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UTILIZATION OF ERTS-1 DATA TO MONITOR AND CLASSIFY EUTROPHICATION OF INLAND LAKES

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15. Supplementary Notes

The Co-investigator Elliott Smith is a staff member at the Cranbrook Institute of Science in Bloomfield Hills, Michigan.

16. Abstract

The report summarizes the technical activity over the reporting period. Significant findings are (1) one acre lakes and one acre islands are detectable; (2) circular lakes of 7.5 acres and greater reach full density; (3) long channels 100 ft wide are detectable; (4) orientation of lakes is independent of scan direction; (5) lake features are observable in enlargements of CCT imagery produced in the Bendix Earth Resources Data Center, (6) a decision surface water outline map is presented that was produced from ERTS CCT. A water color literature review, baseline water quality data of the test lakes, and a discussion of geometric corrections of the CCT decision water surface outline map are also presented.

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Preface

(a) Objective of the Program

1. Determine the minimum size of inland lakes detected by ERTS when considering factors of color, size, shape, and shore definition.

2. Determine correlation of surface color to various indices of eutrophication for preparing charts of eutrophication versus surface color. Such indices are algal count, Secchi Disk transparency, leptopel (detrital) content, macrophyte extent, phosphates, etc.

3. Determine if algal blooms are detectable by ERTS when they occur and color the surface of small inland lakes. Algal blooms are an indicator of enrichment.

4. Determine if changes in leptopel level are detectable by ERTS. This is another measure of eutrophication that can be related to ERTS.

5. Determine the feasibility of establishing classification of levels of inland lake eutrophication by either lake, pond, and swamp taxonomies or by individual indicators such as surface color, transparency, leptopel level, and appearance of algal blooms.

(b) Scope of Work. The scope is to compare the ERTS-1 to ground truth and to aircraft imagery. The ERTS-1 imagery will be that as received from NASA and that as produced by the Bendix data processing facility from the Computer Compatible Tapes. Comparison of the eutrophication monitoring capability will be made for several seasons.

(c) Conclusions. The following findings and conclusions are limited to the information contained in the 16-20 grey levels of the ERTS-1 bulk imagery.

Previous to analyzing imagery for lake color features, the capability of ERTS to resolve lakes by size, shape, band, and background must be determined.

It is concluded that the performance of ERTS for large contrast (water/land) is the same whether the background is high and the target low in signal strength or vice versus. This is based upon the detection of a one acre island in a test lake and a one acre pond detected against the land background. This is true for bands 6 and 7.

It is concluded that the orientation of the lake is independent of ERTS-1 MSS scan direction in bands 5, 6, 7. This has not been determined for band 4. It was observed that for approximately circular lakes greater than 7.5 acres the density of the tone was the same regardless of size. In the range of one acre to 7.5 acres the tonal density tended to decrease. It is not certain that this decrease in tonal density is due to sensor response or to shallow depth and turbidity of these smaller lakes (ponds).

It is concluded that distortion of ponds greater than 7.5 acres will not occur if the shape is elliptical, circular, blocky and not too elongated. This occurs in bands 6 and 7. Two difficulties prevent a similar conclusion for bands 4 and 5. There was a slight haze over the lakes which quite likely enhances the lack of shoreline definition in band 4. In band 5 a banding effect along the scan line is present that creates distortion.

It is not possible to determine from this scene whether color features are discernable because of the haze and banding in bands 4 and 5, respectively. Bands 6 and 7 do not detect sources of lake color from beneath the lake surface. Observation of other ERTS imagery indicates that back scattering from suspended material in water is observable.

Processing of the CCT for other areas with larger water bodies has identified at least 5 distinct water masses. The ERTS-1 CCT for the Oakland County scene described in this report was received at the end of the reporting period, strip imagery of each band prepared and color variations identified for the larger lakes. Further examination of the CCT imagery and additional statistical processing is required for this scene to confirm for how small a lake color variation can be detected. Imagery of Figures 28 and 33 are produced from a CCT at Bendix to a scale of 1:140,000. Figure 33, Band 5, does not have the banding of the imagery received from Goddard and features are observable in the lakes.

Probability density imagery has been prepared of water for other test sites and is included in the report in Figure 34.

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1. INTRODUCTION

The purpose of this report is to review, prior to receipt of ERTS-1 data, preparation phase accomplishments and the accomplishments during the initial review of ERTS-1 imagery. The capability of ERTS-1 to resolve different sizes and shapes of lakes in each MSS band is necessary to correlating ERTS-1 data to lake water color. The results of this task is reported in detail.

The results reported herein will provide a basis for classifying the study lakes as to water quality and average color. Available imagery, through limited, establishes the usefulness of ERTS as a lake monitoring tool. It remains to make specific correlations of imagery and water quality variables on a regular basis for each of the study lakes. This can be done only during the ice-free months. Water color, which is assessed in detail here, is the mediating factor between water quality and remote sensing. New techniques are reported that will be brought to bear on the measurement of lake color *in situ.* A program being developed for detailed water quality monitoring is described.

Statistical decision boundaries of surface water are now obtainable from the Bendix Earth Resources Data Center though processing of the CCT. An example is included and discussed as to geometric corrections and quality.

2. ACCOMPLISHMENTS DURING ERTS-1 DATA PREPARATION PHASE

2.1 REVIEW OF LAKE CHARACTERISTICS.

(a) Water Quality

Four of the subject lakes have been under study since 1969. Weekly or biweekly sampling throughout the year have yielded data that relate to the trophic condition of these lakes. Measurements have included the following:

1. Temperature and dissolved oxygen profiles
2. Water transparency
3. Orthophosphates (soluble)
4. Nitrates & nitrites (soluble)

5. Calcium

6. Potassium

7. Organic carbon (particulate)

8. Phytoplankton (dominant forms)

9. Chlorophyll (particulate)

10. Macrophytes (dominant forms)

Some of this data is summarized in Figures 1-23. Despite seasonal and annual variations in nutrients, organic production, transparency, etc., these data indicate a general level of enrichment for each lake that is characteristic. This permits four of the lakes to be arranged in a sequence according to relative trophic level; in order of increasing enrichment they are: Lake Angelus, Lower Long Lake, Forest Lake, and Island Lake. Less information is so far available about the remaining two study lakes, Orchard and Cass, but they appear to resemble Lake Angelus more closely than the others. Since all six lakes have similar natural surroundings and human development of their shorelines, it is probably no accident that the degree of enrichment of each lake appears to be correlated with its size and depth. Most likely the ratio of lake volume to the area of its watershed is the main factor that influences its rate of cultural eutrophication and present level of enrichment. Until the size and character of each watershed is determined (later in this study), it is not possible to predict which larger number of lakes in Oakland County may show evidence of trophic changes in subsequent ERTS imagery.

Certain information has been derived from the above data on which this classification of trophic levels is based. The following are some conclusions about water quality that are indicated by these results.

1. The depth and volume of oxygen-depleted water in a lake (caused by decay) reflects the amount of organic productivity in surface waters. Figs. 1 and 2 compare these values for Forest and Island Lakes.

2. Water transparency (Secchi disc visibility) is a measure of turbidity or organic matter in suspension. Higher average turbidity is characteristic of more eutrophic lakes (Figs. 3, 4, 5).

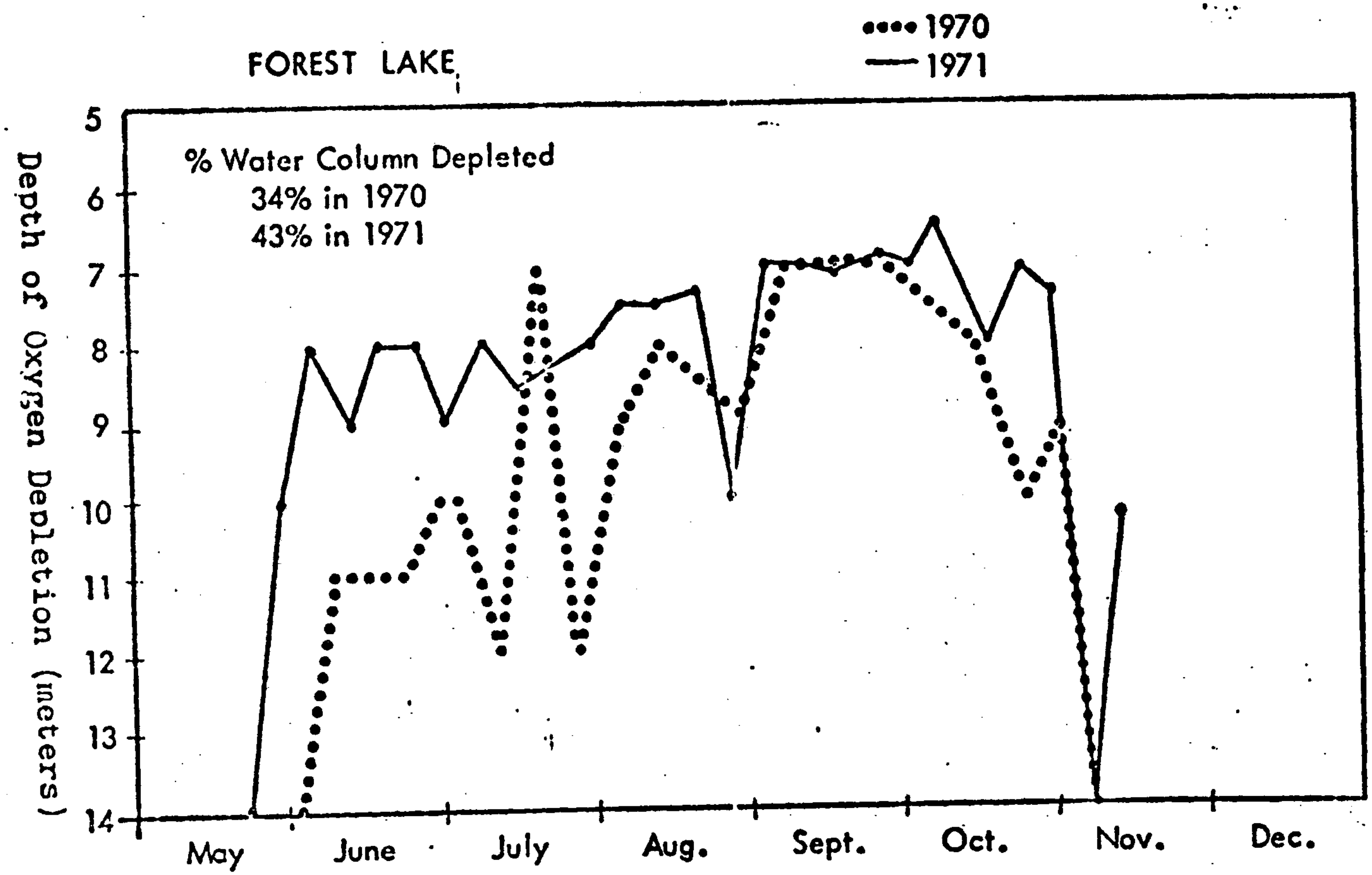


Figure 1. Depth of oxygen depletion in Forest Lake.

