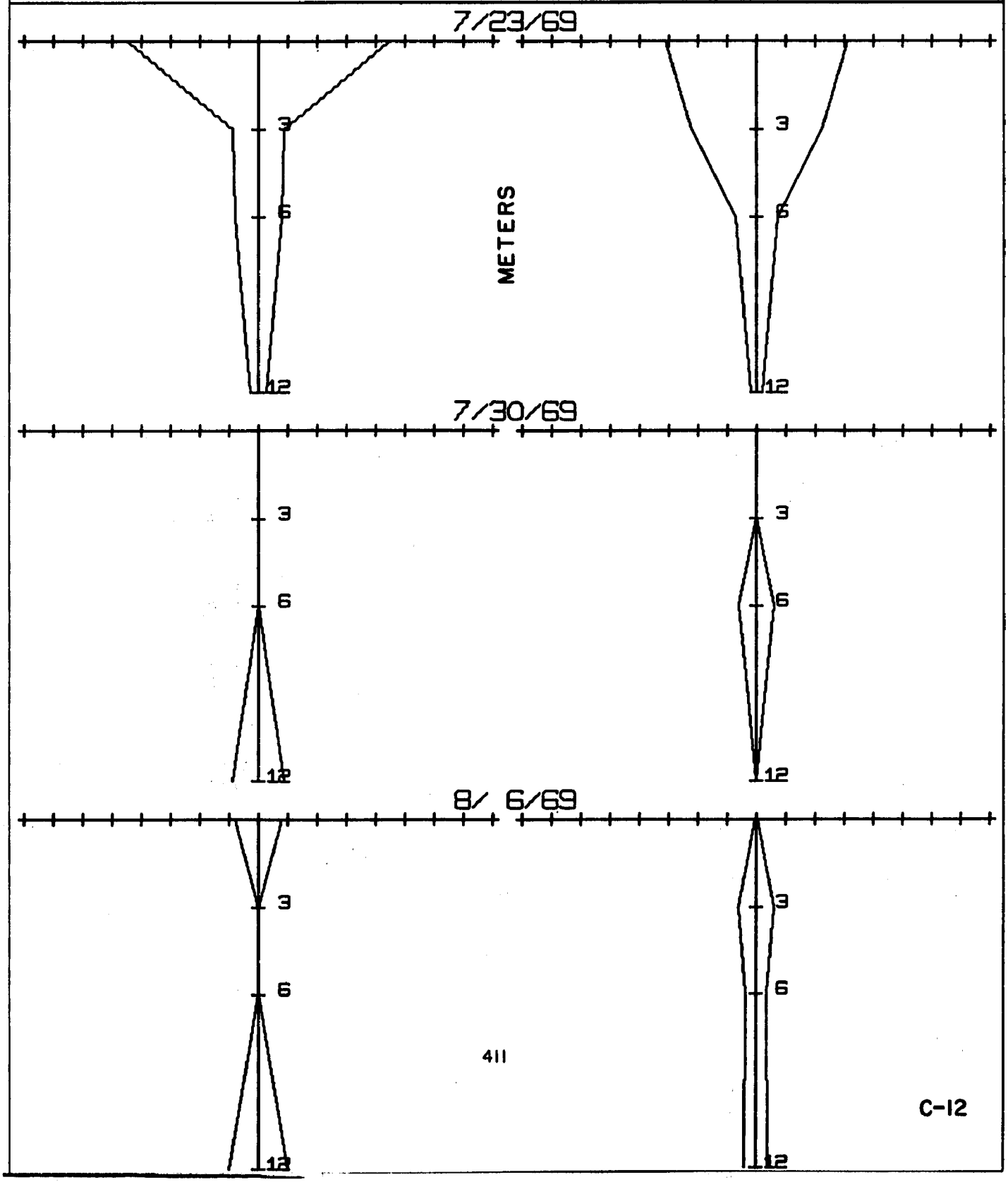


C-12

CHLORELLA VULGARIS

PHY 6

STATION 1 1/4 IN = 18050 CELLS/ML STATION 2



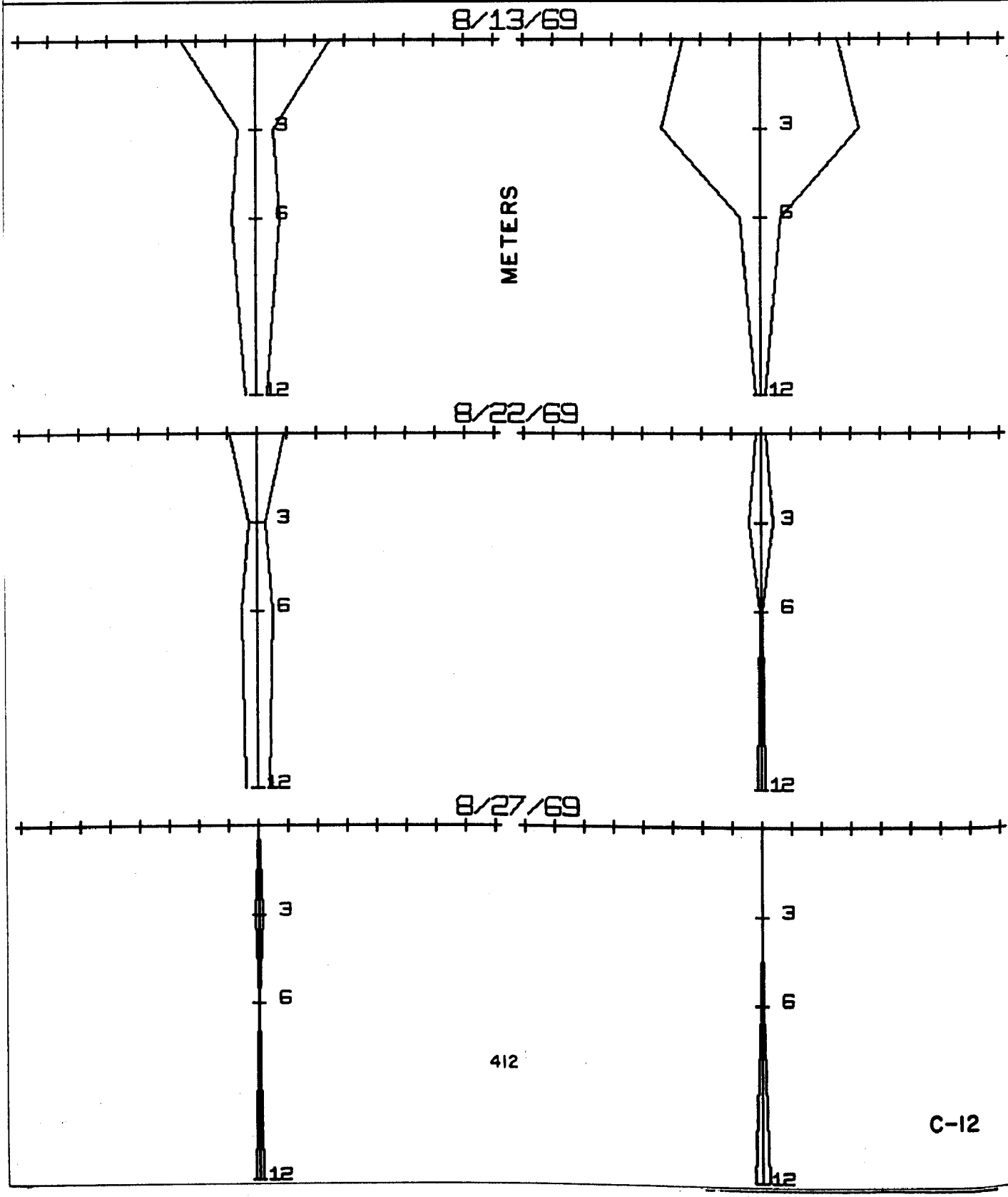
411

C-12

CHLORELLA VULGARIS

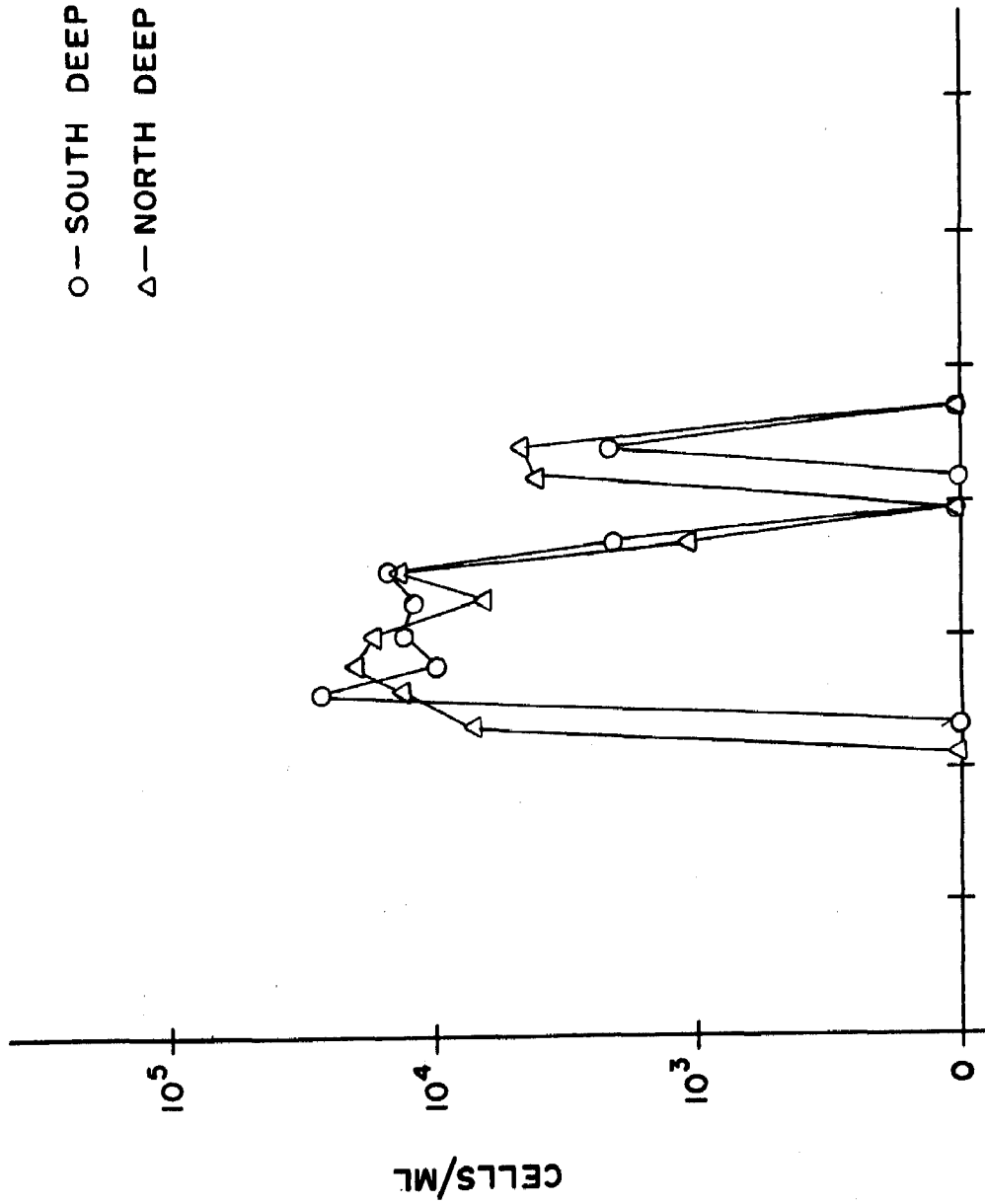
PHY 7

STATION 1 1/4 IN = 18050 CELLS/ML STATION 2



412

C-12

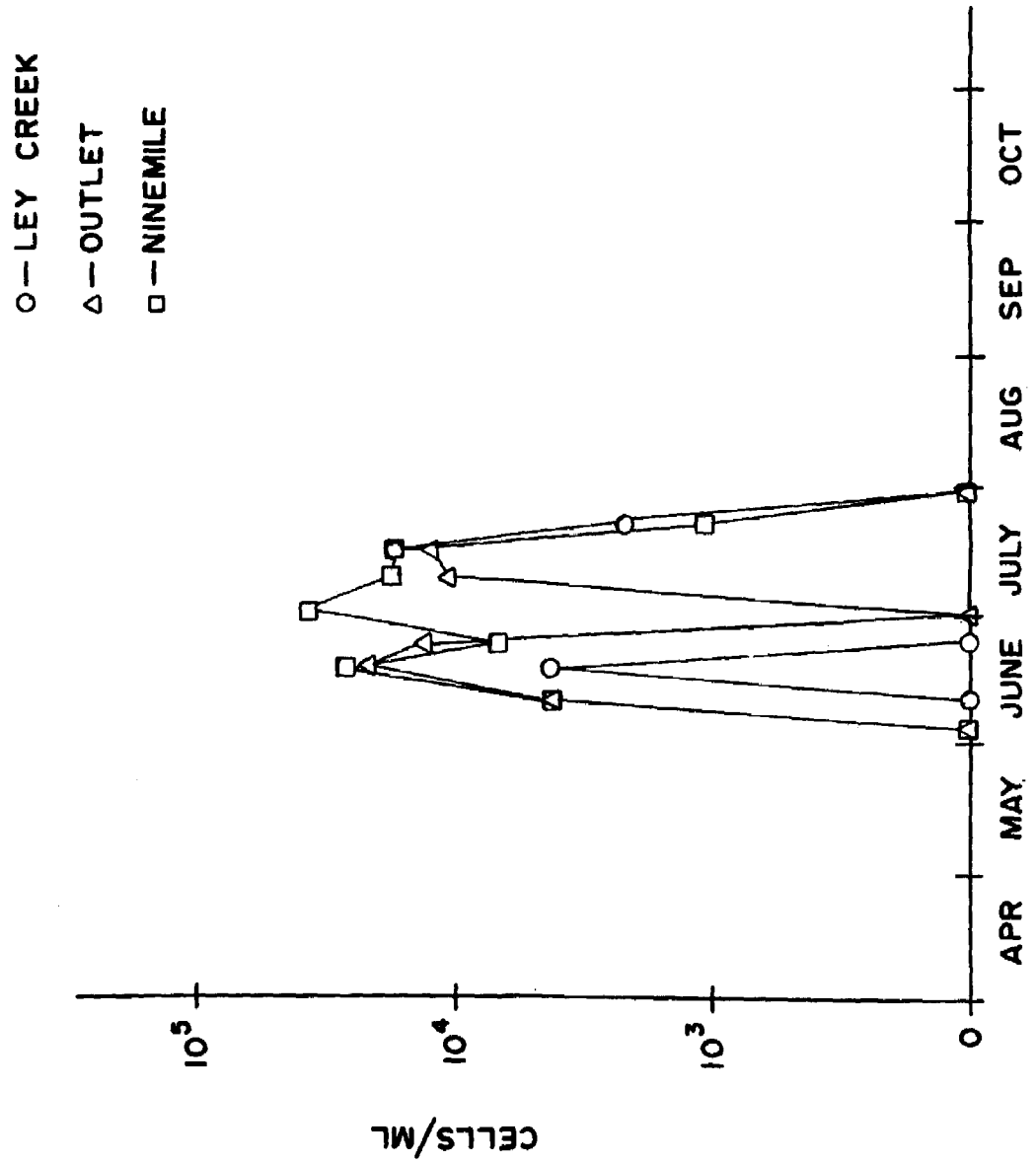


SCENEDESMUS obliquus (TUBE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-13



SCENEDESMUS obliquus (SURFACE SAMPLES)

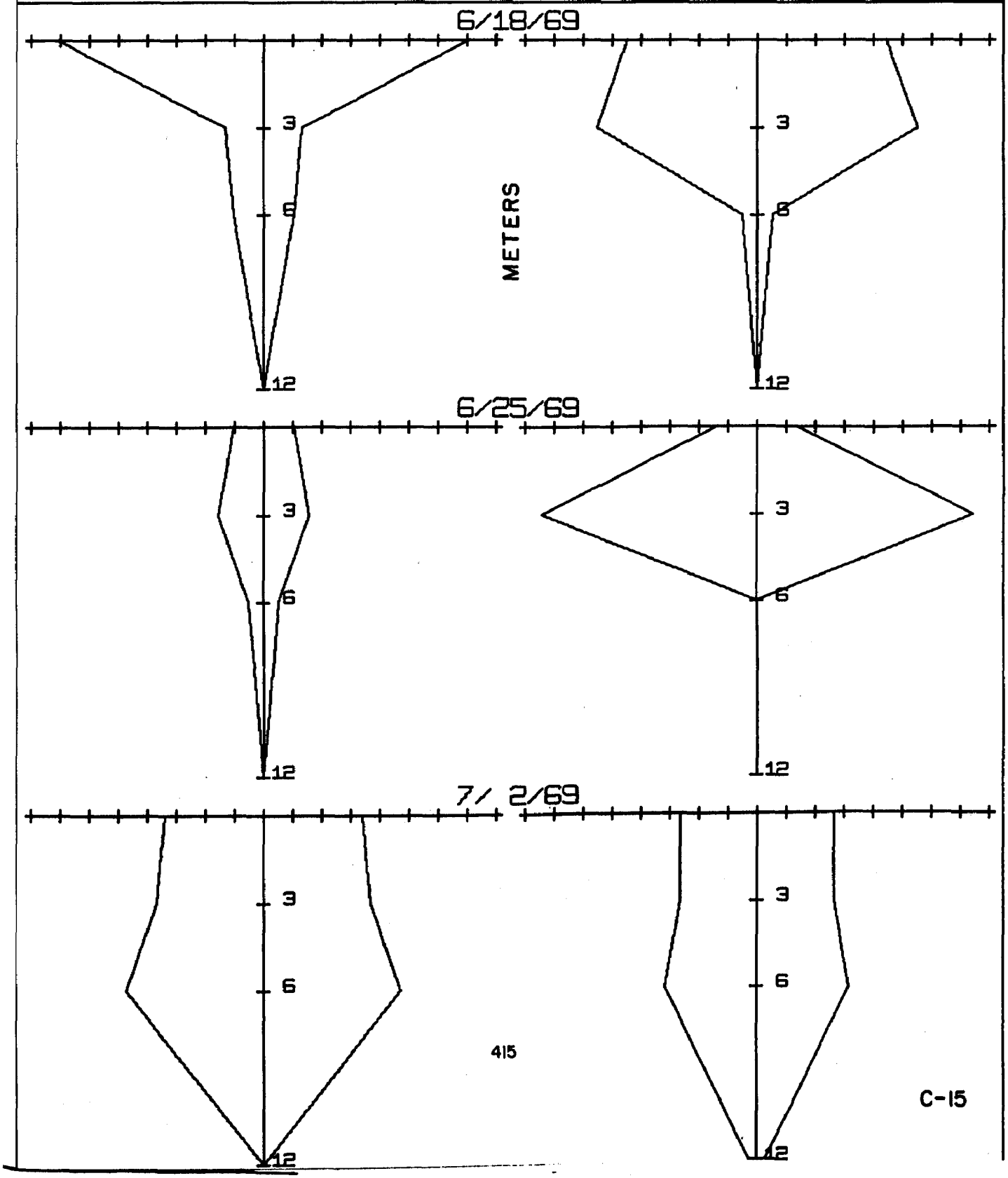
O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-14

