Summary Report

Wisconsin DNR
Lakes Planning Grant

Island Chain of Lakes

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to:	Island Chain of Lakes Management District
date:	6 January 1992

Executive summary

The Island Chain is a popular set of lakes used extensively for recreation. The study of the lakes funded by a Wisconsin Department of Natural Resources Lakes Planning Grant was designed to analyze and report on three main issues concerning water quality. These issues were:

1. nutrient concentrations in the lakes;
2. concentrations of fecal coliform bacteria in shoreline areas; and
3. current trophic status and algal populations found in the lakes.

The sampling and analysis of the lakes emphasized the evaluation of conditions that would support and promote the growth of algae. Nutrient concentrations can be related directly to the biomass of algae. The study examined the levels of major algal nutrients (phosphorus and nitrogen) in the lakes and analyzed concentrations of nutrients in incoming streams that are the main sources of water to the Island Chain of Lakes. Bacteria were sampled in in-shore areas as an indication of potential degradation of water quality from failed septic systems along the lakes, which might indicate increased loading of nutrients. Several independent measures, including oxygen profiles, nutrient concentrations, chlorophyll concentrations, water transparency and algal concentrations, were evaluated to indicate the current trophic (productivity) status of the lakes.

Settlement of the shoreline along the Island Chain of Lakes is increasing. During the course of sampling we observed many apparent zoning violations. Along the lakeshores we found numerous cases of inadequate set-back of structures, some indications of inadequate disposal systems and other cases where disposal systems were apparently lacking. These apparent zoning violations should be evaluated by Rusk and Chippewa Counties. The most serious problems were found along the north and east shores of Island Lake in Rusk County.

Although the lakes vary in size and morphometry, they are all physically connected and three of the lakes occur along the main flow routing of water through the chain. These three lakes, Chain, McCann and Island (CMI), have an apparent brown color. Clear Lake has lower color and is more transparent than the other lakes. It also is influenced more by groundwater inputs and is chemically different from the other lakes.

The largest single source of water to the Island Chain enters via Cedar Creek, which begins as the outlet of Lower Long Lake. There are some indications that nutrient concentrations might increase along Cedar Creek before it enters Chain Lake based on comparisons of nutrient concentrations in Lower Long and Chain Lakes. Some further analysis of this pattern is recommended, although there does not appear to be impact from any agricultural activities along Cedar Creek that would result in elevated nutrient concentrations.

Two small streams entering along the north shore of Chain Lake bring in relatively little total flow to the Chain, but these streams are very highly colored and nutrient concentrations also are high. Ammonia concentrations are particularly elevated compared with other surface water inflows.

All of the lakes stratify each summer and each experiences oxygen depletion in deeper waters. Chain, Island and McCann Lakes have higher concentrations of total phosphorus, which supports greater algal biomass, than does Clear Lake. This higher algal biomass results in a depletion of inorganic nitrogen in surface waters and relatively high pH values in Chain, Island and McCann Lakes. These lakes contained several bloom-forming species of blue-green bacteria during August, and they were present at higher concentrations than in Clear Lake. Chemical conditions in Chain, McCann and Island Lakes would be expected to promote the further growth of bloom-forming blue-green bacteria should concentrations of phosphorus increase, which would result in decreased water transparency and greater depletion of dissolved oxygen in the water column.

Clear Lake, being more transparent than the other lakes, and also having relatively low phosphorus concentrations that are clearly limiting algal growth, is highly susceptible to change from present conditions. Small increases in total phosphorus loading to these lakes would result in perceived changes in transparency and water quality. Currently, much of the southern shoreline of Clear Lake is undeveloped. Any development of the area should proceed with extreme caution because changes in water quality could result. Moreover, due to the long residence time of water in the lake, any changes in loading would be difficult to reverse over the short term. Further analysis of Clear Lake, including some sampling of groundwater inputs and annual monitoring of surface water nutrient concentrations and transparency, is highly recommended. The trophic status of Clear Lake is better than the other lakes, but it is likely more subject to change should nutrient concentrations increase.

Nutrient concentrations remain similar along the lakes from Chain to Island, with some slight decrease in Island Lake. This pattern appears to result from the dominant flow of water entering via Cedar Creek, the lack of significant surface water inputs along the chain, and the relative lack of influence of agricultural or other activities that would produce higher nutrient concentrations along the chain. As a consequence, nutrient concentrations are determined largely from the greater watershed in relation to natural sources of nutrients.

The bacterial survey was conducted as close to shore as possible and on a calm day, but near-shore sources could not be sampled directly. The results of the survey indicated no major problems but there were slightly elevated levels of fecal coliform bacteria in two areas. These two areas were the Arrowhead Bible Camp beach area and the north shore of McCann Lake just east of the Backwoods Resort. The sampling was conducted during a time when there were no visitors at the Arrowhead Camp and higher levels may have been found during a time of active use. The levels observed were above the State standard for drinking water but below the standard for recreational use.

These problems should be re-confirmed and the sources should be identified. While elevated levels were not found in other in-shore areas, several apparent zoning violations and the possibility of failed septic systems in some areas suggest that some specific analysis be conducted to measure shallow groundwater contributions directly. Key areas for this work would be Island Lake and Clear Lake.

The current trophic state of the lakes was estimated based on several measures. Clear Lake is at the lower limit of mesotrophy (moderate productivity), while Chain, McCann and Island Lakes are mesotrophic bordering on eutrophic (more productive). Several problems were found in historical data collected on the Island Chain of Lakes. These problems inhibit a complete evaluation of whether trophic conditions have changed in the lakes over time. Nonetheless, based on secchi disc transparencies, which are reproduced with reasonable accuracy, measured in 1977 and 1991 there does not appear to have been any significant recent change in trophic conditions of the lakes.

Further monitoring of the lakes is warranted. A reasonable approach would be to sample McCann Lake, which is the shallowest and most eutrophic, and Clear Lake, which is most likely to change the fastest in response to inputs. Sampling of McCann Lake could be related to conditions in Chain and Island Lakes. This continued monitoring is suggested by the potential for change in the Chain, McCann and Island Lakes to conditions that would support blooms of blue-green bacteria and by the sensitivity of Clear Lake to additional inputs of phosphorus in the context of increasing development of the lakeshores. Enhanced inspection of properties for zoning violations, particularly related to wastewater disposal, also is highly recommended.

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Introduction

The Island Chain of Lakes is comprised of a large drainage network of four lakes located primarily in Rusk County, Wisconsin. In addition to drainage from the immediate watersheds surrounding each lake, the Island Chain also receives drainage from Lower Long Lake. The flow of water through the chain proceeds from Lower Long Lake via Cedar Creek to Chain Lake, McCann Lake and then to Island Lake (Figure 1). The fourth lake, Clear Lake, receives some water exchange with Chain Lake, but it is fed by additional groundwater inputs (WI DNR 1981).

Each of the four lakes stratifies thermally during the summer. Two of the lakes, Chain and Clear, are approximately 23 m in depth (75') and one lake (McCann) is only half as deep. All of the lakes are brown-stained, although Clear Lake has lower dissolved color. Drainage entering the lakes from some surface water inlets is very darkly colored.

Much of the shoreline along the lakes is developed, with the exception of the southern shore of Clear Lake and along the channel between McCann and Island lakes. The Island Chain of Lakes Association and property owners around the lakes have been concerned that increasing development of the lakeshores and failing septic systems might be affecting the water quality of the lakes. The Island Chain of Lakes Association applied for and received funding from the Wisconsin Department of Natural Resources to conduct an analysis of the the current status of the lakes. This analysis proposed sampling of the lakes and inlet streams during the summer of 1991 to evaluate:

1) the current trophic status of the lakes;

2) potential sources of nutrients to the lakes; and

3) the concentrations of bacteria in in-shore areas.

Characteristics of the study lakes

The entire watershed area is 4093 ha. The largest volume of water entering the Island Chain is from Cedar Creek, which begins as the outlet of Lower Long Lake and enters Chain Lake through a large marshy area. Three additional small surface water inflows were located.

Chain and Island are the largest of the lakes, while Clear Lake is the smallest (Table 1). Chain, McCann and Island Lakes are connected directly by the flow routing of water through the watershed. In addition, Chain and Island Lakes are quite similar in many physical characteristics. McCann is smaller and shallower than these lakes and it also has a very short water residence time.

Clear Lake is deep relative to its surface area and it has the greatest mean depth and a long estimated water residence time compared with the other lakes. Because of groundwater inputs, Clear Lake has lower water color than the other lakes. These differences in physical characteristics influence the pattern of temperature stratification in Clear Lake and chemical conditions throughout the water column.

Methods

Sampling locations were selected based on a survey conducted by boat on 5 May 1991. One sampling site was located at the deepest part of each lake basin (Figures 1-4). In addition, four inlet streams were identified and selected for sampling. These inlets include: the Cedar Creek inflow, two small, darkwater streams on the western side of Chain Lake along Plummer Road and one inlet to the McCann Lake Channel. The initial survey in early May also identified potential locations for sampling in-shore bacterial populations in August.

Water samples were collected at several different sites, depths and times throughout the summer of 1991. In addition, a variety of analyses were conducted on the lakes, at UW-EC and at the State Laboratory of Hygiene. A summary of these analyses is given in Table 2.

The lakes and inlet streams were sampled once each month from May through August. All of the sites were accessed by boat, except for the two inlets on the western side of Chain Lake, which were sampled along Plummer Road. On each sampling date, surface water samples were collected at each site. Sampling began at Cedar Creek and moved down the Island Chain. A two person crew normally conducted the sampling; this crew was greatly assisted by Dr. Owen Marshall, who also allowed use of his boat.

Table 1. Physical characteristics of Island Chain of Lakes.

	Chain	McCann	Clear	Island
Watershed area (ha)[a]	3322	3432	[b]	4093
Lake area (ha)	189	53.8	38.4	214
Volume (X $10^6 m^3$)	10.5	2.4	3.4	14.0
Maximum depth (m)	22.5	11.5	22.5	16.5
Mean depth (m)	5.5	4.4	9.1	6.5
Water residence (yr)[c]	1.9	0.4	25	2.0

[a] includes Lower Long Lake drainage area

[b] receives some water exchange from Chain Lake; is fed mainly by seepage

[c] estimated by WI DNR (1981)

