

SUMMER THERMAL STRUCTURE
IN THE WESTERN END OF
LAKE ONTARIO WITH
REFERENCE TO THE COHO
SALMON FISHERY

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Executive Summary

A 20-year collection of temperature profiles from the western end of Lake Ontario is used to establish the mean and the standard deviation of the depths of selected temperatures preferred by coho salmon from May through September. This information is compared with data available from 1983, a year that appears to have had an unusually warm, calm summer. Slight differences (warmer surface temperatures, increase in depth of selected isotherms) exist between the 1983 data and the 20-year average but excursions of the 1983 data beyond one standard deviation of the 20-year historical data are rare. This research was conducted at the request of the Ontario Ministry of Natural Resources to assist that Ministry in their fishery management program of salmon stock in Lake Ontario.

Précis de la Direction

À partir d'un ensemble de profils de température prélevés dans la partie ouest du lac Ontario pendant les dernières 20 années, on établit les moyennes et les écarts-type des profondeurs des températures préférées par les saumons coho pour les périodes de mai à septembre. Une analyse semblable faite avec des données obtenues en 1983, année remarquable pour le chaleur de son été, montre que les effets de cette chaleur sont à peine discernables et que les déviations de 1983 par rapport aux moyennes de 20 ans sont presque toutes dans l'intervalle d'un écart-type. Cette étude fut entreprise sur la demande de la Ministère des Ressources Naturelles de l'Ontario.

INTRODUCTION

It is well-known that fish exhibit strong preferences for specific water temperature ranges, according to species and season. Coho salmon, in particular, favour temperatures in the neighbourhood of 12°C in summer. This temperature is located in the seasonal thermocline, a region of pronounced temperature gradient between a warm upper layer called the epilimnion and a cool lower layer called the hypolimnion. Not only is the vertical extent of this temperature range limited to a few metres, but also the location of water of these temperatures within the water column varies considerably from place to place within the lake and from time to time. This variability is due to physical effects, the controlling processes being the flux of heat across the water surface, the surface wind stress, and the hydrodynamics of lakes. Assuming that coho salmon move vertically to maintain themselves in contact with water at their preferred temperature, then one can say that a knowledge of the physical behaviour of Lake Ontario is relevant to the task of finding fish.

This report is written in response to a request from the Ontario Ministry of Natural Resources for help in defining the depths of water temperatures thought to be preferred by coho salmon in Lake Ontario during the summer months. Of particular interest is the extent to which the exceptionally warm and calm summer of 1983 may have produced an anomalous temperature distribution in Lake Ontario.

Thermal Structure of Lake Ontario - Spatial and Temporal Variations

A full discussion of the thermal properties of lakes can be found in standard limnological textbooks (Wetzel, 1975). The most pronounced temporal variations in thermal structure are those of seasonal time-

scale. During the cool season, November to May, temperature differences through the lake are small - one or two degrees Celsius at most. These differences are significant but we shall not discuss them here. From May to November, the surface waters are substantially warmer than the bottom waters, and indeed the warm surface waters float on the cool sub-surface waters like oil on vinegar. The wind is unable to overcome this extra stability and the lake remains stratified until enough heat is lost in the fall to reduce the surface temperature (and increase the surface density) making it easier to mix the lake to vertical homogeneity once more. Fig. 1 represents an average of 20 years' of temperature profile data in the archives at the National Water Research Institute. It is constructed by computing the average depth of selected temperatures based on the available data at a location near Toronto on the 100 m depth contour (Boyce, Robertson and Ivey, 1984). The sequence of weekly-averaged temperature profiles obtained at any deep-water site in the Lake for any full year would not be greatly different from the picture presented here. The heating season extends from mid-March to mid-September.

The thermal structure varies substantially at time-scales much shorter than the seasonal. Fig. 2 again represents the depths of selected isotherms as functions of time but here the data comes from an array of 21 thermistors strung out on a 100 metre cable moored at the above-mentioned site off Toronto in the summer of 1980. Temperatures are read and stored every 10 minutes. The month of September is shown here. The figure also includes a representation of the wind at Toronto Island Airport. The depth of the 12 degree isotherm is of particular interest to this study. The extreme movement of this

isothermal surface is plus or minus 10 m with respect to what might be termed the seasonal depth. These excursions are relatively rare. The wavelike motion of the isotherm at periods close to 16 hours is associated with internal waves strongly modified by the earth's rotation. Associated with these regular oscillations of the thermocline zone are currents resulting in nearly circular motions of the water at the internal wave period. The internal wave motions are noticeable after every major wind event.

The interface between the warm upper layer and the cold lower layer is dynamically "slippery"; the two layers are able to slide over one another with little friction. Thus, a strong and persistent wind can push the warm layer downwind over top of the cool layer. At the upwind side of the lake, cool water is brought to the surface (upwelling) while at the downwind shore, the upper layer becomes thicker (downwelling). An example of this redistribution of water caused by a strong wind is shown in Fig. 3. The prevailing wind direction in summer is such that upwelling occurs frequently on the northwest shore of the lake. During the period of calm following a storm event, the lake starts to return to the original state with surface and thermocline horizontal.

A spectrum of the vertical displacement of isothermal surfaces shows how the vertical movements are distributed with respect to frequency or period (Fig. 4). This diagram shows that on the average, the largest variations are associated with long period events, seasonal processes and storms. At higher frequencies, the variations become rapidly weaker, with the notable exception, so clearly visible in Fig. 2,

of internal waves near the local inertial frequency (period ≈ 17 hrs.). This diagram also shows that the vertical displacements of the 4.5°C isotherm, located well below the thermocline, are larger than the displacements of the 8° isotherm located within the main thermocline - with the exception of motions in the inertial frequency band.

Common experience tells us that the weather in one year may differ substantially from the weather in the next. Since the thermal structure of the lake is the result of meteorological effects, wind and heat flux, then we should expect variations in the lake's thermal structure from year to year as well. These certainly occur; they modify, but they do not disrupt the picture shown in Fig. 1. Perhaps the most significant changes observed from year to year are shifts in the dates at which complete stratification is obtained in the lake or the dates when stratification disappears in the fall. Abnormally warm periods with light winds yield abnormally high surface temperatures.

Results

Against this cursory treatment of the thermal variability observed in Lake Ontario in the summer months, we proceed now to a statistical assessment of the depths of the specific temperatures preferred by coho salmon. The data for this evaluation have been collected over the past 20 years during the many scientific cruises carried out on the lake. The observations are in the form of temperature profiles made from the surface to the bottom with a recording instrument. The date, geographical co-ordinates, total water depth, and a string of temperature-depth pairs representative of the tempera-

ture profile are stored in a computer-accessible form in the NWRI archives. We have defined 7 different sub-populations of the total set of all existing profiles spanning the years 1962 to 1982, one for each month of the year from May through November.

The variability within each of these sub-populations will be due to the processes outlined above, interannual variations, seasonal heating and cooling, responses to major wind events (upwellings and downwellings), and internal waves. Within each of these groups is an additional factor - that of geographical position in the lake. Because of the prevailing summer winds, for example, the surface water is cooler on the northwest shore of the lake and warmer on the southeast and there is a persistent dip of the thermocline from northwest to southeast. We have therefore, further subdivided each of the monthly sub-populations into 18 geographical zones, as depicted in Fig. 5. The zones are defined somewhat arbitrarily by a combination of meridians of longitude and the depth contours 0, 50 and 100 metres - the latter reflecting the observations that the near-shore zones are frequently the most variable. All of the factors mentioned above will contribute to the variance of whichever parameters we choose to extract for analysis.

We have computed for each month and for each zone, the mean depth of the isothermal surfaces at 10, 11, 12, 13, and 14°C the standard deviations of the isotherm depths about these means, the minimum and maximum observed depth of the isotherm depths, and the number of profiles available in each of the subsets. The number of profiles can range from 105 for zone 3 in August to 1 for zone 15 in May. We feel that at least 12 profiles should be available in order

to form a stable estimate of the mean and standard deviation of the isotherm depths, and even then, we might wonder how evenly these samples were distributed over the 20 years of records, although this facet could be checked. A similar analysis has been performed for the water surface temperature. These computations are presented in Tables A- Appendix A to this report. For the months of June through September, the surface temperature and the depths of the 12°C together with their respective standard deviations are displayed in Figs. 6 and 7. Similar figures are presented for the 10 and 14° C isothermal surfaces in Appendix B (Figs. B-1 and B-2).

Identical calculations were performed for the data available in 1983. These are also reported in Table A. The horizontal distribution and frequency of sampling in 1983 reflects the needs of the field programs undertaken in that year, one of which was a detailed sampling off the mouth of the Niagara River. We have computed standard deviations, but because of the limited samples, we consider them to be unreliable. 1983 values are entered between parentheses on the Figs. 6, 7, and the figures of Appendix B.

Fig. 6a indicates that, generally speaking, surface temperatures in June of 1983 are warmer than the average in the western end of the lake. In July, (Fig. 6b) they are once more warmer than average in the zones where they are reported. In September, 1983 (Fig. 6d) the mid-lake surface temperatures are slightly warmer than average.

The average depth of the 12°C isotherm surface in June, ranges from 4.2 m in zone 14 to 14.1 m directly across the lake in zone 18. With the exception of zone 12, the observations of the depths of the 12° isotherm in 1983 are within one standard deviation of the observed

average depths of the 12° surface. In zone 12, the single 1983 observation is inconclusive. In July, the average depth of the 12°C isotherm ranges from a minimum of 6.2 m in zone 14 to a maximum of 14.9 m in zone 17. The few 1983 observations favour the impression that the 12° isotherm is slightly deeper than average in July, 1983. In August, the average depth of the 12° isotherm ranges from 9.3 m on the north shore of the lake and dips to 20.5 m in zone 17. The 1983 observations indicate a greater 12°C depth than average in the southwest corner of the lake, and somewhat less than average along the north-shore in September, the average depths of the 12°C surface range from 13.6 to 20.3 m. With the exception of zone 4 (one observation in 1983) and zone 2, where the 1983 values seem low, the 1983 values are not greatly different from the historical mean.

The few measurements available in 1983 and their distribution do not allow a detailed comparison with the historical averages. It is clear that the differences are not extreme. August, 1983, would seem to have yielded significantly higher than average surface temperatures and a slightly greater thermocline depth.

The 1983 data available to this study are not sufficient to compute a reliable heat budget of the entire lake and to determine thereby whether the lake had gained significantly more heat than average by the time of maximum heat content. Simulation models such as those employed by Lam and Schertzer (1983) could be used to answer this question.

