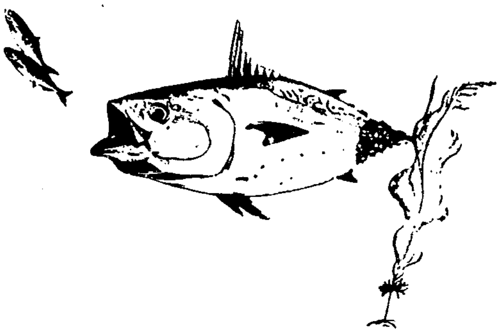


Watershed Analysis for Church Pine, Round and Big Lake (Polk County, Wisconsin) With Recommendations for Improved Water Quality and Watershed Management

Report No. LT-R4695

Submitted to:

Church Pine, Round and Big Lake
Protective and Rehabilitation District
P.O. Box 261
New Richmond, Wisconsin 54017

Submitted by:

Lim Tech Consultants
3416 University Avenue S.E.
Suite 200
Minneapolis, Minnesota 55414
(612) 331-7385

October 1987

Summary

A comprehensive watershed evaluation was conducted on Church Pine, Round, and Big Lake in 1987. This evaluation included watershed delineation, land-use characterization, and water quality assessment. Hydrological and nutrient-loading patterns were estimated and compared to observations of water quality and of land-use. A residents survey was also conducted to identify any areas of water quality, land-use, or lake-use that were of special concern. Based upon the sum of these observations, the following conclusions are made:

1) Water flows from Big Lake into Round Lake, influenced by both the increased water levels on Big Lake and the large size of its watershed. The only outlet of water on Round Lake is through evaporation, therefore a long-term trend for increased dissolved solids in Round Lake is predicted if this hydrological pattern should persist.
2) The net flow of groundwater is not significant to any of these lakes.
3) The hydrological retention time for these lakes is relatively long; 7.8 years for Church Pine, 2.9 years for Round, 1.9 years for Big Lake.
4) Water quality on Church Pine and Round Lake, when evaluated by many different types of parameters, is consistently equal to or better than the predicted water quality in the absence of development on the lakes; therefore, it appears that current development within

the watersheds of these two lakes has not resulted in a degradation in water quality.

5) Water quality on Big Lake, when evaluated by these same parameters, is consistently lower than the predicted water quality in the absence of development on the lake; therefore, it appears that current development within the watershed of this lake has resulted in a degradation in water quality.

6) It is unlikely that the shoreline development on Big Lake has resulted in the lower water quality; development outside the immediate shoreline is more likely the source of the water quality degradation.

7) Phosphorus loading on Big Lake is excessive; and the majority of this load (84%) is due to North Creek. This source might provide the only economically feasible opportunity for control of phosphorus loading, and subsequent water quality improvement. A 50% reduction in phosphorus release would be required to result in an acceptable phosphorus loading for Big Lake. Under optimum conditions, mean summer secchi disc readings on Big Lake could increase to about 7.1 feet.

8) Reducing the phosphorus load on Big Lake might result in as much as a 40% reduction in the phosphorus loading on Round Lake.

9) Fecal bacteria concentrations were unacceptably high in North Creek and represent a potential human health risk; additionally, whole feces were reported in North Creek.

10) There is no evidence of the direct release of sewage wastes along most shorelines of all three lakes, with the exception of the west and northwest shores of Round Lake. In this area, low, but consistent, levels of fecal bacteria were reported.

11) The concentrations of algae were normal on Church Pine and Round Lake, and were excessive on Big Lake. The most direct control method would be reducing the phosphorus loading by North Creek.

12) Aquatic weed densities on all three lakes appeared normal, although most residents expressed dissatisfaction with these conditions. Because of the low flushing rate of the lakes, chemical control of weeds is not recommended. A combination of mechanical cutting and harvesting and hand-raking offers a better alternative.

13) Dissolved oxygen concentrations were acceptable in most areas of the lakes, although oxygen levels did become low at times near the bottom sediments and were consistently low in North Creek.

14) Some portions of the past water quality monitoring program could be omitted without reducing the quality and usefulness of the data base, and at the same time reducing costs.

Recommendations

1) Minimum management, aside from recommended weed control, should be conducted on Church Pine and Round Lake.
2) Water quality improvement and algae control efforts on Big Lake should concentrate on phosphorus control within the North Creek watershed.
3) The source(s) of both nutrients and bacteria within the North Creek watershed should be adequately identified, after which control measures can be developed.
4) Water level on Big Lake should be maintained at the lowest acceptable level.
5) The outlet to Big Lake should remain open at all times.
6) Secchi disc records should be continuously maintained and supplemented with comprehensive water quality assessments at five year intervals.

Lake and Watershed Description

The Church Pine, Round and Big Lakes chain lies in Alden and Garfield Townships of Polk County in northwestern Wisconsin (92° 32' E. Long.; 47° 17' N. Lat.) (Fig. 1). Their use is primarily recreational, with both permanent and seasonal residences. This area has neither a public water nor public sewer system. Water is obtained through individual wells and wastes are discharged into individual underground septic tanks or drainage field systems. The number of new residences on the lakes appears to have declined since the late 1950's.

According to U.S. Department of Agriculture data, the general soil type of the surrounding area is described as loamy to sandy and is well- to excessively well-drained. The major exception to this is the area directly adjacent to and east of the eastern shore of Big Lake. This region consists of loamy and silty soils which range from well-drained to poorly-drained (Fig. 2).

The general physical characteristics of the lakes (Fig. 3) are as follows:

	Church Pine	Round	Big
Surface area (acres)	91	40	243
Maximum depth (ft)	45	27	27
Mean depth (ft)	22.9	14.1	17.1
Shoreline length (miles)	2.36	1.07	2.96
Volume (acre-feet)	2,082	562	4,155

Both the relative size and the characteristics of the areas drained by each lake are quite different (Fig. 4), therefore each is evaluated individually. Whereas Church Pine and Round lakes have no known surface inlet, two distinct surface flowages drain into Big Lake (Fig. 4), one from the north and one from the souteast. The general characteristics of the separate watersheds are as follows:

	Church Pine	Round	Big
Watershed area (acres)	370	116	3,310
Watershed area/ Surface area ratio	4.1	2.9	13.6
Land use:			
Wooded (%)	89	84	60
Untilled field or pasture (%)	9	14	7
Tilled field (%)	NS[a]	NS	10
Wetlands (%)	2	3	17
Mixed old field - wooded (%)	NS	NS	5

[a] NS = Not a significant land-use

Based upon height-of-land watershed delineation, it appears that overall drainage pattern is primarily from east to west.

Water drained into Church Pine, Round and Big Lakes enters Horse Creek, which in turn flows into Cedar Lake. Lands to the east of the watershed appear to drain directly into the Apple River to the southeast.

The areas drained by the two surface flows entering Big Lake, which for the purpose of this report are identified as North Creek and South Creek (see Fig. 4), are quite different in some of their land-use characteristics.

	North Cr.	South Cr.
Wooded (%)	48	75
Untilled field or pasture (%)	12	1
Tilled field (%)	16	4
Wetlands (%)	19	19
Mixed old field - wooded (%)	4	NS[a]

[a] NS - not a significant land-use.

The total area drained by North Creek and South Creek are 1,720 acres and 1,220 acres, respectively.

Shorelines of all three lakes have been developed to some degree. Two pertinent characteristics of the shoreline, slope of the bank and degree of development, are described in Figs. 5 and 6, respectively. These characteristics are further described by:

	Church Pine	Round	Big
Number of residences	62	32	91
Residences per mile of shoreline	26.3	29.9	30.7
% steeply sloped	62	9	38
% moderately sloped	21	56	33
% developed (groomed) shoreline	23	21	42

A developed shoreline is defined as areas in which groomed lawns approach within three feet of the shore.

In mid-1940s, a dam was created at the outlet of Big Lake which raised the water level approximately two feet. A fish barrier was constructed in 1985 to control the migration of rough fish, primarily carp, into the lake. Although no evaluation of fish populations was conducted in this study, a species list of aquatic macrophytes was constructed (Table 1). In May and June, the predominant submerged aquatic plant appeared to be the curly-leaf pondweed (Potamogetan crispus) in both Big and Round Lakes. As is its natural cycle, populations deminished by July when other species, such as Vallesinaria americanum, Potamogeton amplifolius, and Ceratophyllum demersum became more predominant. Floating leaf plants occurred in high numbers in the shallow waters around much of Round Lake and in the shallow, northern regions of Church Pine Lake.

Some water quality data have been reported for all three lakes. Data are either from resident monitoring programs, in which water samples are collected and shipped by U.S. mail to the University of Wisconsin - Stevens Point (UWSP) for analysis, or from records kept by the Wisconsin Department of Natural Resources (WiDNR). A summary of pertinent parameters from these data are presented in Tables 2, 3, and 4. The majority of these data are considered unuseable for water quality interpretation primarily due to unacceptable sample holding durations. Some samples were stored up to 98 days prior to analysis. It is a general convention of environmental chemistry that samples be processed and analyzed in a timely manner. As an example, for phosphorous determinations, samples should be analyzed within 24-48 hours after collection. Although the results reported by both UWSP and the WiDNR are considered to be an accurate description of water samples at the time of analysis, based upon reputation alone, these data are not necessarily representative of ambient water quality characteristics on the day sampling was conducted. The differences in reported pH values from the only acceptable data (8.8 reported for Big Lake on September 5, 1973) compared to all other unacceptable data (range of 7.04 to 7.84) provides additional evidence that most of the data reported for the three lakes may not be indicative of actual chemical conditions. Therefore, these data are not considered useful in identifying any possible trends in water quality, although other data, such as secchi disc transparency readings, temperature profiles, and dissolved oxygen profiles are useable.

Secchi disc transparency data are available for all three lakes from ice out to ice on for the years 1985 and 1986 (Figs. 7 and 8, respectively). The general trend appears to be a decrease in transparency on all three lakes in late April to early May, after which a significant increase in water clarity occurs, reaching a maximum in late May. Subsequently, transparency declines throughout the summer and reaches a minimum in late August, afterwhich it increases through the fall months. Secchi disc readings rarely fall below 7 feet on Church Pine Lake, 6 feet on Round Lake and 4 feet on Big Lake. An exception to this trend was observed on Big and Round Lakes in 1985 (Fig. 7), when much lower secchi disc readings were observed. These lower readings appeared to be correlated with chemical applications for weed control on these lakes. Chemicals were not applied to Church Pine Lake and it continued its normal trend in water clarity. Decreased water clarity was not observed in 1986 (Fig. 8) when all the lakes were harvested for weeds.

Temperature and dissolved oxygen profile analyses were conducted by the WiDNR on several dates in 1973, 1977 and 1978 on both Big and Church Pine Lakes. Results from each analysis are summarized in Figs. 9 to 17.

Big Lake appeared to have two periods of oxygen reduction, one in late winter and another in late summer. The lowest dissolved oxygen levels were just above the bottom, and did not fall below 1.2 mg O_2/L in 1977 or 1978. Data from September 5, 1973 (Fig. 9), indicated anoxic conditions on Big Lake at depths below 20 feet. Although deeper waters were slightly cooler than surface waters at mid-summer, no strong thermocline was observed. By November (Fig. 11) and again by May (Fig. 13) the lake had mixed completely and was reoxygenated.

Conditions on Church Pine Lake followed a similar trend in 1977 and 1978. Reduced dissolved oxygen levels were observed in late summer and winter at depths greater that 30 feet (Figs. 14 and 16, respectively). Reoxygenation of the deeper waters had occurred by November and again by May (Figs. 15 and 17, respectively). A strong thermocline developed at about 20 feet (6 meters) depth in late summer.

These data indicate that Big and Church Pine Lakes are dimectic and Church Pine develops a thermocline, whereas Big Lake does not.

TABLE 1. Species list of aquatic macrophytes observed in Church Pine, Round and Big Lakes.

Common Name	Scientific Name
Watershield	*Brasenia schreberi*
Marsh marigold	*Caltha palustris*
Sedges	*Carex* spp.
Muskgrass	*Chara* sp.
Coontail	*Ceratophyllum demersum*
Burhead	*Echinodorus* sp.
Milfoil	*Myriophyllum exalbescens*
Bushy pondweed	*Najas flexilis*
Bushy pondweed	*Najas marina*
Water lily	*Nuphar* sp.
Water lily	*Nymphaea* sp.
Reed canary	*Phalaris* sp.
Cane grass	*Phragmites* sp.
Pondweed	*Potamogeton amplifolius*
Pondweed	*P. crispus*
Pondweed	*P. filiformis*
Pondweed	*P. natans*
Pondweed	*P. pectinatus*
Pondweed	*P. robbinsii*
Arrowhead	*Sagittaria* spp.
Bulrush	*Scirpus* spp.
Bur reed	*Sparganium* spp.
Cattail	*Typha latifolia*
Water celery	*Vallisneria americana*

Table 2. Selected data on Big Lake.

Date	9/5/73	8/18/77	10/19/77	3/6/78	5/1/78	11/11/84	4/18/85	11/11/85	4/16/86	11/3/86
Source[a]	DNR	DNR	DNR	DNR	DNR	UWSP	UWSP	UWSP	UWSP	UWSP
Alkalinity (mg/L)	77	78	81	92	83	79	62	84	82	84
Conductivity (umohm/cm)	-	172	158	199	146	170	181	164	168	176
Nitrate-N (ug/L)	-	30	220	150	30	300	300	< 10	240	80
Total N (ug/L)	-	1,020	640	610	850	550	520	420	360	630
Reactive P (ug/L)	-	11	13	7	9	26	6	2	12	15
Total P (ug/L)	-	40	50	20	20	28	30	50	22	40
pH	8.8	7.7	7.8	7.8	7.7	7.77	7.66	7.48	7.31	7.72
Sample holding time (days)	0	55	26	36	41	-	> 5	-	> 5	-
Acceptability of data	Yes	No	No	No	No	No	No	No	No	No

---

[a] DNR= Wisconsin Department of Natural Resources; UWSP= University of Wisconsin - Steven's Point.

Table 3. Selected data on Round Lake.

Date	11/11/84	4/18/85	11/11/85	4/16/86	11/3/86
Source[a]	UWSP	UWSP	UWSP	UWSP	UWSP
Alkalinity (mg/L)	72	69	72	66	76
Conductivity (umohm/cm)	154	159	146	155	144
Nitrate-N (ug/L)	280	< 10	< 10	40	10
Total N (ug/L)	460	470	680	540	740
Reactive P (ug/L)	10	< 2	2	5	10
Total P (ug/L)	55	25	30	20	20
pH	7.79	7.84	7.54	7.62	7.62
Sample holding time (days)	-	> 5	-	> 2	-
Acceptability of data	No	No	No	No	No

[a] UWSP= University of Wisconsin - Steven's Point.

Table 4. Selected data on Church Pine Lake.

Date	8/3/77	10/19/77	3/6/78	5/1/78	11/11/84	4/18/85	11/11/85	4/16/86	11/3/86
Source[a]	DNR	DNR	DNR	DNR	UWSP	UWSP	UWSP	UWSP	UWSP
Alkalinity (mg/L)	59	63	70	66	58	57	60	56	60
Conductivity (umohm/cm)	124	125	153	125	122	133	118	120	120
Nitrate-N (ug/L)	$<$ 20	30	100	50	40	$<$ 10	10	70	10
Total N (ug/L)	520	500	610	700	460	360	420	440	680
Reactive P (ug/L)	$<$ 4	8	$<$ 5	9	8	2	2	8	$<$ 2
Total P (ug/L)	$<$ 10	30	10	30	25	10	12	10	10
pH	7.9	7.6	7.5	7.6	7.82	7.68	7.48	7.04	7.59
Sample holding time (days)	98	26	36	-	$>$ 5	$>$ 5	-	$>$5	-
Acceptability of data	No	No	No	No	No	No	No	No	No

---

[a] DNR= Wisonsin Department of Natural Resources; UWSP= University of Wisconsin - Steven's Point.

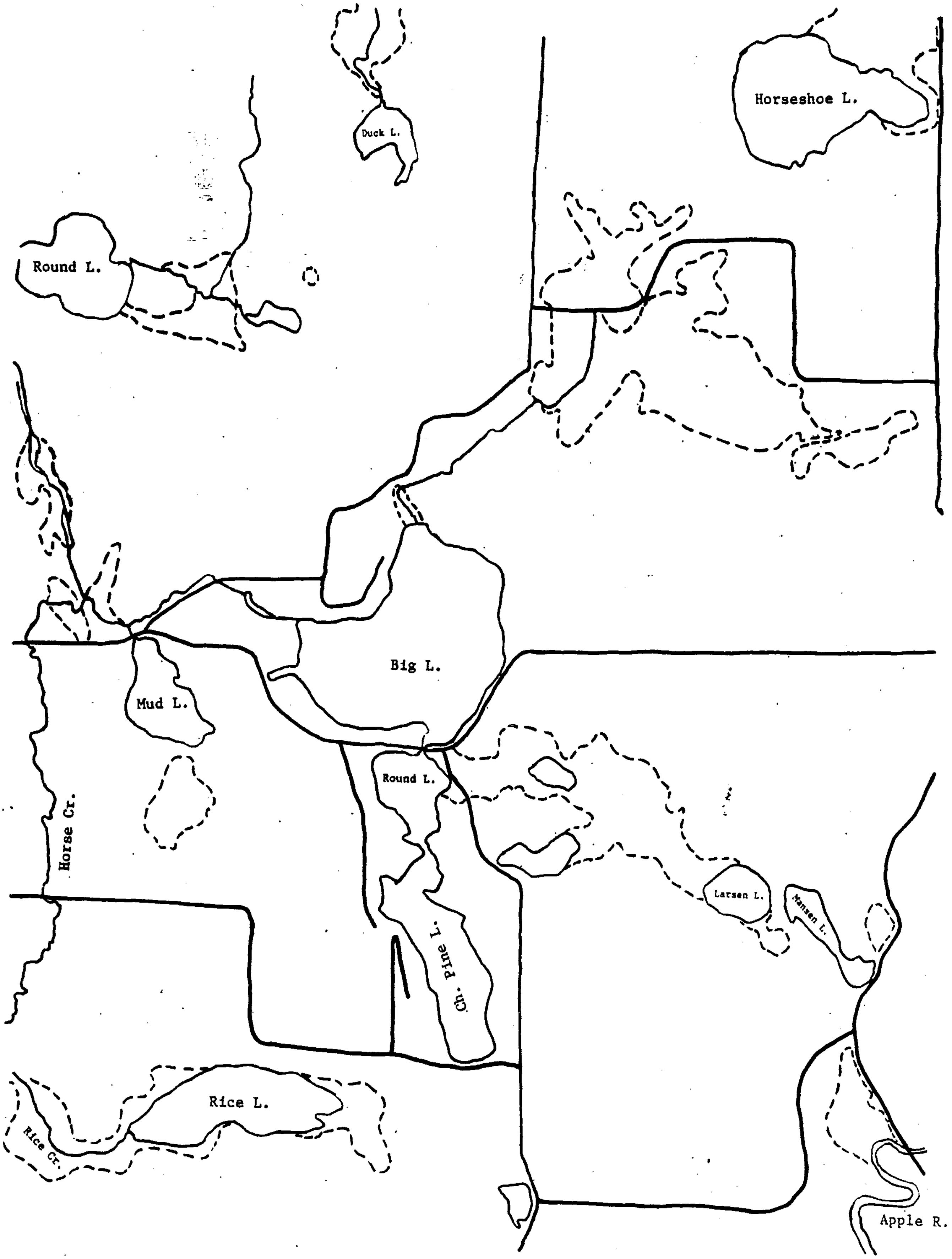


Fig. 1. Study site. Dashed lines indicate locations of wetlands.

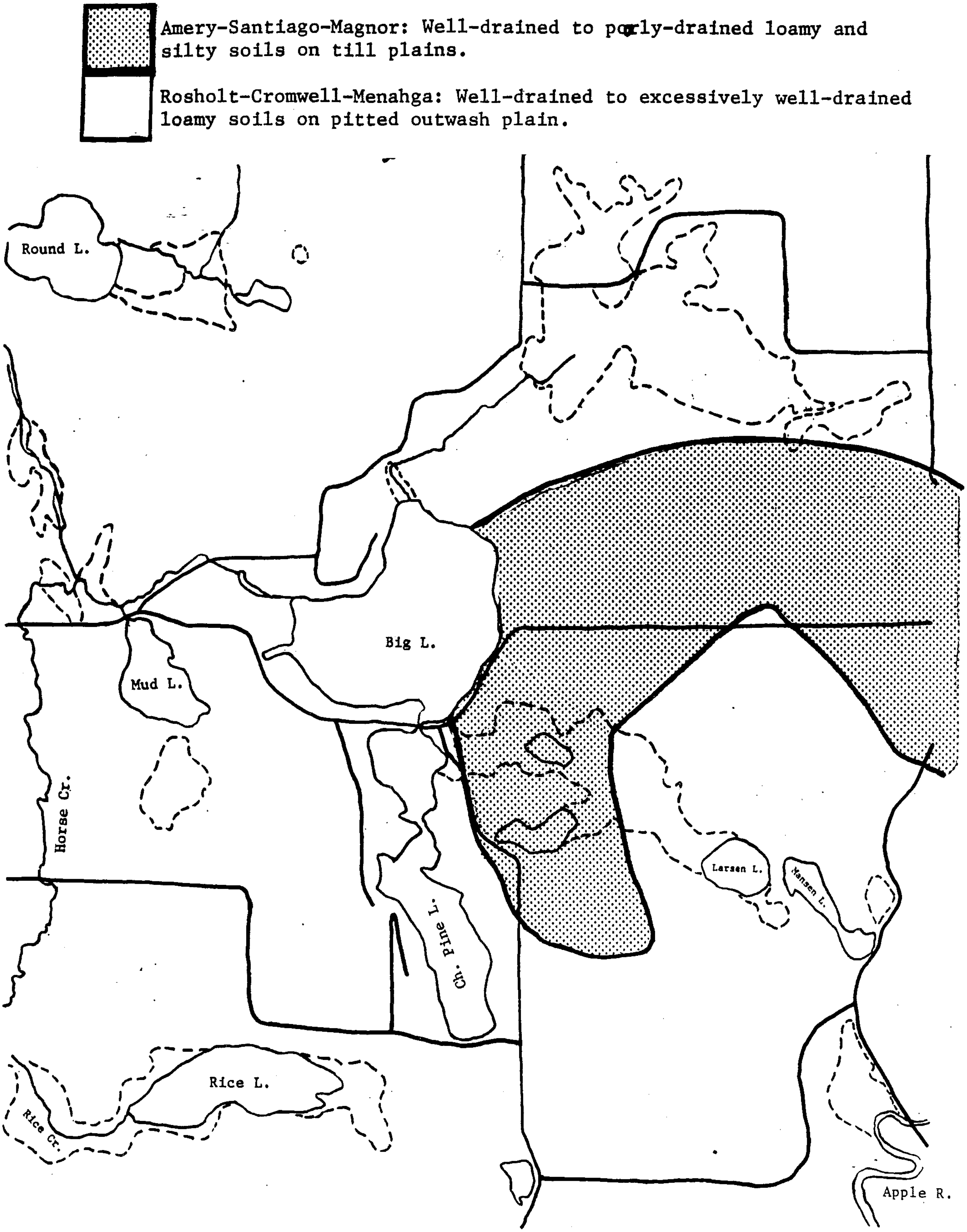


FIG. 2. Local soil types.

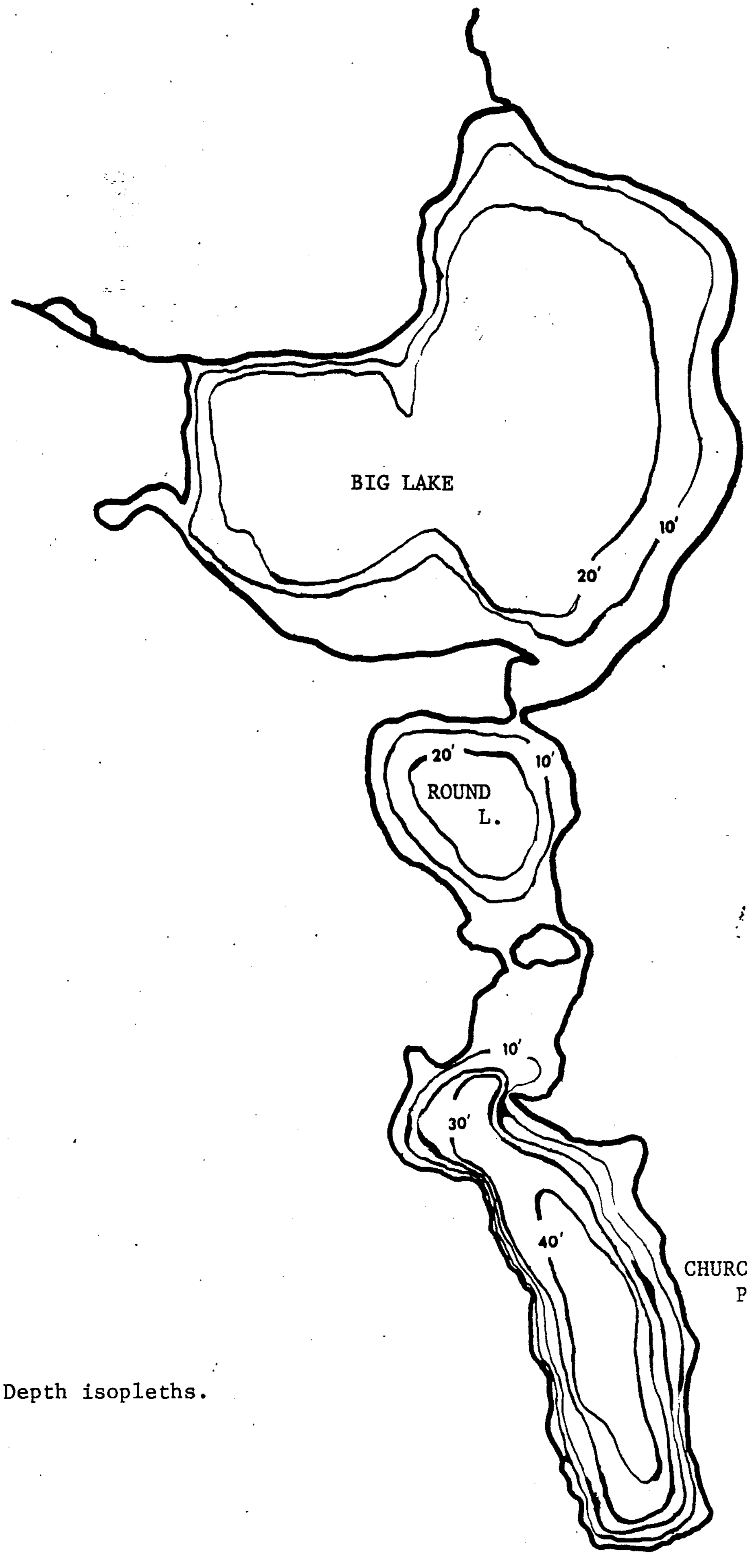


Fig. 3. Depth isopleths.

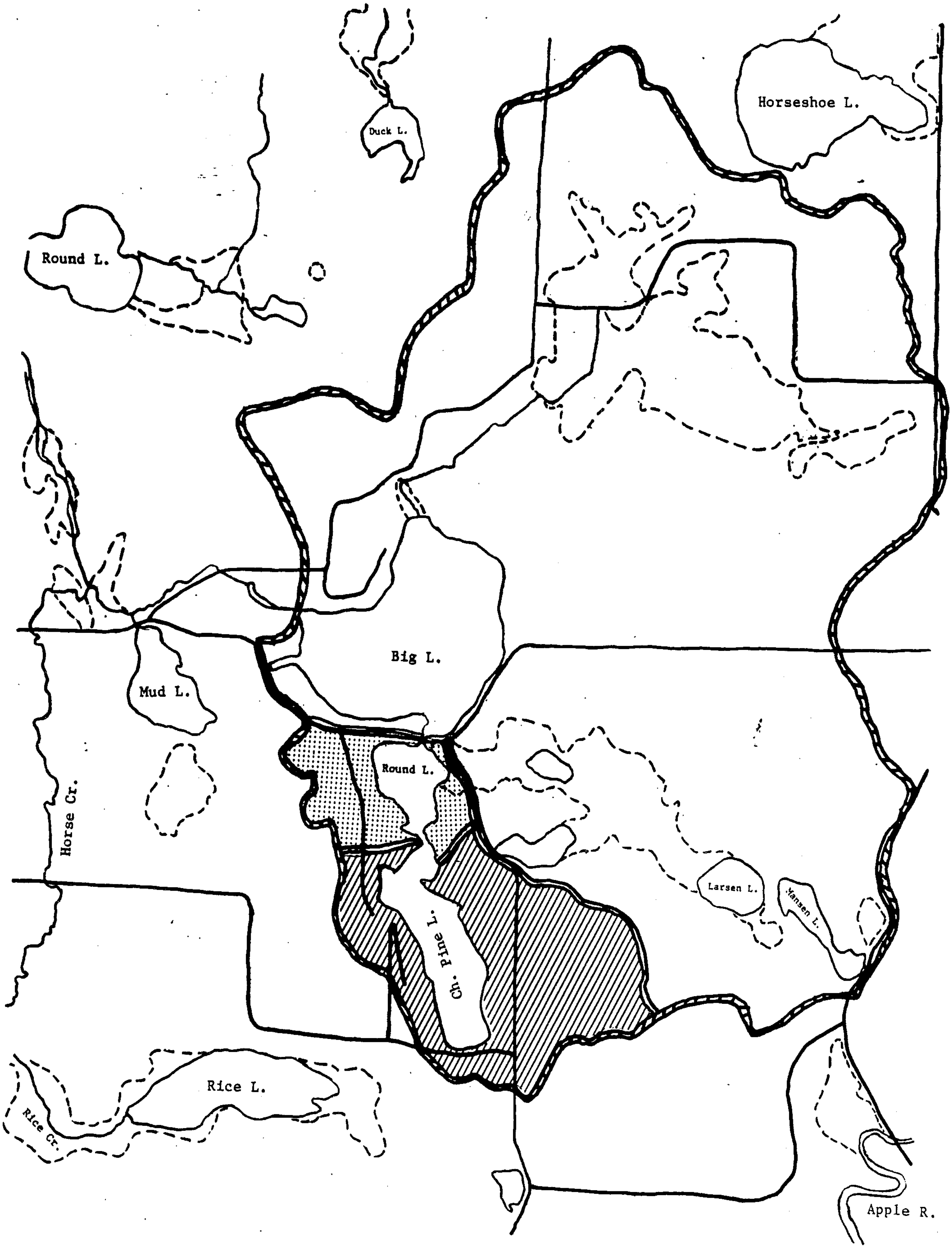


Fig. 4. Area watersheds and sub-drainage basins.