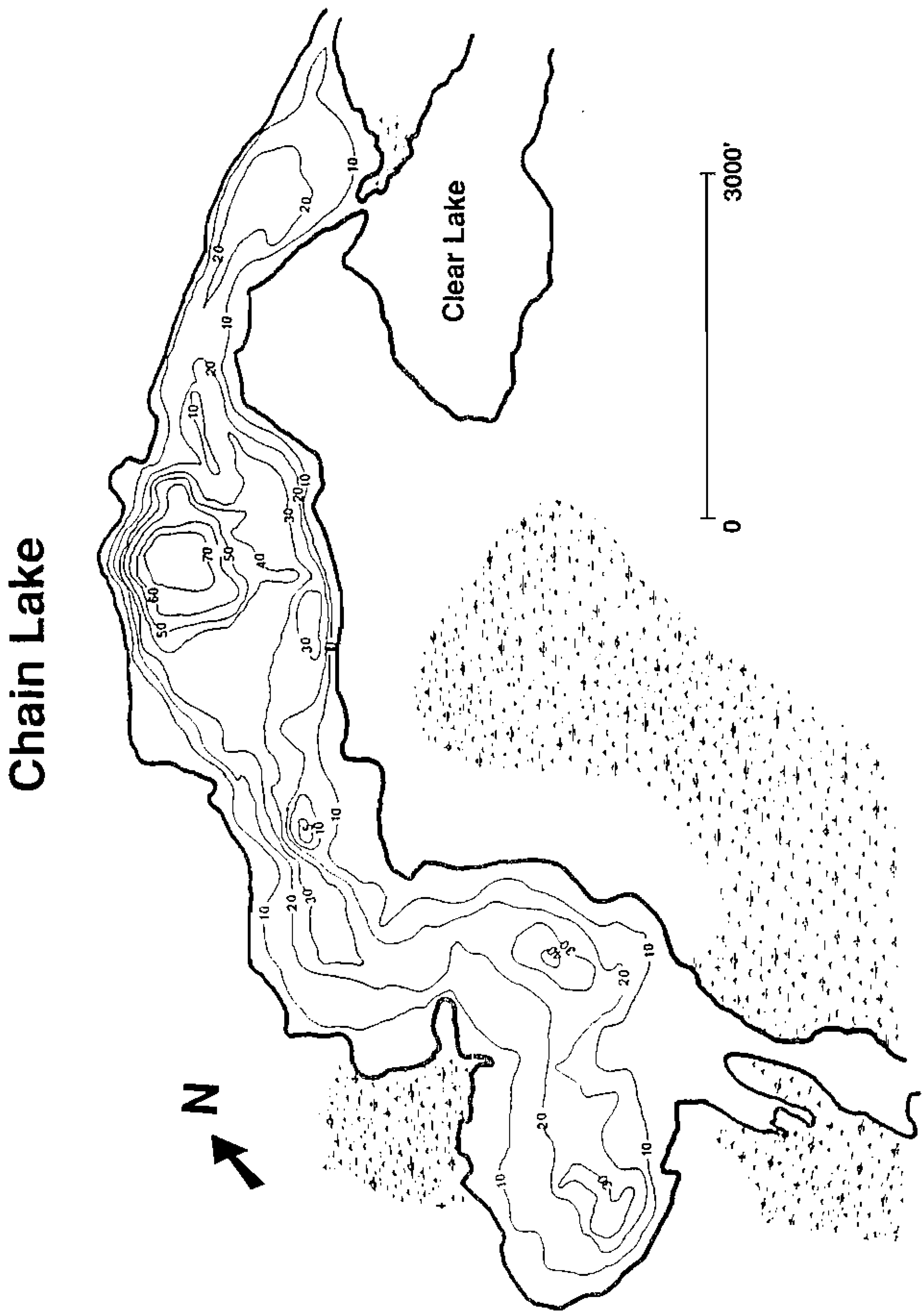


FIGURE 1

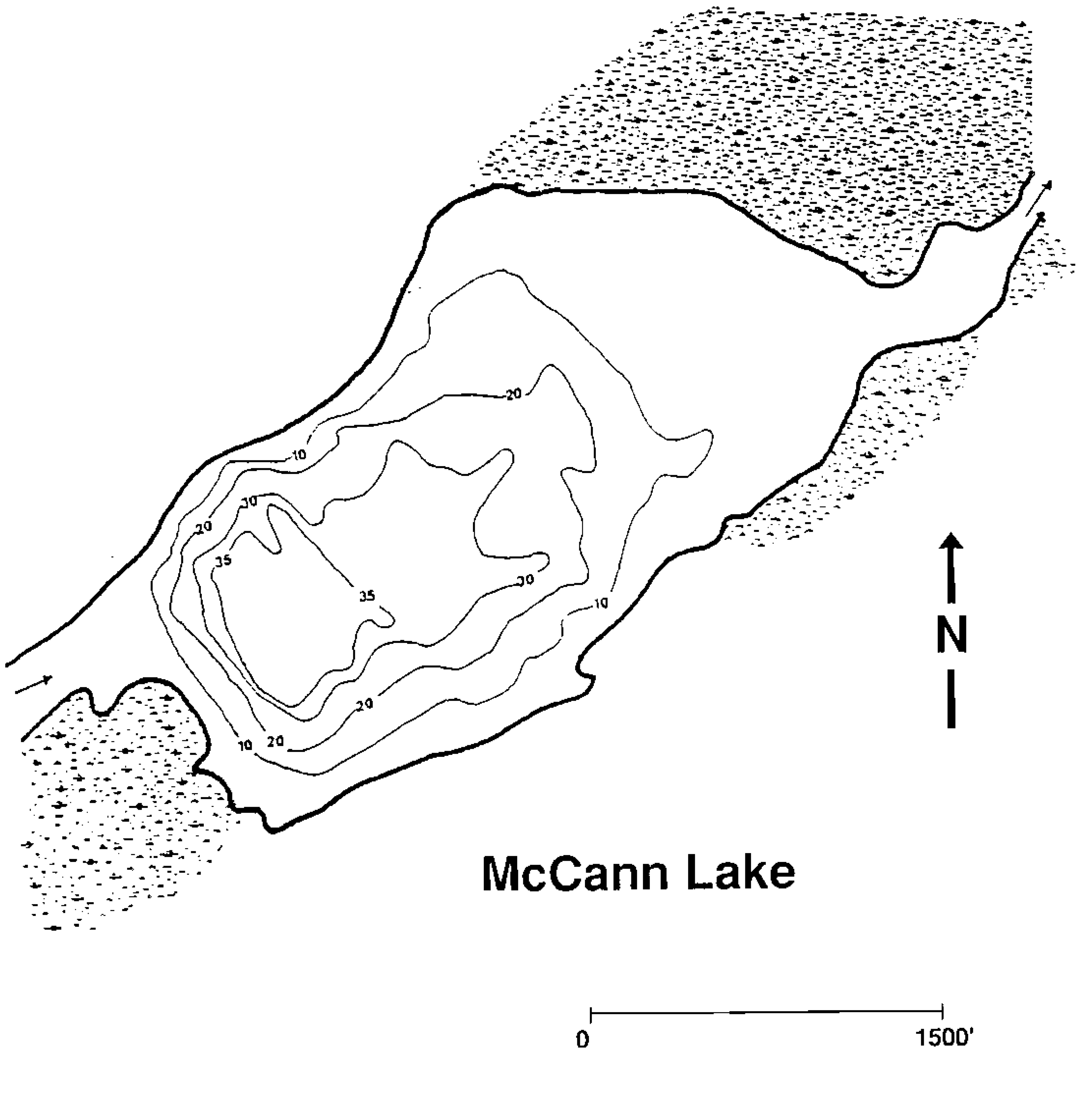


FIGURE 2

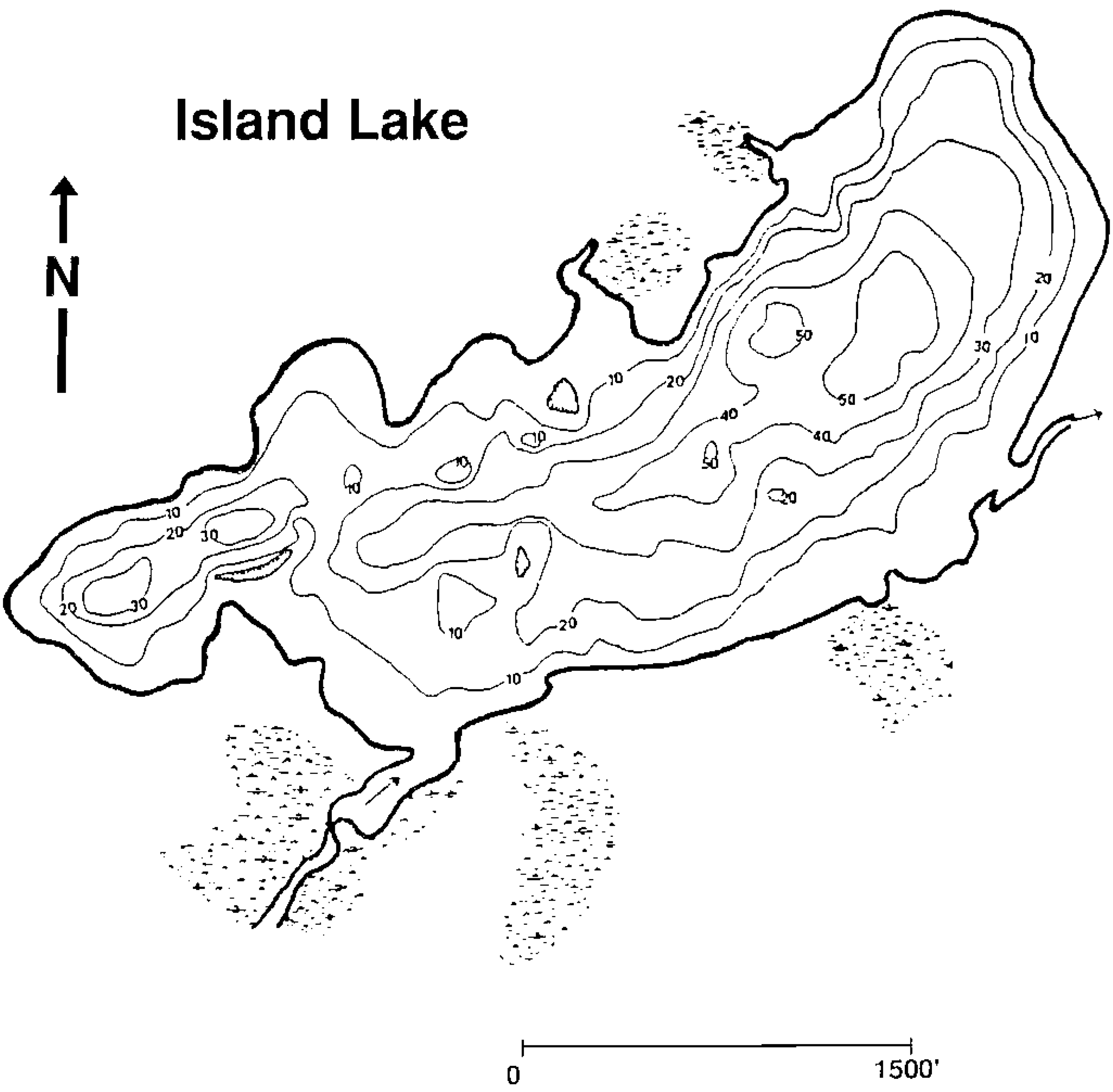


FIGURE 3

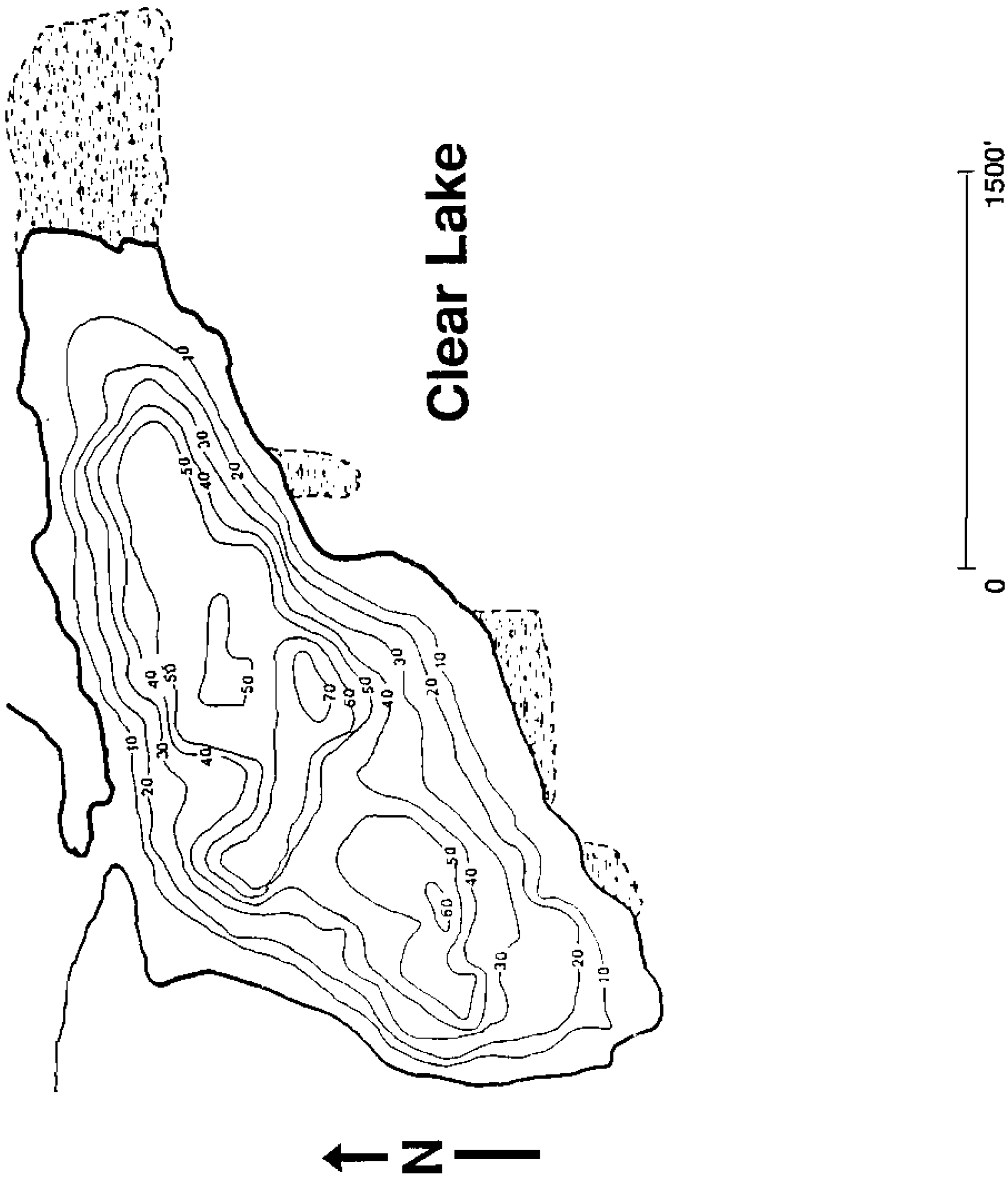


FIGURE 4

Table 2. 1991 sampling and analysis for Island Chain of Lakes.

	Monthly	August (0.5m)	August (deep)[a]	Inlets
Temperature/oxygen profile	X	X		
Secchi disc transparency	X	X		
pH	X	X	X	X
Alkalinity	X	X	X	X
Color	X	X	X	X
Total phosphorus	X	X	X	X
Soluble phosphorus	X	X	X	X
Total nitrogen	X	X	X	X
Chlorophyll a		X		
Algal sample collected	X	X		
Algal sample counted		X		
Coliform bacteria		[b]		

[a] sample collected at various depths depending upon a lake's maximum depth

[b] synoptic survey of bacteria conducted with multiple samples in each lake

The deepwater sampling location in each lake was located by depth finder and an anchor was lowered to maintain position. A Secchi disc was used to measure the transparency of the lakes. Then, a Yellow Springs Instruments (YSI) meter was used to measure oxygen and temperature of the water column. The meter was calibrated in air and checked against an oxygen measurement by Winkler titration. In addition, quality control samples were collected from the water column, titrated by the Winkler method and checked against oxygen measurements based on the YSI meter. Using the YSI meter allowed for rapid and complete measurement of the water column at 1 m increments. It is important to note that the YSI meter does not produce absolutely accurate readings and is approximate at low levels. Nonetheless, the YSI meter is useful in indicating the general distribution of oxygen in the lakes.

Three plastic bottles of different sizes were filled at each site at a depth of 0.5 m. These bottles had been prepared and quality-assured by the State Laboratory of Hygiene for specific analyses requiring different preservation steps and analytical procedures. Immediately upon filling the samples were placed in a cooler containing ice and freezer pacs.

A 1.5 m integrated sample of the surface water was collected each month at each site and preserved for the analysis of algal species. The August sample was counted using an inverted microscope technique to determine species presence and algal abundance. All species identifications and counting were done by an experienced analyst, Dr. Lloyd Ohl of the Department of Biology, UW-EC.

Upon returning from each field trip, samples were prepared for shipment to the State Laboratory of Hygiene. Samples were cooled to 4° C. if they had not reached that temperature and H_2SO_4 was added as a preservative to one of the sample bottles. Normally samples from two sites were packed together with ice in one cooler with the appropriate sample identification forms. The coolers were taped together and shipped via priority mail for arrival the next day at the State Laboratory of Hygiene.

A synoptic survey of coliform bacterial concentrations was conducted on 13 August 1991. Several samples were collected in sterilized bottles from the in-shore areas of each lake. These samples were cooled and shipped overnight to the State Lab for analysis.

Analyses conducted at the State Lab followed standard protocols and the results are supported by extensive quality control/quality assurance procedures. Results from the State Lab also can be compared to other lake sampling projects supported by the Lakes Planning Grant Program. Analytical results were reported from the State Lab to the WI DNR in Spooner and then forwarded to UW-EC. Data for the project was entered into a Quattro Pro 3.0 spreadsheet on a Zenith 386 SX computer. Hard copies of data reports from the State Lab are filed at the DNR and UW-EC.

Results and Discussion

Temperature and dissolved oxygen

All sampling was conducted as planned and as outlined in Table 2. The sampling dates were 23 May, 23 June, 24 July and 13 August 1991. Samples were collected from each of the stations on all of the sampling dates, with the exception of one of the small streams (UNS-2), which had no flow during July and August. Some problems were encountered in reporting of the data from the State Lab of Hygiene, but eventually all data were received except for some limited analyses for Clear Lake on the July sampling date.

Each of the lakes had warmed considerably and was stratified by the first sampling date in May (Figures 5-20). Surface water temperatures reached a maximum July. Cooler weather in August resulted in lower temperatures in the surface layer (epilimnion). The thickness of the epilimnion varied between 2 and 5 meters. Chain and Clear Lakes had cooler bottom water (hypolimnetic) temperatures due to their greater depths, which prohibited lengthy circulation of the water column. The relative protection of Clear Lake also resulted in generally higher surface water temperatures than in Chain or Island Lakes.

On 23 May, oxygen was present throughout the water column in all of the lakes, although some reduction in oxygen with depth was observed, particularly in McCann Lake. Oxygen consumption in deeper waters continued throughout the summer with depletion of oxygen and anaerobic conditions at depths > 6 m in Chain, McCann and Island Lakes. Due to slighly higher transparency (z_{sd}) and the abrupt pattern of stratification, Clear Lake developed a slight metalimnetic (middle layer) oxygen maximum in June and July. Oxygen depletion did occur in deeper waters and by August the water column was anoxic below 10 m.

Flow routing of water

Chemical conditions in the lakes are influenced by the composition and relative volumes of the inlet streams and the flow routing of water through the chain. Large differences were found in the composition of the inlet streams (Table 3). The two, small darkwater streams entering Chain Lake had relatively low alkalinity and pH, very high dissolved color and very high concentrations of total phosphorus and ammonia. While these two streams do not contribute a large volume of water to the lake, they are expected to influence nutrient concentrations in the shallow embayments where they enter. The inlet to the McCann Lake channel contributes a small volume of higher alkalinity water containing moderate concentrations of phosphorus and nitrogen.