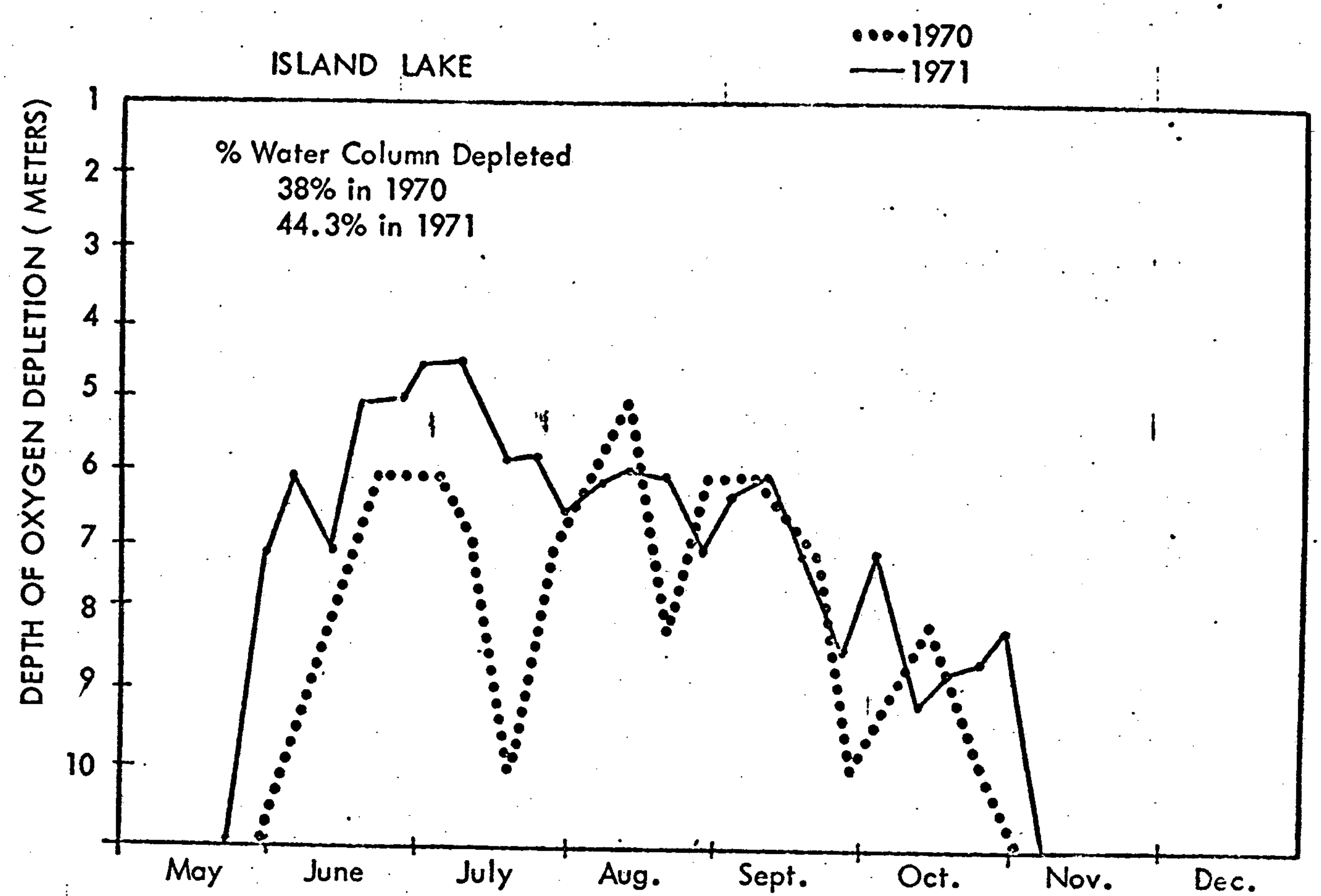


FIG. 2 : DEPTH OF OXYGEN DEPLETION IN ISLAND LAKE

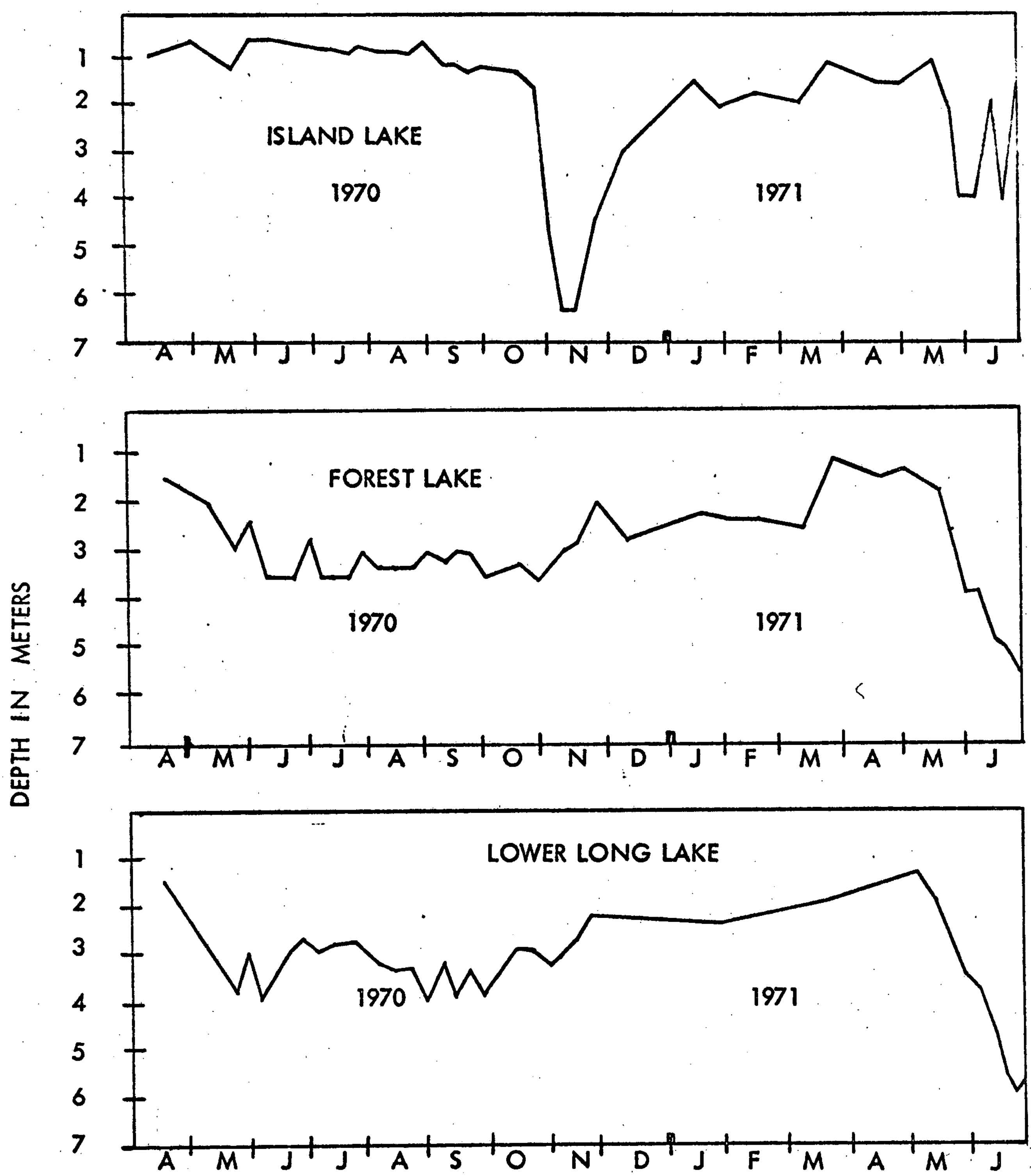


FIG. 3 : WATER TRANSPARENCY (SECCHI DISC) READINGS: ISLAND, FOREST AND LOWER LONG LAKES, APRIL 1970 - JUNE 1971

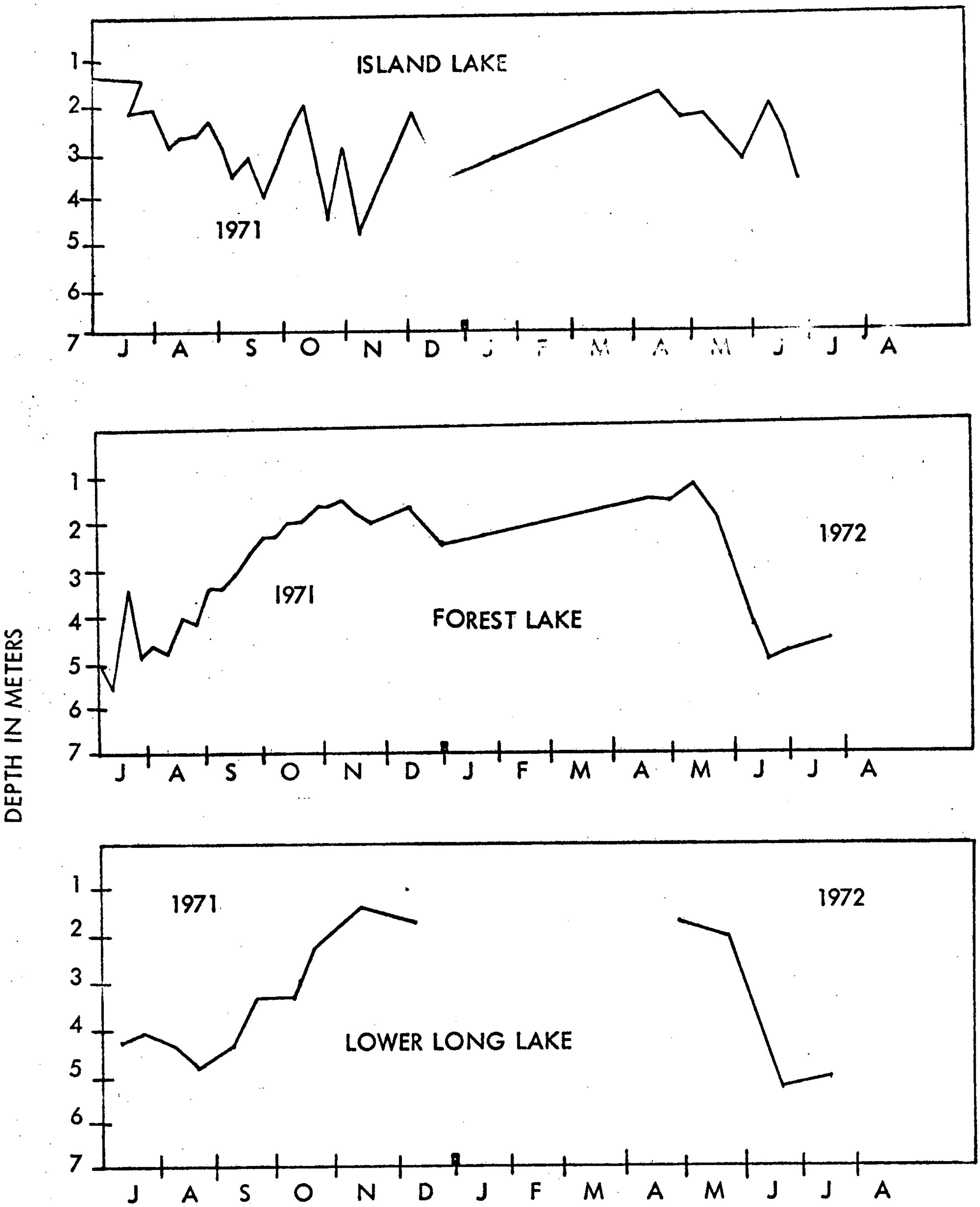


FIG. 4: WATER TRANSPARENCY (SECCHI DISC) READINGS : ISLAND, FOREST, AND LOWER LONG LAKES, JULY 1971 - AUGUST 1972

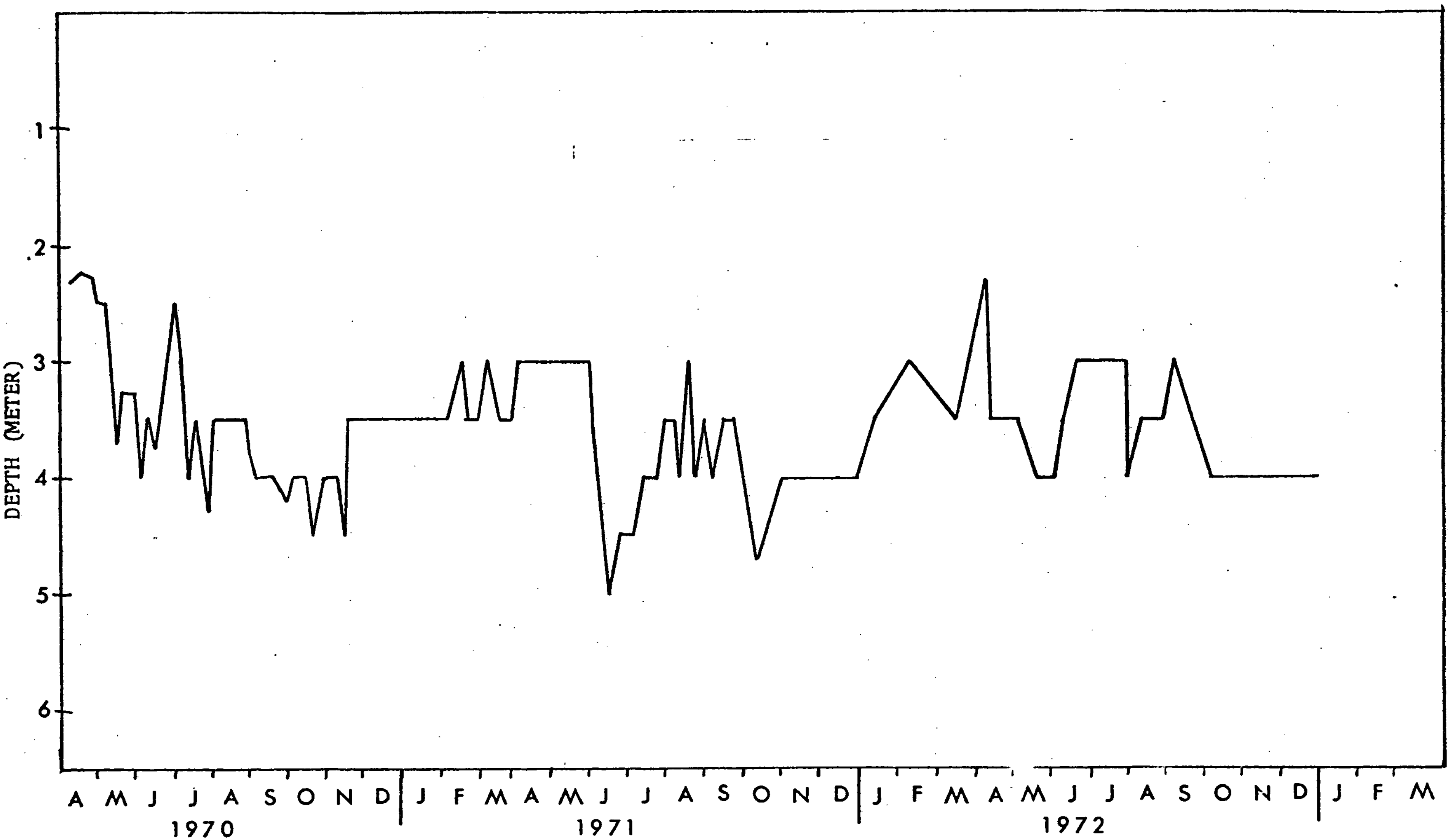


FIG. 5: WATER TRANSPARENCY OF LAKE ANGELUS

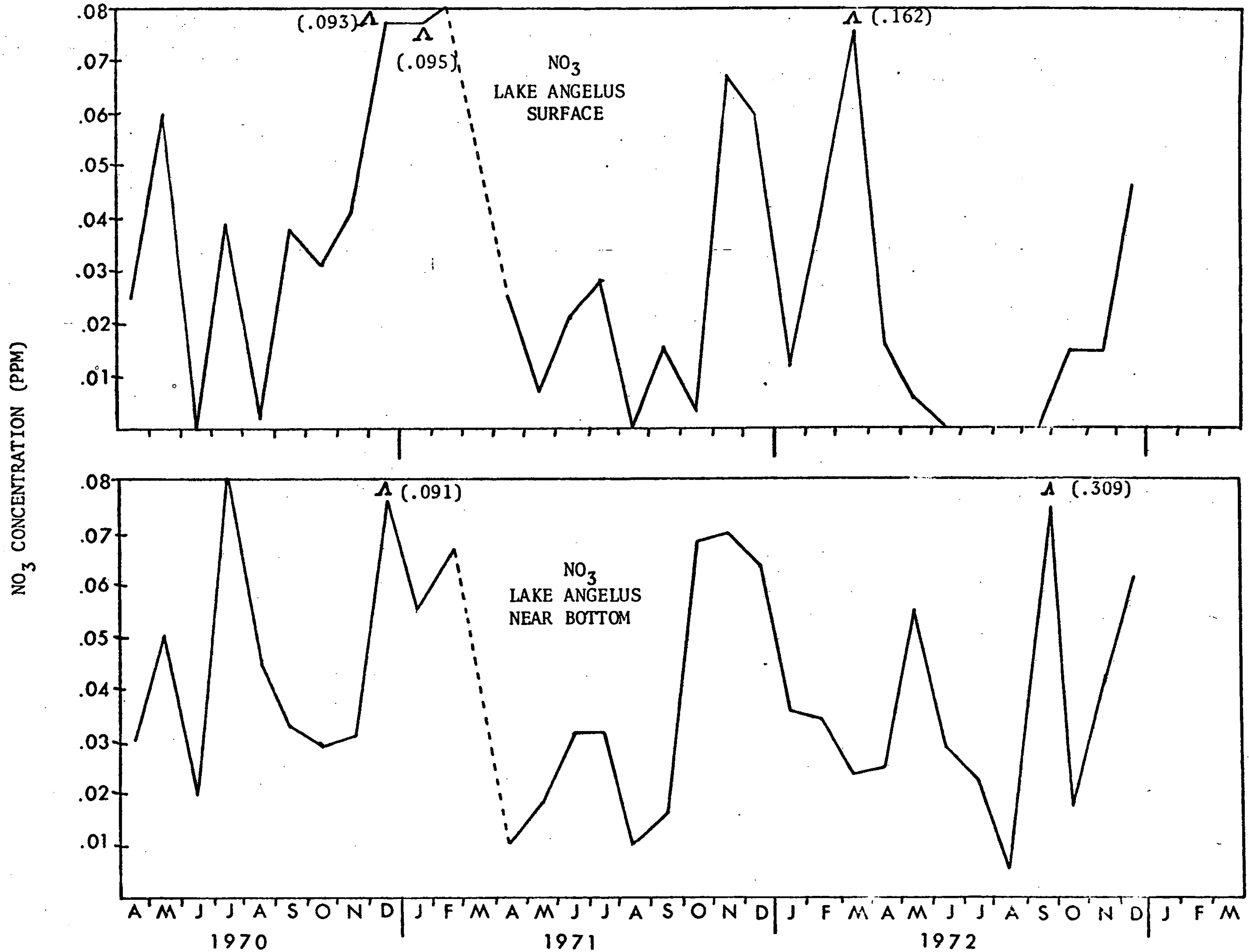


FIG. 6 : CONCENTRATIONS OF NITRATE NITROGEN IN SURFACE AND BOTTOM WATERS OF LAKE ANGELUS

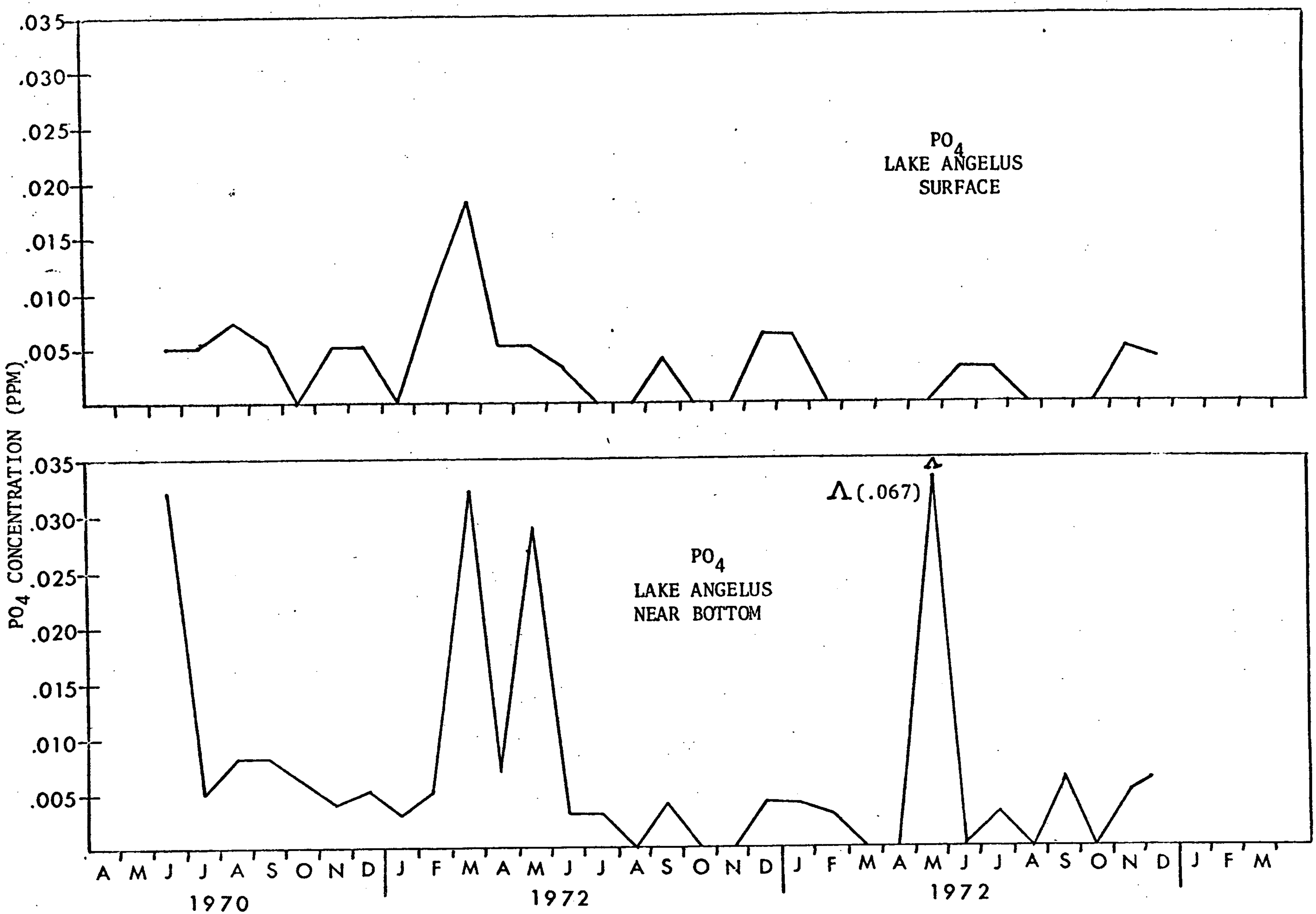


FIG. 7: CONCENTRATIONS OF SOLUBLE PHOSPHATE IN SURFACE AND BOTTOM WATERS OF LAKE ANGELUS

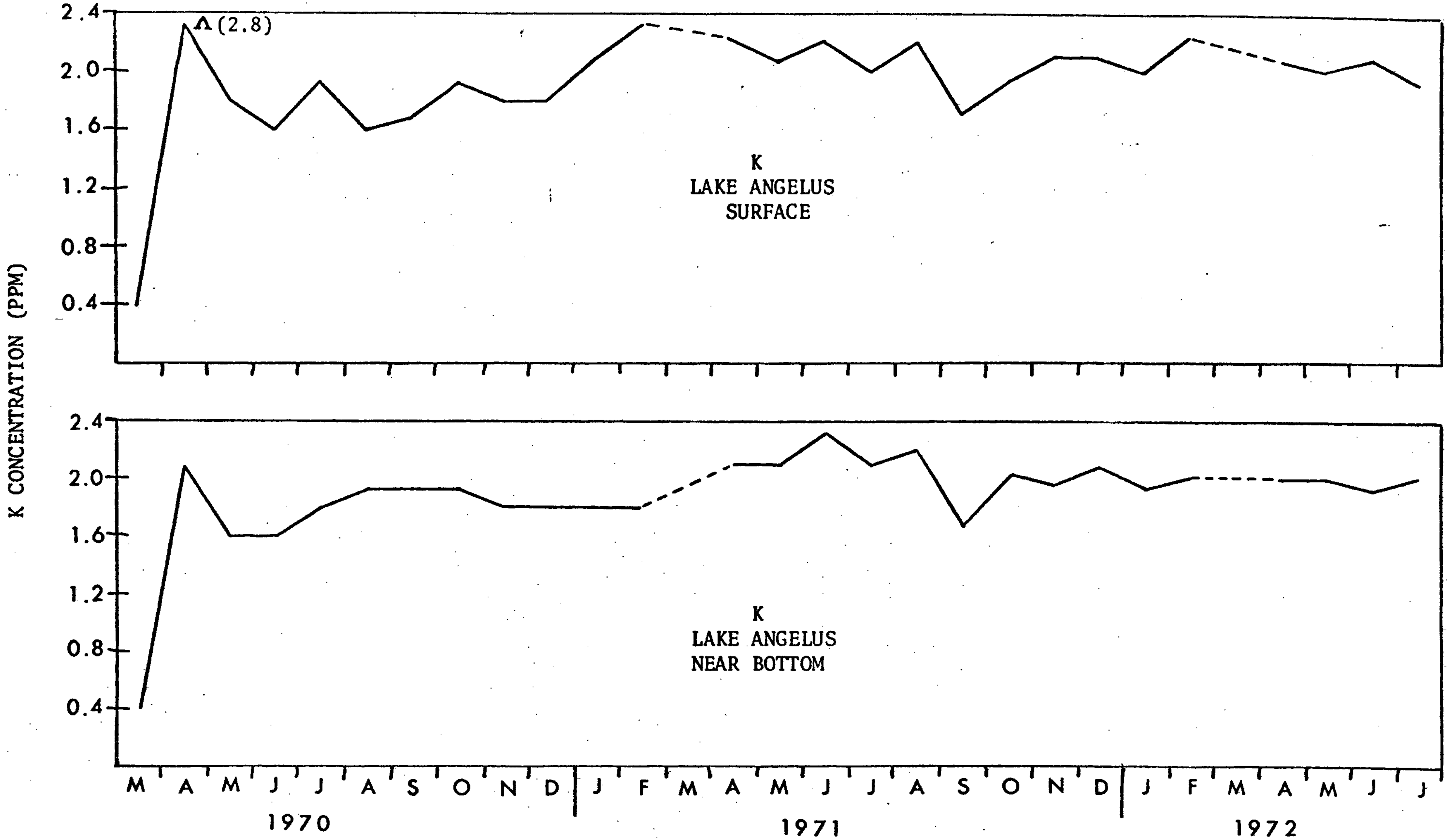


FIG. 8: CONCENTRATIONS OF POTASSIUM IN SURFACE AND BOTTOM WATERS OF LAKE ANGELUS

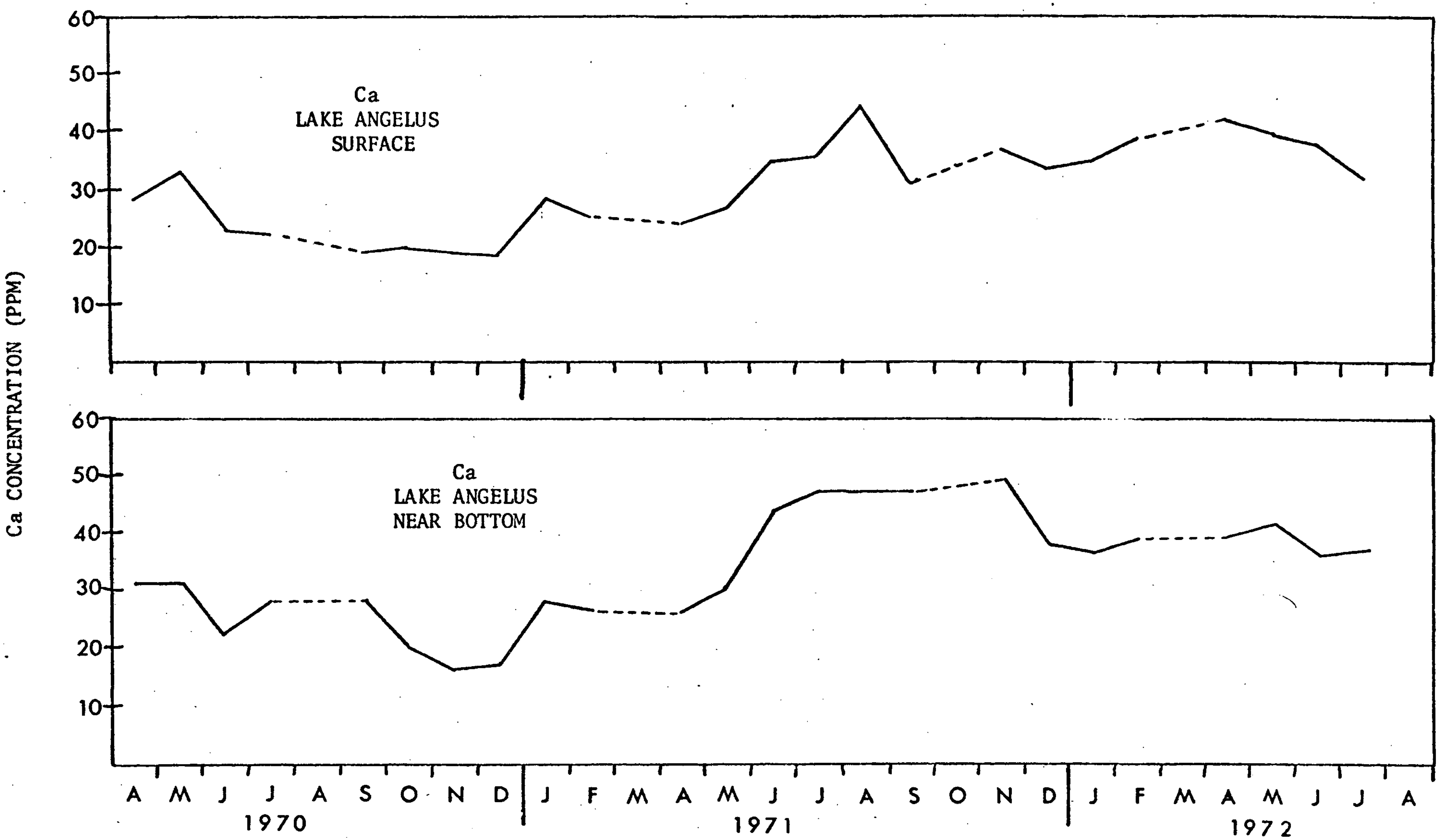


FIG. 9: CONCENTRATIONS OF CALCIUM IN SURFACE AND BOTTOM WATERS OF LAKE ANGELUS

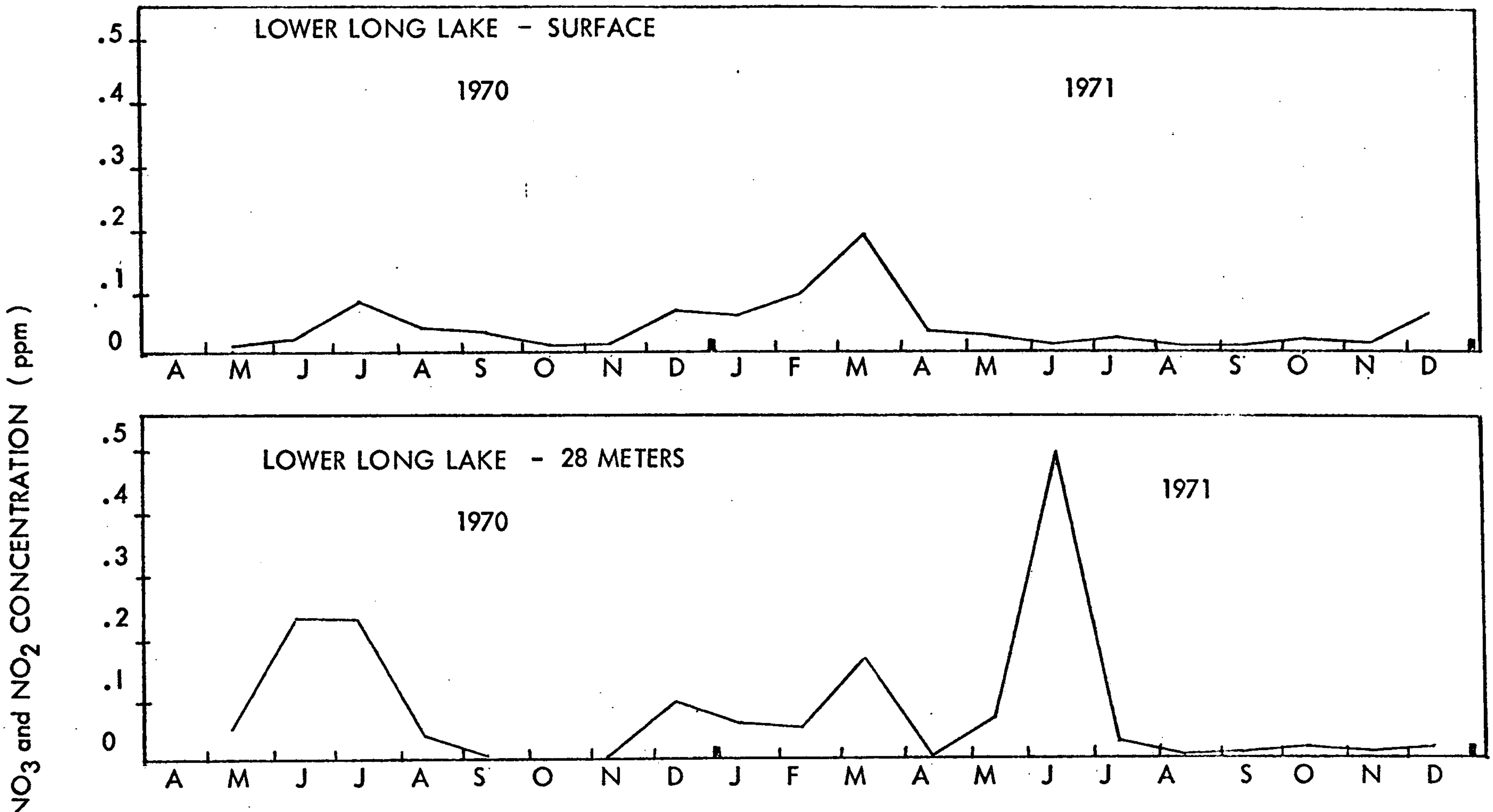


FIG. 10: CONCENTRATIONS OF REACTIVE NITRATE, PLUS NITRITE IN SURFACE AND BOTTOM WATERS OF LOWER LONG LAKE

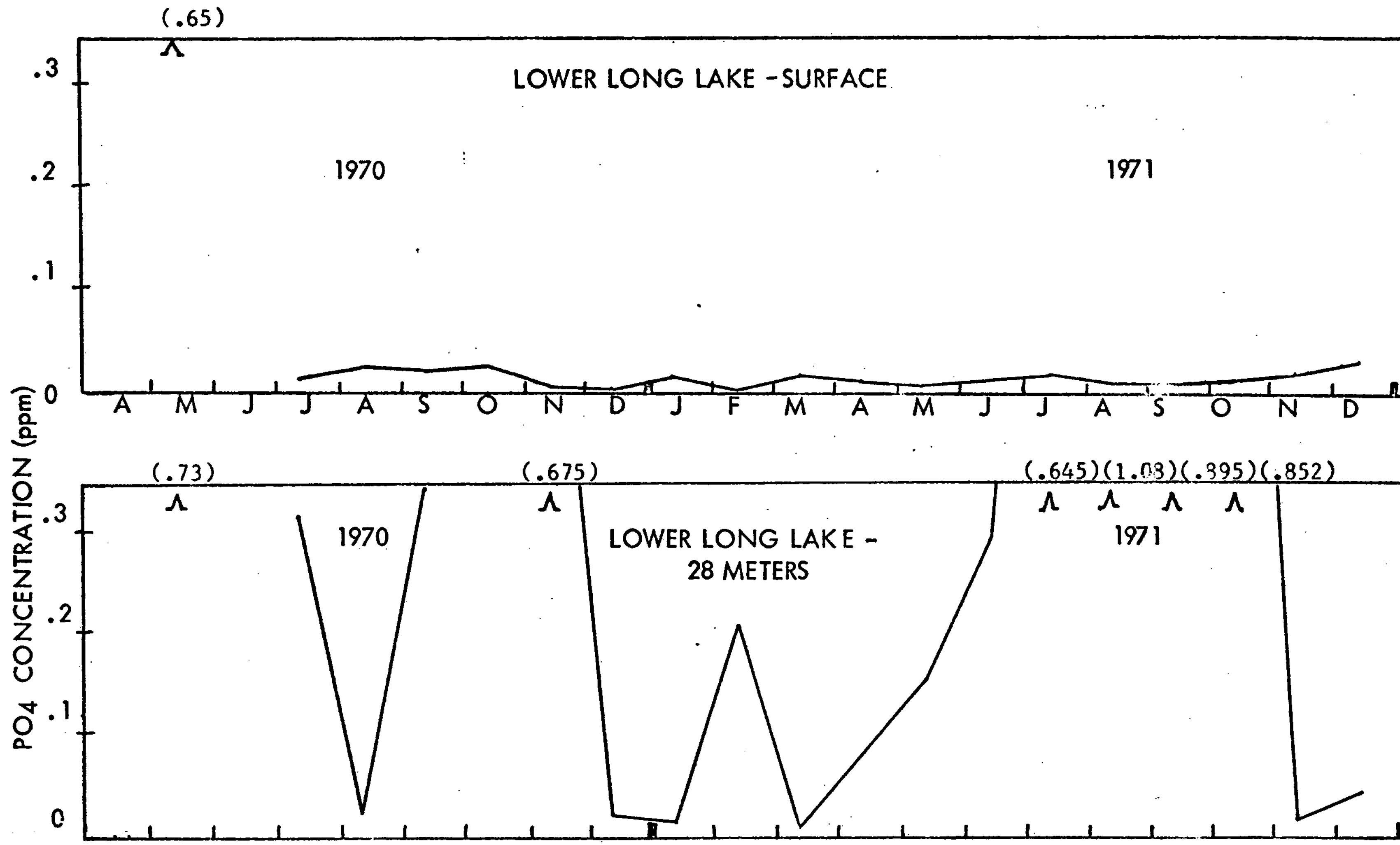


FIG. 11: CONCENTRATIONS OF SOLUBLE REACTIVE PHOSPHATE IN SURFACE AND BOTTOM WATERS OF LOWER LONG LAKE

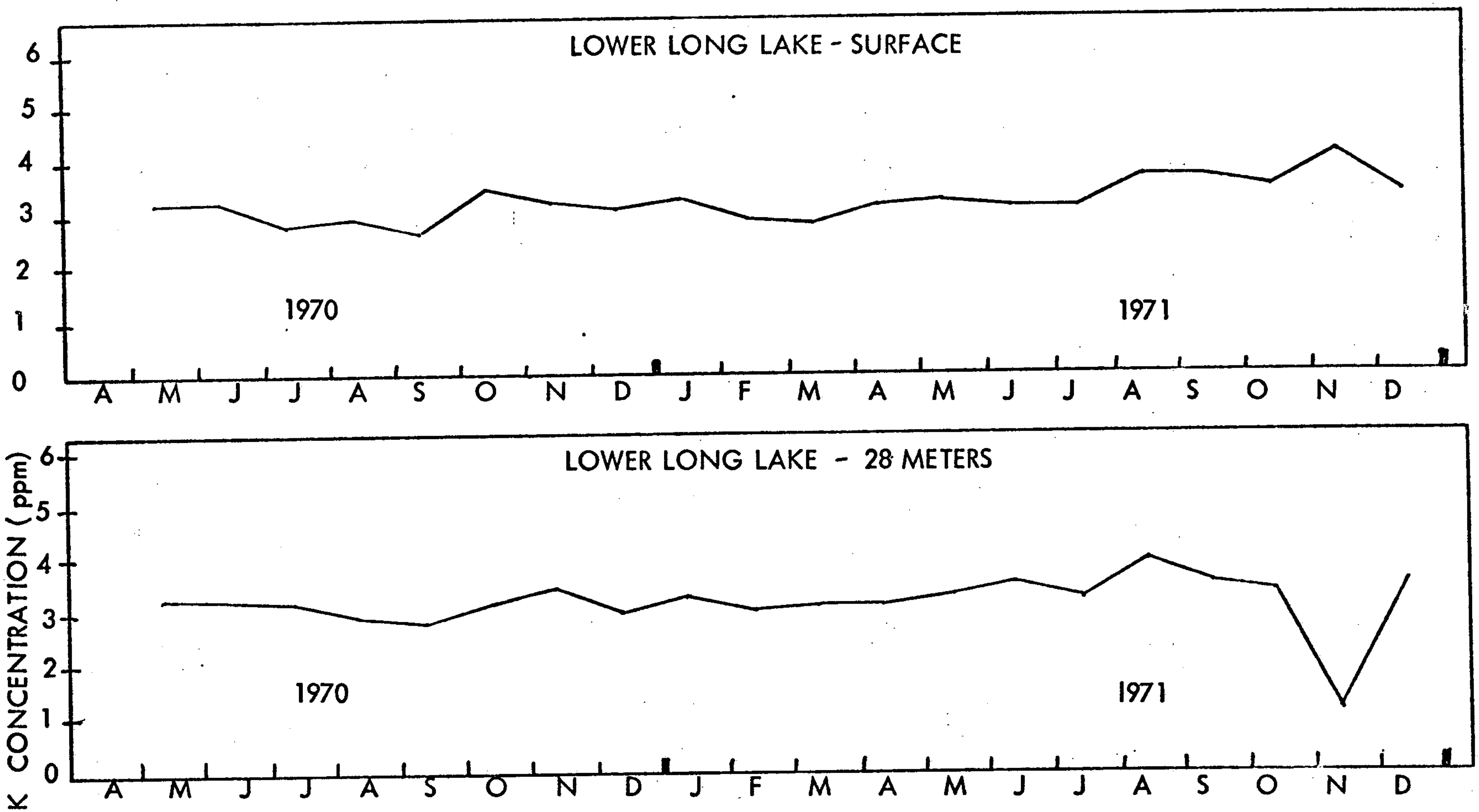


FIG. 12: CONCENTRATIONS OF POTASSIUM IN SURFACE AND BOTTOM WATERS OF LOWER LONG LAKE

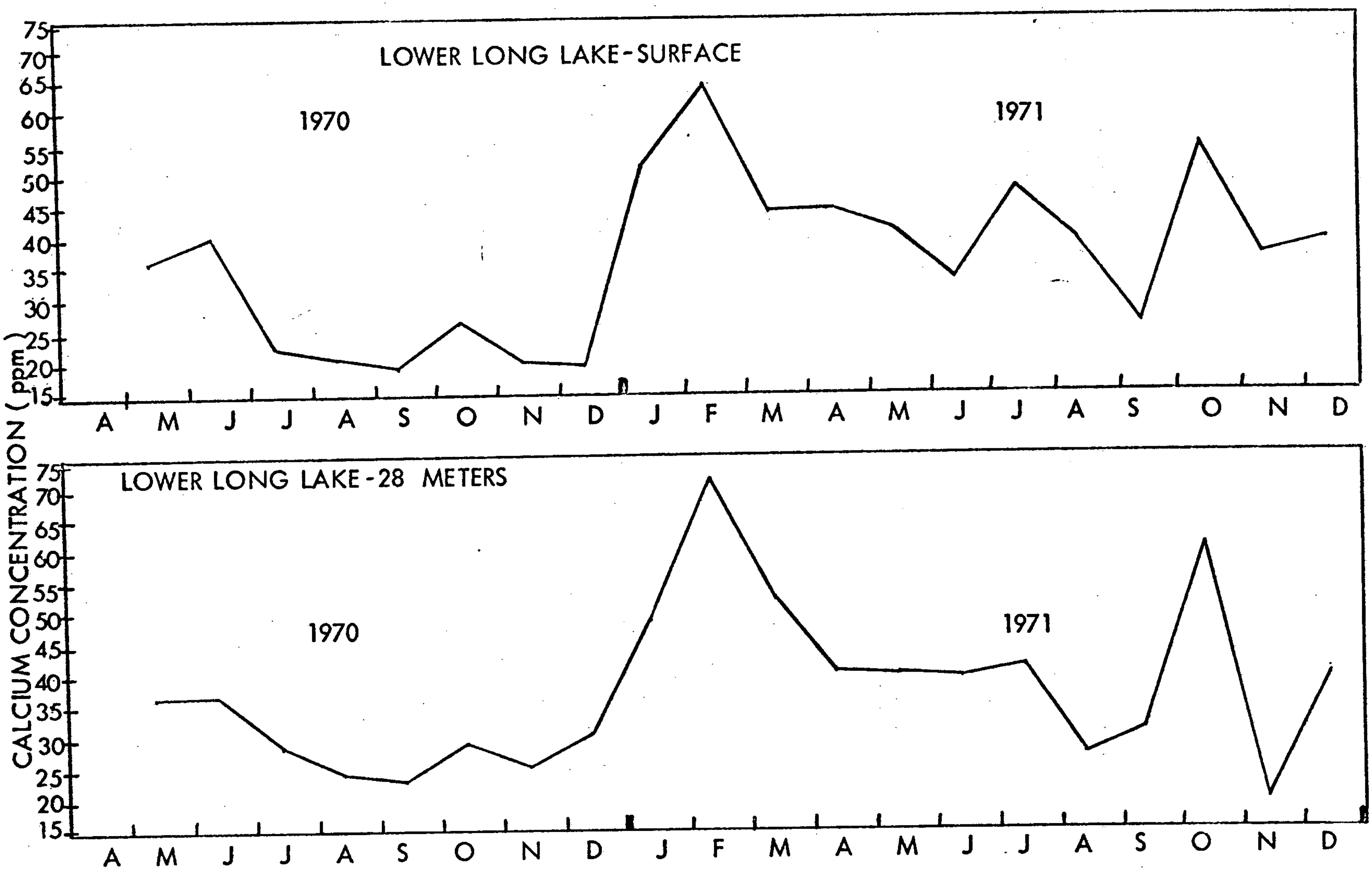


FIG. 13: CONCENTRATIONS OF CALCIUM IN SURFACE AND BOTTOM WATERS OF LOWER LONG LAKE

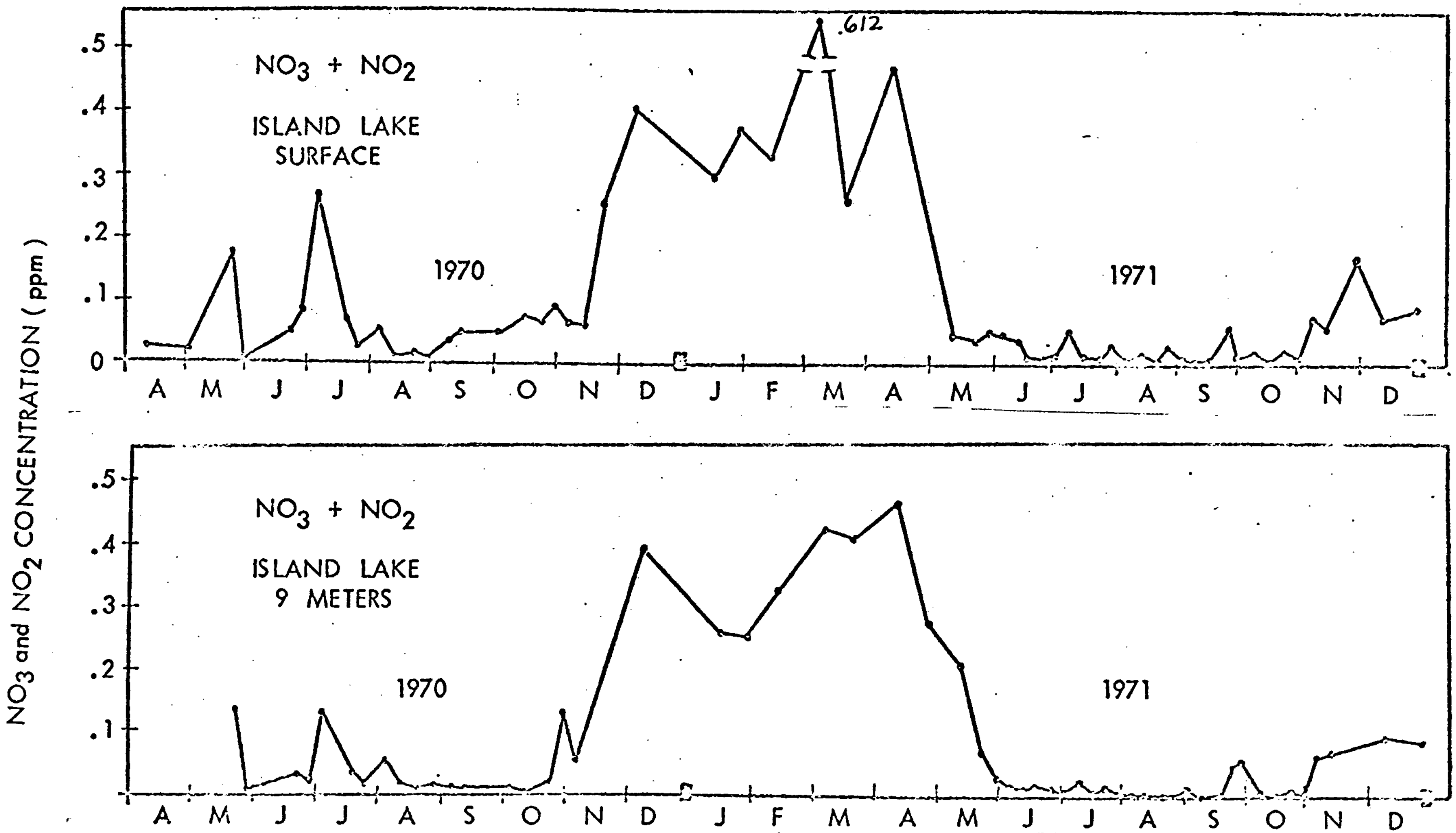


FIG. 14 : CONCENTRATIONS OF REACTIVE NITRATE AND REACTIVE NITRITE IN SAMPLES FROM ISLAND LAKE

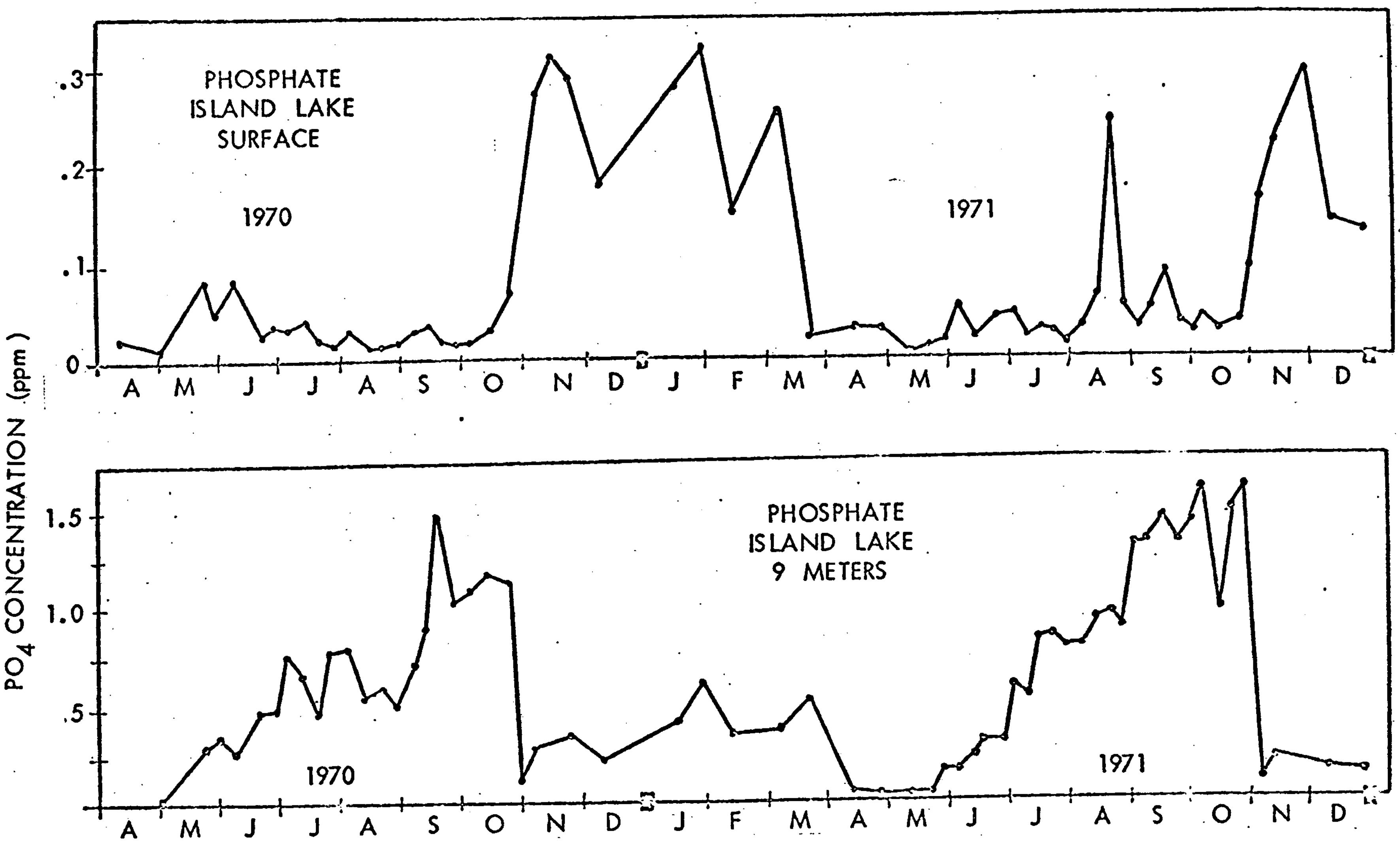


FIG. 15 : CONCENTRATION OF REACTIVE PHOSPHATES
IN ISLAND LAKE

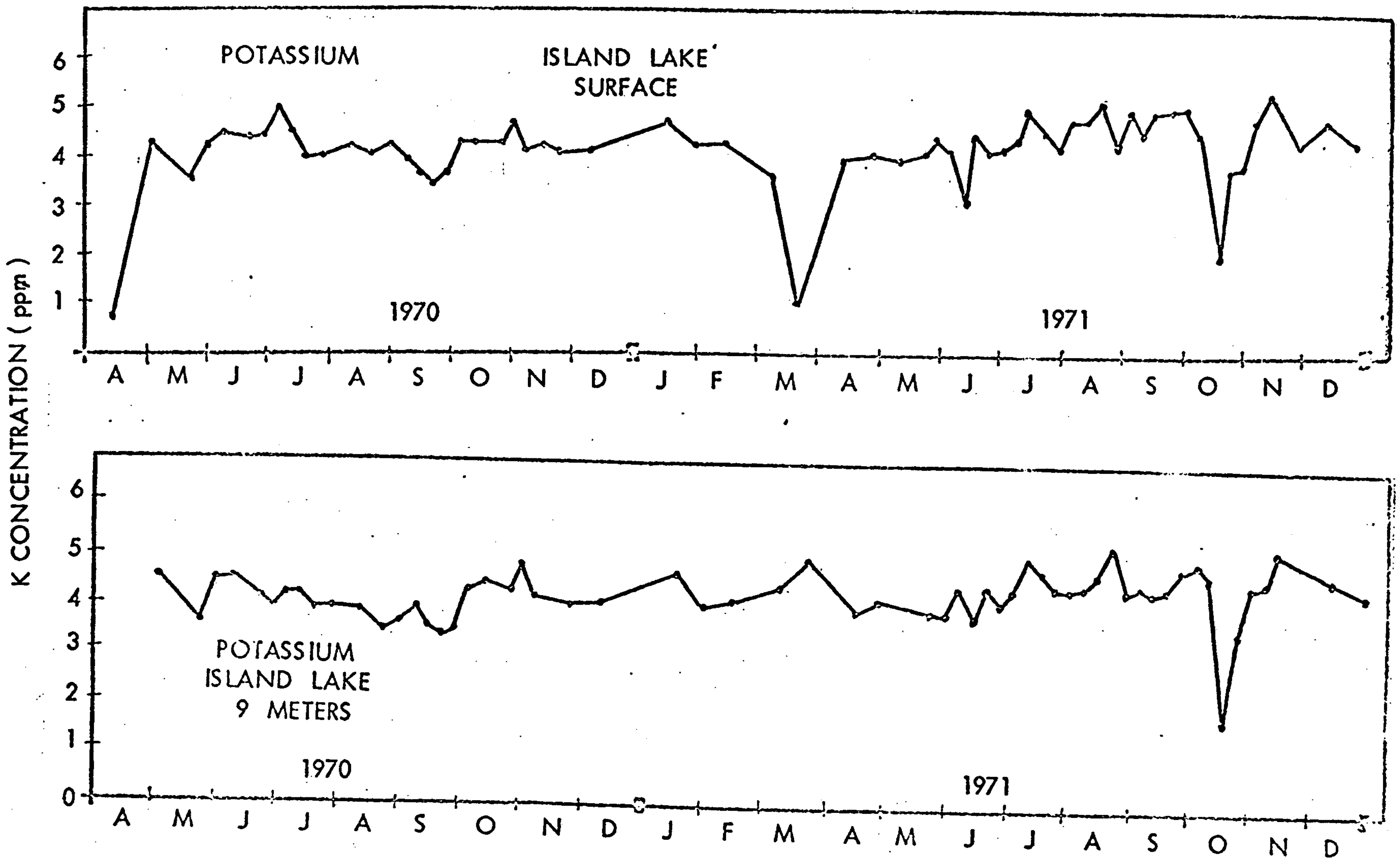


FIG. 16: CONCENTRATIONS OF POTASSIUM IN ISLAND LAKE

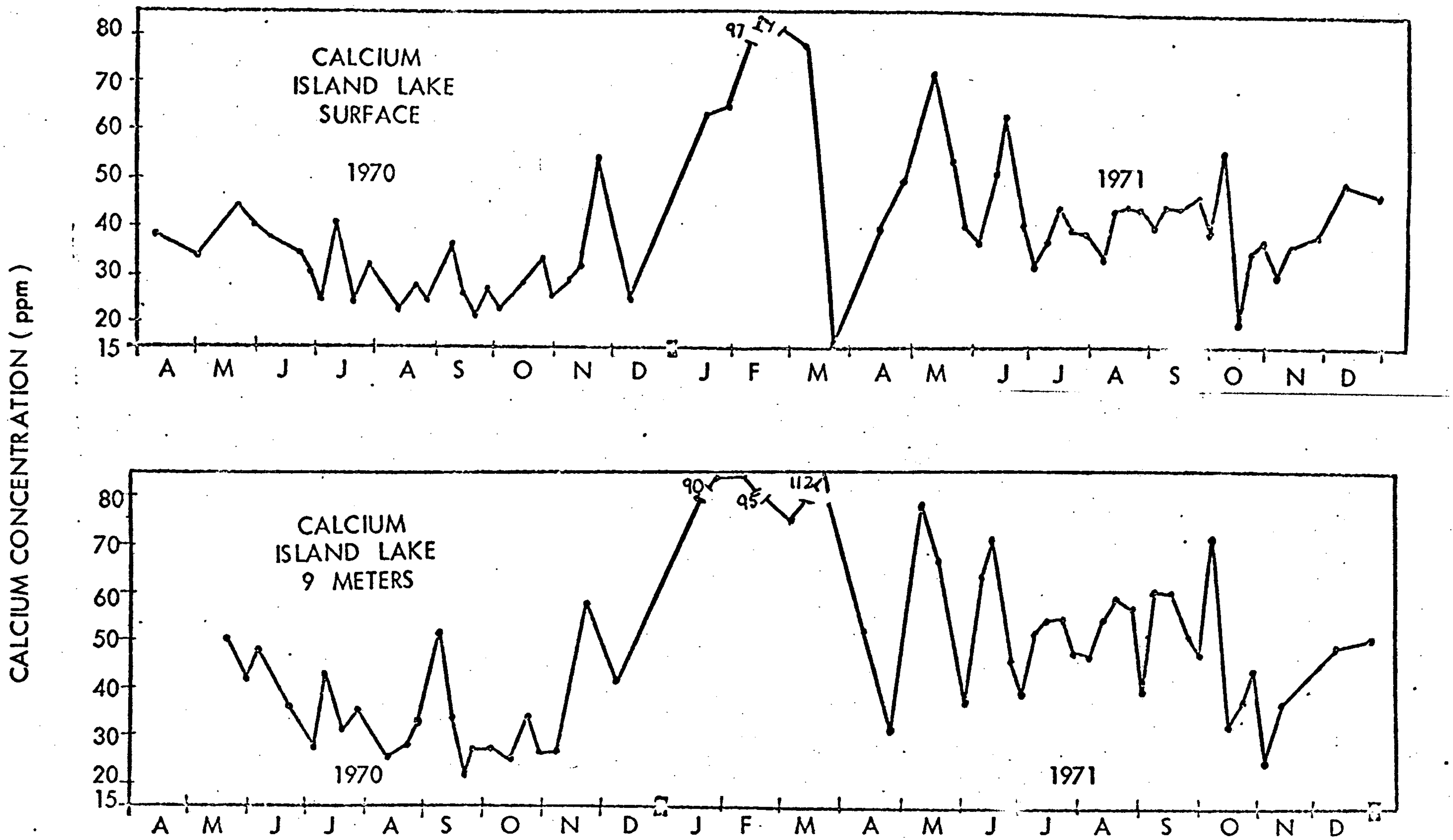


FIG. 17: CONCENTRATION OF CALCIUM IN ISLAND LAKE

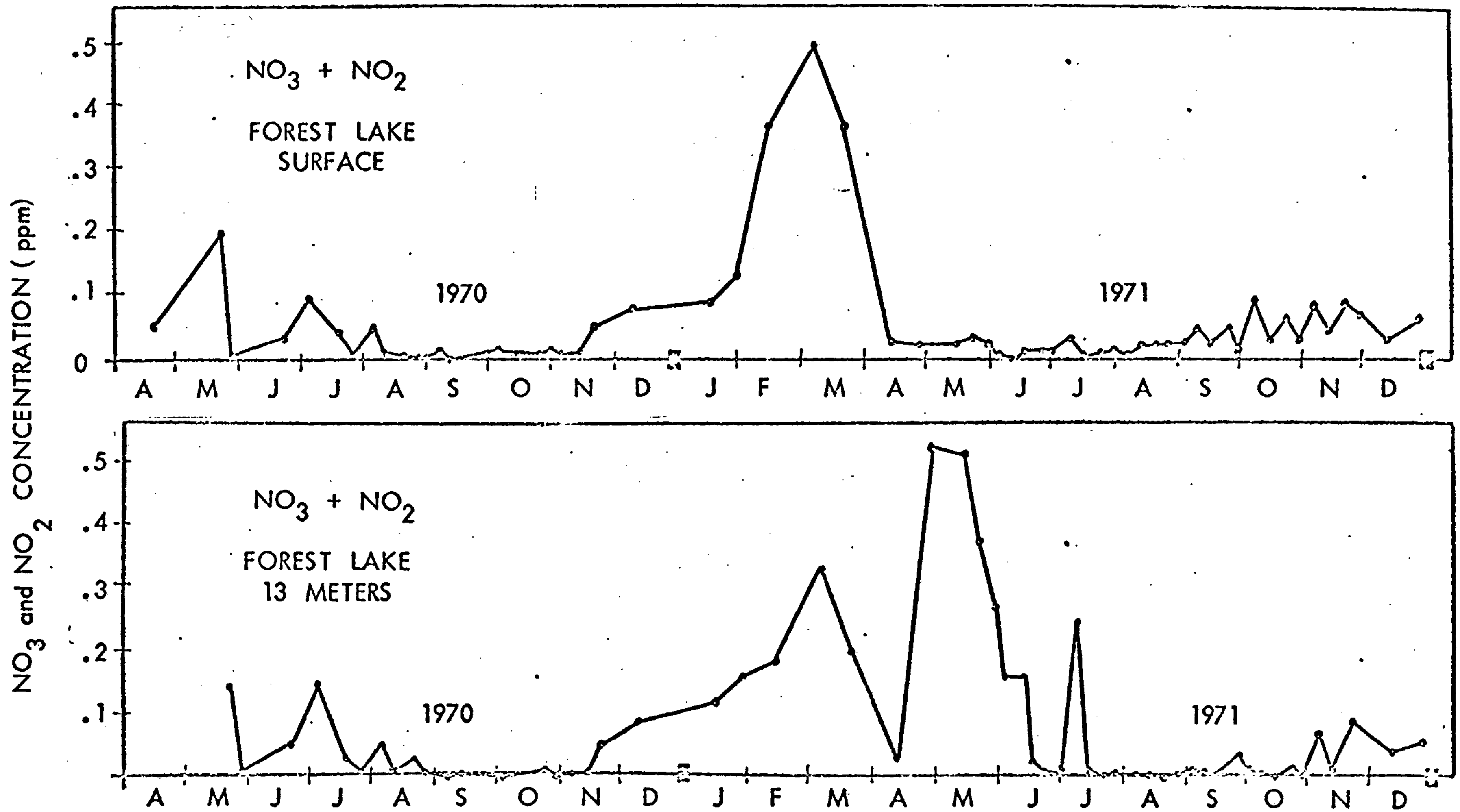


FIG. 18: CONCENTRATION OF REACTIVE NITRITE PLUS REACTIVE NITRATE IN SAMPLES OBTAINED IN FOREST LAKE

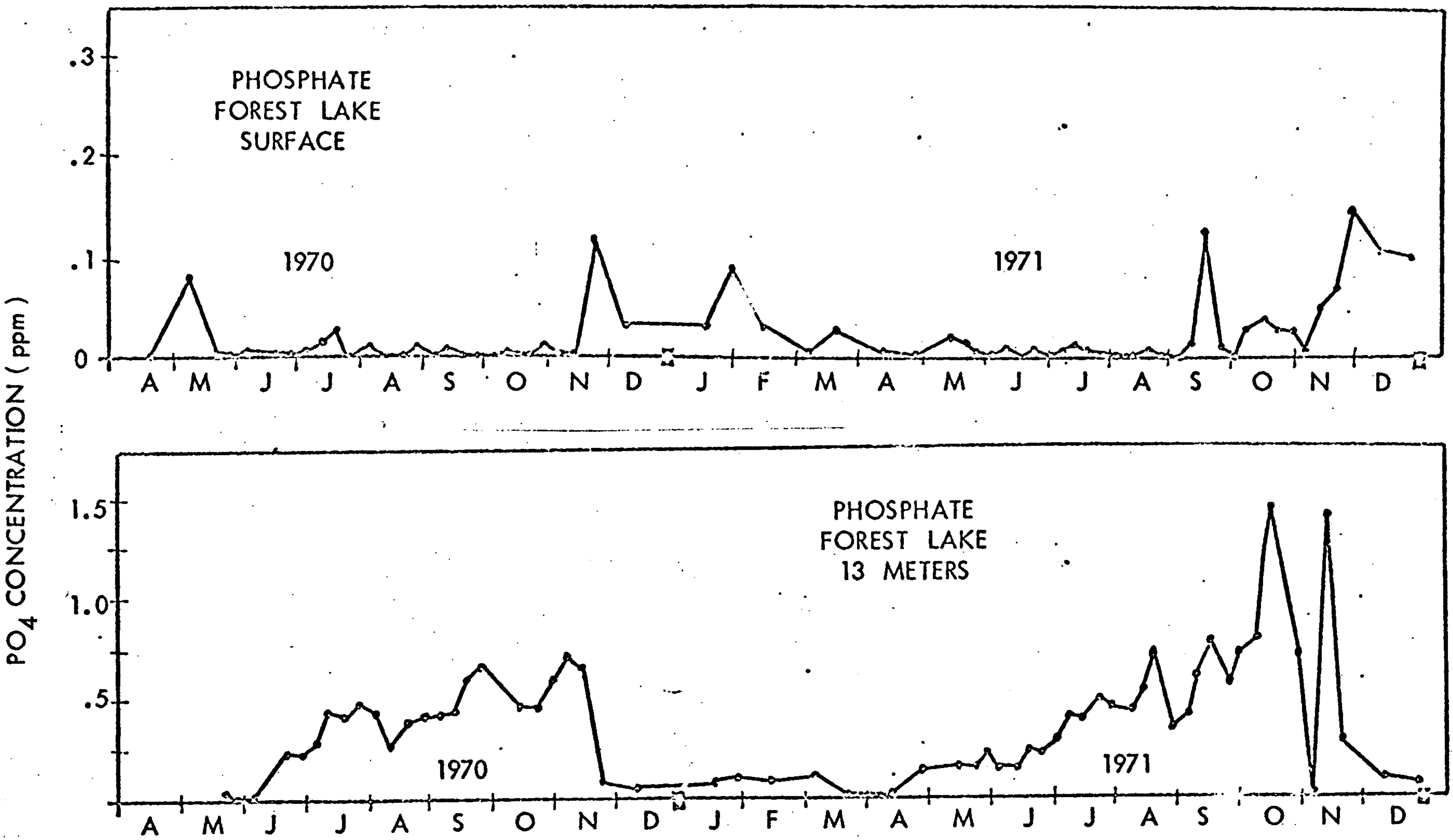


FIG. 19 : CONCENTRATIONS OF SOLUBLE REACTIVE PHOSPHATES IN FOREST LAKE

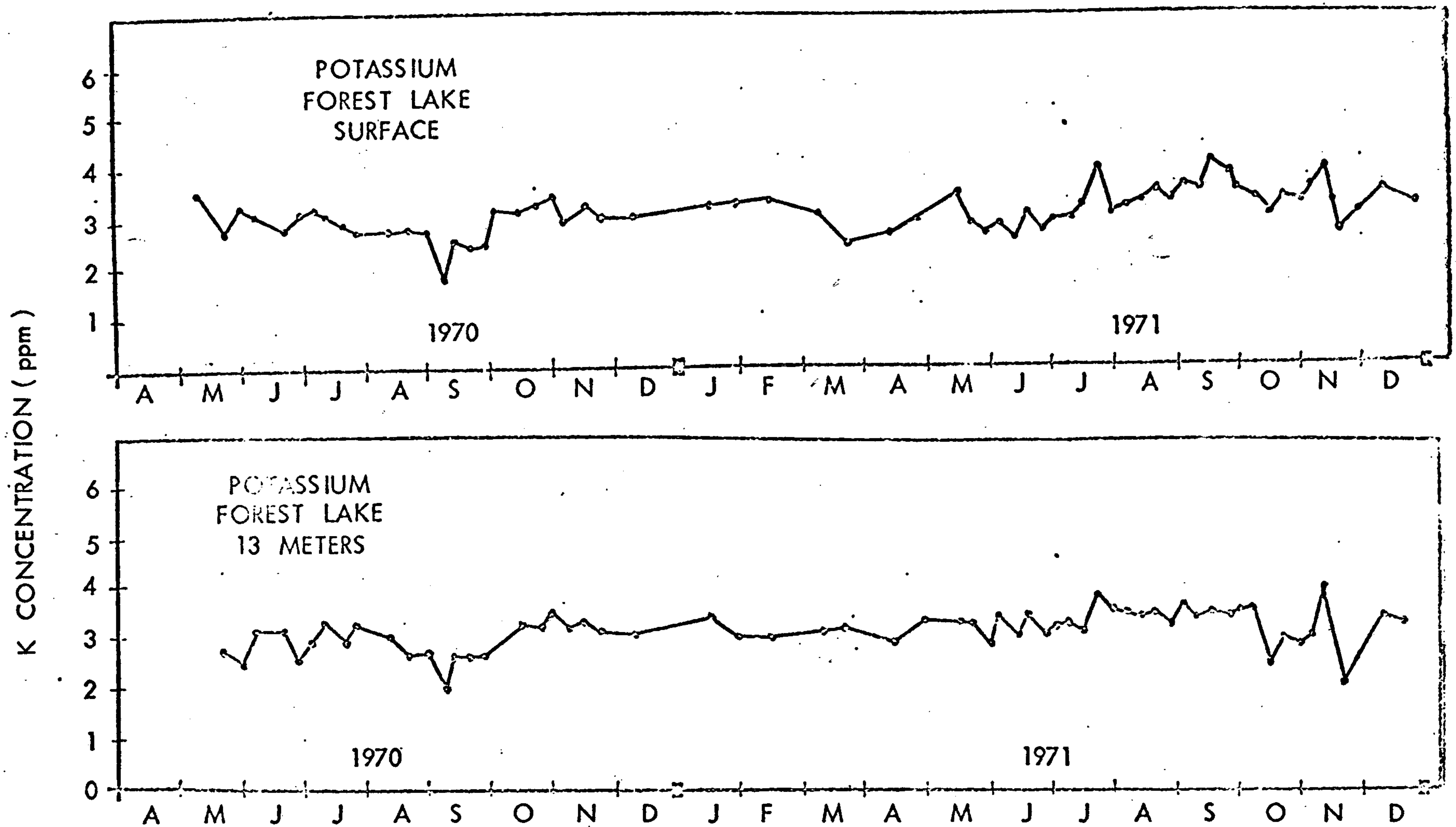


FIG. 20 : CONCENTRATIONS OF POTASSIUM IN FOREST LAKE

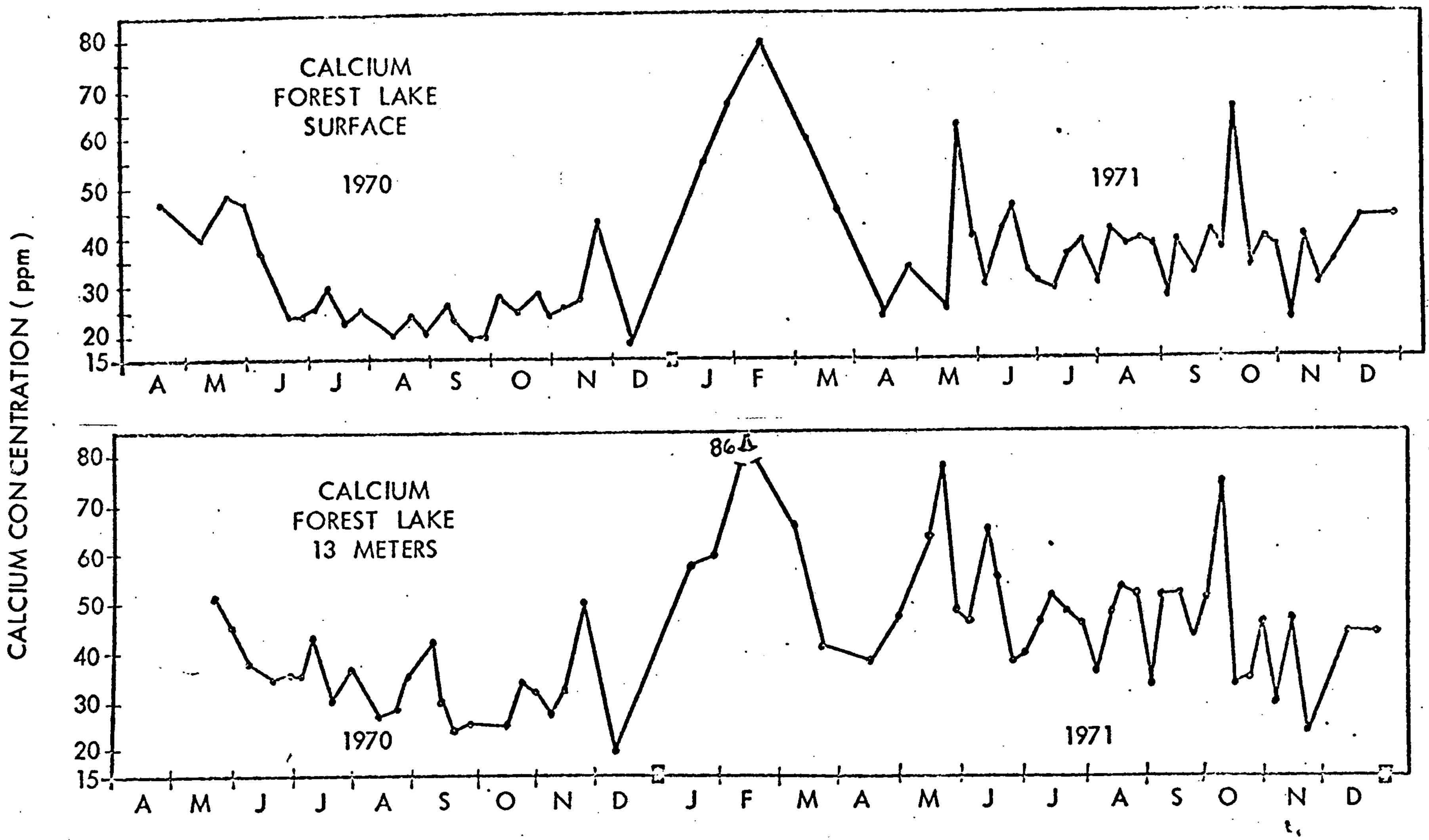


FIG. 21 : CONCENTRATIONS OF CALCIUM IN FOREST LAKE

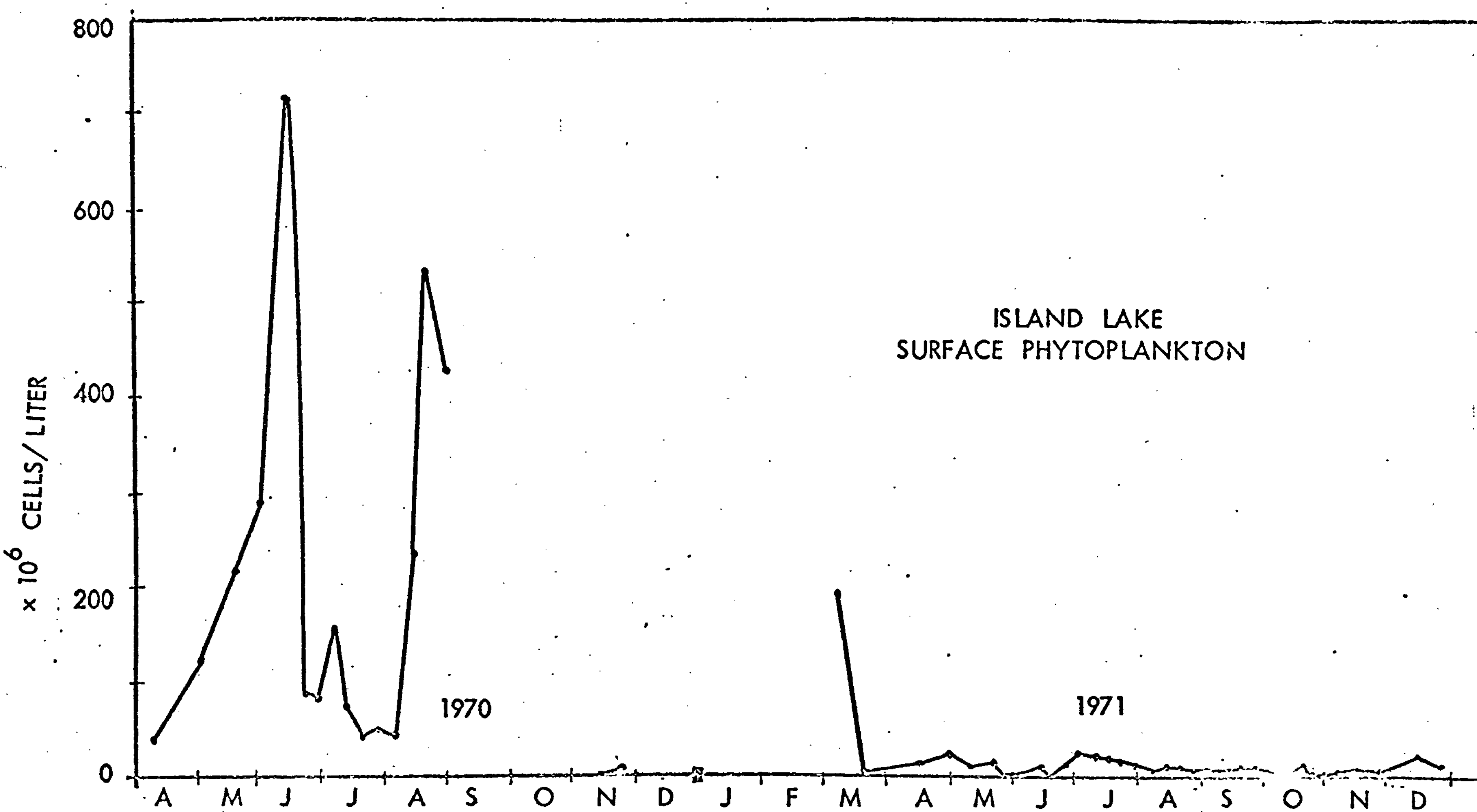


FIG. 22: PHYTOPLANKTON COUNTS OF ISLAND LAKE SURFACE SAMPLES, FROM APRIL 1970 THROUGH DECEMBER 1971

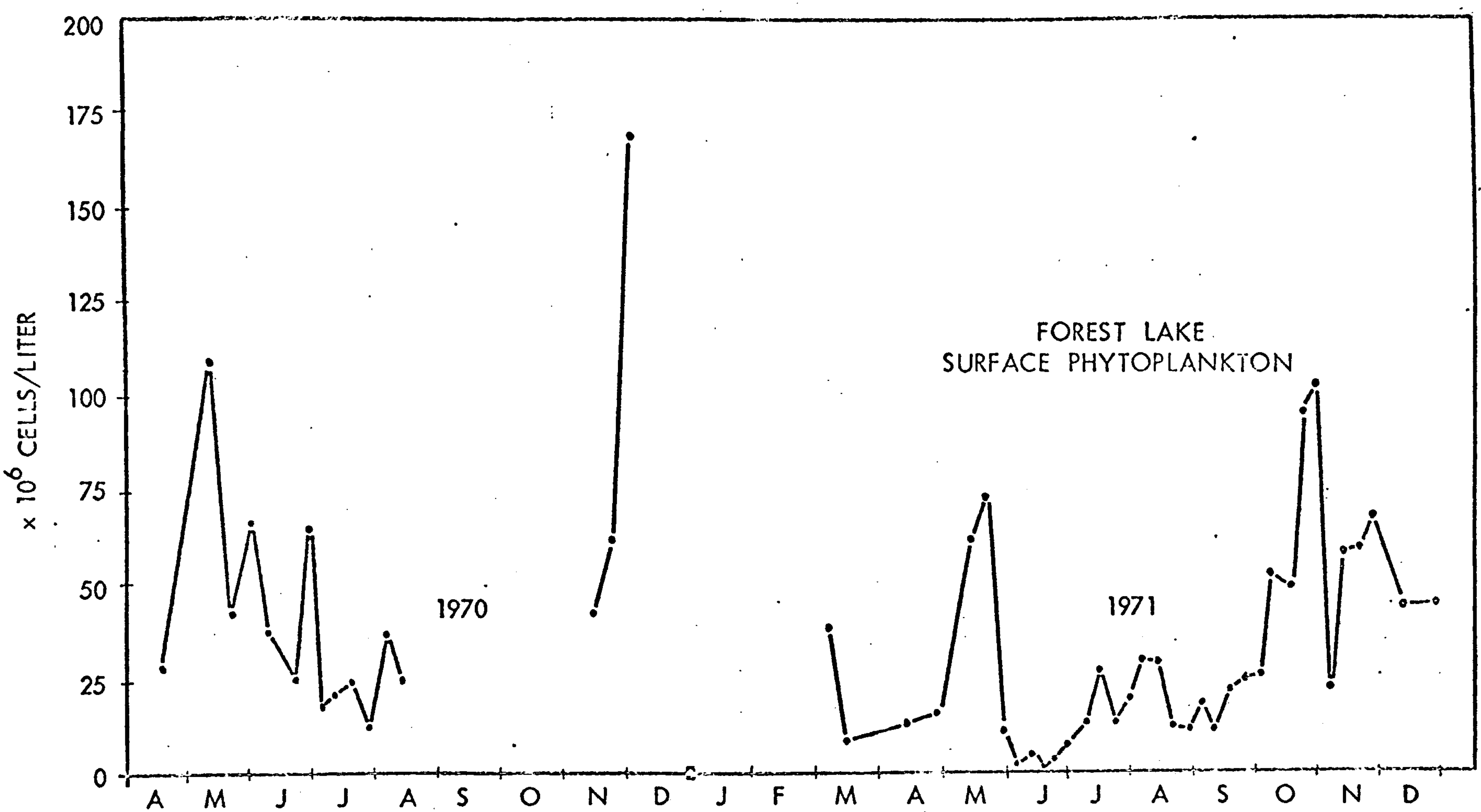


FIG. 23: PHYTOPLANKTON COUNTS OF SURFACE SAMPLES OF FOREST LAKE, FROM APRIL 1970 THROUGH DECEMBER 1971

3. Concentrations of nutrients (nitrogen, phosphorus, calcium, potassium) and their seasonal fluctuations in lakes indicate the extent to which artificial enrichment is taking place. Detailed study of Figures 6-21 has provided this information.

4. Periodic plankton counts (i.e., Figures 22, 23) have indicated variations in the types and numbers of phytoplankton, which are related to enrichment levels.