References

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Table Captions

Table 1. Depth of the 12° C isotherm (mean and standard deviation in meters) plus number of observations by month of the year and by zone (Fig. 5). Table 1a summarizes the 20-year historical data. Table 1b reports the equivalent information for 1983.

Table 2. Mean and standard deviation of surface temperature (degrees Celsius) plus number of observations by month of the year and by zone. Table 2a summarizes the 20-year historical data. Table 2b reports the 1983 data.

Table 1 a

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1 NO. OF OBS.	4								18			
MEAN DEPTH(M)	17	5.96	3.84	4.11	4.15	12.45	13.86	12.97				
ST. DEV.	2.36	2.27	2.25	1.19	1.19	11.94	13.57	13.59				
2 NO. OF OBS.	2	2.4	2.93	5.10	8.52	13.38	13.05	13.19				
MEAN DEPTH(M)	1.6	2.4	2.89	4.66	4.71	8.61	8.61	8.61				
ST. DEV.	1.6	2.4	2.89	4.66	4.71	8.61	8.61	8.61				
3 NO. OF OBS.	3	3.05	6.30	8.93	10.5	13.3	13.3	13.3				
MEAN DEPTH(M)	1.6	2.6	4.21	4.17	6.65	10.57	10.57	10.57				
ST. DEV.	1.6	2.6	4.21	4.17	6.65	11.62	11.62	11.62				
4 NO. OF OBS.	2	2.62	4.59	6.56	6.56	11.57	11.57	11.57				
MEAN DEPTH(M)	1.6	2.62	4.59	6.56	6.56	11.57	11.57	11.57				
ST. DEV.	1.6	2.62	4.59	6.56	6.56	11.57	11.57	11.57				
5 NO. OF OBS.	5	1.39	2.90	4.65	5.93	8.70	8.70	8.70				
MEAN DEPTH(M)	1.6	2.2	3.9	5.5	5.5	10.41	10.41	10.41				
ST. DEV.	1.6	2.2	3.9	5.5	5.5	10.73	10.73	10.73				
6 NO. OF OBS.	4	1.33	4.64	5.90	10.77	16.30	16.30	16.30				
MEAN DEPTH(M)	1.6	1.50	3.61	3.19	5.17	10.33	10.33	10.33				
ST. DEV.	1.6	1.50	3.61	3.19	5.17	10.33	10.33	10.33				
7 NO. OF OBS.	3	1.37	4.63	7.93	11.62	15.37	15.37	15.37				
MEAN DEPTH(M)	1.6	1.37	4.63	7.93	11.62	15.37	15.37	15.37				
ST. DEV.	1.6	1.37	4.63	7.93	11.62	15.37	15.37	15.37				
8 NO. OF OBS.	3	0.91	5.02	8.14	11.06	15.75	15.75	15.75				
MEAN DEPTH(M)	1.6	0.91	5.02	8.14	11.06	15.75	15.75	15.75				
ST. DEV.	1.6	0.91	5.02	8.14	11.06	15.75	15.75	15.75				
9 NO. OF OBS.	2	0.77	3.39	3.13	4.87	12.49	12.49	12.49				
MEAN DEPTH(M)	1.6	0.77	3.39	3.13	4.87	12.49	12.49	12.49				
ST. DEV.	1.6	0.77	3.39	3.13	4.87	12.49	12.49	12.49				
10 NO. OF OBS.	5	1.14	6.91	8.41	11.34	15.50	15.50	15.50				
MEAN DEPTH(M)	1.6	1.14	6.91	8.41	11.34	15.50	15.50	15.50				
ST. DEV.	1.6	1.14	6.91	8.41	11.34	15.50	15.50	15.50				
11 NO. OF OBS.	3	1.32	2.65	3.07	4.10	5.72	5.72	5.72				
MEAN DEPTH(M)	1.6	1.32	2.65	3.07	4.10	5.72	5.72	5.72				
ST. DEV.	1.6	1.32	2.65	3.07	4.10	5.72	5.72	5.72				
12 NO. OF OBS.	4	1.23	5.27	9.24	10.94	20.90	20.90	20.90				
MEAN DEPTH(M)	1.6	1.23	5.27	9.24	10.94	20.90	20.90	20.90				
ST. DEV.	1.6	1.23	5.27	9.24	10.94	20.90	20.90	20.90				
13 NO. OF OBS.	1	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
MEAN DEPTH(M)	1.6	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
ST. DEV.	1.6	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
14 NO. OF OBS.	1	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
MEAN DEPTH(M)	1.6	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
ST. DEV.	1.6	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
15 NO. OF OBS.	1	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
MEAN DEPTH(M)	1.6	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
ST. DEV.	1.6	1.93	3.34	3.34	3.10	8.74	8.74	8.74				
16 NO. OF OBS.	2	2.16	4.62	7.38	11.57	15.41	15.41	15.41				
MEAN DEPTH(M)	1.6	2.16	4.62	7.38	11.57	15.41	15.41	15.41				
ST. DEV.	1.6	2.16	4.62	7.38	11.57	15.41	15.41	15.41				
17 NO. OF OBS.	2	2.70	4.62	7.38	11.57	15.41	15.41	15.41				
MEAN DEPTH(M)	1.6	2.70	4.62	7.38	11.57	15.41	15.41	15.41				
ST. DEV.	1.6	2.70	4.62	7.38	11.57	15.41	15.41	15.41				
18 NO. OF OBS.	5	1.78	4.15	12.17	17.96	26.51	26.51	26.51				
MEAN DEPTH(M)	1.6	1.78	4.15	12.17	17.96	26.51	26.51	26.51				
ST. DEV.	1.6	1.78	4.15	12.17	17.96	26.51	26.51	26.51				

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	NO. OF OBS. ST.DEV.											
2	NO. OF OBS.											
3	MEAN DEPTH(M) ST.DEV.											
4	NO. OF OBS. ST.DEV.											
5	NO. OF OBS. ST.DEV.											
6	NO. OF OBS.											
7	NO. OF OBS. ST.DEV.											
8	NO. OF OBS. ST.DEV.											
9	NO. OF OBS. ST.DEV.											
10	NO. OF OBS. ST.DEV.											
11	NO. OF OBS. ST.DEV.											
12	NO. OF OBS. ST.DEV.											
13	NO. OF OBS. ST.DEV.											
14	NO. OF OBS. ST.DEV.											
15	NO. OF OBS. ST.DEV.											
16	NO. OF OBS. ST.DEV.											
17	NO. OF OBS. ST.DEV.											
18	NO. OF OBS. ST.DEV.											