Cedar Creek contributes the largest volume of water to the lakes. The chemical composition of this inlet was reflected in the conditions observed in Chain, McCann and

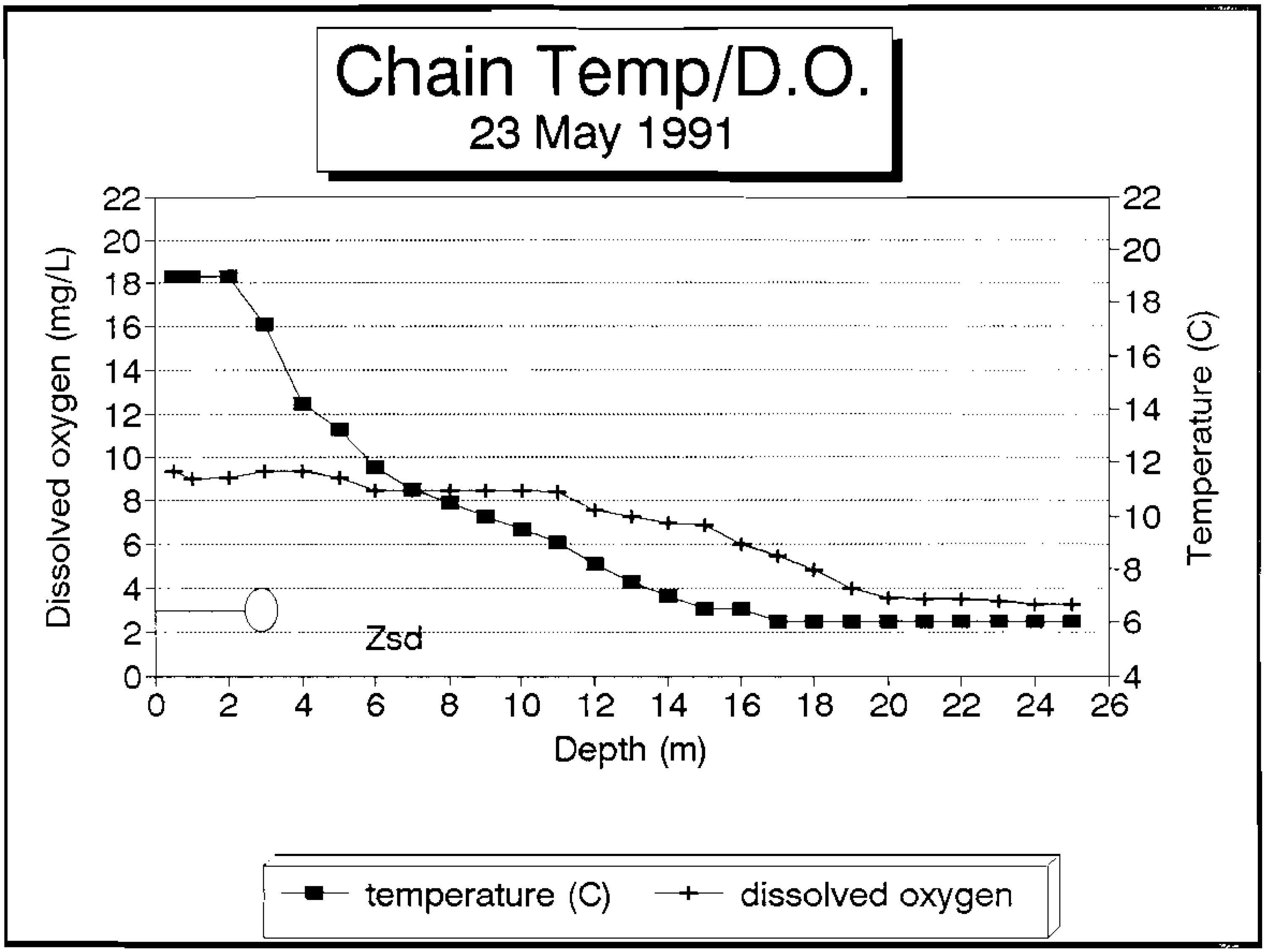
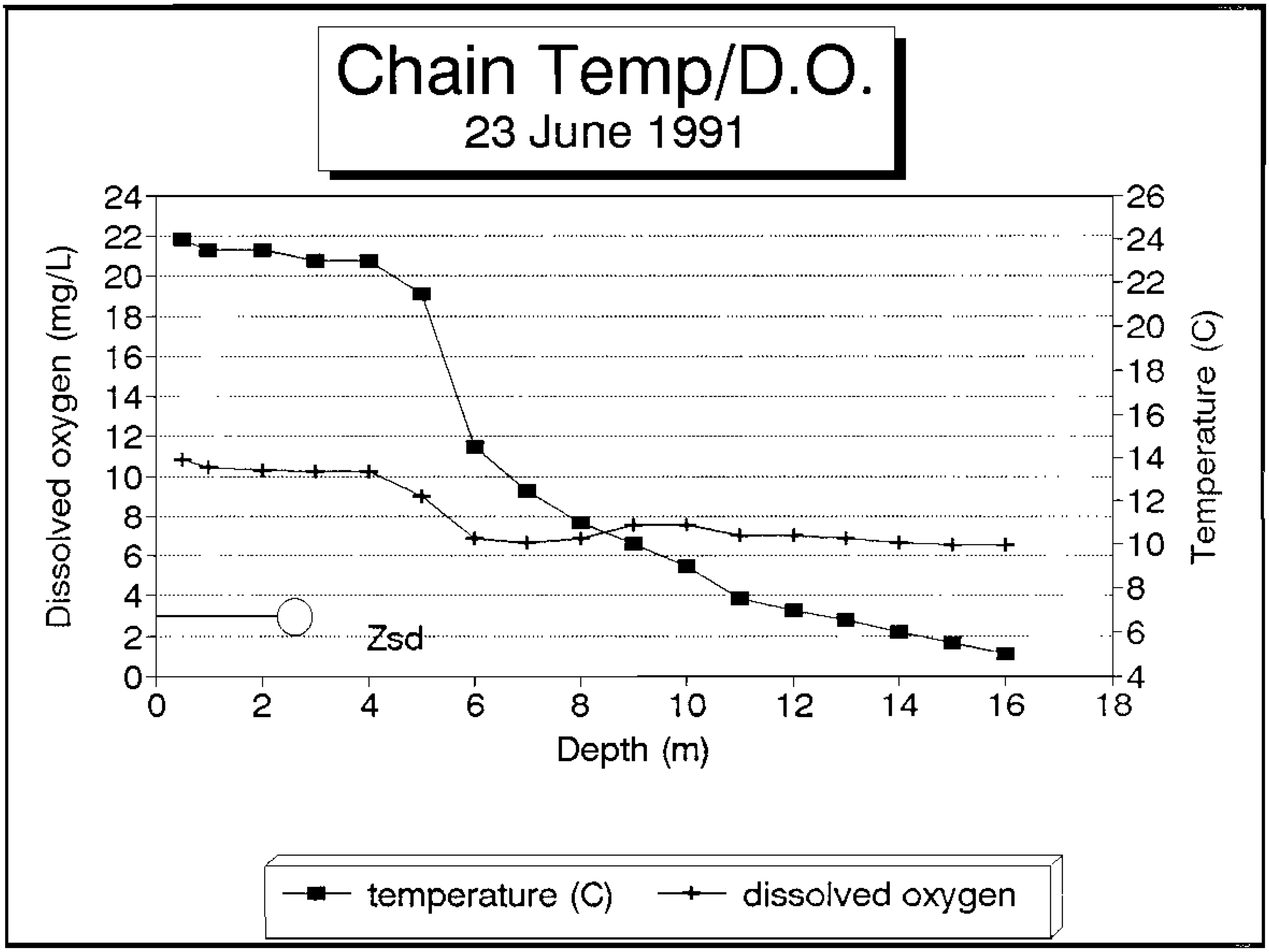
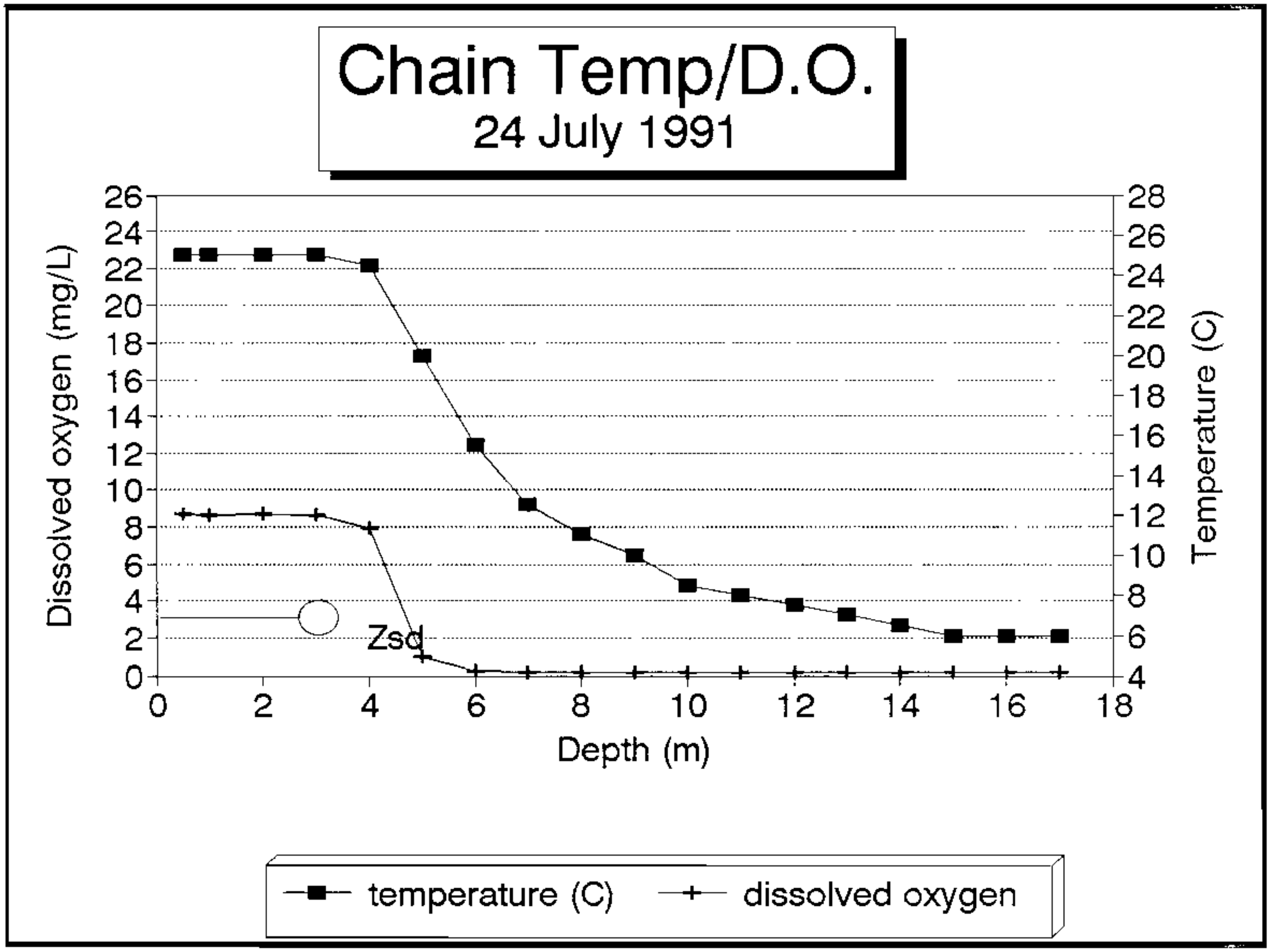

Chain Temp/D.O.
23 May 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
2
4
6
8
10
12
14
16
18
20
22
24
26
temperature (C)
dissolved oxygen

FIGURE 5



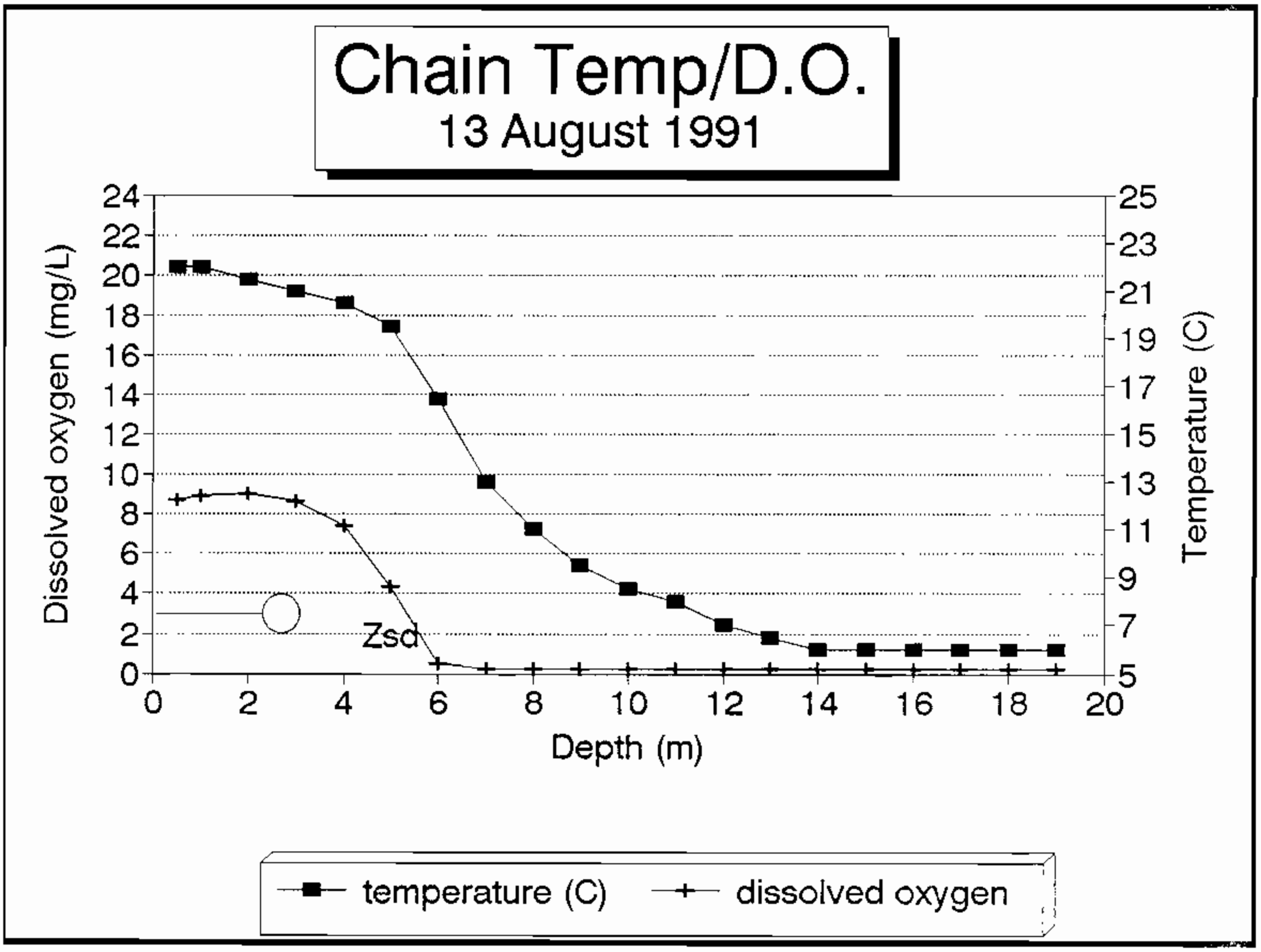
Chain Temp/D.O.
23 June 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
temperature (C)
dissolved oxygen

FIGURE 6



Chain Temp/D.O.
24 July 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
temperature (C)
dissolved oxygen

FIGURE 7



Chain Temp/D.O.
13 August 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
2
4
6
8
10
12
14
16
18
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22
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5
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9
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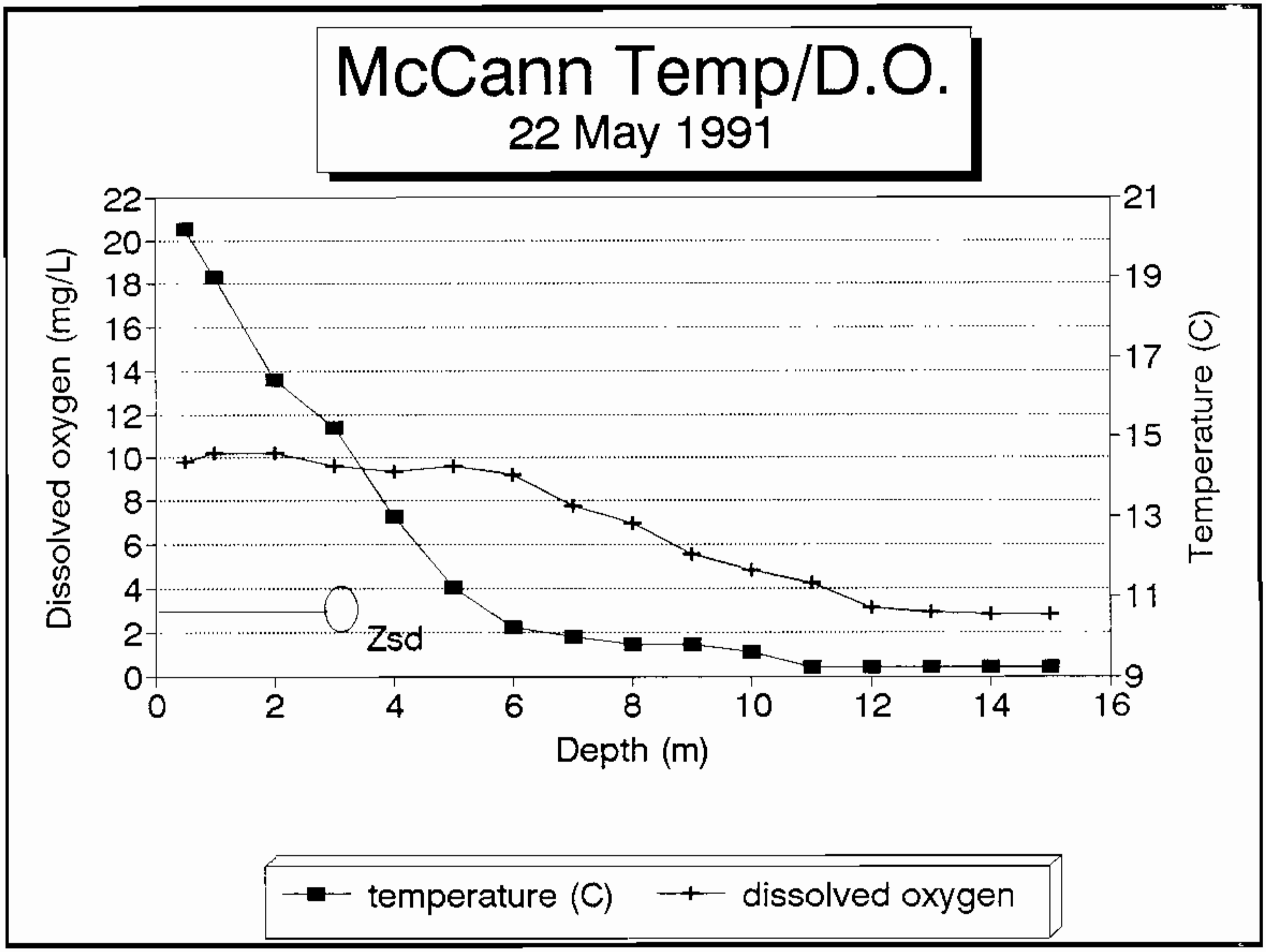
13
15
17
19
21
23
25
temperature (C)
dissolved oxygen