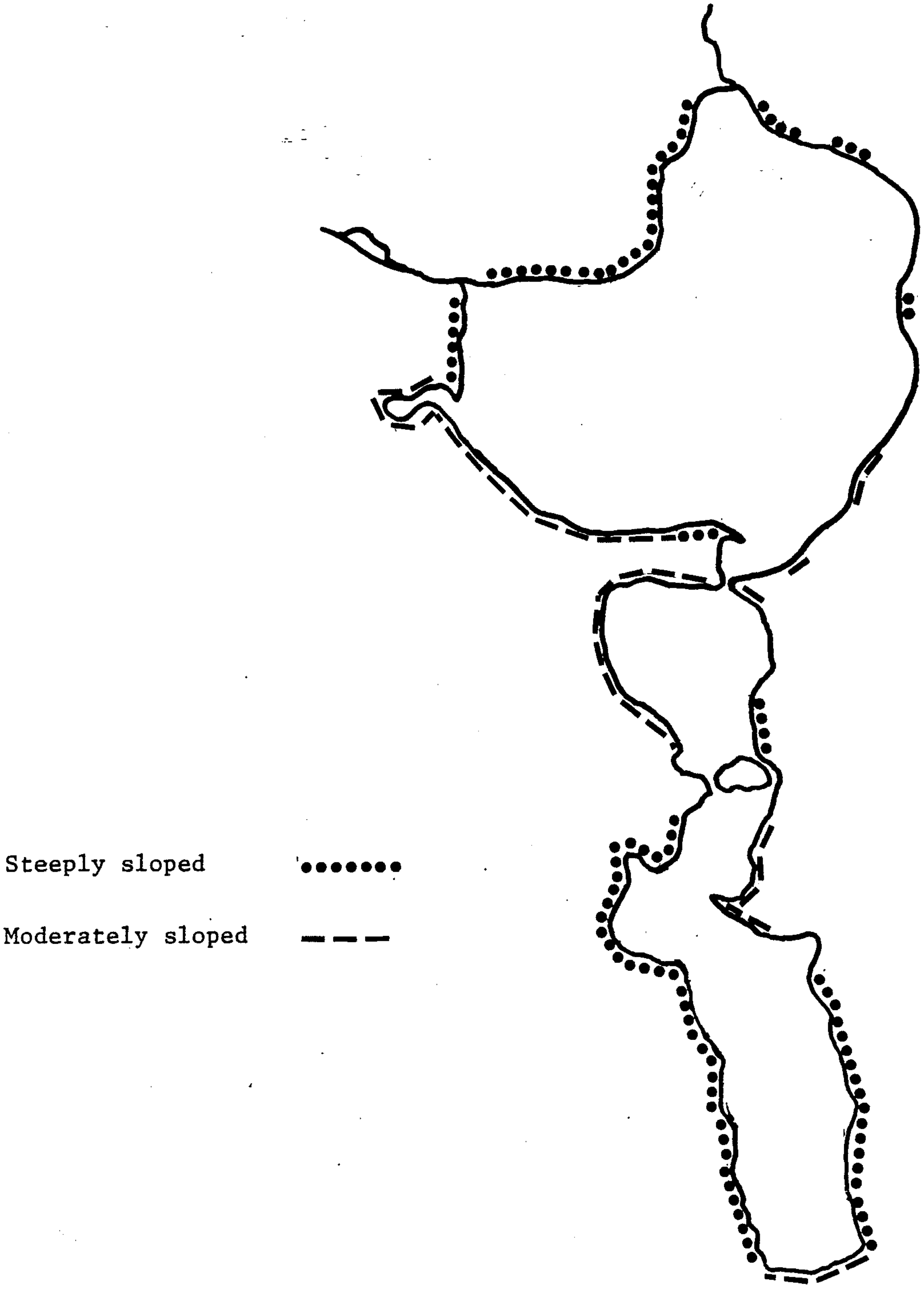


Fig. 5. Approximate areas of steeply or moderately sloped shoreline banks.

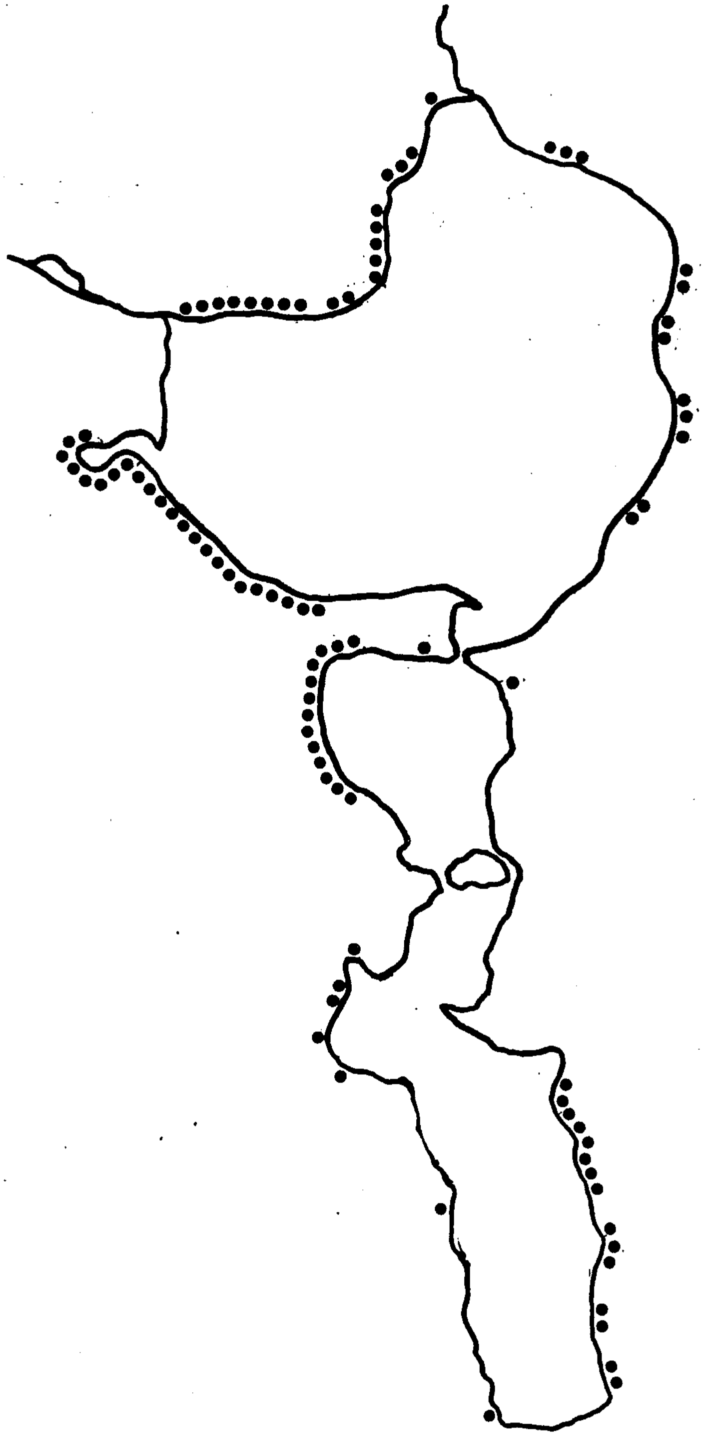
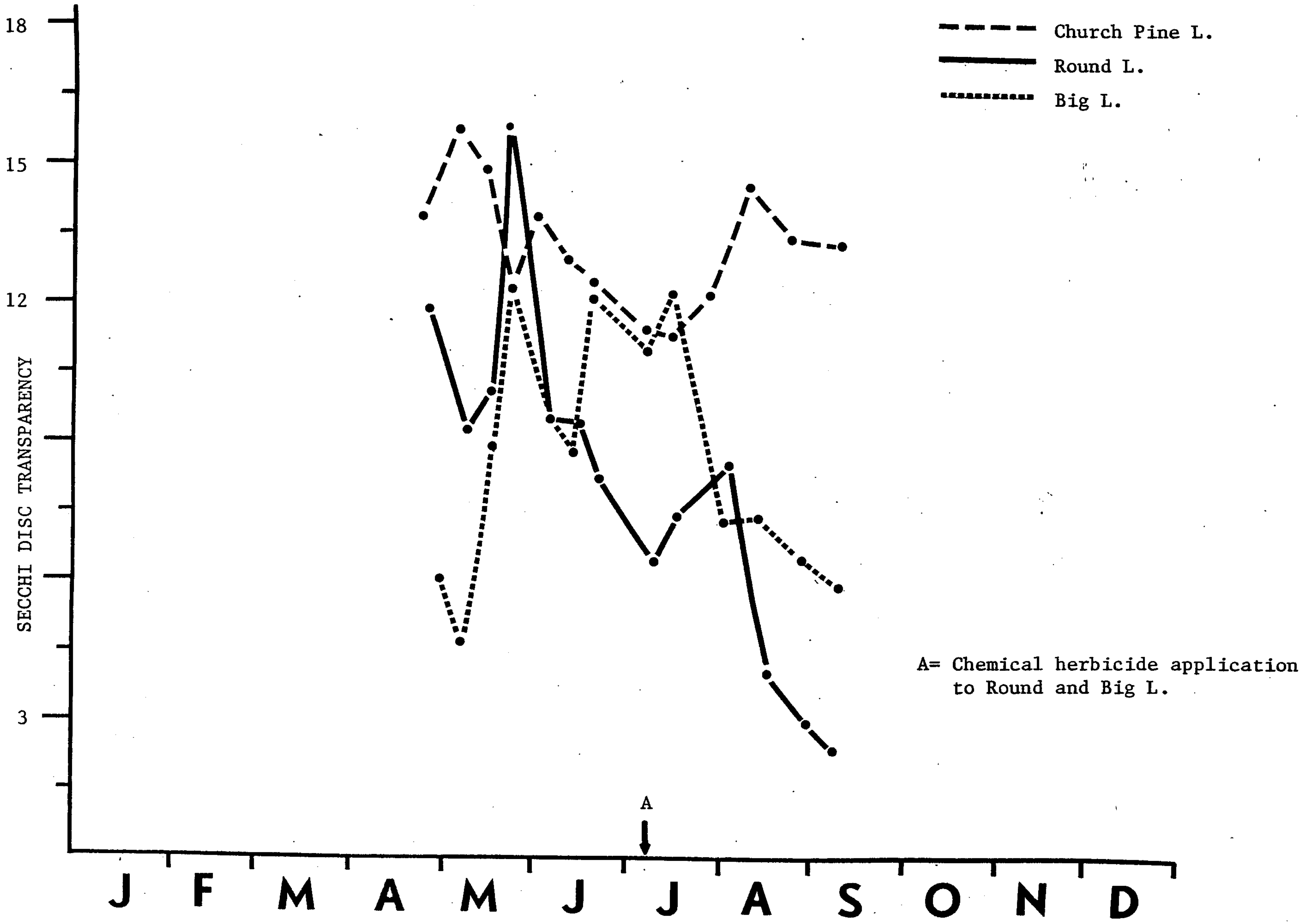


Fig. 6. Approximate areas of developed (groomed) shoreline banks.



A= Chemical herbicide application
to Round and Big L.

Fig. 7. Secchi disc transparency readings in 1985.

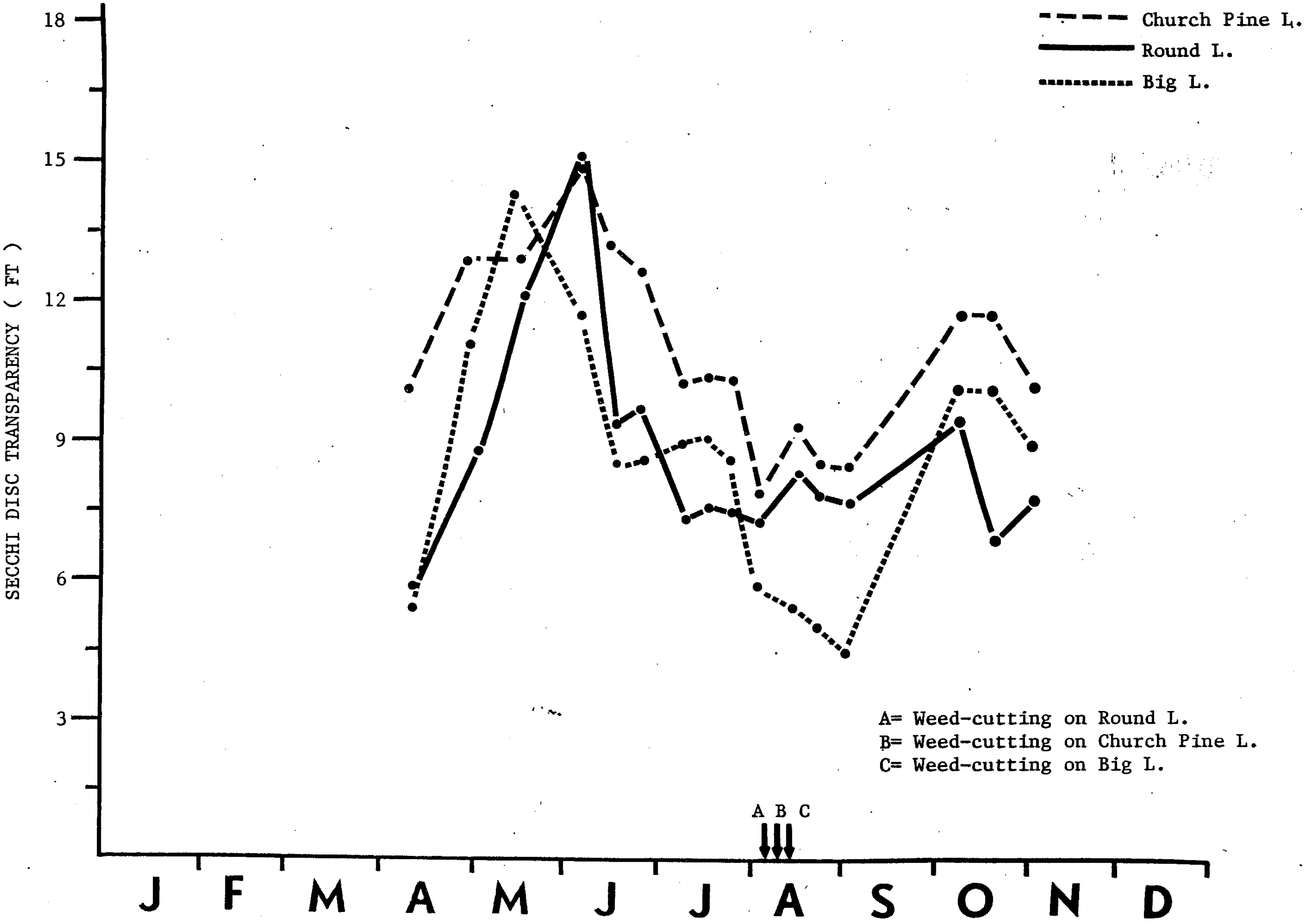


Fig. 8. Secchi disc transparency readings in 1986.

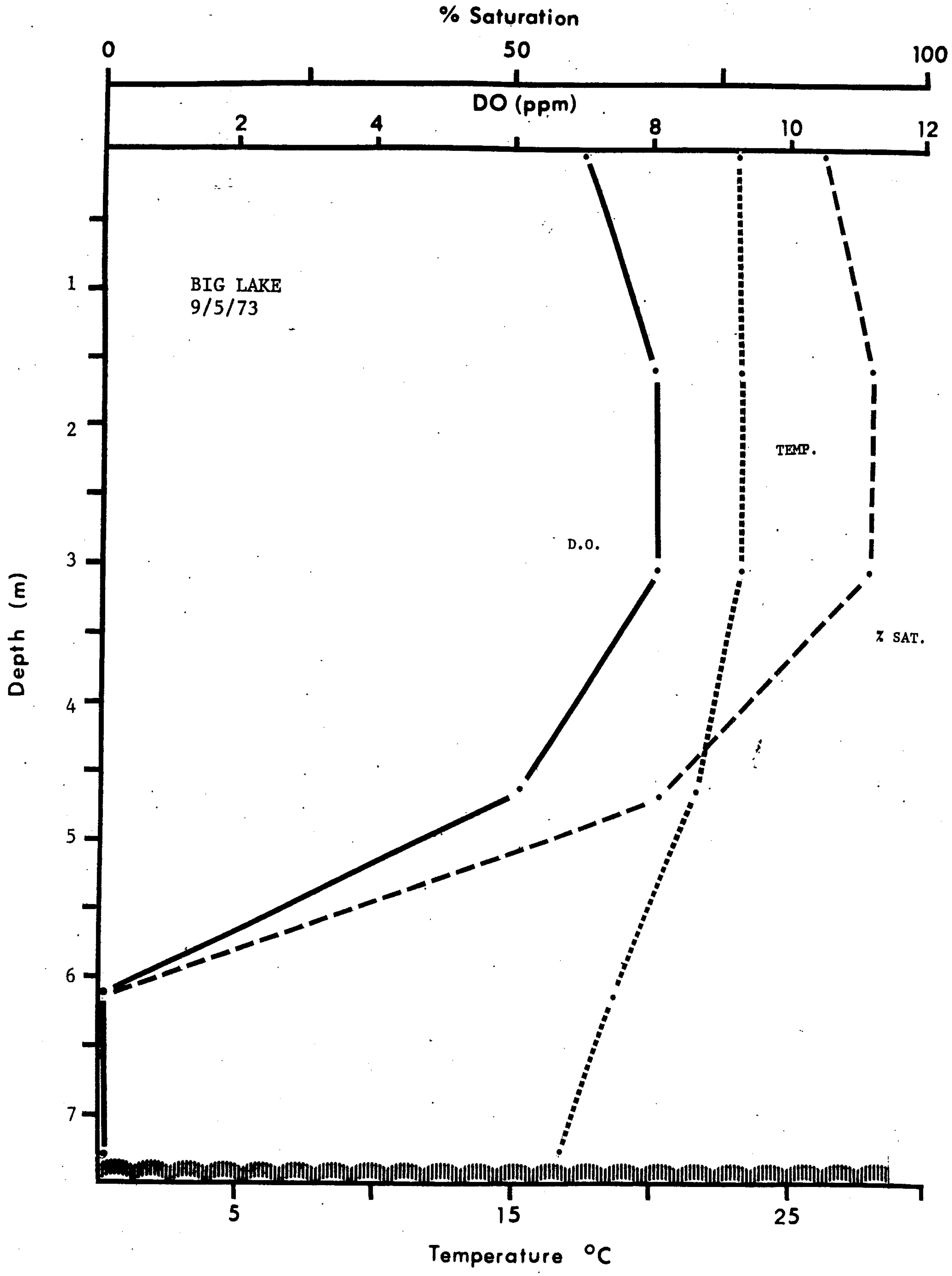
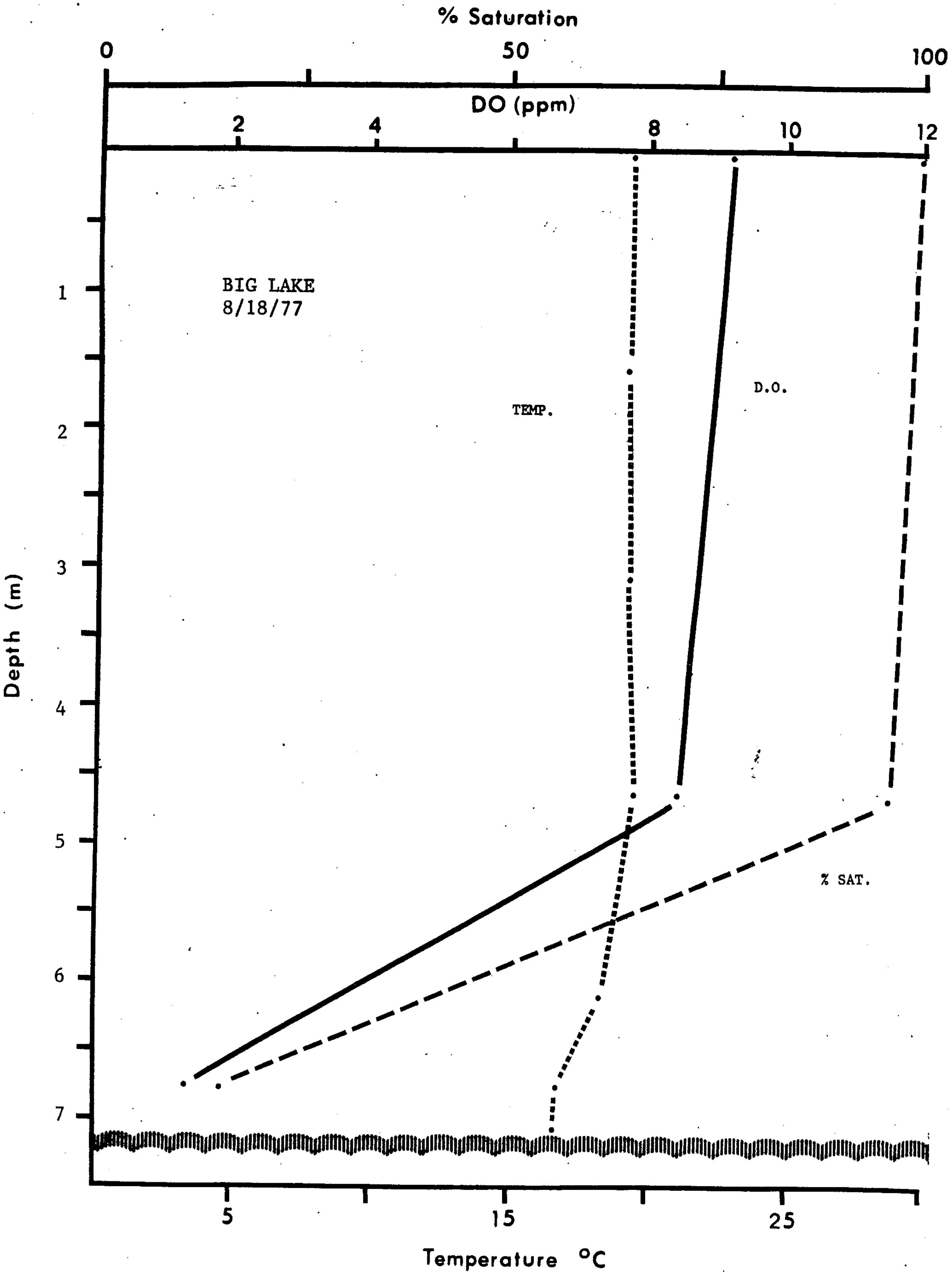
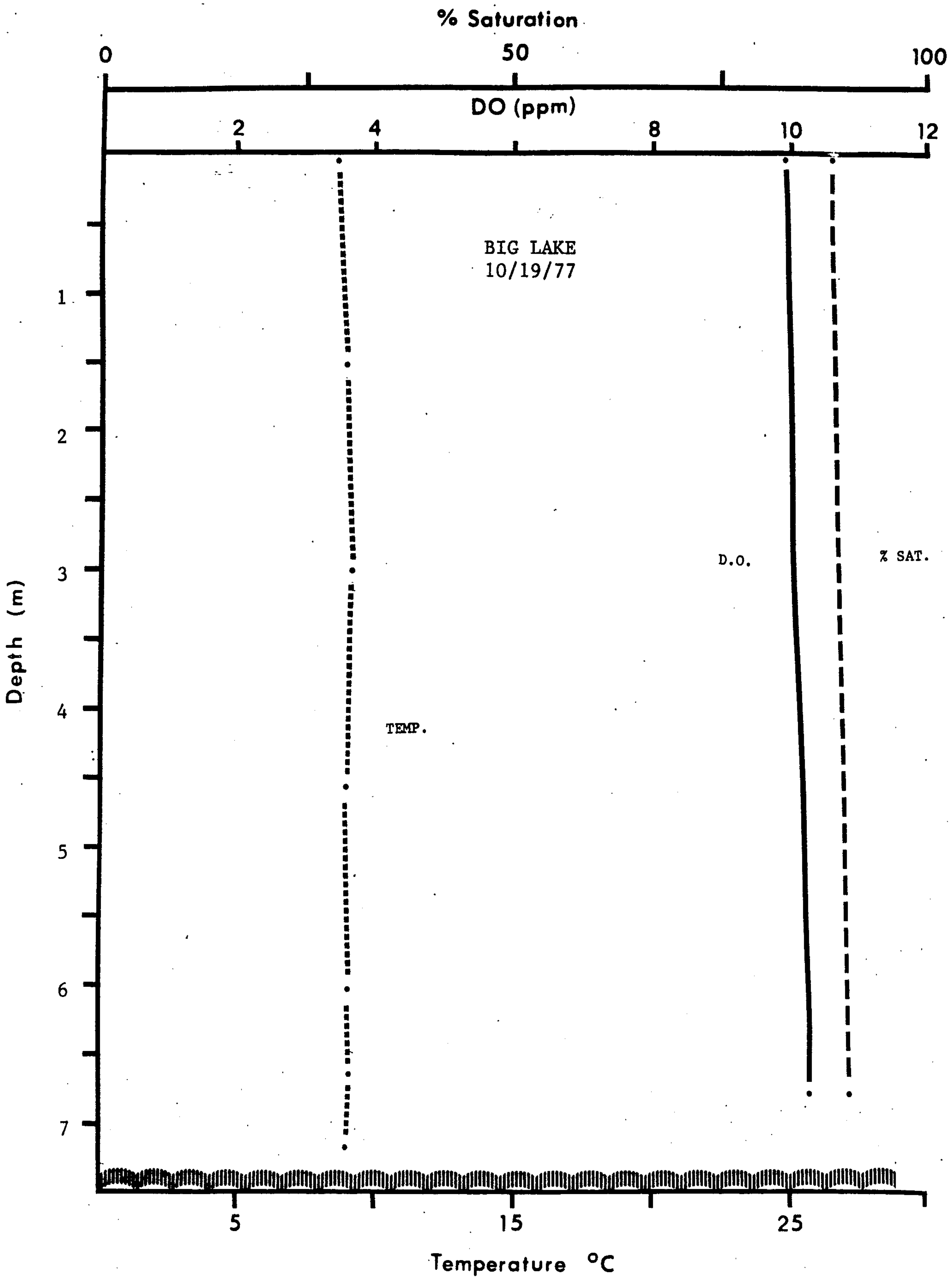

% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
BIG LAKE
9/5/73
TEMP.
D.O.
% SAT.
Depth (m)
1
2
3
4
5
6
7
5
15
25
Temperature °C

Fig. 9.



% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
BIG LAKE
8/18/77
TEMP.
D.O.
% SAT.
Depth (m)
1
2
3
4
5
6
7
5
15
25
Temperature °C

Fig. 10.



% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
BIG LAKE
10/19/77
Depth (m)
1
2
3
4
5
6
7
TEMP.
D.O.
% SAT.
5
15
25
Temperature °C

Fig. 11.

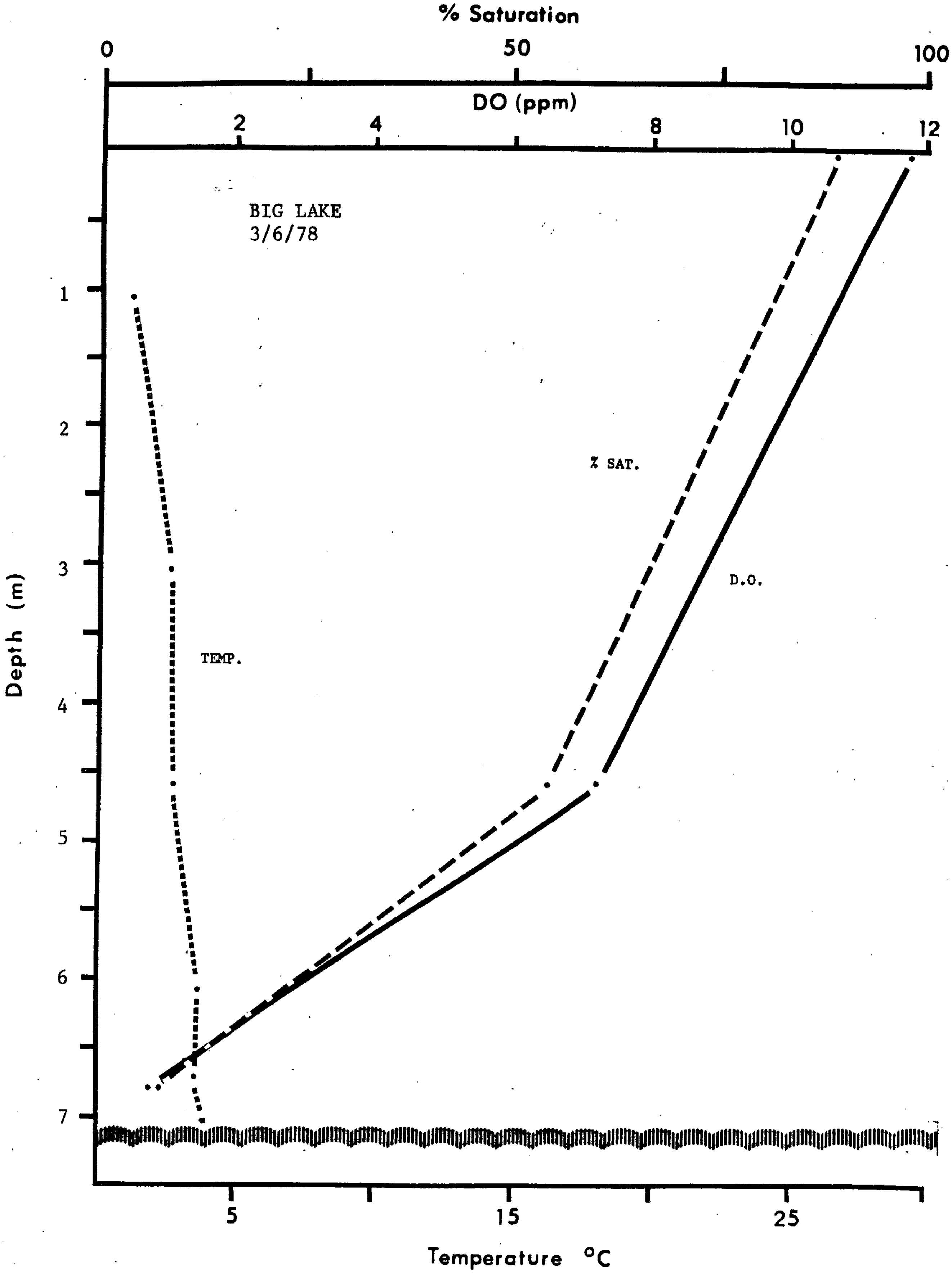

% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
BIG LAKE
3/6/78
% SAT.
D.O.
TEMP.
Depth (m)
1
2
3
4
5
6
7
5
15
25
Temperature °C

Fig. 12.

