Province of British Columbia
Ministry of Environment
ASSESSMENT AND PLANNING DIVISION

FULLER LAKE WATER QUALITY INVESTIGATIONS 1981-03

WORKING REPORT

by

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ABSTRACT

In 1966 and 1980 nuisance algal blooms occurred in Fuller Lake, which is located in the District of North Cowichan, B.C. The bloom conditions appear to be the consequence of elevated lake phosphorus concentrations. Phosphorus appears to come primarily from non-point sources around the lake. The contributions from residential, commercial, recreational and natural non-point sources are detailed. Results indicate that most of the phosphorus entering the lake originates from human activity.

Algal blooms appear to follow periods of high winter precipitation. Above normal precipitation and runoff causes increased leaching of phosphorus that has accumulated in the soil. The result is elevated summer phosphorus and algal concentrations. In the future nuisance algal blooms may be expected to follow periods of high winter precipitation unless measures are taken to reduce phosphorus concentrations.

Various techniques can be used to reduce the lake's phosphorus concentrations. Successful reduction will reduce or eliminate the occurrence of algal blooms in the lake. The easiest technique would be to increase the lake's flushing rate. At present the Corporation of the District of North Cowichan controls a six inch line into the lake. The line carries water which is diverted from Millar Creek, and which is of excellent quality. Diversion of Millar Creek will displace lake water containing high nutrient concentrations through the outflow. The result will be a reduced lake phosphorus concentration and improved water quality.

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ACKNOWLEDGEMENT

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1. BACKGROUND

This report was written in response to complaints about the water quality of Fuller Lake (1 km south of Chemainus) in the summer and fall of 1980. Inquiries were received from private citizens and the Regional District. A request for a report was received from the regional fisheries biologist of the Fish and Wildlife Branch.

The available water quality data were collected largely during 1979 by the Aquatic Studies Branch (then Water Investigations Branch) as part of a larger project dealing with the effects of settlement, development and land use within watersheds on lake water quality.

This report outlines the general water quality of Fuller Lake and makes some suggestions as to possible methods of improving the water quality and avoiding another large algal bloom such as occurred in 1980 and in the past.

B.C. Research was contracted by the District of North Cowichan in 1966 to investigate an algal bloom (Schaumberg, 1966). Schaumberg noted that in years previous to the 1966 bloom, the lake water had appeared clear and free of significant heavy algal growth. A similar observation was made before the 1980 bloom. The sampling during the growing season of 1979 showed very low algal growth. However, during 1980 large growths of algae appeared.

The 1966 bloom was predominantly the blue-green algal genus *Anabaena*, and Schaumberg attributed the problem to residential development and sewage disposal by way of septic tank-tile field systems contributing nutrients to the lake. The 1980 bloom was also *Anabaena*.

2. LAKE AND WATERSHED CHARACTERISTICS

Some of the morphometric measurements for the lake and the watershed are listed in Table 1. Fuller Lake is a small, relatively shallow lake (Figure 1) with a very small watershed. The watershed (Figure 2) has a variety of land uses contained in it.

Table 1: Lake and Watershed Morphometry

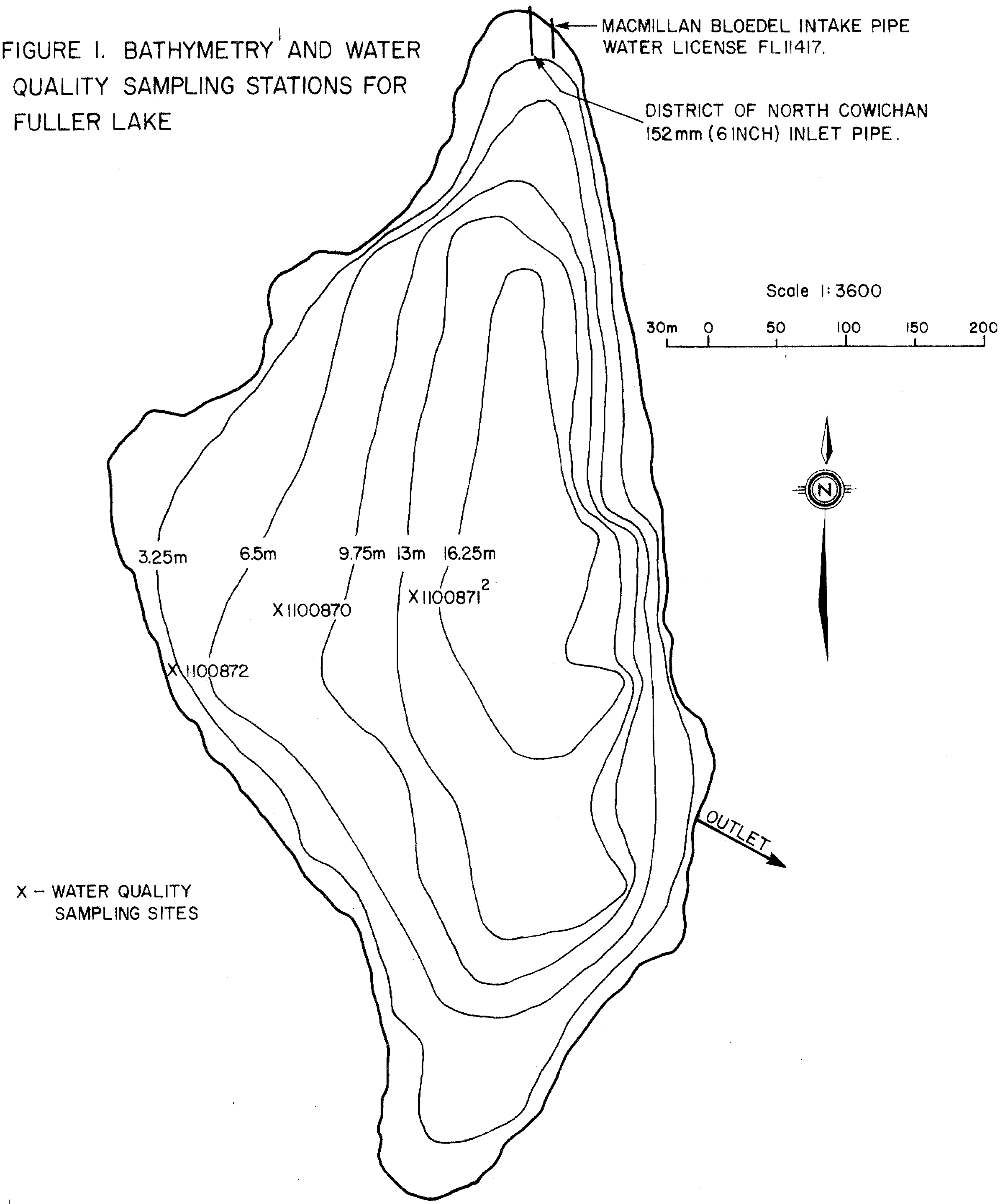
Watershed	Lake
Area - 61.1 ha (excl. lake)	Area - 24.1 ha Volume - 1200 dam^3 Elevation - 45.8 m Mean Depth - 8.5 m Maximum Depth - 17 m

Table 2: Land use and cover in the Fuller Lake watershed

Land use and cover class	Code[1]	Area (ha)	Fraction of Watershed (%)
Urban and built-up land			
- Residential	11	8.62	14.1
- Commercial and Services (include rec. centre)	12	2.38	3.9
- Industrial	13	3.10	5.1
- Transportation, Communications Utilities	14	5.47	8.9
- Mixed urban and built-up	15	1.40	2.3
- Open and other (park, golf course, riding ring)	16	3.09	5.1
Agricultural land			
- pasture	21	2.38	3.9
Forest land			
- coniferous	31	10.61	17.4
- deciduous	32	1.15	1.9
- mixed	33	16.42	26.9
Barren land			
- gravel pit	41	6.50	10.6
TOTALS		61.12	100.0

[1] See Figure 2

FIGURE I. BATHYMETRY[1] AND WATER QUALITY SAMPLING STATIONS FOR FULLER LAKE



[1] Bathymetric survey conducted by the Lake Survey Unit, Fish and Wildlife Branch, May, 1958.

[2] Ministry of Environment, Environmental Quality Information System (EQUIS) Station Identity Number.