Table 1 b

Table 2 a

SURFACE TENSILE STRENGTH

DECEMBER			
NOVEMBER			
OCTOBER			
SEPTEMBER			
AUGUST	JULY	JUNE	MAY
MARCH	APRIL	MAY	JUNE
JANUARY	FEBRUARY	MARCH	APRIL
DECEMBER	NO. OF OBS.	MEAN TEMP.	ST. DEV.
1	2.49	1.51	.49
2	.85	1.54	.33
3	6.0	1.19	1.32
4	1.59	.81	.95
5	1.06	.9	.55
6	1.15	1.15	.9
7	1.55	1.56	.55
8	2.87	2.12	1.56
9	1.04	.99	.61
10	1.11	.8	.38
11	1.90	1.68	1.56
12	2.0	1.56	.74
13	2.57	2.09	1.49
14	1.56	1.62	.67
15	3.11	2.76	1.66
16	2.72	.77	.79
17	1.24	.68	.49
18	1.50	1.12	.50
19	3.33	2.12	.93
20	1.56	1.66	.63
21	3.11	2.15	.69
22	2.9	1.74	.74
23	1.24	.72	.49
24	1.33	1.12	.50
25	3.33	2.12	.93
26	1.56	1.66	.63
27	3.11	2.15	.69
28	2.9	1.74	.74
29	1.24	.72	.49
30	1.33	1.12	.50
31	3.33	2.12	.93
32	1.56	1.66	.63
33	3.11	2.15	.69
34	2.9	1.74	.74
35	1.24	.72	.49
36	1.33	1.12	.50
37	3.33	2.12	.93
38	1.56	1.66	.63
39	3.11	2.15	.69
40	2.9	1.74	.74
41	1.24	.72	.49
42	1.33	1.12	.50
43	3.33	2.12	.93
44	1.56	1.66	.63
45	3.11	2.15	.69
46	2.9	1.74	.74
47	1.24	.72	.49
48	1.33	1.12	.50
49	3.33	2.12	.93
50	1.56	1.66	.63
51	3.11	2.15	.69
52	2.9	1.74	.74
53	1.24	.72	.49
54	1.33	1.12	.50
55	3.33	2.12	.93
56	1.56	1.66	.63
57	3.11	2.15	.69
58	2.9	1.74	.74
59	1.24	.72	.49
60	1.33	1.12	.50
61	3.33	2.12	.93
62	1.56	1.66	.63
63	3.11	2.15	.69
64	2.9	1.74	.74
65	1.24	.72	.49
66	1.33	1.12	.50
67	3.33	2.12	.93
68	1.56	1.66	.63
69	3.11	2.15	.69
70	2.9	1.74	.74
71	1.24	.72	.49
72	1.33	1.12	.50
73	3.33	2.12	.93
74	1.56	1.66	.63
75	3.11	2.15	.69
76	2.9	1.74	.74
77	1.24	.72	.49
78	1.33	1.12	.50
79	3.33	2.12	.93
80	1.56	1.66	.63
81	3.11	2.15	.69
82	2.9	1.74	.74
83	1.24	.72	.49
84	1.33	1.12	.50
85	3.33	2.12	.93
86	1.56	1.66	.63
87	3.11	2.15	.69
88	2.9	1.74	.74
89	1.24	.72	.49
90	1.33	1.12	.50
91	3.33	2.12	.93
92	1.56	1.66	.63
93	3.11	2.15	.69
94	2.9	1.74	.74
95	1.24	.72	.49
96	1.33	1.12	.50
97	3.33	2.12	.93
98	1.56	1.66	.63
99	3.11	2.15	.69
100	2.9	1.74	.74
101	1.24	.72	.49
102	1.33	1.12	.50
103	3.33	2.12	.93
104	1.56	1.66	.63
105	3.11	2.15	.69
106	2.9	1.74	.74
107	1.24	.72	.49
108	1.33	1.12	.50
109	3.33	2.12	.93
110	1.56	1.66	.63
111	3.11	2.15	.69
112	2.9	1.74	.74
113	1.24	.72	.49
114	1.33	1.12	.50
115	3.33	2.12	.93
116	1.56	1.66	.63
117	3.11	2.15	.69
118	2.9	1.74	.74
119	1.24	.72	.49
120	1.33	1.12	.50
121	3.33	2.12	.93
122	1.56	1.66	.63
123	3.11	2.15	.69
124	2.9	1.74	.74
125	1.24	.72	.49
126	1.33	1.12	.50
127	3.33	2.12	.93
128	1.56	1.66	.63
129	3.11	2.15	.69
130	2.9	1.74	.74
131	1.24	.72	.49
132	1.33	1.12	.50
133	3.33	2.12	.93
134	1.56	1.66	.63
135	3.11	2.15	.69
136	2.9	1.74	.74
137	1.24	.72	.49
138	1.33	1.12	.50
139	3.33	2.12	.93
140	1.56	1.66	.63
141	3.11	2.15	.69
142	2.9	1.74	.74
143	1.24	.72	.49
144	1.33	1.12	.50
145	3.33	2.12	.93
146	1.56	1.66	.63
147	3.11	2.15	.69
148	2.9	1.74	.74
149	1.24	.72	.49
150	1.33	1.12	.50
151	3.33	2.12	.93
152	1.56	1.66	.63
153	3.11	2.15	.69
154	2.9	1.74	.74
155	1.24	.72	.49
156	1.33	1.12	.50
157	3.33	2.12	.93
158	1.56	1.66	.63
159	3.11	2.15	.69
160	2.9	1.74	.74
161	1.24	.72	.49
162	1.33	1.12	.50
163	3.33	2.12	.93
164	1.56	1.66	.63
165	3.11	2.15	.69
166	2.9	1.74	.74
167	1.24	.72	.49
168	1.33	1.12	.50
169	3.33	2.12	.93
170	1.56	1.66	.63
171	3.11	2.15	.69
172	2.9	1.74	.74
173	1.24	.72	.49
174	1.33	1.12	.50
175	3.33	2.12	.93
176	1.56	1.66	.63
177	3.11	2.15	.69
178	2.9	1.74	.74
179	1.24	.72	.49
180	1.33	1.12	.50
181	3.33	2.12	.93
182	1.56	1.66	.63
183	3.11	2.15	.69
184	2.9	1.74	.74
185	1.24	.72	.49
186	1.33	1.12	.50
187	3.33	2.12	.93
188	1.56	1.66	.63
189	3.11	2.15	.69
190	2.9	1.74	.74
191	1.24	.72	.49
192	1.33	1.12	.50
193	3.33	2.12	.93
194	1.56	1.66	.63
195	3.11	2.15	.69
196	2.9	1.74	.74
197	1.24	.72	.49
198	1.33	1.12	.50
199	3.33	2.12	.93
200	1.56	1.66	.63
201	3.11	2.15	.69
202	2.9	1.74	.74
203	1.24	.72	.49
204	1.33	1.12	.50
205	3.33	2.12	.93
206	1.56	1.66	.63
207	3.11	2.15	.69
208	2.9	1.74	.74
209	1.24	.72	.49
210	1.33	1.12	.50
211	3.33	2.12	.93
212	1.56	1.66	.63
213	3.11	2.15	.69
214	2.9	1.74	.74
215	1.24	.72	.49
216	1.33	1.12	.50
217	3.33	2.12	.93
218	1.56	1.66	.63
219	3.11	2.15	.69
220	2.9	1.74	.74
221	1.24	.72	.49
222	1.33	1.12	.50
223	3.33	2.12	.93
224	1.56	1.66	.63
225	3.11	2.15	.69
226	2.9	1.74	.74
227	1.24	.72	.49
228	1.33	1.12	.50
229	3.33	2.12	.93
230	1.56	1.66	.63
231	3.11	2.15	.69
232	2.9	1.74	.74
233	1.24	.72	.49
234	1.33	1.12	.50
235	3.33	2.12	.93
236	1.56	1.66	.63
237	3.11	2.15	.69
238	2.9	1.74	.74
239	1.24	.72	.49
240	1.33	1.12	.50
241	3.33	2.12	.93
242	1.56	1.66	.63
243	3.11	2.15	.69
244	2.9	1.74	.74
245	1.24	.72	.49
246	1.33	1.12	.50
247	3.33	2.12	.93
248	1.56	1.66	.63
249	3.11	2.15	.69
250	2.9	1.74	.74
251	1.24	.72	.49
252	1.33	1.12	.50
253	3.33	2.12	.93
254	1.56	1.66	.63
255	3.11	2.15	.69
256	2.9	1.74	.74
257	1.24	.72	.49
258	1.33	1.12	.50
259	3.33	2.12	.93
260	1.56	1.66	.63
261	3.11	2.15	.69
262	2.9	1.74	.74
263	1.24	.72	.49
264	1.33	1.12	.50
265	3.33	2.12	.93
266	1.56	1.66	.63
267	3.11	2.15	.69
268	2.9	1.74	.74
269	1.24	.72	.49
270	1.33	1.12	.50
271	3.33	2.12	.93
272	1.56	1.66	.63
273	3.11	2.15	.69
274	2.9	1.74	.74
275	1.24	.72	.49
276	1.33	1.12	.50
277	3.33	2.12	.93
278	1.56	1.66	.63
279	3.11	2.15	.69
280	2.9	1.74	.74
281	1.24	.72	.49
282	1.33	1.12	.50
283	3.33	2.12	.93
284	1.56	1.66	.63
285	3.11	2.15	.69
286	2.9	1.74	.74
287	1.24	.72	.49
288	1.33	1.12	.50
289	3.33	2.12	.93
290	1.56	1.66	.63
291	3.11	2.15	.69
292	2.9	1.74	.74
293	1.24	.72	.49
294	1.33	1.12	.50
295	3.33	2.12	.93
296	1.56	1.66	.63
297	3.11	2.15	.69
298	2.9	1.74	.74
299	1.24	.72	.49
300	1.33	1.12	.50
301	3.33	2.12	.93
302	1.56	1.66	.63
303	3.11	2.15	.69
304	2.9	1.74	.74
305	1.24	.72	.49
306	1.33	1.12	.50
307	3.33	2.12	.93
308	1.56	1.66	.63
309	3.11	2.15	.69
310	2.9	1.74	.74
311	1.24	.72	.49
312	1.33	1.12	.50
313	3.33	2.12	.93
314	1.56	1.66	.63
315	3.11	2.15	.69
316	2.9	1.74	.74
317	1.24	.72	.49
318	1.33	1.12	.50
319	3.33	2.12	.93
320	1.56	1.66	.63
321	3.11	2.15	.69
322	2.9	1.74	.74
323	1.24	.72	.49
324	1.33	1.12	.50
325	3.33	2.12	.93

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1 NO. OF OBS.												
1 MEAN TEMP.	2.59	3.19	4									
2 ST. DEV.	1	1	1									
2 NO. OF OBS.	2.29	3.29	2									
3 ST. DEV.	2.60	3.19	2									
3 NO. OF OBS.	2.40	2.70	3									
4 MEAN TEMP.	2.33	3.10	3									
4 NO. OF OBS.	2.29	3.10	2.9									
5 MEAN TEMP.	2.41	3.10	2.9									
5 NO. OF OBS.	2.60	3.19	2.9									
6 MEAN TEMP.	2.59	3.37	3	1.40								
6 NO. OF OBS.	2.59	3.37	3	1.40								
7 MEAN TEMP.	3.23	3.64	4	1.82								
7 NO. OF OBS.	3.21	3.64	4	1.82								
8 MEAN TEMP.	2.53	3.67	4	1.82								
8 NO. OF OBS.	2.53	3.67	4	1.82								
9 MEAN TEMP.	2.50	3.10	5	1.75								
9 NO. OF OBS.	2.50	3.10	5	1.75								
10 MEAN TEMP.	2.49	3.10	5	1.75								
10 NO. OF OBS.	2.49	3.10	5	1.75								
11 MEAN TEMP.	3.00	4.10	5	2.4								
11 NO. OF OBS.	3.00	4.10	5	2.4								
12 MEAN TEMP.	3.14	4.21	4	2.14								
12 NO. OF OBS.	3.14	4.21	4	2.14								
13 MEAN TEMP.	2.50	3.68	5	2.75								
13 NO. OF OBS.	2.50	3.68	5	2.75								
14 MEAN TEMP.	2.70	4.17	5	2.65								
14 NO. OF OBS.	2.70	4.17	5	2.65								
15 MEAN TEMP.	2.08	1.94	4	1.42								
15 NO. OF OBS.	2.08	1.94	4	1.42								
16 MEAN TEMP.	2.70	3.17	5	2.5								
16 NO. OF OBS.	2.70	3.17	5	2.5								
17 MEAN TEMP.	3.45	3.27	4	2.55								
17 NO. OF OBS.	3.45	3.27	4	2.55								
18 MEAN TEMP.	2.90	4.79	8	8.89								
18 NO. OF OBS.	2.90	4.79	8	8.89								
18 MEAN TEMP.	2.90	4.79	8	8.89								

Table 2 b

Figure Captions

- Figure 1) Average depth of selected isothermal surfaces for 20 years of data collected near the 100 m depth contour off Toronto.
- Figure 2) Depths of the 12, 8, and 4.5° C isothermal surfaces for the month of September, 1980 as measured by a 21-thermistor array located on the 100 m depth contour off Toronto. A stick-vector plot of six-hourly averaged winds at Toronto is shown above the water temperature data.
- Figure 3) Surface temperature and depth of the 13° C isothermal surface (thermocline) based on temperature profiles collected at positions indicated on the surface temperature plot between 18 and 21 September, 1972. At this time the lake is close to maximum heat content and the distribution of surface temperature and thermocline depth is the result of previous strong winds out of the west.
- Figure 4) Power spectra of the time-series of records of isotherm depths (4.5° C and 8.0° C) over the three-month period July through September 1980. The last third of this record is shown in Fig. 2.
- Figure 5) Definition of zones in the Western end of Lake Ontario.
- Figure 6) Average and standard deviation of surface temperatures for the 18 zones and the months of June through September. Results from the 20-year historical set are unbracketed; 1983 results are bracketed.
- Figure 7) Similar to Fig. 6 except that the numbers shown are depths of the 12° C isotherm in metres.