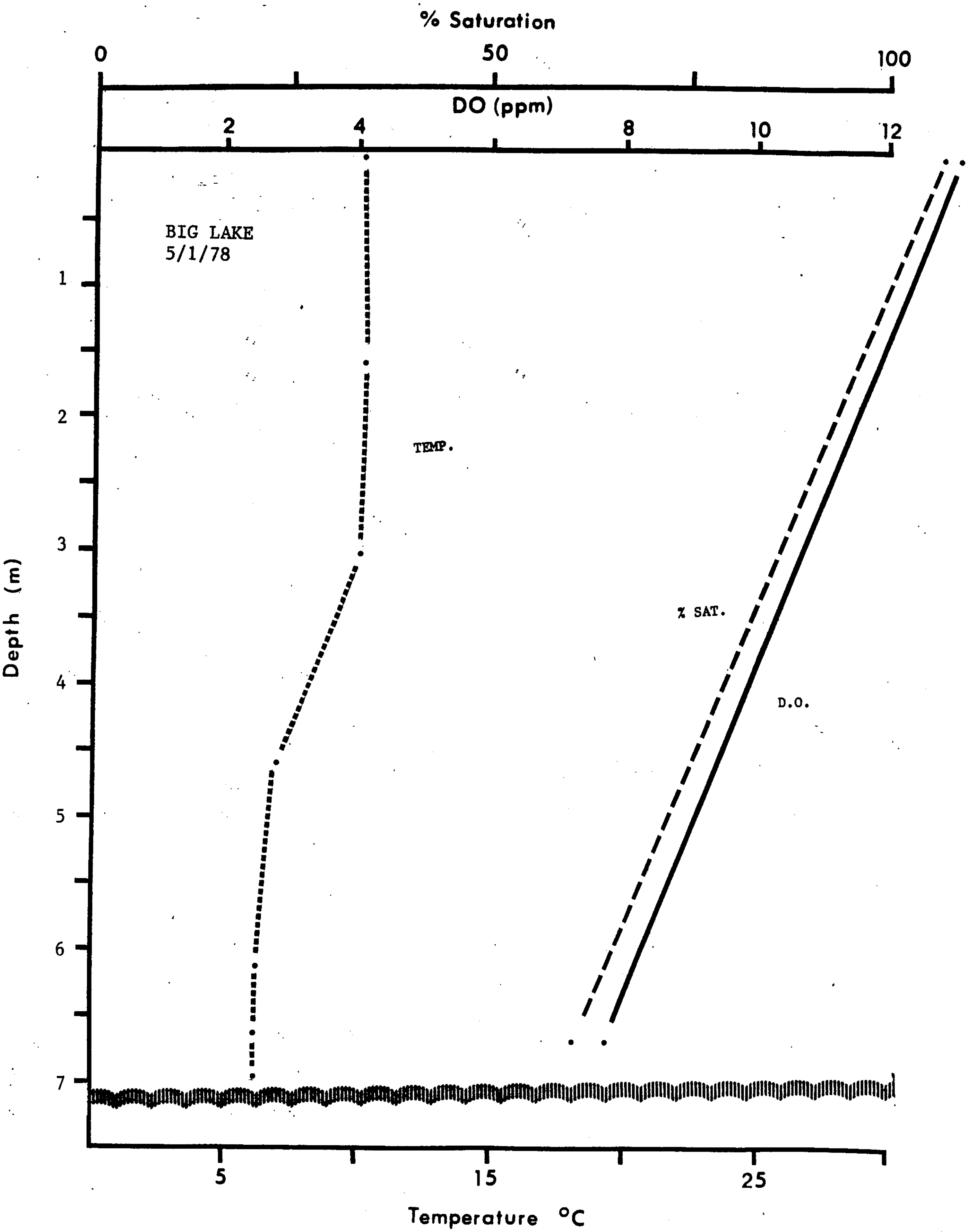
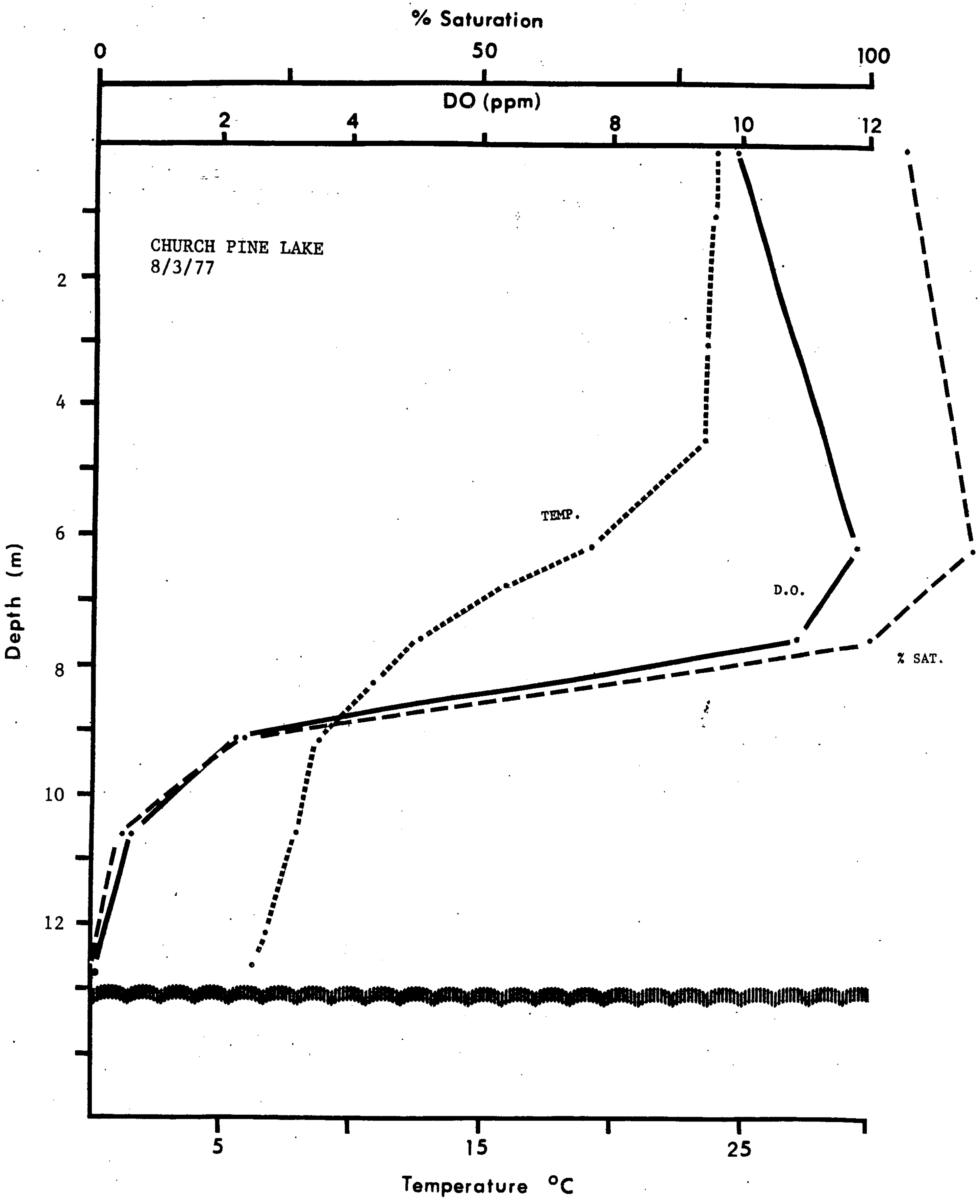

% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
BIG LAKE
5/1/78
TEMP.
% SAT.
D.O.
Depth (m)
1
2
3
4
5
6
7
5
15
25
Temperature °C

Fig. 13.



% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
CHURCH PINE LAKE
8/3/77
TEMP.
D.O.
% SAT.
Depth (m)
2
4
6
8
10
12
5
15
25
Temperature °C

Fig. 14.

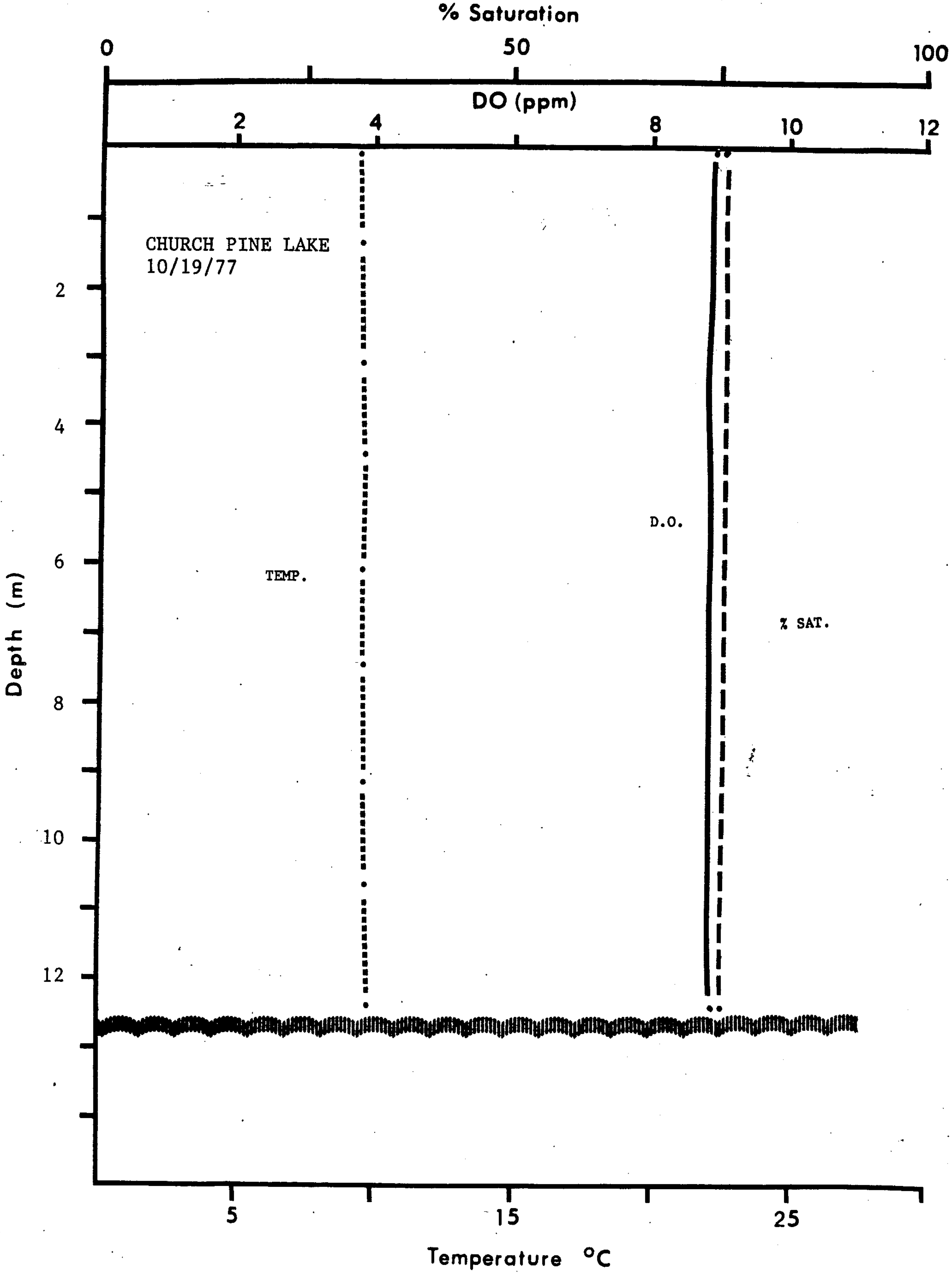
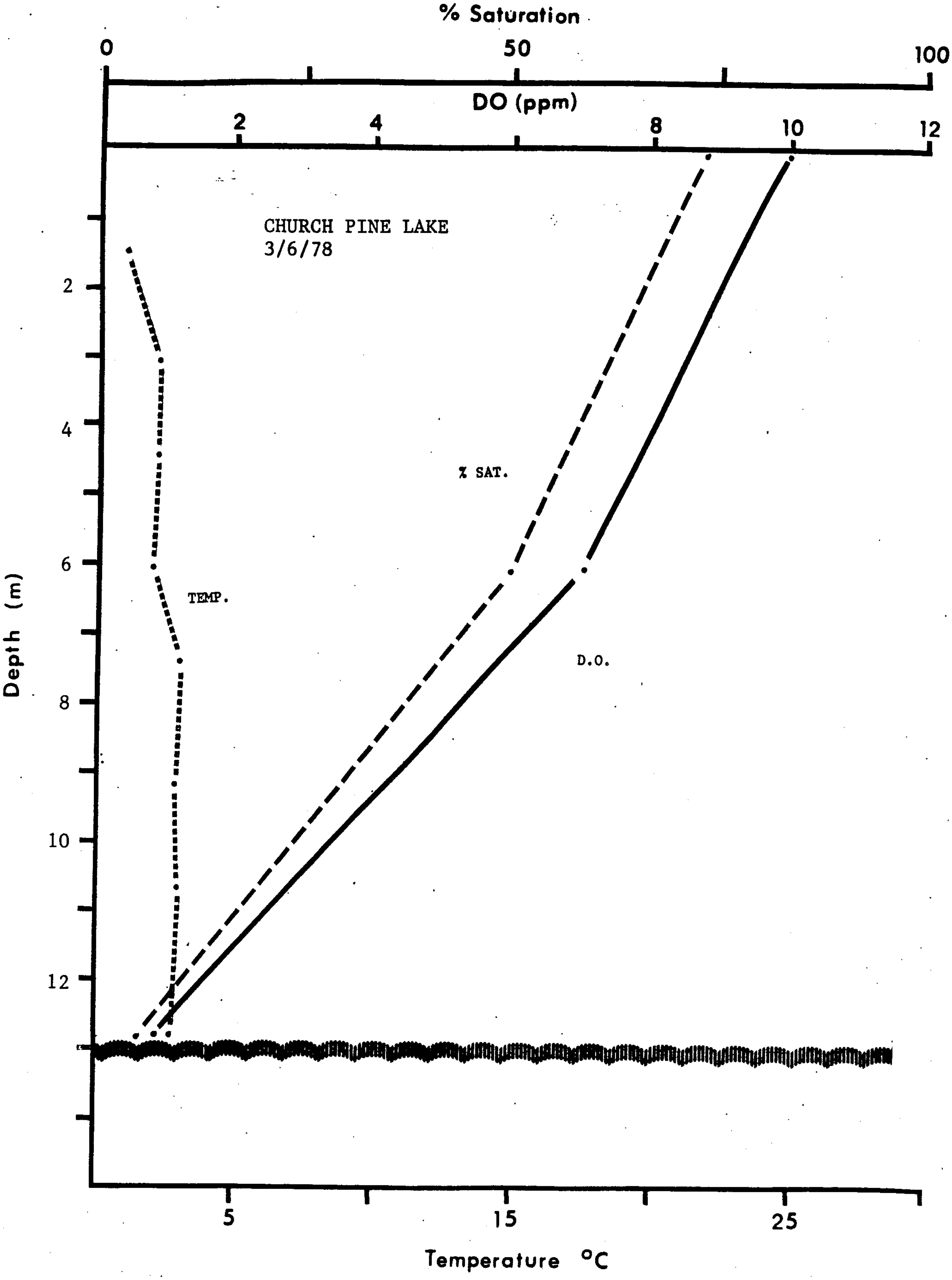

% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
CHURCH PINE LAKE
10/19/77
TEMP.
D.O.
% SAT.
Depth (m)
2
4
6
8
10
12
5
15
25
Temperature °C

Fig. 15.



% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
CHURCH PINE LAKE
3/6/78
% SAT.
TEMP.
D.O.
Depth (m)
2
4
6
8
10
12
5
15
25
Temperature °C

Fig. 16.

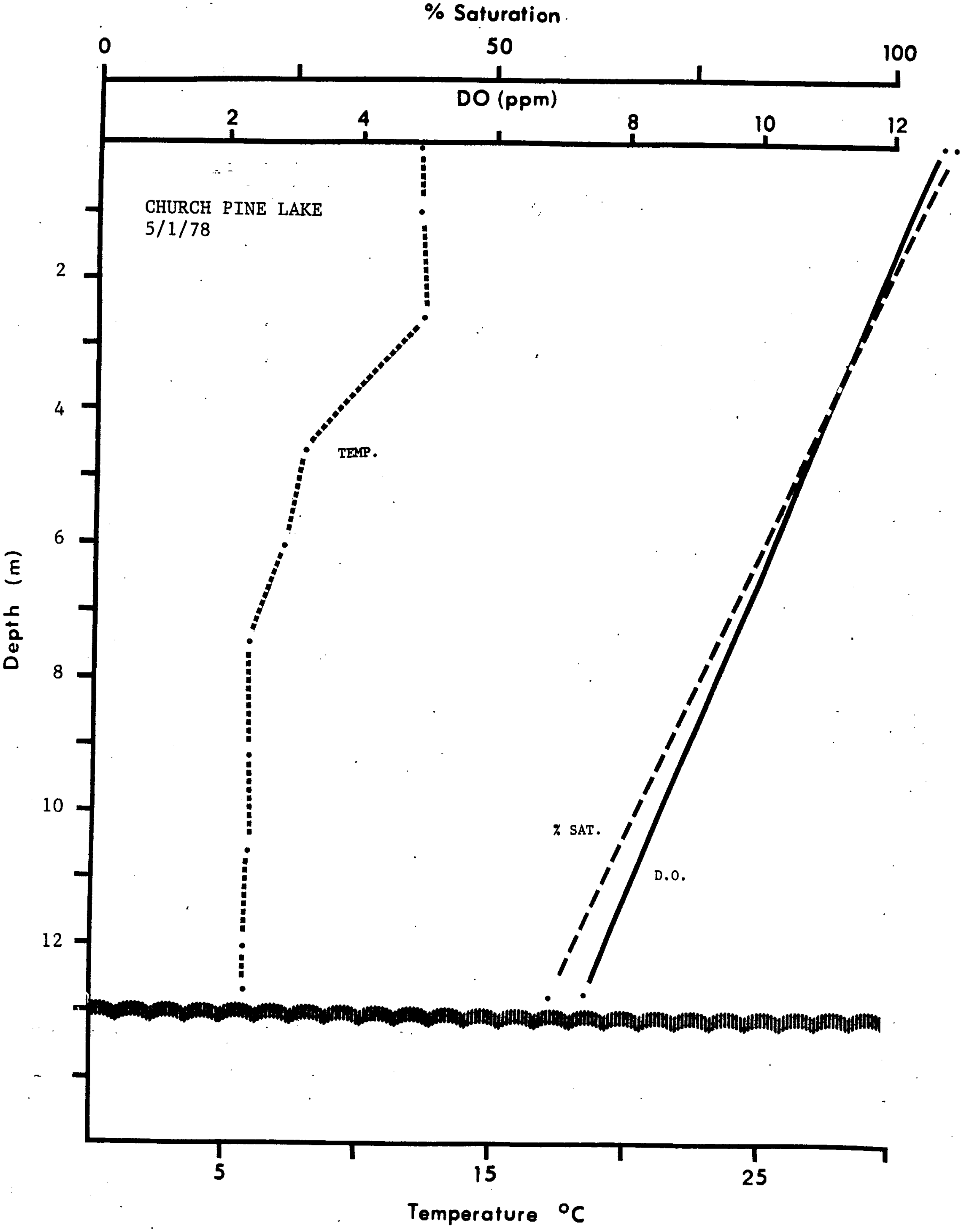

% Saturation
0
50
100
DO (ppm)
2
4
8
10
12
CHURCH PINE LAKE
5/1/78
TEMP.
% SAT.
D.O.
Depth (m)
2
4
6
8
10
12
5
15
25
Temperature °C

Fig. 17.

Residents Survey

In order to evaluate the impressions and opinions of the area residents concerning water quality and lake-use, a questionnaire (Fig. 18) was distributed in July 1987, which was to be returned by mail. This questionnaire also intended to provide information on land-use and individual weed management strategies used by the area residents.

Results:

Questionnaires are completed and returned by 64 residents, which is approximately 35% of the lake population. Of the questionnaires returned, 37% were from Church Pine Lake residents, 16% from Round Lake residents, and 47% from Big Lake residents. About 58% of the responses were from seasonal residents and 42% from permanent residents.

A mean ranking of the various lake problems reported by the residents was calculated for each lake individually. Severity of a particular problem was ranked from 1 to 5, 1 being the value for a particular situation ranked worst by all respondents and 5 being the value given if no respondents reported that situation as being a problem. The mean ranking and standard deviation (in parenthesis) for each lake is:

	Church Pine	Round	Big
Weeds	2.52 (1.40)	1.60 (0.70)	2.14 (1.48)
Algae	4.53 (1.23)	3.70 (0.95)	2.97 (1.27)
Water level	4.17 (1.27)	3.30 (1.57)	3.93 (1.44)
Boat traffic	2.13 (1.62)	2.30 (1.06)	2.93 (1.39)
Fishing quality	3.71 (1.40)	3.30 (1.57)	3.90 (1.32)
Odors	4.83 (0.48)	4.60 (0.70)	4.21 (1.32)

The standard deviation can be interpreted as an indication of the general consensus of the population on that issue. A larger standard deviation correlates with a lower agreement among respondents on that issue. Of those respondents indicating problems with weeds and algae, most indicated that August was the time of year that the problem was most acute.

About 19% of respondents indicated that they fertilized their lawn. The majority of residents indicated that they used hand-raking (63%) to control weeds. Only 15% indicated that they used chemical herbicides on their shoreline. Of those residents using hand-raking to control weeds, 58% indicated general satisfaction with the results.

Residents presented numerous comments on water quality and lake-use. Several also provided suggestions on remedial action. The following summarizes these comments (C) and suggestions (S). The number of respondents expressing a similar comment or suggestion is indicated in brackets.

(C) Church Pine, Roung and Big Lakes are too small to safely operate high-powered boats at high speeds. [26]

- (S) A maximum engine power restriction should be inacted and enforced. [6]
- (S) Limit and enforce allowable hours for operation of large boats. [5]
- (S) Area should be regularly patrolled by local law enforcement officials. [3]
- (S) Restrict and enforce the number of boats allowed at one time on the lake. [2]
- (S) Enforce existing laws regulating boat traffic. [2]
- (S) Improve and maintain signs describing restrictions. [1]
- (S) Boat launch on Church Pine Lake should be closed June through August. [1]
- (S) Because these are public waters, nothing can be done to restrict boating. [1]
- (S) Maximum speed limits for the lakes should be inacted and enforced. [1]

(C) Excessive noise, trash, and use as a public beach at the boat launch on Church Pine Lake should be controlled. [9]

- (S) Increase facilities to include trash collection, parking, toilets, and a designated swimming area. [2]
- (S) Local law enforcement officials should patrol this area regularly. [2]

(C) The effectiveness of septic systems should be evaluated, and if a significant portion are found to be polluting the lake, alternatives should be developed. [7]

(C) Water quality is general good. [4]

(C) Fish population should be more effectively stocked. [4]

(C) Chemicals should not be used on or near the lakes. [3]

(C) Weed harvesting is ineffective and should be decreased. [2]

(C) Weed harvesting on the lakes should be increased. [2]

(C) Connecting channels between lakes should be deepened. [2]

(C) Water draining into Big Lake from culvert by the Big Lake Store is of poor quality. [1]

(C) Persons raking, cutting or harvesting weeds should remove them from the lake. [1]

(C) All lakes should be accessible by pontoon boat. [1]

(C) Garfield Township should develop an approved dump. [1]

(C) Outlet from Big Lake should be closed during dry weather. [1]

Fig. 18. Resident questionaire.

Church Pine, Round and Big Lakes Residents Survey:

Please fill out and return in envelope provided.

Name ____________________ Polk Co. Address (if different)

Address ____________________ ____________________

____________________ ____________________

Phone ____________________ Phone ____________________

Which lake do you live on? ___Church Pine ___Round ___Big

How long have you been a resident? ____________________

Is your residence __________ permanent or __________ seasonal?

How do you rank the problems on your lake (rank 1 to 4, 1 being the worst problem, leave blank anything that is not a problem).

________ Weeds

________ Algae

________ Water level

________ Boat traffic

________ Fishing quality

________ Odors

________ Other ____________________

________ Other ____________________

How long ago did these problems begin to arise?

____

Approximately when during the year are these problems the worst?

____

Do you fertilize your lawn? __________ Yes __________ No

What type(s) of weed control method(s) have you tried on your shoreline?

_____ None

_____ Hand-raking

_____ Mechanical harvester

_____ Chemicals (Which, if you know?
____________________________)

_____ Other ____________________

Were you satisfied with the results? ________ Yes ________ No

Do you have any other comments on lake quality and/or lake use that you feel may be important?

____

____

____

Water Quality Assessment

In order to develop an understanding of select pertinent physical, chemical, and biological factors which might influence general water quality and the success of water quality management of Church Pine, Round and Big Lakes, an assessment of selected parameters was conducted from February 1987 to September 1987.

Methods:

All three basins, including surface inlets and the outlet were sampled monthly from March 1987 to September 1987. An additional sample was collected from North Creek in February 1987. Locations of sample sites are found in Fig. 19.

At each in-basin site, a sample was taken at a depth of 2 meters. Samples were filtered within 2 to 5 minutes and filtrated water was placed in a polyethylene sample bottle and stored on ice. Filtered residue was retained for subsequent suspended solids analysis. A composite sample was collected for each lake comprising of approximately equal portions of unfiltered water from each in-basin sample site (sites 1, 2, 3 for Church Pine Lake; 5, 15 for Round Lake; 9, 10, 12 for Big Lake). These samples were used to determine chlorophyll *a*, chlorophyll *b*, chlorophyll *c*, pheophytin *a*, algal biomass, total unfiltered phosphate, and particulate phosphate. At each in-basin site, a secchi disc transparency reading was taken. At mid-lake sites, discrete samples were collected at various depths and analyzed for dissolved oxygen, temperature, pH, and conductivity.

At surface flow sites (7, 11, 13) samples were taken at mid-stream and mid-depth. Water samples were taken and treated in the same manner as previously described. Stream flow was also estimated.

All samples were stored on ice until analyzed. Most analyses were conducted within 12 hours of sample collection and no samples were held more than 24 hours before analysis. Analyses for selected parameters were conducted using methods described by the American Public Health Association (APHA) (Standard methods for the examination of water and waste water, 16th Ed.). The specific methods used were:

Algal biomass	APHA #1002H
Alkalinity, calcium	APHA #403
Alkalinity, total	APHA #403
Chlorophyll *a*	APHA #1002G
Chlorophyll *b*	APHA #1002G
Chlorophyll *c*	APHA #1002G
Conductivity[a]	APHA #205
Dissolved solids	by calculation
Hardness, total	APHA #314B
Iron, soluble	APHA #315B
Nitrate, dissolved	APHA #418B
Nitrite, dissolved	APHA #419
Oxygen, dissolved[a]	APHA #421F
pH[a]	APHA #423
Pheophytin *a*	APHA #1002G
Phosphate, dissolved acid-hydrolysible	APHA #424B
Phosphate, dissolved ortho (reactive)	APHA #424G
Phosphate, dissolved organic	APHA #424
Phosphate, dissolved total	APHA #424C
Phosphate, particulate (filterable)	APHA #424
Phosphate, total (unfiltered)	APHA #424C
Suspended solids (filterable)	APHA #209C

[a] Analysis conducted on-site.

Quality assurance measures also included replication of at least 10% of all analyses. The mean agreement between replicates was 93.6%.

During July and August, samples were also collected to be analyzed for total coliform bacteria and for the human fecal coliform bacterium, _Escherichia_ _coli_. Samples were taken approximately 20 feet from shore at the locations shown in Fig. 20. Samples were collected in sterilized plastic containers (Whirl-pac) at a depth of 6-12 inches below the water surface. Samples were placed on ice and analyzed within 12 hours. Total coliform bacteria were enumerated by APHA method #908A. The fecal bacterium _E_. _coli_ was enumerated by selective media (4-methylumbelli feryl-B-D-glucuronide).

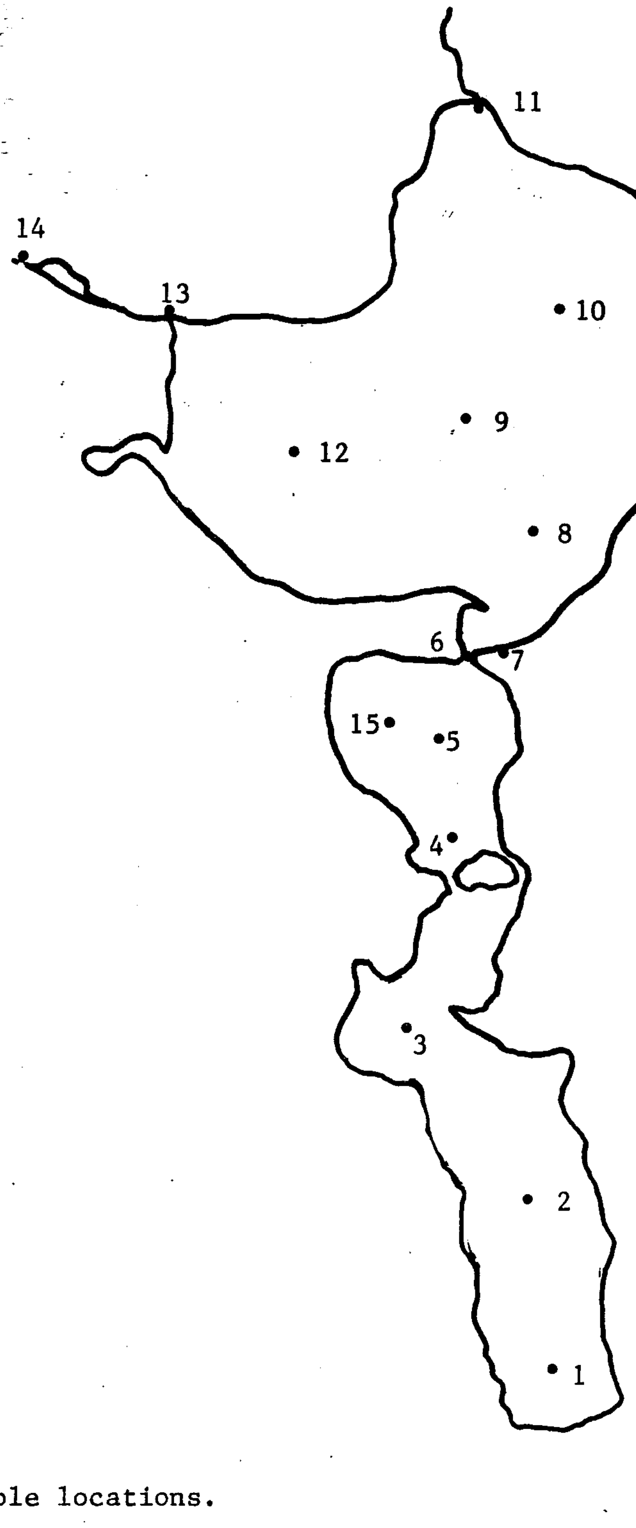


Fig. 19. Sample locations.

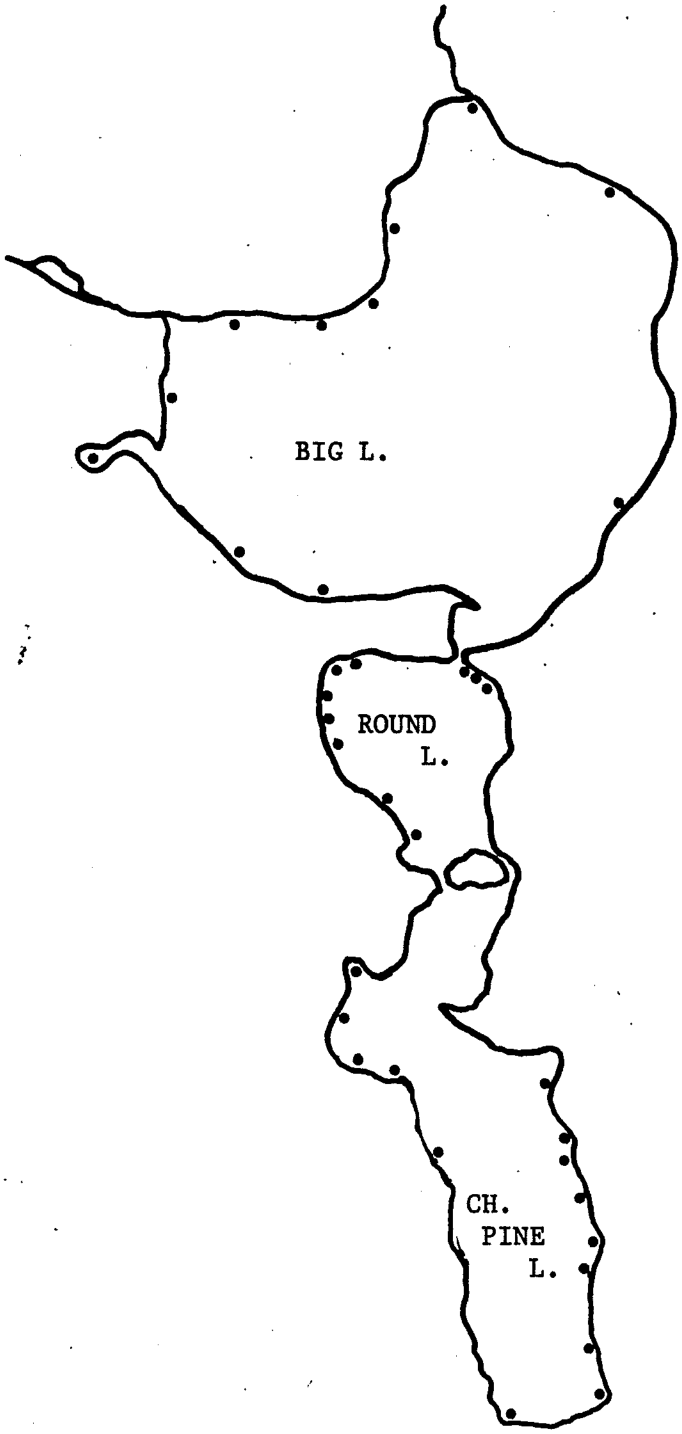


Fig. 20. Locations of bacterial sample sites.