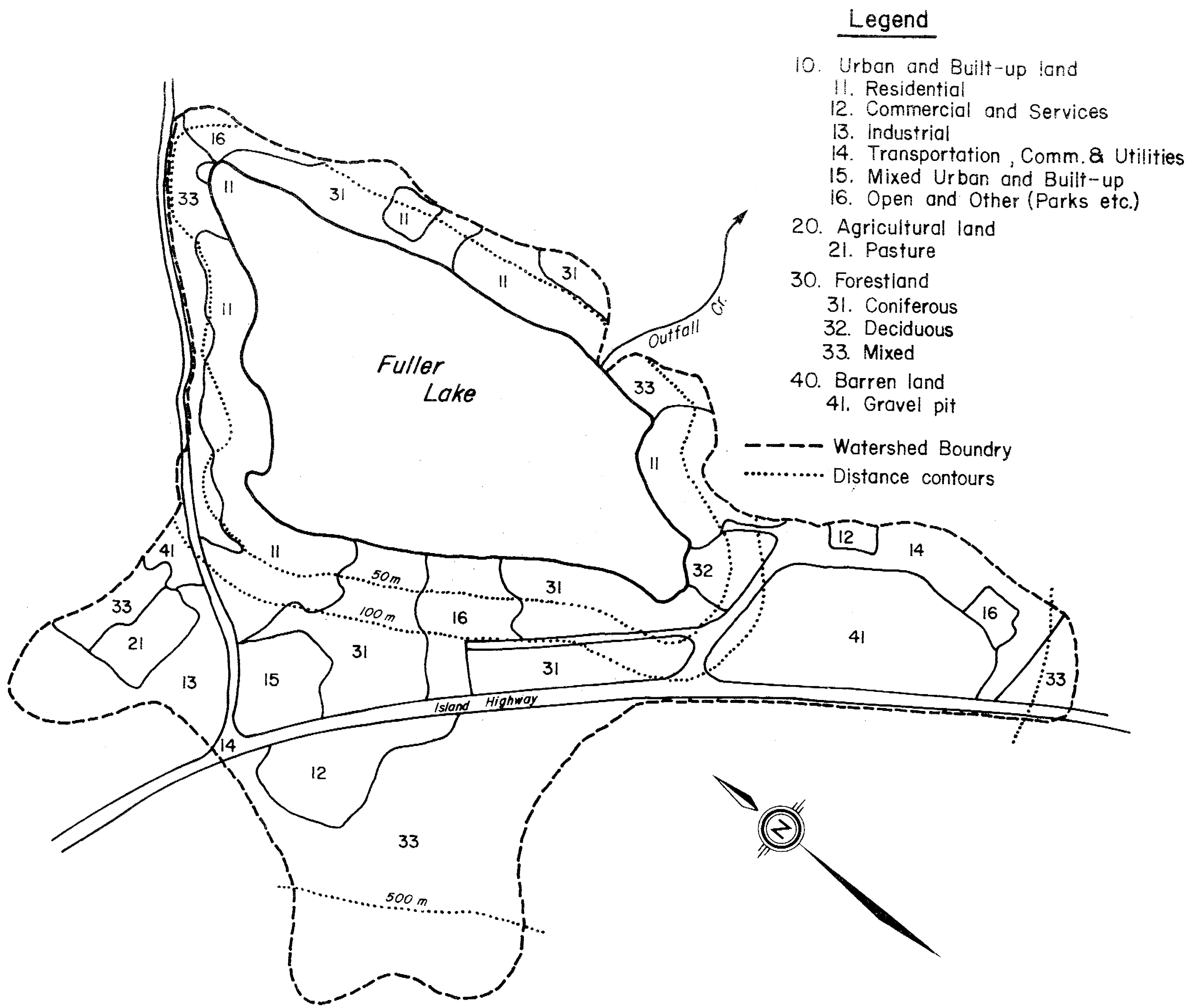


FIGURE 2. FULLER LAKE WATERSHED – LAND USE AND COVER

The largest percentage of land in the watershed is forest (46.1%) followed in amount by residential areas (14.1%) (Table 2). The majority of residences (17 of 26) are located within 50 metres of the shoreline of the lake.

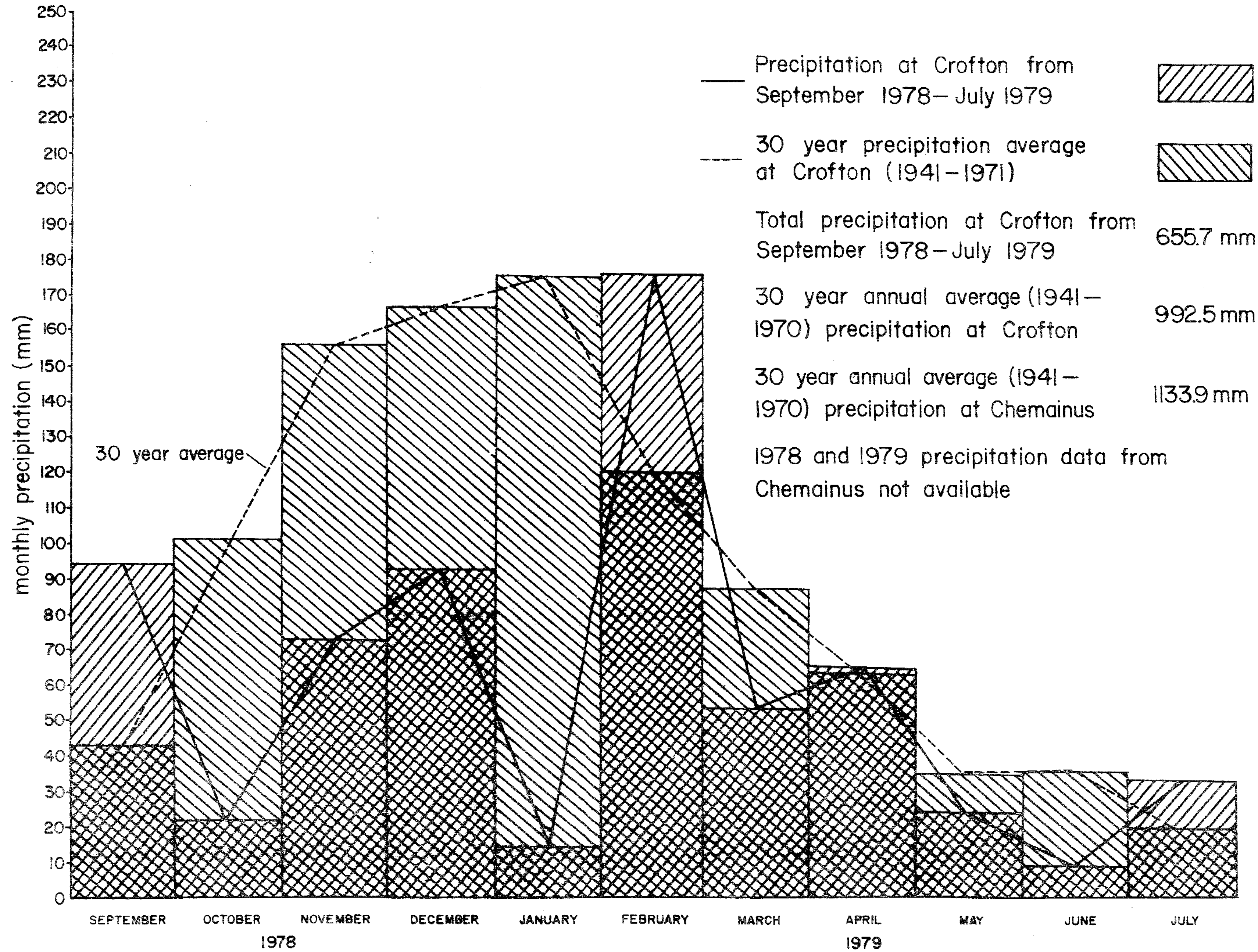
3. WATER BALANCE

The most important factor in determining water quality in Fuller lake, appears to be water exchange. Because of the very small watershed, a very low amount of runoff would be expected from the watershed. The 30 year (1941-1970) mean annual precipitation at Chemainus (1.5 km northeast of Fuller Lake) is 1130 mm (Figure 3). Over the area of the watershed (61.1 ha) this amounts to 690 dam^3, however, only a portion of this reaches the lake. Watershed runoff for the Fuller Lake area was estimated at 5.5 dam^3/ha (Obedkoff, pers. comm.). Using this ratio the estimated average runoff reaching the lake is 338 dam^3/year. Rainfall on the lake surface would be expected to be 1130 mm, however evaporation would be expected to return 429 mm to the atmosphere. This evaporation estimate is based on a three year mean (1977-79) for Saanichton (Agriculture Canada). Therefore, the net rainfall on the lake surface would be 700 mm and contribute 168 dam^3/year to the lake. The sum of net rainfall on the lake (168 dam^3) and rainfall on the watershed reaching the lake (338 dam^3) gives a mean annual water inflow of 504 dam^3. Since the volume of the lake is 1200 dam^3, the water exchange rate is 0.42, or a theoretical filling time of 2.4 years. This is a relatively slow "flushing" rate.

Not all of the water which enters the lake is from the watershed. The District of North Cowichan maintains a metered 152 mm (6 inch) inlet pipe into the lake to augment the inflow volume to the lake.

The lake level from our observations, (no regular gauging done), appears to fluctuate by one to one and one-half metres over the course of a year. Maximum lake elevation appears to occur in the December through April period and then decreases to a minimum in August and September.

FIGURE 3. CROFTON PRECIPITATION FOR SEPTEMBER 1978 THROUGH JULY 1979, AND THE 30 YEAR (1941 – 1970) MONTHLY PRECIPITATION AVERAGE AT CROFTON *



* Information supplied by the Air Management Branch, Ministry of Environment.