FIGURE 1

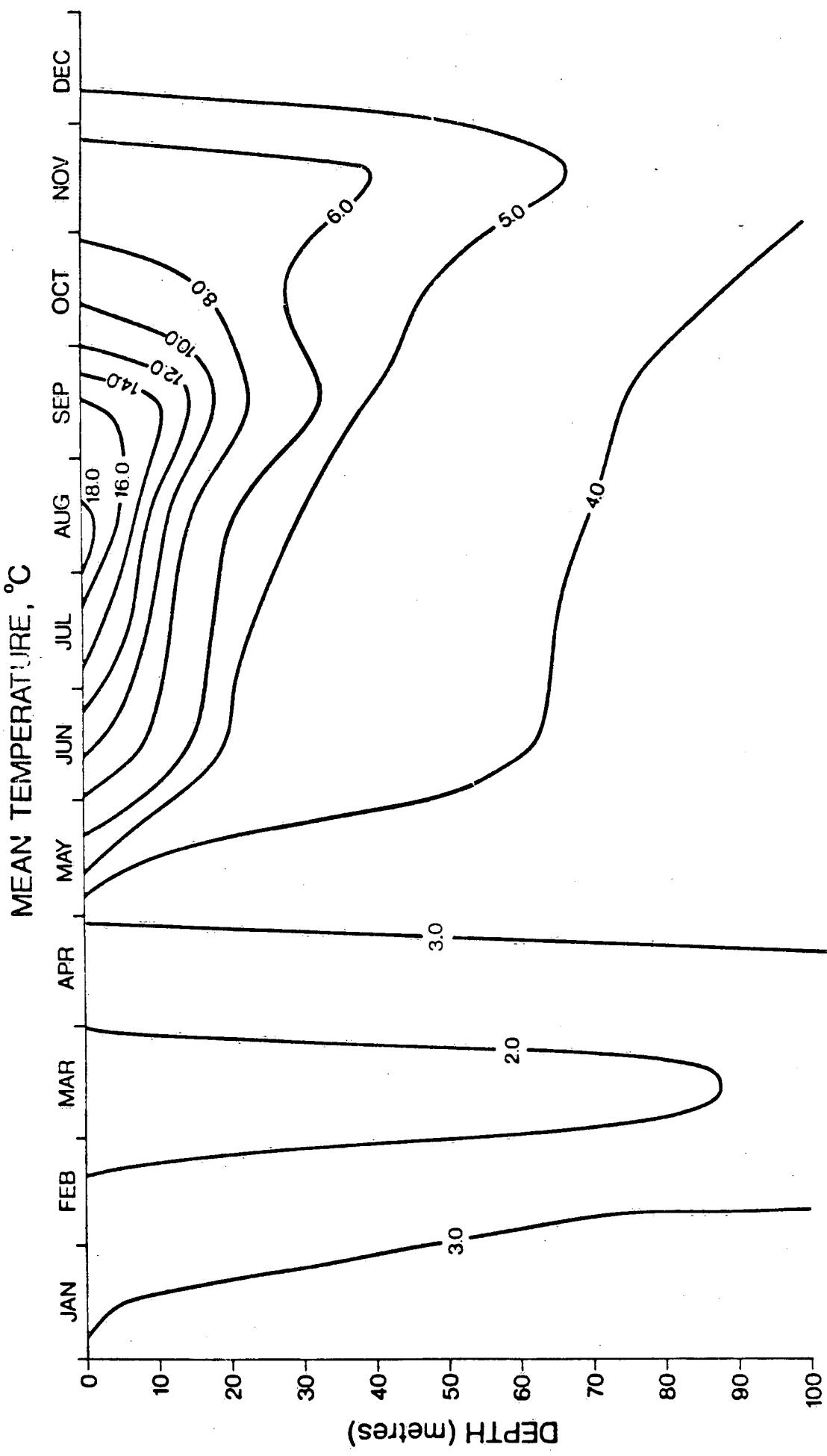


FIGURE 2

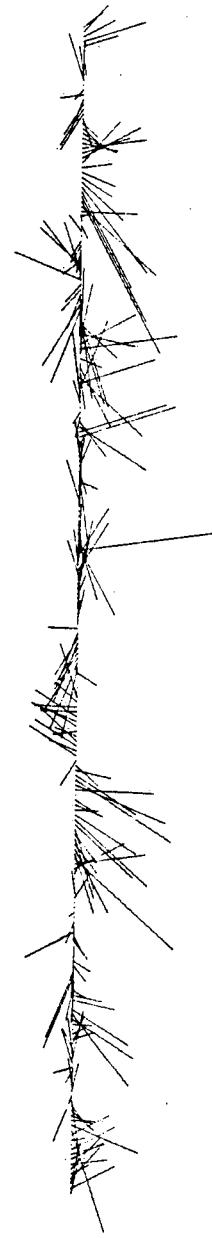
LAKE ONTARIO 1980

1 1 1 2 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21 1 22 1 23 1 24 1 25 1 26 1 27 1 28 1 29 1 30 1

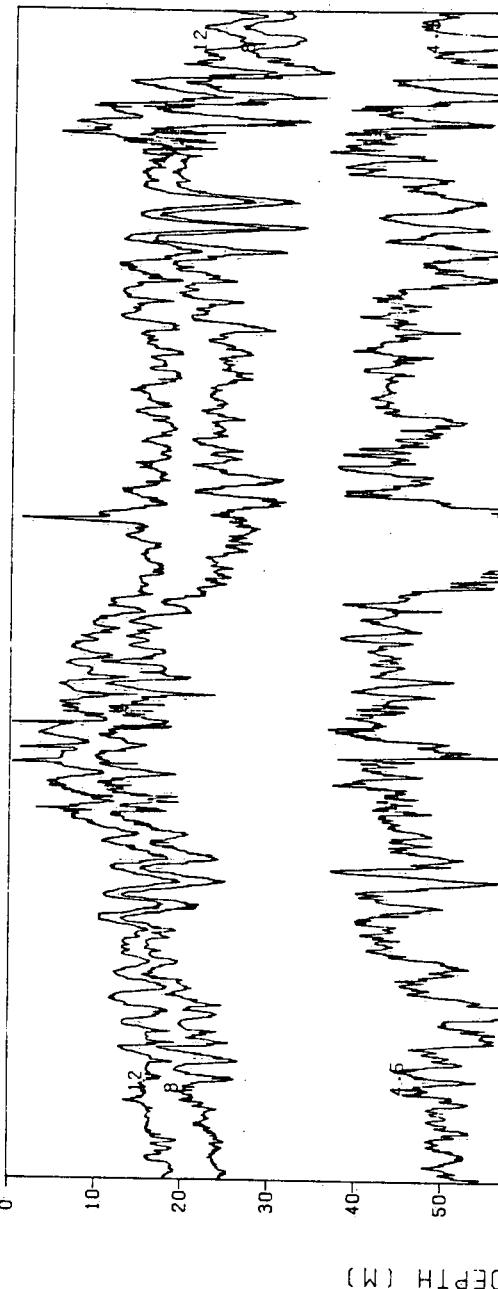
SEPTEMBER

TORONTO SURFACE WINDS
MIND VECTORS
10 m./hr. OFFSHORE (138°)

ALONGSHORE (228°)

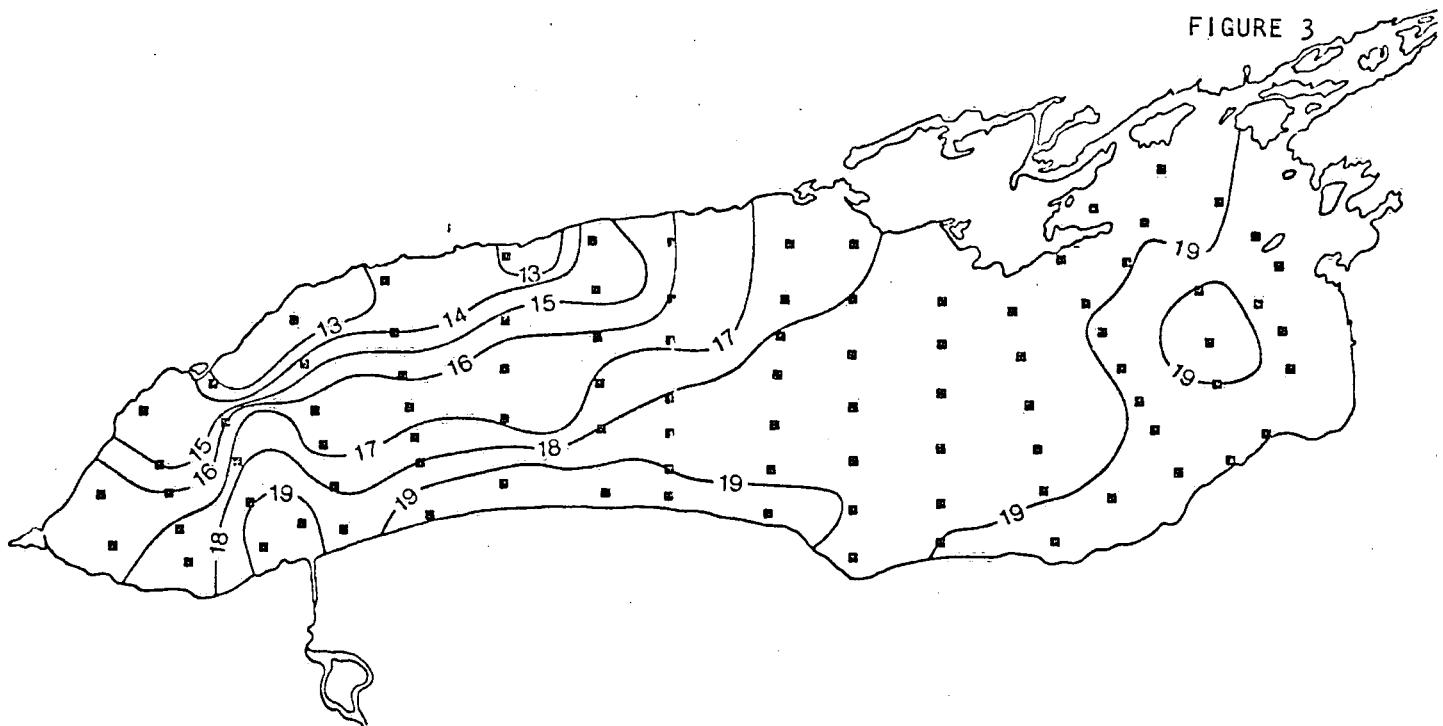


1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21 1 22 1 23 1 24 1 25 1 26 1 27 1 28 1 29 1 30 1