While the amounts of soluble nutrients (such as nitrogen and phosphorus) in lake waters indicate a certain potential for eutrophication, measurements of organic production are better indicators of actual trophic levels. Suspended and dissolved organic matter, living and dead, varies daily in surface waters. However, average concentrations of phytoplankton and organic carbon are representative of a lake's trophic condition and water color. Although this color is discussed in some detail below it is important to note here the rationale for monitoring a wide range of water quality variables that influence a lake's color and visibility to remote sensors.

Other than the base levels of organic production in lakes, periodic events such as plankton blooms are indicators of trophic state. It is generally agreed that the frequency of blooms and the particular algae causing them are related to water quality and to stages of eutrophication. (Palmer, 1959). Some of these events are regular seasonal phenomena that should not be confused with evolutionary changes in water quality or character. Here, it becomes essential that concurrent changes are monitored in many lakes within a given area, particularly over the span of two or more growing seasons. The ERTS satellite is well suited for this kind of monitoring where consistent, broad coverage is important. This improves one's chances of separating events in lakes that accompany climatic cycles from those events that signify genuine trophic changes in particular lakes.

2.2 WATER QUALITY MONITORING PROGRAM.

(a) While the measurements above have furnished useful information about the relative trophic condition of study lakes, additional data will be needed to characterize water quality and color at the time of satellite or aircraft overflights. A monitoring program has been designed to provide "ground truth" that most likely will account for all lake color variations observed by the satellite. Furthermore, it will provide basic data on trophic levels. A combination of in situ and laboratory studies will take into account any discrepancies between "apparent" lake color (in situ) and the colors of isolated components, such as phytoplankton or detritus. All sampling will be accomplished within two hours (before and after) of remote sensing of the study lakes. The monitoring, which will begin as soon as the lakes are ice-free, will include the following measurements (Figure 24):

1. Particulate Ash/Dry Weight: to find the ratio of inorganic to organic particulate matter in suspension. Mineral particles (i.e., clays) may influence water color and turbidity on occasion.

2. Solute Color: to estimate the color of filtered water according to the platinum-cobalt scale. Solutes (i.e., humic substances) account for brown coloration in some waters.

3. Particulate Color: to find the reflectance spectra of particles filtered from water. These include algae, zooplankton, detritus, and minerals.