Over an undetermined number of years, diverted water has been put in over a period of two to three months in the spring and two to three months in the autumn (Hardy, pers. comm.). The only period this inflow has been gauged was the autumn of 1980 when between September 3rd and October 23rd, 52.4 dam^3 flowed into the lake. The water is supplied as surplus water when the water from Millar Creek would otherwise be flowing over the diversion dam. If this input can be assumed to occur each year, which apparently it can, approximately 100 dam^3 additional water enters the lake; this is about 8% of the lake volume. This would increase the estimated flushing rate from 0.42/year to 0.5 or reduce refilling time from 2.4 years to 2.0 years.

Outflow from Fuller Lake is also controlled. The MacMillan Bloedel sawmill draws water from the lake through a 300 mm (12 inch) pipe. The intake is 1.7 m below the lake surface at normal lake high water. The volume drawn from the lake is 12,000 m^3 per month, or 144 dam^3 per year or about 12% of the lake volume over a one year period. The water is used for cooling and for back-up fire protection.

The outlet stream has been dammed to control the lake level so flow only occurs at high water level and high flow periods. No records of flow are available.

4. LAKE STRATIFICATION - TEMPERATURE AND DISSOLVED OXYGEN

The lake was first sampled in March, 1979. At that time the lake was more or less isothermal from top to bottom (Figure 4). The dissolved oxygen was similarly almost equal top to bottom at or near 100% saturation (Figure 5). These characteristics indicate the lake was well-mixed at this time.

By the end of April a strong thermal gradient had been established with a epilimnion at 11°C, a thermocline between 3 and 7 metres and a hypolimnion below 8 metres at 4.9-5.2°C. The oxygen had decreased in the hypolimnion at this time. As the summer progressed the thermocline gradually became deeper and narrower (Figure 4) and the epilimnion volume gradually increased. By October

FIGURE 4. TEMPERATURE: TIME-DEPTH DIAGRAM FOR FULLER LAKE (1979) AT STATION 1100871

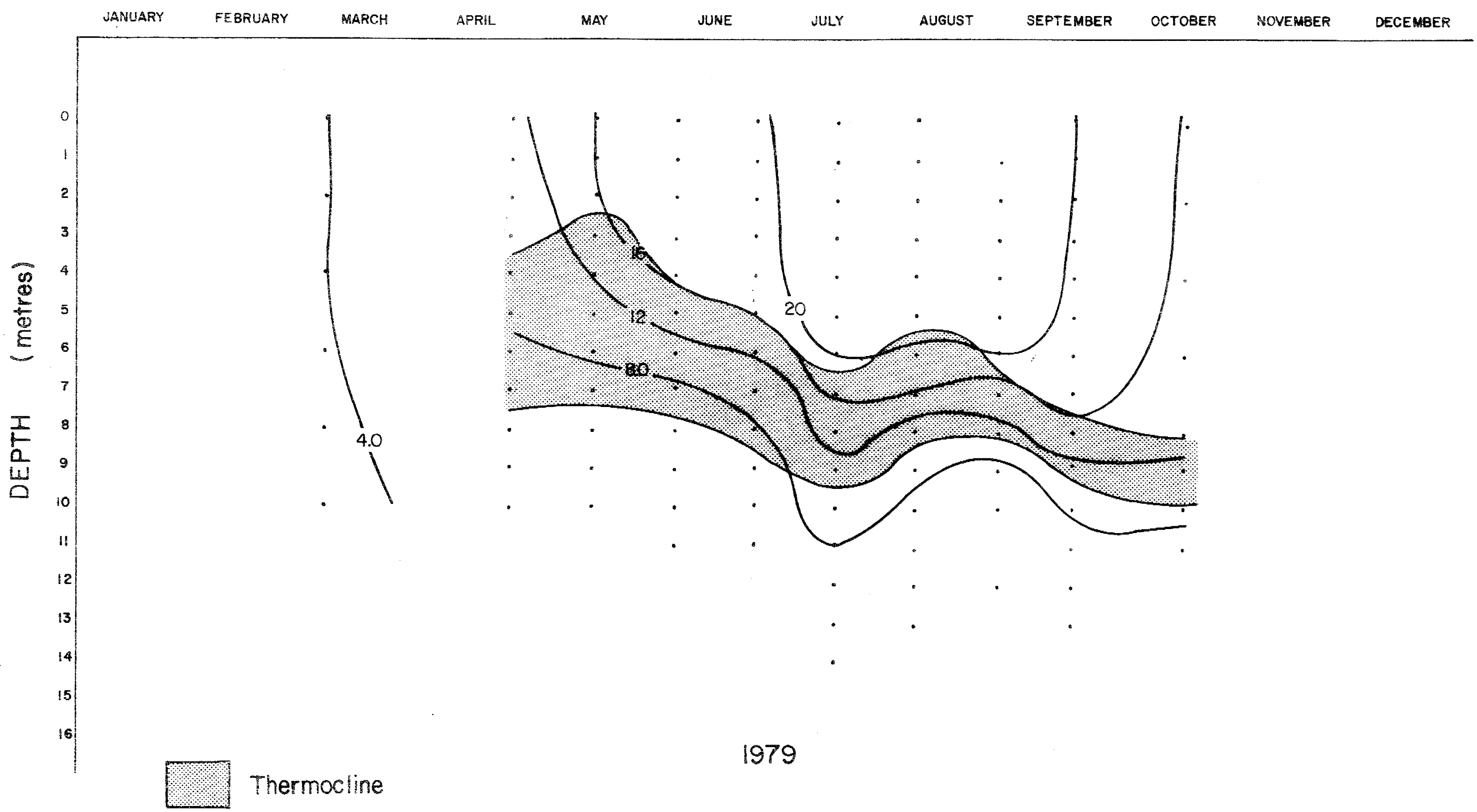
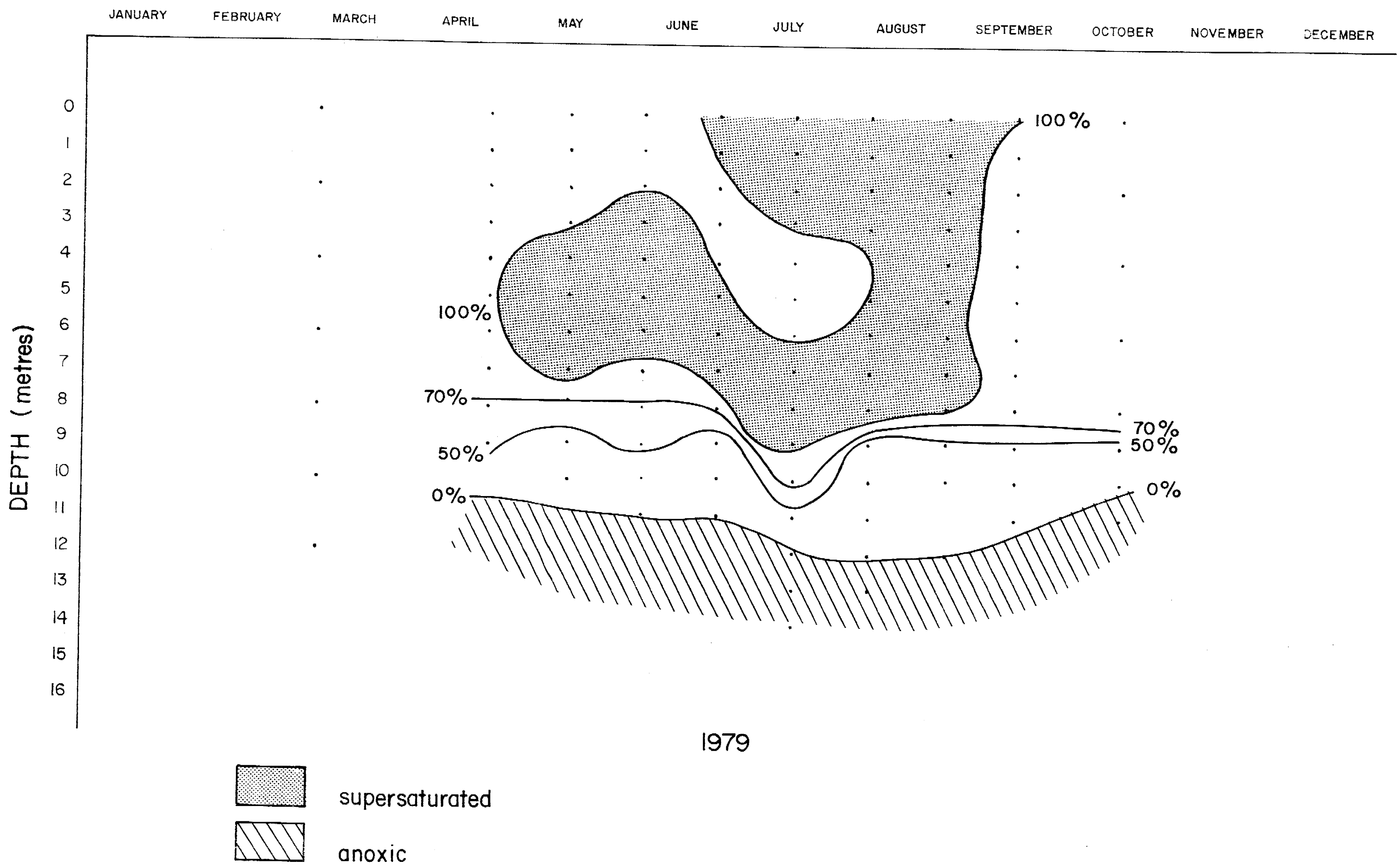


FIGURE 5. DISSOLVED OXYGEN (PERCENT SATURATION): TIME – DEPTH DIAGRAM FOR FULLER LAKE (1979) AT STATION 1100871



the epilimnion occupied the top 8 metres of the lake and the thermocline a narrow band between 8 and 10 metres. Destratification would have been expected to occur sometime in November and the lake would then have been free mixing until spring stratification.