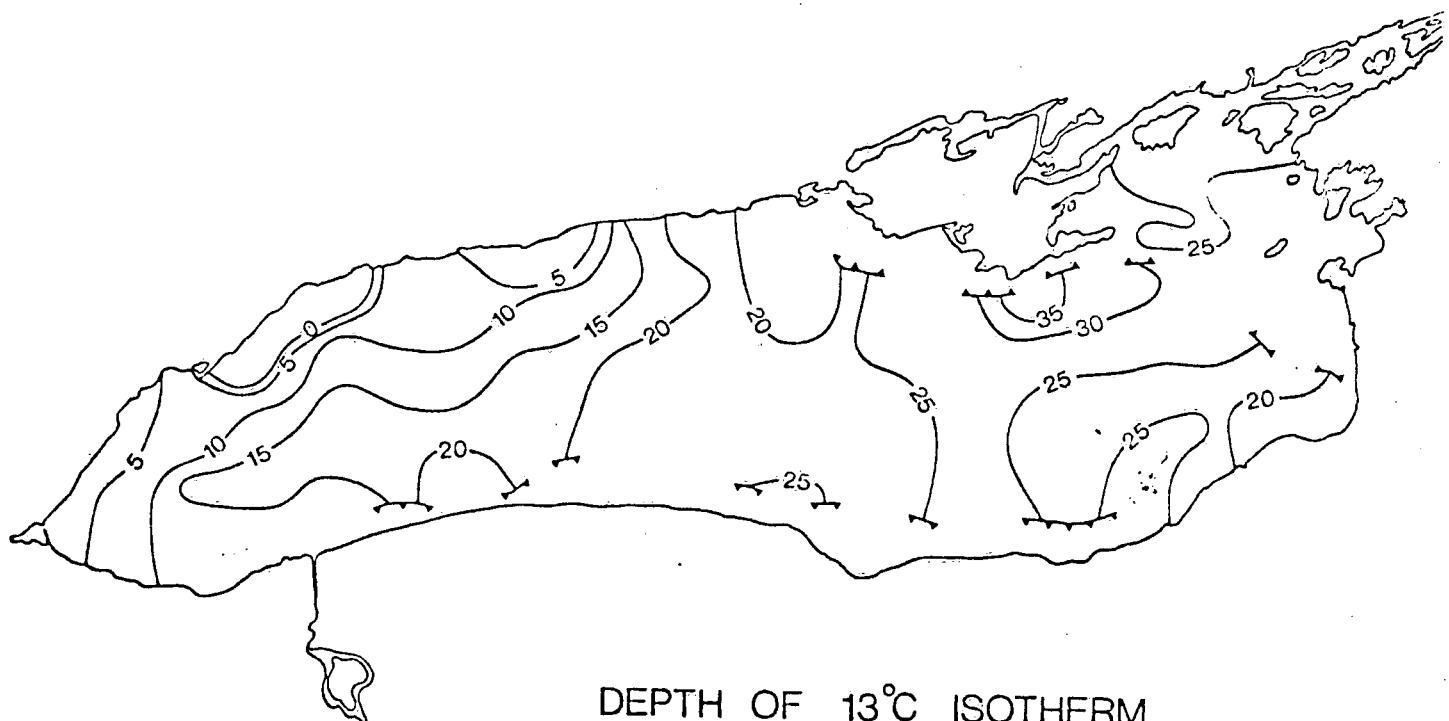


LAKE ONTARIO ISOThERM PLOT - TORONTO - (100 METRES) SEPTEMBER, 1980
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

FIGURE 3



SURFACE TEMPERATURE ($^{\circ}\text{C}$)