4. Particulate Carbon: to measure the amount of organic carbon (living and dead) in suspension. This is a chemical problem, whereas step (1) is gravimetric.

5. Particulate Carbohydrate: to measure the amount of organic carbohydrate (sugars) in suspension. The ratio of carbon to carbohydrate varies with the efficiency of recycling of organic matter.

6. Particulate Nitrogen: to measure the amount of organic nitrogen in suspension. The ratio of carbon to nitrogen reflects the sources and state of organic matter.

7. Particulate Chlorophyll: to estimate the amount of living plant material in suspension. This varies with the productivity of the lake and affects water color.

8. Planton Slides: to identify and estimate numbers of dominant algal forms in suspension. These vary with trophic conditions in the lake.

9. Particulate ATP: to estimate the amount of living organic matter in suspension. The ratio of living to non-living organic matter varies with the recycling rate and trophic level of the lake.

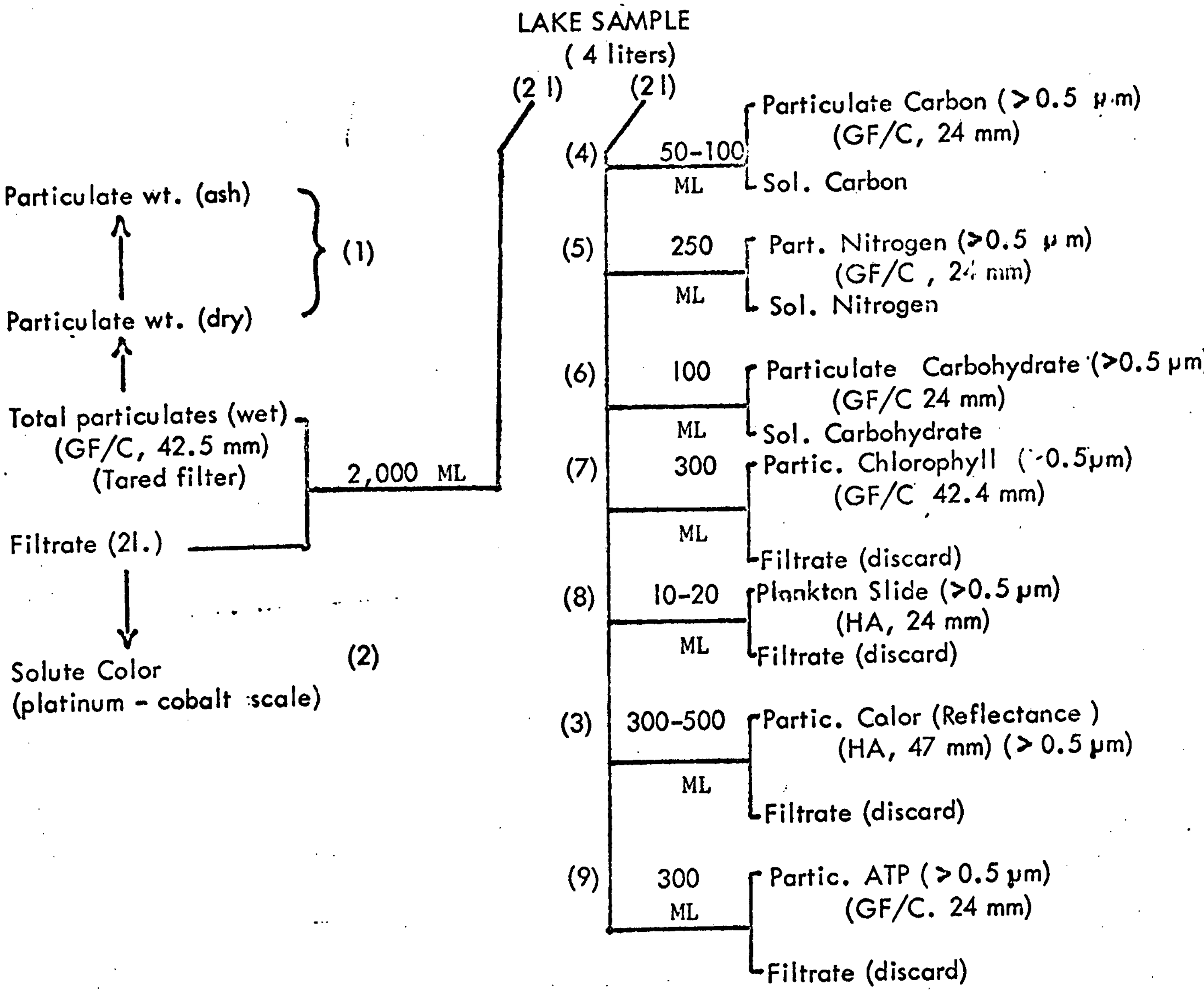


Fig. 24. WATER ANALYSIS PROCEDURES (GROUND TRUTH)

GF/C - Whatman glass filters
HA - Millipore cellulose filters

(b) Field Studies

In addition to these laboratory measurements performed on water samples, other measurements will be made *in situ* at the time of overflights.

1. Water Transparency: to estimate transparency and light penetration using the Secchi disc. Its depth of disappearance varies with the turbidity (under constant light conditions).

2. Spectral Radiometry: to measure the intensity of upswelling and downwelling light in the MSS bands (ERTS) at the lake's surface. This varies with the water color and turbidity, incident light being constant.

3. Water Color: to estimate the spectral color of water by comparison to the Forel-Ule Scale (22 blue to brown standards). This varies with the quantity and quality of solids in the water.

4. Water Temperature: to measure temperature at the lake's surface. This may influence the water's productivity, other factors being equal.

5. Water pH: to measure pH of surface water, since solute color is often affected (increased) by increasing pH.

6. Miscellaneous Observations: to make note of any other phenomena, particularly at the water's surface, which might influence the appearance of the lake to remote sensors. Examples would be algal scums, organic films, floating or emergent vegetation, turbidity plumes, etc.

2.3 REVIEW: REMOTE SENSING OF NATURAL WATERS

(a) Remote Sensing of Water Color

Not even pure water appears colorless to an overhead observer since it scatters blue light and absorbs light strongly at the red end of the visible spectrum (James & Birge, 1938). Natural waters are never pure, however, and their coloration is highly variable (Hutchinson, 1957) as a result of numerous physical, chemical, and biological factors. In a lake or other water body these factors combine in a highly complex way to produce an overall color. Water colors, as observed underwater, at the lake's surface and from above, are not necessarily the same. However, it is possible to characterize water color at each of these levels by any number of visual or analytical means.