Results

A summary of the results of the water quality analyses conducted February - September 1987 are presented in Tables 4 - 9. A complete record of the results of each water sample collected and analyzed, and any pertinent observations made, is found in Appendix I. Results of the bacterial analyses conducted on June 12 and July 17, 1987 are found in Fig. 21.

Table 4. Mean values and range (in parentheses) for selected parameters for Church Pine Lake in 1987.

DATE	MARCH 7	APRIL 17	MAY 15	JUNE 12	JULY 17	AUGUST 6	SEPTEMBER 25
Algal biomass (ug dry wgt/L)	- -	281 -	<7 -	161 -	121 -	161 -	<7 -
Alkalinity, total (mg/L as $CaCO_3$)	51.2 (43.6-61.6)	49.4 (48.5-49.9)	57.8 (54.3-61.7)	54.3 (51.4-58.7)	54.3 (51.4-57.3)	52.9 (51.4-54.3)	50.2 (45.5-55.8)
Chlorophyll a (ug/L)	- -	4.2 -	<0.1 -	2.4 -	1.8 -	2.4 -	<0.1 -
Chlorophyll b (ug/L)	- -	1.2 -	3.9 -	6.5 -	1.8 -	3.6 -	1.1 -
Chlorophyll c (ug/L)	- -	1.1 -	4.4 -	6.1 -	<0.1 -	2.7 -	2.1 -
Conductivity (uohm/cm)	135 (134-135)	131 (131)	138 (137-138)	132 (131-134)	137 (138-139)	128 (126-130)	130 (129-130)
Dissolved solids (mg/L)	87.5 (87.1-87.8)	85.2 (85.2)	89.5 (89.1-89.7)	86.0 (85.2-87.1)	90.2 (89.7-90.4)	83.0 (81.9-84.5)	84.5 (83.2-86.5)
Hardness, EDTA (mg/L as $CaCO_3$)	55.4 (53.0-59.9)	43.4 (42.0-44.3)	64.5 (63.8-65.8)	63.8 (61.8-65.8)	57.8 (57.8)	57.5 (57.0-57.8)	55.8 (53.8-57.8)
Iron, soluble (ug/L)	82 (75-90)	80 (80)	48 (20-80)	33 (20-85)	<10 (<10-10)	<10 (<10)	<10 (<10)
Nitrate (ug/L as N)	890 (791-939)	838 (444-1,231)	360 (344-393)	956 (790-1,285)	463 (196-696)	163 (96-245)	323 (167-514)
Nitrite (ug/L as N)	10 (9-11)	12 (6-19)	6 (6-7)	10 (6-15)	4 (4)	4 (3-5)	6 (4-7)
Oxygen, dissolved (mg/L) (percent saturation)	10.9 78%	8.8 87%	7.2 76%	8.8 100%	8.1 100%	8.4 105%	8.0 86%
pH	7.87 (7.85-7.90)	7.98 (7.90-8.10)	7.90 (7.60-8.10)	8.55 (8.50-8.65)	8.83 (8.70-8.95)	8.87 (8.80-8.95)	8.43 (8.05-8.65)
Pheophytin a (ug/L)	- -	6.5 -	9.2 -	4.4 -	0.9 -	3.0 -	4.3 -
Phosphorus, ortho (ug/L as P)	105 (97-115)	38 (29-48)	4 (2-5)	25 (<2-53)	<2 (<2)	<2 (<2)	<2 (<2-2)
Phosphorus, acid-hydrolysible (ug/L as P)	17 (2-43)	12 (<2-21)	<2 (<2)	<2 (<2-2)	<2 (<2)	<2 (<2)	<2 (<2-2)
Phosphorus, organic (ug/L as P)	13 (7-23)	10 (9-11)	<2 (<2-2)	2 (<2-7)	<2 (<2)	<2 (<2)	<2 (<2-5)
Phosphorus, total dissolved (ug/L as P)	137 (115-150)	60 (46-80)	4 (2-5)	28 (<2-53)	<2 (<2)	<2 (<2)	4 (<2-9)
Phosphorus, particulate (ug/L as P)	- -	<2 -	14 -	<2 -	5 -	<2 -	4 -
Phosphorus, total unfiltered (ug/L as P)	>137 -	60 (46-80)	18 (16-19)	28 (2-53)	5 (5)	<2 (<2)	8 (4-13)
Secchi disc transparency (feet)	- -	>14.0 (>14.0)	15.3 (14.9-15.5)	13.5 (13.0-14.1)	12.4 (12.1-12.5)	11.1 (10.0-12.0)	14.6 (13.2-15.6)
Suspended solids, filterable (mg/L)	1.6 (1.4-1.8)	0.8 (0.6-0.9)	1.5 (0.9-2.3)	3.2 (2.0-4.8)	2.8 (2.2-3.2)	1.4 (1.2-1.6)	1.5 (0.8-2.4)

Table 5. Mean values and range (in parentheses) for selected parameters for Round Lake in 1987.

DATE	MARCH 7	APRIL 17	MAY 15	JUNE 12	JULY 17	AUGUST 6	SEPTEMBER 25
Algal biomass (ug dry wgt/L)	– –	543 –	174 –	121 –	194 –	389 –	147 –
Alkalinity, total (mg/L as $CaCO_3$)	51.2 –	70.5 –	75.7 (74.9-76.4)	71.2 (69.0-73.4)	67.5 (67.5)	67.6 (66.1-69.0)	70.5 –
Chlorophyll a (ug/L)	– –	8.1 –	2.6 –	1.8 –	2.9 –	5.8 –	2.2 –
Chlorophyll b (ug/L)	– –	6.6 –	6.1 –	6.5 –	1.8 –	11.0 –	2.0 –
Chlorophyll c (ug/L)	– –	6.4 –	5.4 –	5.6 –	0.1 –	10.2 –	1.3 –
Conductivity (uohm/cm)	178 –	169 –	170 (170)	161 (161)	154 (152-156)	150 (149-151)	171 (167-176)
Dissolved solids (mg/L)	115.7 –	109.9 –	110.5 (110.5)	104.7 (104.7)	100.1 (98.8-101.4)	97.6 (96.9-98.2)	111.5 (108.6-114.4)
Hardness, EDTA (mg/L as $CaCO_3$)	78.7 –	61.6 –	79.8 (77.8-81.7)	79.8 (79.8)	73.8 (73.8)	70.8 (69.8-71.8)	77.8 –
Iron, soluble (ug/L)	105 –	25 –	110 (80-140)	10 (<10-20)	20 (<10-40)	<10 (<10)	<10 –
Nitrate (ug/L as N)	1,087 –	644 –	318 (244-392)	542 (392-692)	346 (296-395)	173 (148-198)	167 –
Nitrite (ug/L as N)	13 –	6 –	7 (6-8)	5 (2-8)	5 (4-5)	3 (2-4)	6 –
Oxygen, dissolved (mg/L) (percent saturation)	11.2 82%	7.2 72%	8.7 94%	8.8 99%	8.5 106%	8.6 106%	6.4 69%
pH	7.35 –	8.10 –	8.33 (8.30-8.35)	8.45 (8.20-8.70)	9.00 (9.00)	9.05 (9.05)	7.88 (7.80-7.95)
Pheophytin a (ug/L)	– –	6.6 –	4.7 –	5.2 –	0.8 –	11.5 –	5.7 –
Phosphorus, ortho (ug/L as P)	91 –	39 –	8 (4-12)	6 (<2-12)	<2 (<2)	<2 (<2)	2 –
Phosphorus, acid-hydrolysible (ug/L as P)	– –	<2 –	<2 (<2)	5 (2-7)	<2 (<2)	4 (<2-7)	<2 –
Phosphorus, organic (ug/L as P)	– –	31 –	2 (2)	10 (3-17)	<2 (<2)	<2 (<2)	1 –
Phosphorus, total dissolved (ug/L as P)	127 –	70 –	10 (5-14)	21 (17-24)	<2 (<2-2)	4 (<2-7)	3 –
Phosphorus, particulate (ug/L as P)	– –	6 –	70 –	<2 –	2 –	8 –	6 –
Phosphorus, total unfiltered (ug/L as P)	>127 –	76 –	80 (75-84)	21 (17-24)	3 (2-4)	12 (8-15)	9 –
Secchi disc transparency (feet)	– –	12.0 –	12.9 (12.4-13.3)	12.3 (13.0-11.5)	10.3 (10.2-10.4)	8.5 (8.5)	8.7 (8.0-9.3)
Suspended solids, filterable (mg/L)	2.2 –	0.3 –	2.2 (2.1-2.2)	3.6 (3.3-3.9)	2.7 (2.6-2.8)	4.3 (3.2-5.4)	2.6 (2.1-3.1)

Table 6. Mean values and range (in parentheses) for selected parameters for Big Lake in 1987.

DATE	MARCH 7	APRIL 17	MAY 15	JUNE 12	JULY 17	AUGUST 6	SEPTEMBER 25
Algal biomass (ug dry wgt/L)	– –	228 –	87 –	161 –	248 –	1,072 –	536 –
Alkalinity, total (mg/L as CaCO$_3$)	64.0 –	69.5 (64.6-76.4)	83.7 (82.2-85.2)	80.5 (77.8-82.2)	78.1 (76.4-81.4)	79.8 (73.4-85.2)	81.3 (76.4-86.6)
Chlorophyll a (ug/L)	– –	3.4 –	1.3 –	2.4 –	3.7 –	16.0 –	8.0 –
Chlorophyll b (ug/L)	– –	<0.1 –	4.3 –	6.6 –	3.1 –	13.0 –	3.4 –
Chlorophyll c (ug/L)	– –	<0.1 –	0.4 –	5.8 –	0.6 –	8.7 –	0.9 –
Conductivity (uohm/cm)	207 (198-215)	187 (183-190)	189 (188-191)	186 (184-188)	188 (186-189)	178 (174-179)	194 (193-195)
Dissolved solids (mg/L)	134.3 (128.7-139.8)	121.4 (119.0-123.5)	123.1 (122.2-124.2)	121.1 (119.6-122.2)	122.0 (120.9-122.9)	114.9 (113.0-116.4)	125.9 (125.5-126-8)
Hardness, EDTA (mg/L as CaCO$_3$)	84.7 (83.8-85.5)	80.9 (73.5-85.5)	89.0 (87.7-89.7)	89.7 (89.7)	88.7 (87.7-90.7)	87.0 (85.7-87.7)	91.7 (89.7-93.7)
Iron, soluble (ug/L)	38 (35-40)	67 (45-95)	38 (30-45)	37 (30-40)	23 (<10-40)	<10 (<10)	24 (21-29)
Nitrate (ug/L as N)	284 (244-323)	462 (204-739)	446 (226-546)	475 (438-543)	302 (8-497)	280 (147-496)	449 (372-506)
Nitrite (ug/L as N)	7 (6-7)	8 (6-11)	4 (4)	8 (6-12)	2 (<1-3)	4 (3-4)	12 (8-15)
Oxygen, dissolved (mg/L) (percent saturation)	10.2 73%	9.3 91%	7.4 80%	7.7 86%	7.5 91%	8.2 101%	5.3 57%
pH	7.30 (7.25-7.35)	7.95 (7.85-8.05)	8.08 (8.05-8.10)	8.52 (8.45-8.60)	8.85 (8.85)	9.08 (9.05-9.10)	8.19 (8.10-8.25)
Pheophytin a (ug/L)	–	8.2 –	4.8 –	5.2 –	1.8 –	11.0 –	7.3 –
Phosphorus, ortho (ug/L as P)	115 (100-129)	26 (<2-56)	11 (5-16)	14 (4-27)	<2 (<2)	<2 (<2)	70 (53-92)
Phosphorus, acid-hydrolysible (ug/L as P)	6 (5-7)	11 (<2-34)	18 (6-29)	1 (<2-2)	<2 (<2)	<2 (<2-4)	42 (7-84)
Phosphorus, organic (ug/L as P)	13 (8-18)	8 (<2-18)	50 (45-65)	4 (<2-10)	<2 (<2)	2 (<2-6)	58 (4-156)
Phosphorus, total dissolved (ug/L as P)	134 (123-144)	46 (18-91)	95 (67-120)	19 (7-27)	8 (<2-17)	3 (<2-6)	148 (91-240)
Phosphorus, particulate (ug/L as P)	– –	30 –	19 –	4 –	6 –	18 –	15 –
Phosphorus, total unfiltered (ug/L as P)	>134	76 (48-121)	114 (86-139)	23 (11-31)	14 (6-23)	21 (18-24)	163 (106-255)
Secchi disc transparency (feet)	– –	13.2 (12.0-14.0)	13.6 (12.2-14.5)	13.1 (12.3-13.7)	10.8 (10.5-11.0)	5.1 (4.9-5.4)	8.6 (6.1-11.0)
Suspended solids, filterable (mg/L)	1.1 (0.9-1.3)	1.5 (0.8-2.4)	1.3 (1.2-1.5)	4.7 (3.7-6.6)	3.5 (3.0-4.2)	4.6 (4.5-4.7)	2.7 (2.1-3.8)

Table 7. Characteristics of North Creek in 1987.

DATE	FEBRUARY 28	MARCH 7	APRIL 17	MAY 15	JUNE 12	JULY 17	AUGUST 6	SEPTEMBER 25
Discharge (L/sec)	125	114.9	90.4	72.6	59.2	5	45.5	34.8
Alkalinity, total (mg/L as $CaCO_3$)	-	55.1	58.7	76.4	107.2	114.5	101.3	76.4
Conductivity (uohm/cm)	183	169	178	157	220	270	255	210
Dissolved solids (mg/L)	118.9	109.9	115.7	102.1	143.0	175.5	165.8	136.5
Hardness, EDTA (mg/L as $CaCO_3$)	111.0	87.5	77.0	105.7	119.6	117.6	115.6	99.7
Iron, soluble (ug/L)	510	375	505	450	1,250	860	1,300	790
Nitrate (ug/L as N)	944	742	793	792	1,039	466	520	353
Nitrite (ug/L as N)	11	8	7	8	11	34	30	9
pH	-	7.15	7.15	7.25	7.35	7.75	7.50	7.55
Phosphorus, ortho (ug/L as P)	10	14	48	91	40	9	15	12
Phosphorus, acid-hydrolysible (ug/L as P)	3	21	50	5	8	3	6	6
Phosphorus, organic (ug/L as P)	13	54	162	12	5	11	7	7
Phosphorus, total dissolved (ug/L as P)	26	89	260	108	53	23	28	25
Phosphorus, particulate (ug/L as P)	16	7	<2	3	1	5	30	3
Phosphorus, total unfiltered (ug/L as P)	42	96	260	111	54	28	58	28
Suspended solids, filterable (mg/L)	9.1	4.1	2.0	2.8	10.3	6.5	5.7	5.5

Table 8. Characteristics of South Creek in 1987.

DATE	MARCH 7	APRIL 17	MAY 15	JUNE 12	JULY 17	AUGUST 6	SEPTEMBER 25
Discharge (L/sec)	14.2	39.0	0	0	0	0	0
Alkalinity, total (mg/L as $CaCO_3$)	-	22.0	-	-	-	-	-
Conductivity (uohm/cm)	78	-	-	-	-	-	-
Dissolved solids (mg/L)	50.7	-	-	-	-	-	-
Hardness, EDTA (mg/L as $CaCO_3$)	34.2	22.2	-	-	-	-	-
Iron, soluble (ug/L)	555	105	-	-	-	-	-
Nitrate (ug/L as N)	986	945	-	-	-	-	-
Nitrite (ug/L as N)	14	5	-	-	-	-	-
pH	6.60	-	-	-	-	-	-
Phosphorus, ortho (ug/L as P)	102	45	-	-	-	-	-
Phosphorus, acid-hydrolysible (ug/L as P)	7	8	-	-	-	-	-
Phosphorus, organic (ug/L as P)	20	3	-	-	-	-	-
Phosphorus, total dissolved (ug/L as P)	129	56	-	-	-	-	-
Phosphorus, particulate (ug/L as P)	28	-	-	-	-	-	-
Phosphorus, total unfiltered (ug/L as P)	157	-	-	-	-	-	-
Suspended solids, filterable (mg/L)	2.9	0.1	-	-	-	-	-

Table 9. Characteristics of the outlet to Big Lake in 1987.

DATE	MARCH 7	APRIL 17	MAY 15	JUNE 12	JULY 17	AUGUST 6	SEPTEMBER 25
Discharge (L/sec)	51.8	15.0	0	12.9	0	5.3	23.8
Alkalinity, total (mg/L as $CaCO_3$)	70.4	67.5	-	76.4	-	82.2	85.2
Conductivity (uohm/cm)	148	178	-	187	-	179	195
Dissolved solids (mg/L)	96.2	115.7	-	121.6	-	116.4	126.8
Hardness, EDTA (mg/L as $CaCO_3$)	70.1	85.8	-	91.7	-	84.1	87.7
Iron, soluble (ug/L)	65	95	-	<10	-	<10	27
Nitrate (ug/L as N)	450	742	-	493	-	197	284
Nitrite (ug/L as N)	<5	8	-	7	-	3	10
pH	7.40	8.15	-	8.65	-	9.05	8.10
Phosphorus, ortho (ug/L as P)	91	20	-	13	-	<2	63
Phosphorus, acid-hydrolysible (ug/L as P)	6	63	-	1	-	<2	14
Phosphorus, organic (ug/L as P)	32	6	-	4	-	12	8
Phosphorus, total dissolved (ug/L as P)	129	89	-	19	-	12	84
Phosphorus, particulate (ug/L as P)	11	3	-	1	-	54	15
Phosphorus, total unfiltered (ug/L as P)	140	92	-	20	-	66	99
Suspended solids, filterable (mg/L)	2.9	0.7	-	2.3	-	13.5	2.4

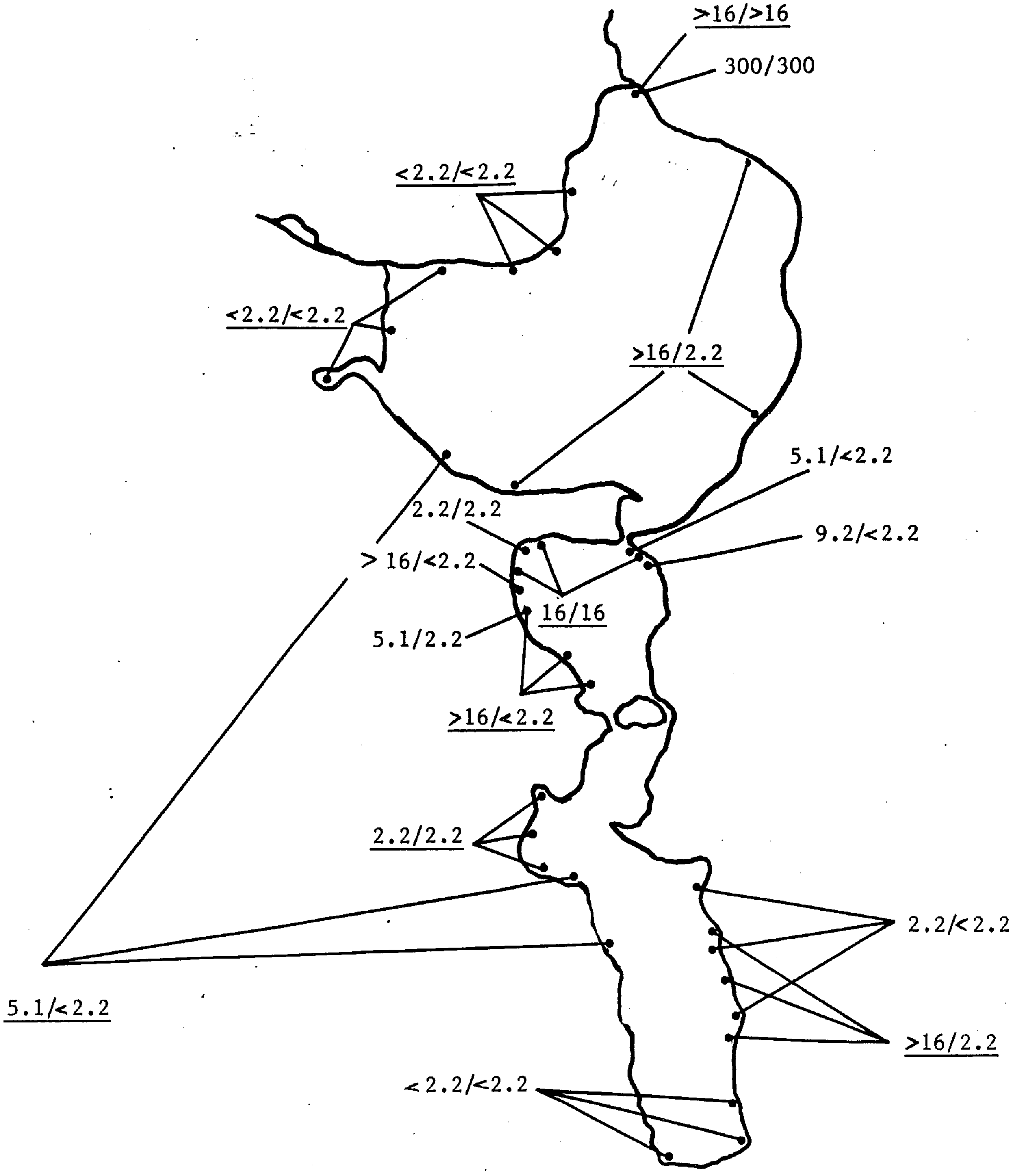


Fig. 21. Concentrations of total coliform bacteria / *E. coli* (as MPN/100 ml) in samples collected June 12 (underlined) and July 17. Some samples, those indicating more than one site, were analyzed as composites.

Discussion and Conclusions

The weather conditions over the term of this project were not considered to be representative of average conditions. Specific pertinent conditions which could have influenced results were:

1. Winter 1986-1987 was very dry. During this period very little snow cover accumulated on the ice, thus allowing increased sunlight penetration to the water column.
2. Winter 1986-1987 and spring 1987 were unusually warm. Mean temperatures December - February were approximately 10°F higher than normal. With the exception of 3 days, everyday in February 1987 the temperature rose above 32°F; and over 50% of days in February had temperatures above 40°F.
3. Spring 1987 was unusually dry.
4. Late summer (July - September) 1987 produced higher rainfall, but rain events were often of high intensity and short duration. A higher percentage of water produced by such rain events is thought to occur as overland run-off compared to rain events of lower intensity and longer duration.

These changes in climatic conditions will be compared to observations on water quality and will provide evidence to support some conclusions. However, recommendations based upon those conclusions will be made assuming the long-term mean conditions.

Discussions and conclusions will be made separately on eight general issues, although several of these are interrelated. The issues addressed are:

A. Hydrological Patterns
B. General Water Quality
C. Effects of Development
D. Nutrient Loading
E. Bacterial Water Quality
F. Algae and Weeds
G. Dissolved Oxygen
H. Water Quality Monitoring

A. Hydrological Pattern

The general description of the over-all water flow pattern for this area (see pages 2 - 3) illustrates some of the more important hydrological influences on these lakes. Approximately 87% of the combined watershed of Church Pine, Round, and Big Lake (see Fig. 4) drains into Big Lake. Approximately 89% of the Big Lake watershed drains through the two surface flows, North and South Creek. The highest flow rate for North Creek was recorded February 28, and flow declined linearly throughout the summer (Fig. 22). Flow rate recorded on July 17 was unusually low; the result of strong winds from the south which prevailed for the 2 days prior to sampling and created a temporary sand bar at the mouth of North Creek. Because inclusion of this data would unnecessarily lower the predicted yearly discharge and loadings, estimates of these parameters were made based upon all data, excluding July.

South Creek, which drains an area about 71% that of North Creek, had measurable flow on only 2 sample dates, March and April (Fig. 22). Flow was irratic; on April 17 flow rate was 65.8 L/sec at 9:00 am and 12.2 L/sec at 3:30 pm South Creek was estimated to have drained approximately 138,870 m^3 of water into Big Lake in 1987. Based upon the apparent topography, it is thought that prior to the construction of the road which runs north-south along the east side of Round and Church Pine Lake, a portion of the water drained by the South Creek watershed might have been released into Round Lake. Construction of this road might have effectively isolated Round Lake from this surface flow. Water movement in the South Creek watershed appeared to be diffuse through the predominately cattail marsh. Water did not appear to condense into a well-defined surface flowage until it was very near its mouth on Big Lake.

In contrast, North Creek, although also flowing through large cattail marshes, became a condensed flow after it passed through the culvert under road which divides the northern portion of the marshes. Therefore, it is erroneous to assume that the hydrological effects usually associated with water passing through a marsh occur on North Creek. These effects include increased water loss due to evapotranspiration, a buffering of extremes in flow during rain events, and various changes in water chemistry. Although no flow estimates were made on North Creek other than at its inlet to Big Lake, a subjective estimate is that the volume of water flow increased 2 - 5 fold from the area of the culvert to the mouth. It is estimated that North Creek drained about 1,771,520 m^3 of water into Big Lake in 1987.

The uneven flow rate recorded at the outlet to Big Lake (Fig. 22) was primarily the result of the closing off of the outlet by boards placed at the dam. No water was being released from Big Lake on May 15 and July 17. Discharge from the outlet was highest on March 7, which coincided with the highest discharge rate on North Creek. Discharge was lowest in mid- to late-summer, although this is the period which received the heaviest rain events. Flow had increased significantly in

September. It is estimated that a total volume of 570,490 m^3 of water was discharged through the outlet in 1987, although, due to the artificial control of this discharge, this estimate is tenuous.

No surface flows enter Church Pine Lake other than overland run-off during rain events. On most sampling days, no flow was observed in either direction between Church Pine and Round Lake, although on a few days a small flow was noted from Church Pine into Round Lake. On all sampling days, a small flow was observed from Big Lake into Round Lake. This flow was too low to measure accurately, but was estimated to be several liters/sec.

No measurements of influent ground water were made on any of the lakes. To estimate the significance of ground water to the hydrological pattern, a water balance analysis was conducted (Table 10). The net water balance calculated relates to changes in water stage (level) on the lakes as well as the tenuous nature of the discharge estimate for Big Lake. The first conclusion from this analysis is that although influent and effluent groundwater most certainly occurs, its net significance is small. The second conclusion is that the hydrological retention time for all three lakes is relatively long; 7.8 and 2.9 years for Church Pine and Round Lake, respectively. The retention time for Big Lake is shorter (1.9 years), but still significant. The third conclusion is that the only process for the release of water from Round Lake is through evaporation. Because evaporation has the effect of concentrating salts in the water, it could be predicted that the concentrations of dissolved materials would increase over time in Round Lake. Unfortunately, no historical data are available for Round Lake for comparison.

The most important influence on the movement of water from Big Lake into Round Lake is the water level on Big Lake. Prior to the construction of the dam at the outlet of Big Lake which raised water levels about 2 feet, water flow was probably from Round Lake into Big Lake. Raising water levels forced more water into Round Lake, due to the large watershed of Big Lake compared to Round Lake. Importantly, it should be noted that waters from Big Lake are higher in dissolved solids, nutrients, and generally lower quality than those of Round Lake. Therefore, it is concluded that maintaining water level on Big Lake at the lowest level acceptable to the shoreline residents, and maintaining a flow through the outlet will have two benefits: a) a decrease in the retention time for Big Lake, thus increasing the "flushing" of the lake; and b) reducing the flow of lower quality waters from Big Lake into Round Lake.

Table 10. Water budget for Church Pine, Round and Big Lake in 1987.

	Church Pine	Round	Big
Inputs (m^3 x 1,000/yr)			
Direct precipitation	275.7	121.2	736.2
Shoreline run-off	49.9	33.8	62.7
Surface inflows:			
North Creek	---[a]	---	1,771.5
South Creek	---	---	138.9
Big Lake	---	78.9[b]	---
Ground water	NS[c]	NS	NS
Total	325.6	233.9	2,709.3
Outputs (m^3 x 1,000/yr)			
Direct evaporation	263.7	115.9	704.1
Surface outlet			
Outlet	20-30	---	570.5
Round Lake	---	---	78.9
Ground water	NS	NS	NS
Total	283.7-293.7	115.9	1,432.2
Net	+ 31.9 - + 41.9	+ 118.0	+ 1,277.1
Hydrological Retention Time (yrs)	7.8	2.9	1.9

[a] --- = Does not apply.

[b] Based upon an average flow from Big Lake at 5 L/sec occurring 6 months/year.

[c] NS = Not a significant source.