DEPTH OF 13°C ISOTHERM

SEPT. 18-21, 1972 LAKE ONTARIO

ISOTHERM DEPTHS, 4.5°C AND 8.0°C
July, August, September 1980

FIGURE 4

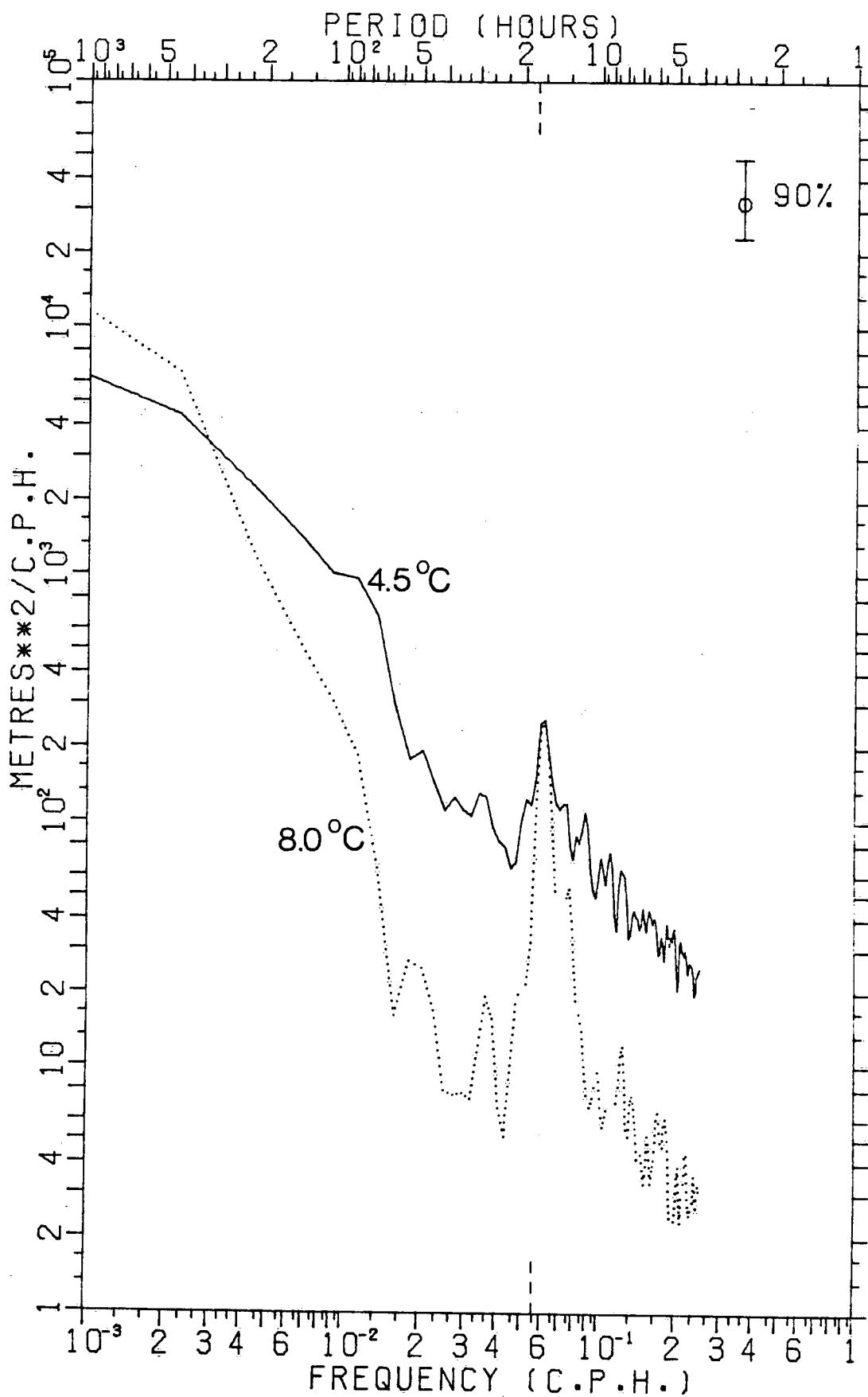


FIGURE 5

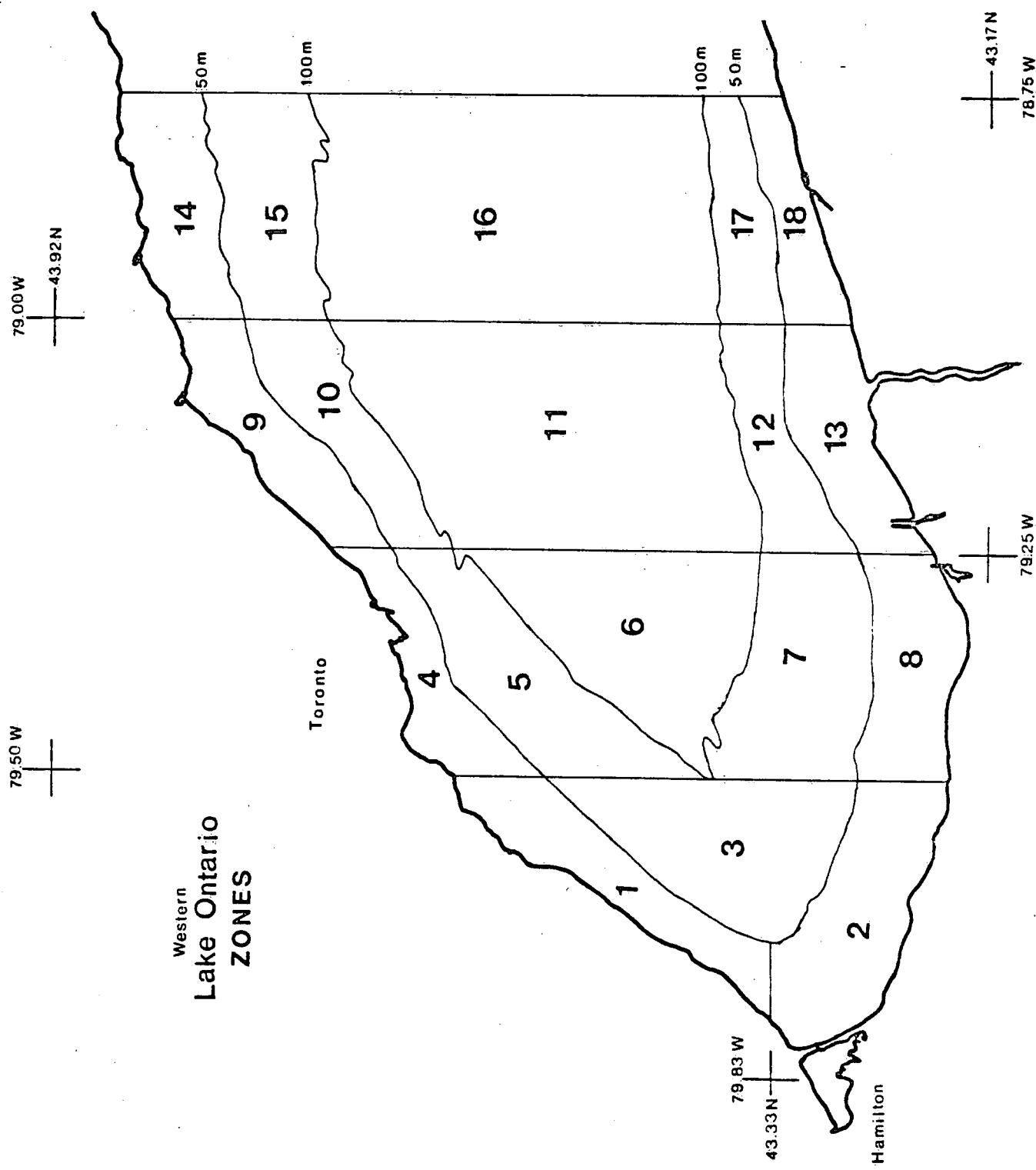


FIGURE 6 a

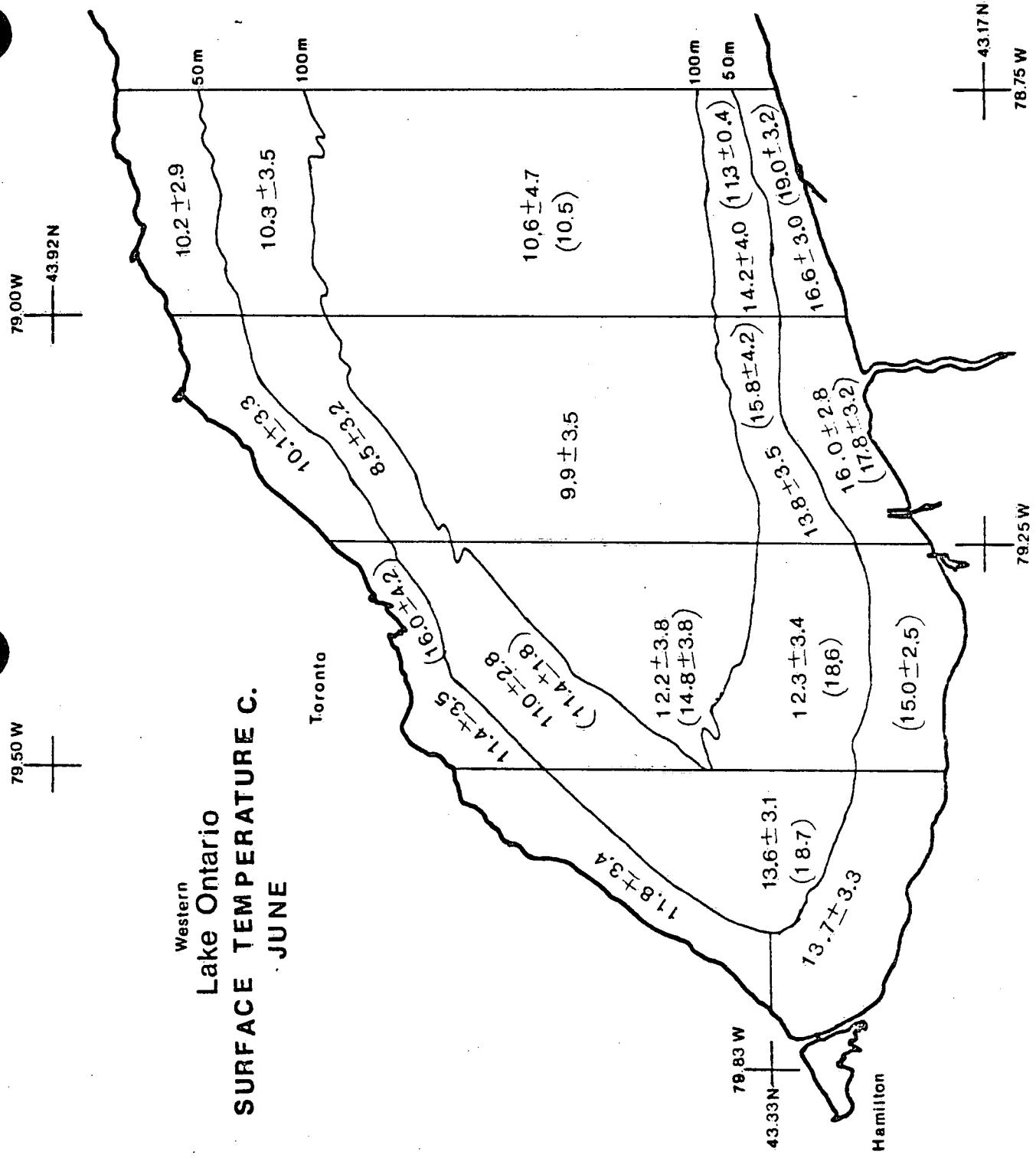


FIGURE 6 b