SCENEDESMUS OBLIQUUS PHY 8

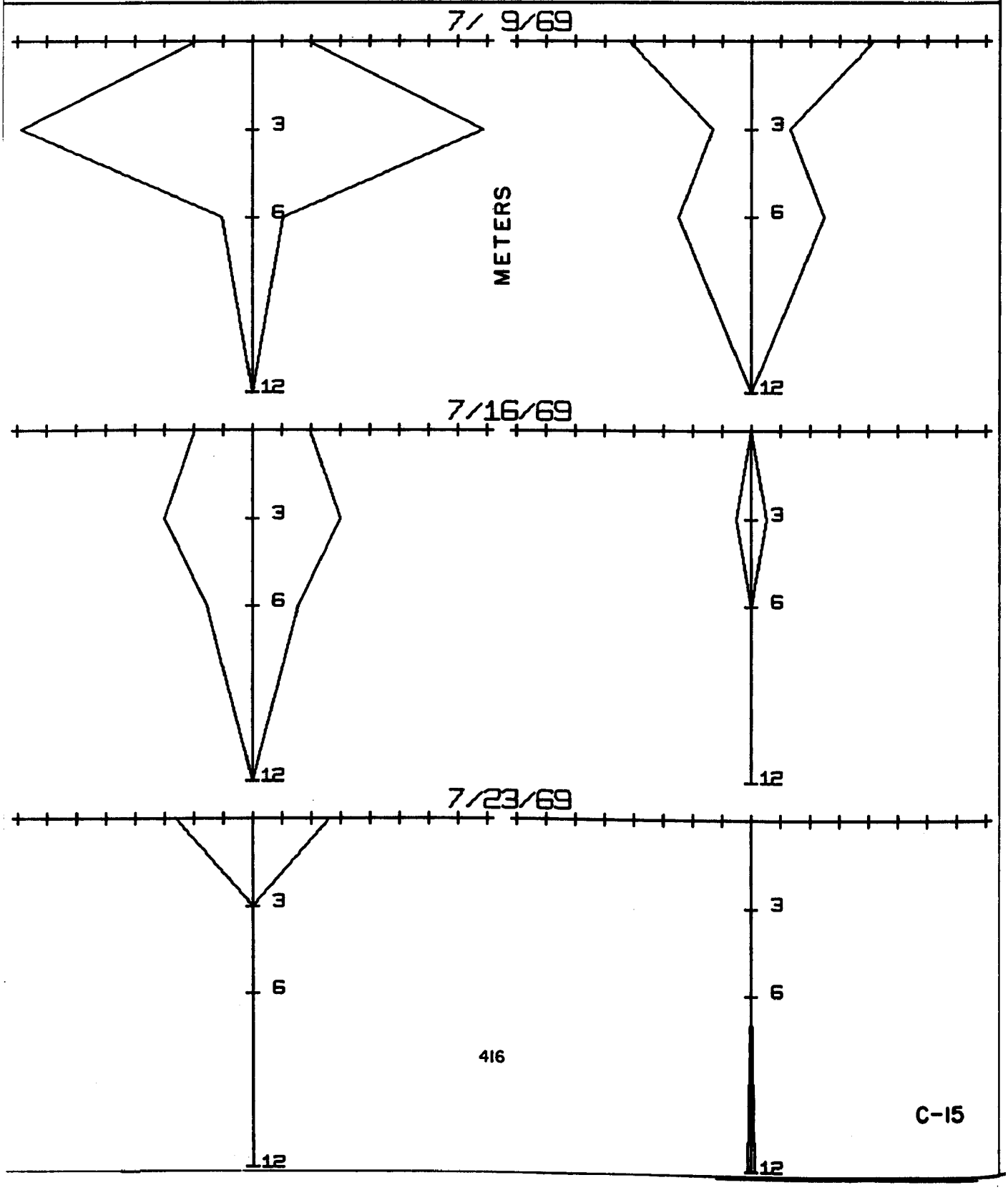
STATION 1 1/4 IN = 4000 CELLS/ML STATION 2



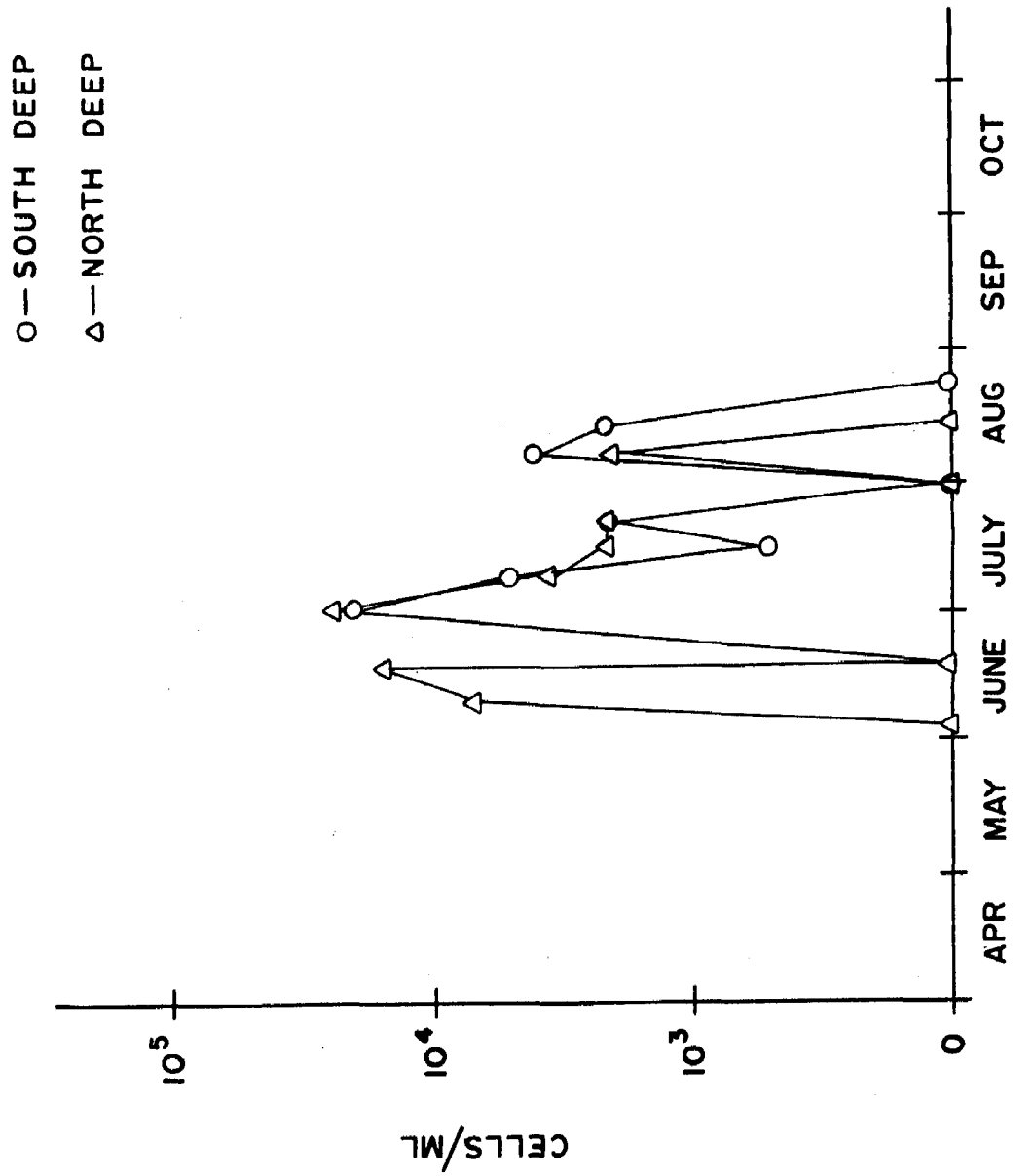
C-15

SCENEDESMUS OBLIQUUS PHY 9

STATION 1 1/4 IN = 4000 CELLS/ML STATION 2



C-15

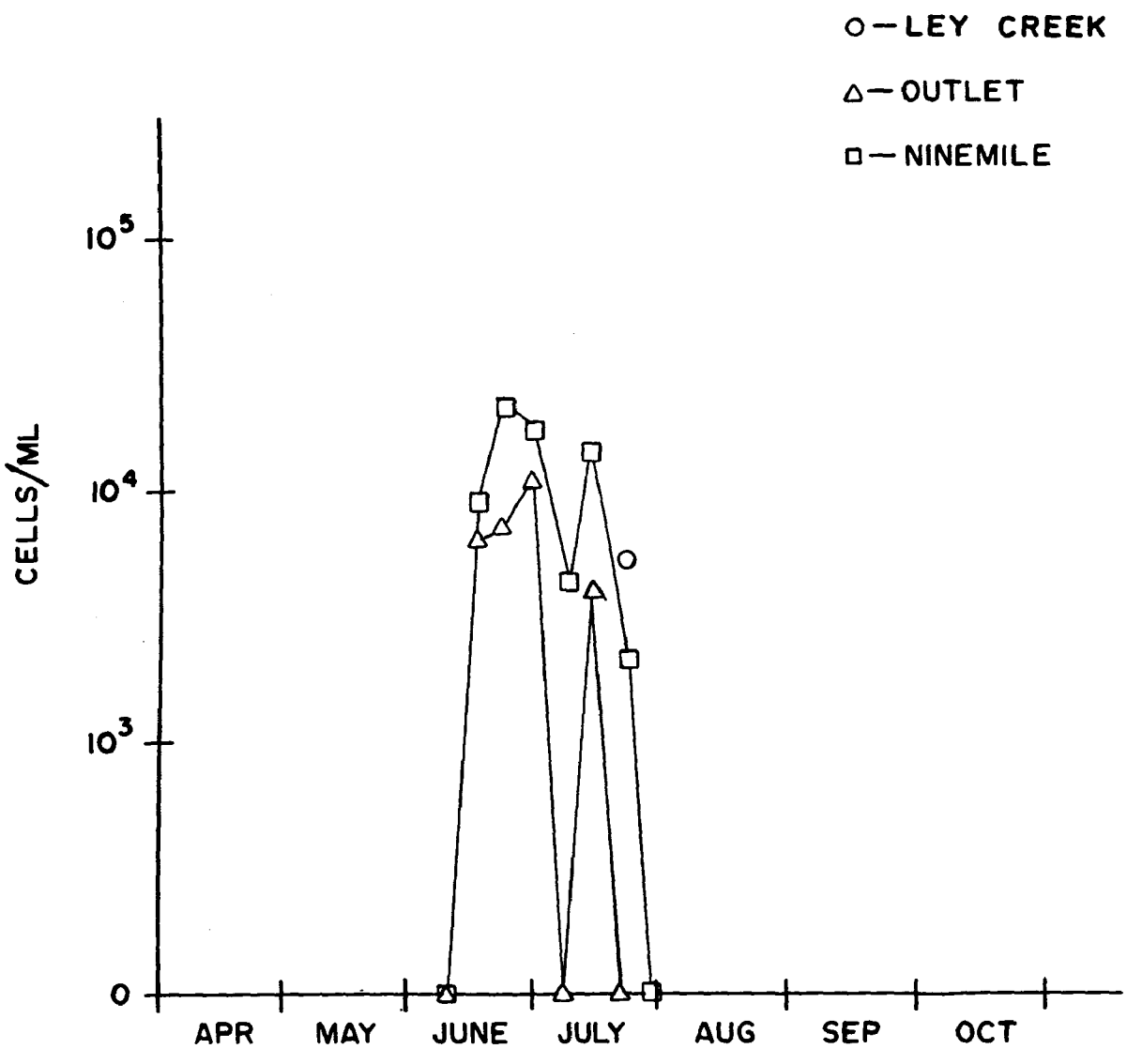


SCENEDESMUS quad. (TUBE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-16



418

SCENEDESMUS quad. (SURFACE SAMPLES)

O'BRIEN & GERE
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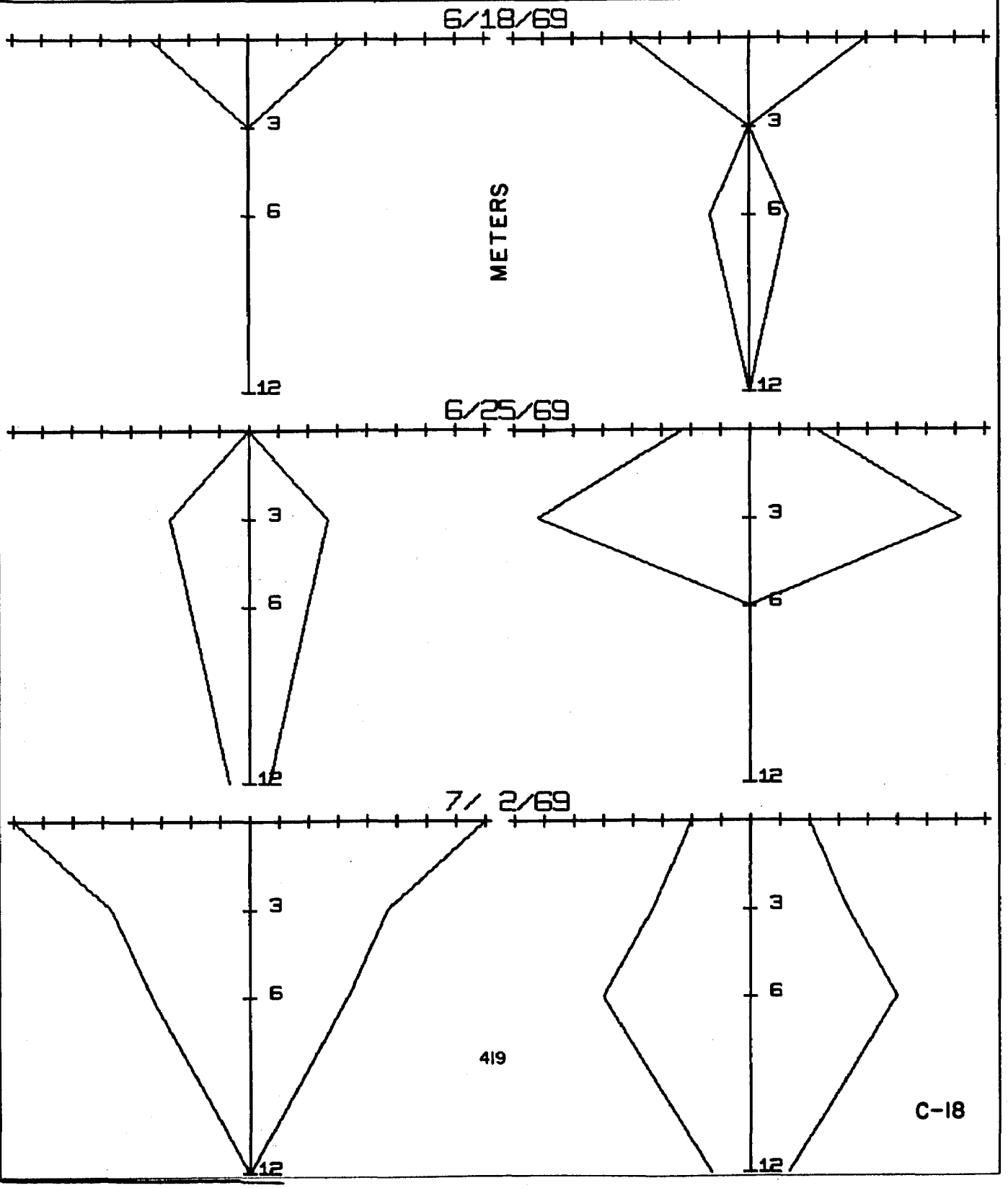
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-17

SCENEDESMUS QUADRICAUDA PHY10

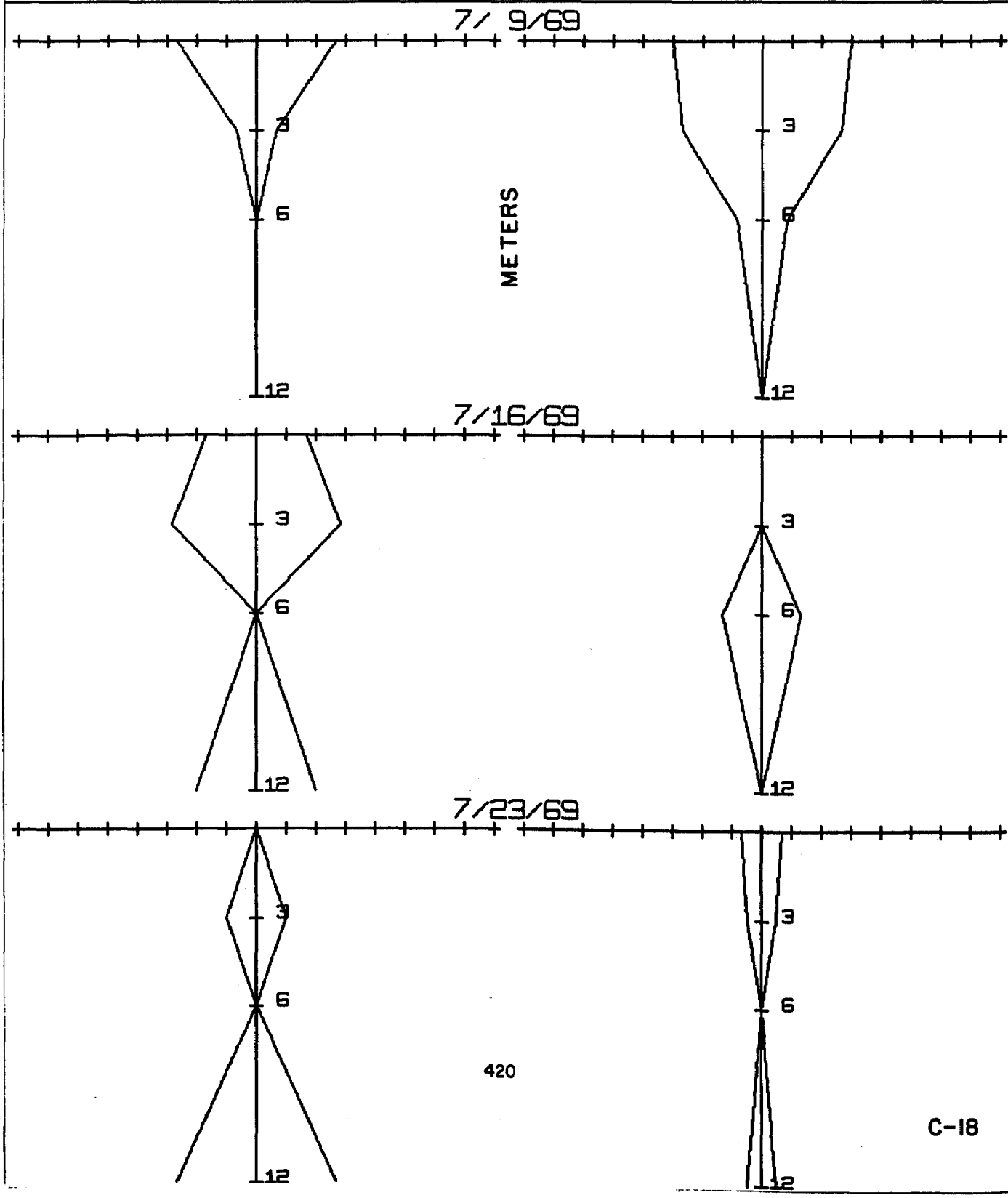
STATION 1 1/4 IN = 3150 CELLS/ML STATION 2