The development of remote sensing (as opposed to in situ monitoring) as a tool for measuring water color is clearly justified for several reasons.

1. Color variations, which reflect differences in water quality, have long been noted by aerial observers over natural waters of all types.

2. Many natural and artificial constituents of water, both living and non-living, are known to be colored.

3. Color variations in water are often of such scale and subtlety that they are apparent only to an aerial observer or sensor.

4. Multispectral sensors on space platforms (ERTS) have recently made possible a degree of color discrimination and monitoring coverage that was never before possible with human observers.

5. Water color promises to be a mediating variable between water quality and the "images" of natural waters recorded by remote sensors.

(b) Remote Sensing of Water Quality

The utility of remote sensors in measuring water quality have been widely discussed in recent years (Clapp, 1972; Colwell, 1967; Duntley, 1965; Ewing, 1967; Gramms & Boyle, 1971; Jamison, 1967; Kiefer & Scherz, 1971; Oswald, 1967; Piech & Walker, 1971 a-b; Ramsey, 1968; Scherz, 1967). Yet, few studies have focused on the application of satellite sensors to measurement of biological production or trophic levels in natural waters. Perhaps none have applied to inland lakes, where water color and trophic levels are subject to particularly broad variations (Juday & Birge, 1933). Nevertheless, much information has been published that is peripheral to this study of lake eutrophication with ERTS. While this information is still being assimilated, a few pertinent references are noted as follows:

1. Industrial effluents have been traced by their characteristic colors or turbidity (Piech et al, 1969; Wezernak & Polcyn, 1970; Strandberg, 1967).

2. Heated effluent and other thermal effects have been monitored by infrared sensors (Shenk, 1972; Richards & Massey, 1966).

3. Phytoplankton and plant chlorophylls have been estimated in marine and freshwaters (Hom, 1967; Clark et al, 1970; Clark, 1965; Clark, 1969; Carter, 1967).

4. Some progress is being made in location of aquatic animals (fish) by remote sensing (Ewing, 1967; Kelly & Conard, 1969).

5. Atmospheric effects on ocean color are being studied (Curran et al, 1972).

6. Natural circulation and mixing of river and ocean waters have been described (Atwell, 1972).

7. Bottom topography and reflectance have been mapped (Vary, 1969; Polcyn et al, 1971; Polcyn & Sattinger, 1969).

c. Remote Sensing and Eutrophication

A succession of fundamental relationships must be explored before there can be developed a reliable method for monitoring trophic levels by remote sensors (ERTS).

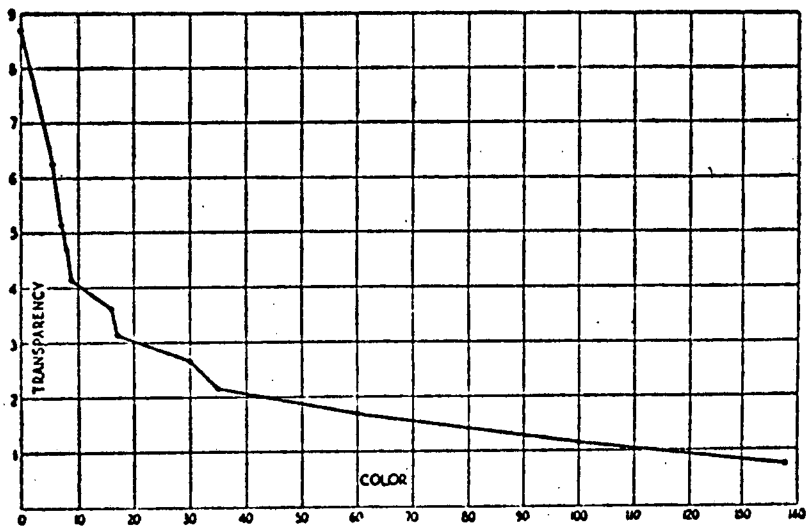
1. First, good indicators of trophic state are selected, as described earlier (above). These are discussed more thoroughly elsewhere (Greeson, 1969; Lee, 1970; Mackenthun and Ingram, 1967; Hutchinson, 1957).