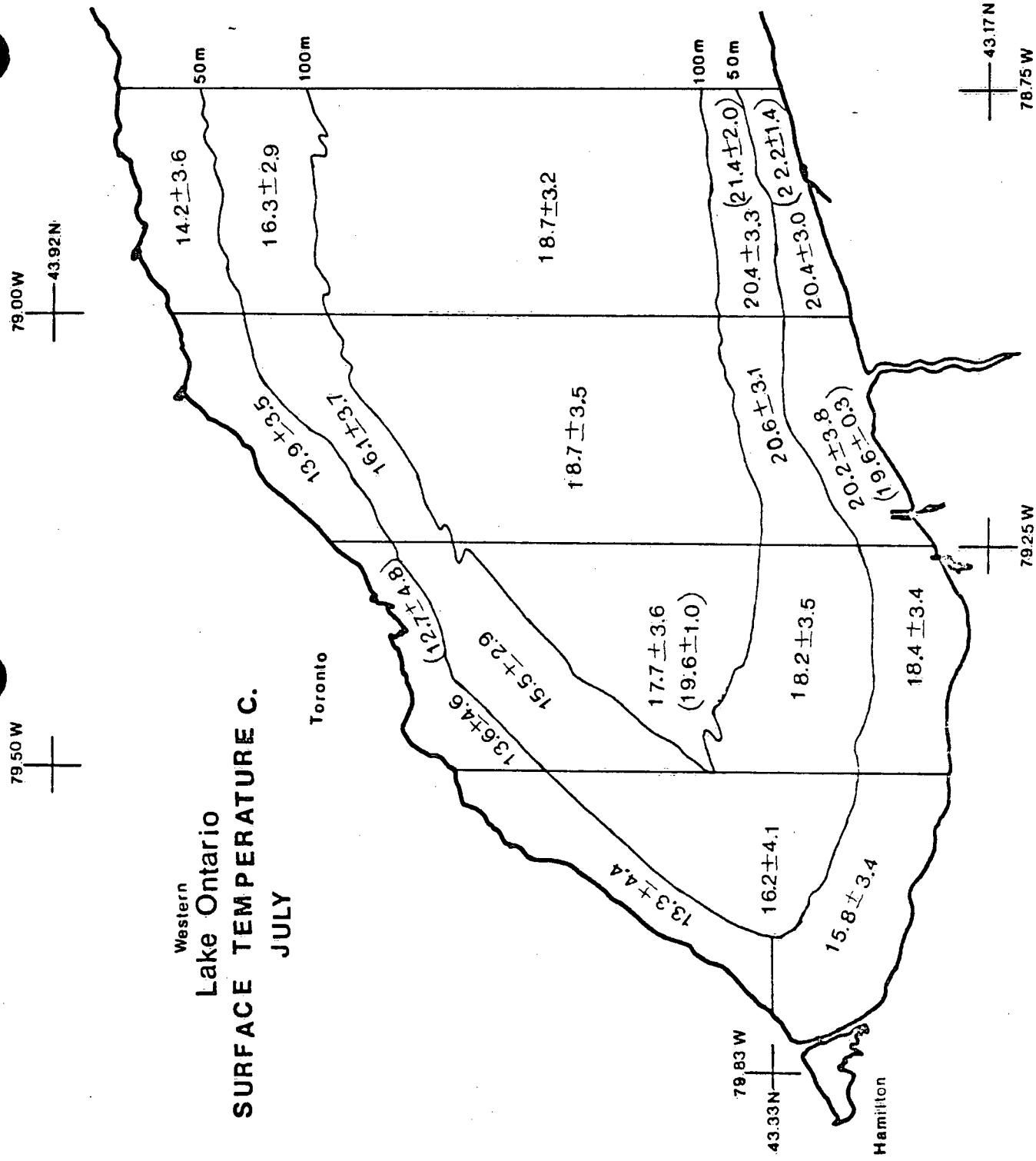


FIGURE 6 c

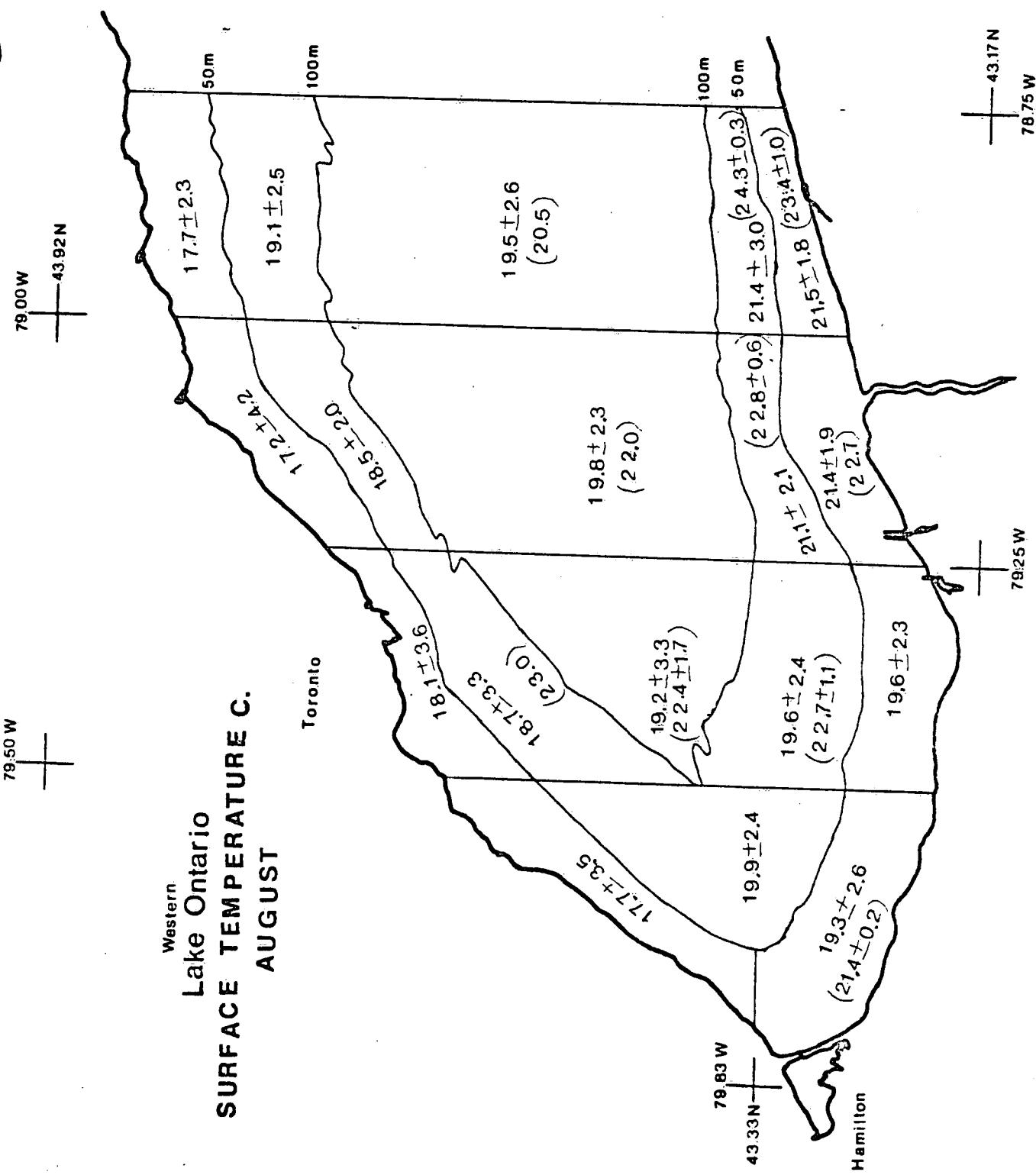


FIGURE 6 d

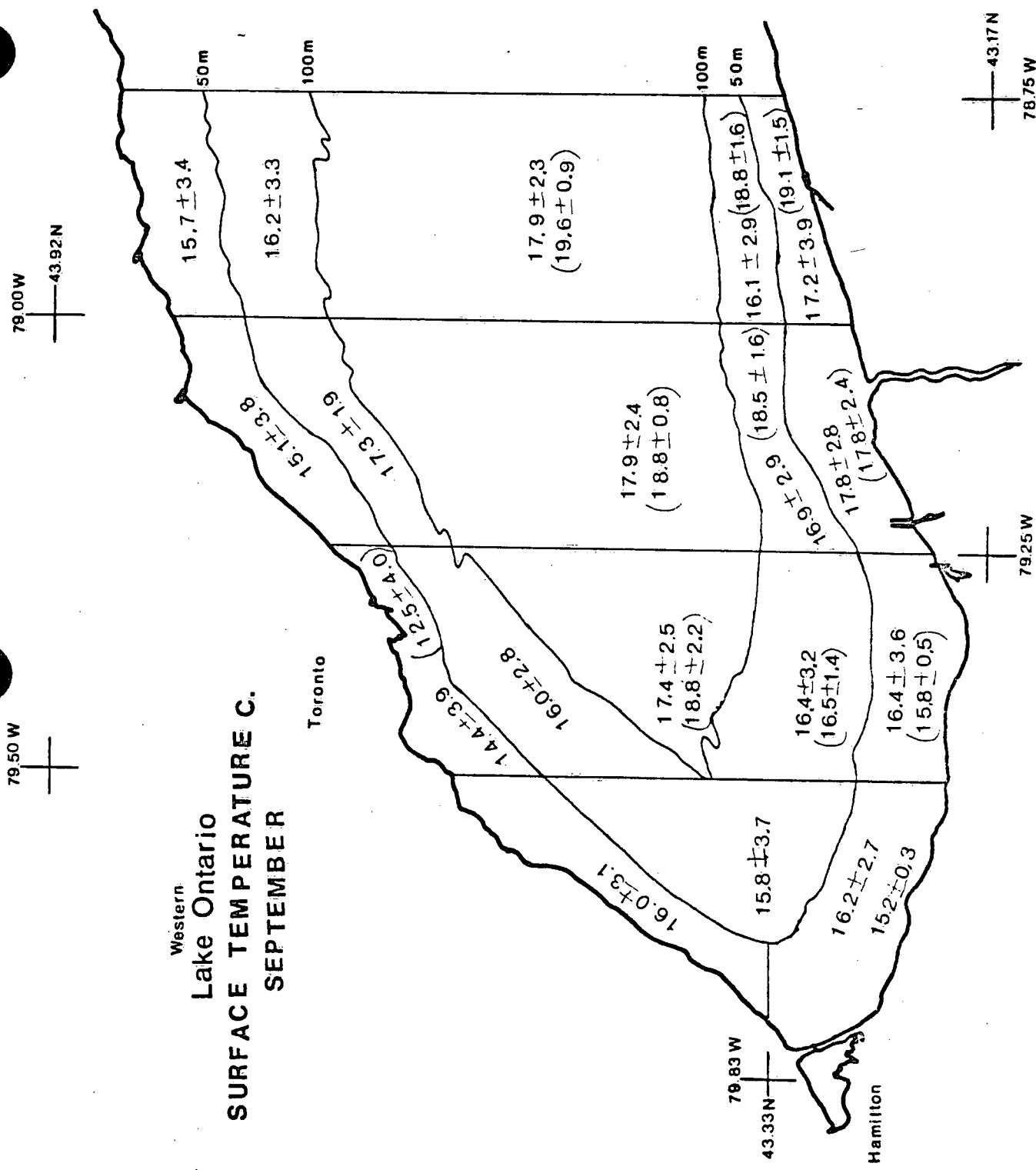


FIGURE 7 a

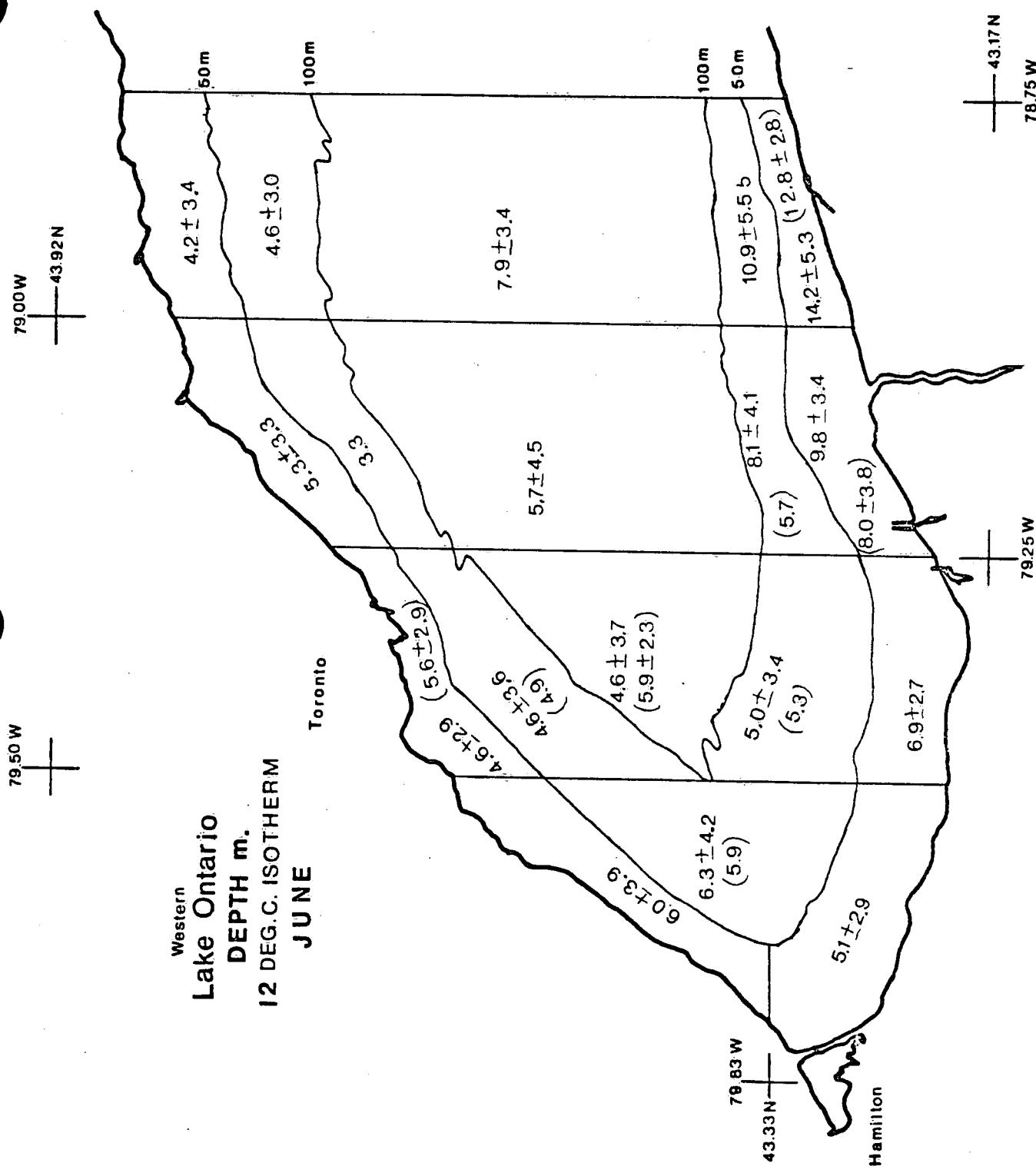


FIGURE 7 b

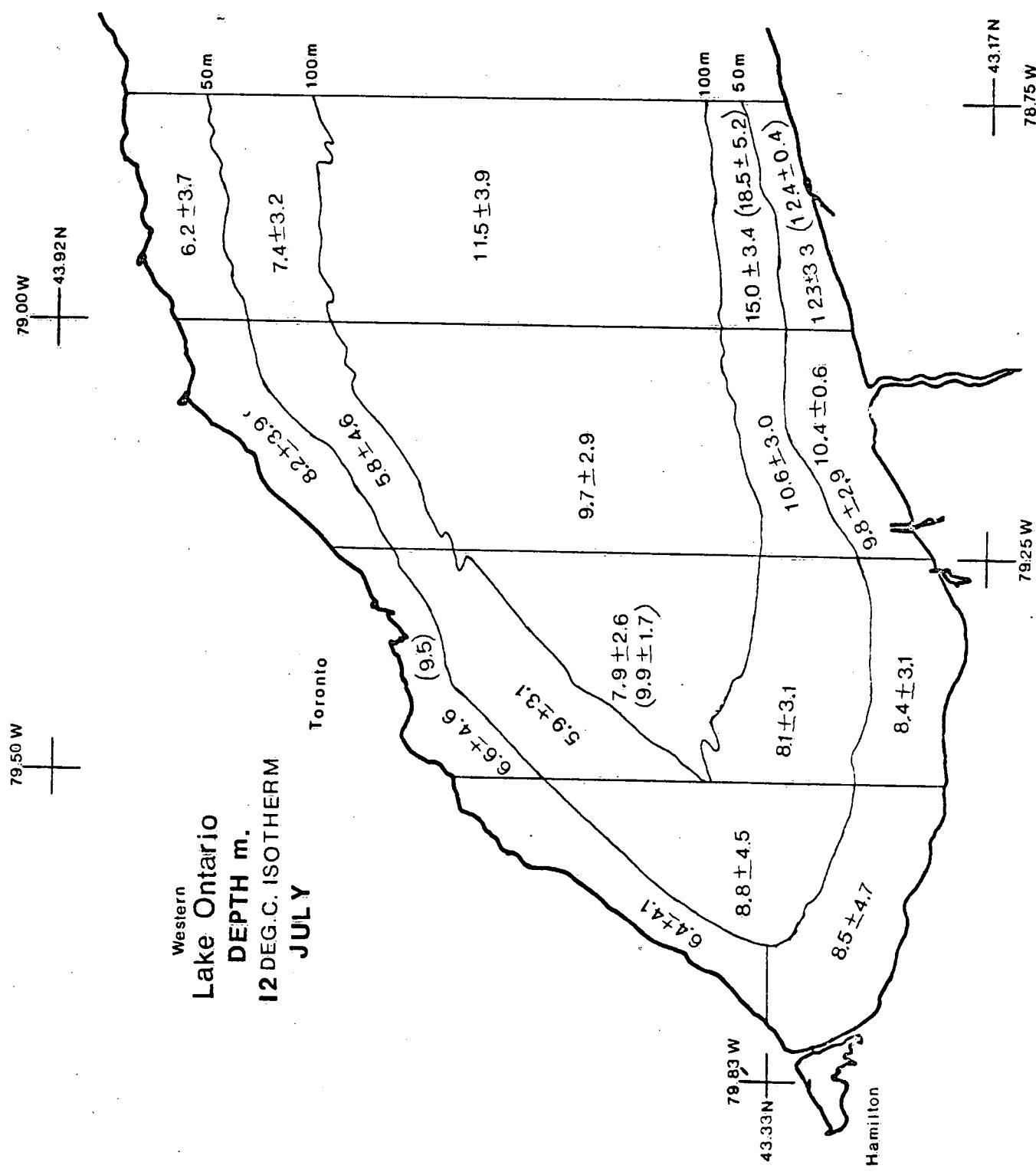


FIGURE 7 c

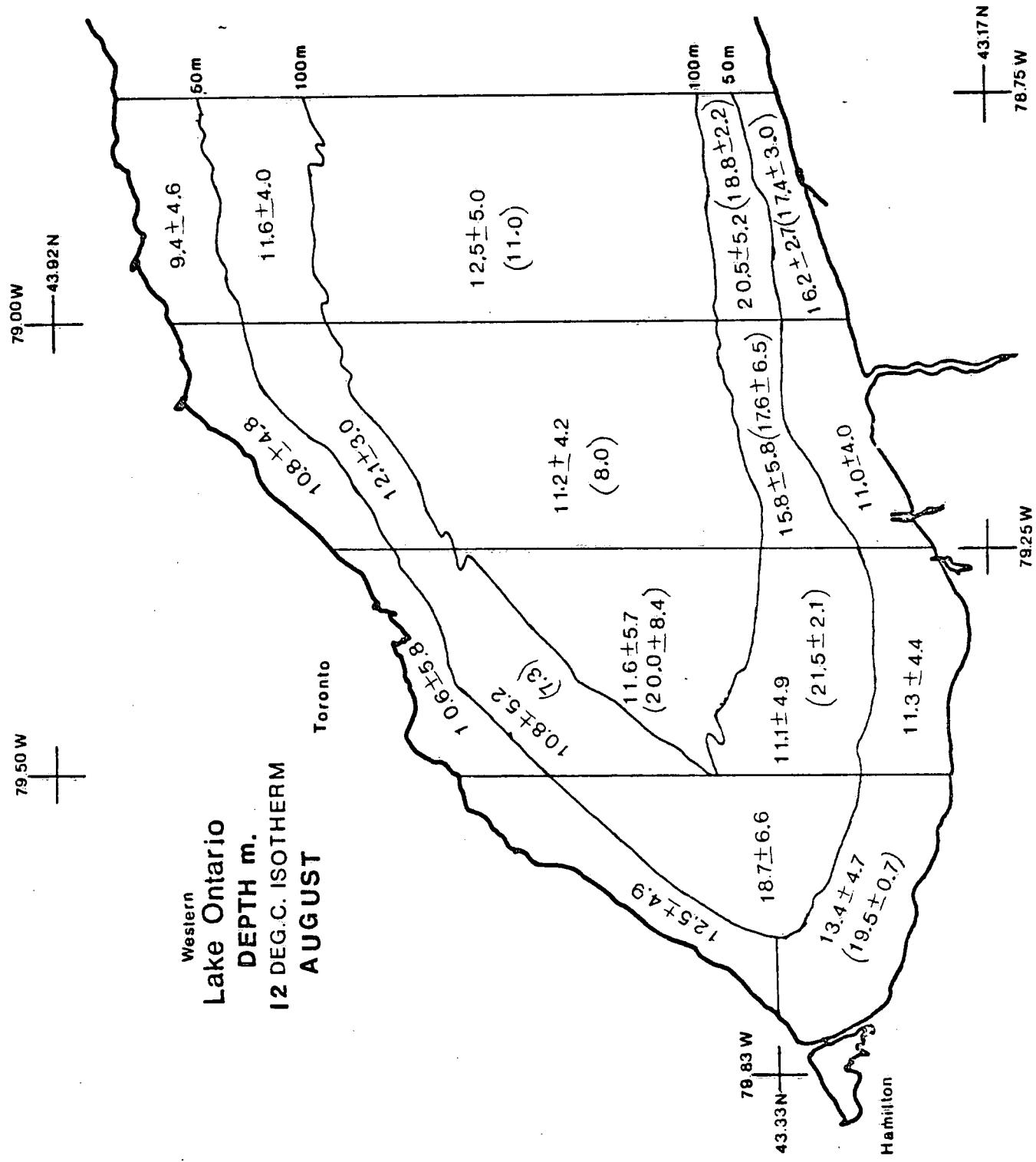