FIGURE 8


McCann Temp/D.O.
22 May 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
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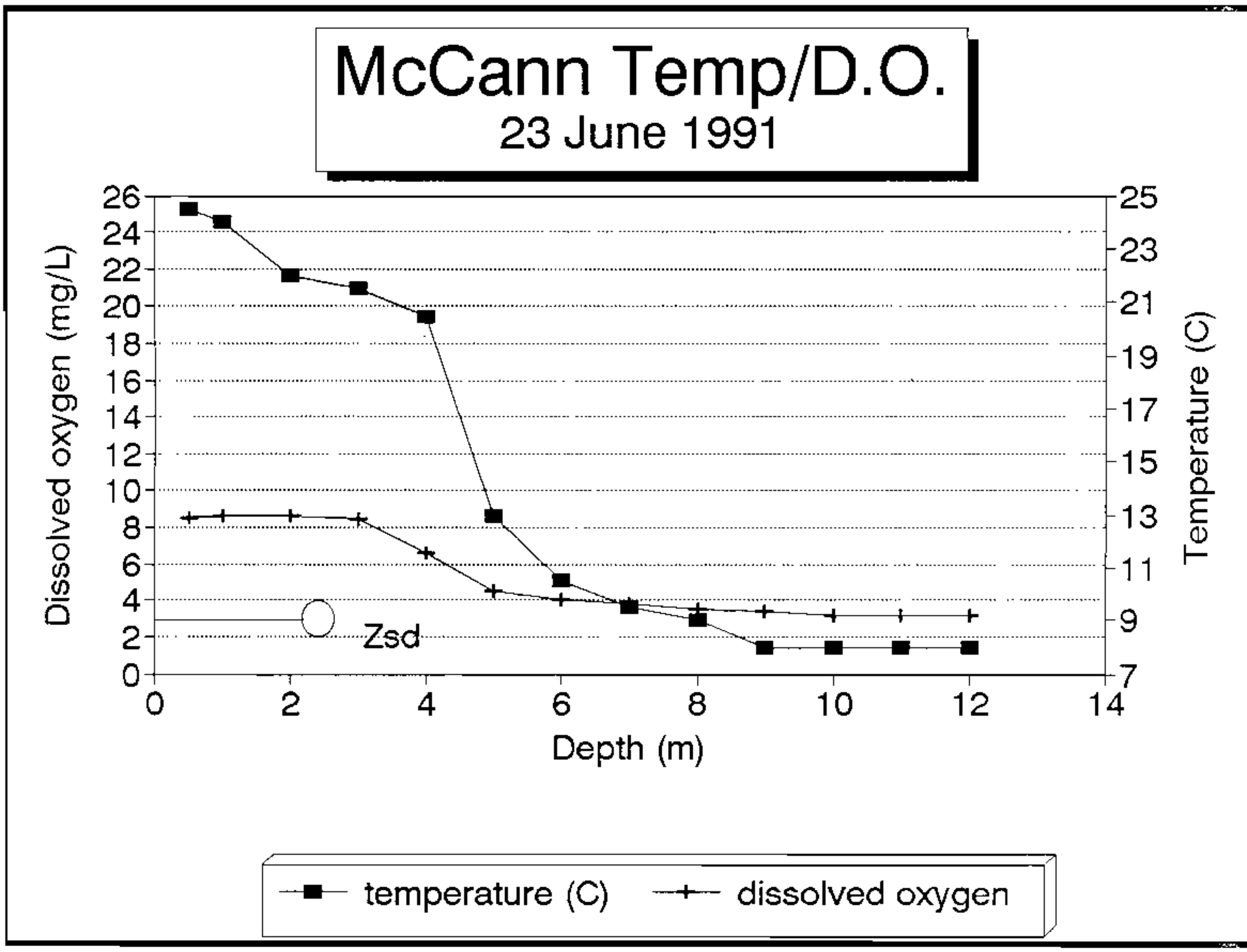
17
19
21
temperature (C)
dissolved oxygen

FIGURE 9


McCann Temp/D.O.
23 June 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
2
4
6
8
10
12
14
16
18
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21
23
25
temperature (C)
dissolved oxygen

FIGURE 10

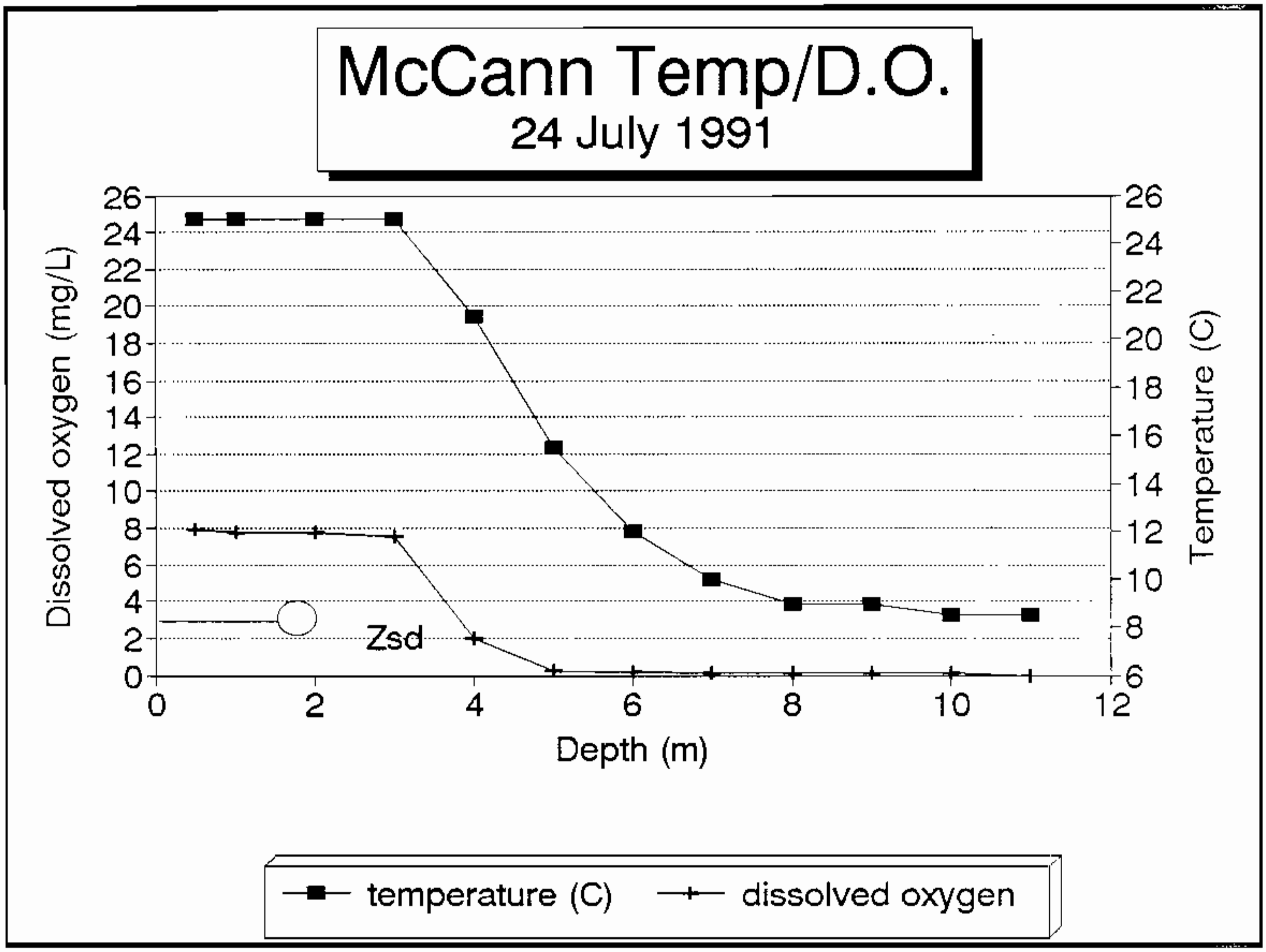
McCann Temp/D.O.
24 July 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
temperature (C)
dissolved oxygen
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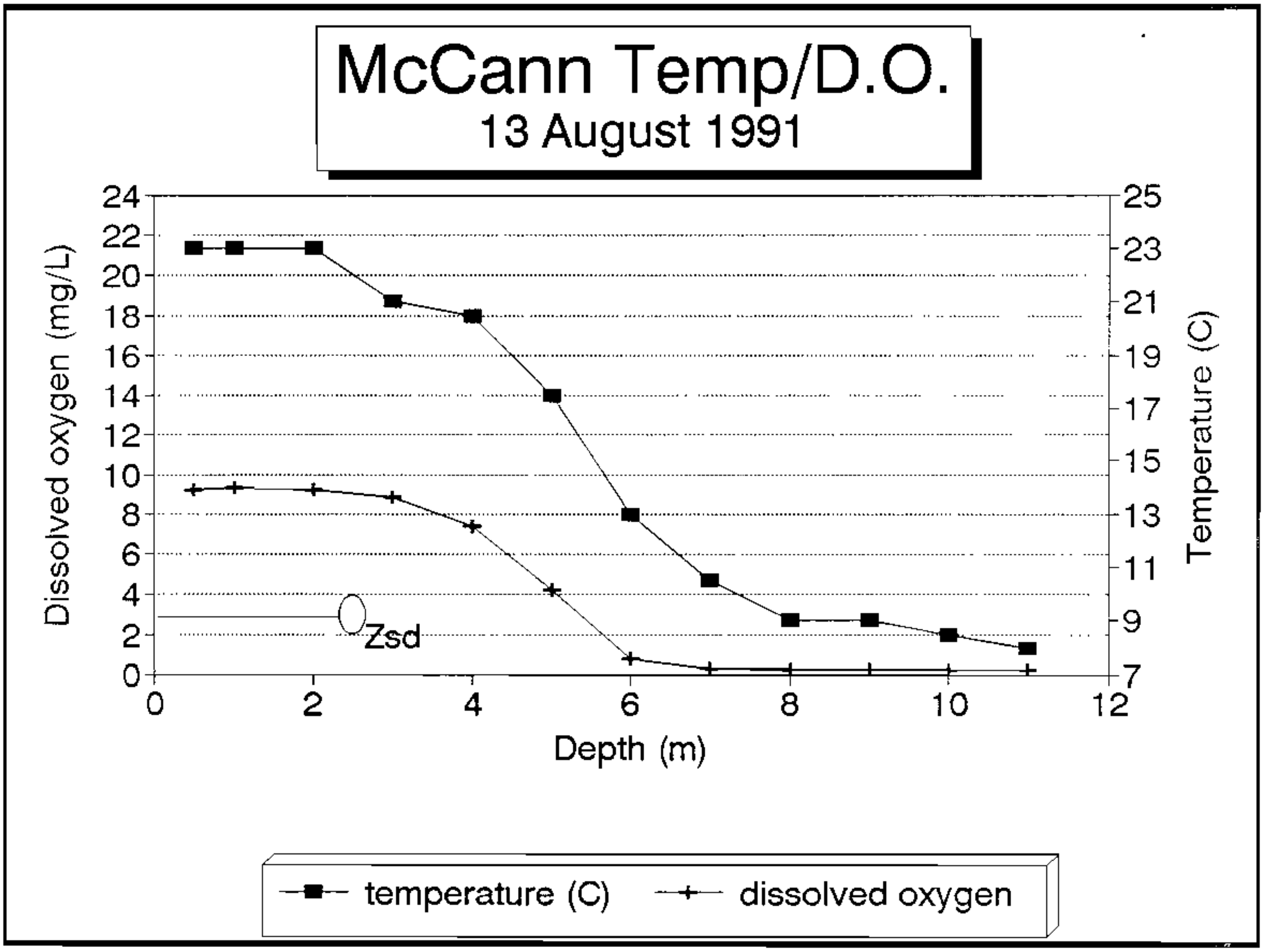
FIGURE 11


McCann Temp/D.O.
13 August 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
2
4
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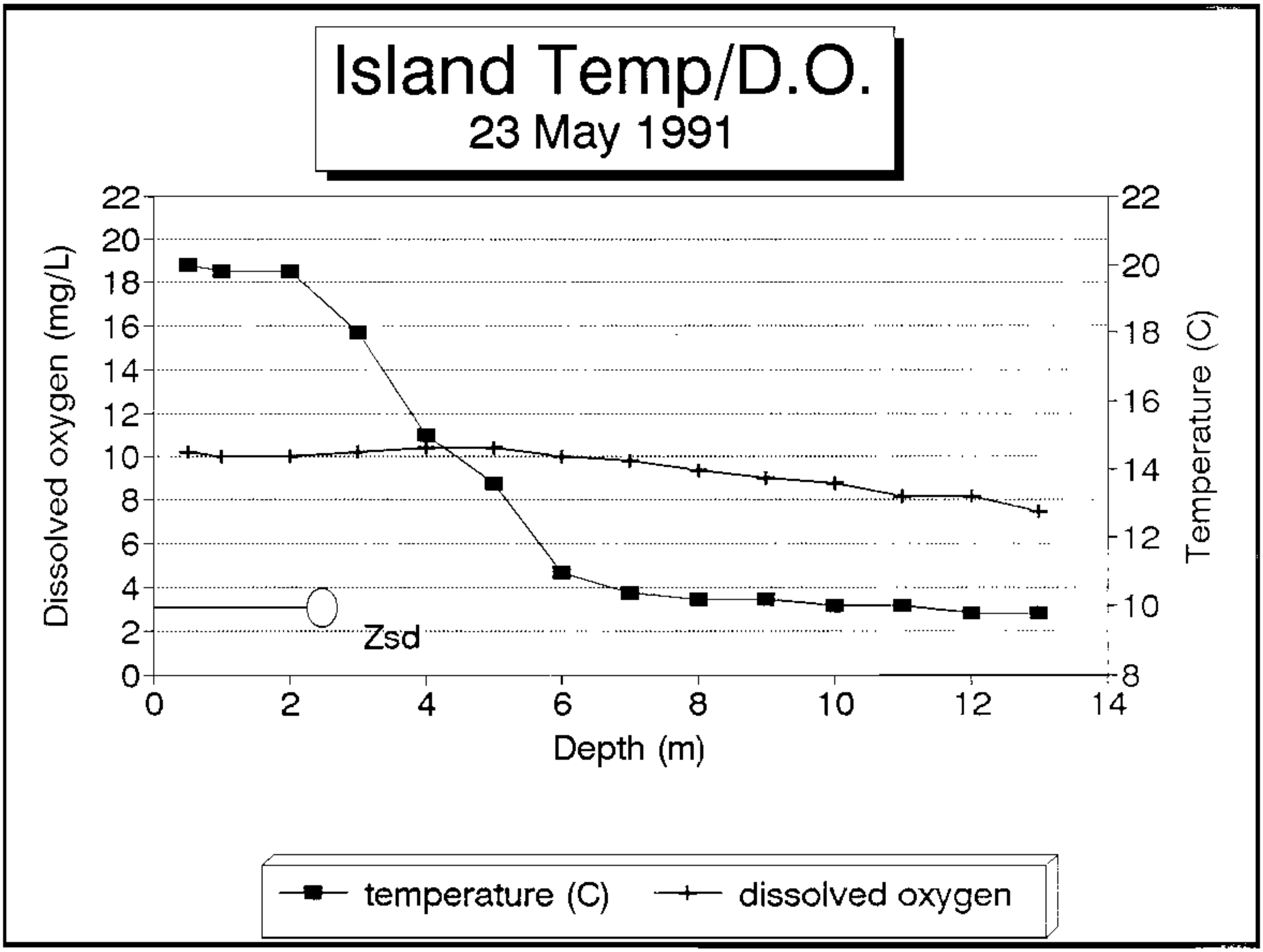
8
10
12
temperature (C)
dissolved oxygen