The oxygen concentrations in the epilimnion and thermocline were either close to saturation or at supersaturation levels (up to 137 percent saturation) throughout the period of measurement. However, in the hypolimnion, rapid deoxygenation took place such that after July all oxygen concentrations were at less than 10 percent saturation. The low oxygen values persisted through the summer and fall until fall overturn. Particularly notable are the peaks of oxygen concentrations in the thermocline area (Figures 6 and 7).

5. WATER QUALITY

Two entirely different impressions emerge from the data for Fuller Lake, depending on whether the 1979 or 1980 data are viewed. The 1979 data represent an entire season of sampling (March through October) whereas in 1980 only three samplings were taken in response to the algal bloom.

The 1979 samplings were, in general, indicative of good water quality. The water clarity (Figure 8) varied between 2.8 and 7.5 metres as measured by Secchi disc depth. The amount of algae, measured as chlorophyll 'a' never exceeded 5 mg/m^3 and was, except for one occasion, always below 2 mg/m^3 in the surface water (Figure 9).

Nutrient values also were very low in 1979. Epilimnion phosphorus values ranged from 9 to 16 g/L (Figure 10). These concentrations would, by most conventions (e.g., Wetzel 1975) fall into the mesotrophic or oligo-mesotrophic category. The ortho-phosphorate concentrations demonstrate the low nutrient condition (Figure 11). Thirty analyses were done, and only three samples indicated concentrations higher than the laboratory detection limits.