C-18

SCENEDESMUS QUADRICAUDA PHY11

STATION 1 1/4 IN = 3150 CELLS/ML STATION 2



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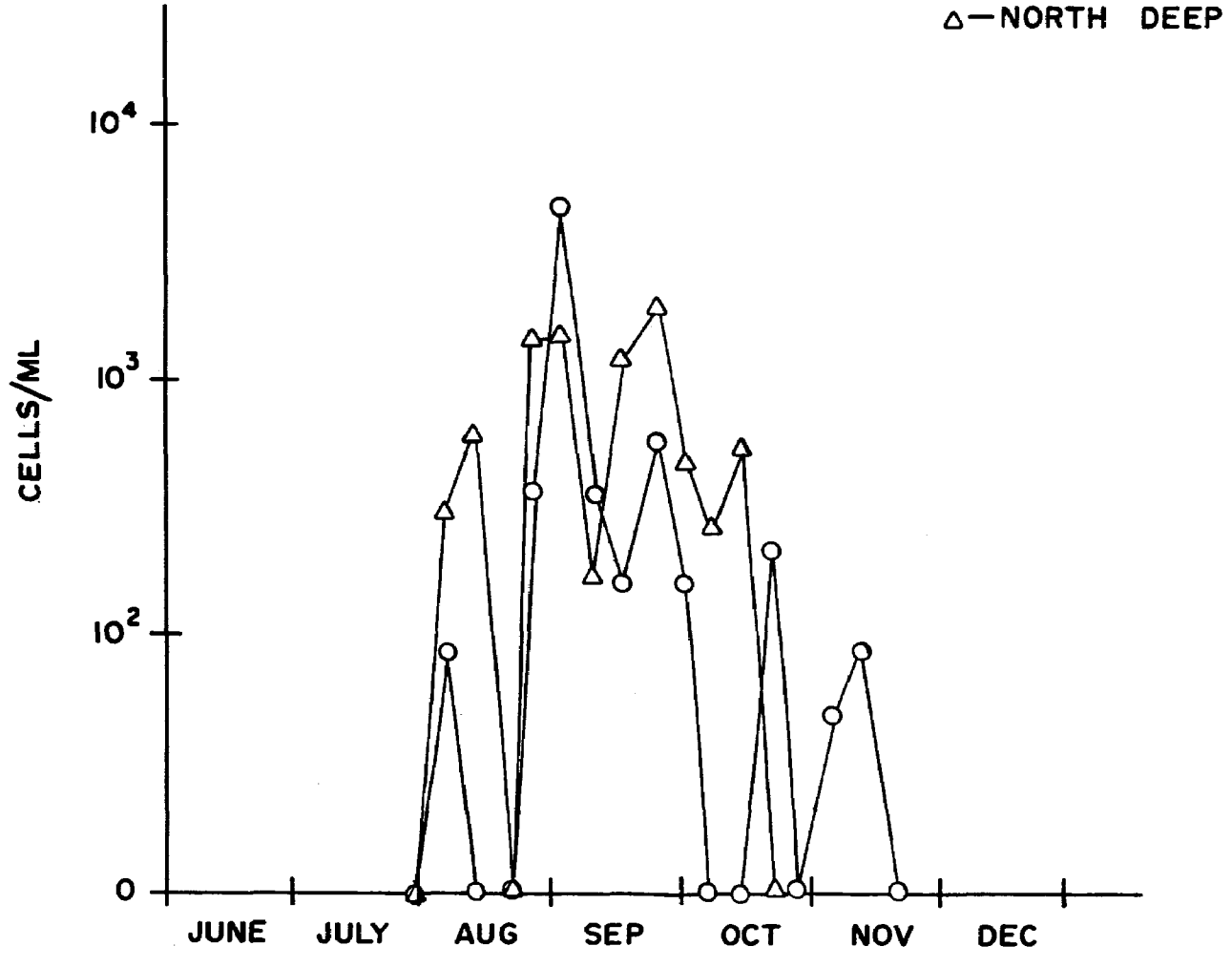


421

APHANIZOMENON flos-aquae (TUBE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-19

422

APHANIZOMENON flos-aquae
(SURFACE SAMPLES)

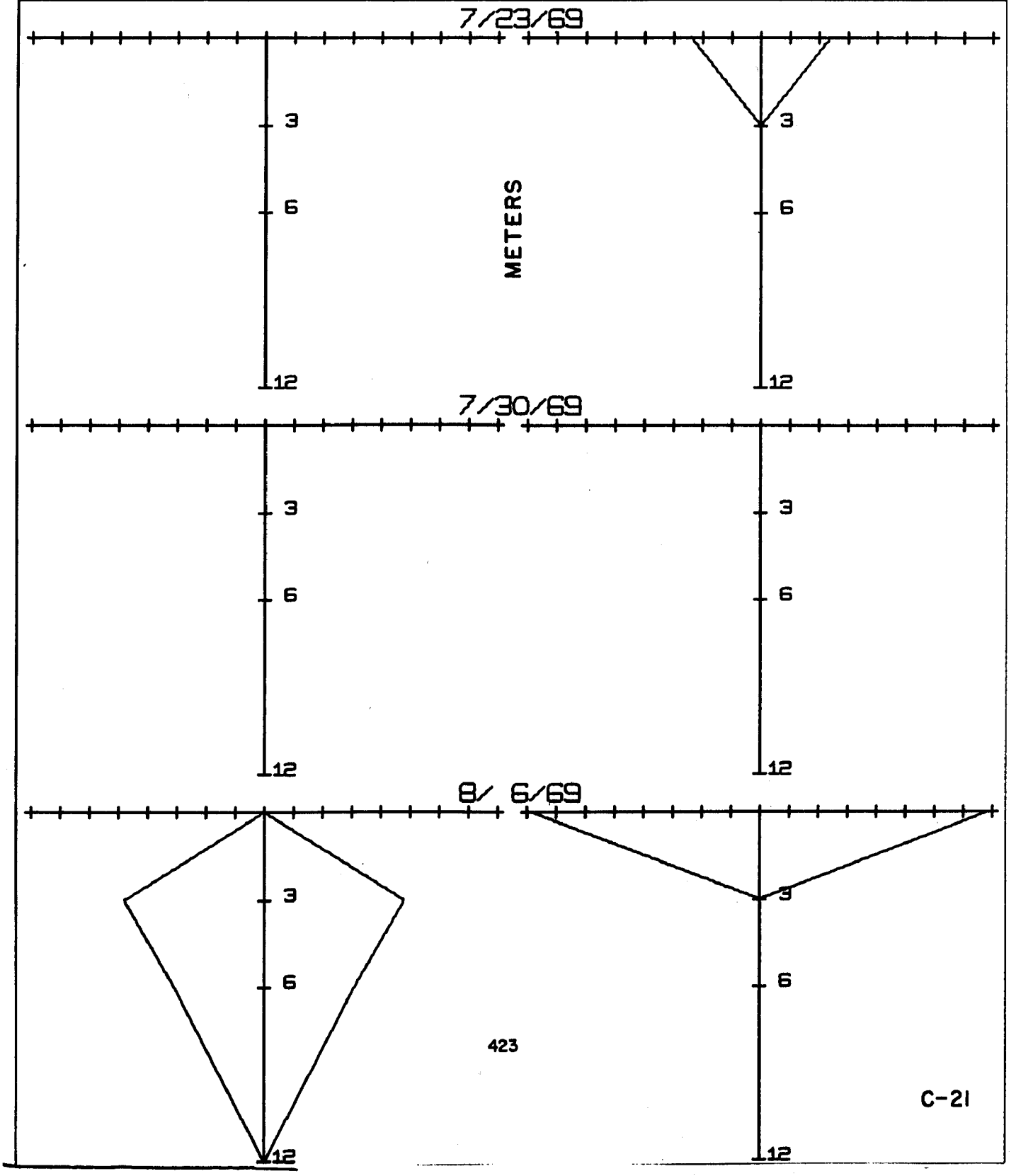
O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C20

APHANIZOMENON FLOS-AQUAE PHY14

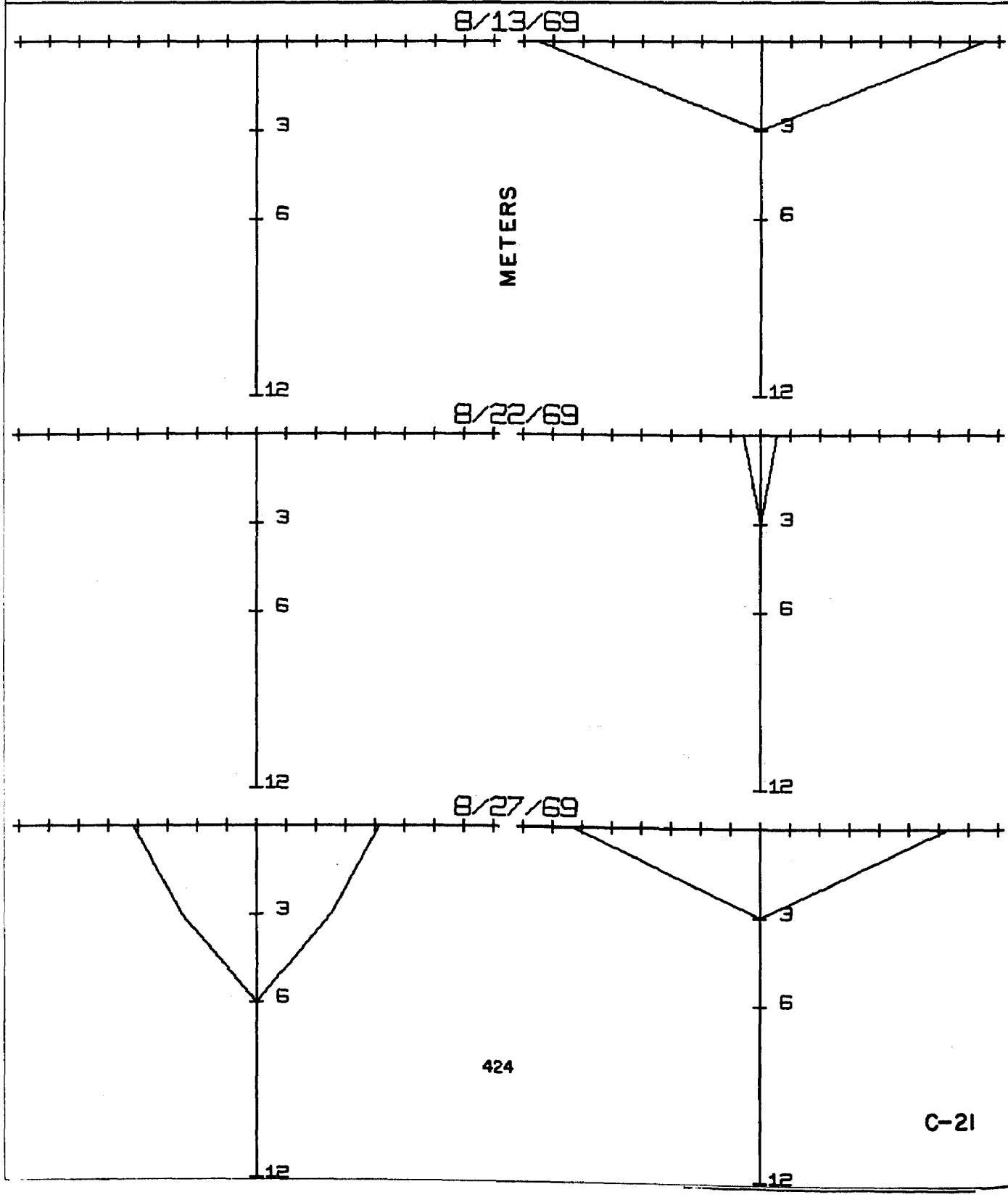
STATION 1 1/4 IN = 50 CELLS/ML STATION 2



C-21

APHANIZOMENON FLOS-AQUAE PHY15

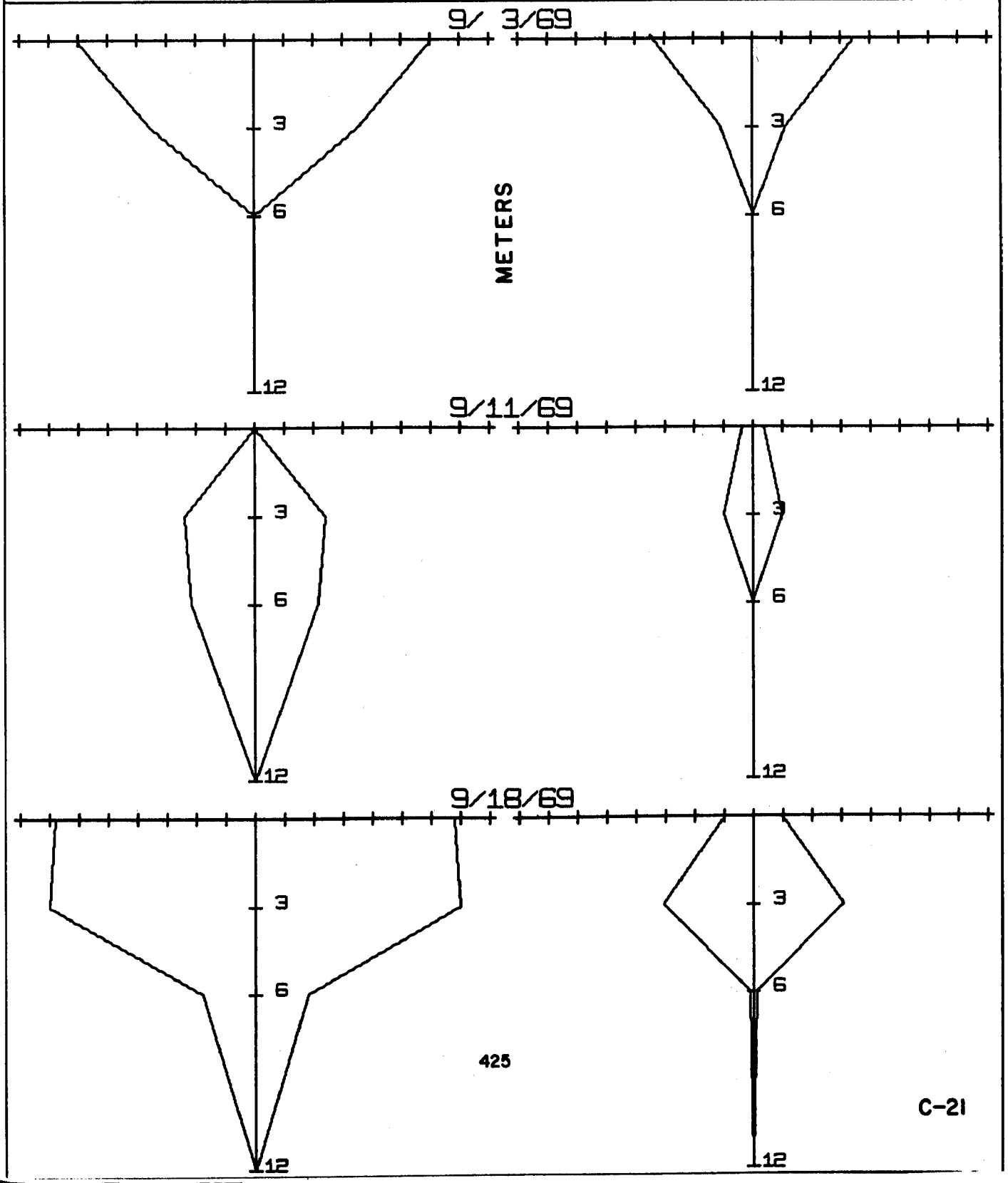
STATION 1 1/4 IN = 200 CELLS/ML STATION 2