FIGURE 12


Island Temp/D.O.
23 May 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
temperature (C)
dissolved oxygen
22
20
18
16
14
12
10
8
6
4
2
0
0
2
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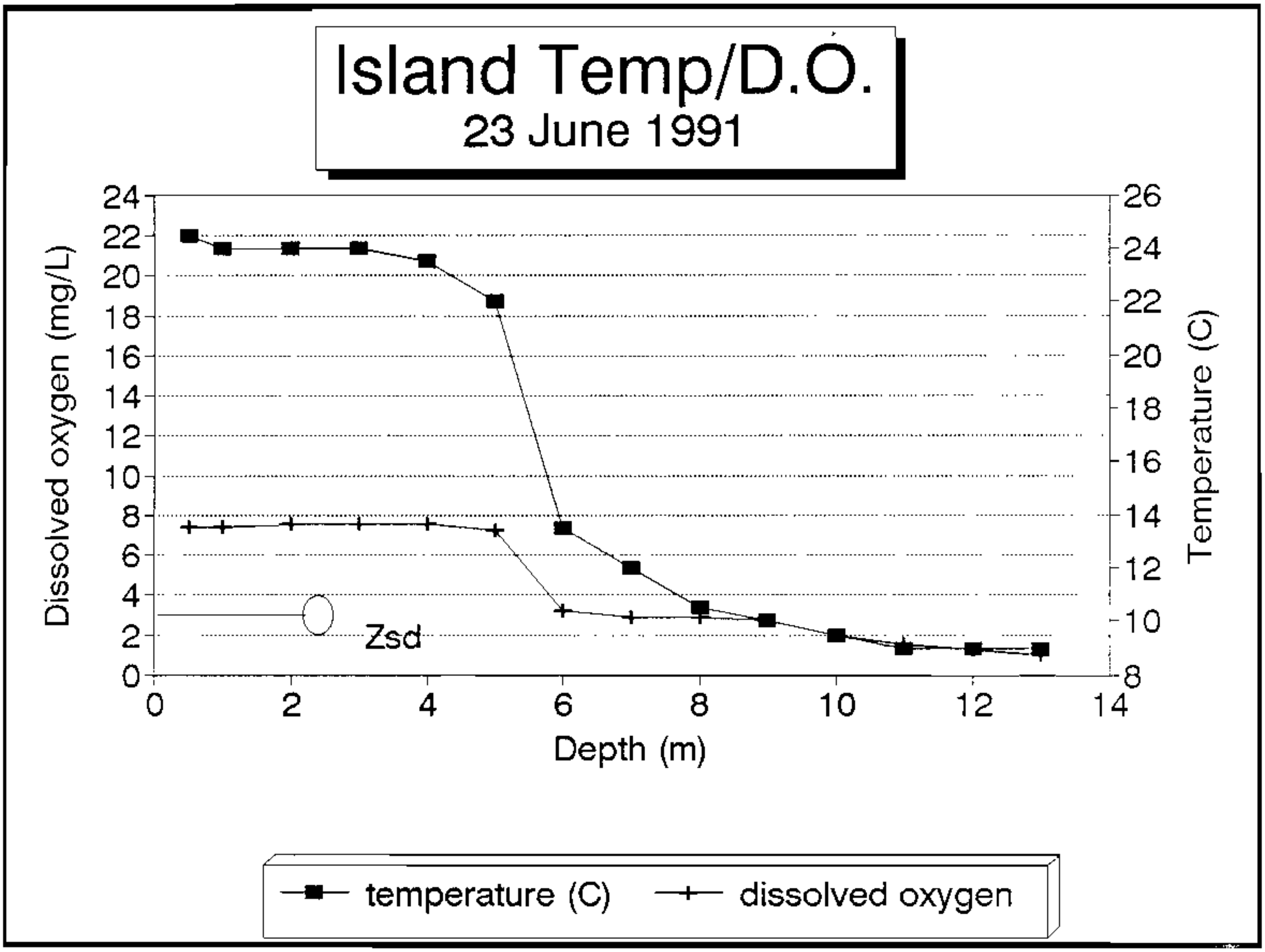
12
14

FIGURE 13


Island Temp/D.O.
23 June 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
2
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14
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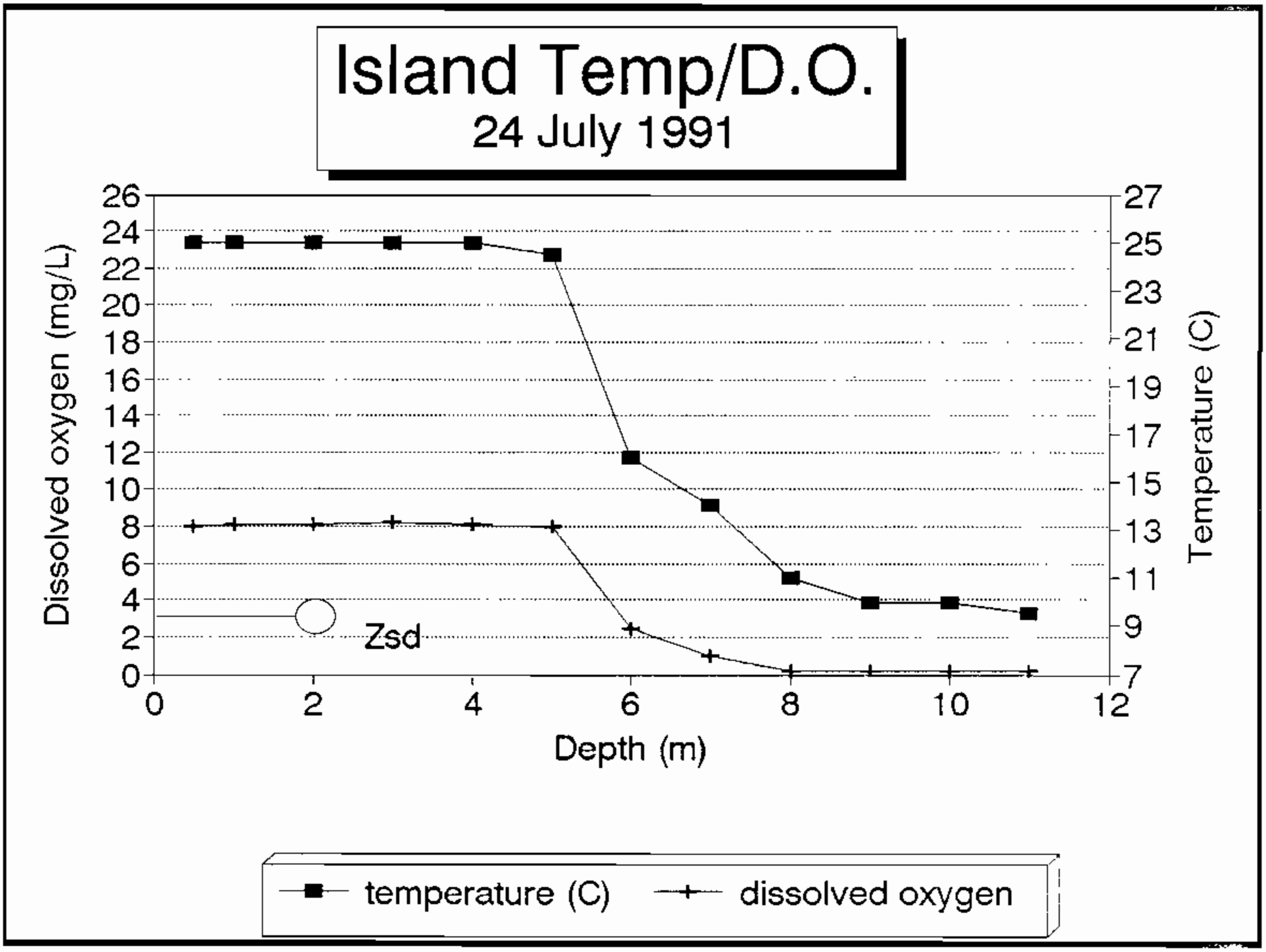
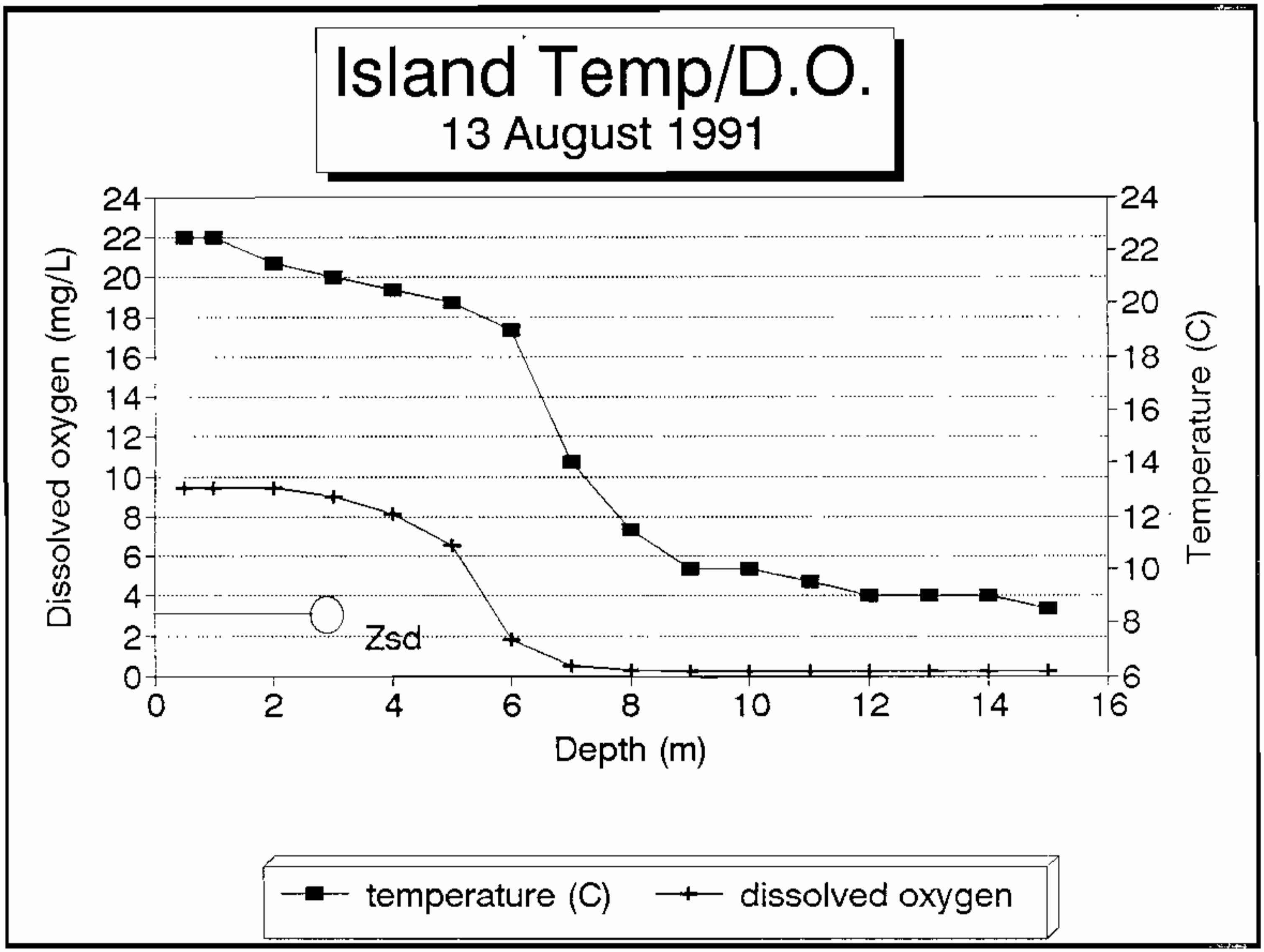
18
20
22
24
26
temperature (C)
dissolved oxygen

FIGURE 14



Island Temp/D.O.
24 July 1991
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Dissolved oxygen (mg/L)
27
25
23
21
19
17
15
13
11
9
7
Temperature (C)
Zsd
0
2
4
6
8
10
12
Depth (m)
temperature (C)
dissolved oxygen

FIGURE 15



Island Temp/D.O.
13 August 1991
24
22
20
18
16
14
12
10
8
6
4
2
0
Dissolved oxygen (mg/L)
Zsd
0
2
4
6
8
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Depth (m)
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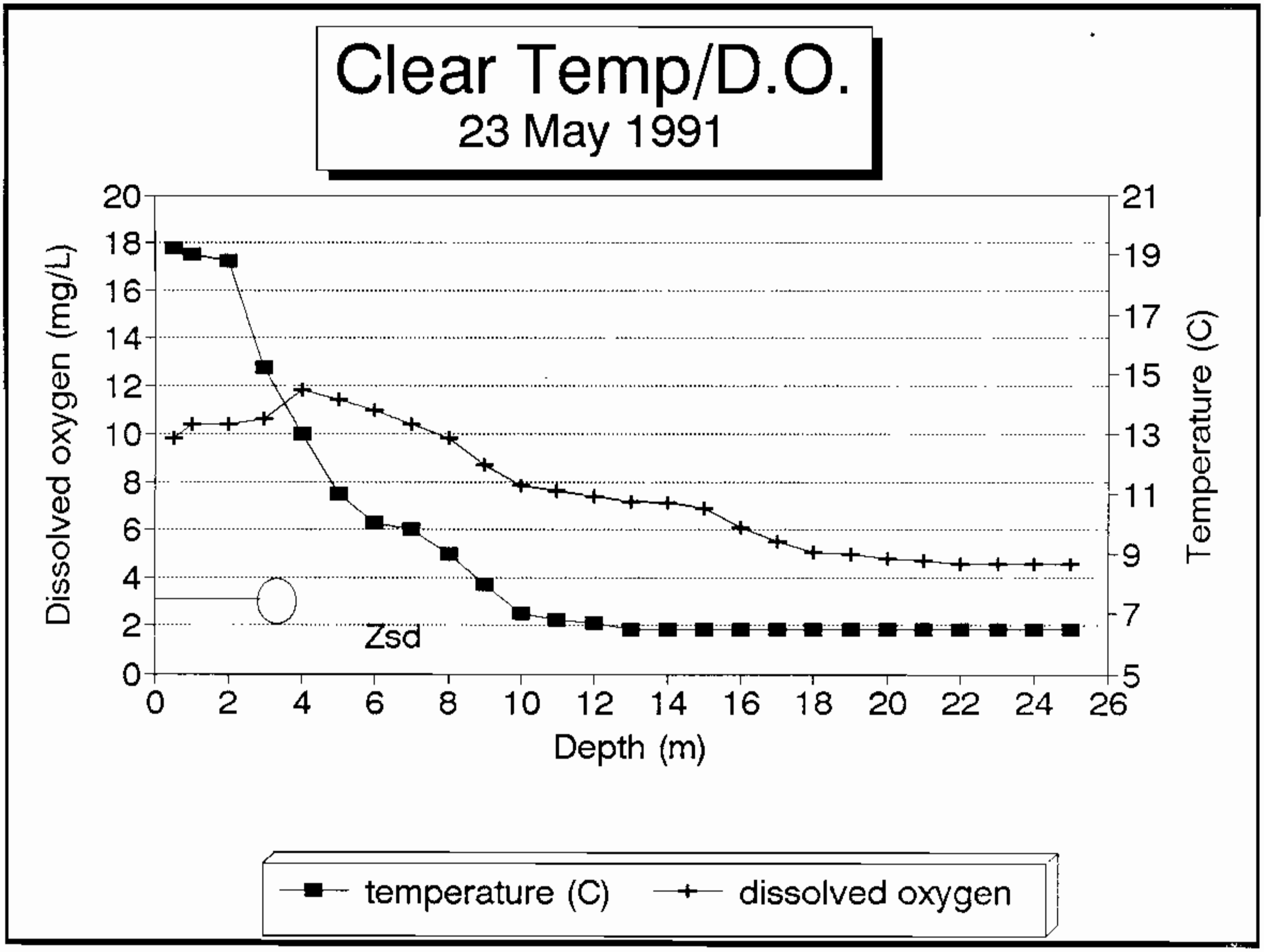
6
Temperature (C)
temperature (C)
dissolved oxygen