FIGURE 6. TEMPERATURE AND DISSOLVED OXYGEN PROFILES AT STATION 1100871 ON JUNE 5, 1979

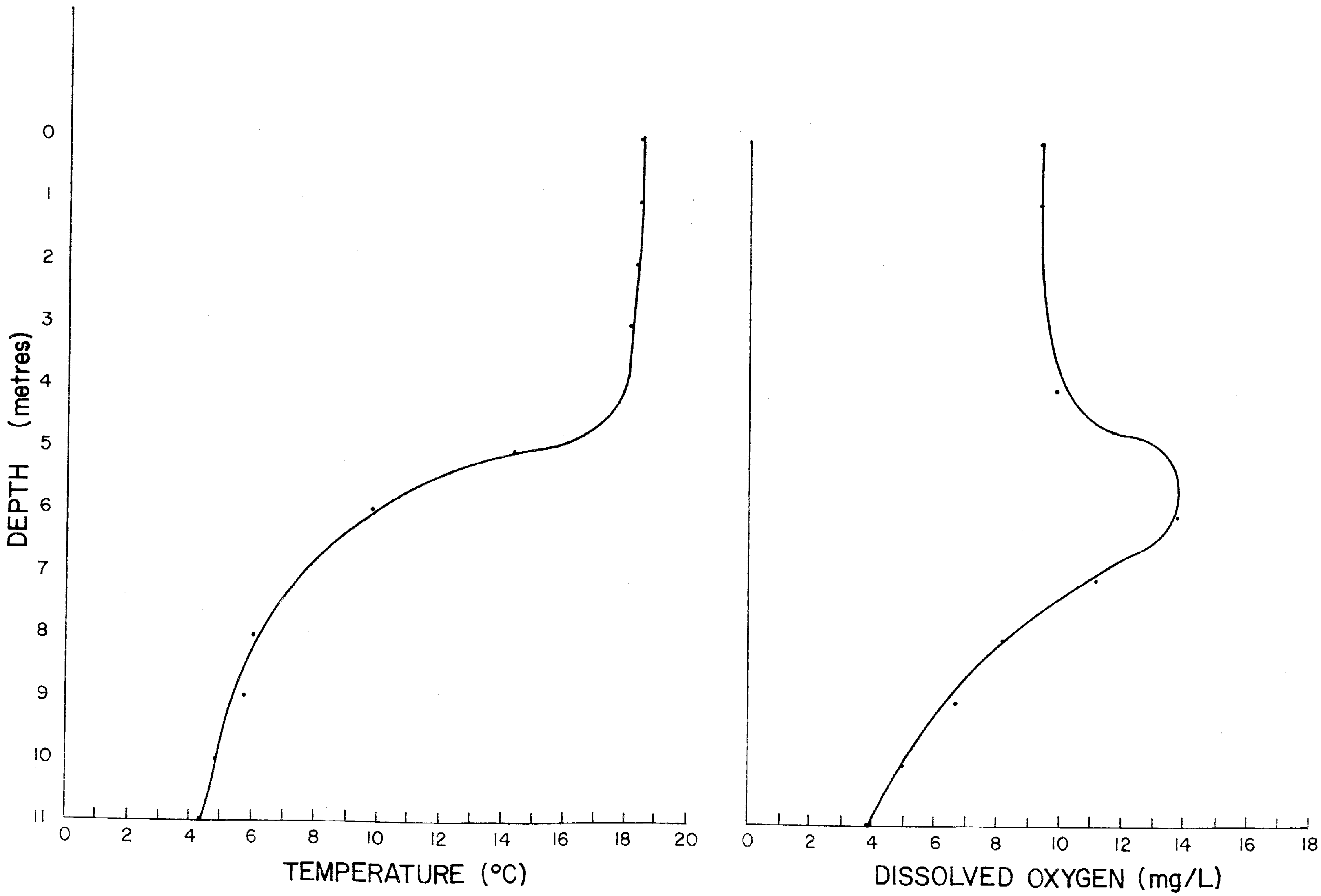


FIGURE 7. TEMPERATURE AND DISSOLVED OXYGEN PROFILES AT STATION 1100871 ON AUGUST 28, 1979

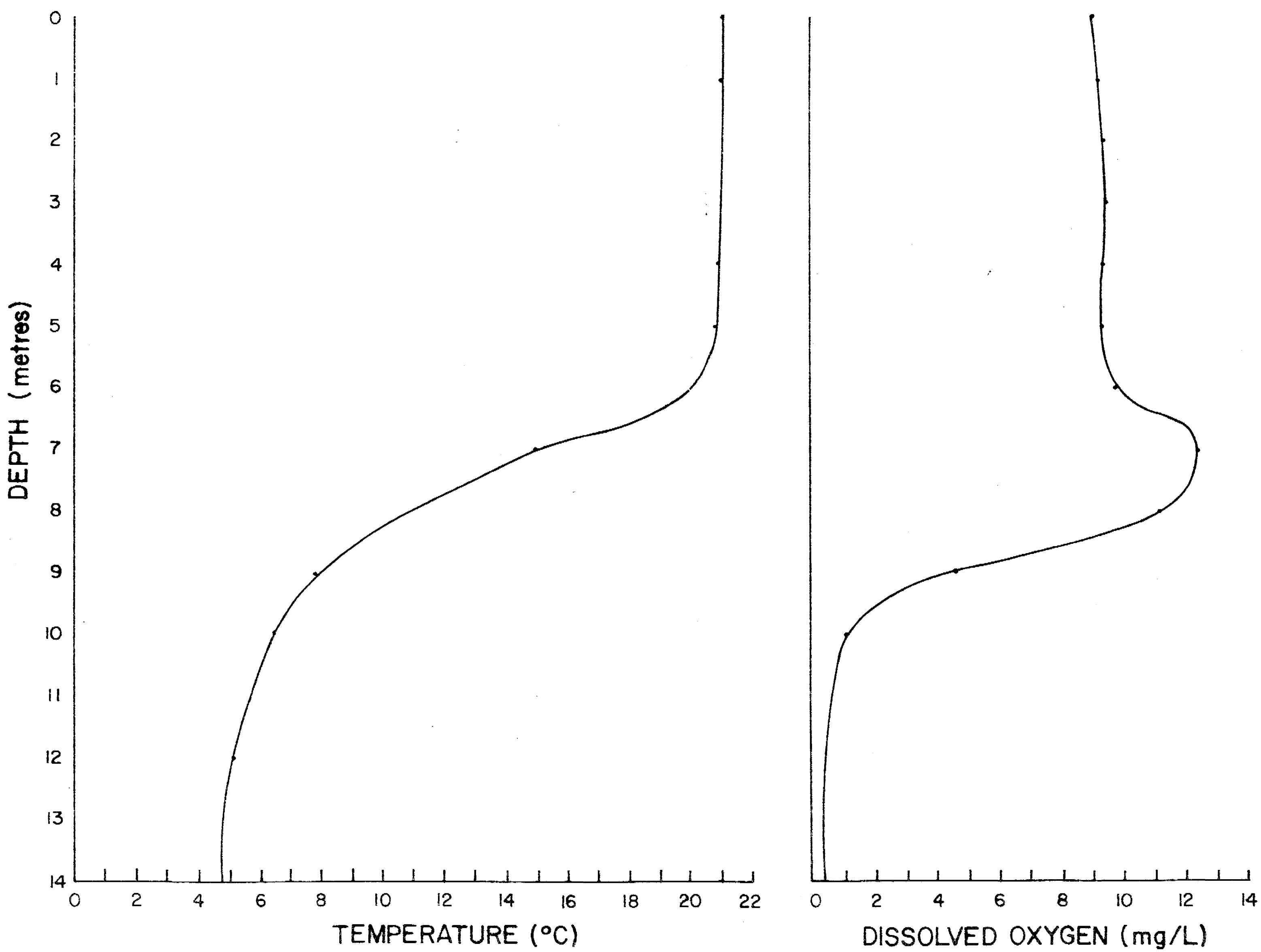


FIGURE 8. FULLER LAKE WATER CLARITY (SECCHI DISC DEPTH) AT STATION 1100871, FOR 1979.

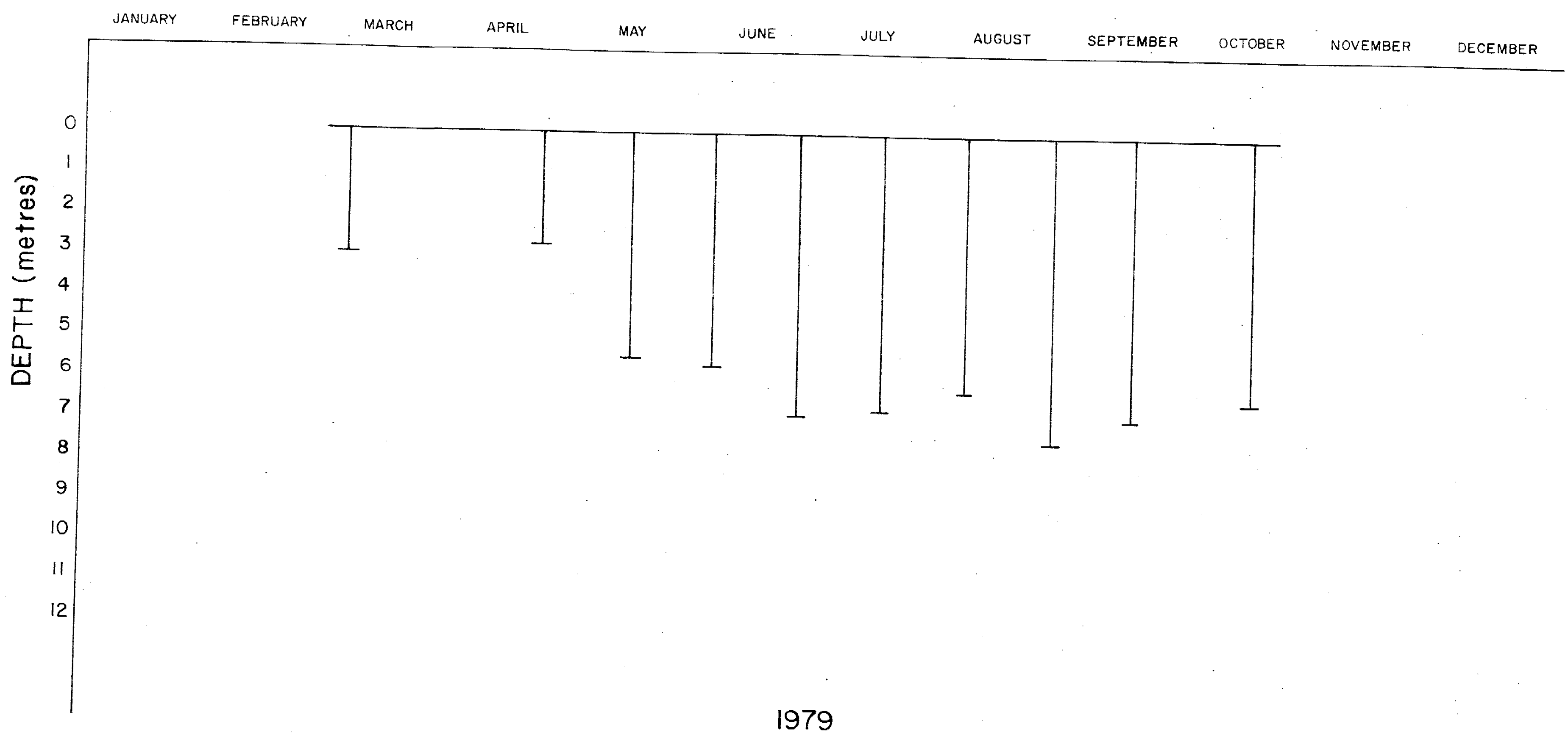


FIGURE 9. TIME - DEPTH DIAGRAM FOR CHLOROPHYLL (mg/m^3) AT STATION 1100871, FOR 1979.

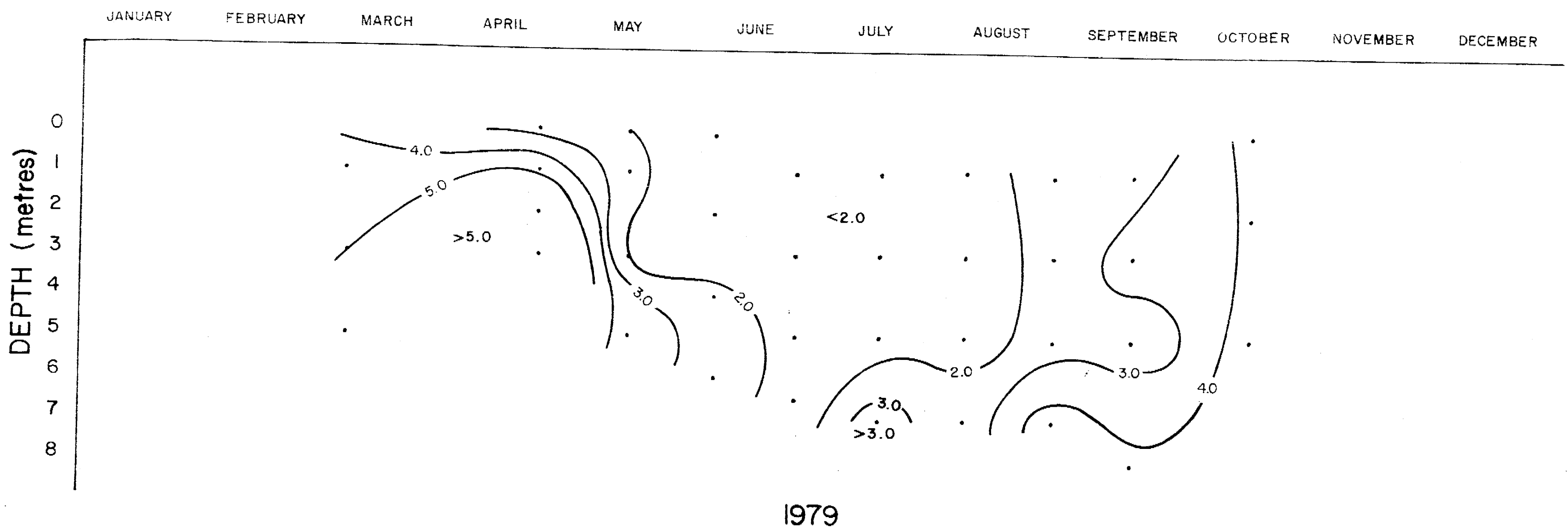


FIGURE 10. TIME-DEPTH DIAGRAM FOR TOTAL PHOSPHORUS (mg/L) AT STATION 1100871, FOR 1979.