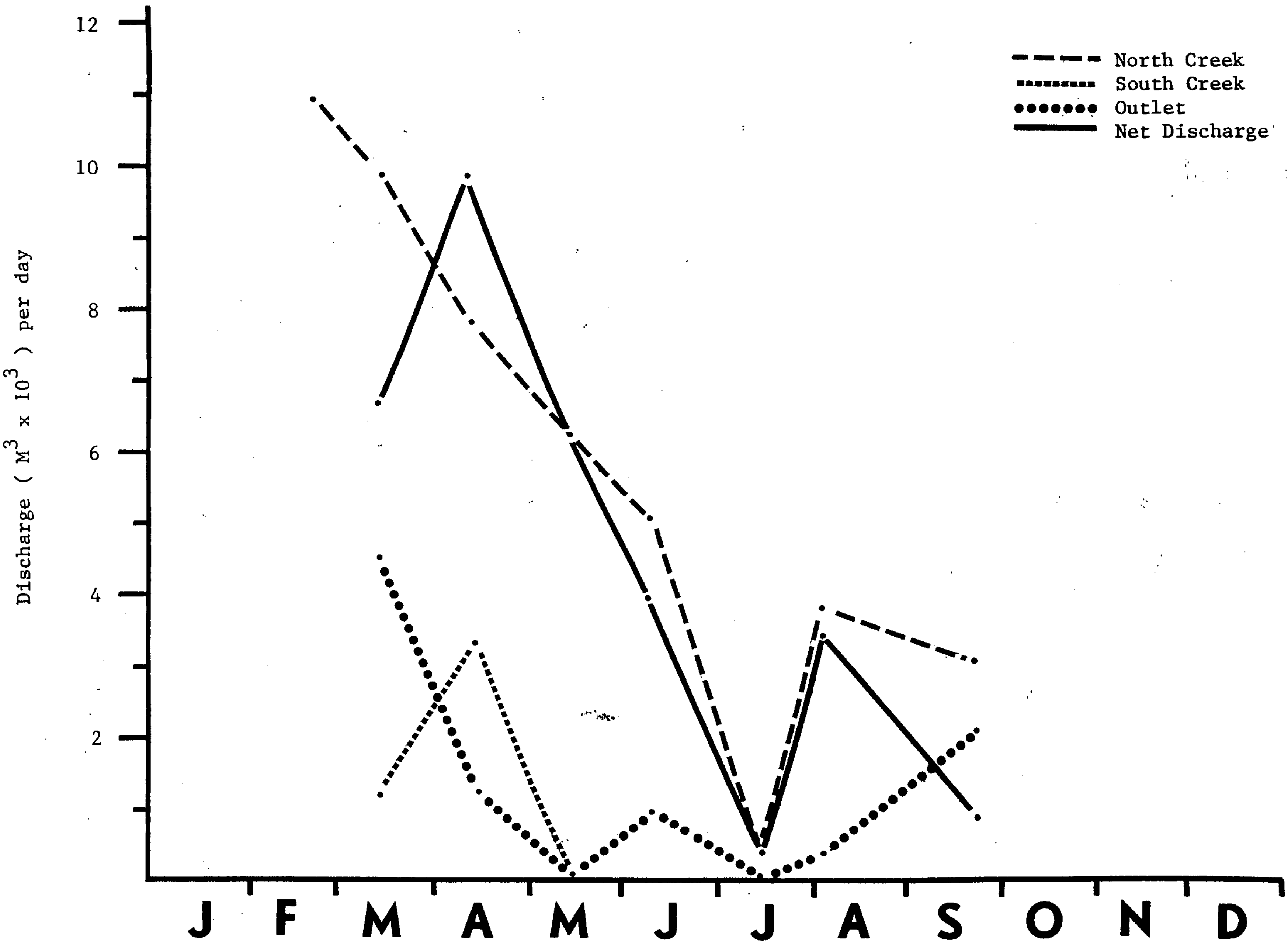


Fig. 22. Daily water dicharge in 1987 from North Creek, South Creek, Outlet, and the net discharge.

B. General Water Quality

Lakes in general differ greatly in size, shape, volume, watershed area, and water chemistry. Because lakes and their water qualities differ naturally, it is misleading to describe the water quality of any one lake as good or bad. A more realistic approach is to compare current water quality to the natural condition, which is the predicted water quality in the absence or near absence of adverse human influence. Based upon an analysis of numerous lakes in North America by Vighi and Chiaudani, the natural conditions of a lake can be predicted with reasonable confidence using its Morphoedaphic Index (MEI), which incorporates factors of water chemistry and the size and shape of the lake basin. The calculated MEI and the predicted values for several water quality factors are:

	Big	Round	Church Pine
MEI_{alk} [a]	0.311	0.330	0.159
Secchi disc transparency (ft.) [b]	7.1	7.1	9.3
Chlorophyll a (ug/L) [b]	7.5	7.5	4.4
Total phosphorus (ug/L) [b]	18.7	19.1	14.1

[a] Based upon alkalinity.

[b] Mean summer (June-August) value.

Therefore, the conclusion is that in the absence of adverse human influence, Big and Round Lake should be very similar in water transparency, chlorophyll a and total phosphorus concentrations. Church Pine Lake would have a higher water transparency and lower chlorophyll a and total phosphorus concentrations. Based upon this description of the predicted natural condition of each lake, the actual conditions observed in 1987 can be placed in better perspective.

The actual secchi disc transparency readings in 1987 (Fig. 23), averaged equal to or slightly better than the predicted value on both Church Pine and Round Lake. Summer water transparency was lower than predicted for Big Lake. Comparison with records of secchi disc readings in 1985 (see Fig. 7) and 1986 (see Fig. 8) demonstrated the same trend of Church Pine and Round Lake averaging at or above their predicted values, and Big Lake averaging below its predicted value. The important exception to this was in 1985 on Round Lake. The secchi disc readings in late summer dropped well below its predicted value. This observation appeared to correspond to the application of a chemical herbicide to Round Lake. A similar decrease in water clarity was observed on Big Lake which received herbicide at the same time.

Mean summer concentrations of both chlorophyll a (Fig. 24) and total phosphorus (Figs. 25 - 27) followed the same trend as secchi disc readings with Church Pine and Round Lake doing as well as or better than predicted and Big Lake doing worse than predicted. Presumably due to the dry conditions in early summer, the total phosphorus levels were well below the predicted values for Church Pine and Round Lake, and despite those conditions Big Lake contained more phosphorus than predicted.

Water quality can also be expressed as an index or rating value. Several types of water quality indices were calculated (Figs. 28 - 29), and compared to the predicted natural values. In the absence of adverse influence of man, all three lakes would be classified as mesotrophic, although Big and Round Lake would be approaching eutrophic conditions. The corresponding predicted Tropic State Index is 49 for Big and Round Lake, and 45 for Church Pine. Again, the trend of Church Pine and Round Lake having mean summer values close to predicted values and Big Lake having lower water quality indices than predicted was observed. The unweighted multiplicative water quality index (after Fulsilier) calculated in Fig. 29 does not directly relate to predicted values, but rather rates lake quality in comparison to lakes in general, with a rating of 100 being the highest and 0 being the lowest quality. In mid-summer, both Church Pine and Round Lake ranked about 80, while Big Lake was well below this on most days.

Another aspect of water quality is the subjective determination of acceptability. In the residents survey conducted in July 1987 (see pages 9 - 13), respondents from Big Lake were more concerned about algae problems, which is the most visible factor of water quality, than respondents from either Church Pine or Round Lake. This might be interpreted as an independent rating of water quality. Residents rating of water quality, based on algae, is 19% lower on Round Lake and 35% lower on Big Lake compared to Church Pine Lake.

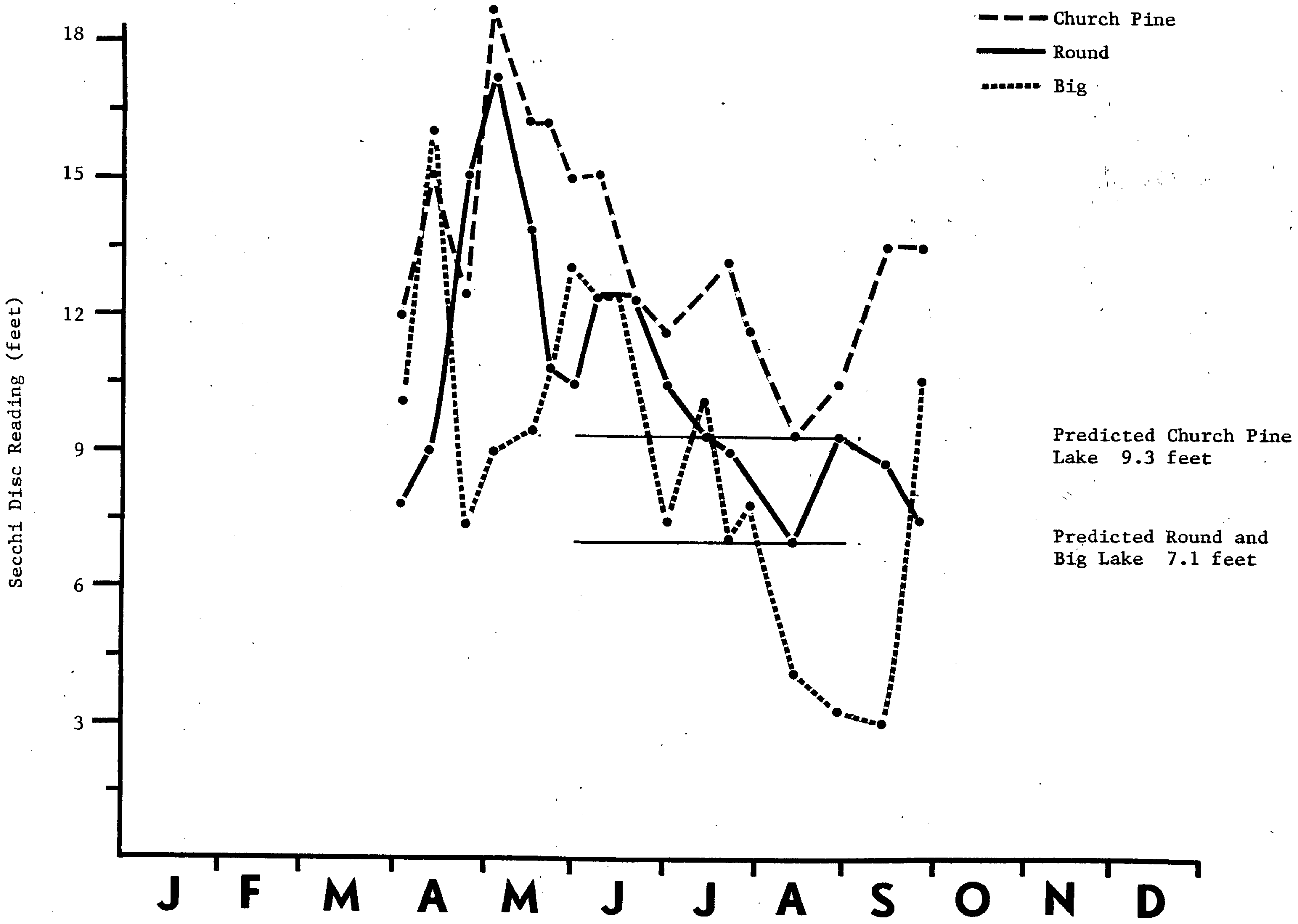


Fig. 23. Secchi Disc Tranparency readings for Church Pine, Round And Big Lake in 1987.

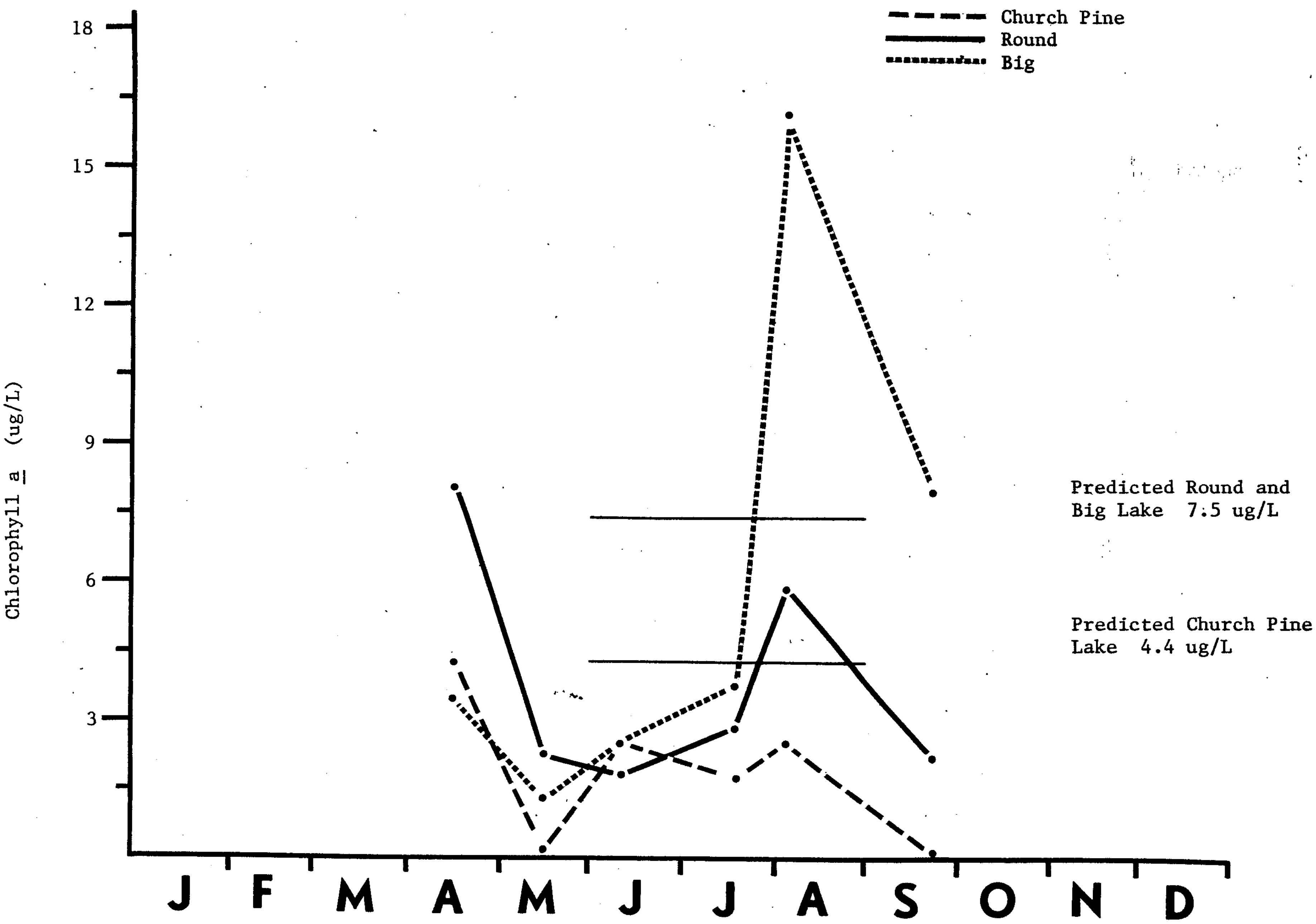


Fig. 24. Chlorophyll a concentrations in 1987.

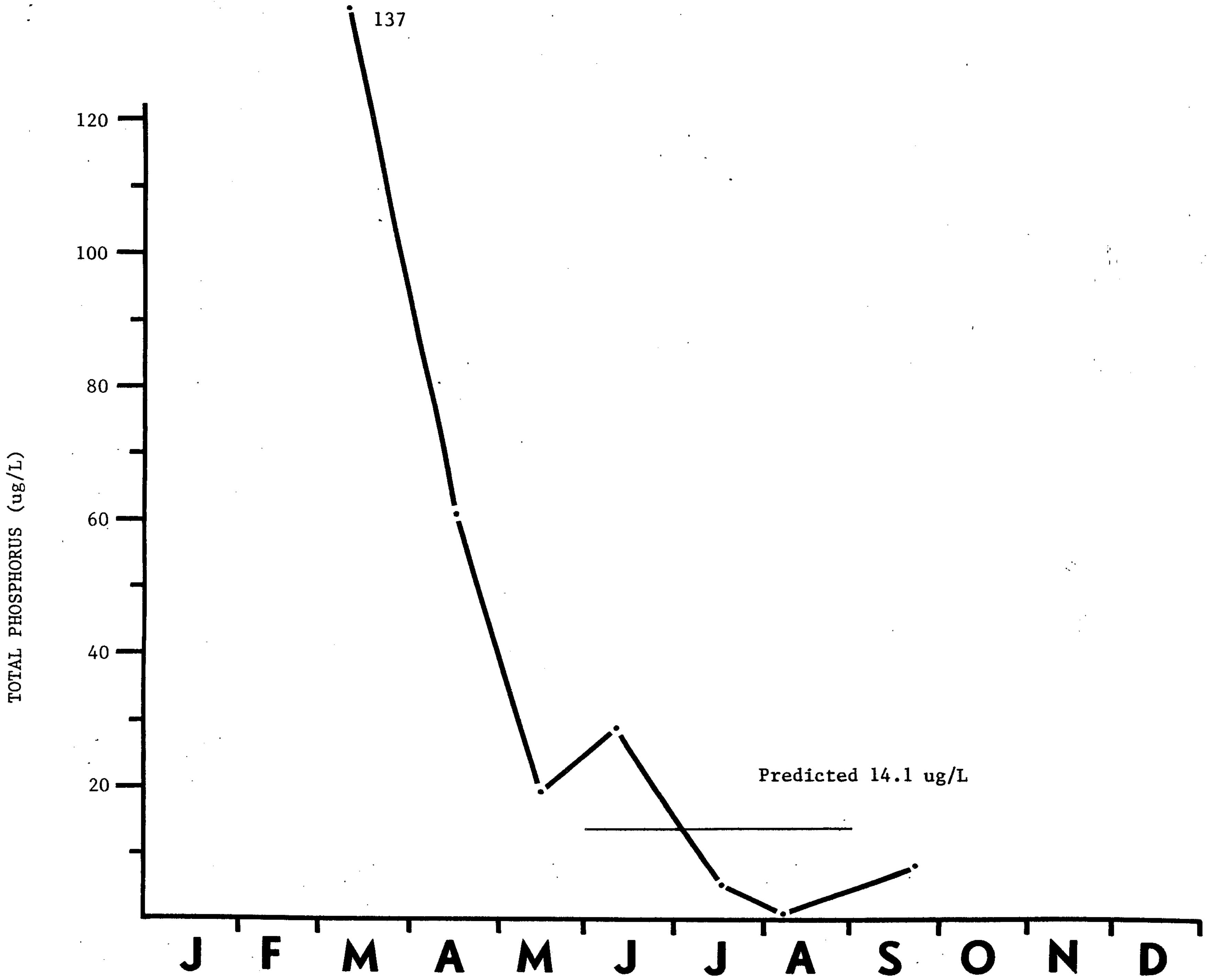


Fig. 25. Mean Total Phosphorus (unfiltered) concentrations in Church Pine Lake in 1987. Predicted summer total phosphorus level is based on MEI_{alk}.

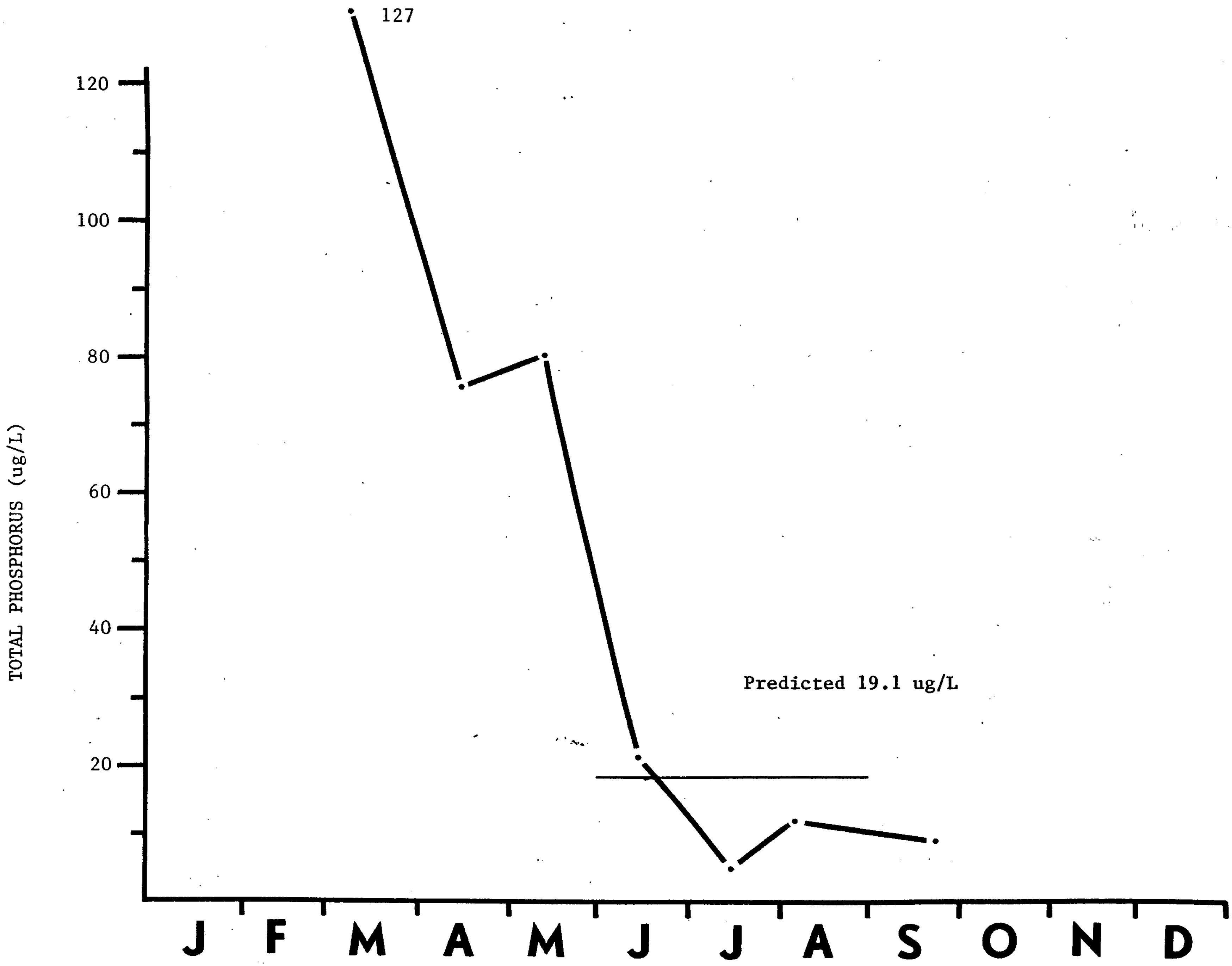


Fig. 26. Mean Total Phosphorus (unfiltered) concentrations in Round Lake in 1987. Predicted summer total phosphorus level is based on MEI_{alk}.

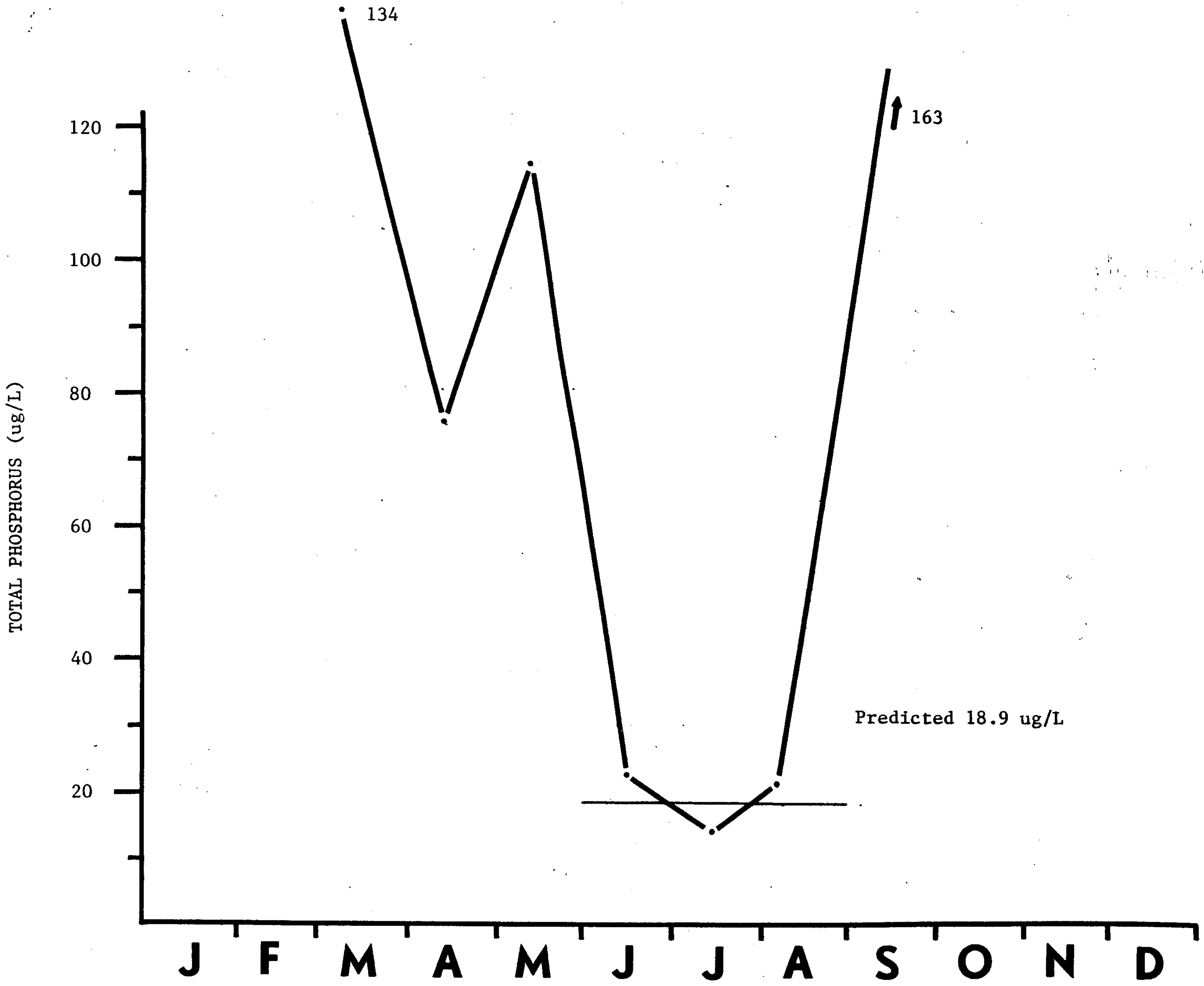


Fig. 27 . Mean total phosphorus concentrations in Big Lake in 1987 in unfiltered samples. Predicted summer total phosphorus level is based on MEI_{alk}.

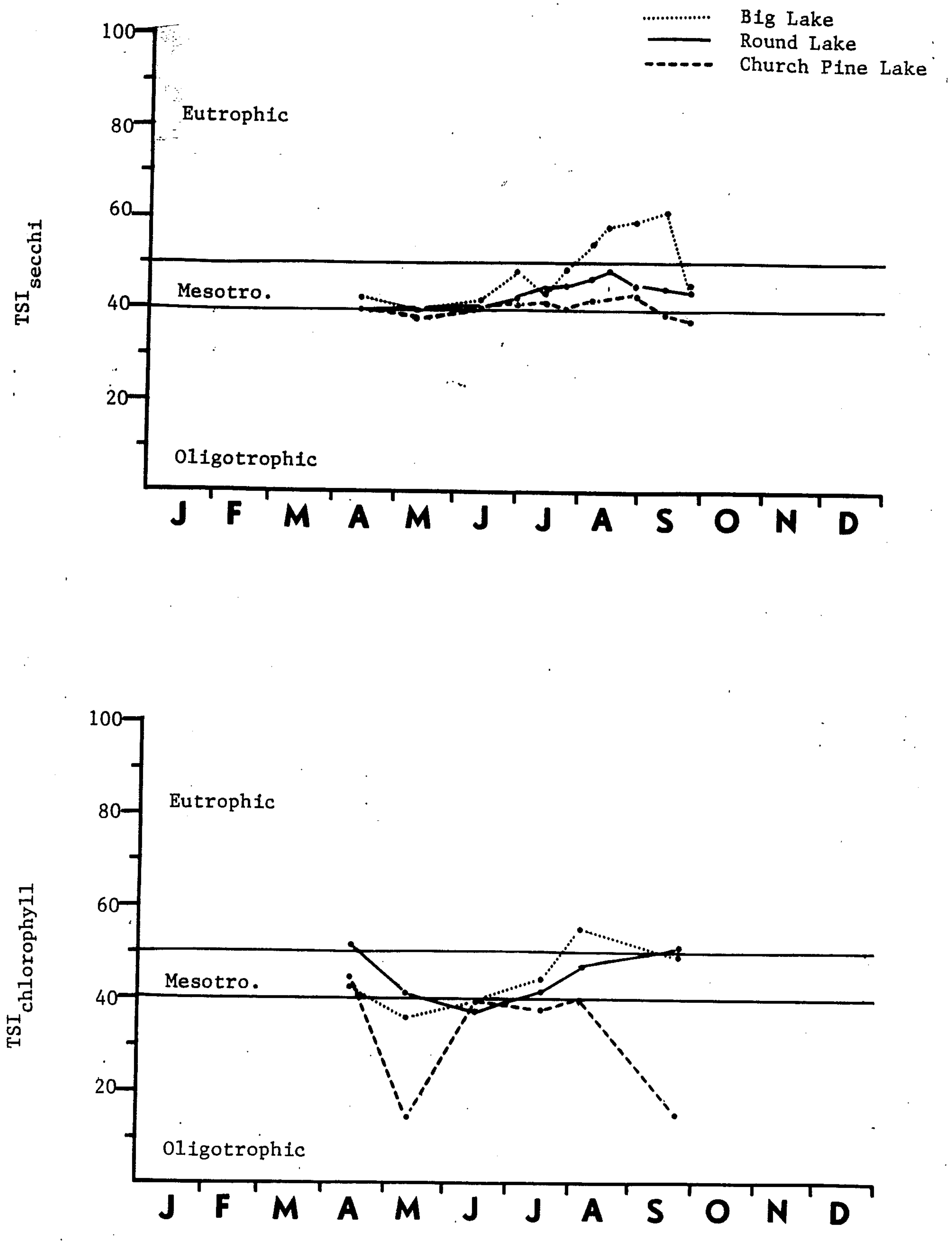


Fig. 28. Trophic State Index (TSI) based on secchi disc transparency and chlorophyll a concentration on Big, Round, and Church Pine Lakes in 1987.

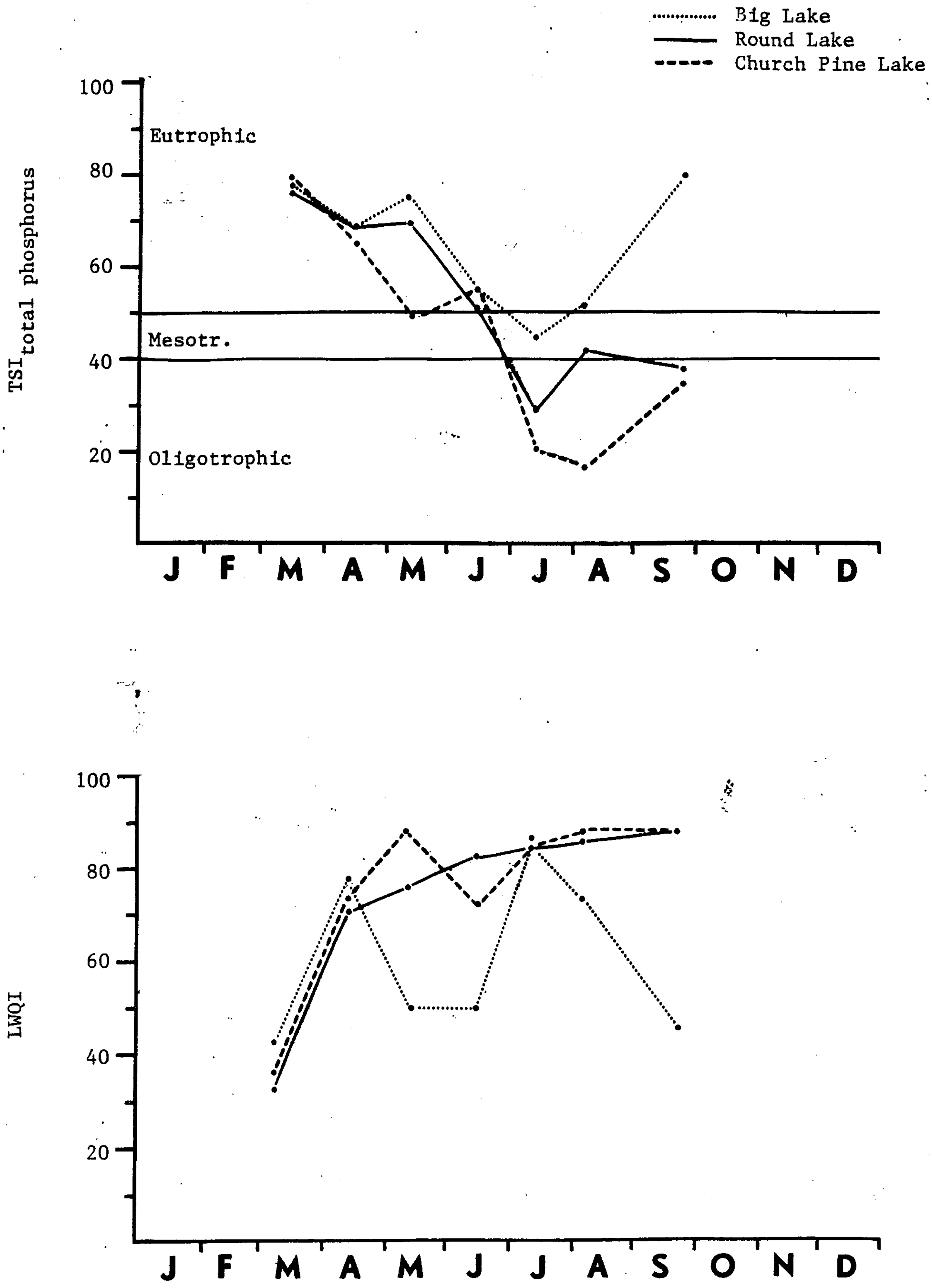


Fig. 29. Trophic State Index (TSI) based on total phosphorus and an unweighted multiplicative water quality index (LWQI) on Big, Round, and Church Pine Lake in 1987.