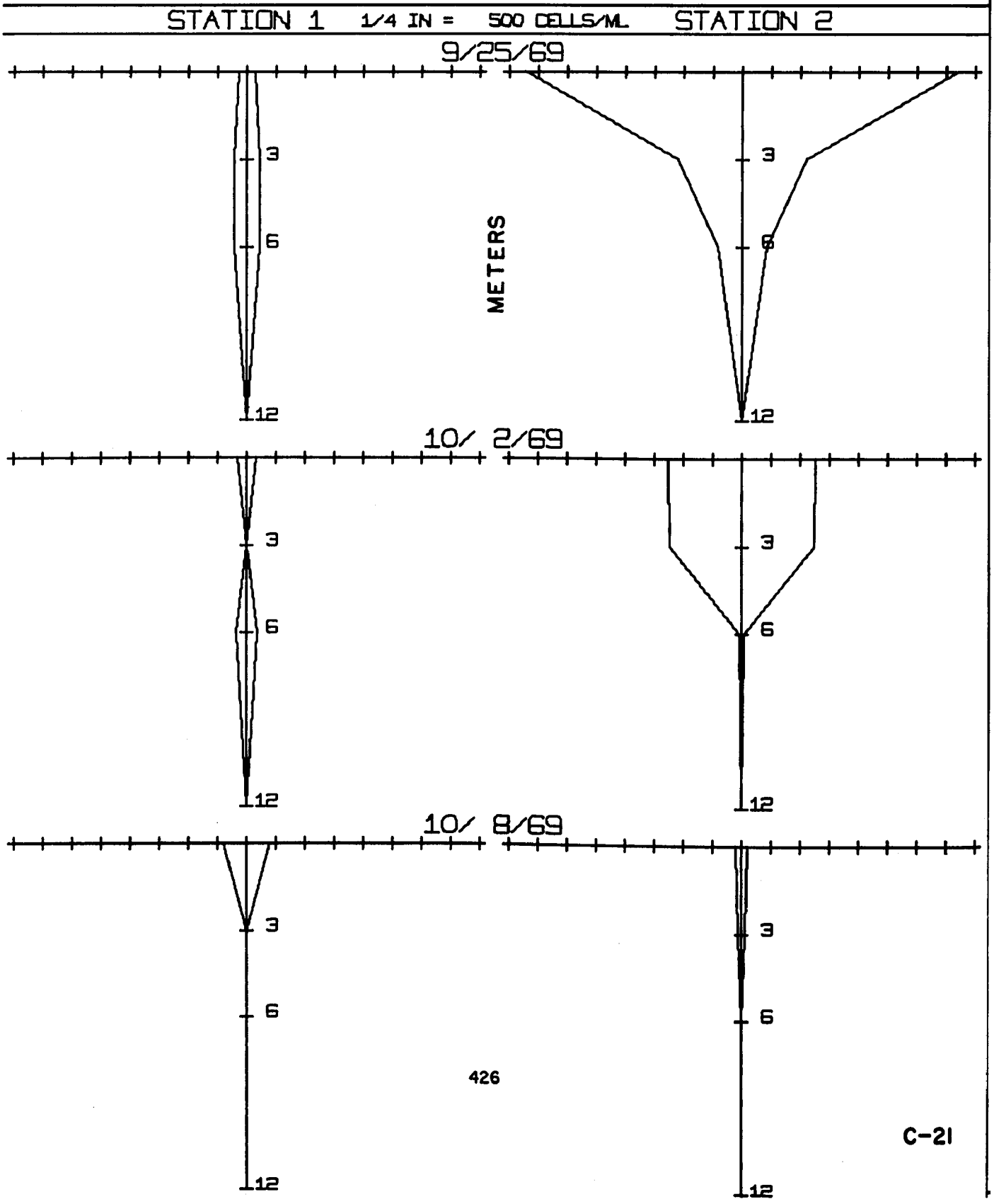
C-21

APHANIZOMENON FLOS-AQUAE PHY16

STATION 1 1/4 IN = 500 CELLS/ML STATION 2

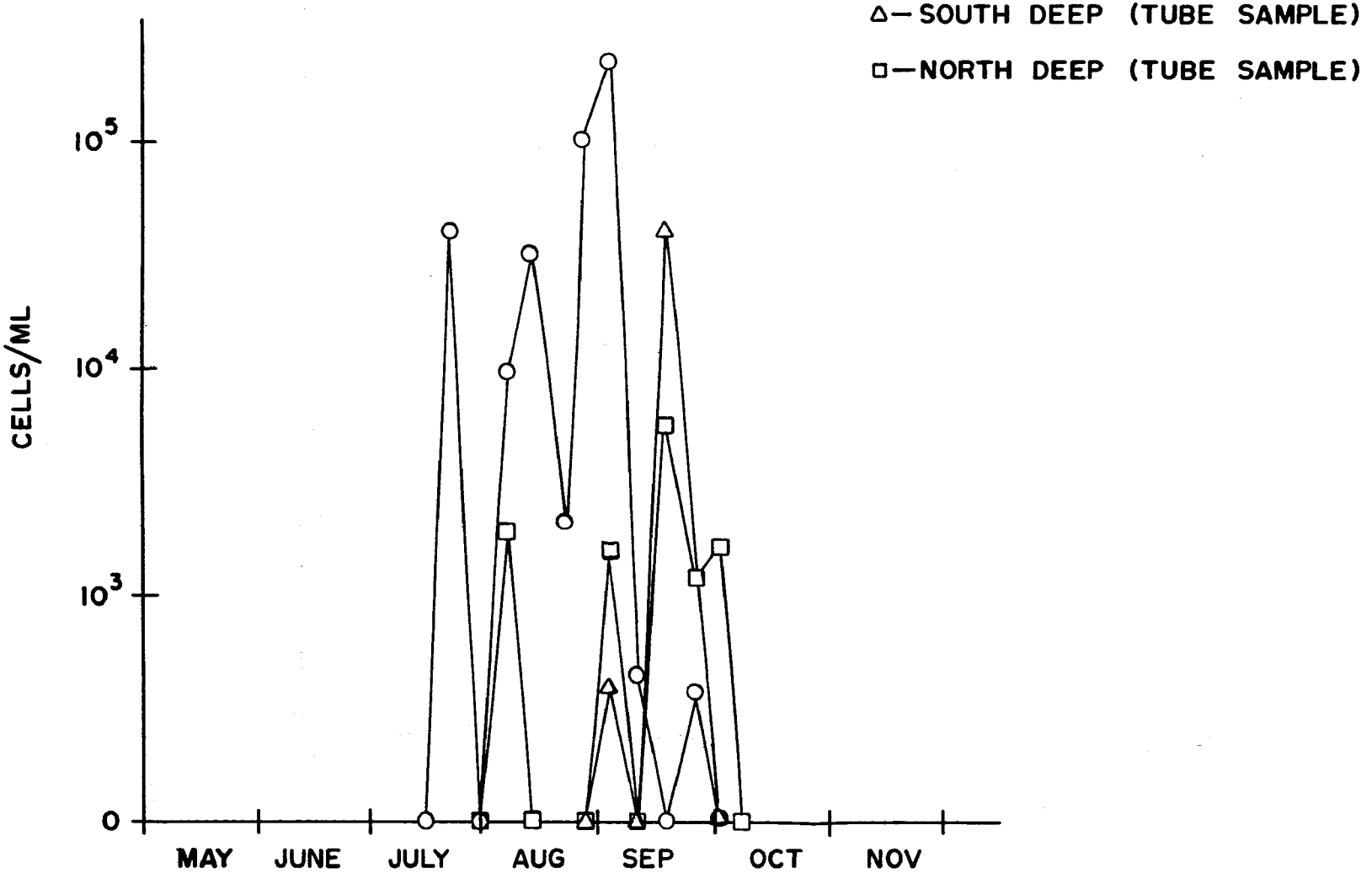


APHANIZOMENON FLOS-AQUAE PHY17



C-21

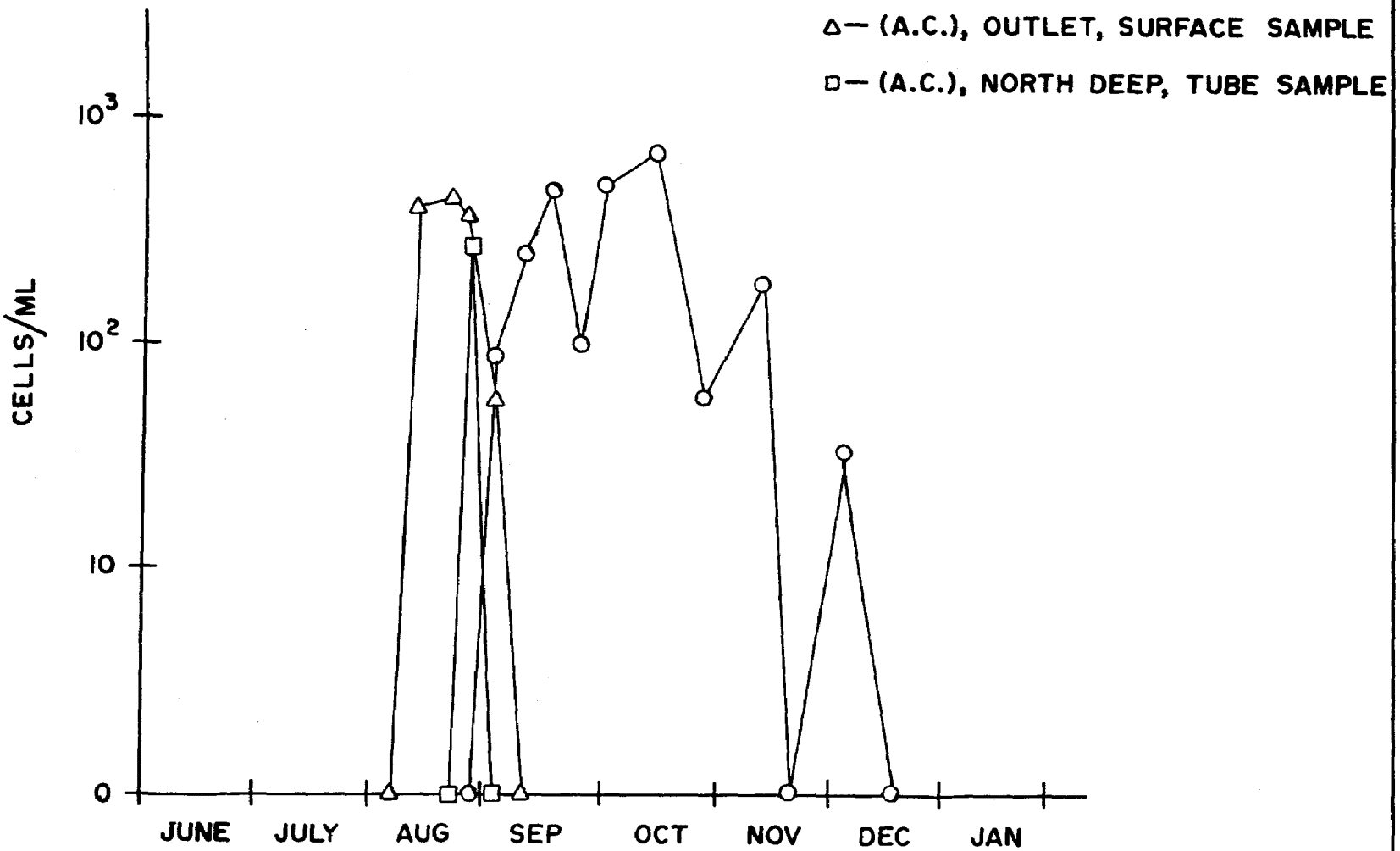
POLYCYSTIS aeruginosa



O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C22



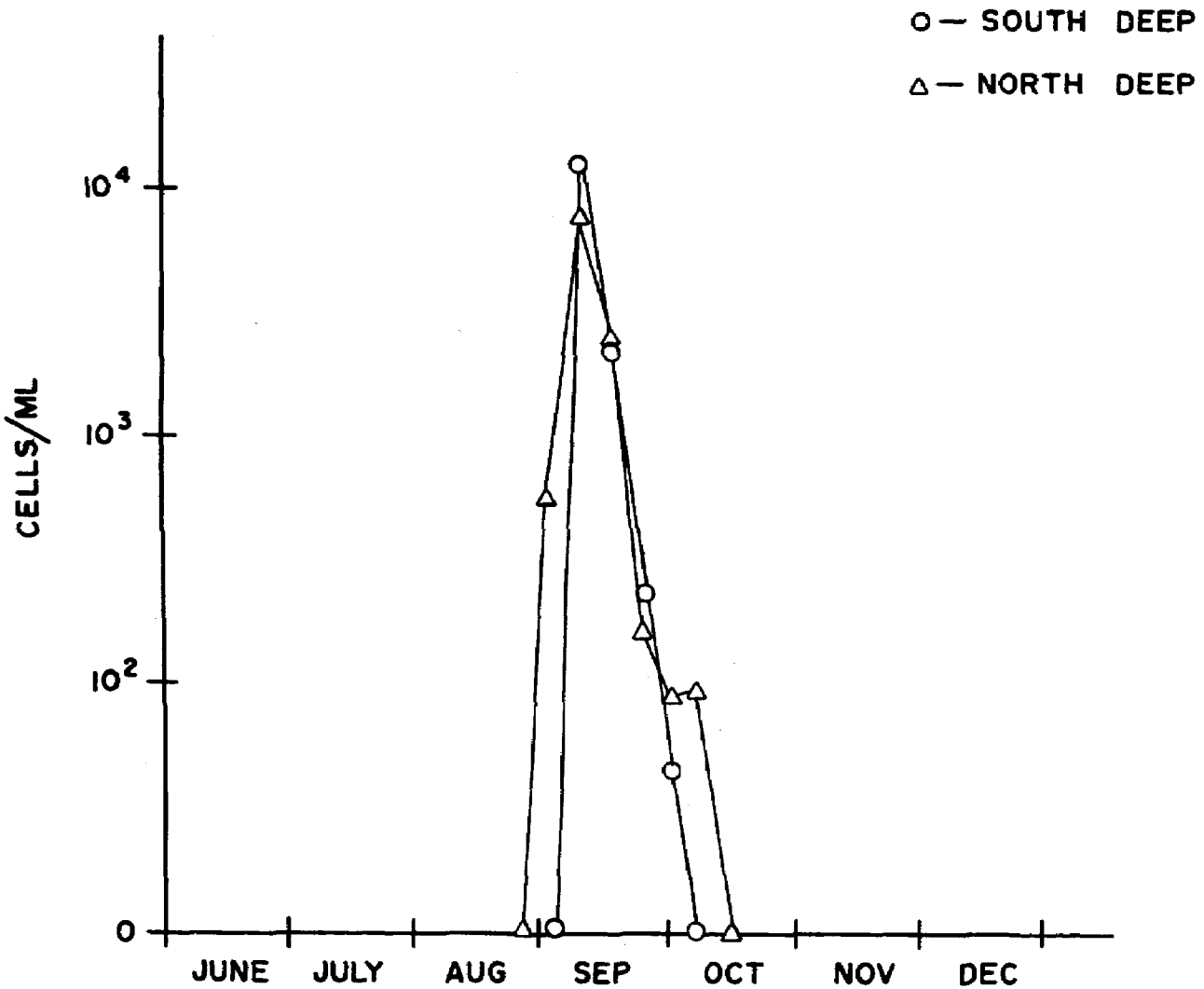
428

ANABAENA circinalis
FRAGILARIA crotonensis

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-23



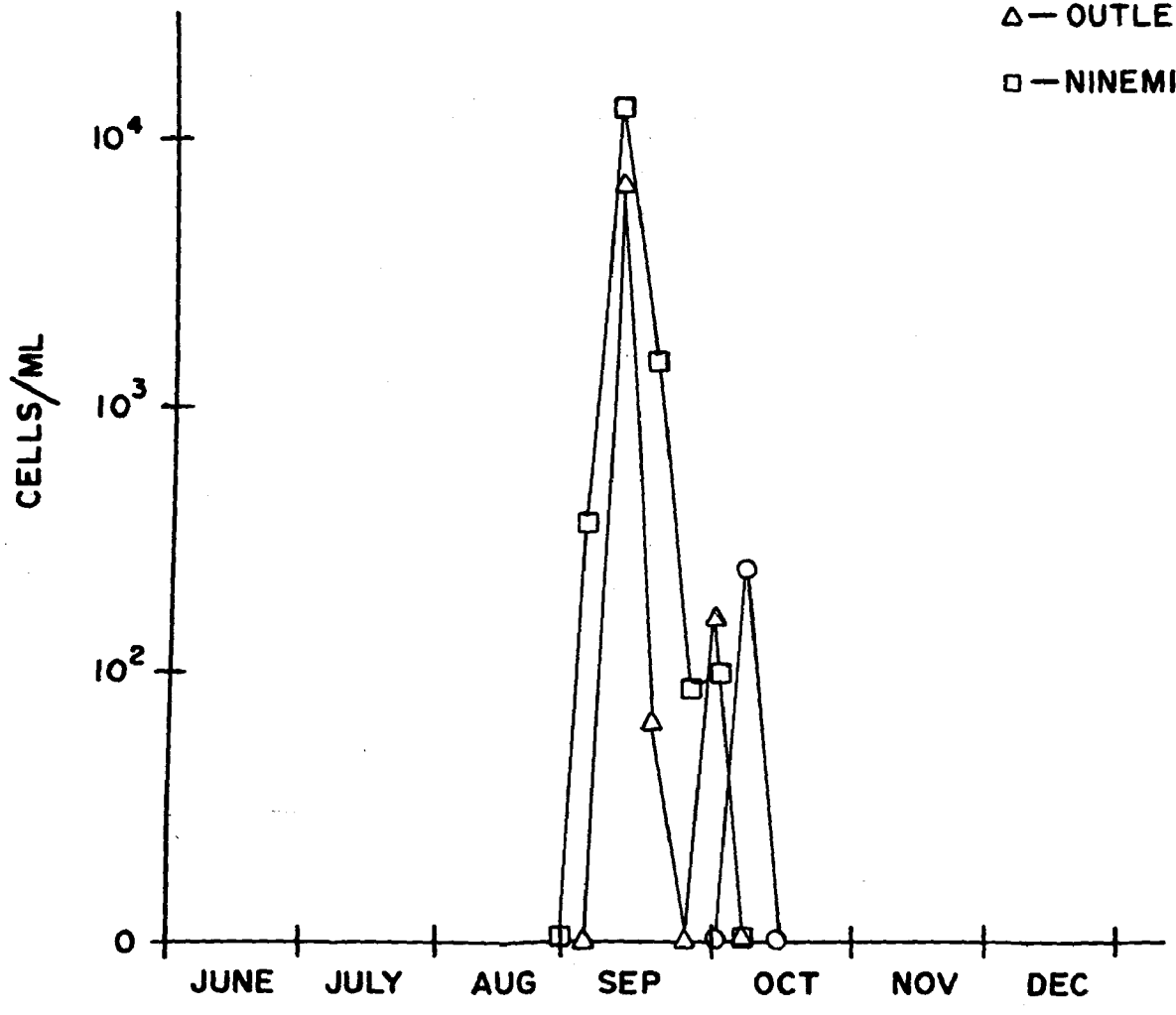
429

MELOSIRA granulata (TUBE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C24



430

MELOSIRA granulata (SURFACE SAMPLES)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

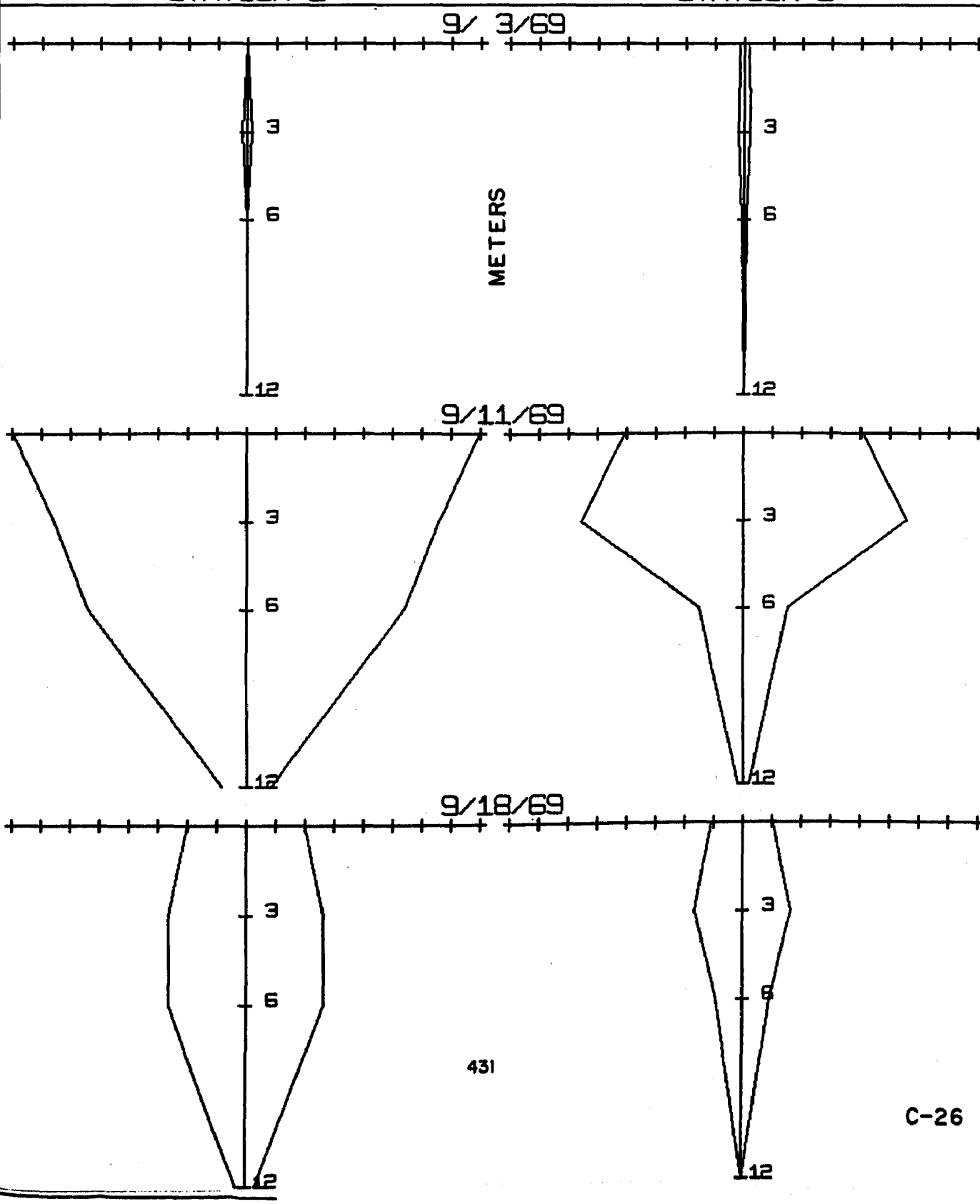
DATE:
SCALE:
FILE NO.:

C-25

MELOSIRA GRANULATA

PHY12

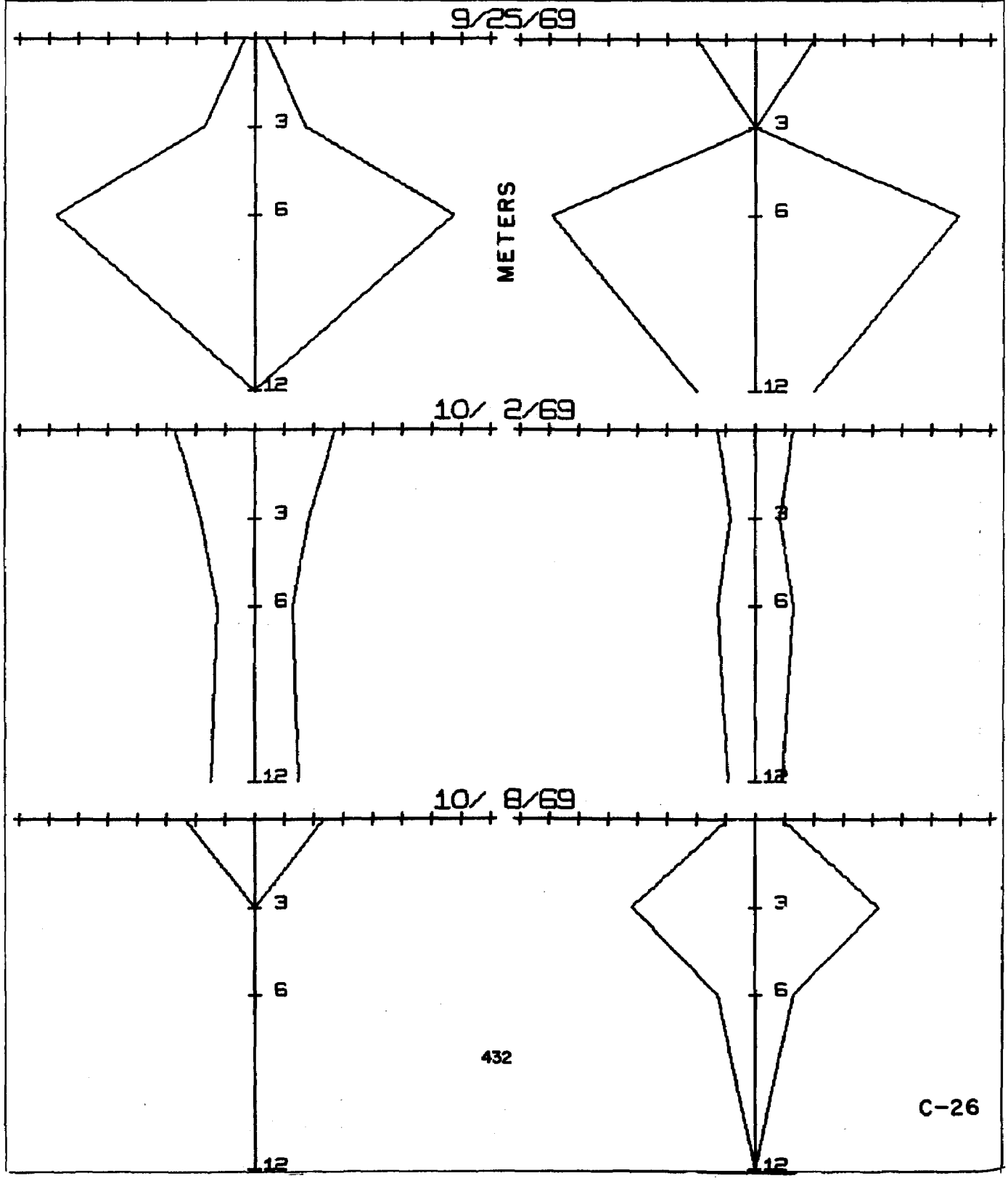
STATION 1 1/4 IN = 1875 CELLS/ML STATION 2



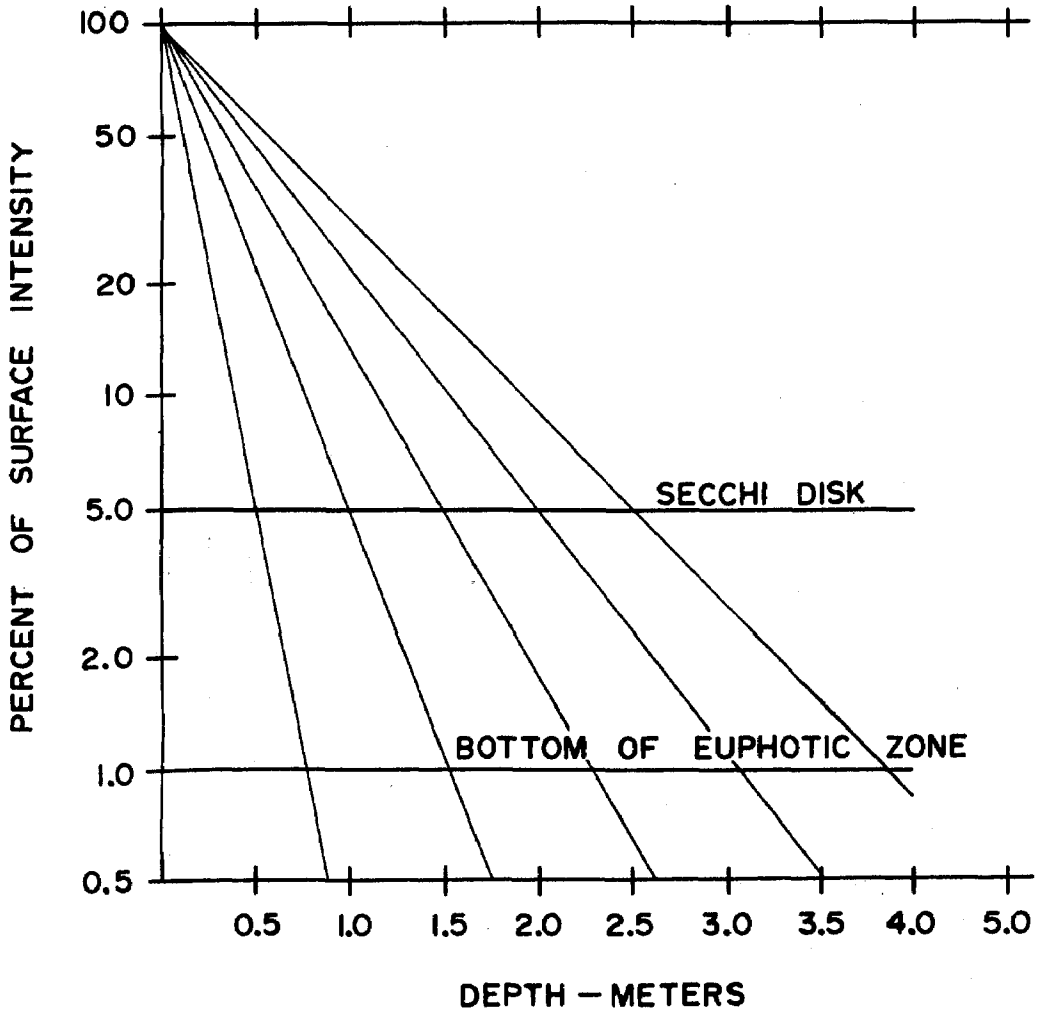
MELOSIRA GRANULATA

PHY13

STATION 1 1/4 IN = 30 CELLS/ML STATION 2



C-26



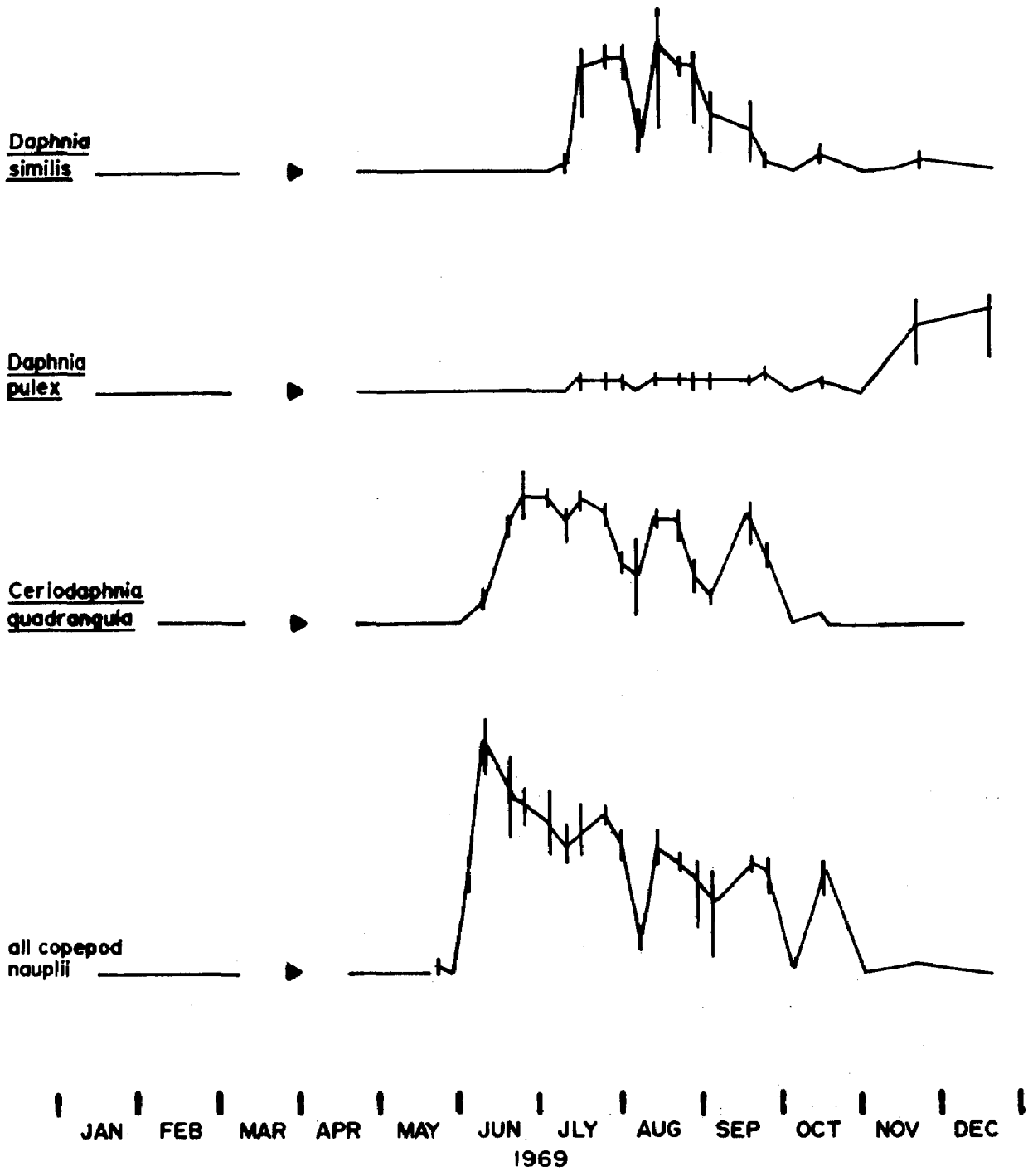
433

EUPHOTIC ZONE DETERMINATION
(SEE TEXT)

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

C-27



APPROXIMATE NUMBERS PER 100 LITERS

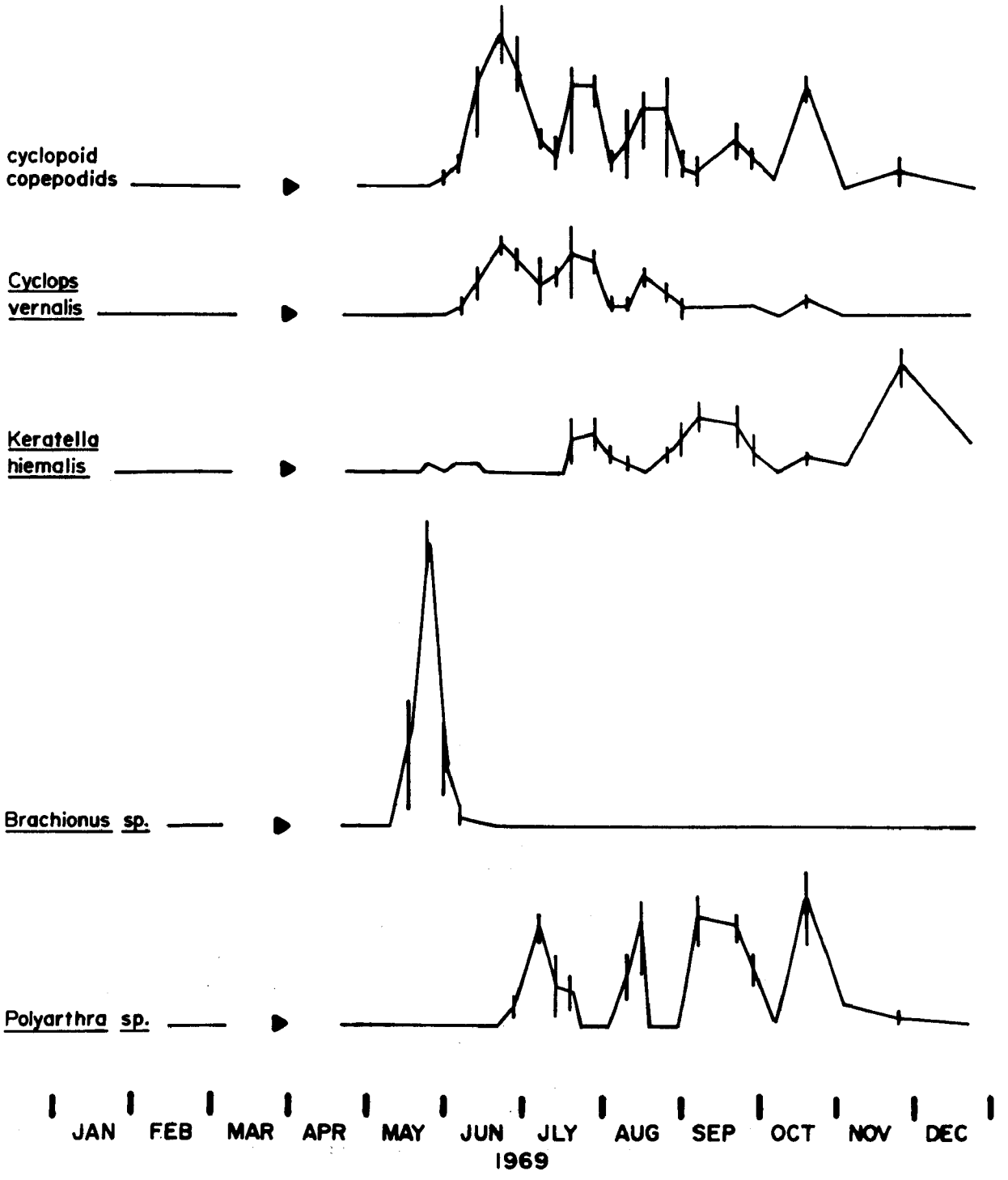
434

ONONDAGA LAKE ZOOPLANKTON

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

028



APPROXIMATE NUMBERS PER 100 LITERS

435

ONONDAGA LAKE ZOOPLANKTON

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

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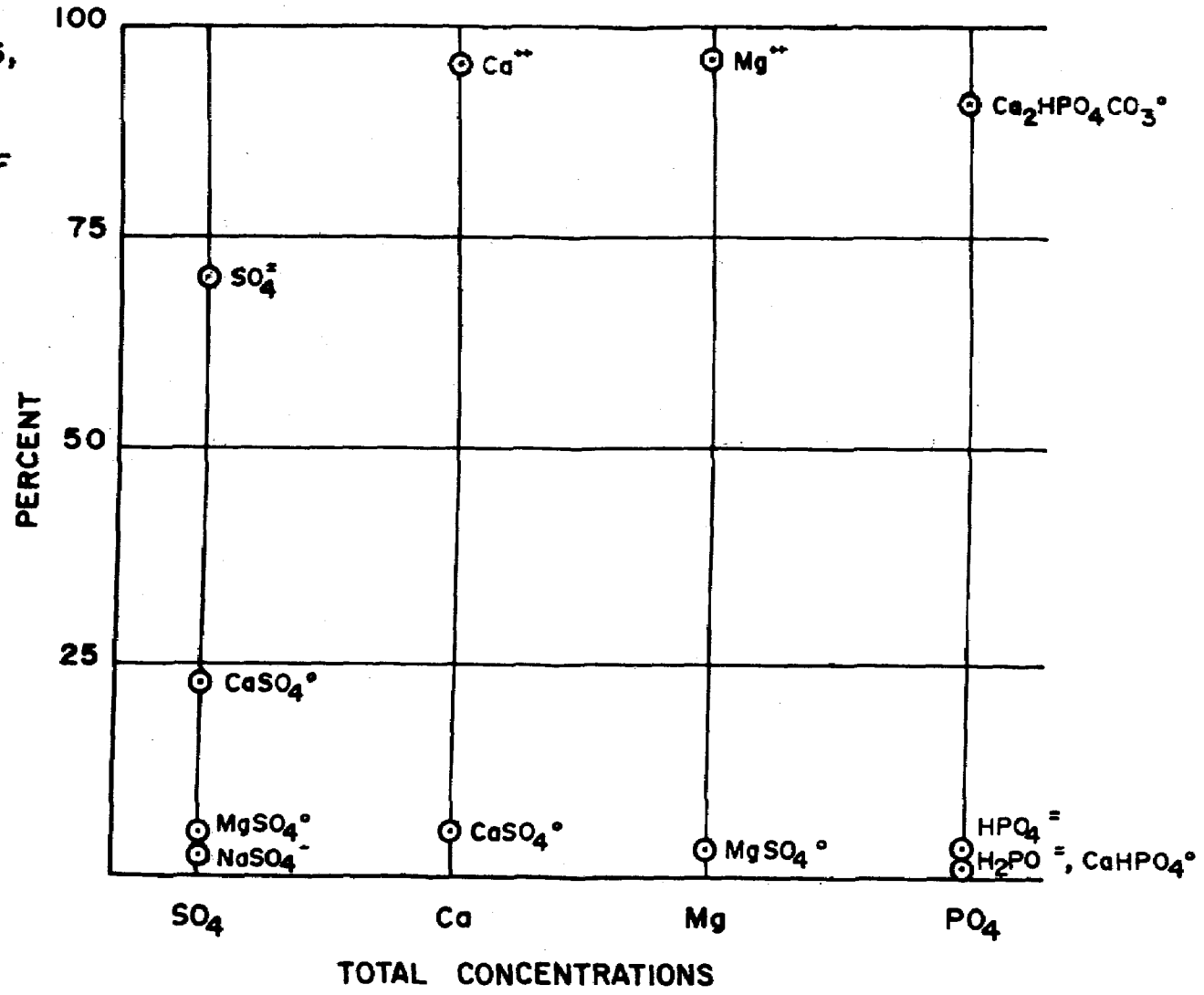
SCALE:
FILE NO.:

030

PERCENTAGE CONCENTRATIONS OF IONS, ION PAIRS, RELATIVE TO TOTAL CONCENTRATION OF CHEMICAL SPECIES



436

TYPICAL DISTRIBUTION OF DISSOLVED IONS AND ION PAIRS

O'BRIEN & GERE
ENGINEERS, INC.
SYRACUSE, NEW YORK

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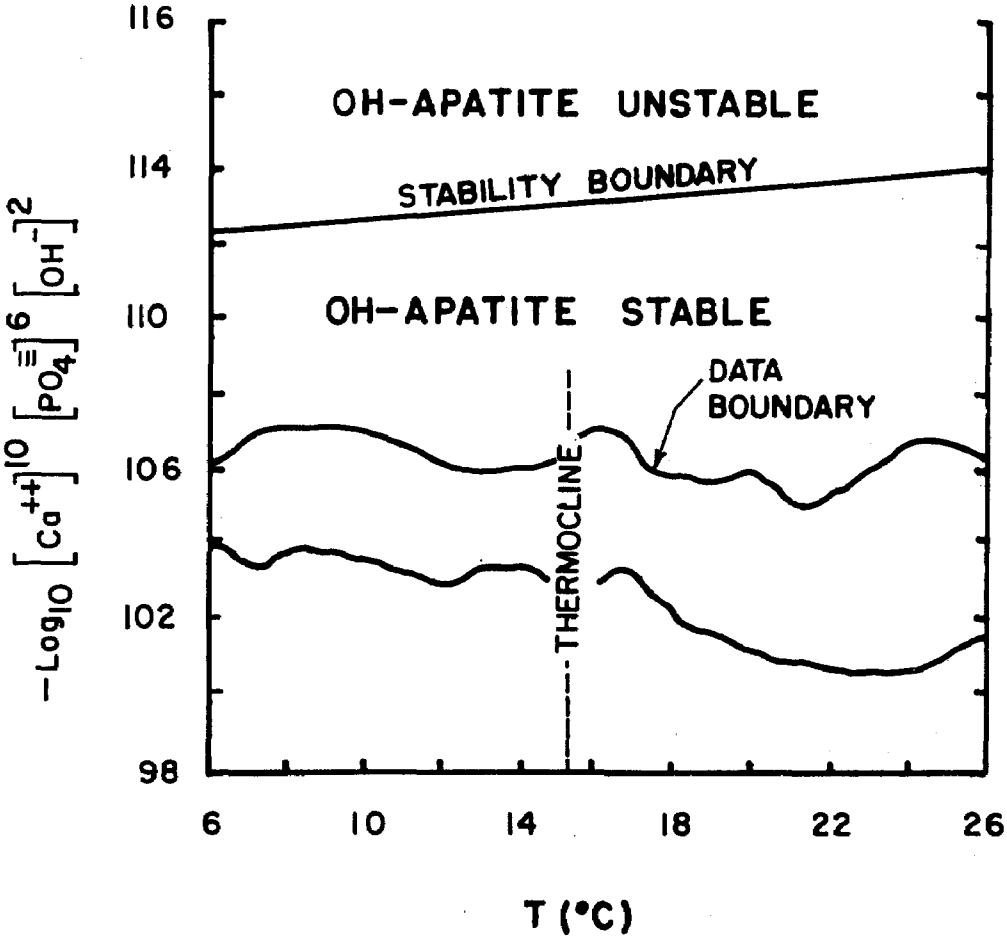
FILE NO.:

D-1



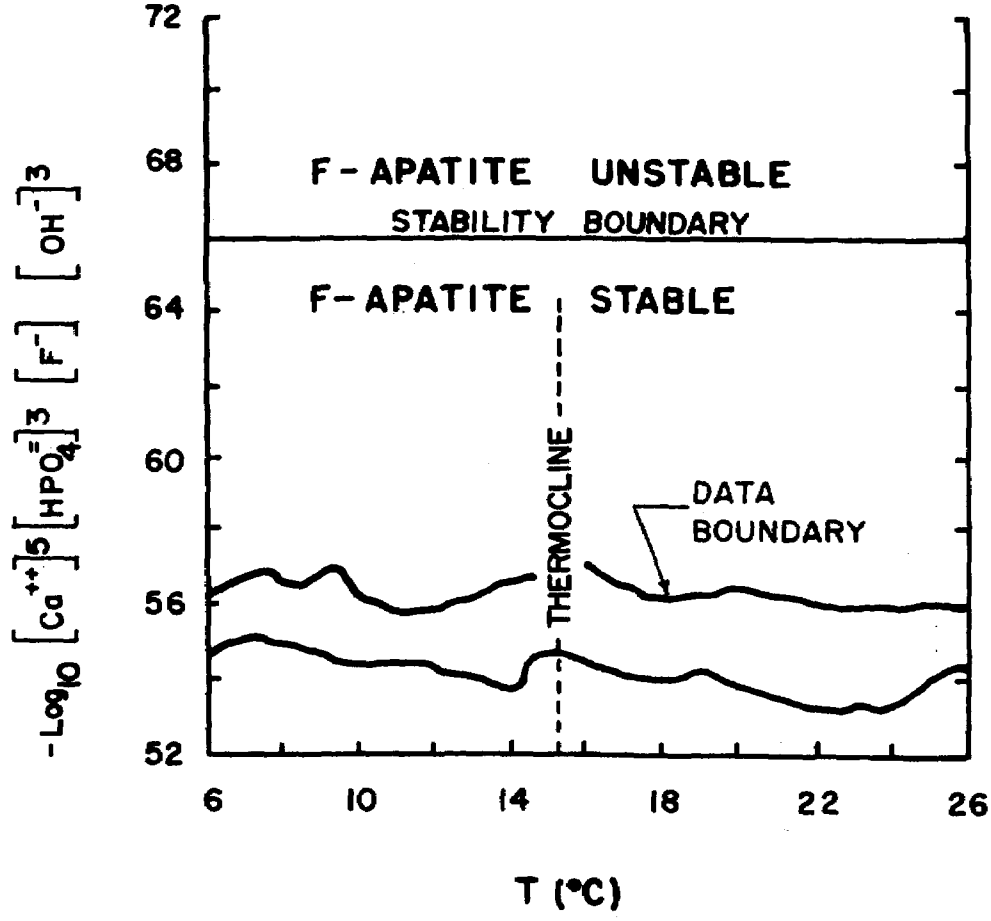
437

STABILITY DIAGRAM FOR HYDROXYAPATITE JUNE-OCT 69

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-2



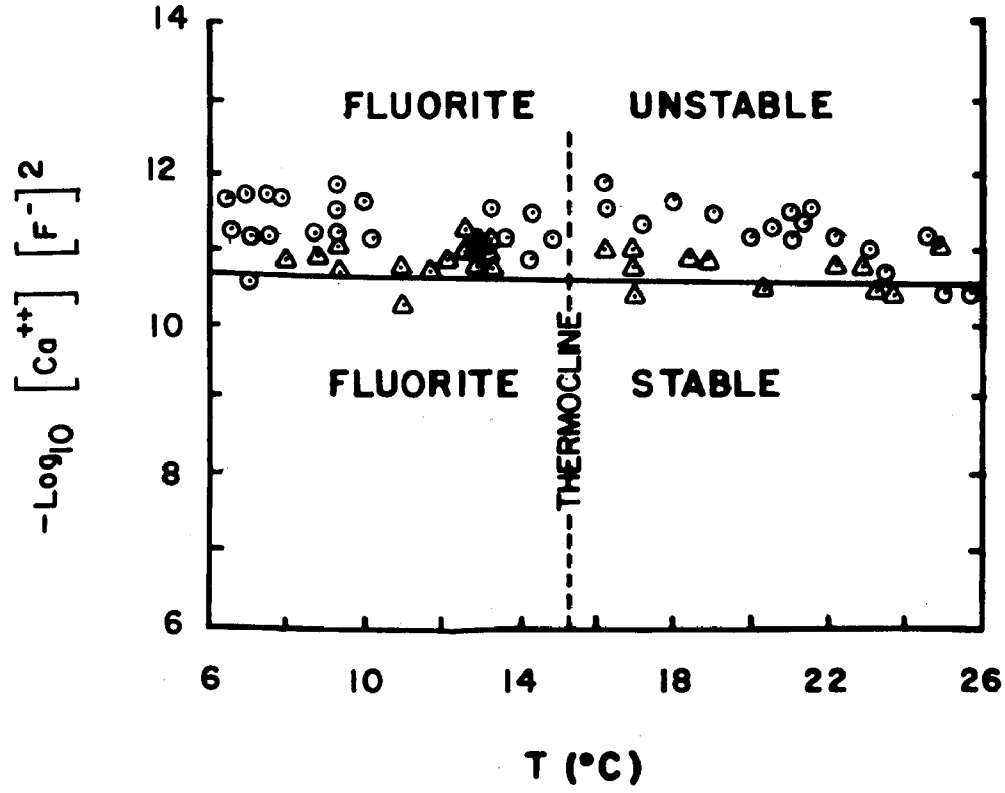
438

STABILITY DIAGRAM FOR FLUORAPATITE JUNE-OCT 69

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-3



⊙ JUNE 18 – JULY 16 1969

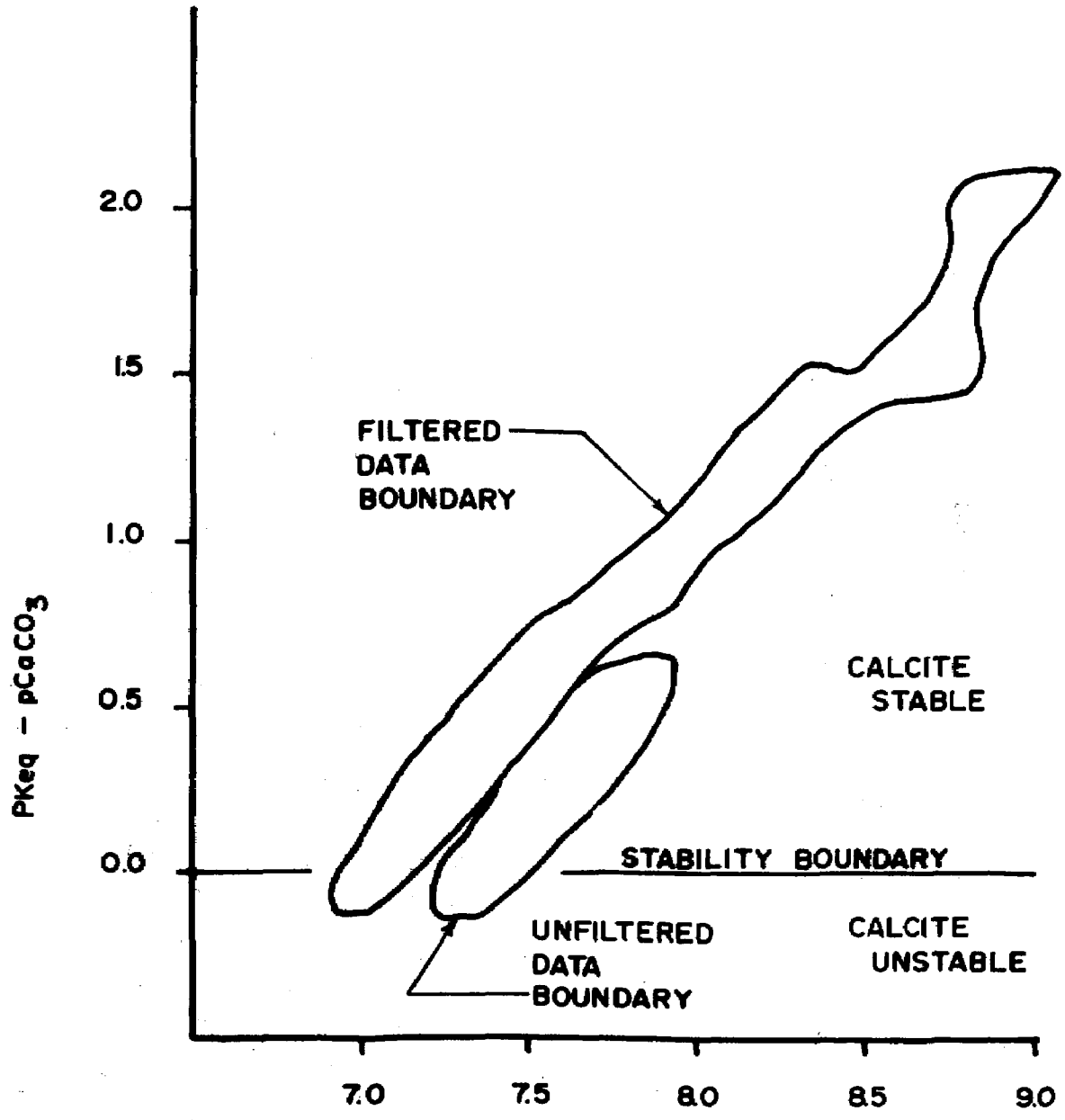
△ JULY 16 – OCT 29 1969

439

STABILITY DIAGRAM FOR FLUORITE JUNE–OCT 69

O'BRIEN & GERE
ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:



FILTERED WATER —
6/25/69 – 8/6/69
UNFILTERED WATER
FALL 1969

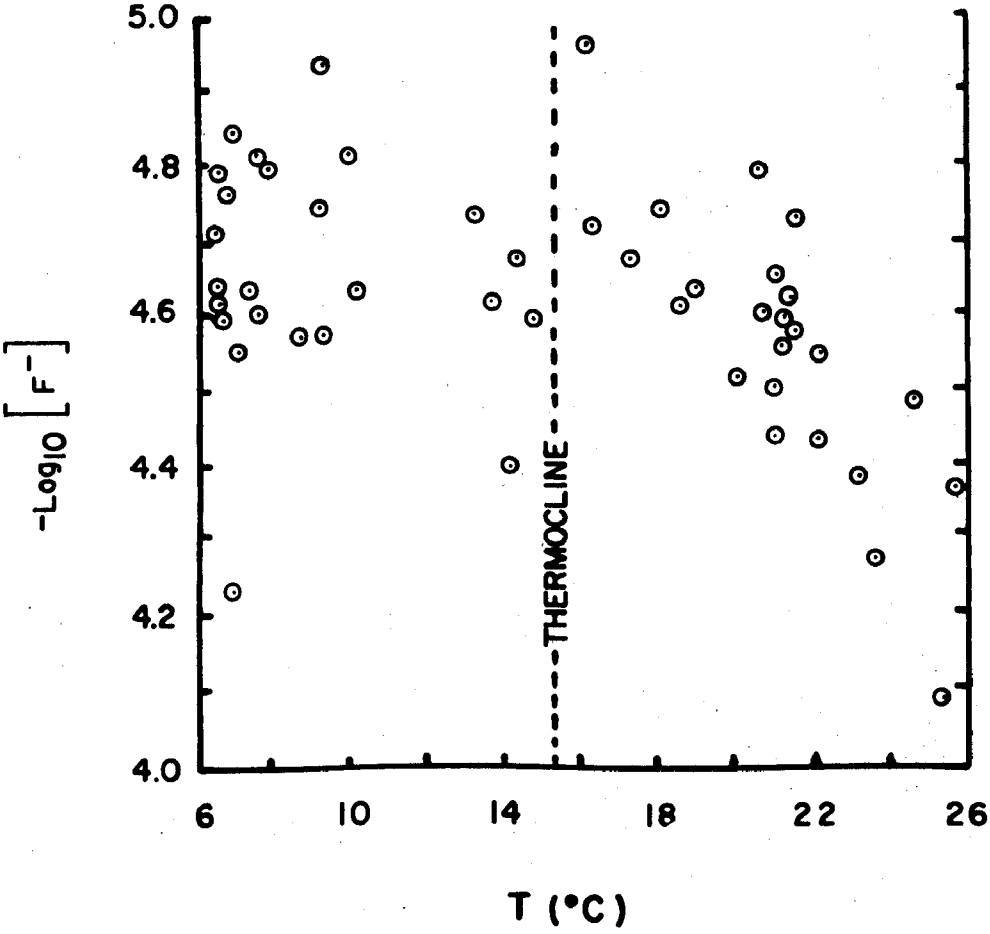
440

CALCITE–WATER EQUILIBRIUM MODEL

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-5



⊙ – DATA POINTS

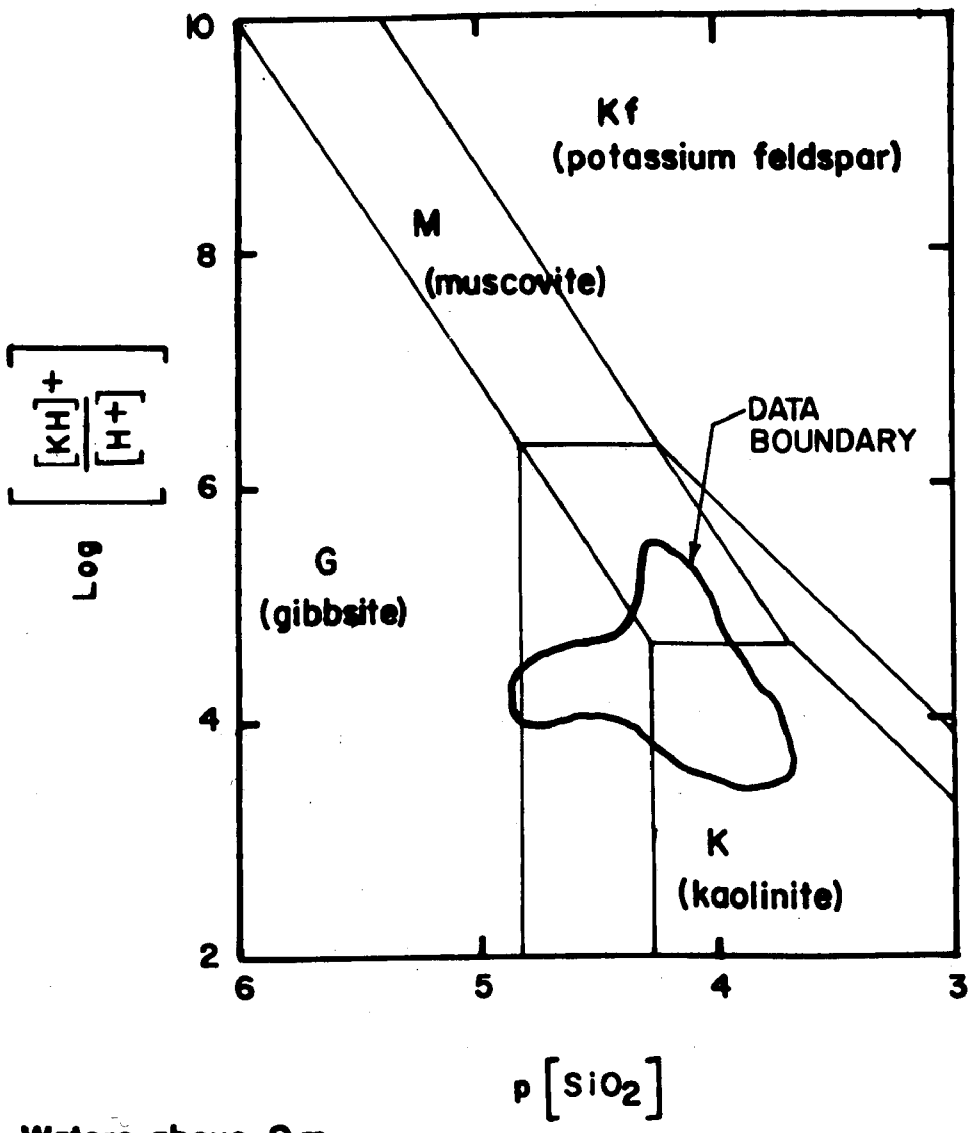
441

FLUORIDE ACTIVITY

JUNE – OCT 69

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:



Waters above 9 m.

20° C Model

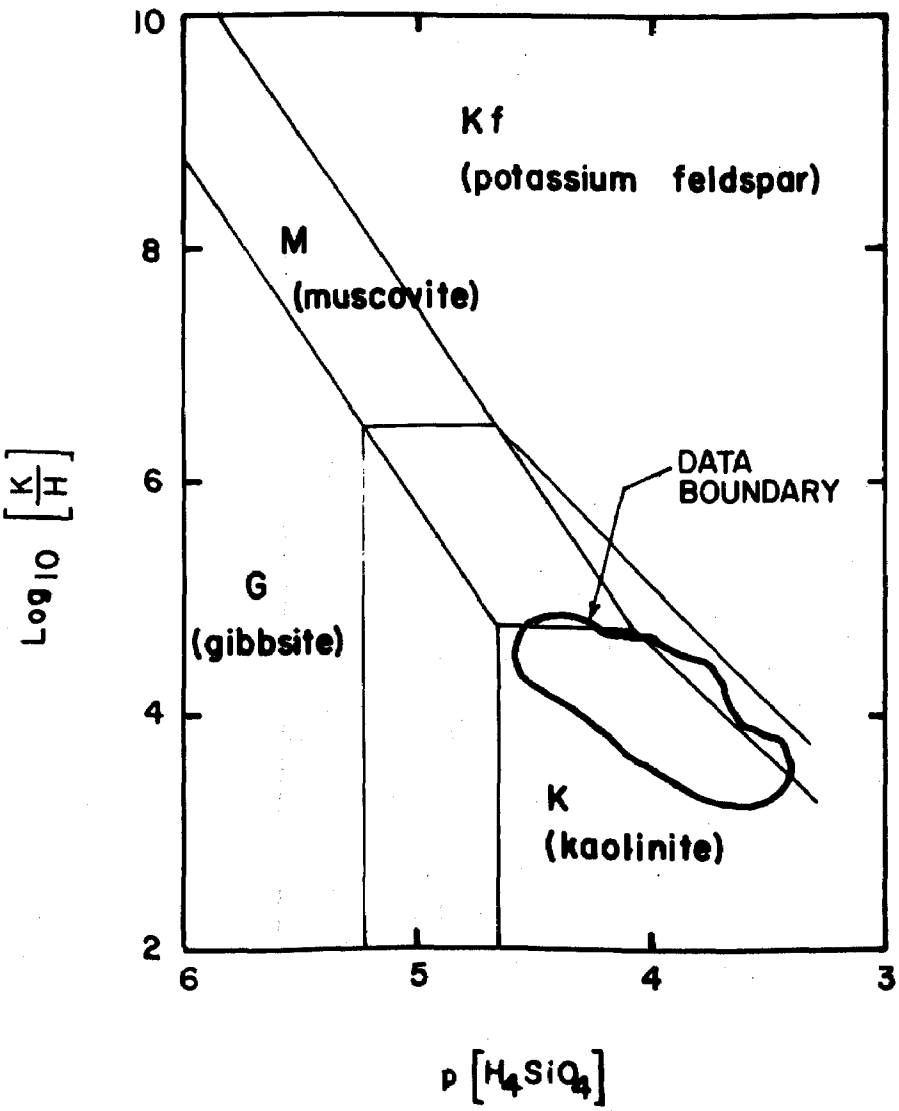
442

STABILITY DIAGRAM FOR POTASSIUM MINERALS, KAOLINITE, AND GIBBSITE

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-7



Waters below 9 m.