2. Then, the relationships between trophic indicators and water color are defined. Some indicators, like phytoplankton, transparency, and carbon are related directly to water color, as shown by Juday and Birge (1933), Figure 25 (a & b) and Figure 26. These and other such relationships have been described by Black (1963), Palmer (1962), and Yentsch (1960).

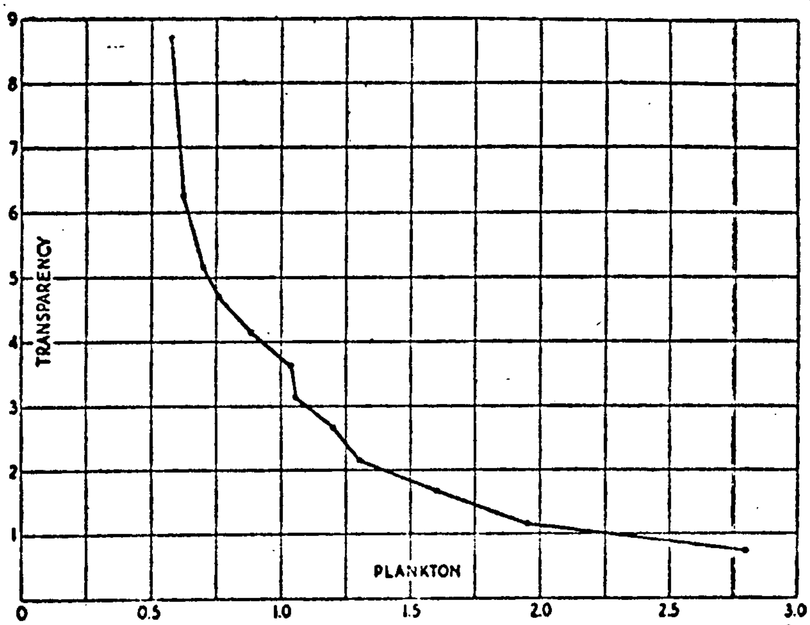
3. Third, the correlations between water color and remote imagery are elucidated. Most studies to date have dealt with this problem in the sea (Curran & Hovis, 1972; Clark et al, 1970; Ramsey, 1968; Piech & Walker, 1971 a; White, 1969). Relatively little work has been done on the color of lakes, even though ground truth gathering is more convenient (Scherz, 1967; Scherz et al, 1969; Robinove, 1965). Aircraft sensors are used in the transitional stages between ground and satellite.

4. Finally, the application of satellite sensors to water quality monitoring in lakes is refined. This is an objective of the present research.

Fig. 25a. Correlation of Water Transparency with Color and Plankton Content (from Juday & Birge, 1933: p. 213-215.) Based on a sample of 530 Wisconsin lakes and ponds.



The relation between the transparency and the color of the water. The transparency is represented by the depth, in meters, at which the Secchi disc disappears from view and the color is indicated in terms of the platinum-cobalt standard.



The relation between the transparency and the plankton content of the water. The results for plankton show the amount of dry organic matter per liter of water in the centrifuge catches.

Fig. 25b. Correlation of Water Color with Organic Carbon (from Juday & Birge, 1933: p. 232-233)

Based on a sample of 530 Wisconsin lakes and ponds.

TABLE VIII

The relation between the color of the surface waters of the lakes in northeastern Wisconsin and the amount of organic carbon in them. The lakes are separated into groups on the basis of their brown color in comparison with the platinum-cobalt standard; the maximum, minimum and mean quantities of organic carbon are indicated in milligrams per liter of water for the various color groups, as well as the number of lakes in each group. The lakes are grouped by color ranges of 10 up to 69, but the number in the various 10 groups above this color is so small that they have been combined into larger color groups in order to obtain a fair mean. See Fig. 5.

Color	Number of lakes	Organic Carbon		
		Maximum	Minimum	Mean
0	56	4.5	1.2	3.0
1—9	57	6.4	1.7	3.6
0—9	113	6.4	1.2	3.3
10—19	101	12.5	2.1	4.6
20—29	77	12.2	2.2	5.7
30—39	46	15.0	3.9	7.7
40—49	23	12.5	4.9	8.3
50—59	27	12.3	5.3	9.2
60—69	22	13.0	4.0	10.3
70—99	44	16.6	7.5	12.1
100—129	40	22.4	6.0	14.3
130—159	15	19.6	12.3	16.0
160—199	9	24.8	14.5	17.1
200—340	12	25.8	13.5	21.4

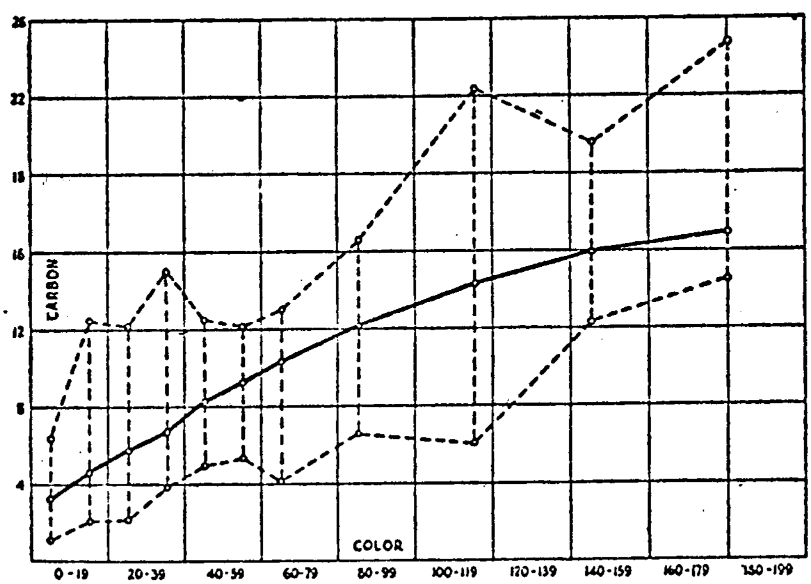
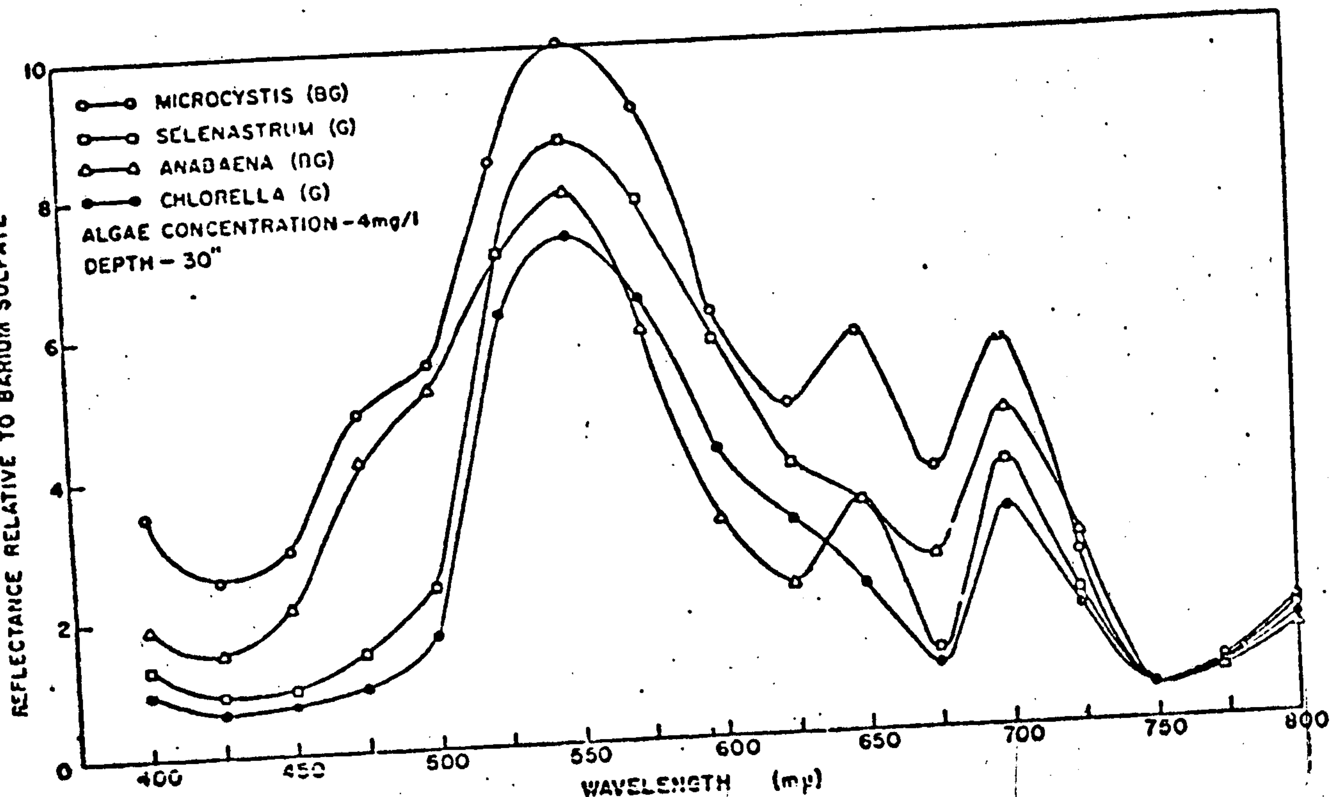
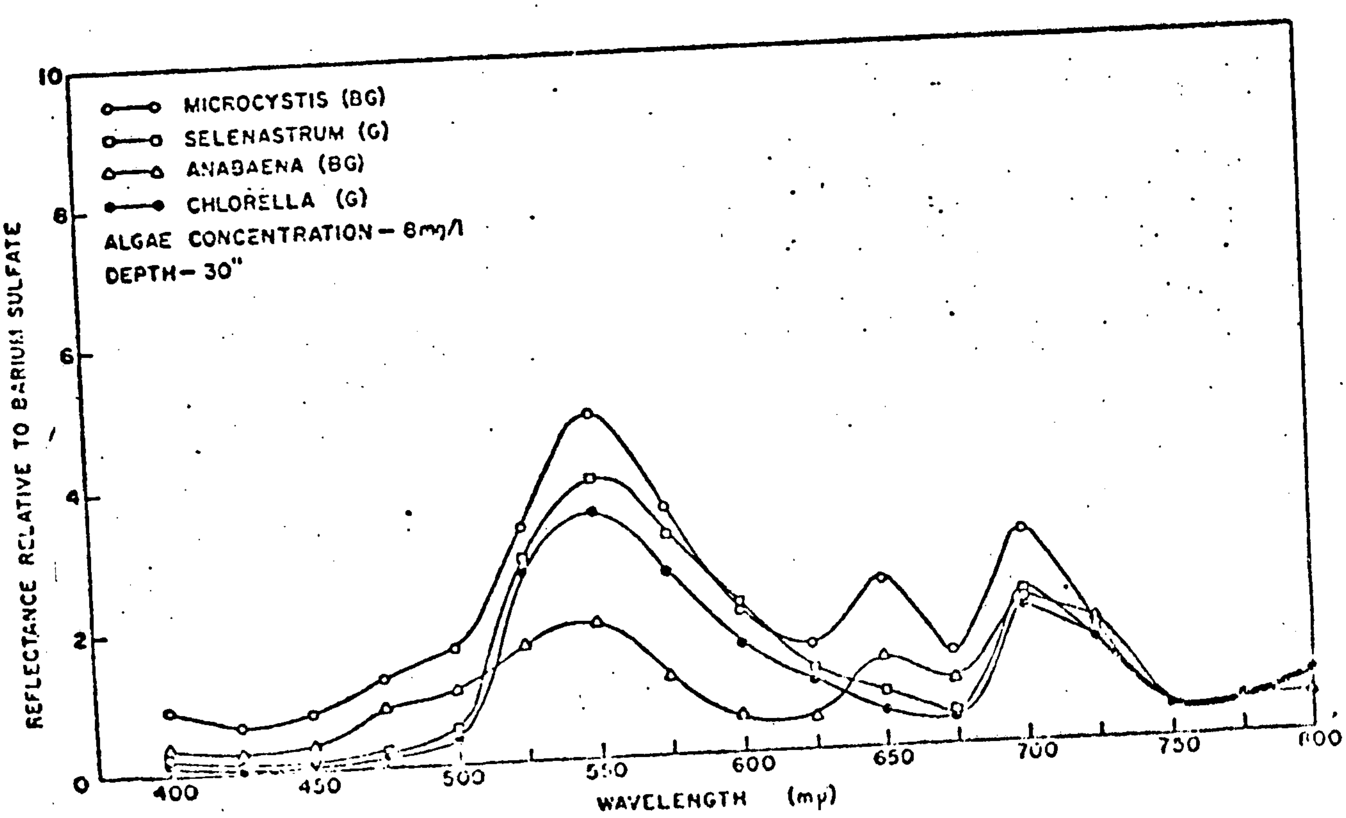


FIG. 5. The relation between the color of the water and its organic carbon content. The upper curve shown by a broken line represents the maximum amounts of organic carbon found in the various color groups; the lower broken line curve shows the minimum amounts of organic carbon. The solid line curve between them indicates the mean quantities of organic carbon in the various color groups. (See Table VIII).

Fig. 26. Reflectance Spectra of Unialgal Cultures (from Gramms & Boyle, 1971; p. 7-8)





3. ACCOMPLISHMENTS DURING INITIAL ERTS-1 DATA REVIEW

3.1 ERTS IMAGERY INTERPRETATION

(a) Study Area

Only two sets of images received since ERTS-1 launch have provided partial coverage of the study area (Oakland County, Michigan). In that of 24 August 1972 (prior to contract) only two of the six study lakes (Orchard and Angelus) were visible due to greater than 50% cloud cover. In imagery of 28 September 1972, five of the six lakes (exclusing Lake Angelus) were visible.

In the latter scene (Figure 27) a part of the study area, representing approximately 50 square miles, is marked off. This sub-area has been examined closely with respect to lake features. The objective was to determine what effects, if any, the size and character of lakes have on their resolution and appearance in ERTS imagery.

(b) Image Resolution of Lakes

Photographic images (8 x 10 in.) of the sub-area were studied with a binocular scope and hand lenses. Little difference in the image-resolution of lakes was noted between negative transparencies and positive prints of Bands 6 and 7. Due to atmospheric haze lakes were poorly resolved in Band 4, and only moderately distinct in Band 5. The named lakes and ponds visible in the sub-area are listed (according to acreage) in Table 1. Some of their physical and image characteristics are given as well (Table 2). Those lakes not visible in Bands 4 and 5 are marked (+).

1. Lake Size and Resolution: Examples of the smallest ponds (or channels) that can be resolved are shown in a magnified view of the sub-area (Figure 28) and on an Oakland County Planning Commission (OCPC) map excerpt (Figure 29). The smallest of these are approximately 200 feet in diameter, or less than one acre in surface area (Figure 28, 29, 31, 32). These appear as gray spots in the B/W imagery. Elongated ponds or channels which are approximately 100 feet in width (Figure 28, center and upper middle) are also visible, but are without definite shape in the imagery.

   Larger ponds that appear as black (full density) images (Figure 28) are approximately 550 ft. in diameter, or 7.5 acres in area

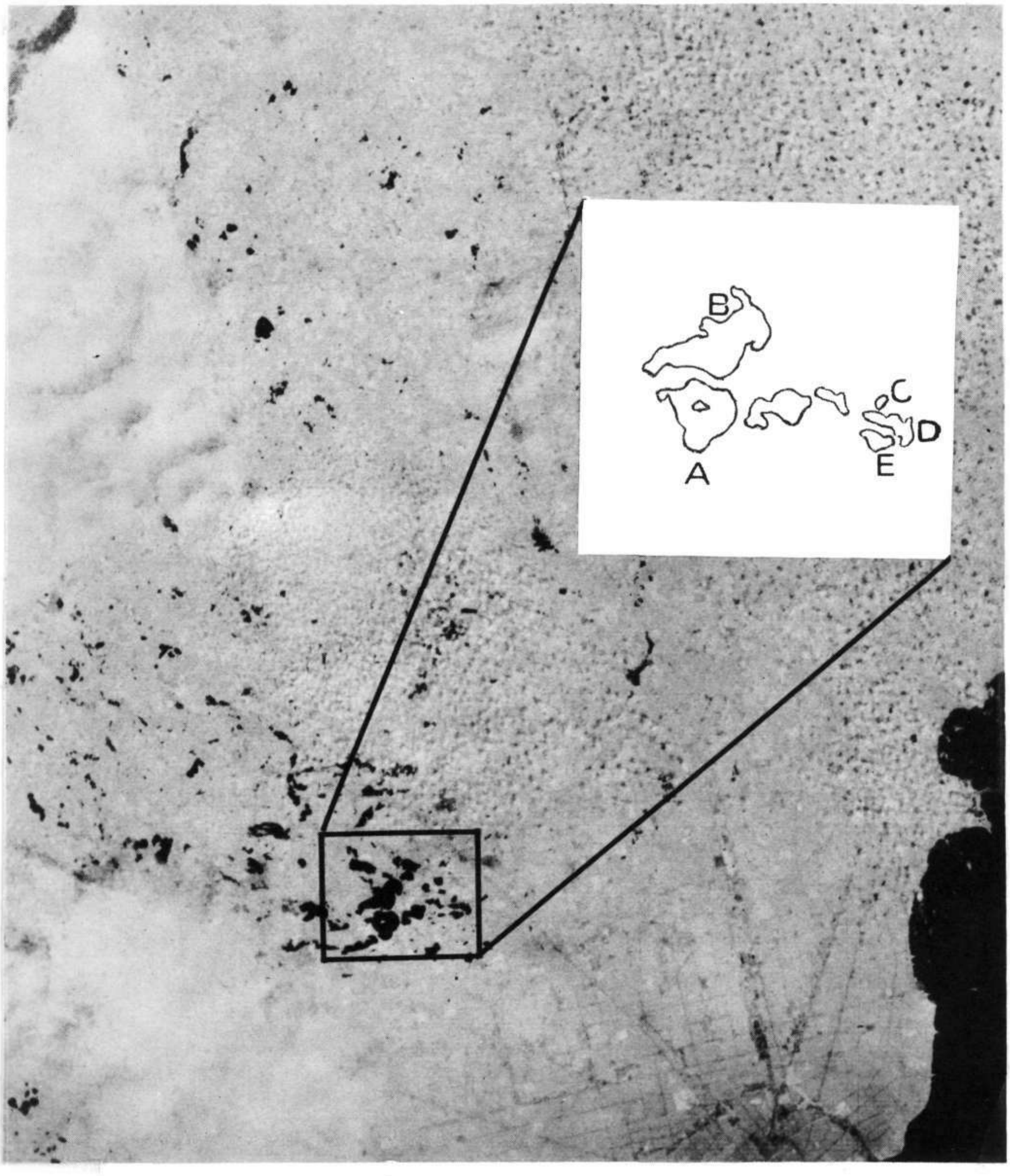


Figure 27 Oakland County Lakes
(Scene 1067-15463-7)

A. Orchard Lake
B. Cass Lake
C. Forest Lake
D. Lower Long Lake
E. Island Lake

in area. Their greater image density map be a simple function of sensor response or, possibly, may be related to their shallow depth and generally more turbid waters. This question will be resolved later by ground truth.

In conclusion, the smallest of the six study lakes (Forest Lake, at 40 acres) is amply large enough to appear in full image density.

2. Lake Orientation and Resolution: No apparent differences were noted (in Bands 6 and 7) in the resolution of small elongated ponds that are oriented with the direction of scan (west to east) and those that are aligned normal to scan lines (north to south). Figures 28 and 29 show examples of each general orientation that are of comparable size.

   Similarly, no apparent distortion or displacement of small ponds was observed in Bands 6 and 7. Some distortion (banding effect) was noted, however, in Band 5, and is described below.

3. Surface Water and Resolution: Some comparison of lakes with swamps or marshes is possible. In the NASA (bulk) imagery wetlands, in contrast to open-water lakes or ponds, are rarely apparent in Bands 6 and 7, but do appear in Bands 4 and 5. For example, a 40-acre swamp adjoining Forest Lake (Figure 29, lower right), contains some open water but is predominantly emergent grasses and shrubs. A similar swamp is nearby between Upper and Lower Long Lakes. These wetlands are visible as gray areas in the Bendix (CCT) imagery, Bands 5, 6 and 7 (Figure 29).

   Another interesting area in this connection is Otter Lake (Figures 28 and 29, upper center), which forms a shallow marsh at its southern end. As might be expected only the northern two-thirds of this lake is clearly visible in Bands 6 and 7.