C. Effects on Development

Development within a watershed can adversely affect water quality, although not all developments will have this result. Since 1959, the number of residences have increased 18% on Big Lake, 25% on Round Lake, and 26% on Church Pine Lake. The current density of residences are approximately equal on Round and Big Lake (about 30 per mile of shoreline), and slightly lower on Church Pine (about 26 per mile). The percentage of groomed shoreline on Big Lake is about twice that of Round and Church Pine Lake.

The conclusion has been made that the water quality on Church Pine and Round Lake is not lower than would be predicted if no development had occurred on these lakes. On the other hand, water quality on Big Lake is lower than would be predicted. Therefore, it can be concluded that development within the Church Pine and Round Lake watershed has to date not adversely affected water quality, but water quality of Big Lake has been adversely affected by development within its watershed.

As stated previously, the degree of shoreline development on all three lakes does not differ greatly. The density of residences are approximately equal on Round and Big Lake. When expressed as residences per volume of water, Church Pine is 27% more dense and Round 61% more dense compared to Big Lake. Assuming that the residences of Big Lake are similar to those on the other lakes, the conclusion made is that the shoreline development on Big Lake is an unlikely source of water quality degradation. Development outside the immediate shoreline area is a more likely source, and it is this area in which Big Lake differs most from both Church Pine and Round.

The land within the Church Pine and Round Lake watersheds is primarily wooded (84-89%), with smaller portions being untilled field (9-14%) or wetlands (2-3%). Little or no tilled fields occur in either watershed. Wooded land comprises about 60% of the Big Lake watershed, 22% is tilled amd untilled field and 17% is wetland (see page 2).

D. Nutrient Loading

A conclusion has been developed that water quality is approximately equivalent to the predicted natural condition on Church Pine and Round Lake, and is lower than predicted natural condition on Big Lake. Water quality degradation of this type is almost always the result of excessive nutrient loading. Important sources of nutrients include:

Surface flows and run-off
Ground water
Direct Precipitation
Release from sediments

Other sources, many the result of human activity, might be important in some cases.

Aquatic life requires many different types of nutrients. The essential nutrient which is in the lowest supply limits the amount of growth a given aquatic system can support; therefore is termed the limiting nutrient. The limiting nutrient often falls to very low concentrations during periods of high productivity. Phosphorus becomes the limiting nutrient for the majority of freshwaters.

In 1987, phosphorus levels on all three lakes dropped substantially in summer (see Figs. 25 - 27), while the concentrations of other important nutrients, such as nitrate, remained high (Fig. 30). Although iron concentration also dropped during the summer (Fig. 31), this is more likely the result of precipitation of iron, not its use as a nutrient.

Furthermore, the requirement for iron is low. It is therefore concluded that phosphorus is the limiting nutrient on all three lakes, and the degree of phosphorus loading has the greatest influence on water quality.

A phosphorus loading budget for each lake was calculated (Table 11). Ground water is generally low in phosphorus, and it has also been concluded little net flow on groundwater enters these lakes, therefore ground water is not considered to be an important source of phosphorus. Dissolved oxygen concentrations were generally high (discussed later), and although substantial increases in phosphorus concentration in upper waters were observed with the fall over-turn, the release of phosphorus from sediments should not be high and probably does not significantly affect summer water quality.

The majority of phosphorus entering Church Pine Lake is directly from precipitation, and comprises almost 80% of its total phosphorus loading. Very little phosphorus is released from Church Pine Lake, amounting to less than 5% of the total input. A total of 9.9 kg of phosphorus was estimated to enter Church Pine Lake yearly. The most significant source of phosphorus to Round Lake was that entering as water flows from Big into Round Lake. This source comprises 55% of the total phosphorus load. A total of 9.8 kg of phosphorus was estimated to enter Round Lake in 1987.

There were more independent sources of phosphorus entering Big Lake compared to the other two lakes. A total of 201.1 kg of phosphorus was estimated to enter the lake in 1987. About 84% of that total entered through North Creek, 10% through direct precipitation, 5% through South Creek, and 1% through shoreline run-off. Big Lake lost about 124.5 kg of phosphorus through its outlet and water released to Round Lake. This resulted in a net gain of 76.6 kg of phosphorus in 1987. This takes into account a net loss of about 38.1 kg of phosphorus which occurs during the late fall and winter when waters high in phosphorus are released through the outlet.

Lakes of different sizes and hydrological patterns can assimilate different degrees of phosphorus loading without degradation in water quality. Based upon work by Vollenweider, the degree of phosphorus loading in relation to these parameters was evaluated (Figs. 32 and 33). Based upon both mean depth and flushing rate, the conclusion is the same; Church Pine and Round Lake have an acceptable rate of phosphorus loading, whereas this rate for Big Lake is excessive. This conclusion is consistent with actual observations of water quality.

Only about 11% of the phosphorus loading for Big Lake is due to precipitation falling directly on the lake or its shores, which is an uncontrolable source. Only 1% is due to South Creek, which, although probably controlable, comprises too small a source to warrant the expenditure of any time or resources for nutrient control. Therefore, North Creek is the only phosphorus source for which control might be economically feasible, and there are no indications suggesting that this source cannot be controlled.

The trends in phosphorus, nitrate, dissolved and suspended solids discharge into Big Lake are described in Figs. 34 - 36. The maximum rate of discharge of phosphorus from North Creek did not occur at the same time of maximum discharge of water (see Fig. 22). Highest water discharge was in February but maximum phosphorus discharge did not occur until April. Phosphorus discharge dropped rapidly through the spring and early summer and appeared to level off by late summer. It is interesting to note that the maximum discharge of nitrate, dissolved and suspended solids did correlate with maximum water discharge. It is also significant to note that during the period highest discharge of total phosphorus from North Creek (March - May), 97% of the phosphorus was in a dissolved form.

A phosphorus budget was calculated for North and South Creek (Table 12), based upon the assumption that atmospheric deposition was the only significant input of phosphorus to the watersheds. The South Creek watershed receives 104.6 kg of phosphorus yearly and released 9.1 kg, which results in a net retention of 95.5 kg yearly. This agrees well with what would be the predicted phosphorus release in run-off from this watershed. On the other hand, the North Creek watershed receives 147.4 kg of phosphorus yearly, but released 168.6 kg, which calculates to a 21.1 kg yearly deficit. Clearly, other significant phosphorus sources besides atmospheric deposition must be present within the North

Creek watershed. These sources could contribute for up to 10 times more phosphorus than precipitation. It is the identification of these sources and the evaluation of their relative importance to phosphorus loading from North Creek that must be conducted to determine the most effective and cost-efficient control of phosphorus loading of Big Lake.

A calculation was made to estimate the degree of phosphorus control which would be required to place Big Lake into an acceptable degree of phosphorus loading (Figs. 37 and 38). It is concluded that approximately a 50% reduction in the phosphorus load from North Creek would be necessary to result in an acceptable phosphorus load for Big Lake. Because reducing the phosphorus content in Big Lake will reduce the phosphorus load to Round Lake, its nutrient-load regime would also be predicted to improve by as much as 40%. The hydrological retention-time for Big Lake, 1.9 years, would predict that with effective control of phosphorus loading from North Creek, water quality improvements might not be evident for several years. It would also be predicted that the maximum improvement in water quality would increase the mean summer secchi disc transparency reading to about 7.1 feet.

Table 11. Phosphorus budget for Church Pine, Round and Big Lake in 1987.

	Church Pine	Round	Big
Inputs (kg/yr)			
Direct precipitation	7.8	3.4	20.8
Shoreline run-off	2.1	1.0	2.7
Surface inflows:			
North Creek	---[a]	---	168.5
South Creek	---	---	9.1
Big Lake	---	5.4[b]	---
Ground water	NS[c]	NS	NS
Total	9.9	9.8	201.1
Outputs (kg/yr)			
Surface outlet	---	---	119.1
Round Lake	NS	---	5.4
Ground water	NS	NS	NS
	NS	NS	124.5
Net	+ 9.9	+ 9.8	+ 76.6

[a] --- = Does not apply.

[b] Based on a mean inflow concentration from Big Lake of 68.5 ug/L.

[c] NS = Not a significant input or output.

Table 12. Phosphorus budget for North Creek and South Creek watershed in 1987.

	North Creek	South Creek
Inputs (kg/yr)		
Direct precipitation	147.4	104.6
Output (kg/yr)		
Surface outflow	168.5	9.1
Net (kg/yr)	- 21.1	+ 95.5

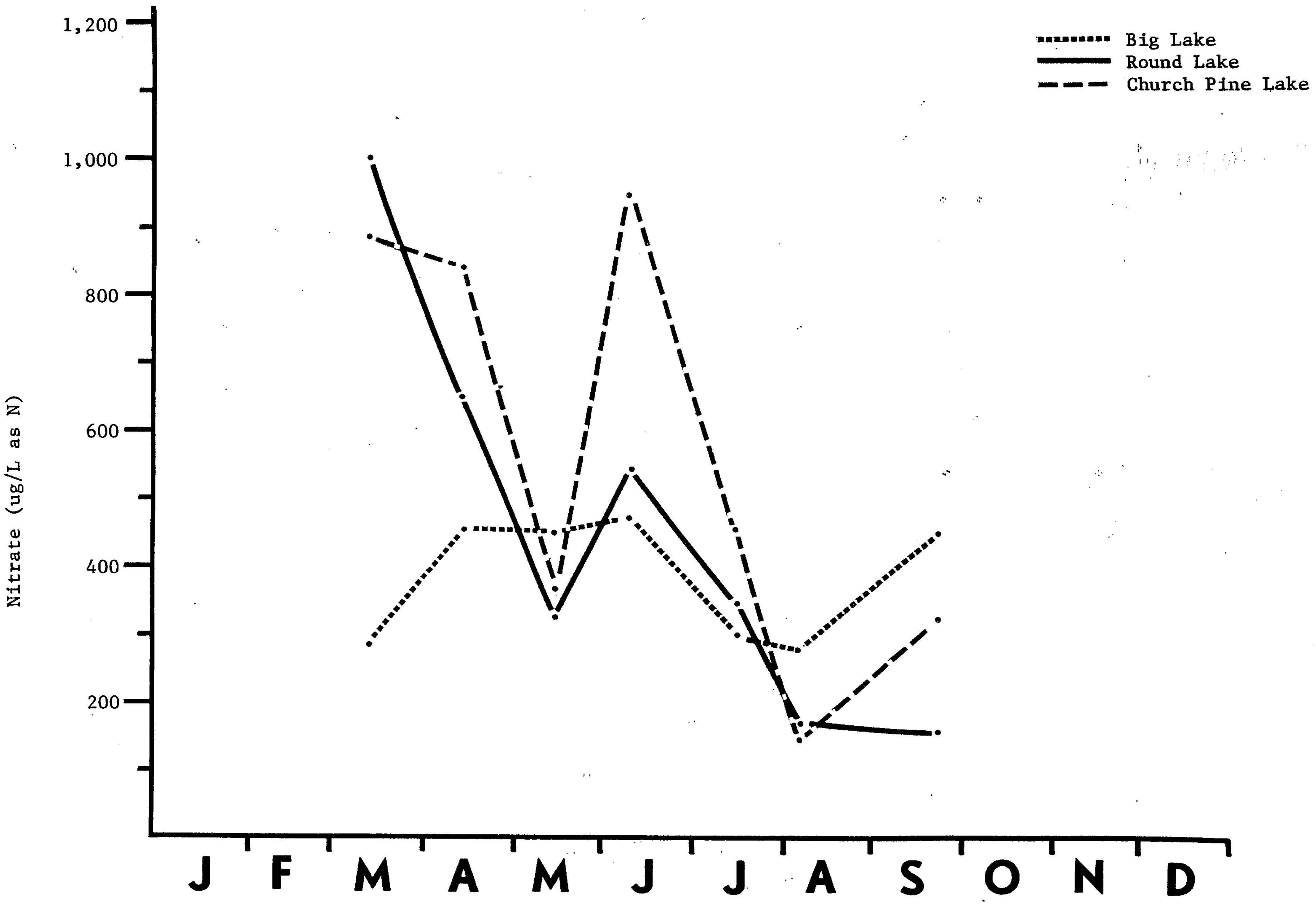


Fig. 30. Mean nitrate concentrations in 1987 on Big, Round, and Church Pine Lakes.

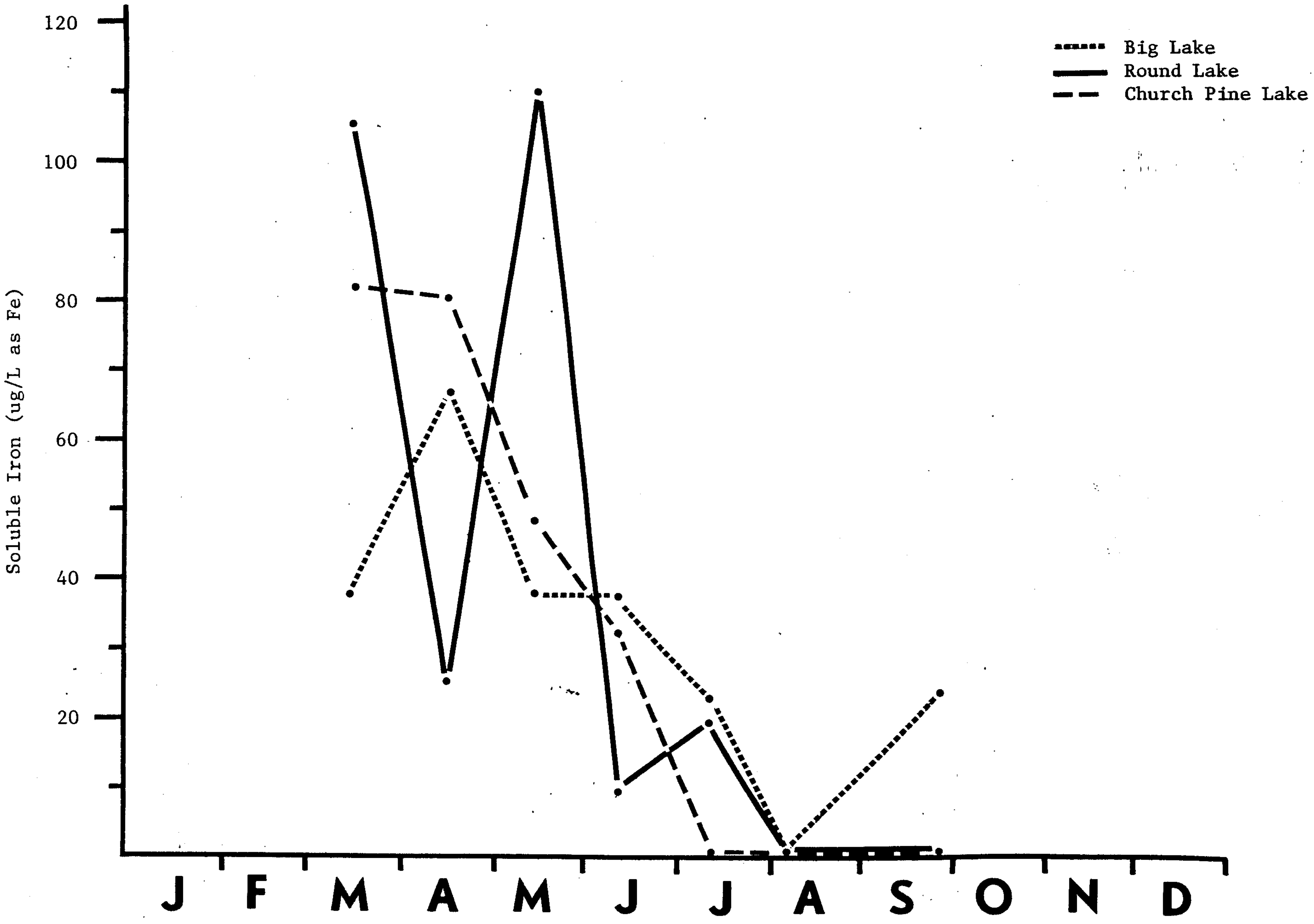


Fig. 31. Mean soluble iron concentrations in 1987 on Big, Round, and Church Pine Lakes.

Fig. 32. Assessment of phosphorus loading of Church Pine, Round and Big Lake in 1987, based on mean inflow concentration versus mean depth (after Vollenweider).

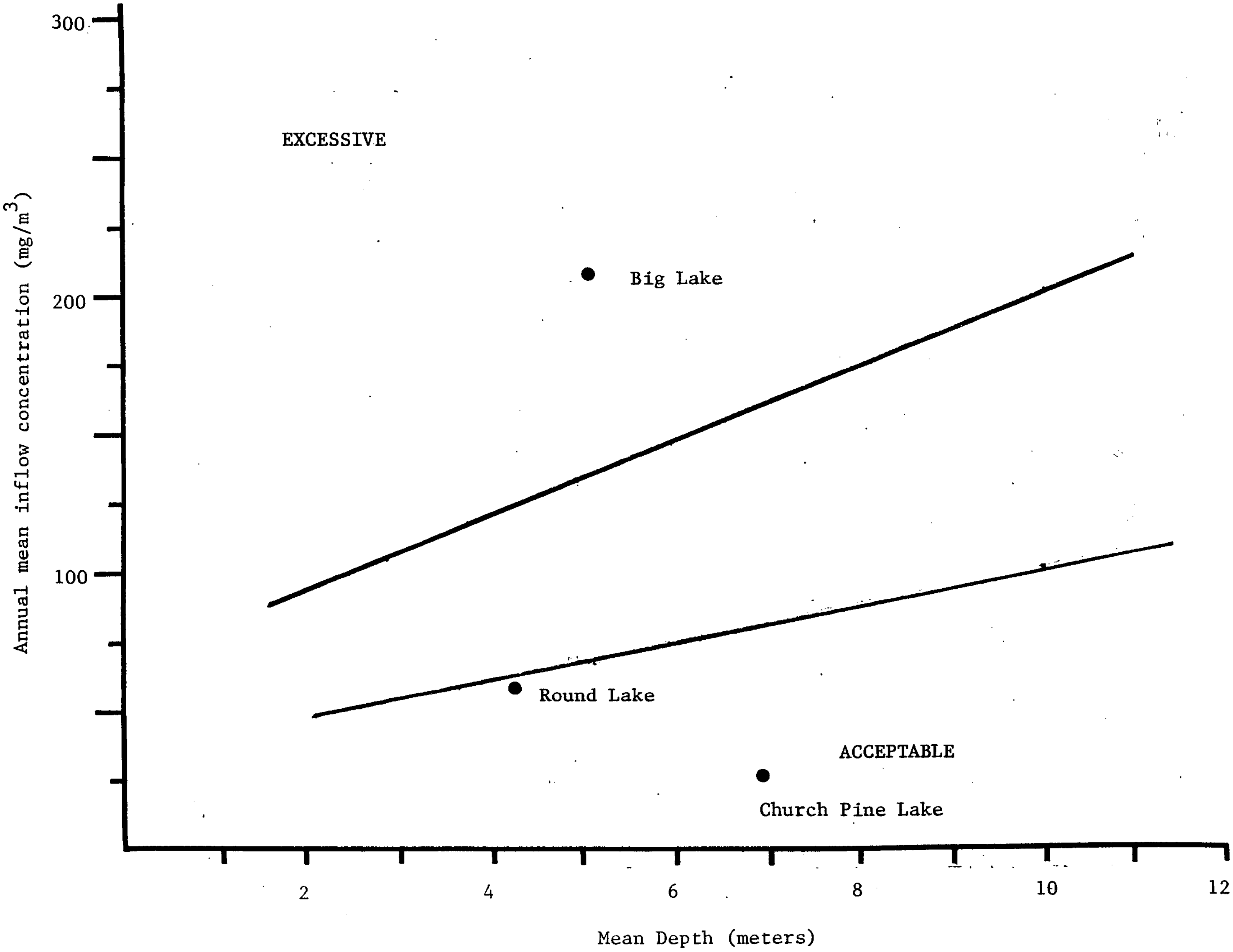
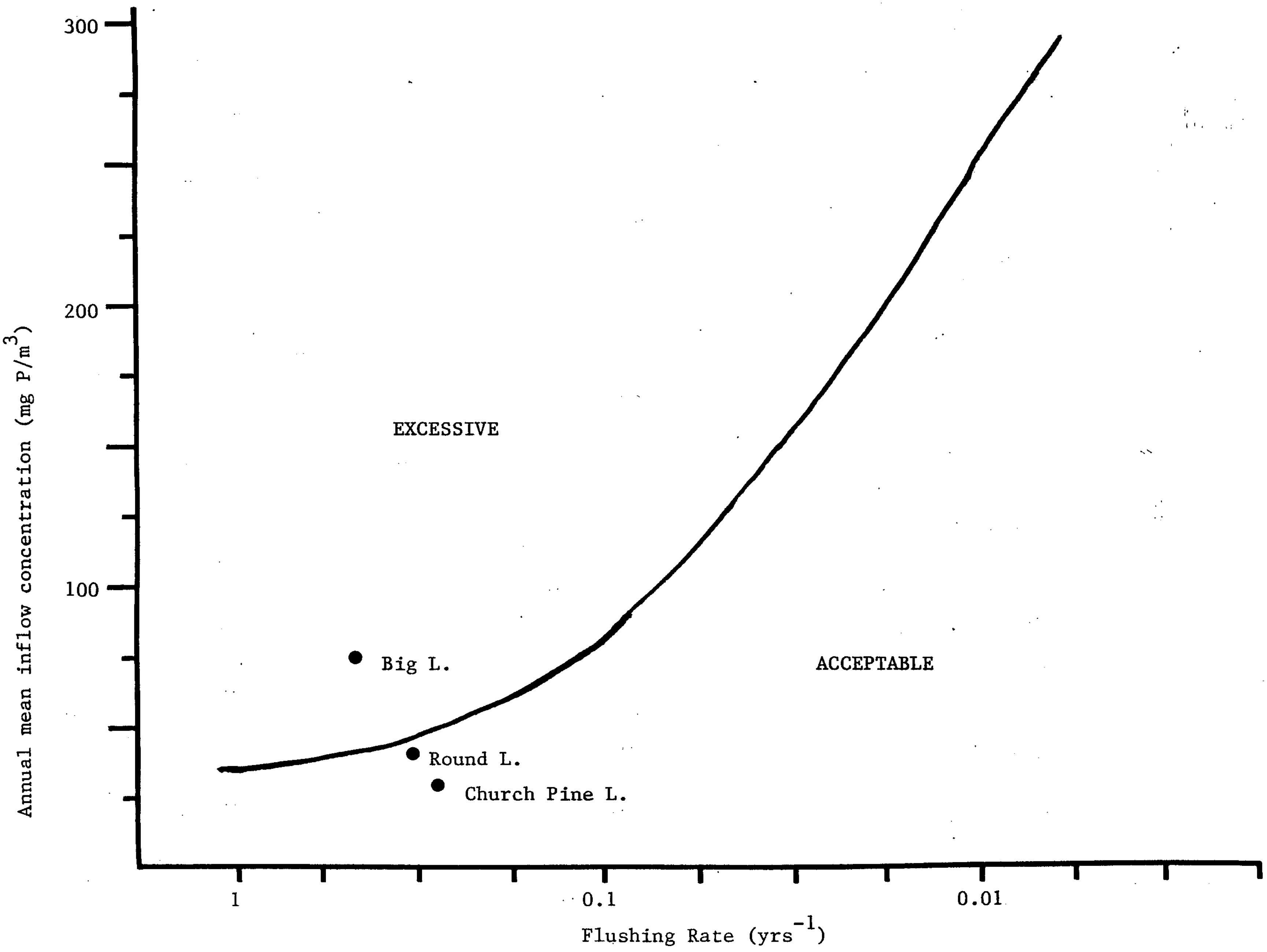


Fig. 33. Assessment of phosphorus loading of Church Pine, Round, and Big Lake in 1987, based on mean inflow concentration versus flushing rate. (after Vollenweider).



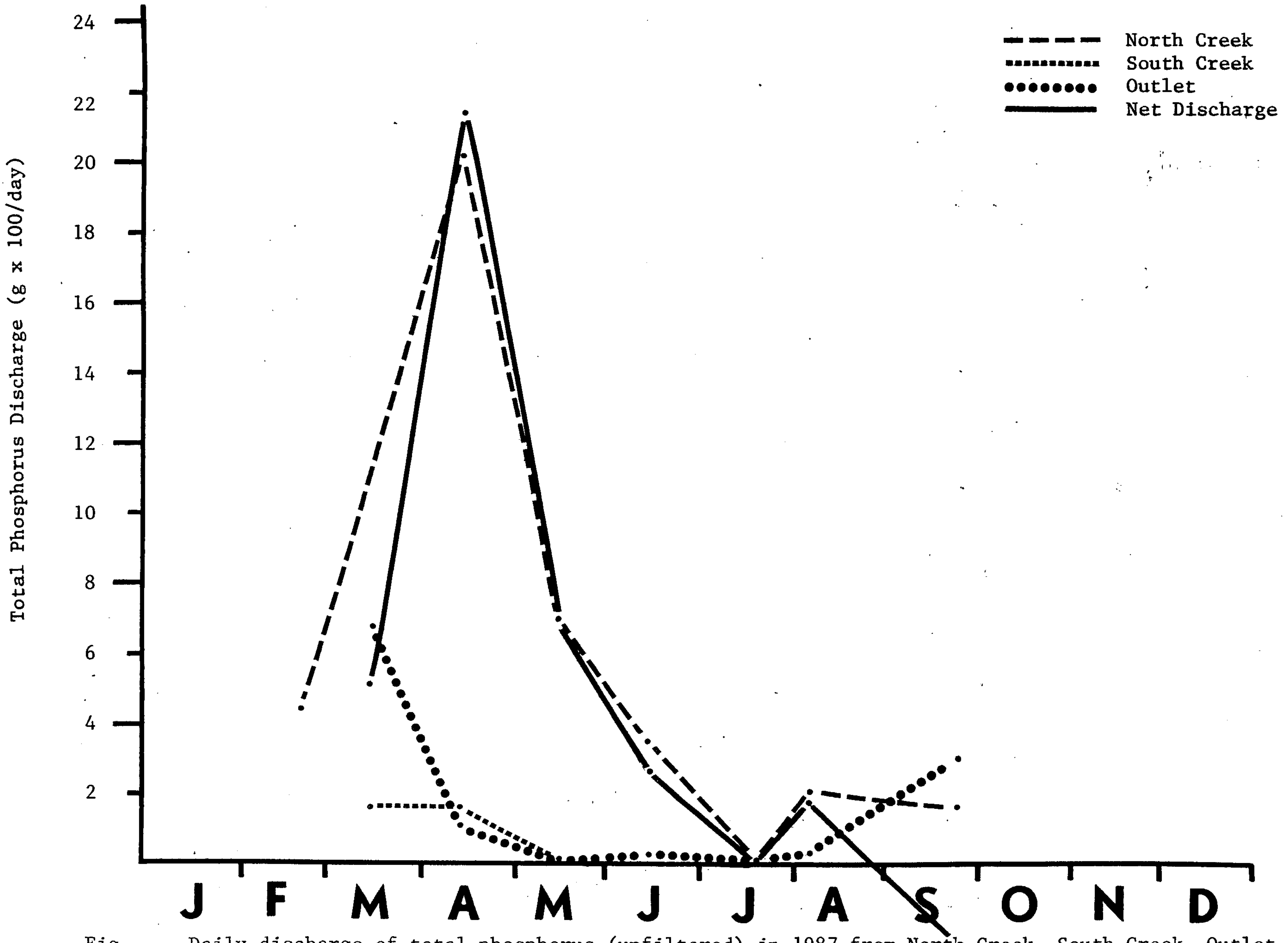


Fig. 34. Daily discharge of total phosphorus (unfiltered) in 1987 from North Creek, South Creek, Outlet, and the net discharge.