10°C Model

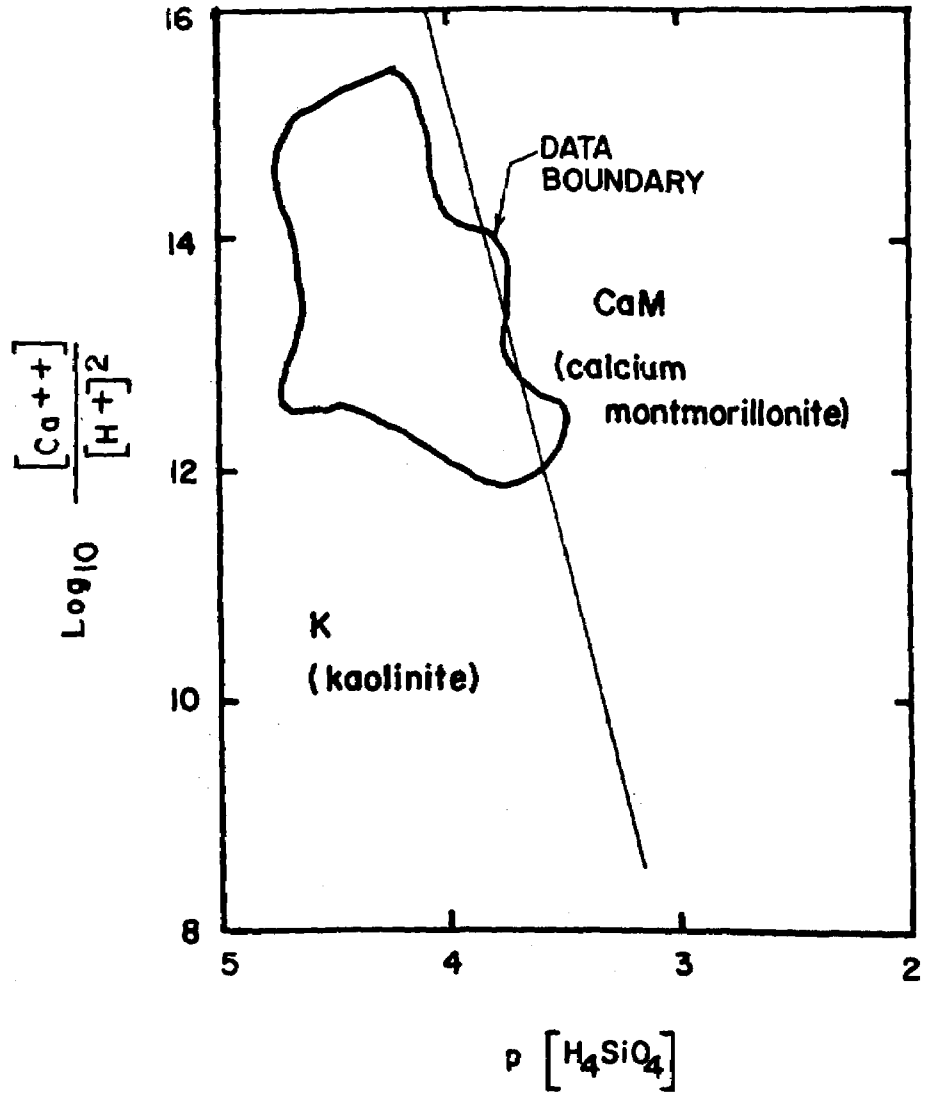
443

STABILITY DIAGRAM FOR POTASSIUM MINERALS, KAOLINITE, AND GIBBSITE

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-6

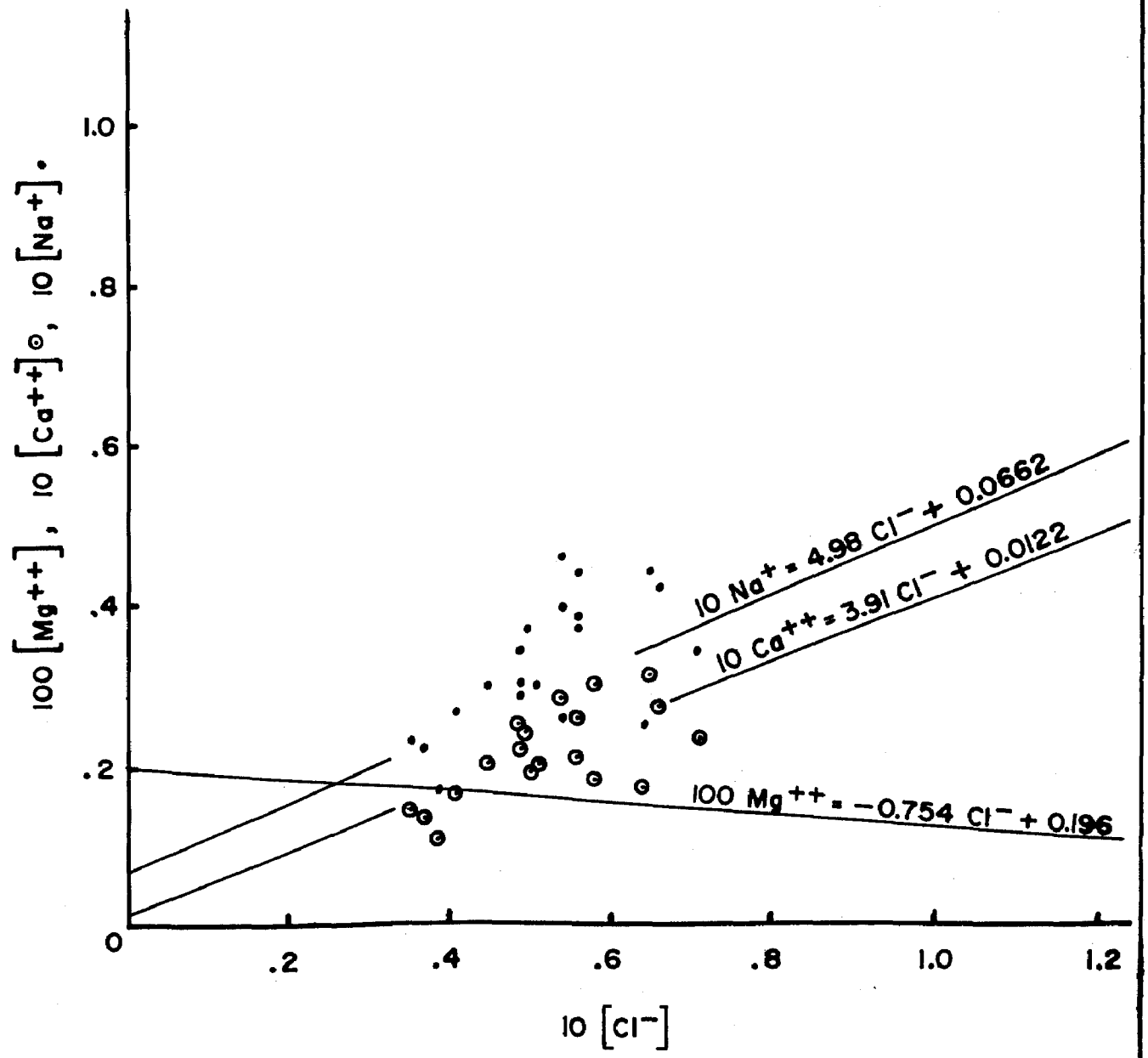


STABILITY DIAGRAM FOR KAOLINITE – Ca – MONTMORILLONITE

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-9



DATA POINTS FOR Mg NOT SHOWN

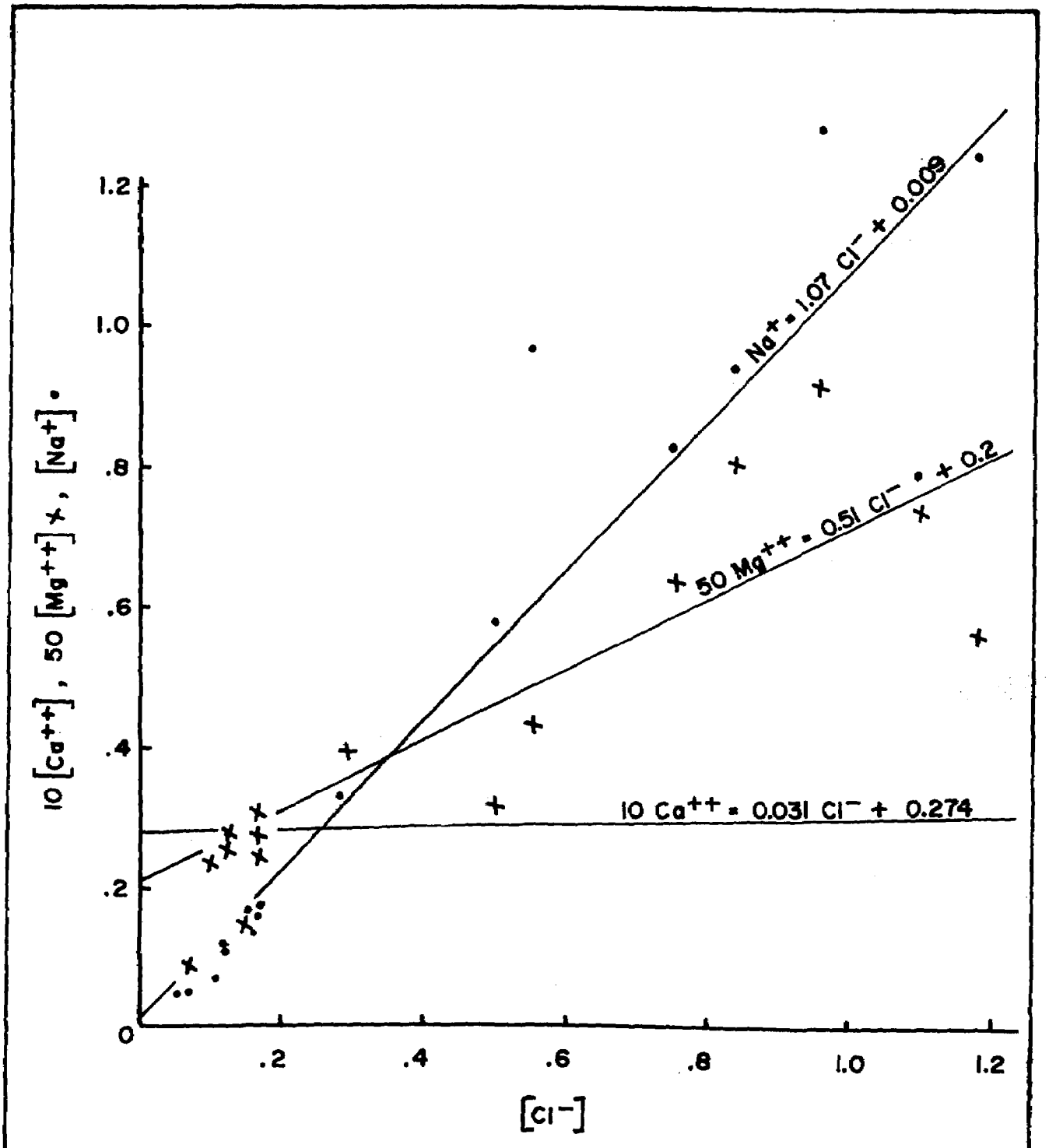
445

LEAST SQUARES
LINEAR REGRESSIONS FOR
ONONDAGA LAKE WATER

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-10



DATA POINTS FOR Ca NOT SHOWN

LEAST SQUARES
LINEAR REGRESSIONS FOR
SEDIMENT ENCLOSED WATERS

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-11

SEDIMENT PROFILES OF BENTHIC CORES

447

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

D-13

BLACK "CLAY"

BROWN "CLAY"

BROWN SAND

BANDING, WHITE, LIGHT & DARK GREY

WHITE OR GREY

MOTTLING
black-brown = bb
grey-brown = gb

BROWNISH – GREY

COMPACT

SCALE :
1 CM. = 30 CM.

TABLE D-1

ONONDAGA LAKE STUDY

Chemical Data from Sediment Enclosed Waters (Piston Core), 1969

(mg/l)

Station	Depth in Seds. (m)	Cl	Na	Ca	Mg	K	Alk.	pH
815 A	1	5,800	3,150	1,050	133.	30.8	800	7.50
815 A	4	38,500	18,200	1,250	357.	29.5	600	8.15
818 A	1	4,298	2,540	1,890	127.	35.6	1,200	7.65
818 A	4	26,500	--	--	--	--	400	7.90
818 B	1	3,849	1,630	1,740	115.	34.8	900	7.50
818 B	4	18,500	--	--	--	--	500	7.60
819 A	1	17,393	13,300	581	133.	84.5	700	7.85
819 A	4	18,992	22,300	653	206.	88.	500	7.70
819 B	1	2,400	1,090	748	42.4	27.3	800	7.60
819 B	4	9,900	7,620	849	188.	87.1	700	7.80
820 A	1	4,400	2,660	1,090	133.	41.4	900	7.70
820 A	4	29,288	21,500	1,520	387.	54.6	1,100	7.50
820 B	1	6,000	3,930	1,210	151.	37.5	700	7.60
821 A	1	5,150	3,510	1,070	78.7	39.6	700	7.55
821 A	4	40,900	28,600	1,090	272.	--	400	8.10
821 B	1	5,900	3,690	1,020	121.	37.	1,000	7.50
821 C	1	26,300	19,100	1,380	287.	35.1	900	7.80
821 C	4	33,500	29,500	1,520	436.	54.6	400	7.20

TABLE D-2

Chemical Data from Sediment-Enclosed Waters (Piston Core), 1968

(mg/l)

Station	Depth in Seds. (m)	Cl	Na	Ca	Mg	K	Alk.	pH
910	1.2	13,550	4,950	2,700	--	115.	1,010	6.5
912	0.2	2,300	2,670	758	16	232.	2,750	11.3
912	0.5	1,950	2,670	380	52	154.	800	8.2
912	1.2	2,000	3,000	490	6	257.	2,710	11.8
913 A	0.5	5,300	3,340	539	220	51.5	1,010	7.52
913 A	0.8	8,000	6,000	587	304	26.	1,070	7.45
913 A	1.2	11,050	7,840	550	376	64.	890	7.50
913 B	1.3	2,550	2,670	587	268	45.	2,470	7.7
916 A	0.8	7,450	5,500	795	20	84.	1,690	11.7
916 A	1.5	19,350	--	123	20	244.	1,650	9.3
919 A	0.5	5,800	2,500	550	216	109.	180	8.95
919 A	1.8	5,600	2,500	623	150	58.	904	9.0
920 A	0.3	5,800	2,500	342	--	64.	880	7.15
920 A	0.6	5,400	2,400	858	12	90.	1,160	11.0
920 A	1.7	10,000	3,680	233	500	64.	1,960	7.8
920 B	0.3	8,800	7,940	477	310	31.	1,810	7.2
920 B	1.0	14,200	7,500	500	490	38.5	1,150	6.9
920 B	1.3	9,600	3,420	612	--	38.5	540	7.52

TABLE D-3

ONONDAGA LAKE STUDY

Chemical Data for Sediment-Enclosed Waters (Gravity Core), 1969

(mg/l)

Station	Depth in Seds. (m)	Cl	Na	Ca	Mg	K	Si	OP
721 A	0.9	37,200	4,540	812	119.	23.	51.	2.5
723 A	0.3	15,500	8,230	1,330	339.	27.5	59.	2.
723 A	--	26,000	16,900	799	242.	77.4	56.2	7.5
724 A	0.5	4,500	2,780	1,060	--	33.9	52.5	3.
724 B	0.3	11,500	6,530	1,080	--	54.5	40.	3.5
724 B	1.45	36,000	20,600	1,840	--	162.	43.5	2.
724 C	0.3	5,000	2,420	1,100	--	31.5	62.	12.5
724 C	1.6	35,000	20,100	3,260	--	227.	50.	--
724 D	0.7	3,000	1,330	1,200	--	104.	10.	0.
724 D	2.1	6,500	4,840	918	--	102.	7.5	2.
731 A	0.5	6,500	3,870	1,090	--	20.6	5.5	1.5
731 A	--	22,000	14,600	1,200	--	23.	67.5	.5
801 A	--	2,500	823	666	--	16.9	37.	6.5
807 A	0.5	6,000	2,060	2,640	--	47.2	16.	.5
807 A	1.7	63,000	12,800	--	--	26.6	22.	0.
807 B	0.5	6,000	1,730	2,250	--	35.1	18.	1.
808 A	0.5	--	133	290	--	33.9	56.	4.5
808 B	0.5	2,000	865	1,160	--	26.6	57.2	1.5
808 B	--	1,500	865	450	--	29.0	57.2	6.
808 B	--	2,000	666	290	--	26.6	41.	2.5
811 A	0.5	2,000	799	741	--	29.	41.	1.5
811 B	--	--	413	363	--	9.7	33.5	1.5
812 A	0.5	7,500	1,800	2,830	26.6	32.7	12.5	0.
812 A	--	2,500	945	1,740	7.8	43.6	17.5	0.
812 A	--	1,740	958	1,740	7.8	25.4	7.5	0.
812 B	0.5	19,000	4,690	9,510	45.3	98.	10.5	0.2
812 B	--	52,500	11,800	21,000	72.6	290.	13.5	0.