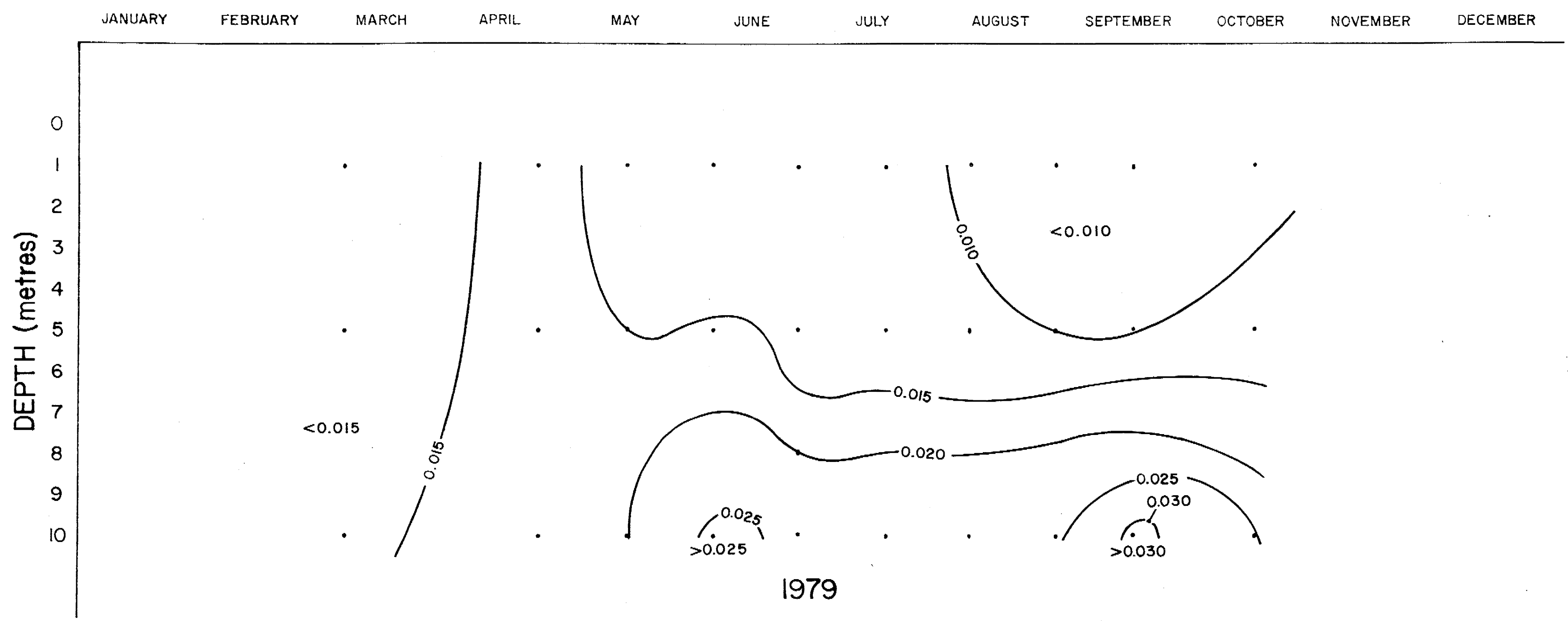
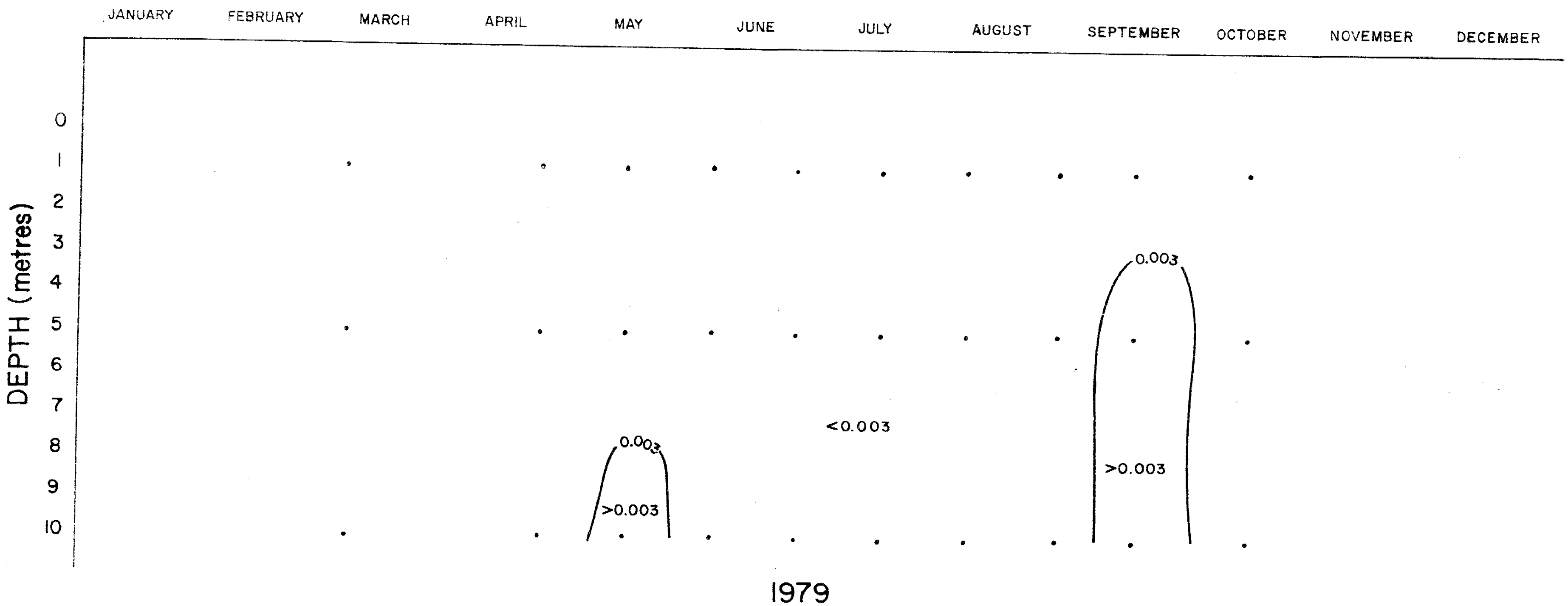


FIGURE 11. TIME – DEPTH DIAGRAM FOR ORTHO PHOSPHORUS (mg/L) AT STATION 1100871, FOR 1979



One further point which should be noted is the apparent absence of any internal regeneration of phosphorus despite low oxygen tensions in hypolimnetic waters. There is some increase in hypolimnetic concentrations but this appears only to be from a reflection of sedimentation of algal cells from the photic zone rather than internal loading.

Nitrogen values (Figure 12) were also relatively low, indicative of a moderately productive lake and not likely to cause algal blooms.

The nitrogen to phosphorus ratio at spring overturn 1979 was 27 to 1 (by weight) implying that of the two major nutrients, phosphorus was limiting.

Table 3 summarizes 1979 water chemistry characteristics of Fuller Lake and contrasts it to the data collected in 1980.

In 1980, a number of water quality parameters had changed appreciably. Particularly notable are the maximum values of pH (9.2 relative units), suspended organic material (21 mg/L), turbidity (25 N.T.U.), and organic carbon (18.5 mg/L). All of these results are a consequence of heavy algal growth in the water. Nutrient levels were also considerably different with nitrogen (total) at 2 mg/L (compared to a maximum of 0.55 ug/L in 1979) and total phosphorus at 33 ug/L at the surface and 86 ug/L at the bottom (compared to maxima of 16 and 31 ug/L in surface and bottom waters in 1979).

Assuming the October, 1980 samples are representative of the nutrient concentrations of May through September, then the concentrations in 1980 were much higher than for the same periods in 1979. The presence of nuisance levels of algae in 1980 is attributed to the high 1980 nutrient concentrations.

The sources of nutrient entering Fuller Lake are discussed in the next section.

FIGURE 12. TIME DEPTH DIAGRAM FOR TOTAL NITROGEN (mg/L) AT STATION 1100871, FOR 1979.