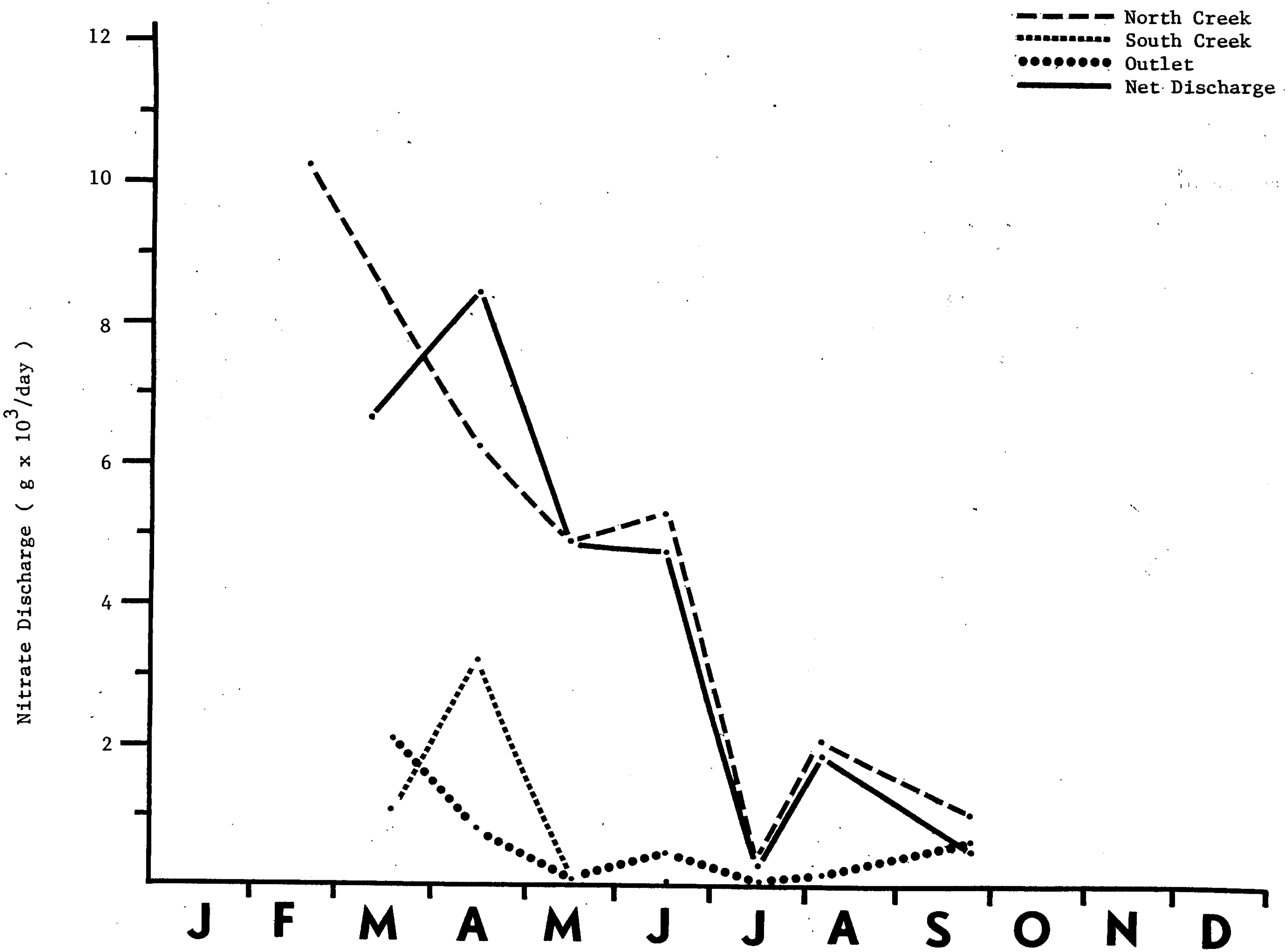
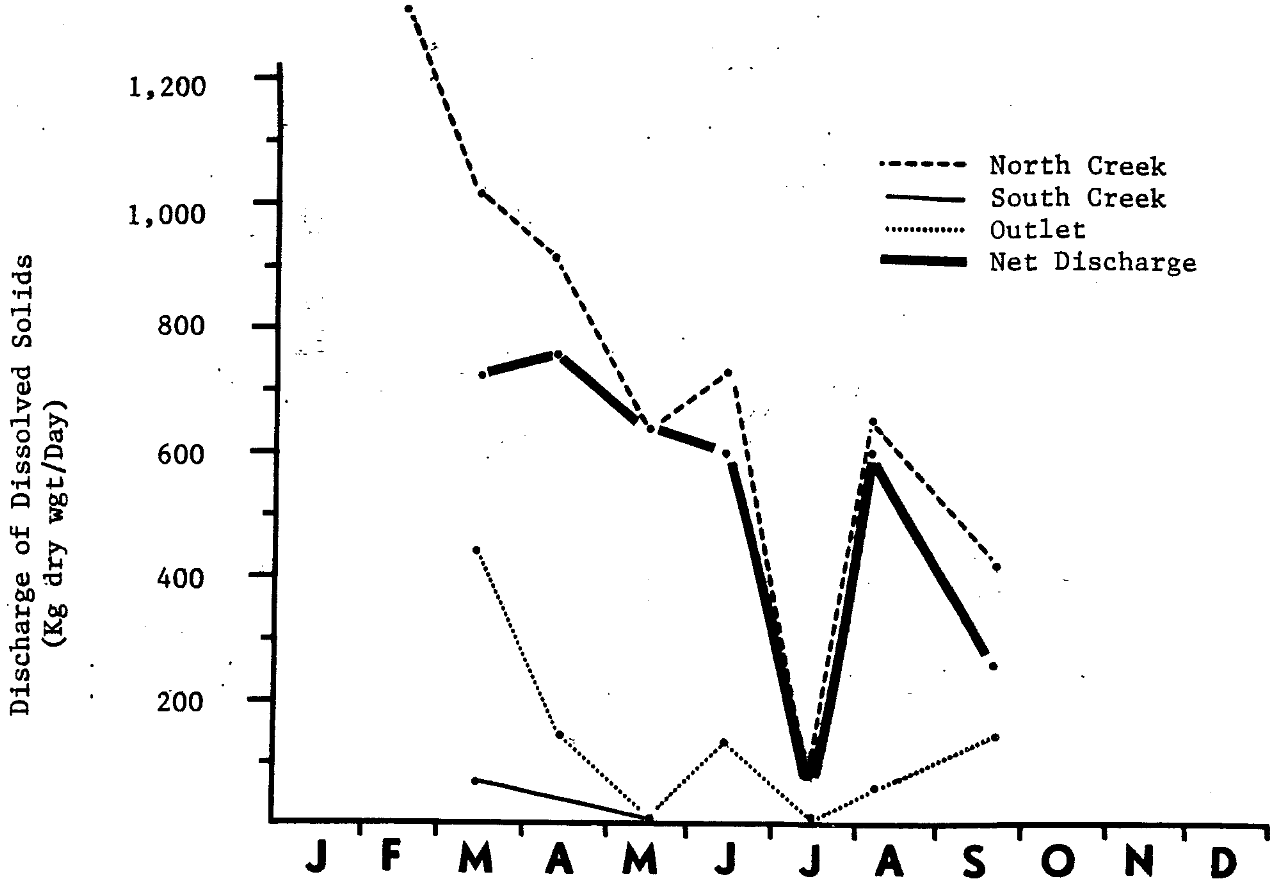


Fig. 35. Daily discharge of nitrate in 1987 from North Creek, South Creek, Outlet, and the net dicharge.



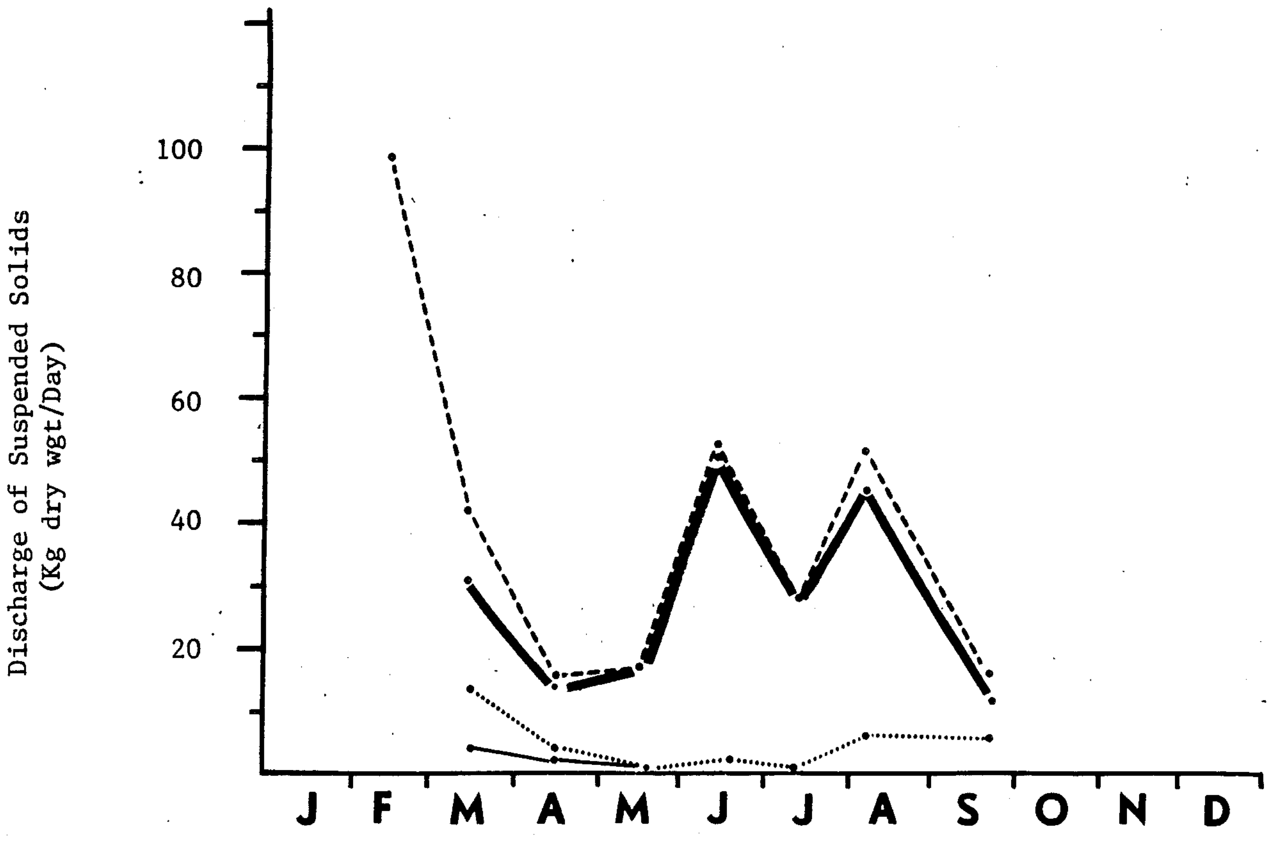


Fig. 36 . Daily discharge of dissolved solids and suspended solids from North Creek South Creek, the Outlet, and the net discharge.

Fig. 37. Predicted effect of a 50% reduction in phosphorus loading from North Creek on over-all phosphorus loading of Big and Round Lake (after Vollenweider).

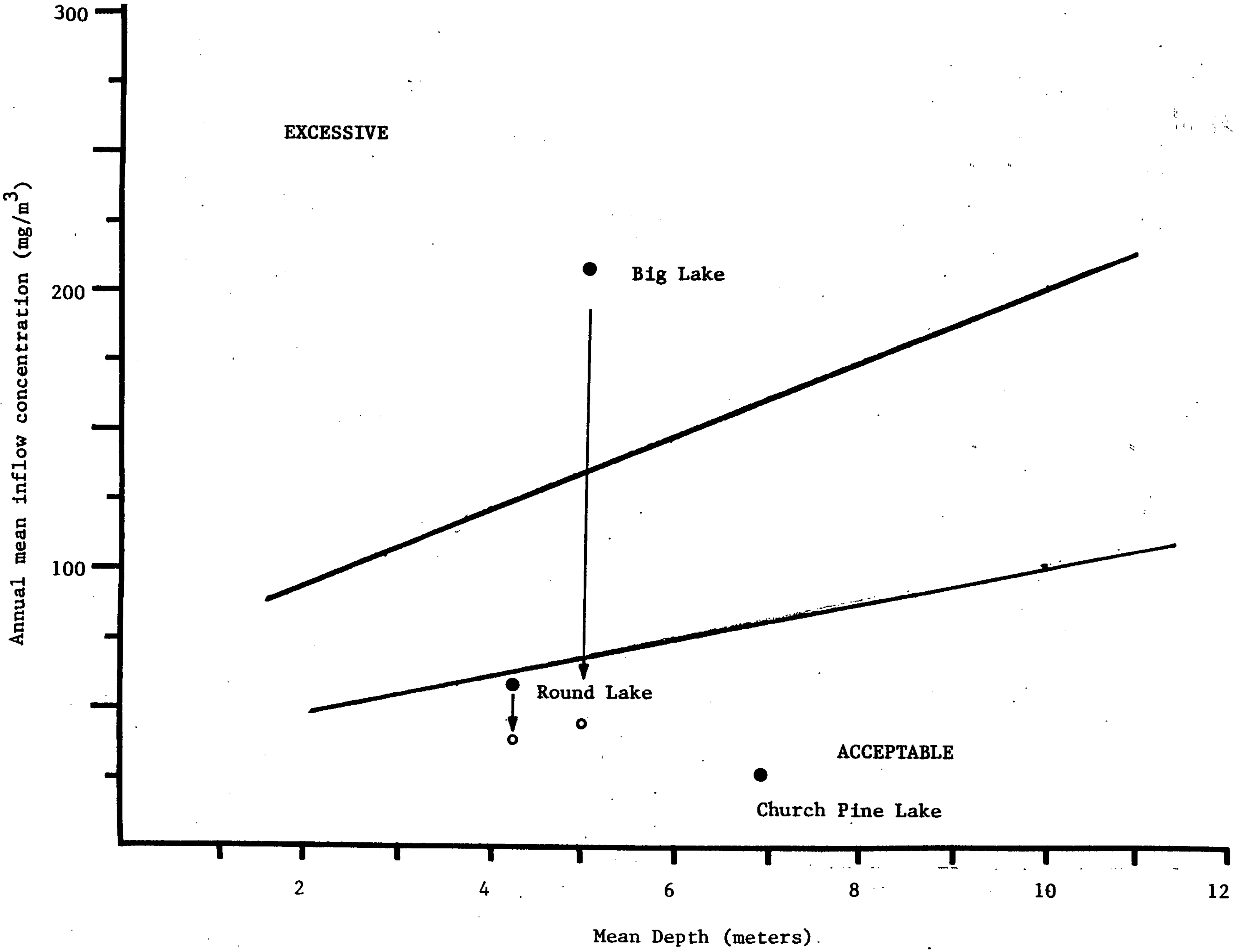
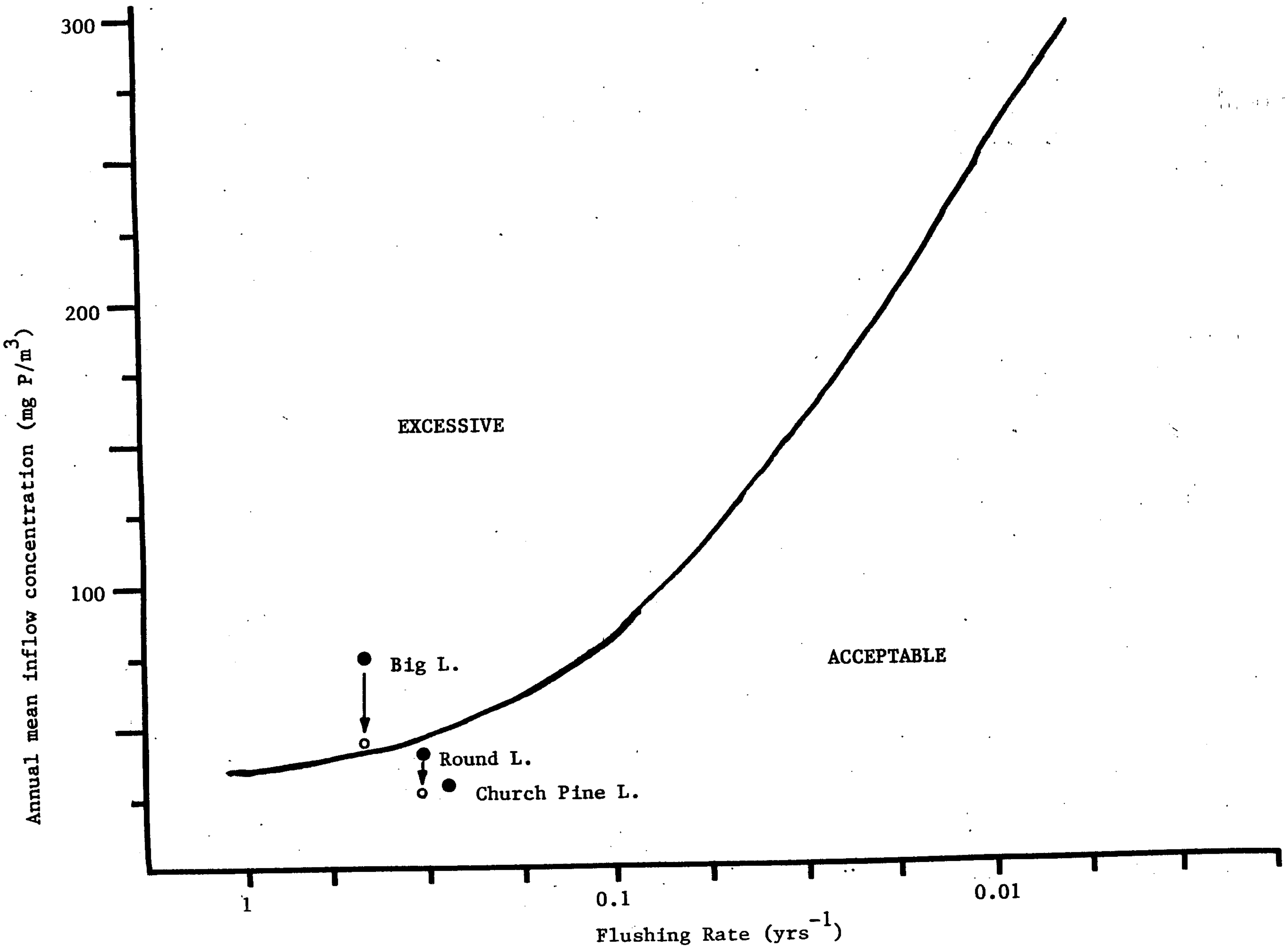


Fig. 38. Predicted effect of a 50% reduction in phosphorus loading from North Creek on over-all phosphorus loading of Big and Round Lake (after Vollenweider).



E. Bacterial Water Quality

Bacterial assays were conducted on June 12 and July 17 (see Fig. 21). On June 11, approximately 2 inches of rain fell, and this reflected in a substantial increase in total coliform bacteria concentrations in many samples, although fecal coliform bacteria concentrations were low in most areas. On June 12, high fecal coliform and E. coli concentrations were recorded in two samples, one taken at the mouth of North Creek on Big Lake, and a composite sample taken from three locations on the north and northwestern shores of Round Lake. On July 17, three locations sampled had detectible levels of E. coli, the mouth of North Creek, and two sites on the western shore on Round Lake. It is therefore concluded that fecal bacteria which might present a human health risk do not occur in significant concentration over the majority of the lakes, with the exception of North Creek, and possibly the western shore of Round Lake. This is consistent with the conclusion that little influent groundwater enters these lakes.

The fecal bacteria concentrations in North Creek were unacceptably and consistently high. It should also be strongly noted that whole feces were observed in North Creek on August 6. These feces were not of bovine or pig origin, although both occur in the North Creek watershed. Regardless of the origin, either human or animal, the bacterial water quality of North Creek is low and has a strong potential for a human health risk. The origin of this problem is not known, and will need to be identified to be effectively controlled. Traditionally, the origin of fecal bacteria pollution as either human or animal has been estimated by the ratio of total fecal coliform - total fecal streptococcus bacteria. Because of differential die-off rates and the unknown retention time of bacterially contaminated water by the North Creek watershed, this technique will be unreliable in identifying the source of the fecal bacteria. The North Creek watershed was also found to be a major source of nutrient loading, although the nutrient and bacteria problems do not necessarily have the same source.

Fecal bacteria concentrations were lower on Round Lake than on North Creek, although detectible levels were consistently observed. Because of this consistency, the conclusion is that a bacterial water quality problem might be occurring on the west shore of Round Lake. This is also supported by the observation that the highest E. coli concentration occurred within 24 hours after a 2 inch rain fall. Because concentrations were not extremely high, this contamination poses a lower potential human health risk than North Creek, although some risk does exist. Determination of the source of these bacteria, if conducted, should include the analysis of samples from shallow wells along this shoreline.

F. Algae and Weeds

The productivity of algae on these lakes followed the same trend as degree of phosphorus loading. As discussed earlier, algal productivity (measured as chlorophyll a) was normal on Church Pine and Round Lake, and excessive on Big Lake. The perception of an algae problem by the residents (see page 10) was closely correlated ($r = 0.95$) to actual measured chlorophyll a concentrations.

On all three lakes, a pulse of algal productivity was observed in spring, presumably in response to high dissolved phosphorus concentrations which accumulated during the winter. This pulse affected both chlorophyll a and secchi disc readings (see Figs. 24 and 23), but had subsided by May. The spring algal pulse represented the period of highest algal biomass on both Church Pine and Round Lake (Fig. 39).

Development of algal blooms depends not only on the total phosphorus content of the water, but also on the form in which the phosphorus occurs. The trends in the concentrations of various forms of phosphorus on each lake are found in Figs. 40 - 42. Dissolved forms of phosphorus, which are the most available to algae, predominate in spring and occur primarily as ortho (reactive) phosphate. Organic and acid-hydrolysible forms of phosphorus were in highest concentration in winter and early spring and again in fall, presumably after over-turn. Dissolved forms of phosphorus were reduced to very low levels during the summer, and the majority of the total phosphorus was contained in the particulate (filterable) form, which is least available to algae.

Because the current algal density on Church Pine and Round Lake represents the natural condition and is generally acceptable to the residents, it is concluded that it would be unwise to expend time or resources on any algal control methods at the present time. The current algal density on Big Lake is higher than the natural condition, and at least a portion of residents find it unacceptable; therefore algal control measures might be considered. The most direct and presumably cost-efficient control technique would be nutrient-load reduction.

Aquatic weeds are considered by the residents to be a minor nuisance on Church Pine Lake and a major nuisance on Round and Big Lake. The problem on the later two lakes did not appear to be great in open water (i.e., did not impede boat traffic), and was limited to the shallow parameter waters where weeds would be expected to grow well. The subjective observation was made that weed growths on Round and Big Lake were not substantially different from most lakes and did not appear to represent a polluted condition. Additionally, the exotic nuisance weed, eurasian milfoil, was not observed. Based solely upon the unacceptability of this condition expressed by the majority of residents, it is recommended that weed control measures be taken.

The most important considerations in determining the best weed control method are 1) Is the control method cost effective? 2) How long does the treatment last? and 3) Does the treatment produce adverse side-effects? The most common weed control methods are generally chemical or mechanical (harvesting).

The use of chemical weed control is not recommended on Big or Round Lake for several reasons. Chemicals are species specific, which results in only certain types of weeds being affected by any one chemical. Because weeds die and decay in the water, the resulting increase in nutrients can significantly add to the nutrient loading of the lake. For example, if an area containing 200 lbs. of weeds were treated on Round Lake, the phosphorus release could equal as much as 10% of the total yearly phosphorus input to the lake. Because of the low flushing rate for these lakes, such increases can have a sustained impact. The secchi disc records from 1985 (see Fig. 7) suggest that lower water quality has correlated with herbicide application on Big and Round Lake in the past.

Mechanical methods of weed control are recommended as being the most effective, cost-efficient, and having the least adverse side-effects. Mechanical cutting harvesting has been used in recent years and should continue. Harvesting equipment becomes less effective in deep (greater than 6 - 7 feet) and shallow (less than 2 - 3 feet) water, therefore operation time should be concentrated on the intermediate depth. Shallow areas can be controlled by hand-raking; the majority of residents found this to produce generally acceptable results.

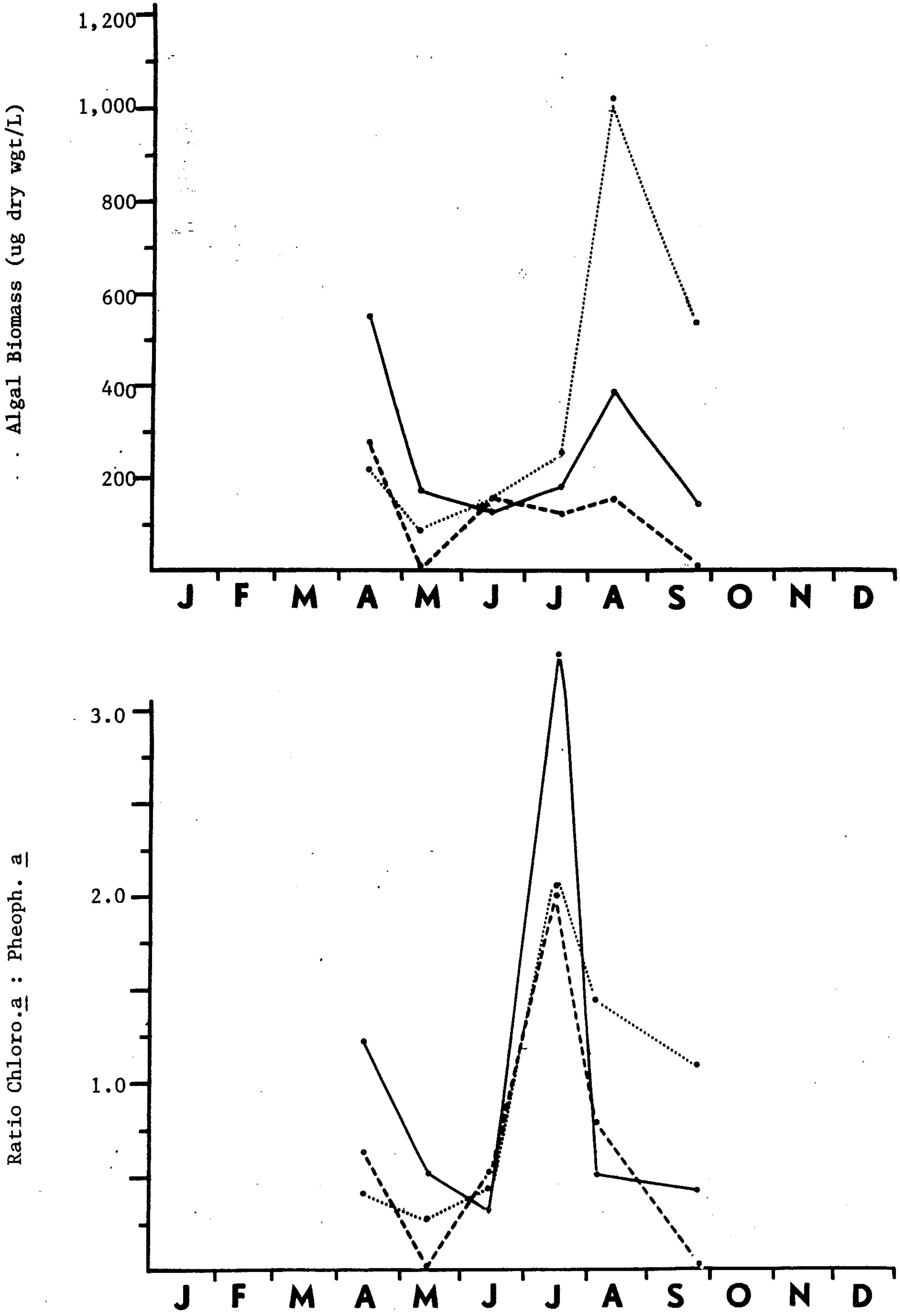


Fig. 39. Characteristics of the algal community in 1987 on Big Lake (……………), Round Lake (————), and Church Pine Lake (-------).

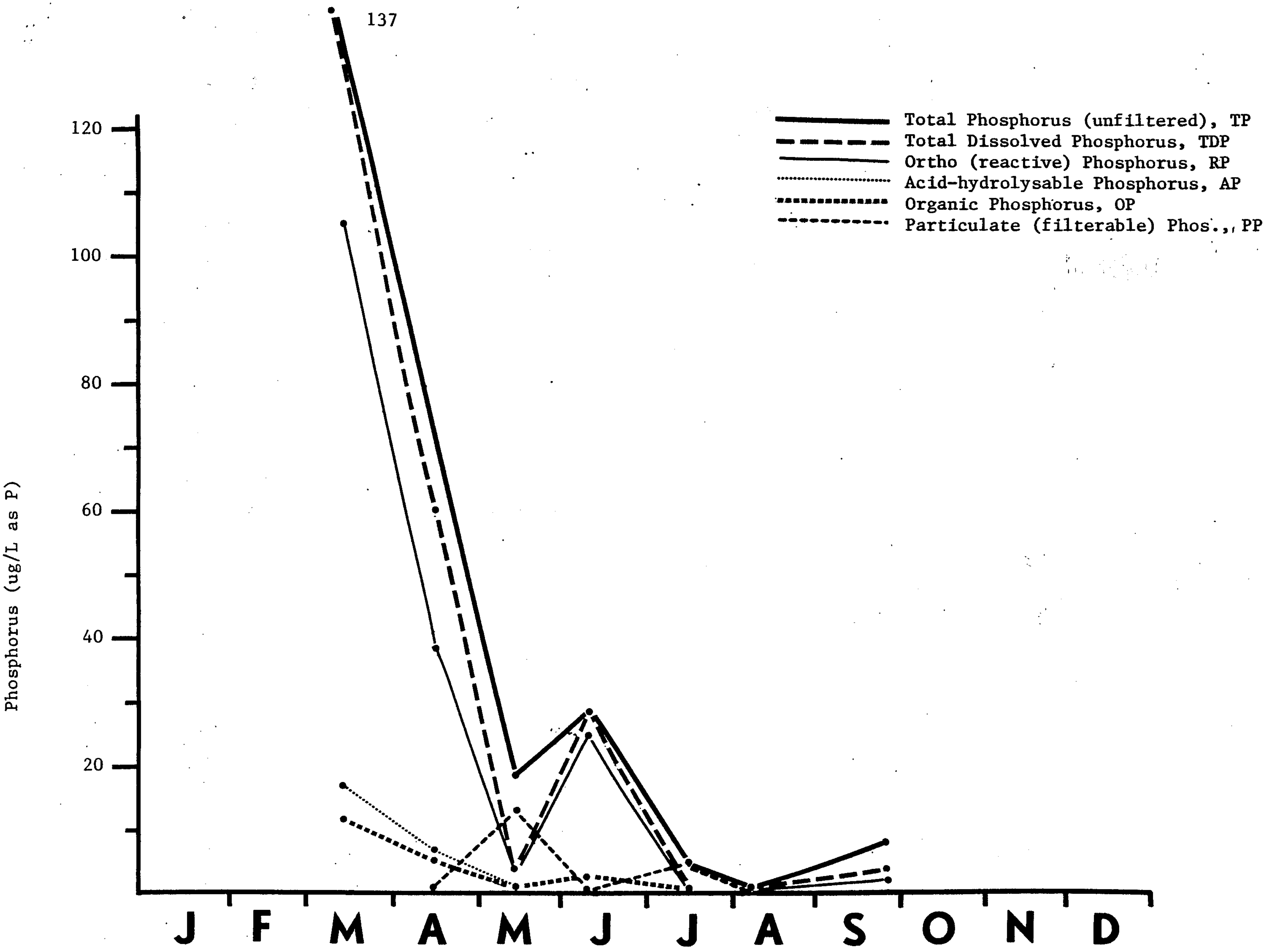


Fig. 40. Mean concentrations of different forms of phosphorus in 1987 on Church Pine Lake.