   Further study will resolve the question of how much floating or emergent vegetation a lake may contain and still show the image

TABLE 1. NAMED LAKES VISIBLE IN ERTS-1 IMAGERY (Sept. 28, 1972) OF OAKLAND COUNTY (Scene 1067-15463)

Lake Name	ERTS Band Visibility				Area (Acres)	Max. Depth (Feet)	Shore Length (Miles)	Ref. Number*
	4	5	6	7				
Cass	+	+	+	+	1280	123	11.5	331
Orchard	+	+	+	+	788	110	5.7	344
Union	+	+	+	+	465	102	4.0	232
Sylvan	+	+	+	+	458	---	4.7	329
Pine	+	+	+	+	395	90	4.3	347
Elizabeth	+	+	+	+	363	90	3.3	925
Upper Straits	+	+	+	+	323	96	5.5	359
Walnut	+	+	+	+	232	101	3.2	381
Lower Long	+	+	+	+	178	95	3.7	411
Middle Straits		+	+	+	171	55	4.1	263
Green		+	+	+	166	---	3.0	340
Upper Long	+	+	+	+	108	---	2.5	348
Island	+	+	+	+	101	35	2.0	444
Square	+	+	+	+	94	67	1.4	405
Crescent		+	+	+	90.4	40	2.3	918
Hammond	+	+	+	+	85	---	1.5	330
Otter		+	+	+	81	---	1.8	934
Crystal	+	+	+	+	51	---	2.2	969
Forest		+	+	+	40	55	0.8	410
Turtle	+	+	+	+	37	65	1.4	406
Orange			+	+	37	---	1.1	416
Wabeek		+	+	+	25	---	0.9	447
Geneva		+	+	+	19.2	---	0.8	921
Darby		+	+	+	16.5	---	0.7	334
Simpson			+	+	13.2	---	0.5	337
Crawford			+	+	13.0	---	0.5	453
Morse			+	+	13.0	---	0.9	371
Mirror		+	+	+	11.0	25	0.5	367
Sodon			+	+	10	19	0.4	446
Landers			+	+	9.6	---	0.6	342
Scotch		+	+	+	9.3	---	0.6	338
Dawson's Mill Pond			+	+	8	---	1.1	970
Fiddle			+	+	7.5	---	0.6	920
Cross			+	+	7.3	---	0.6	337
Dow			+	+	6.5	---	0.4	346
Mud			+	+	6.2	---	0.5	349
Egg			+	+	5.6	---	0.3	356
Haines			+	+	5.5	---	0.4	449

* As assigned by Humphrys, C. L. 1968.

TABLE 2. IMAGE CHARACTERISTICS OF NAMED LAKES VISIBLE IN ERTS-1 IMAGERY (Sept. 28, 1972) OF OAKLAND COUNTY (Scene 1067-15463)

Lake Name	Lake Shape	Shape Fit: Image/Map	Lake Islands Present/ Absence	Lake Islands ERTS Band Visibility 5	Lake Islands ERTS Band Visibility 6	Var. Image Density (Band 5)
Cass	Elliptical	Good	No			Yes
Orchard	Circular	Good	1	+	+	Yes
Union	Elliptical	Good	No			
Sylvan	Triangular-Square	Good	No			Yes
Pine	Elliptical	Good	No			Yes
Elizabeth	Rectangular	Good	No			Yes
Upper Straits	Elongate	Good	No			Yes
Walnut	Square	Good	No			
Lower Long	Elongate	Good	No			Yes
Middle Straits	Elongate	Good	No			Yes
Green	Elongate	Good	No			
Upper Long	Elongate	Good	No			
Island	Triangular	Good	3	-	-	Yes
Square	Square	Good	No			
Crescent	Elongate	Fair	2	+	+	
Hammond	Circular	Good	No			
Otter	Elliptical	Poor	No			
Crystal	Elongate	Good	No			
Forest	Circular	Good	8	-	-	Yes
Turtle	Elliptical	Good	No			
Orange	Elliptical	Good	No			
Wabeek	Rectangular	Good	No			
Geneva	Elliptical	Good	No			
Darby	Square	Good	No			
Simpson	Elliptical	Fair	No			
Crawford	Elliptical	Good	No			
Morse	Rectangular	Fair	No			
Mirror	Elliptical	Fair	No			
Sodon	Circular	Fair	No			
Landers	Rectangular	Good	No			
Scotch	Elliptical	Good	No			
Dawson's Mill Pond	Elongate	Poor	No			
Fiddle	Elongate	Poor	No			
Cross	Elliptical	Good	No			
Dow	Square	Poor	No			
Mud	Rectangular	Fair	No			
Egg	Elliptical	Fair	No			
Haines	Triangular	Fair	No			

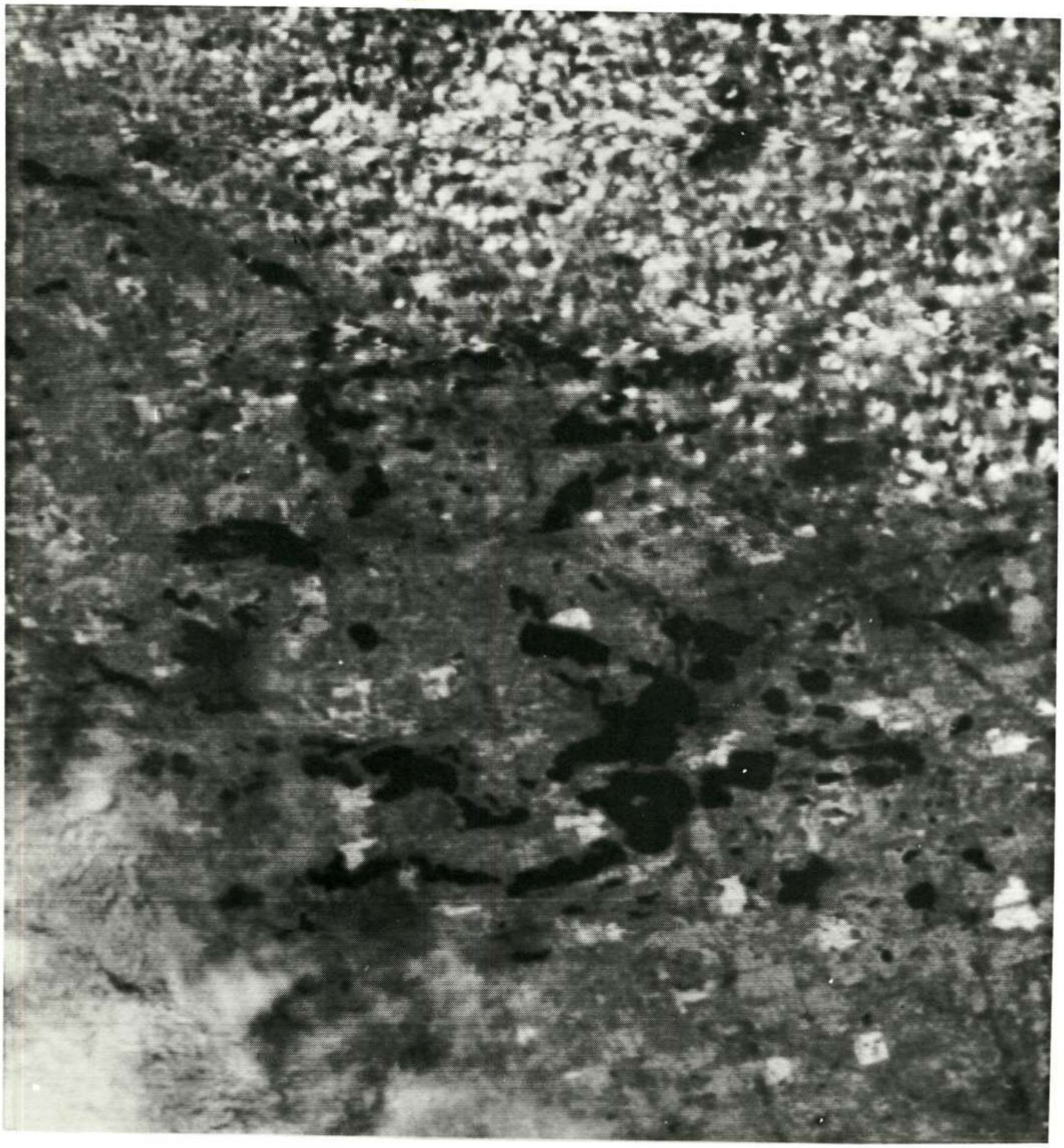


Figure 28 Enlargement of ERTS Study Sub-Area
as Shown in Figure 27
(1067-15463 Band 7)

Figure 29. OCPC Map of ERTS Study-Sub Area
as in Figure 28

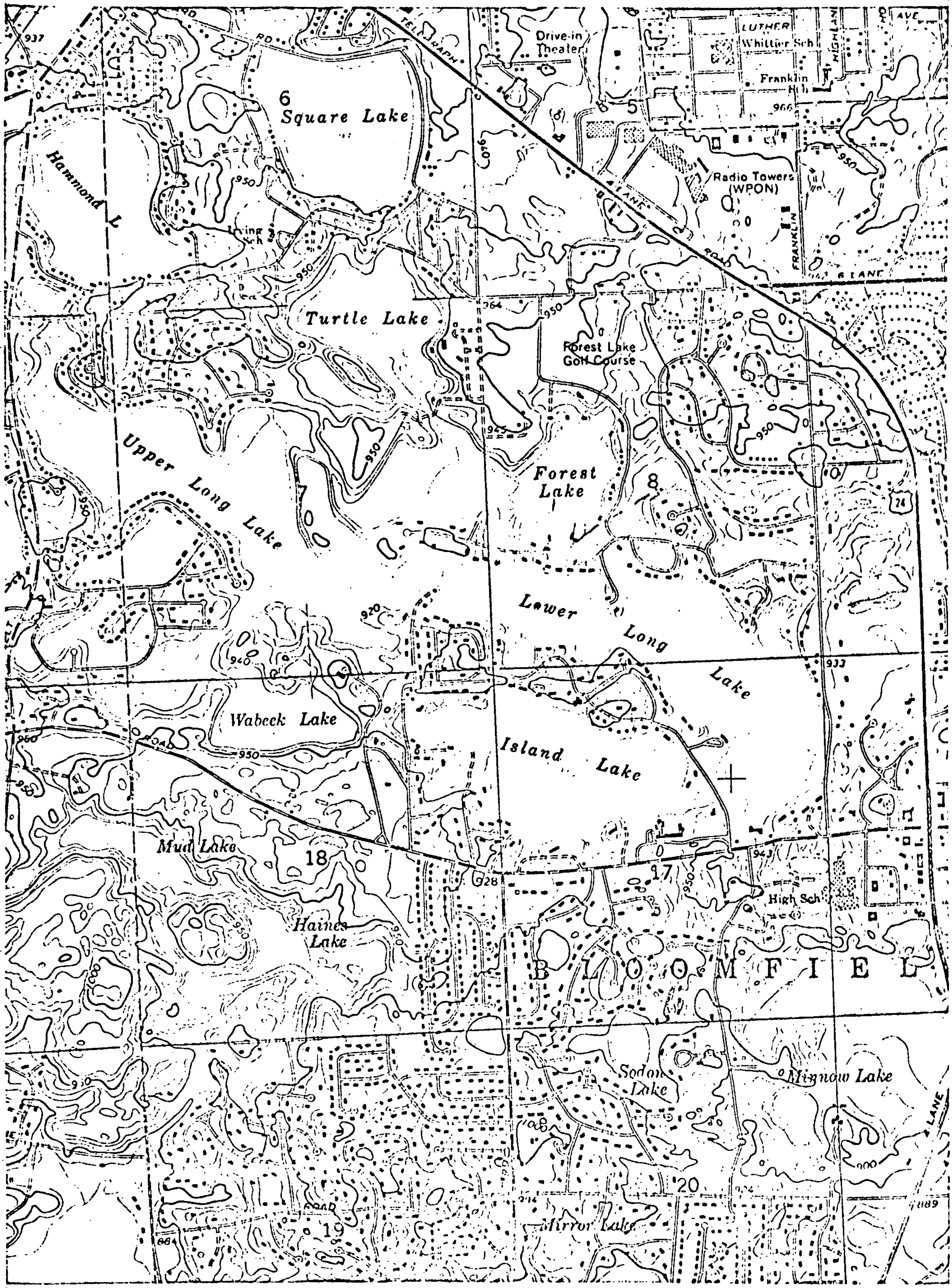
characteristics of "open water." This information will be essential to the classification of lakes and trophic level measurement in unfamiliar areas.

4. Lake Islands and Resolution: Of the study lakes, Angelus (Figure 31) contains an island of approximately one acre in area, which is barely visible in Bands 6 and 7 of imagery taken on August 24. Therefore, the conclusion is that ERTS resolution is approximately the same whether it concerns a light object in a dark field (islands on water) or a dark object in a light field (ponds on land). Other lake island visible in the imagery (Figures 28 and 29), such as Apple Island in Orchard Lake, are considerably larger (Figure 32).

5. Variable Density of Lake Images: Lakes in the study sub-area have been examined closely in all four bands of the imagery (Figure 28). In certain lakes patterns of variable density were noted, particularly in the negative transparency images. These lakes are identified in Table 2. With few exceptions the variations in water "color" were evident only in Band 5 (.6 - .7 microns). However, because of banding effects and partial cloud cover it is still unclear whether these tonal effects represent real differences in water quality. Under better atmospheric conditions Bands 4 and 5 would be expected to record differences in water color that are within the visible spectrum (blue to red). Water colors of green, green-yellow, yellow, yellow-brown, and red-brown are common occurrences among the six study lakes. Surface phenomena, such as algal blooms (of cyanophytes) that are seen occasionally on the lakes, may well be detectable in Bands 6 and 7 (near IR) as well.

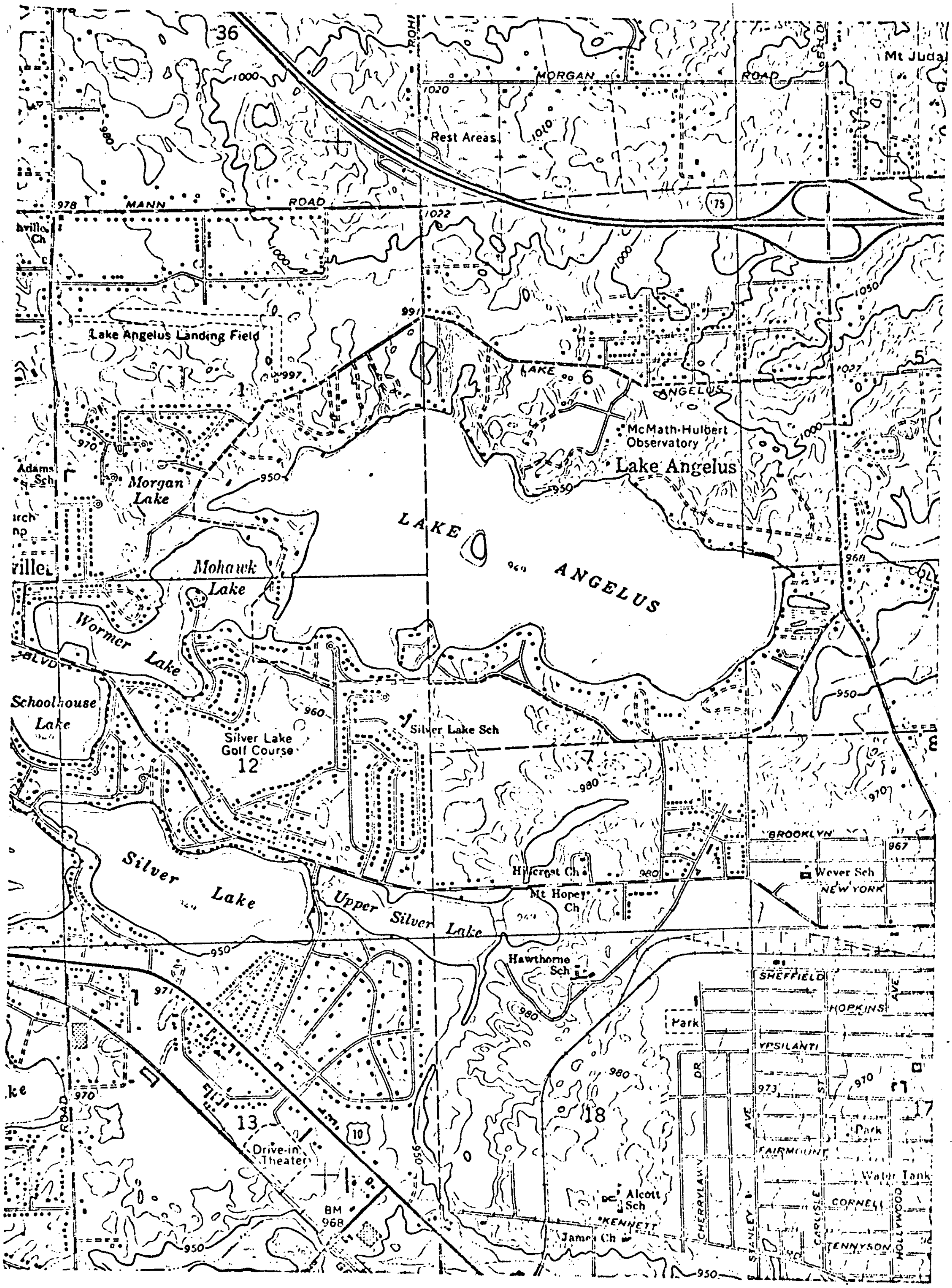
6. Artifacts in Imagery: In Band 5 (and possibly in Band 4) some distortion and displacement of certain lakes was observed. The effects of these were a false merging of some adjacent lakes, and a false separation of bi-lobed lakes. Both effects occurred with the lateral direction of scan (west to east). An example is seen in the artificial "separation" of the north and south portions of Sylvan Lake (Figure 33, upper middle). Additionally, the shapes of several lakes were deformed in comparison with their corresponding images in Bands 6 and 7 (Table 2). These effects may have occurred in transcription of the imagery in Band 5 alone since they are not apparent in Bands 6 and 7.

Fig. 30. USGS MAP (EXCERPT) OF LOWER LONG, ISLAND, AND FOREST LAKES AND VICINITY (1968).



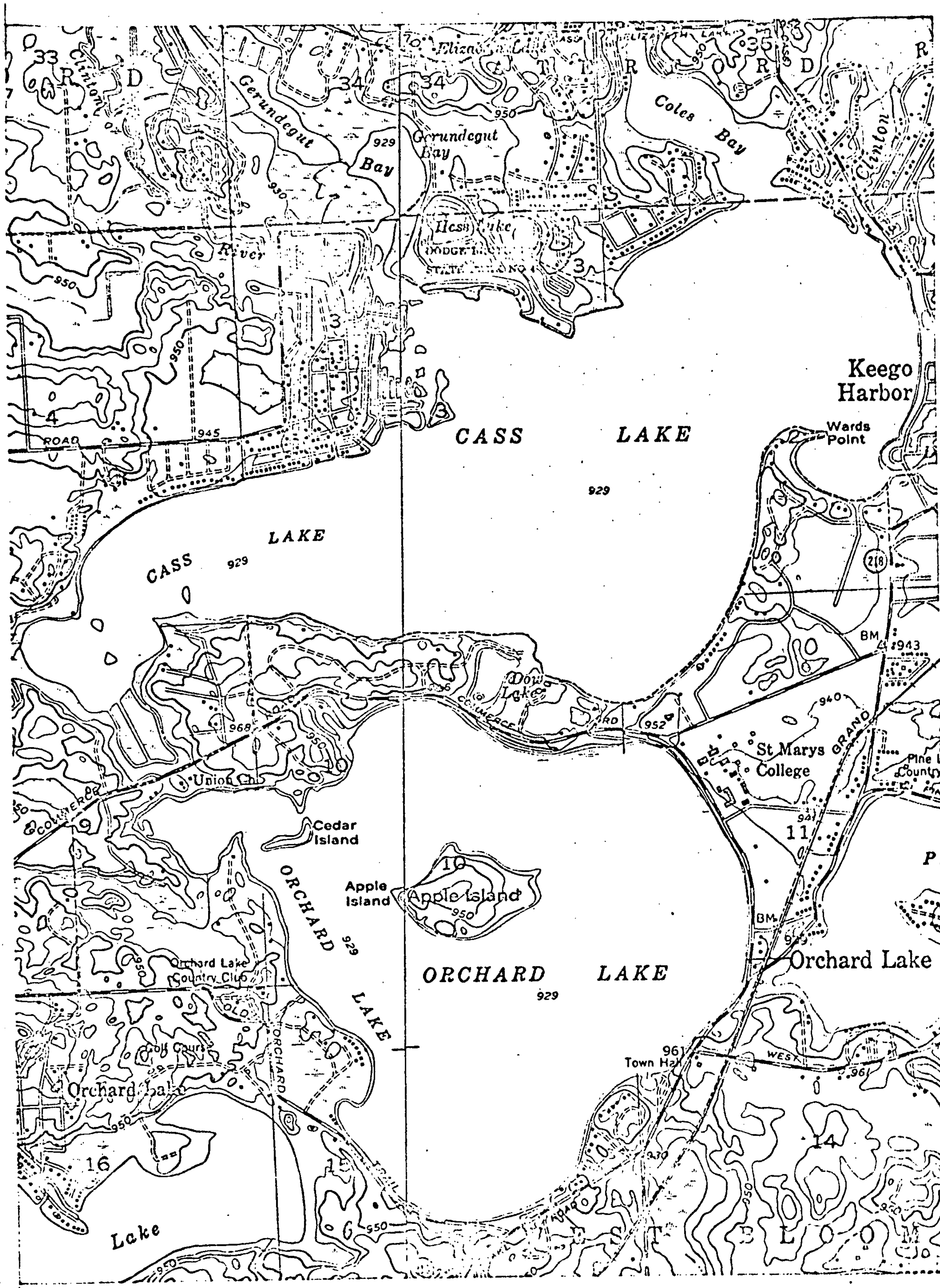
USGS 7.5 min. Series (1:24,000) Pontiac South Quadrangle, Michigan - Oakland Co.

Fig. 31. USGS MAP (EXCERPT) OF LAKE ANGELUS AND VICINITY (1968)



USGS 7.5 min. Series (1:24,000) Pontiac North Quadrangle, Michigan - Oakland Co.