TABLE D-4

ONONDAGA LAKE STUDY

Chemical Data from Lake Water, Station 7, 1969

(mg/l)

Sample (Date)	Depth in Seds. (m)	Cl	Na	Ca	Mg	K
611	3	1,350	391	426	27.	12.8
611	12	1,900	590	708	27.5	17.
618	15	1,850	586	688	31.	14.5
625	3	1,300	511	517	27.8	13.4
625	12	1,750	641	752	29.	15.1
521	12	1,700	792	983	40.5	17.4
716	0	1,250	528	548	58.1	14.3
723	9	1,750	847	977	69.	17.2
813	0	1,450	605	654	30.3	17.2
827	18	1,800	684	818	62.7	16.9
903	6	2,000	853	858	30.3	24.2
918	0	1,600	678	792	30.3	16.4
918	12	1,750	678	871	29.	15.4
1008	18	1,900	895	1,200	47.6	17.3
1023	3	2,000	865	1,040	32.1	21.1
1121	6	2,000	1,020	1,060	41.7	22.3
1121	9	1,900	1,060	1,110	40.	23.
1204	12	2,500	782	931	31.5	17.3
1204	15	2,350	958	1,080	33.9	20.6
1218	18	2,300	1,000	1,250	33.9	18.2

Twenty samples chosen at random for Least Squares Regression Analysis

TABLE D-5

ONONDAGA LAKE STUDY

Sediment Shaking Tests

(mg/l)

Station	OP	SI	ALK.	pH	Dry Wgt. (mg)
913 A2D	.2	14.0	5.0	6.0	.3195
913 A2S	trace	11.4	5.0	6.1	
912 1D	.03	>40.0	5.0	7.5	.3350
912 1S	.4	>40.0	5.0	6.2	
912 2D	.04	13.2	10.0	6.1	.2910
912 2S	.2	14.5	15.0	6.2	
912 3D	trace	18.0	15.0	7.9	.3230
912 3S	.08	31.5	10.0	5.8	
920 AD	.12	>40.0	15.0	6.4	.4935
920 AS	.26	>40.0	15.0	6.0	
916 A3D	.18	5.5	30.0	6.45	.3822
916 A3S	.16	4.5	30.0	6.3	
919 B3D	.16	4.4	20.0	6.3	.4065
919 B3S	.4	9.5	10.0	6.2	
917 A1.0D	.2	5.0	30.0	7.4	.3010
917 A1.0S	.08	4.8	20.0	6.2	
913 B2D	.32	4.5	20.0	6.7	.3785
913 B2S	.16	12.0	20.0	6.8	
802 ED	trace	25.4	10.0	9.0	.2670
802 ES	trace	10.0	5.0	8.75	
919 A1.8D	trace	9.6	5.0	6.55	.2910
919 A1.8S	trace	12.5	5.0	6.5	

TABLE D-5

ONONDAGA LAKE STUDY

Sediment Shaking Tests

(mg/l)

Station	OP	SI	ALK.	pH	Dry Wgt. (mg)
910 2D	trace	10.2	5.0	6.1	.3125
910 2S	trace	9.0	5.0	6.2	
913 B3D	trace	13.2	5.0	6.1	.3505
913 B3S	trace	12.2	5.0	6.3	
920 B-1.3D	.28	13.2	10.0	5.0	.3605
920 B-1.3S	.16	10.0	0	3.3	
910 3D	.24	6.9	5.0	7.1	.3630
910 3S	.16	6.9	5.0	6.5	
919 A5D	.28	13.2	5.0	6.3	.3770
919 A5S	.30	10.2	5.0	6.5	
913 B3D	.82	19.5	5.0	6.4	.3810
913	.16	6.9	5.0	6.5	
913 A1.0D	.04	24.8	10.0	5.1	.4060
913 A1.0S	.16	27.8	20.0	7.1	
919 A5D	.42	22.8	10.0	5.0	.3175
919 A5S	.08	5.5	15.0	5.7	
920 A1.7D	.52	27.0	10.0	6.2	.3260
920 A1.7S	.08	6.9	20.0	6.5	
920 A3D	trace	16.5	10.0	6.6	.3540
920 A3S	trace	28.0	20.0	6.3	
919 B.7D	.12	6.9	5.0	5.8	.3330
919 B.7S	trace	10.4	5.0	5.85	
918 B.7D	.96	27.8	5.0	6.3	.3150
918 B.7S	.12	11.8	5.0	6.3	

TABLE D-5

ONONDAGA LAKE STUDY

Sediment Shaking Tests

(mg/l)

Station	OP	SI	ALK.	pH	Dry Wgt. (mg)
916 A1D	.28	8.0	10.0	5.4	.3155
916 A1S	.18	6.0	20.0	5.9	
916 A2D	trace	12.0	10.0	6.3	.3260
916 A2S	trace	24.5	10.0	5.6	
916 B1D	.45	9.2	10.0	5.9	.3265
916 B1S	.24	6.0	20.0	6.1	
913 A3D	.60	12.0	20.0	6.1	.3050
913 A3S	.12	6.96	20.0	6.2	
912 1D	trace	23.2	10.0	4.9	.2910
912 1S	.14	33.50	5.0	4.55	
917 A7D	.36	24.0	10.0	5.8	.3005
917 A7S	.12	6.0	20.0	6.0	
920 B1AD	.54	25.44	10.0	6.0	.2160
920 B10S	trace	4.8	20.0	6.1	
923 A.SD	trace	19.0	20.0	9.0	.2690
923 A.5S	trace	27.0	10.0	5.8	
917 A3D	.2	11.0	5.0	6.4	.3310
917 A3S	.16	16.5	5.0	6.2	
920 A1.7D	.14	8.5	5.0	6.4	.3260
920 A1.7S	.04	10.0	5.0	6.4	
916 B2D	.16	16.5	5.0	6.3	.3610
916 B2S	trace	6.0	5.0	6.3	

TABLE D-6

ONONDAGA LAKE STUDY

Jenkins Samples (mg/1)

June 30, 1969

Station	DO	CL	SiO_2	OP	TP	pH	ALK
617 B-U	1.0		0.75	0.0	2.0	7.00	200
617 B-D	8.4		1.35	0.0	5.0	6.28	50
619 B-U			1.60	0.0	3.5	7.80	160
619 B-D	10.0		0.70	0.0	3.0	9.88	40
South Deep-D	1.4		1.90	2.0	3.5	6.81	100
Unmarked	1.2		3.50	5.0	11.0	6.90	240
623 A-D	6.4		0.80	0.0	4.5	6.85	40
618 A-D	6.0		0.50	0.0	8.5	6.10	20
South Deep-U	1.2		3.75	2.0	6.0	6.78	240
624 A-D	8.4		0.00	0.0	27.5	6.20	20
623 A-U	5.8		0.50	0.0	35.5	7.05	160
624 A-U	1.6		1.25	2.0	2.0	7.04	200
618 A-U	3.6		2.80	2.0	24.5	6.80	180
626 A-D	3.5		0.70	2.0	4.0	6.98	60
626 A-U	1.5		1.10	0.0	30.5	6.90	200

TABLE D-6

ONONDAGA LAKE STUDY

Jenkins Samples (mg/l)

July 11, 1969

Station	DO	CL	SIO_2	OP	TP	pH	ALK
617 B-U			5.5	0.5	Not	7.30	260
617 B-D			0.0	1.5	Run	6.75	60
619 B-U			2.5	2.0		7.10	170
619 B-D			1.5	0.5		7.50	70
South Deep-D		450	15.0	3.0		7.05	150
Unmarked		50	18.5	5.5		6.90	300
623 A-D		200	2.5	0.0		7.15	120
618 A-D		1,800	0.0	0.5		6.80	110
South Deep-U		1,850	23.0	3.0		7.10	310
624 A-D		1,500	18.0	0.0		6.40	60
623 A-U							
624 A-U		300	14.5	1.5		7.30	240
618 A-U		250	15.5	3.0		6.80	240
626 A-D		1,100	4.5	0.0		7.00	110
626 A-U		1,300	7.5	1.5		7.60	260
617 A-D		850					
617 A-U		200					
619 A-D		2,750					
619 A-U		450					

TABLE D-6

ONONDAGA LAKE STUDY

Jenkins Samples (mg/l)

July 22, 1969

Station	DO	CL	SIO_2	OP	TP	pH	ALK
617 B-U					Not	7.15	230
617 B-D					Run		
619 B-U		1,750	0.50	0.6		7.20	150
619 B-D							
South Deep-D		0	0.50	0.4		6.60	30
Unmarked		1,700	5.15	2.4		7.10	300
623 A-D		0	0.0	0.4		6.85	30
618 A-D		0	0.0	0.4		6.25	10
South Deep-U		0	5.25	2.4		7.25	320
624 A-D		0	0.0	0.4		6.45	20
623 A-U							
624 A-U		1,400	2.30	1.6		7.20	210
618 A-U							
626 A-D		0	0.0	0.4		6.55	20
626 A-U		1,100	1.85	1.4		7.10	260
Harbor Br-D		0	0.0	1.2		6.50	20
Harbor Br-U		1,100	1.60	1.6			
619 A-U		1,000	5.40	1.0		7.25	260

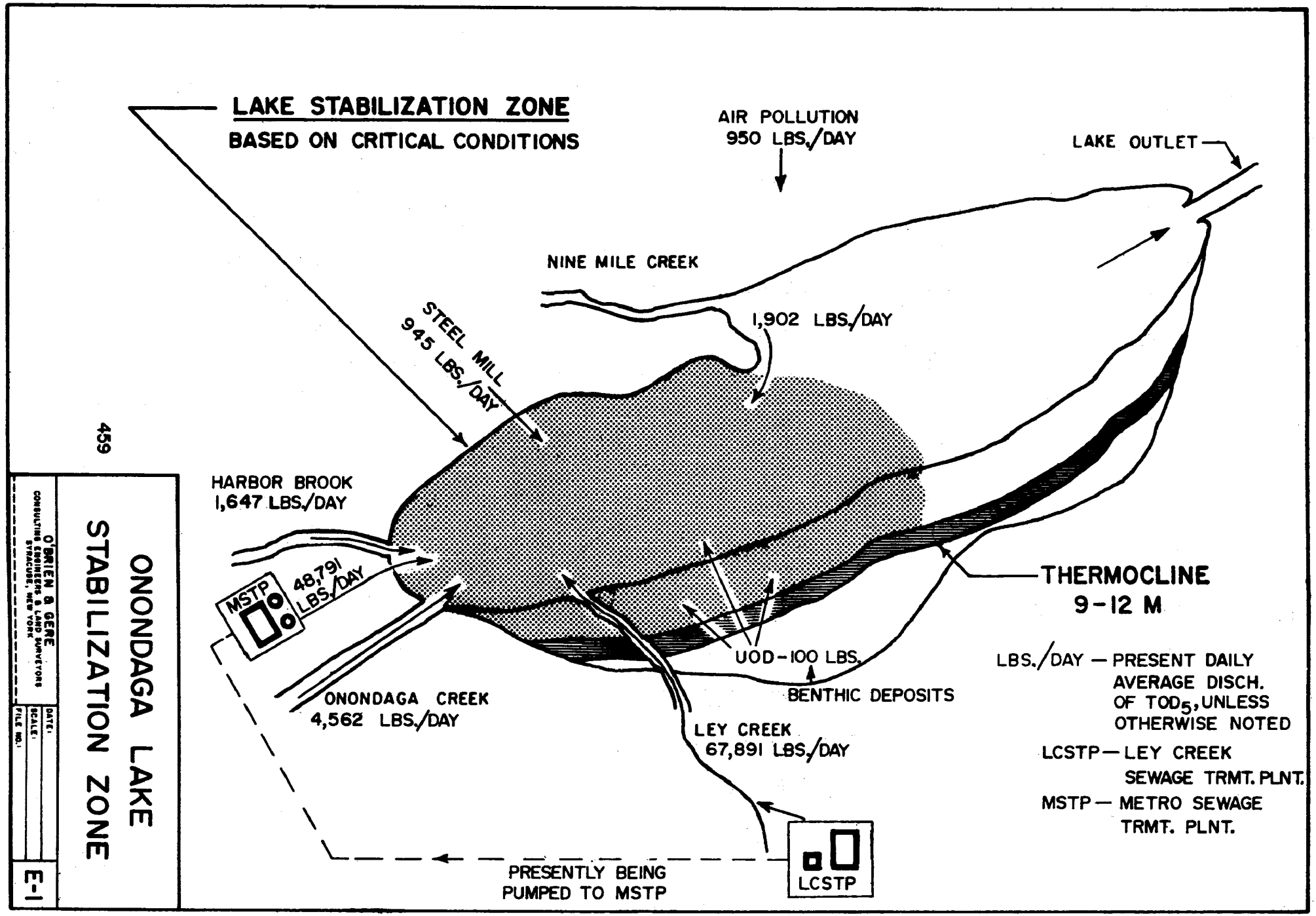
TABLE D-6

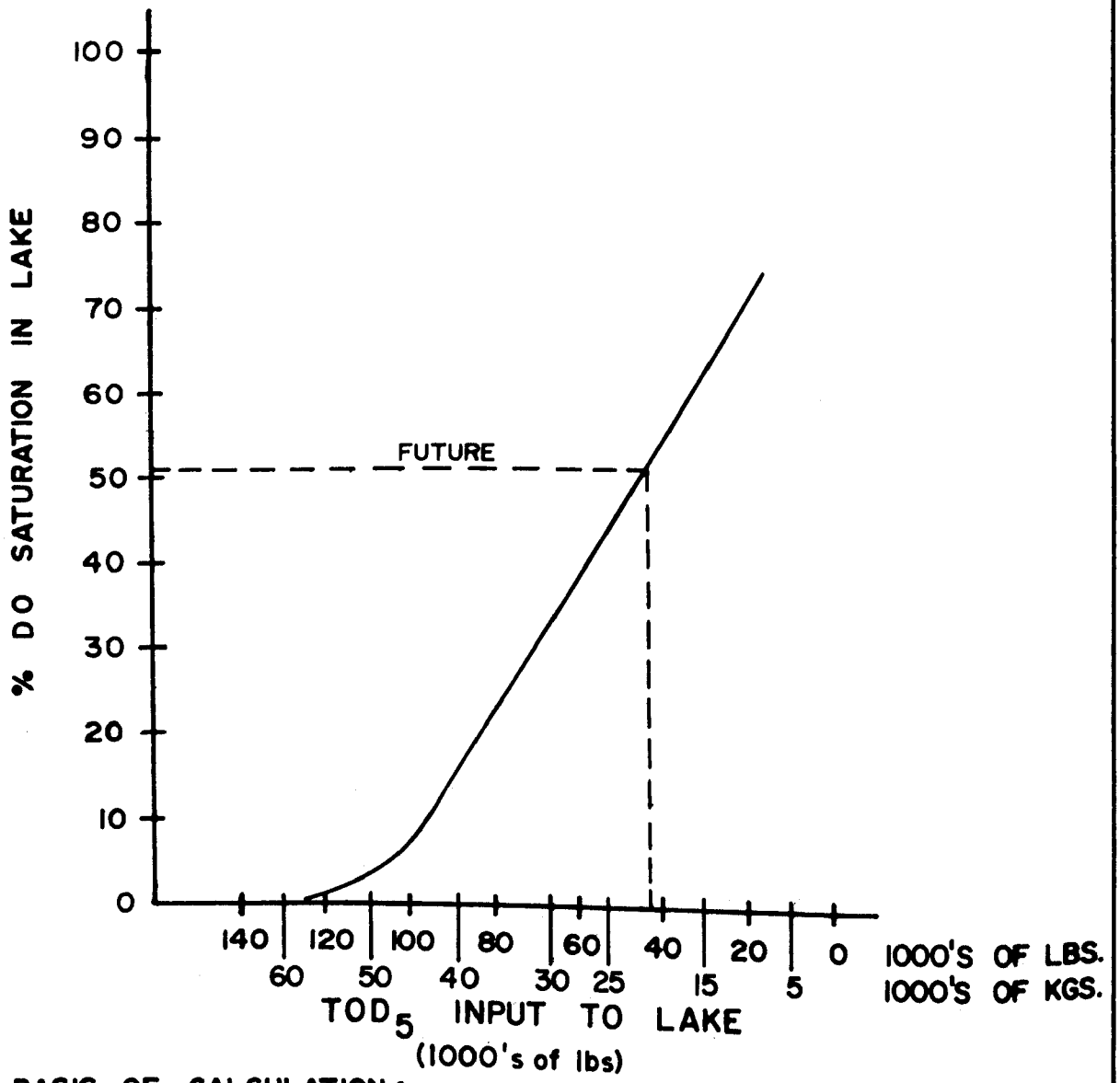
ONONDAGA LAKE STUDY

Jenkins Samples (mg/l)

August 11, 1969

Station	DO	CL	SIO_2	OP	TP	pH	ALK
617 B-U					Not	7.40	200
617 B-D		0	0.0	0.0	Run	6.15	20
619 B-U		1,900	0.0	0.0		7.70	140
619 B-D							
South Deep-D		0	0.0	0.8		6.40	60
Unmarked		1,800	23.13	3.60		7.40	350
623 A-D		0	0.0	0.0		7.30	320
618 A-D		100	8.25	0.4		7.10	120
South Deep-U		1,850	20.50	2.6		7.45	330
624 A-D		0	0.0	0.0		6.55	20
623 A-U		0	0.0	0.0		6.75	20
624 A-U		1,550	9.88	0.5		7.30	220
618 A-U		1,650	19.50	1.60		7.40	300
626 A-D		0	0.0	0.4		6.75	50
626 A-U		1,100	9.88	1.60		7.55	280
629 A-D						6.75	40


LAKE STABILIZATION ZONE
BASED ON CRITICAL CONDITIONS
AIR POLLUTION
950 LBS./DAY
LAKE OUTLET
NINE MILE CREEK
1,902 LBS./DAY
STEEL MILL
945 LBS./DAY
HARBOR BROOK
1,647 LBS./DAY
MSTP
48,791
LBS./DAY
ONONDAGA CREEK
4,562 LBS./DAY
LEY CREEK
67,891 LBS./DAY
THERMOCLINE
9-12 M
UOD-100 LBS.
BENTHIC DEPOSITS
LBS./DAY — PRESENT DAILY AVERAGE DISCH. OF TOD5, UNLESS OTHERWISE NOTED
LCSTP — LEY CREEK SEWAGE TRMT. PLNT.
MSTP — METRO SEWAGE TRMT. PLNT.
PRESENTLY BEING PUMPED TO MSTP
LCSTP
459
ONONDAGA LAKE
STABILIZATION ZONE
O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK
DATE:
SCALE:
FILE NO.:
E-1



BASIS OF CALCULATION:

CRITICAL CONDITIONS

LAKE TEMP	17.4 °C
DO IN LAKE (OLDO)	0.66 MG/L
BOD_5 IN LAKE ($OLBOD_5$)	6.41 MG/L
DEOXYGENATION RATE (K_1)	0.18/DAY
DO SATURATION	9.46 MG/L
TOD_5 INPUT (TULBS)	126,800 LBS./DAY

NOTE: PROJECTION CURVE ACCOUNTS FOR NITROGENEOUS OXYGEN DEMAND, NOD = 0.28 BOD

LAKE DO VS BOD INPUT

O'BRIEN & GERE
CONSULTING ENGINEERS & LAND SURVEYORS
SYRACUSE, NEW YORK

DATE:
SCALE:
FILE NO.:

E-2

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM

5 Organization

6 Title

Onondaga Lake Study

10 Author(s)

O'Brien & Gere - Consulting Engineers for Onondaga County Dept. of Public Works, Division of Drainage & Sanitation

16 Project Designation

FWQA Research & Development 11060 FAE

21 Note

22 Citation

23 Descriptors (Starred First)

*Eutrophication, trophic status, *Dissolved oxygen saturation, sediments, phosphate bearing minerals

25 Identifiers (Starred First)

saline, *Onondaga Lake, Syracuse, New York

27 Abstract

Physical, chemical, biological and geochemical investigations were conducted to determine the trophic status of a saline lake on the edge of Syracuse, New York.

The lake was found to be dimictic, and although lake waters are vertically stratified, they are well mixed horizontally.

The lake supports a wide variety of phytoplankton, zooplankton and fish which is surprising in light of the trophic level.

Mineral-water equilibria studies showed phosphate bearing minerals form throughout the year in all zones of the lake. Calcite, which is prevalent throughout most of the year, constitutes most of the lake's sediments.

It was determined that projected waste treatment facilities will result in an increase in the DO saturation level of the epilimnion from 10 to 50% and a reduction of 70% of total phosphorus now discharging to the lake. Mineral formation of the above minerals will not be reduced measureably following the operation of these same facilities.

Abstractor	Institution

WR:102 (REV. JULY 1969)
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