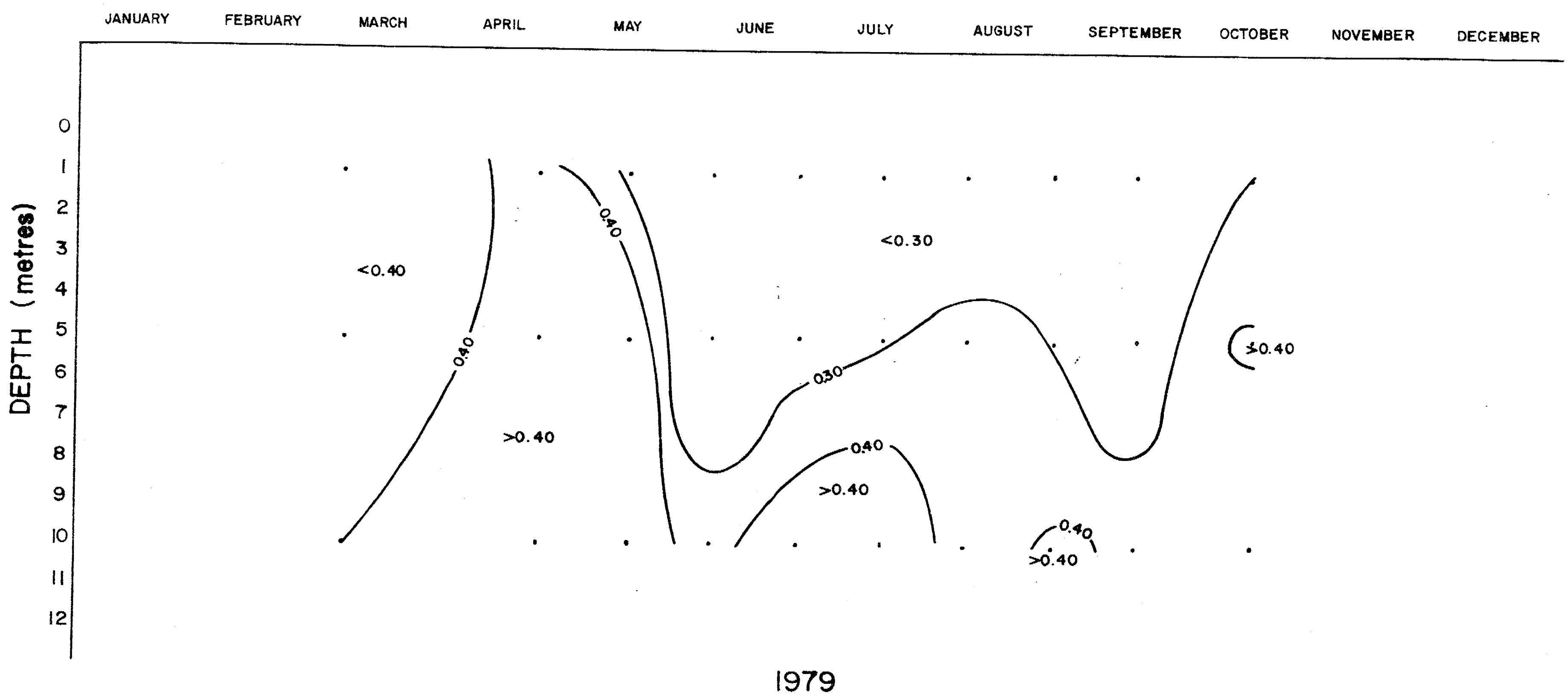


Table 3: Comparative Water Chemistry for 1979 (ten sampling dates) and 1980 (three sampling dates)

	1979		1980	
Parameter	Range	Mean	Range	Mean
pH	6.1-7.4	7.0	6.6-9.2	7.7
1 residue 105 (mg/L)	20-48	30	42-58	45.5
2 residue NF 105 (mg/L)	-	-	4-21	6.8
3 residue F 105 (mg/L)	-	-	34-42	38.6
4 residue 550 (mg/L)	-	-	18-22	20.5
5 residue NF 550 (mg/L)	-	-	1-3	1.75
6 residue NF VO (mg/L)	-	-	15-21	18.75
specific conductance (umho/cm)	50-55	52.2	54-65	57.6
7 turbidity (N.T.U.)	0.4-2.0	1.0	2.5-25	8.2
8 colour (TAC)	2-16	5	-	-
total alkalinity (mg/L)	8.3-12.9	11.5	11.5-18.5	13.9
organic carbon (mg/L)	L1-4	2.7	3-15	6.25
hardness (mg/L)	9.4-13.1	11.8	14.9-16.6	15.4
ammonia - Nitrogen (µg/L)	9-294	33	18-645	135.0
nitrate - Nitrogen (µg/L)	L20-80	30	-	L20
organic nitrogen (µg/L)	200-2000	363	250-2000	770.0
ortho phosphorus (µg/L)	L3-6	3	L3-46	6.6
total phosphorus (µg/L)	3-35	12	6-86	24.6
chlorophyll 'a' (µg/m^3)	1.1-5.0	2.7	4.5-67.0	17.3

Note:
1. total solids
2. suspended solids
3. dissolved solids
4. inorganic solids
5. suspended inorganic solids
6. suspended organic solids
7. N.T.U.: Nephelometric Turbidity Units
8. T.A.C.: Total Absorbed Colour

6. NUTRIENT SOURCES

No direct waste discharges to Fuller Lake are known. With one exception, all nutrients from outside the lake therefore are from diffuse sources. The exception is the piped diversion to the lake from Millar Creek. This inflow adds some nutrients. Besides external diffuse sources, some internal loading or recycling of nutrients from sediments could occur. However, from available water quality data (see previous section) this source does not appear to be significant.

Diffuse sources include rain falling directly on the lake, surface drainage, and ground water from areas of human activity such as lawn watering and domestic waste disposal to ground by means of septic tank drainfields. The possibility exists of groundwaters from outside the watershed entering through lake bottom sediments. This source will not be considered for Fuller Lake since no information is available.

Land use and cover in the Fuller Lake watershed is depicted in Figure 2. A summary of land use and cover class areas was presented in Table 2. In addition to private homes, several commercial and industrial, and various public use and recreational establishments exist in the watershed. These include a large motel, a restaurant, a building supply firm, a park with public tennis courts and beach, a winter sports centre and a riding ring. All are expected to contribute some nutrients to Fuller Lake.

7. POTENTIAL PHOSPHORUS CONTRIBUTIONS BY SOURCES

Potential phosphorus loading to the watershed is that amount of phosphorus which enters or is applied to soils of the watershed from natural (e.g., precipitation) or human (e.g., lawn fertilization) sources. This amount can be estimated but with some uncertainty. The following will outline estimates for sources considered pertinent to Fuller Lake. The next section will use these estimates of potential phosphorus to derive estimates of amounts actually entering the lake, taking into account losses in passing through the soil.

7.1 Private Residences

Phosphorus contributions from private residences were estimated as follows:

- 26 residences within watershed ranked by distance from lake
- 3 persons/residence/year assumed as occupancy rate
- 1.5 kg total phosphorus/person/year assumed for domestic wastewater (based on figures for typical residential dwellings with standard water-using fixtures and appliances)
- 50% of residences assumed to use lawn and garden fertilizers or manure on 280 m^2 (3000 ft^2) at 34 kg P/hectare (30 lb/acre)

Table 4: Summary of Potential Phosphorus Loading from Private Residences

Distance Zone (m)	No. of Residences	Total P from Wastewater (kg/yr)	Total P from Lawn and Garden Fert. (kg/yr)
0-50	17	76.5	8.4
50-100	4	18.0	1.9
100-500	2	9.0	0.9
> 500	3	13.5	1.9
Totals	26	117.0	13.1

7.2 Motel

Phosphorus contributions from the motel were estimated as follows:

- 30 units with 2 persons/unit assumed
- 100% occupancy in July and August (30 units x 2 per. x 2/12 yr = 10 per.-yrs)
- 80% occupancy in June and Sept (30 units x 2 per. x 0.8 x 2/12 yr = 8 per.-yrs)
- 50% occupancy other months (30 units x 2 per. x 0.5 x 8/12 yr = 20 per.-yrs)
- 1.5 kg total phosphorus/person/yr assumed (same as for residential dwelling)

- motel in 100-500 metre distance zone

Total potential phosphorus loading from the motel is estimated at 57 kg/year.

7.3 Winter Sports Centre

Though the facility itself is located just inside the topographically defined Fuller Lake watershed, waste disposal is to the east just outside the watershed. Therefore, no potential phosphorus loading from the facility to the watershed was calculated.

7.4 Riding Ring - Chemainus Western Horseman's Riding Club

Immediately south of the parking lot of the winter sports centre is a riding ring leased by the above club from the Municipality. Phosphorus contributions from this facility were calculated as follows (basic information from Mr. Earl O'Niel, Rec. Dir., Corp. of Dist. of N. Cowichan, and Mrs. Joyce Steffenson, Chemainus Western Horseman's Riding Club):

- 6 shows/yr (April-Sept) with 50 horses and riders per one day show (50 horses x 6/365 = 1 horse-yr; 50 riders x 6/365 = 1 person-yr)
- assume 2 spectators/horse and rider (50 x 2 x 6/365 = 2 person-yrs)
- occasional practices by individual riders throughout year considered insignificant
- 0.12 kg total phosphorus/person/year assumed for toilet waste
- 11.4 kg total phosphorus/horse/year assumed for waste left on site; assume 1/2 (5.7 kg) stays on site; remainder hauled away

Total potential phosphorus loading estimated for use of the riding ring = 6.1 kg/yr (0.4 kg by riders and spectators; 5.7 kg from horses).

7.5 Public Park and Beach

A public park of about 1.8 hectares (estimated lawn area = 0.75 ha) is located between the highway and Fuller Lake (west side of lake). Phosphorus contributions from the public park were estimated as follows:

- lawn area, washroom and changing facilities, sewage disposal area all in the 0-50 metre distance zone
- 150-200 people (say 175) use the park on a good day (O'Niel, pers. comm.)

so assume 8 days in June, 16 days in July and 16 days in August

- population equivalent of public park = 40/365 days x 175 persons/day = 19 person-yrs.
- 0.12 kg total phosphorus/person/year assumed for toilet waste
- 55 kg (120 lb) 30-3-10 fertilizer used on lawn area annually (Dougherty, pers. comm.)