Fig. 32. USGS MAP (EXCERPT) OF ORCHARD AND CASS LAKES AND VICINITY (1968)



USGS 7.5 min. Series (1:24,000) Walled Lake - Pontiac South Quadrangles
Michigan - Oakland County

Figure 33 Enlargement of ERTS Study Sub-Area,
as Shown in Figure 27
(1067-15463, Band 5)

(c) Summary of Image Characteristics (by Band)

The following summarizes the interpretive value of ERTS imagery taken on September 28, 1972.

1. Band 4 (.5 - .6m): Lakes in Band 4 are not readily identifiable. The lake images are observable but very faint, and extraction of useful information from this band on this particular day is probably not possible. Wetlands are identifiable, but are faint and easily confused with lakes.

2. Band 5 (.6 - .7m): This band was useful in determining that image densities varied within several of the larger lakes; however, certain problems were noted that limited interpretation and, on some smaller lakes, left doubt as to whether true water color was visible. These problems are:

   a. A banding effect seemed to smear some lake images and distorted the shapes of others in the NASA imagery. Bendix imagery is used in this report to avoid the problem.

   b. Atmospheric haze interfered seriously with resolution in Band 4, and variable cloud cover may have contributed to "color" differences observed within some lakes seen in Band 5.

3. Band 6 (.7 - .8m): Resolution of lakes was good in this band. Slight tonal differences were noted for some lakes and wetlands. Lakes as small as one acre, though faint, were visible enough to locate on a map. Lakes of six acres or larger had discernable shapes in the imagery.

4. Band 7 (.8 - 1.1m): Lake resolution and contrast was good in this band also, but no wetlands were visible. Since water penetration is less than for Band 6, Band 7 is potentially less useful for comparing with sub-surface water color.

3.2 PROCESSING OF ERTS CCT

The processing of the CCT is important because of the greater number of grey levels in the data. There are between three to four times as many for the CCT as for the bulk processed imagery. Because of the small size of the features and the limited signal strengths from in depth back scattering from the water, the greater number of grey levles are necessary to sort out the various contributions to lake water color.

The first step is to develop software that will automatically produce either probability density imagery of water or place boundaries around all surface water separating it from land and dominantly vegetative wetlands. This step conforms to the shoreline definition shown in bands 6 or 7. However, all four bands are employed in processed imagery or Cal Comp boundary plots. The Cal Comp plot of water boundaries is shown (See Figure 34). Also no CCT was received for the test area in time for extensive processing and the scene in Figure 34 is, therefore, of another area. This scene is near San Francisco Bay, and has a scale of 1:250,000 (Army Map Surface) as shown in Figure 35.

The CCT is raw data and requires geometric correction. Correction to the accuracy of bulk processing imagery requires the annotation tape prepared in the Ground Data Handling System at Goddard Space Flight Center which is not available to other Data Processing Centers. Bendix has introduced the corrections of (1) making the picture elements square (2) Earth rotation; (3) approximation for image skew due to earth rotation. Other corrections will be added if they (1) prove necessary, (2) be made without the annotation tape and (3) are not too time consuming for the accuracy increase.

Figures 28 and 33 are produced from the CCT of the scene in each band in the Bendix Earth Resources Data Center. The imagery is a 70 mm strip which is not corrected geometrically. The imagery is used for feature interpretation. Areal measurements require development of correction factors by the interpreter as based upon comparative distances on maps or between ground control points.

A third type of processed data is probability density imagery. Although the Bendix Earth Resources Data Center is now able to produce such imagery, it has not been used for such a purpose because ground truth is required to select training sets. Probability density imagery will be used for ERTS-1 data gathered in the spring and summer of 1973.

4. NEW TECHNOLOGY

There has been no new technology developed to date.

5. SUBSEQUENT WORK PLANNED

(a) During the coming two months (before spring thaw) the CIS staff will try out field procedures for lake sampling and for measurements of water color and spectral irradiance. Water analysis procedures will be tried in the laboratory.

Figure 34 Automatic Data Processing
Plot of Surface Water

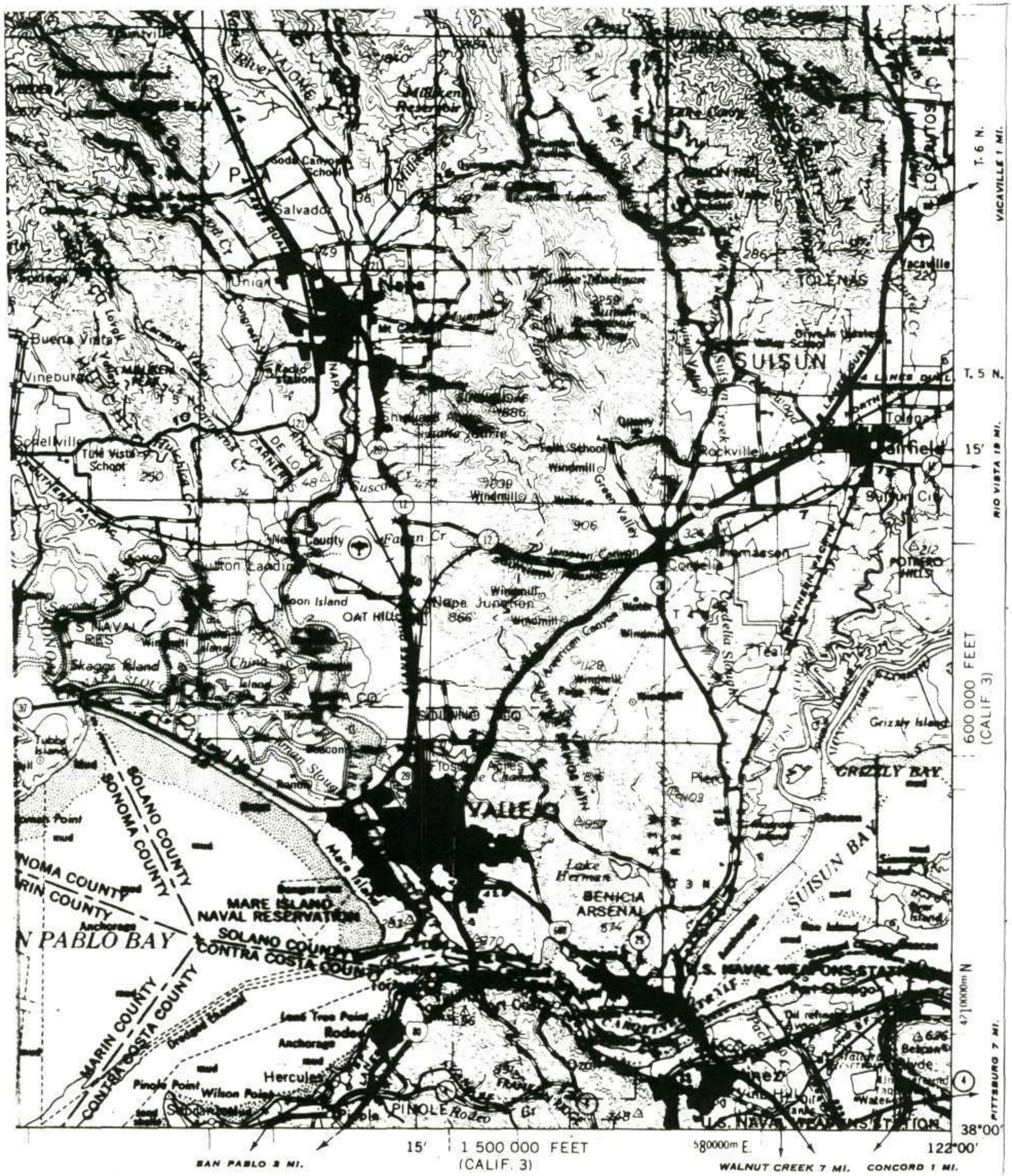


Figure 35 AMS 1:250,000 Map
Corresponding to Figure 34

(b) As soon as CCT's arrive Bendix and Cranbrook will continue analysis of the September 28 imagery and compare image density patterns in lakes to their bathymetry maps. Then it will be possible to describe color patterns in lake waters and show how these are influenced by bottom reflection and by water color itself.

(c) The critical review of past and present studies of remote sensing and water quality will continue throughout this project.

(d) When the lakes are free of ice, ground truth gathering will begin and will coincide with each ERTS pass (every 18 days). The intervening time will be used to gather supplemental data (on bathymetry, water quality, etc.) and to analyze results.

(e) Bathymetry (depth contour) maps of the study lakes are in preparation and will be presented along with the CCT analysis in the next progress report.

6. CONCLUSIONS AND RECOMMENDATIONS

The main accomplishments of this program to date are the following:

(a) Water quality data collected over the past three years for Lower Long, Island, Forest Lakes and Lake Angelus have been tabulated and compared for the purpose of classifying these lakes as to relative trophic level (degree of eutrophication). Although all four are midly to moderately eutrophic, they can be arranged in a series of increasing enrichment, thus: Angelus, Lower Long, Forest, Island. Orchard and Cass Lakes, though less well known, are closer in quality to Angelus (mildly eutrophic). Very limited data were collected for Orchard and Cass Lakes from two State-sponsored (Department of Natural Resources) surveys done in 1940 and 1971. Further study of these lakes is being carried out by CIS.

(b) The above "base-line" data on water quality has been considered carefully in setting up the water analysis procedures (Figure 24) for concurrent ERTS and ground monitoring of lakes planned for the spring-to-fall period, 1973. These procedures were designed to yield the maximum information about both water color and lake trophic state. Any such monitoring program must be a compromise between expediency and data yield, since full coverage of all the lakes within two hours of the ERTS overflights is highly desirable. (Vertical migrations of plankton may influence lake surface color within the space of a few hours. Similarly, pH changes during the day may affect water color.)

An abbreviated program of water analysis will be conducted (as time permits) in between ERTS overflights. This will supplement base-line data on water color and quality.

(c) Special equipment has been designed and constructed for the purpose of estimating water color and lake irradiance in situ. This includes the following:

1. Radiant Power Measuring Instrument (RPMI): designed by Bendix (under contract to NASA) to measure surface and sky irradiance in the four MSS spectral bands of ERTS. This instrument is also being adapted to record reflectance spectra of lakes over the whole visible range (400 - 700 nm), as well as in the ERTS bands. (See Appendix B)

2. Forel-Ule Viewing Device: designed by Cranbrook (CIS) to permit accurate comparison of water color (against a white disc) and the Forel-Ule series of color standards. It may also be used with the cobalt-platinum series of standards.

3. Reflectance Spectrophotometer (modified Bausch & Lomb, Spectronic 20): modified by CIS for use in reading reflectance spectra of particulate matter collected on Millipore filters. This is new technique.

(d) The literature concerned with water color and quality, and its measurement by remote sensors has been surveyed. Further study of these references in the light of recent ERTS imagery will be necessary before a full assessment of this information can be made. References not yet reviewed are included in "Additional References," following.

(e) The analysis of ERTS imagery for Oakland County so far has been limited to two scenes. In both, the study lakes are partially obscured by clouds and atmospheric haze. When lakes were visible (mainly on September 28, 1972), resolution was good in Bands 6 and 7; it was fair in Band 5, and poor in Band 4. However, it is uncertain whether the variable density patterns seen in some lake images are due to differences in water color or are simply atmospheric effects.

The lack so far of computer compatible tapes (CCTs) has been a serious handicap in data analysis. When CCTs are available for the above scene, the image density patterns on selected lakes can be compared to their bathymetry and to low altitude imagery

(Bendix aircraft MSS), to see whether variations in water color are recorded by ERTS. Until then, further interpretation of ERTS imagery, with respect to lake color, is impossible.

The CCT were received during preparation of this report. The imagery in Figures 28 and 33 have been prepared in the Bendix Earth Resources Data Processing Center from the CCT and enlarged to 1:140,000. Detail in Band 5 is sufficiently good to anticipate comparison to bathymetry maps. This imagery has approximately the same number of grey levels as that produced at Goddard Space Flight Center. Further enlargement is possible. However, the development of decision imagery and probability density imagery from the CCT's is expected to yield more fruitful results.

APPENDIX A

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APPENDIX B

Reprint of Significant Results Appearing in Bi-Monthly Progress Report for Period 1 October to 1 December 1972

EXPERIMENT: INVESTIGATION OF TECHNIQUES FOR CORRECTING ERTS DATA FOR SOLAR AND ATMOSPHERIC EFFECTS, MMC #655

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DETAILS OF SIGNIFICANT RESULTS

DISCIPLINE: Sensor Technology SUBDISCIPLINE: Ground Truth

The design and fabrication of five Radiant Power Measuring Instruments (RPMI) for ERTS ground truth have been completed. This report provides the characteristics and pictures of this instrument.

The Radiant Power Measuring Instrument (RPMI), Model 100, provides an ERTS investigator with a capability of obtaining radiometric measurements needed to determine solar and atmospheric parameters that affect the ERTS radiance measurements. With these parameters, ERTS data can be transformed into absolute target reflectance signatures, making accurate unambiguous interpretations possible.

The RPMI is a rugged, hand-carried instrument accurately calibrated to measure both downwelling and reflected radiance within each ERTS multispectral scanner (MSS) band. A foldover handle permits a quick change from wide angle global or sky irradiance measurements to narrow angle radiance measurements from sky and ground targets. These measurements yield ground truth site reflectance and permit calculation of additional parameters such as beam transmittance between spacecraft and ground, and path radiance (path reflectance).

Summary of Characteristics

- Spectral Bands: All measurements made in ERTS MSS bands (0.5 to 0.6 micron (μ); 0.6 to 0.7μ; 0.7 to 0.8μ; and 0.8 to 1.1μ). Bands formed by bandpass filter in switched turret followed by silicon detector.

- Field of View: Two modes

  1. 2π steradian field of view through removable diffuser.
  2. Handle permits 6.0° circular field of view for sky and earth measurements.

- Sensitivity (Measurement Ranges):

  10 range scales permit irradiance measurements from 0.01 to 300.0 watts/meter^2 and radiance measurements from 0.01 to 300 watts/(meter^2 · steradian).

- Calibration Accuracy:

  1. An absolute accuracy of ±5% is maintained over the field operating ranges for a period of over 1 year.
  2. Relative (band to band) accuracy is ± 2.0%.
  3. Repeatability ± 0.5%.

- Frequency Response:

  0 to 1.0 Hz on meter.
  0 to 20 Hz at BNC output.

- Controls: Irradiance/Radiance, Range (10 positions), Band Select (6 positions include the 4 ERTS MSS bands, and a closed and an open position), Meter Zero, Battery Test, and ON/OFF Switch.

- Meter: 3 1/2-inch taut band 1.0% hand calibrated, mirrored scale; scaled 0 to 1.0 and 0 to 3.0 with 50 and 60 divisions, respectively.

- Power Source: 9.0-volt batteries; battery life while operating – 50 to 100 hours.

- Environmental Specifications:

  1. Sealed against dust and humidity to 100%.
  2. Shock and vibration expected in field and aircraft environments.
  3. Storage -55°C to +80°C.
  4. Operational -20°C to +70°C.

- Size: 4 x 7 x 8 in. (10 x 18 x 20 cm).

- Weight: 5.8 pounds (2.6 kg) with batteries.

Measurement Modes

Global Irradiance (H) - 2π steradian field of view for measuring down-welling (incident) radiation in bands identical to ERTS MSS.

Sky Irradiance (H_{SKY}) - Global Irradiance minus direct sun component, in every ERTS MSS band. Angle from zenith to sun is also measured in this mode.

Radiance from Narrow Solid Angles of Sky - Handle serving as field stop permits direct measurements through a 6.0° circular field of view. This mode is also used to measure direct beam solar irradiance.

Reflected Radiation - Used with small calibration panels, cards, to obtain direct measurement of truth site reflectance. Same field of view as above.

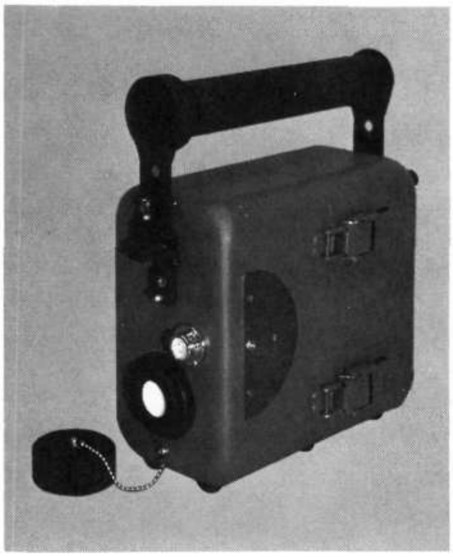
Packaging (See pictures on following page)

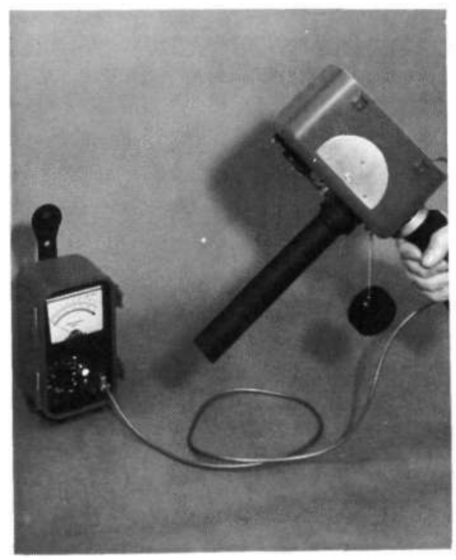
- Handle joins sensor head and meter assembly to form compact unit.
- Sensor head, containing filter wheel and silicon detector, is separated from meter assembly by 6 ft of shielded cable. Sensor head is threaded with standard tripod mounting (1/4-20 tapped hole) to facilitate pointing at sky and ground.
- Bubble level and sun angle measuring device are integral parts of sensor head.
- Foldover handle attached to sensor head permits immediate change from the wide 2π steradian field of view to a narrow one.
- Separate meter assembly facilitates accurate meter reading and permits remote monitoring.

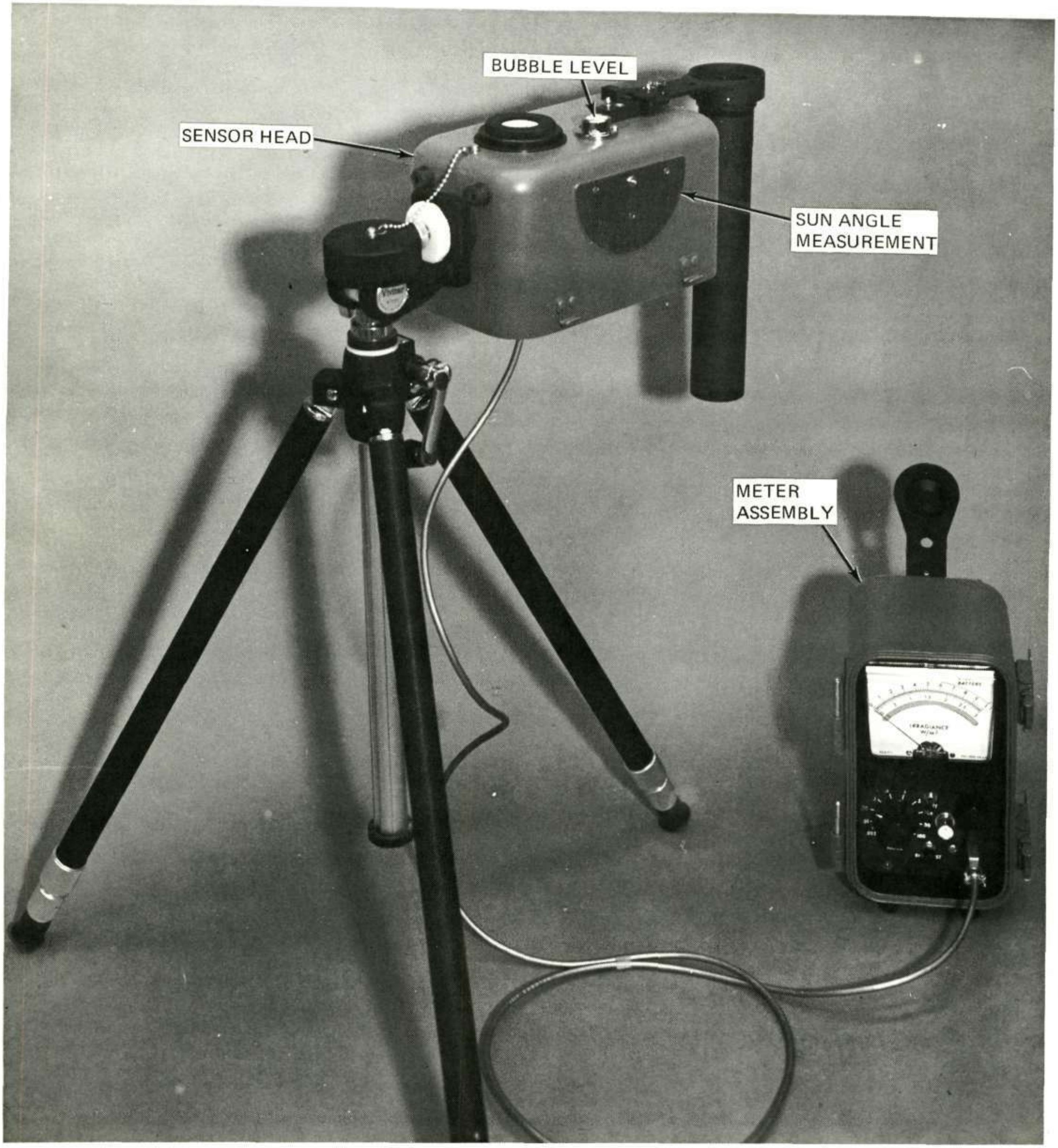
Options

- Filter to match ERTS RBV bands, EREP experiments, etc.
- Circular field of view from 1.0 to 6.0°.

ERTS - Radiant Power Measuring Instrument






BUBBLE LEVEL
SENSOR HEAD
SUN ANGLE
MEASUREMENT
METER
ASSEMBLY