FIGURE 16


Clear Temp/D.O.
23 May 1991
Dissolved oxygen (mg/L)
20
18
16
14
12
10
8
6
4
2
0
Temperature (C)
21
19
17
15
13
11
9
7
5
Zsd
0
2
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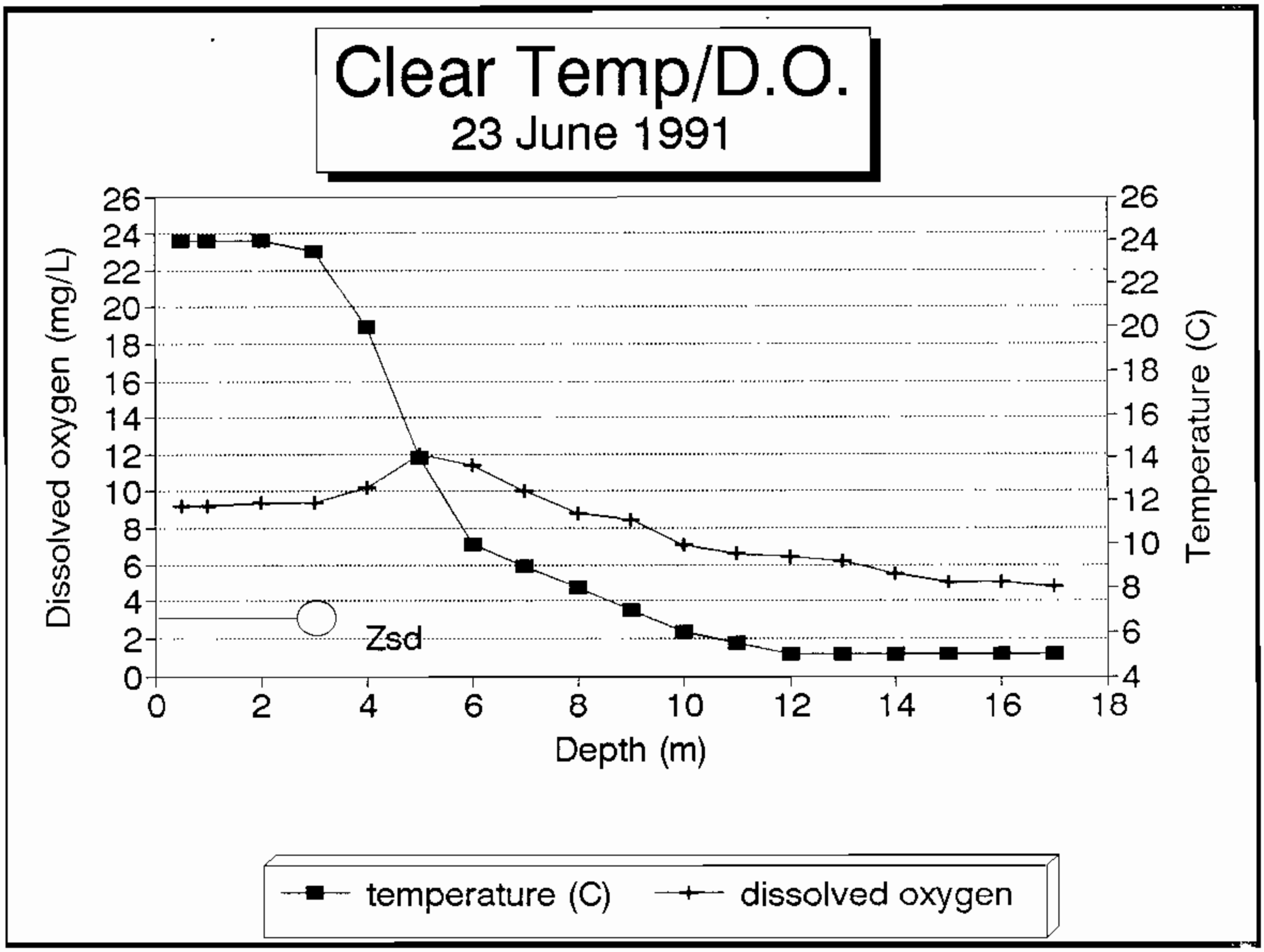
26
Depth (m)
temperature (C)
dissolved oxygen

FIGURE 17



Clear Temp/D.O.
23 June 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
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24
26
temperature (C)
dissolved oxygen

FIGURE 18

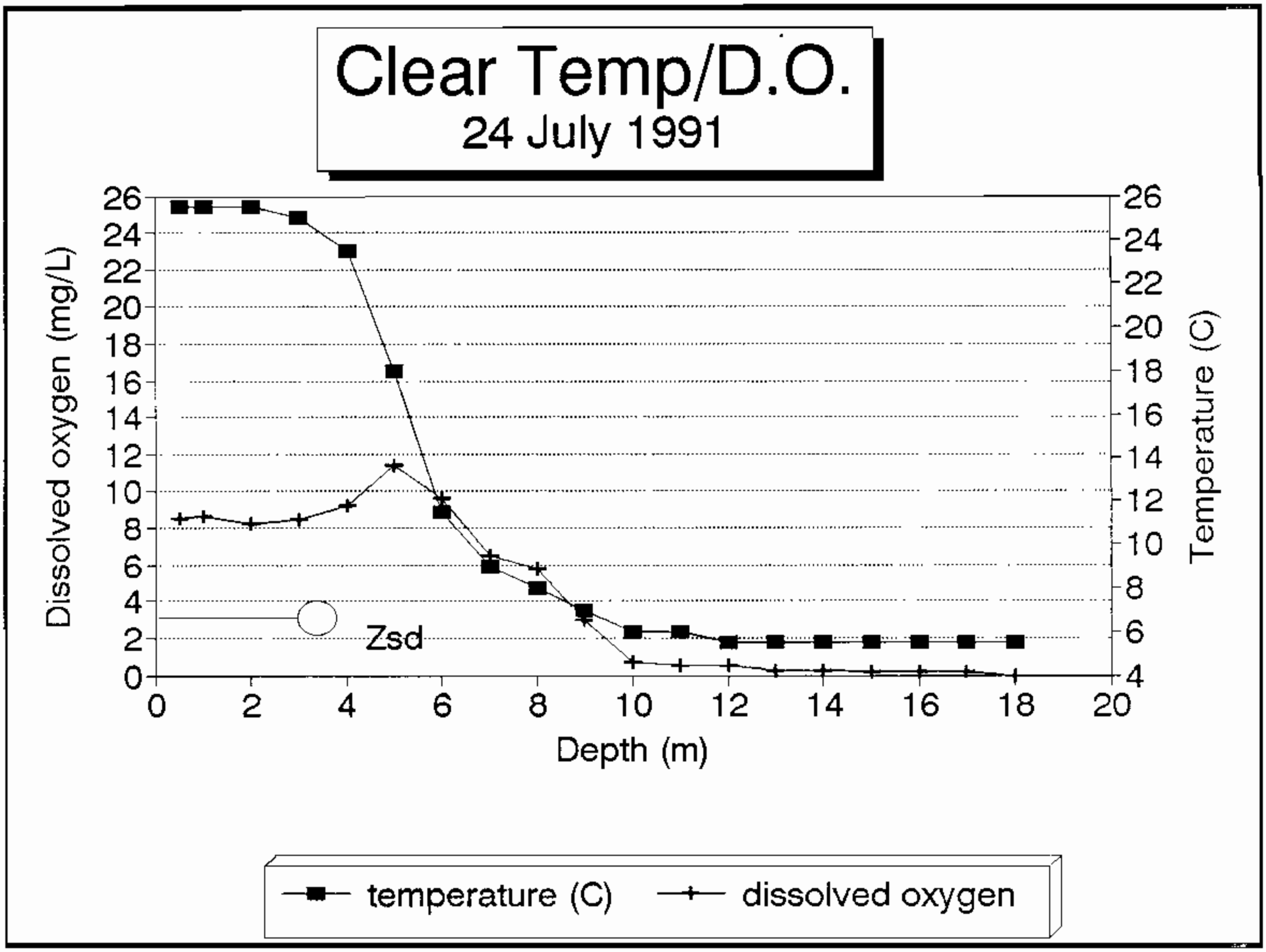
Clear Temp/D.O.
24 July 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
temperature (C)
dissolved oxygen
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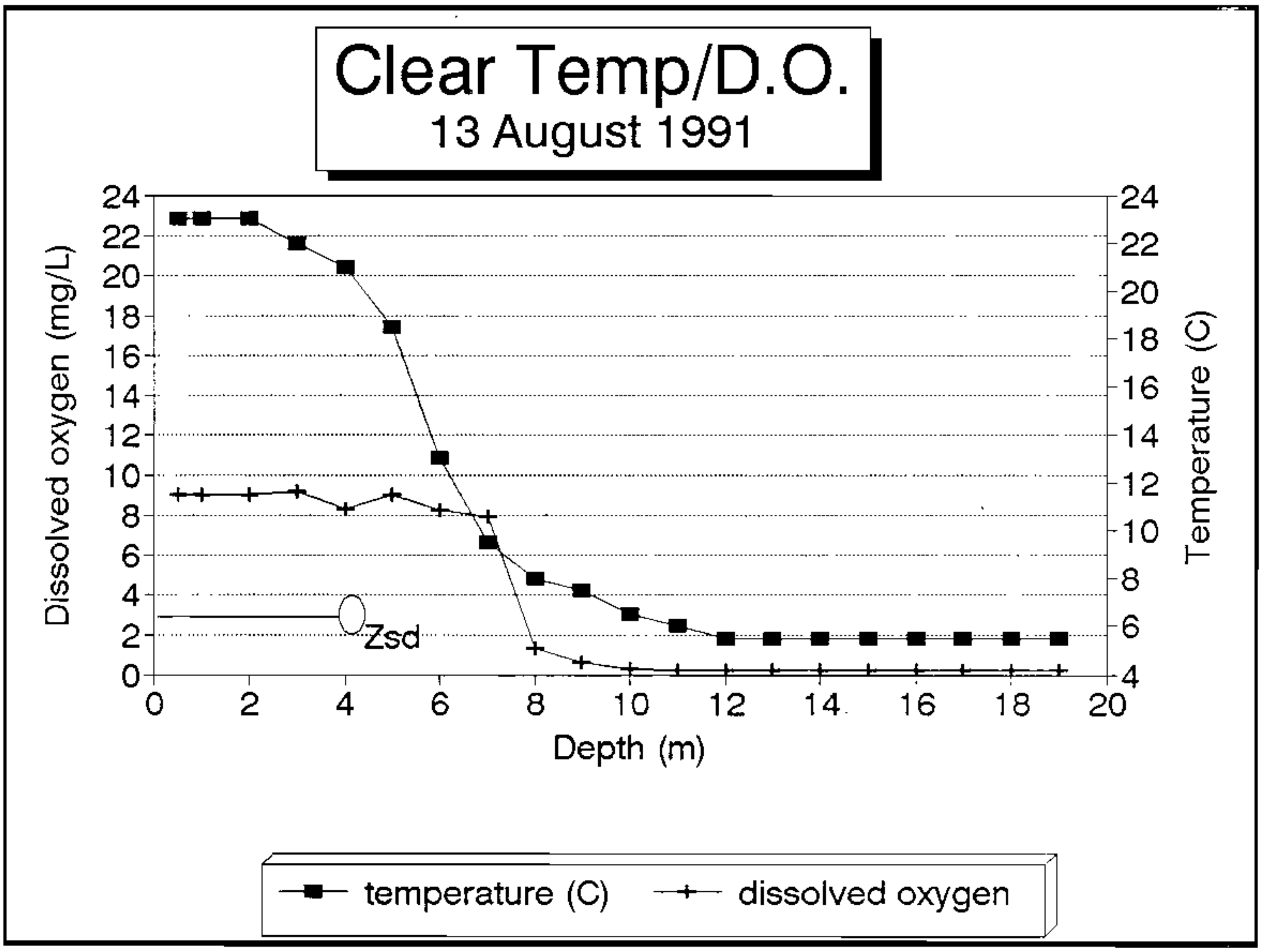
FIGURE 19


Clear Temp/D.O.
13 August 1991
Dissolved oxygen (mg/L)
Temperature (C)
Depth (m)
Zsd
0
2
4
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14
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20
22
24
temperature (C)
dissolved oxygen

FIGURE 20

Table 3. Range of chemical conditions in inlet streams to Island Chain of Lakes, May - August 1991.

	Cedar Cr.	Inlet to McCann	UNS-2[a]	UNS-3
pH	7.8-8.3	8.0-8.1	5.1-5.3	6.0-6.3
Alkalinity (mg/l)	55-61	64-70	4-6	8-20
Color (PCU)	40-50	15-60	>140	>140
Total P (μg/l)	18-23	16-40	53-260	90-210
Soluble P (μg/l)	4-7	3-7	27-190	37-65
NH_3-N (μg/l)	5-13	<5-31	98-106	66-494
NO_3-N (μg/l)	<7-39	<7-80	17-18	<15-52
Total N (mg/l)	0.6	0.5-1.1	1.4-2.6	1.2-1.7
SiO_2 (mg/l)	2.1-4.7	2.8-5.2	2.1-5.4	2.0-7.4

[a] UNS-2 had no flow at the time of the July or August samplings

Island Lakes. Water at the inlet was noticeably stained (color 40-50 PCU) and it contained concentrations of phosphorus and nitrogen that were similar to the lakes.

The flow routing of water and the relative influence of the inlet streams can be on the lakes can be evaluated from individual chemical variables, which also can indicate source areas for nutrients. Water leaving Lower Long Lake has a similar conductance to that of Cedar Creek, indicating a major influence of the lake on the composition of water received in Chain Lake. DNR file data indicate that the concentrations of many substances were in similar ranges in Long Lake and at the Cedar Creek inlet. One striking difference was found in the significantly greater dissolved color of Cedar Creek, which resulted from passage through extensive wetland areas. Although complete data for the time period covered by this study are not available for Lower Long Lake, available data for sampling from 1986-1991 would indicate that total phosphorus and total nitrogen concentrations are lower than in the Island Chain of Lakes. These data would indicate the possibility of slight enrichment of nutrient concentrations from Lower Long to Chain Lake.

Specific conductance, a measure of ionic strength, also can be used to illustrate relationships among the inlets and the lakes. The conductance of Lower Long Lake was equivalent to those of Cedar Creek and Chain, McCann and Island Lakes (Table 4). The ionic composition of the lakes was influenced little by the inflows from the two small streams having much lower conductivity.

The conductivity of Clear Lake is significantly higher than values found in the other lakes (Table 4). Historic data indicate that the pattern was not unique to 1991 and it indicates the difference in the source of the water to Clear Lake. This lake is influenced to some degree by water exchange with Chain Lake, but groundwater inputs produce a lake that is quite different in many respects to others in the chain.

Chemical conditions in the Island Chain of Lakes

A comparison among the lakes can be made using data from August 1991. Dissolved color, pH and alkalinity were similar among Chain, McCann and Island Lakes (Table 5). Surface water pH and alkalinity were higher and other variables such as silica and total phosphorus differed from conditions in the other lakes, again indicating inputs of water of another composition to Clear Lake. Because of the observed differences in chemical conditions, I will proceed first with a description of the results of analyses of surface water in Chain, McCann and Island Lakes (called the CMI Lakes) and then discuss differences between samples collected from surface waters compared with deepwater samples in these lakes before contrasting the conditions observed in Clear Lake.