Total potential phosphorus loading estimated for public park and beach area equals 3.1 kg/year (wastewater = 2.3 kg; lawn fertilization = 0.8 kg)

7.6 Commercial Establishment and Restaurant

A building supply outlet and a restaurant are within the watershed of Fuller Lake. Phosphorus contributions from these establishments were estimated as follows:

- building supply outlet assume 10 persons/day/6 day week for total yearly equivalent of 9 persons (10 x 6/7 = 9 person-yrs)
- restaurant capacity assumed = 40 persons
- 20% of capacity use of restaurant 6 days/week assumed for total yearly equivalent of 7 persons (40 x 0.20 x 6/7 = 7 person-yrs)
- 1.5 kg P/person/yr assumed (same as for residential dwelling)
- both restaurant and building supply in the 100-500 metre distance zone

Total potential phosphorus loading from the above sources estimated at 24 kg/yr (13.5 kg from building supply; 10.5 kg from restaurant).

7.7 Rainfall

Annual rainfall for the Fuller Lake watershed has been estimated at 1130 mm. With areas of 61.1 hectares and 24.1 hectares for the watershed and lake respectively, this amounts to 690 dam^3/yr and 272 dam^3/yr of rainfall. Assuming total phosphorus concentrations of 0.02 mg/L in rainwater, total potential phosphorus loading would be 13.8 kg for rain falling on the watershed and 5.44 kg for rain falling on the lake.

7.8 Summary

A summary of potential loadings of ohosphorus to Fuller Lake is presented in Table 5 in the next section along with estimates of actual phosphorus entering Fuller Lake.

8. PHOSPHORUS CONTRIBUTIONS TO FULLER LAKE

Nutrients added to the watershed undergo adsorption, transformation etc. (reduction in amount) in passing through the soil or over the land surface to Fuller Lake. Watershed characteristics (soil, surficial geology, topography, etc.) would affect these reductions as would distance from the source to the lake. Potential nutrient sources, as estimated in the previous section, would be reduced therefore, and only a fraction would be transmitted. Table 5 presents estimates of potential loadings, proportions of potential loadings estimated to reach the lake, and estimates of actual loadings to the lake. Table 6 presents these estimates on a relative basis.

A check of the total phosphorus loading estimate was also made using a different approach. Total input can be estimated from lake phosphorus concentrations using relationships like those derived by Dillon and Rigler (1975) Reckhow and Simpson (1980) and others. These two models give loading estimates of 0.17 and 0.19 $g/m^2/yr$ or 42 and 46 kg/year based on a lake concentration of 13 ug/L from spring 1979. The difference between the loadings derived from land use (54 kg) and the loading based on lake morphometry and hydrology (42-46 kg) are reflections of these two different approaches. Some of the assumptions in both cases are likely subject to some error, but considering the number of parameters and assumptions in both cases, the results are reasonably close to each other and provide some support for their validity.

Table 5: Sources and Estimated Loadings of Phosphorus to Fuller Lake

Source	Sub-source	Distance Zone (m)	Estimated Potential Loading (kg/yr)	Estimated Proportion Reaching Lake[1]	Estimated Actual Loading (kg/yr)
Residential	wastewater	0-50	76.5	0.3	23.0
		50-100	18.0	0.2	3.6
		100-500	9.0	0.15	1.4
		>500	13.5	0.07	0.9
	lawn fertilization	0-50	8.4	0.3	2.5
		50-100	1.9	0.2	0.4
		100-500	0.9	0.15	0.1
		>500	1.9	0.07	0.1
Motel	wastewater	100-500	57.0	0.15	8.6
Riding-ring	horses	100-500	5.7	0.15	0.9
	riders/spectators	100-500	0.4	0.15	0.1
Park & Beach	wastewater	0-50	2.3	0.3	0.7
	lawn fertilizer	0-50	0.8	0.3	0.2
Commercial	lumber supply	100-500	13.5	0.15	2.0
	restaurant	100-500	10.5	0.15	1.6
Rainfall	on lake	-	5.4	1.0	5.4
	on watershed	0-50	2.9	0.3	0.9
		50-100	1.9	0.2	0.4
		100-500	8.0	0.15	1.2
		>500	1.0	0.07	0.1
	Totals		239.5		54.1

1 Estimates of proportions are based on information on soils, distance to the lake, literature values, and professional judgement.

Table 6: Relative Phosphorus Loading to Fuller lake from Diffuse Sources

Source	Estimated Actual Loading (kg/yr)	Estimated Fraction of Total (%)
Residential - wastewater	28.9	53.4
- lawn fertilization	3.1	5.7
Motel wastewater	8.6	15.9
Riding ring	1.0	1.8
Park and Beach	0.9	1.7
Commercial	3.6	6.7
Rainfall - on lake	5.4	10.0
- on watershed	2.6	4.8
Totals	54.1	100.0

9. DISCUSSION

As can be seen from Table 6, about 60 percent of the phosphorus estimated to be reaching Fuller Lake from diffuse sources is coming from residential wastewater and lawn and garden fertilization. It is possible that lawn and garden fertilization has been over-estimated though only 50% of residents were assumed to use fertilizers or manure on only 280 m^2 (3000 ft^2) of lawn or garden.

Further fractions, each of about 15 percent of total estimated lake phosphorus loading from diffuse sources, come from the motel and from rainfall. Estimated contributions from the motel have been calculated based on wastewater having the same characteristics (flows and phosphorus concentrations) as typical residential wastewater. If no kitchen waste is contributed by the motel, a 40% reduction or about 3.5 kg/yr less phosphorus may be appropriate.

About 10 percent of estimated phosphorus contributions to the lake comes from commercial and recreational uses of the watershed. Both the public park with beach and the riding ring south of the winter sports centre contribute very small amounts. This is largely due to the relatively short period of use during the summer. Also, a relatively low per capita phosphorus contribution (0.12 kg/yr) was used accounting only for toilet wastes (i.e., compared to typical residential wastes of 1.5 kg/yr). It should be recognized that loadings from these two sources are contributed primarily during the summer. However, it is possible that actual entry of most of the phosphorus to the lake would be delayed until fall and winter rains percolate through the soils, flushing some of the phosphorus to the lake.

Entry of nutrients into the lake undoubtedly varies year to year, according to rainfall, and this appears to be the cause for the dramatic difference between 1979 and 1980. Rainfall in December 1978 at Crofton was 36% of the normal monthly mean but during the winter of 1979-1980, very heavy rainfall was recorded. Data for December 1979 at Crofton is not available, but rainfall at Departure Bay for the same time period was 170 percent of the monthly normal. Heavier rainfall could result in watershed soils being more thoroughly flushed and less phosphorus being retained. This would be particularly true of soils receiving septic tank effluent in the zone closest to the lakeshore. Because the lake has a low flushing rate the impact of the increased watershed runoff would be quite pronounced. Increased runoff supplying unusually large amounts of phosphorus probably caused the algal blooms in the summer and fall of 1980.

Similar circumstances occurred prior to the 1966 algal bloom. Rainfall during December 1965 and January 1966 was 50 percent above the 30 year precipitation average for the two months.

10. RECOMMENDATIONS AND CONCLUSIONS

The basic cause of algal blooms in Fuller Lake such as that which occurred in 1980 is believed to be high lake phosphorus concentrations. Lake phosphorus concentrations are a consequence of both water and nutrient (phosphorus) budget components as discussed above. In a lake such as Fuller Lake, where apparently little if any recycling of phosphorus from sediments occurs, phosphorus concentrations are primarily controlled by volumes of runoff water and phosphorus.

Though the shoreline of Fuller Lake is not as highly developed as many other lakes in southwestern British Columbia, human sources are still estimated to be by far the largest contributors of phosphorus to the lake (Table 6). If domestic wastes were collected and removed from the watershed (e.g., sewage collection and treatment at a treatment plant) significant reductions (53 percent) in phosphorus loadings should occur and lake water quality improvements should occur. Costs are recognized and identification of faulty onsite systems, with subsequent site by site improvements, may be more feasible. Lawn and garden fertilization practices may also need to be reviewed.

Before proceeding with costly sewer projects or even onsite improvement projects, additional investigations beyond this very preliminary review would seem prudent. Additional point or diffuse sources may have been overlooked.

Dilution and flushing by increasing water inflow may be a more effective means of improving water quality. Given the existing diversion pipeline into the lake from Millar Creek, and the low nutrient concentrations in Millar Creek, possibilities for increasing inflow should be pursued. Given also the controlled outlet and MacMillan Bloedel's water intake, schedules for timing of withdrawal and intake, or controls of release depths should be reviewed. The most effective summer (post-stratification) withdrawal would be from below the thermocline. Most effective times for bulk release of water would be immediately after fall and spring overturn. It should be possible to develop an overall schedule for diversion inflows and withdrawal/releases that benefit water quality and/or, at the same time, accommodate lake refilling and control structure limitations.

11. REFERENCES CITED

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