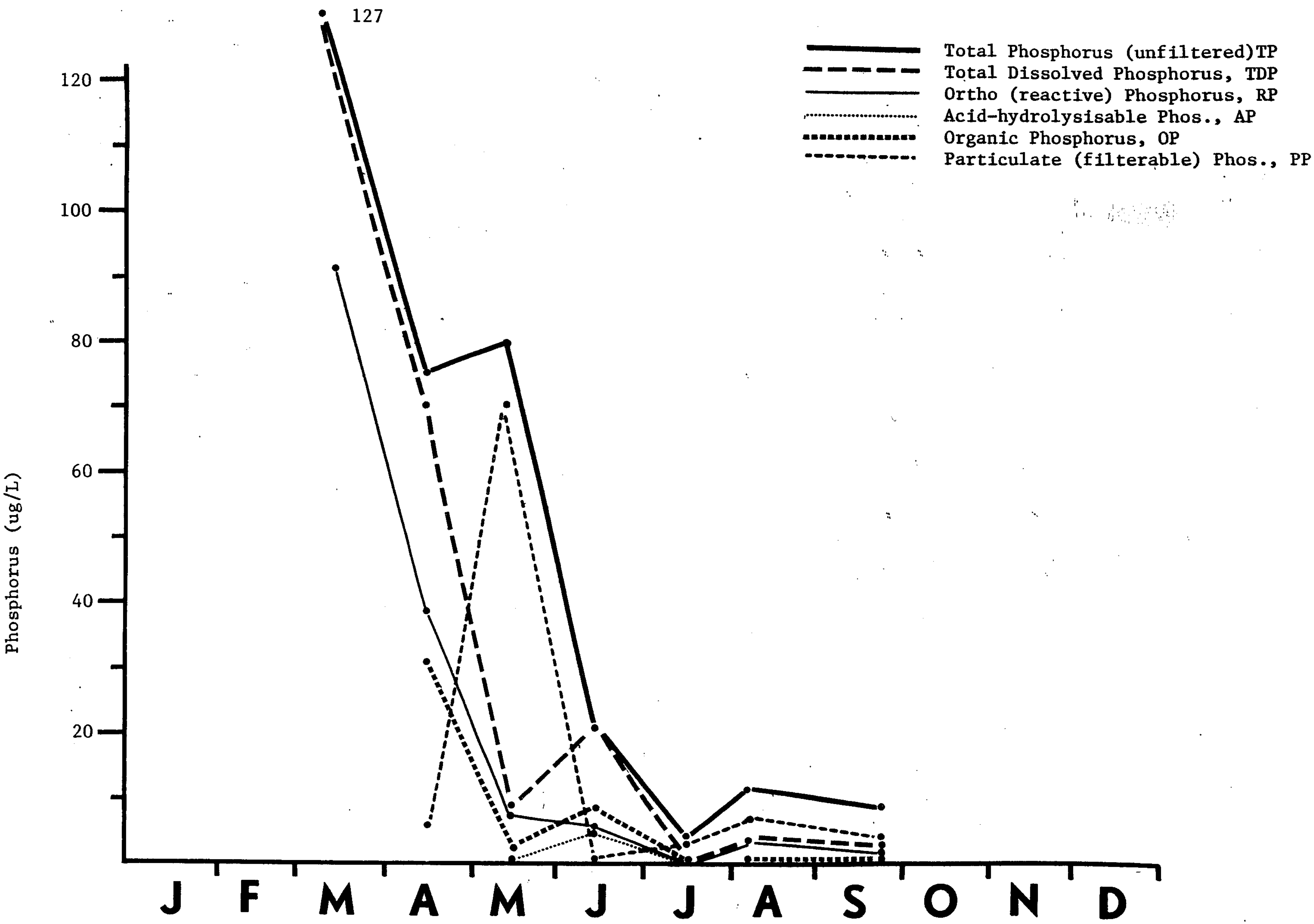


Fig. 41. Mean concentrations of different forms of phosphorus in 1987 on Round Lake.

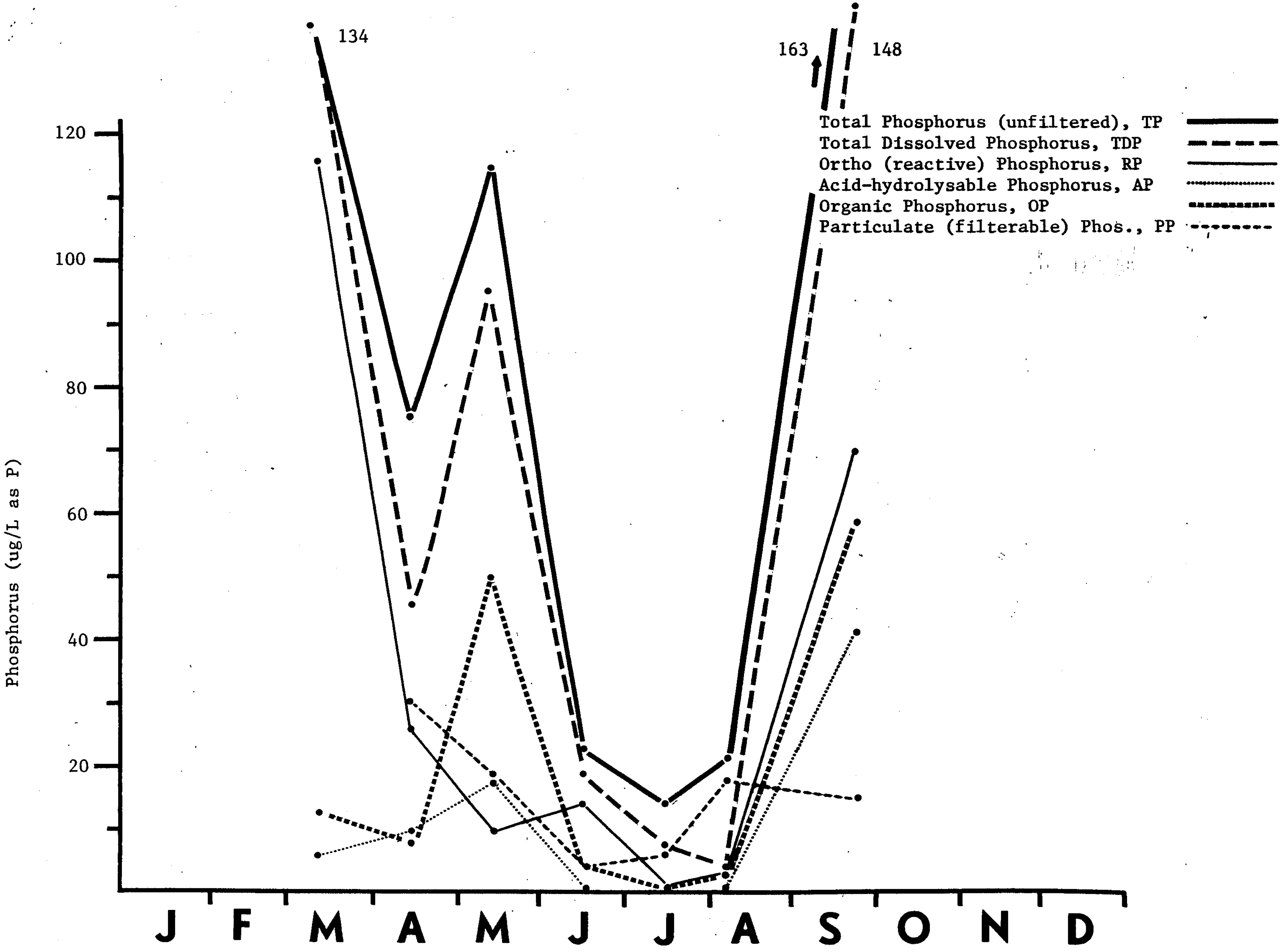


Fig. 42. Mean concentrations of different forms of phosphorus in 1987 on Big Lake.

G. Dissolved Oxygen

The effect of dissolved oxygen concentration on aquatic environments includes not only its obvious requirement by aquatic life, but also its effects on water chemistry and nutrient fluxes. As conditions become anoxic, iron, primarily present in sediments, is converted to its more soluble form, Fe^{+2}. Because iron in its less soluble form, Fe^{+3}, acts to sequester phosphorus in sediments, this solubilization of iron has the indirect effect of increasing the release of phosphorus from sediments.

The minimum oxygen concentration which is acceptable for the healthy maintenance of the aquatic ecosystem depends upon many factors, including seasonal temperature variation and types of organisms present. Based upon a seasonal maximum water temperature of 25°C and the absence of any trout species in all three lakes, a reasonable minimum dissolved oxygen guideline is about 4.0 mg/L. Therefore, areas in which the ambient dissolved oxygen concentration (DO) falls below 4.0 mg/L might be predicted to incur oxygen stress.

Seasonal trends in DO in surface waters (depth = 2 meters) and depth profile are presented in Fig. 43 and Figs. 44 - 46, respectively. In surface waters the DO was highest under ice cover in March, presumably due to the development of a moderate community of algae. DO dropped significantly in April, although this was primarily due to the warming of surface waters; percent saturation values actually increased during this period. Through the summer months DO levels remained relatively constant or increased slightly until September when a sharp drop was observed, especially on Big Lake. DO levels in surface waters of all three lakes remained above 4.0 mg/L on all sampling days.

The DO versus depth analyses (Fig. 44 - 46) indicated acceptable DO levels in the majority of waters, with the exception of those 1 - 2 meters (3 - 6.5 feet) above the sediments where DO levels fell below 4.0 mg/L. Sediments appeared at times to approach or enter anoxia. By mid-April, high DO levels (8.2 - 8.7 mg/L) were found in waters over-lying the sediments in all three lakes. By mid-May, the DO in these waters had been reduced by about 50%, although no significant release of dissolved solids by the sediments had begun. Additionally, a thermocline had begun to develop on Church Pine Lake (Fig. 47). In June, low DO levels were observed approximately 1 meter (3 feet) above the sediments of Big and Church Pine Lake, although Round Lake still appeared to be well oxygenated. By July, a small layer (less than 0.5 m) of low DO water had developed over the sediments on Round Lake, and an increase in dissolved solids in these deep waters had begun. The DO levels were largely unchanged in Church Pine and Big Lake, although the latter had also began to develop higher dissolved solid concentrations in the deeper water. By August, the low DO layer over lying sediments on Church Pine Lake had increased to about 2 - 3 meters (6.5 - 9.8 feet) associated with a slight increase in dissolved solids. The DO levels in August were low in the deep waters of Round and Big Lake, and the high concentrations of dissolved solids remained largely unchanged.

Church Pine had by late September developed a layer of low DO water approximately 3 - 4 meters (10 - 13 feet) thick and higher dissolved solid concentrations near the bottom. The strong thermocline which had developed over the summer appeared to be diminishing. The DO concentrations in the upper waters had decreased significantly on Round and Big Lake, although the decrease was more pronounced on the latter. It is thought that this decrease is not the result of a higher oxygen demand, but rather the mixing of the well-oxygenated upper waters with the poorly oxygenated lower waters. The over-all mean DO concentration on Big Lake was 5.7 mg/L in August and 4.8 mg/L in September. Likewise, the specific conductivity and total dissolved solids in the upper waters were higher in September compared to August, but their mean concentrations throughout the water column were very similar. It was therefore concluded that a complete mixing (over-turn) of Big Lake and a less complete mixing of Round Lake had taken place just prior to sampling in September. Indications were that mixing of Church Pine Lake would probably occur within several days after the September sampling date.

It was concluded the dissolved oxygen concentrations on all three lakes were adequate in most areas. Dissolved oxygen concentratons were consistently low on North Creek which might affect the inhabitability of this stream for some types of aquatic life. It was also concluded that dissolved oxygen levels remained high enough to limit the release of phosphorous from sediments, and although high dissolved solids and nutrients that accumulated in the deep waters were released to the upper waters during fall over-turn, this accumulation did not appear to significantly influence summer water quality.

Fig. 43. Dissolved oxygen concentration (DO) in surface waters (depth = 2 meters) on Church Pine, Round, and Big Lake in 1987

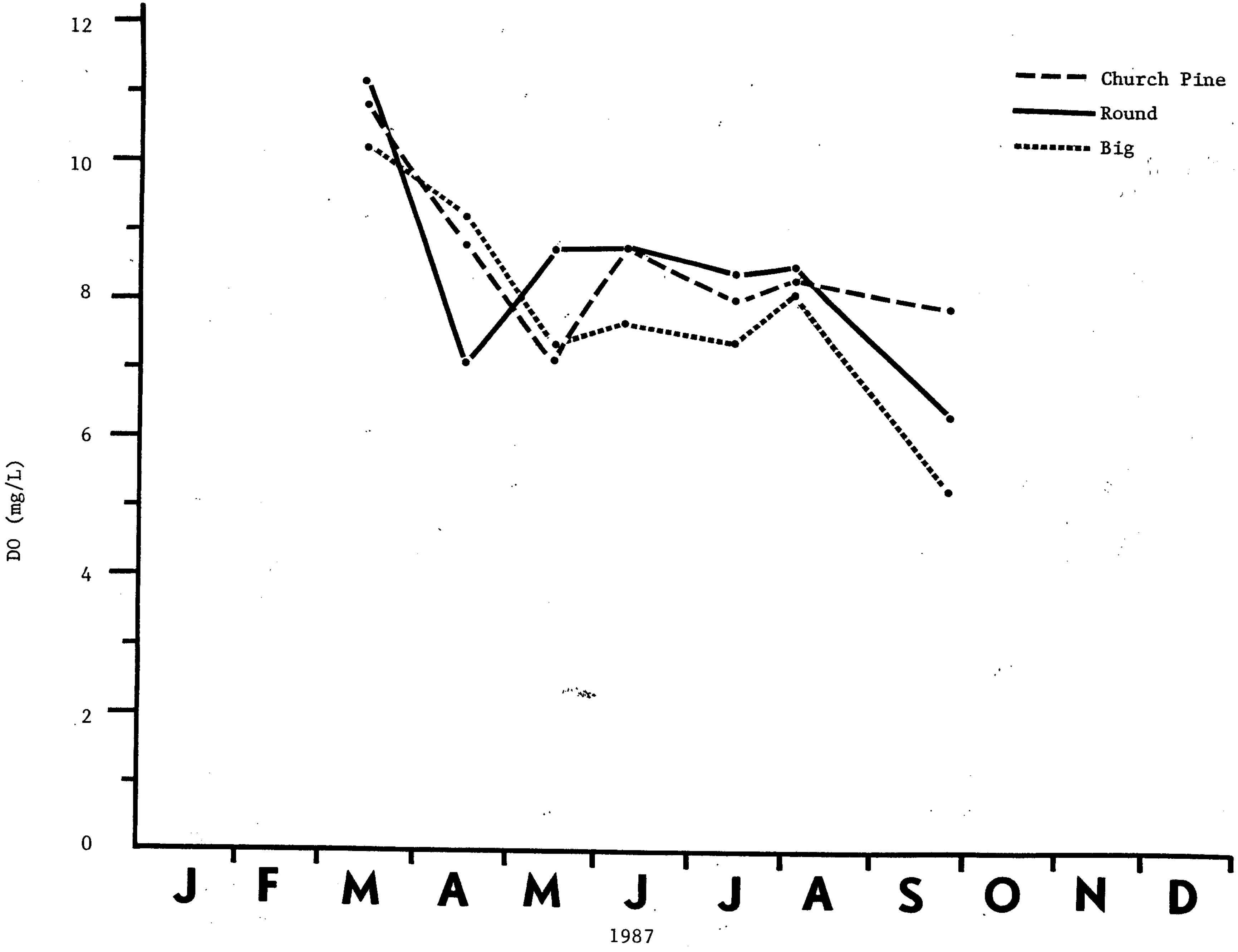


Fig. 44. Trends in dissolved oxygen concentration (DO) verus depth on Church Pine Lake in 1987.

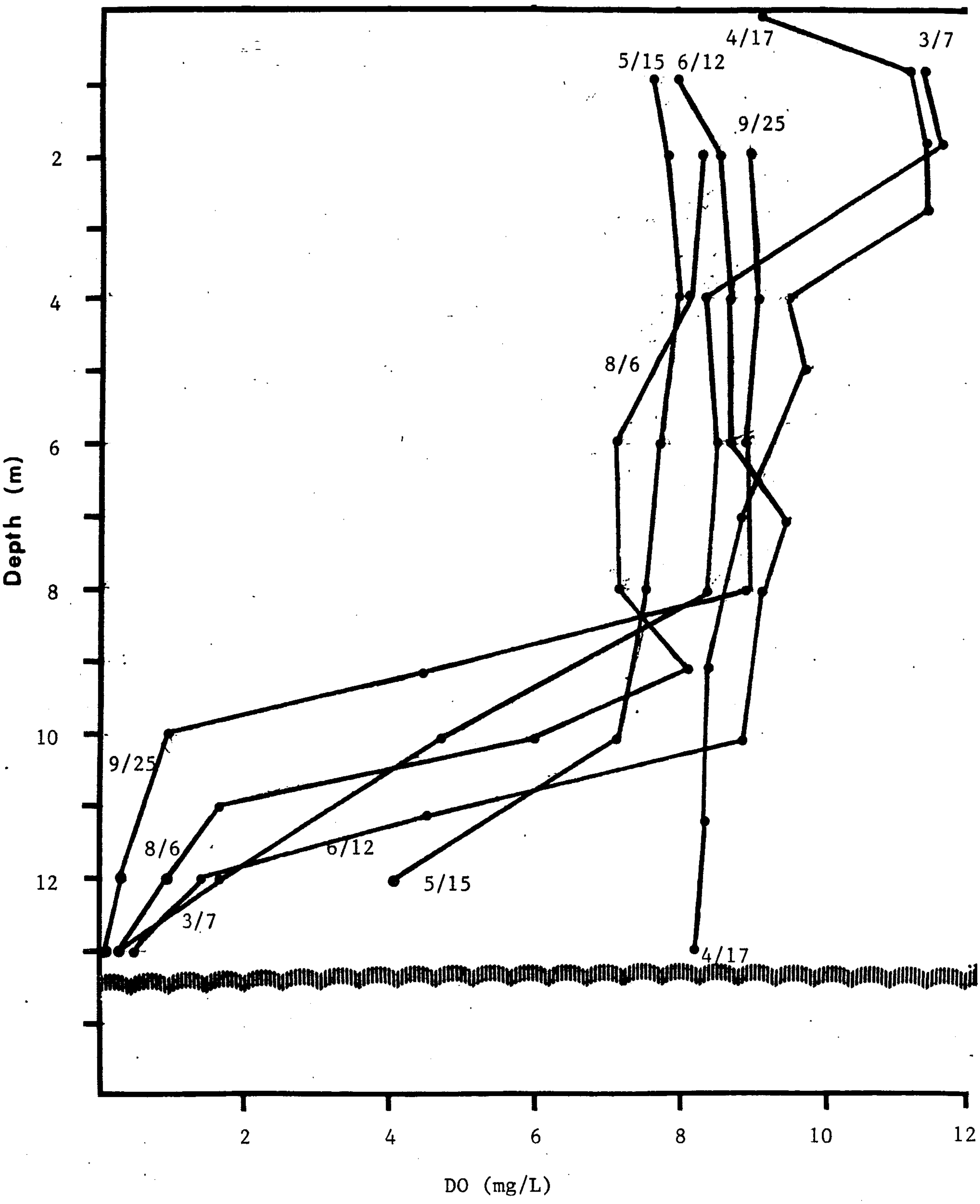


Fig.45. Trends in dissolved oxygen concentration (DO) versus depth on Round Lake in 1987.

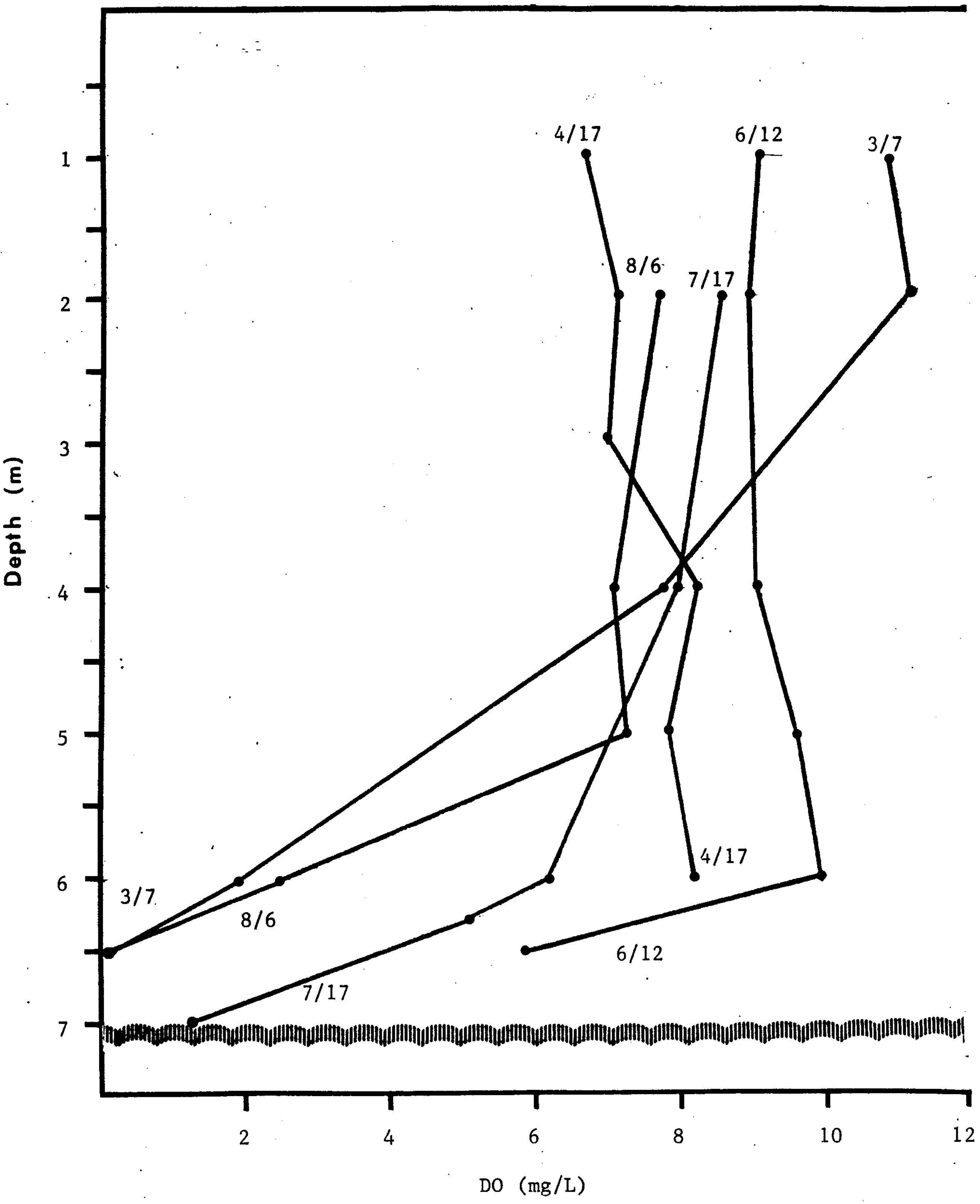


Fig. 46. Trends in dissolved oxygen concentration (DO) versus depth on Big Lake in 1987.

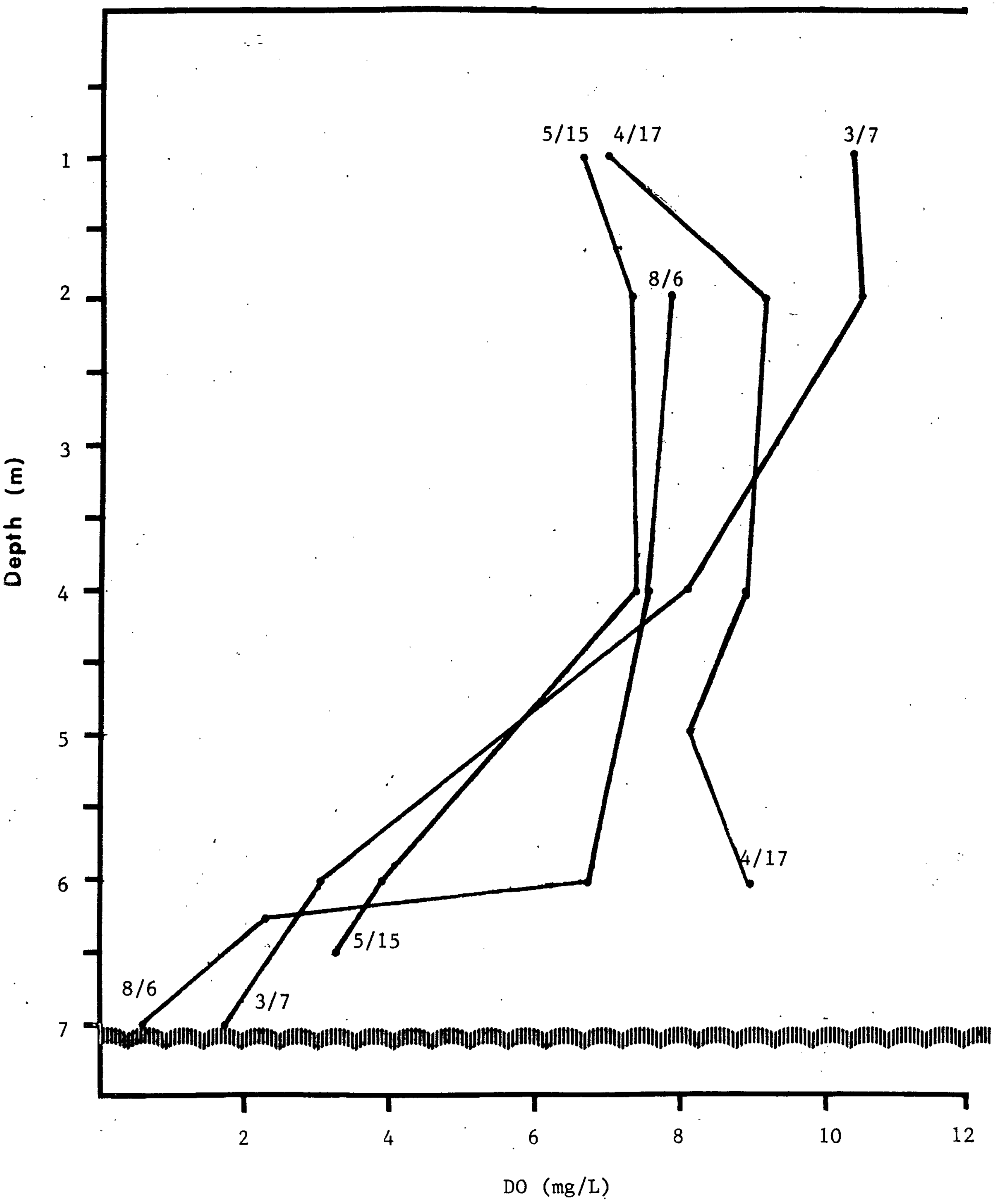
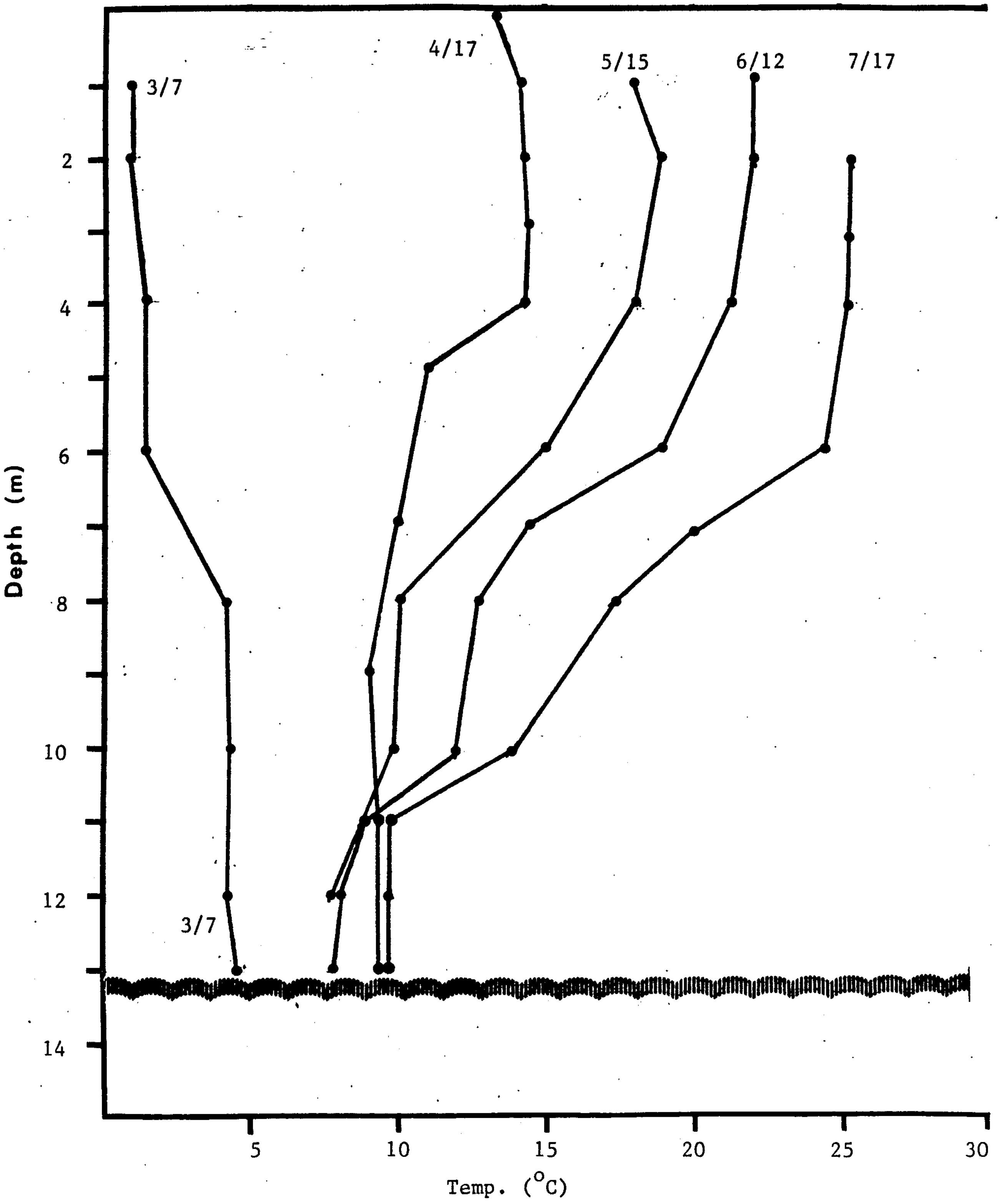


Fig. 47. Trends in temperature versus depth on Church Pine Lake in 1987.



H. Water Quality Monitoring

Development of an effective and cost-efficient monitoring plan is essential to identify trends in water quality and to determine the effectiveness of water quality improvement projects. To be useful, monitoring should 1) provide data on pertinent factors of water quality; 2) provide data at appropriate times of the year; and 3) provide data of acceptable quality.

As discussed earlier (see pages 4 - 5), the majority of historical data is considered unuseable. Aside from the issue of acceptability, data have been generated on many factors of water chemistry which do not relate directly to important water quality issues (e.g., sulfate, chloride, etc.) and other data appear to be somewhat redundant (e.g., calcium, magnesium versus hardness). Furthermore, data have been collected during periods of the year which do not appear to affect summer water quality. As demonstrated by the 1987 data, nutrient levels were very high in winter and early spring, but they dropped rapidly by late spring. The magnitude of these high spring nutrient levels did not appear to relate to subsequent summer water quality. Therefore nutrient data collected in early spring, and likewise, in late fall, does not provide pertinent data, particularly in regard to predicting and evaluating summer water quality. Data on nutrient concentrations would be more pertinent and more directly comparable between years if sampling were conducted between June and August.

Records of secchi disc transparency readings over the years 1985 - 1987 provide an excellent data base and generation of these records should be continued. These records provide the most cost-efficient monitoring technique, and can be compared directly with predicted average summer values discussed earlier (7.1 feet for Big and Round Lake, 9.3 feet for Church Pine Lake) to evaluate water quality.

It is recommended that the District adopt a five-year schedule for comprehensive water quality evaluations, similar to that conducted in 1987. Secchi disc reading records over the interim five years could be evaluated in conjunction with these evaluations. Important potential long-range trends that should be addressed include:

1) Maintenance of good water quality on Round and Church Pine Lake.
2) Increase in dissolved solids in Round Lake.
3) Changes in water quality of Big Lake associated with any water quality improvement activities.

Due to the relatively long hydrological retention time for all three lakes, it is unlikely that measureable long-term trends in water quality would occur in less than 5 years.