All of the CMI lakes are noticeably colored, but dissolved color was relatively low in August. Surface water concentrations of ammonia and nitrate were very low, as were concentrations of soluble reactive phosphorus. Given intermediate total phosphorus

Table 4. Specific conductance of surface waters, Island Chain of Lakes.

	Specific conductance (μS/cm)	
	July 1991	April 1975[a]
Lower Long[b]	123	-
Cedar Creek	125	-
Chain Lake	128	132
UNS-2[c]	43	-
UNS-3[c]	42	-
McCann Lake	124	125
Clear Lake	168	168
UNS-1[d]	143	-
Island Lake	131	138

[a] WI DNR file data

[b] WI DNR data, 04/22/91

[c] darkwater inlet streams to Chain Lake along Plummer Road

[d] inlet to McCann Lake channel

concentrations of 17-21 μg/l, algal productivity had raised surface water pH and reduced concentrations of dissolved nutrients to very low levels. Chemical conditions of surface water in the three lakes were generally similar, but there was some indication of a reduction in total phosphorus concentrations down the chain. This reduction was likely due to removal of phosphorus from the water column following biotic uptake.

Due to anoxic conditions in deeper waters, large differences were found between samples collected at 0.5 m and those taken from the hypolimnion in Island and McCann Lakes (Table 5). Similar differences were not found in Chain Lake, although they were expected based on historic data. Anoxic conditions were present in Chain Lake and all evidence would suggest that the water sampler closed at some intermediate depth, resulting in misleading analyses of chemical conditions. It is expected that the results shown for Chain Lake are not correct and they should approximate the patterns found in the other two lakes.

Alkalinity increased with depth in Island and McCann Lakes and pH declined due to sedimentation processes and dissolution of precipitating $CaCO_3$. There were large increases in the concentrations of total P and soluble reactive P with depth. There also were tremendous increases in ammonia concentrations and some increase in nitrate. McCann is the shallower of the two lakes and it had less volume in the hypolimnion. It experienced the longest period of oxygen depletion; it also had greater relative increases in concentration with depth. The CMI Lakes develop anoxic conditions and have considerable increases in nutrient concentrations with depth.

Clear Lake had lower concentrations of total phosphorus than the CMI Lakes, but much higher concentrations of ammonia and of nitrate in surface waters. The lower level of phosphorus limits productivity of the algae and blue-green bacteria, consequently inorganic nitrogen concentrations are not depleted. Deeper water samples in Clear Lake showed no increases in ammonia or nitrate, but higher concentrations of total P and soluble reactive P.

Algal populations in surface waters

Algal populations were evaluated in two ways. Quantitative sampling and analysis of phytoplankton for samples integrated from the top 1.5 m of the water column. Individual species were identified and enumerated for each of the lakes.

In addition, chlorophyll *a* concentrations, an estimate of algal biomass, were measured for surface waters on the August sampling date. Chlorophyll *a* concentrations ranged from 3 μg/l in Clear Lake to 7 μg/l in McCann Lake. Unfortunately, the sample from Chain Lake did not produce a reliable measurement and the concentration was only estimated.

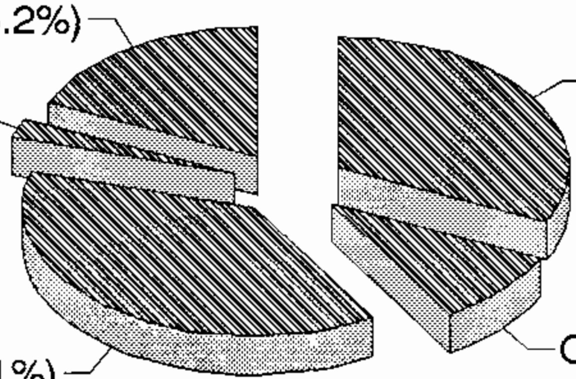
The greatest number of algal cells per ml was found in Chain Lake and the lowest was in Island Lake (Figures 21-24). Very large differences were observed in species

Table 5. Surface vs. deepwater concentrations during August 1991.

	Island		McCann		Clear		Chain[a]	
Depth (m)	0.5	14	0.5	10	0.5	16	0.5	18
°C	22.5	9.0	23.0	8.5	23.0	5.5	22.0	6.0
Secchi (m)	2.75	-	2.5	-	4.5	-	2.25	-
Color (PCU)	15	55	25	130	15	15	20	25
pH	8.3	7.7	8.2	7.5	8.5	7.8	8.2	8.0
Alk (mg/l)	70	89	63	90	90	108	62	63
O_2 (mg/l)	9.4	<0.2	9.2	<0.2	9.0	0.2	8.7	<0.2
ΣP (μg/l)	17	86	18	172	13	140	21	21
SRP (μg/l)	4	44	3	94	3	24	4	6
ΣN (mg/l)	0.5	1.3	0.5	2.2	0.6	1.0	0.7	0.7
NH_3-N (μg/l)	6	805	7	1280	582	593	7	38
NO_3-N (μg/l)	<7	18	<7	32	54	54	<7	<7
SiO_2 (mg/l)	5.2	11	4.5	12	3.2	10	5.4	5.6

[a] results indicate probable premature closure of sampler at intermediate depth

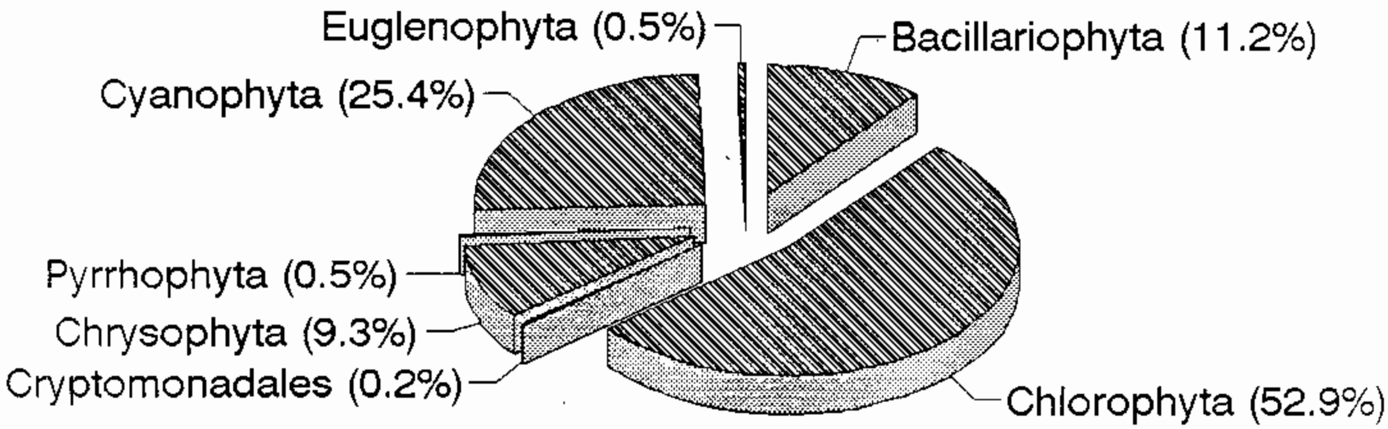
Chain Lake
Phytoplankton - August 1991



Total number of cells =2800/ml

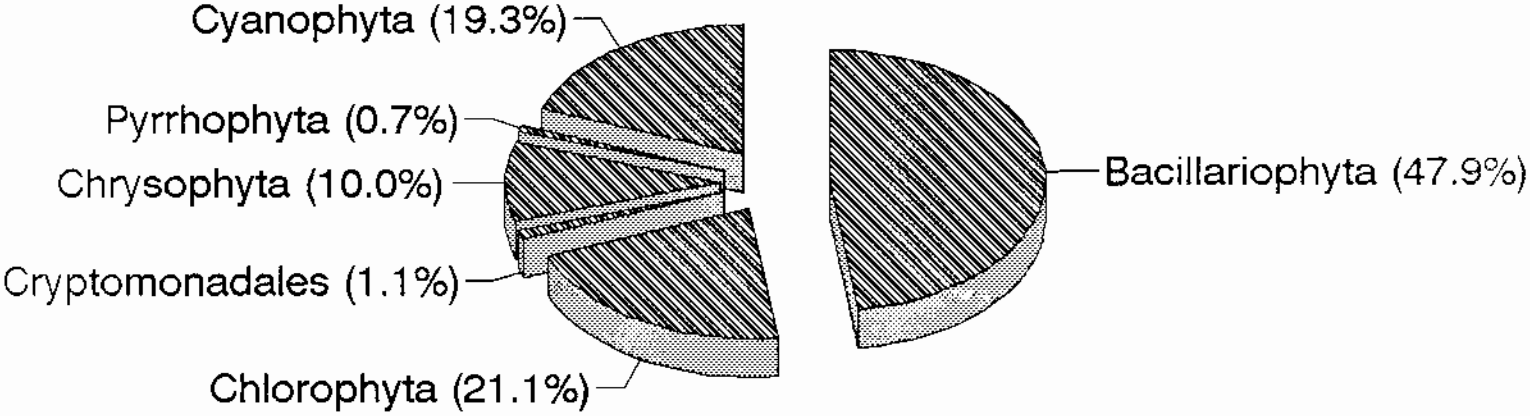
FIGURE 21

McCann Lake
Phytoplankton - August 1991



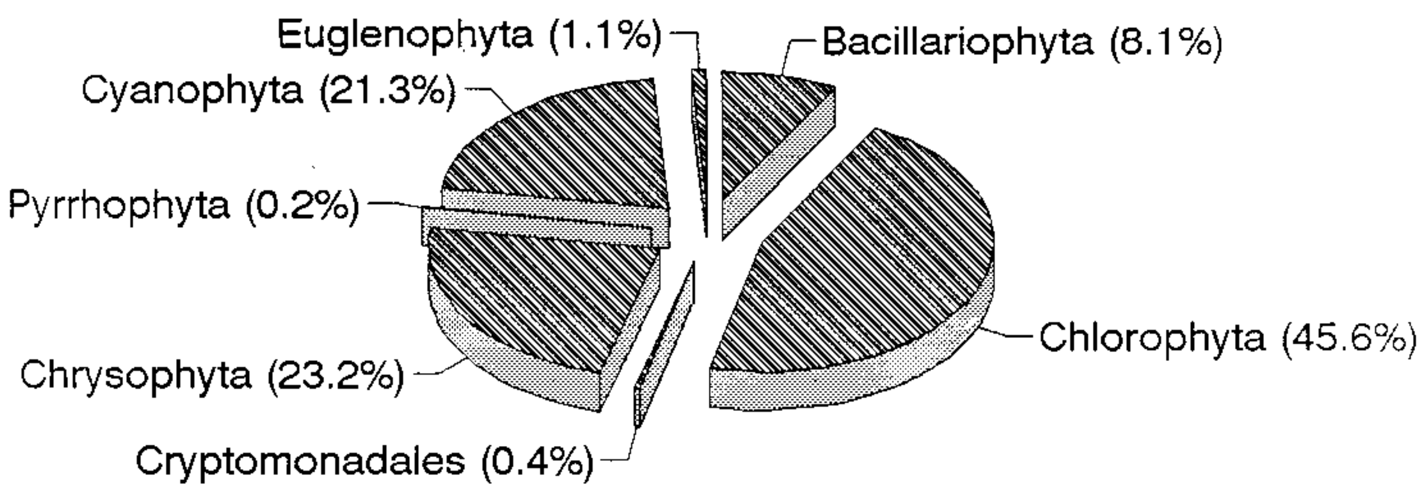
Total number of cells = 2358/ml

Clear Lake
Phytoplankton - August 1991



Total number of cells = 2240/ml

Island Lake
Phytoplankton - August 1991



Total number of cells = 1864/ml

Table 6. Phytoplankton analysis of a 1.5 m integrated surface water sample from Chain Lake. August 12, 1991.

One hundred ml of the integrated sample were preserved by settling in 1% Lugol's solution and concentrated to 20 ml. Ten ml of the concentrated sample were added to a plankton chamber and allowed to settle overnight. The phytoplankton from one 10 mm strip (0.125 mm) was identified and counted.

Taxon	Colonies/ml	Cells/ml	NOTES
BACILLARIOPHYTA			
Asterionella formosa	72	616	all cells infected with chytrids
Fragilaria crotonensis	32	134	"
Melosira granulata v. *angustissima*	32	150	
Stephanodiscus astrea		16	
Stephanodiscus niagarae		8	
CHLOROPHYTA			
Ankistrodesmus falcatus		8	
Chlamydomonas spp.		104	
Eudorina elegans	8	64	
Oocystis spp.	24	56	
Sphaerocystis schroeteri	8	32	
CHRYSOPHYTA			
Chroomonas nordstedtii		544	
Dinobryon sertularia	40	248	protoplasts no longer in loricas
PYRRHOPHYTA			
Ceratium hirundinella		64	
CYANOPHYTA (Cyanobacteria)			
Anabaena circinalis	56		av. length 0.60 mm
Anabaena planctonica	160		av. length 0.392 mm
Anabaena spiroides v. *crassa*	8		av. length 0.25 mm
Anabaena spp.	16		av. length 0.15 mm
Aphanocapsa elachista	32		small colonies due to fragmentation
Aphanizomenon flos-aquae	136		av. length 0.108 mm
Coeleosphaerium naegelianum	72		
Gomphosphaeria aponina	16		
Merismopedia tenuissima	24		

Table 7. Phytoplankton analysis of a 1.5 m integrated surface water sample from McCann Lake. August 12, 1991.

One hundred ml of the integrated sample were preserved by settling in 1% Lugol's solution and concentrated to 20 ml. Ten ml of the concentrated sample were added to a plankton chamber and allowed to settle overnight. The phytoplankton from two 10 mm strips (0.125 mm) was identified and counted for all taxa except *Chlamydomonas* spp., *Chroomonas nordstedtii* and *Aphanocapsa elachista* where one strip was enumerated.

TAXON	Colonies/ml	Cells/ml	NOTES
BACILLARIOPHYTA			
Asterionella formosa	4	32	infected with chytrids
Fragilaria crotonensis	20	24	
Melosira granulata	16	152	
Melosira granulata v. *angustissima*	4	20	
Stephanodiscus astrea		12	
Synedra radians		12	
Tabellaria fenestrata	3	12	
CHLOROPHYTA			
Actinastrum hantzschii	4	32	
Ankistrodesmus falcatus		84	
Chlamydomonas spp.		792	
Crucigenia tetrapedia	16	64	
Kirchneriella lunaris		4	
Kirchneriella subsolitaria	12	48	
Oocystis spp.	36	84	
Scenedesmus spp.	12	32	
Sphaerocystis schroeteri	24	108	
EUGLENOPHYTA			
Euglena sp.		4	
Trachlemonas sp.		8	
CHRYSOPHYTA			
Chroomonas nordstedtii		48	
Dinobryon bavaricum	56	136	
Dinobryon divergens	28	28	
Mallomonas sp.		8	
PYRRHOPHYTA			
Ceratium hirundinella		4	
Peridinium sp.		8	
CRYPTOMONADALES			
Cryptomonas erosa		4	
CYANOPHYTA (Cyanobacteria)			
Anabaena circinalis	28		av. length 0.217 mm
Anabaena flos-aquae	8		av. length 0.131 mm
Anabaena limnetica	12		av. length 0.250 mm
Aphanocapsa elachista	360		lots of fragmentation
Aphanocapsa pulchra	4		
Aphanothece sp.	16		fragmentation?
Aphanizomenon flos-aquae	92		av. length 0.119 mm
Coeleosphaerium naegelianum	32		
Dactylococcopsis acicularis		4	
Gomphosphaeria aponina	4		
Gomphosphaeria lacustris	28		
Merismopedia tenuissima	12		
Oscillatoria limosa	2		av. length 0.375 mm

Table 8. Phytoplankton analysis of a 1.5 m integrated surface sample from Clear Lake. August 12, 1991.

One hundred ml of the integrated sample were preserved by settling in 1% Lugol's solution and concentrated to 20 ml. Ten ml of the concentrated sample were added to a plankton chamber and allowed to settle overnight. The phytoplankton from one 10 mm strip (0.125 mm) were identified and counted.

TAXON	Colonies/ml	Cells/ml	NOTES
BACILLARIOPHYTA			
Asterionella formosa	8	56	infected with chytrids
Fragilaria crotonensis	32	848	" "
Melosira granulata v. *angustissima*	8	136	
Tabellaria fenestrata	8	32	
CHLOROPHYTA			
Ankistrodesmus falcatus		16	
Chlamydomonas spp.		456	
CHRYSOPHYTA			
Chroomonas nordstedtii		216	
Dinobryon sertularia	8	8	
PYRRHOPHYTA			
Ceratium hirundinella		8	
Gymnodinium sp		8	
CRYPTOMONADALES			
Cryptomonas erosa		24	
CYANOPHYTA (Cyanobacteria)			
Anabaena circinalis	8		av. length 0.33 mm
Anabaena planctonica	8		av. length 0.412 mm
Aphanocapsa elachista	168		fragmented
Aphanocapsa pulchra	16		
Aphanothece sp.	32		fragmented?
Aphanizomenon flos-aquae	16		av. length 0.11 mm
Chroococcus sp.	8		
Coeleosphaerium naegelianum	8		
Gomphosphaeria aponina	168		

Table 9. Phytoplankton analysis of a 1.5 m integrated surface sample from Island Lake. August 12, 1991.

One hundred ml of the integrated sample were preserved by settling in 1% Lugol's solution and concentrated to 20 ml. Ten ml of the concentrated sample were added to a plankton chamber and allowed to settle overnight. Two 10 mm strips (0.125 mm) were identified and counted for all taxa except *Chlamydomonas* spp., *Chroomonas nordstedtii* and *Aphanocapsa elachista* where one strip was enumerated.

TAXON	Colonies/ml	Cells/ml	NOTES
BACILLARIOPHYTA			
Fragilaria crotonensis	4	56	
Melosira granulata v. *angustissima*	4	16	
Rhizosolenia eriensis		16	
Stephanodiscus astrea		12	
Tabellaria fenestratea	24	52	
CHLOROPHYTA			
Ankistrodesmus falcatus		16	
Chlamydomonas spp.		456	
Crucigenia tetrapedia	4	16	
Eudorina elegans	4	64	
Nephrocytium limneticum	4	64	
Sphaerocystis schroeteri	4	240	
EUGLENOPHYTA			
Euglena spp.		4	
Trachlemonas spp.		16	
PYRRHOPHYTA			
Ceratium hirundinella		4	
CHRYSOPHYTA			
Chroomonas nordstedtii		376	
Dinobryon sertularia	52	56	lorica separate from protoplast
Mallomonas sp.		4	
CRYPTOMONADALES			
Cryptomonas erosa		8	
CYANOPHYTA (Cyanobacteria)			
Anabaena circinalis	20		av. length 0.242 mm
Anabaena planctonica	8		av. length 0.343 mm
Anabaena spp.	12		av. length o.032 mm
Aphanocapsa elachista	160		
Aphanocapsa pulchra	12		
Aphanizomenon flos-aquae	68		av. length 0.0844 mm
Chroococcus sp.	4		
Coeleosphaerium naegelianum	40		
Gomphosphaeria aponina	8		
Merismopedia tenuissima	68		

composition among the lakes (Tables 6-9 and Figures 21-24). For example, Chain Lake had a large percentage of diatoms (Bacillariophyta) and chrysophytes (Chrysophyta), while McCann and Island Lakes were dominated by green algae (Chlorophyta) and they had a large population of blue-green bacteria (Cyanobacteria). Roughly half the algal population in Clear Lake was comprised of diatoms, and about 20% each of green algae and blue-green bacteria.

Species composition was very similar in Island and McCann Lakes. Although Chain and Clear Lakes both had significant populations of diatoms and similar percentages of blue-green bacteria, there were large differences in species composition in both groups. The most abundant diatom in Clear Lake, *Fragilaria crotonensis*, was present at much lower concentrations in Chain Lake, where *Asterionella formosa* was most abundant. All of the CMI Lakes contained several bloom-forming species of blue-green bacteria and these were present at concentrations higher than those found in Clear Lake.

Trophic state evaluation

Trophic state of the lakes was evaluated using Carlson's Trophic State Index (TSI), which can be calculated based on secchi disc transparency, and total phosphorus and chlorophyll *a* concentrations (Carlson 1977; Reckhow and Chapra 1983). Because transparency is commonly lowest during late summer and surface blooms of blue-green bacteria can often occur at this time, which might affect recreational uses, data from the August sampling was summarized to evaluate the trophic state of each lake. In addition, because of the lower dissolved color in the lakes during August, its influence on secchi disc transparencies was less.

Calculated TSI values based on secchi disc, total phosphorus and chlorophyll *a* measurements are shown for each lake in Figure 25. In general, these results indicate that the trophic condition of Clear Lake is better than those in the CMI Lakes. Each of the CMI Lakes falls within the upper range of mesotrophic condition, while Clear Lake has lower TSI values. Of the CMI Lakes, McCann appears to have slightly worse conditions than the other two lakes, but it is similar to Chain Lake, especially when the estimated chlorophyll concentration for Chain Lake is considered. While the TSI values do not indicate excessive impairment of water quality, it should be noted that the lakes are in a range of phosphorus concentrations where additional inputs would result in enhanced algal growth and an increased probability of blue-green blooms during summer. Clear Lake, in particular, appears to be especially sensitive to increases in P loading.

Synoptic survey of in-shore bacterial concentrations

An extensive sampling was conducted along in-shore areas in each lake to evaluate concentrations of fecal coliform bacteria. Elevated concentrations of fecal

Trophic State - Island Chain

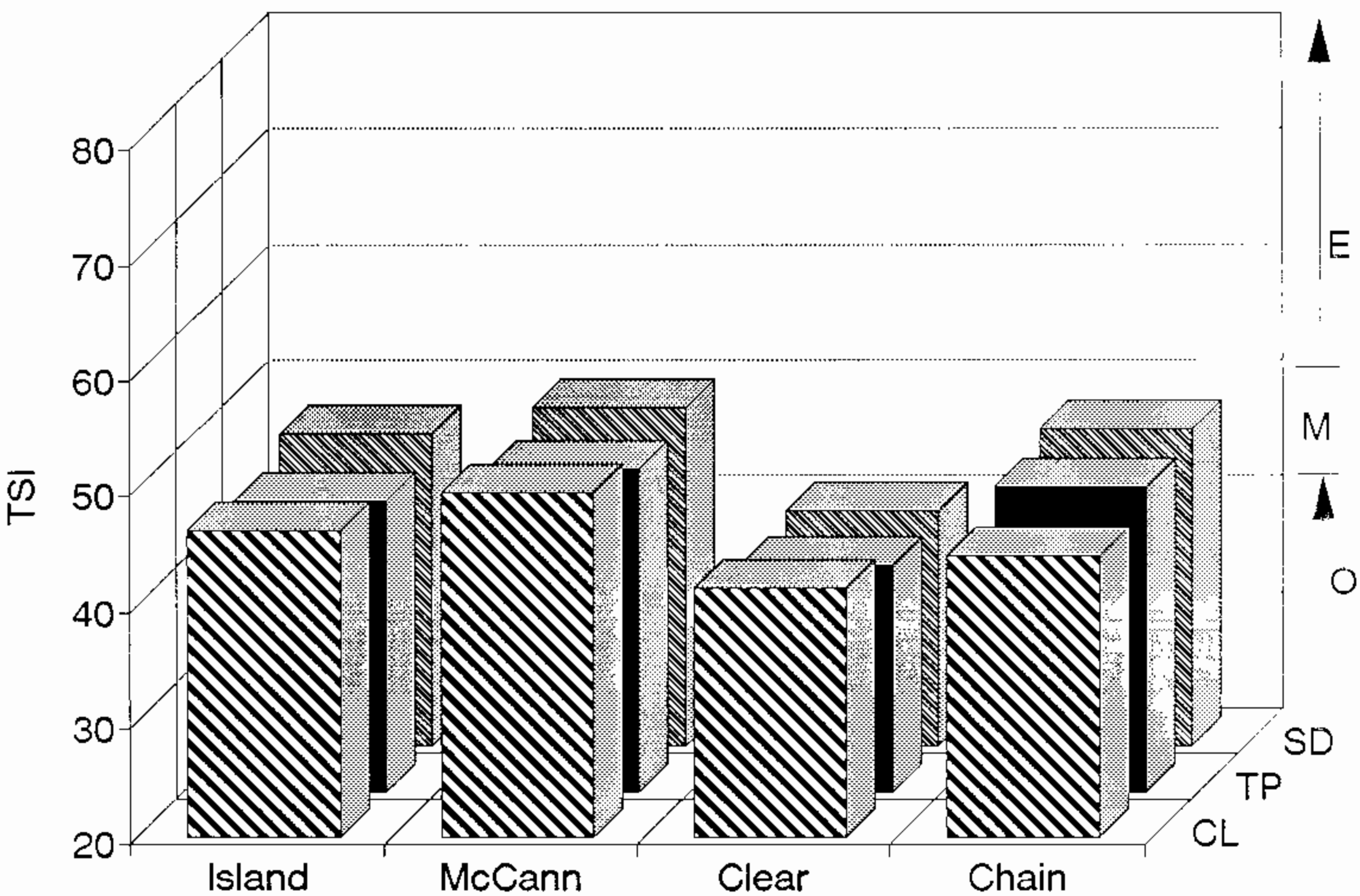


FIGURE 25

coliforms would indicate contamination of surface waters with human or animal wastes. Although more than 25 samples were collected from the lakes, only two samples had concentrations, which exceeded NR102 WI Administrative Code standards for drinking water. The samples were less than the limit of 200/100 ml for geometric means of multiple samples for recreational use. The two areas with measurable concentrations included the shoreline in front of the Arrowhead Bible Camp and along the northern shoreline of McCann Lake. These samples may indicate faulty or leaking septic systems nearby. Because of the intensive use of the Arrowhead Bible Camp during the summer and the lack of use during the days prior to sampling, bacterial concentrations may be elevated along the swimming beach. The concentrations of bacteria are not alarming, but some additional analysis of bacterial concentrations is warranted to ensure safe conditions for Arrowhead visitors.

Even though fecal coliform concentrations were generally low (< 10 colonies/100 ml), the sampling can only be used as an initial screening. It was conducted to determine whether there were serious problems that could be identified quickly. Samples were collected as close to shore as possible, but mixing with lakewater can occur rapidly in-shore. Samples having concentrations < 10 colonies/100 ml do not demonstrate that no failure of septic systems or direct dumping is occurring. They only indicate that any potential contamination did not result in elevated levels except for the two samples noted. In-shore residents near the two areas should evaluate their source of drinking water if it involves direct withdrawal from the lakes.

Historical conditions in the Island Chain of Lakes

I have characterized the present condition of lakes in the Island Chain, but an important question is whether these conditions have changed over time, either being degraded or improved. Because of the increased development of the lakeshore along the lakes and numerous apparent zoning violations, including drains that go straight towards the lakes, some degradation of water quality could be expected. In an attempt to determine whether conditions had changed, I evaluated several sources of historic information. These sources included: WI DNR file data generously supplied by Dick Lillie of DNR Research in Madison, the WI DNR Feasibility Study Results report from 1981 and a study conducted by Cory Laboratories in 1977-78.

WI DNR file data and reported oxygen distributions during August 1977 (WI DNR 1981) indicate each lake has a documented occurrence of oxygen depletion in deeper waters. Oxygen profiles from 1977 suggest similar patterns to those observed in 1991. In both years, oxygen declined with depth generally below 6 m. However, in 1991 anoxic conditions were found at shallower depths than those reported for 1977. Whereas anaerobic conditions were observed at 7.5 - 9.0 m in 1977, oxygen declined to 0 mg/l at 6 - 7 m in the CMI Lakes and 9 - 10 m in Clear Lake. This apparent increase in the volume of anoxic waters in the CMI Lakes could indicate an increase in organic matter production in surface waters and a corresponding increase in decomposition occurring in water below the epilimnion.

Several problems were found in the historic data reported for total phosphorus and chlorophyll concentrations. In many cases the data were listed with inadequate precision and no or an inadequate description of methods. Total phosphorus data were reported to the nearest 0.01 mg/l, suggesting inadequate discrimination of concentrations significant to an evaluation of trophic condition. In many other cases the data were remarkably variable so as to indicate inadequate precision; the Cory Laboratory data in particular do not appear to be reliable. Chlorophyll *a* data showed large variations and on many data sheets the concentration listed was changed and noted by (?). Other discrepancies were noted, such as one sampling in 1977 when total phosphorus concentrations were listed as extremely low and unlikely concentrations ($< 10\ \mu g/l$) for all of the lakes. As a consequence, it is difficult to use historic data for nutrients or chlorophyll to evaluate possible changes in the condition of the lakes.

Some summary evaluation of trophic conditions in the lakes was done in the 1981 DNR report, but incomplete data were reported and TSI values were based on the apparently inadequate measurements of total phosphorus and chlorophyll. The TSI values reported indicated all of the lakes, including Clear Lake, were meso- to eutrophic based on phosphorus concentrations.

No TSI values based on secchi disc transparencies were reported. Given the relatively close correlation among TSI values calculated from the three variables based on 1991 data, evaluation of 1977 secchi disc measurements might be a check on the quality of the analyses for phosphorus and chlorophyll and an evaluation of their use in estimating earlier trophic condition. Secchi disc is relatively easy to measure and it is easily replicated with good precision by different samplers. I examined DNR file data for secchi disc measurements and then used all July or August readings from 1975 - 1977 to calculate a TSI based on secchi disc transparencies. These estimates ranged from 38 in Clear Lake, 43 - 48 in Chain Lake, 47 - 48 in McCann and 49 - 50 in Island Lake, similar to values based on chlorophyll but substantially lower than those based on earlier phosphorus measurements. These results suggest problems associated with earlier measurements of total phosphorus. The TSI values for 1977 secchi disc measurements were similar to conditions observed in 1991; Clear Lake in both years had better visibility and we can infer lower total phosphorus and chlorophyll concentrations than did the CMI Lakes. No significant change in TSI values was found between the two years.

Summary and Conclusions

The Island Chain is a popular set of lakes used extensively for recreation. Settlement of the shoreline is increasing and there are many apparent zoning violations that can be observed along the lakeshores. These apparent zoning violations should be evaluated by both Rusk and Chippewa Counties. The most serious violations were observed along the north and east shorelines of Island Lake in Rusk County.

Although the lakes vary in size and morphometry, they are all physically connected and three of the lakes occur along the main flow routing of water through the chain. These three lakes, Chain, McCann and Island (CMI), have an apparent brown color. Clear Lake has lower color and is more transparent than the other lakes. It also is influenced more by groundwater inputs and is chemically different from the CMI lakes.

All of the lakes stratify each summer and each experiences oxygen depletion in deeper waters. The CMI Lakes have higher concentrations of total phosphorus, which supports greater algal biomass, than does Clear Lake. This higher algal biomass results in a depletion of inorganic nitrogen in surface waters and relatively high pH values. Such conditions would be expected to promote the growth of bloom-forming blue-green bacteria should concentrations of phosphorus increase.

Clear Lake, being more transparent than the other lakes, and also having relatively low phosphorus concentrations that are clearly limiting algal growth, is highly susceptible to change from present conditions. Small increases in total phosphorus loading to these lakes would result in perceived changes in transparency and water quality. Currently, much of the southern shoreline of Clear Lake is undeveloped. Any development of the area should proceed with extreme caution because changes in water quality could result. Moreover, due to the long residence time of water in the lake, any changes in loading would be difficult to reverse over the short term.

The bacterial survey indicated some elevated levels of fecal coliform bacteria in two areas. These problems should be re-confirmed and the sources should be identified. While elevated levels were not found in other in-shore areas, several apparent zoning violations and the possibility of failed septic systems in some areas suggest that some specific analysis be conducted to measure shallow groundwater contributions directly. Key areas for this work would be Island Lake and Clear Lake.

Further monitoring of the lakes is warranted. A reasonable approach would be to sample McCann Lake, which is the shallowest and most eutrophic, and Clear Lake, which is most likely to change the fastest in response to inputs. Sampling of McCann Lake could be related to conditions in Chain and Island Lakes. This continued monitoring is suggested by the potential for change in the CMI Lakes to conditions that would support blooms of blue-green bacteria and by the sensitivity of Clear Lake to additional inputs of phosphorus in the context of increasing development of the lakeshores.

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