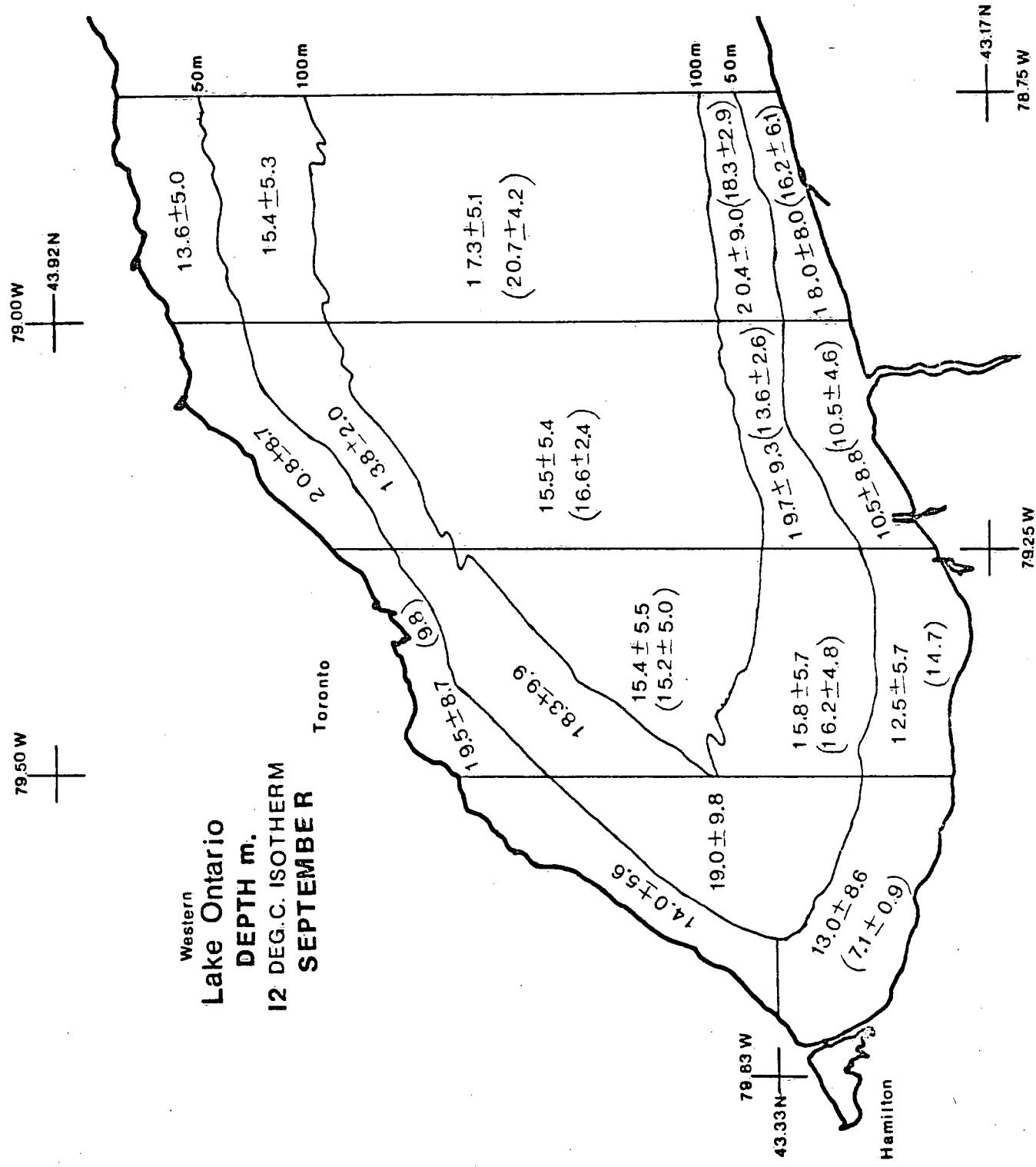


FIGURE 7 d



APPENDIX A

Tables identical to Tables 1a and 1b for the 10, 11, 13, and 14° C
isothermal surfaces.

REFLECTIONS OF THE 10.0 DEG.C. ISOTHERM

DEPTH(M) 0 45 91.0 DEG.C. 15.0

DEPTH(H) OF THE 13.0 MEG.C. ISOTHERM

DEPTH(M) OF THE 13.0 DEG.C ISOTHERM IN 93

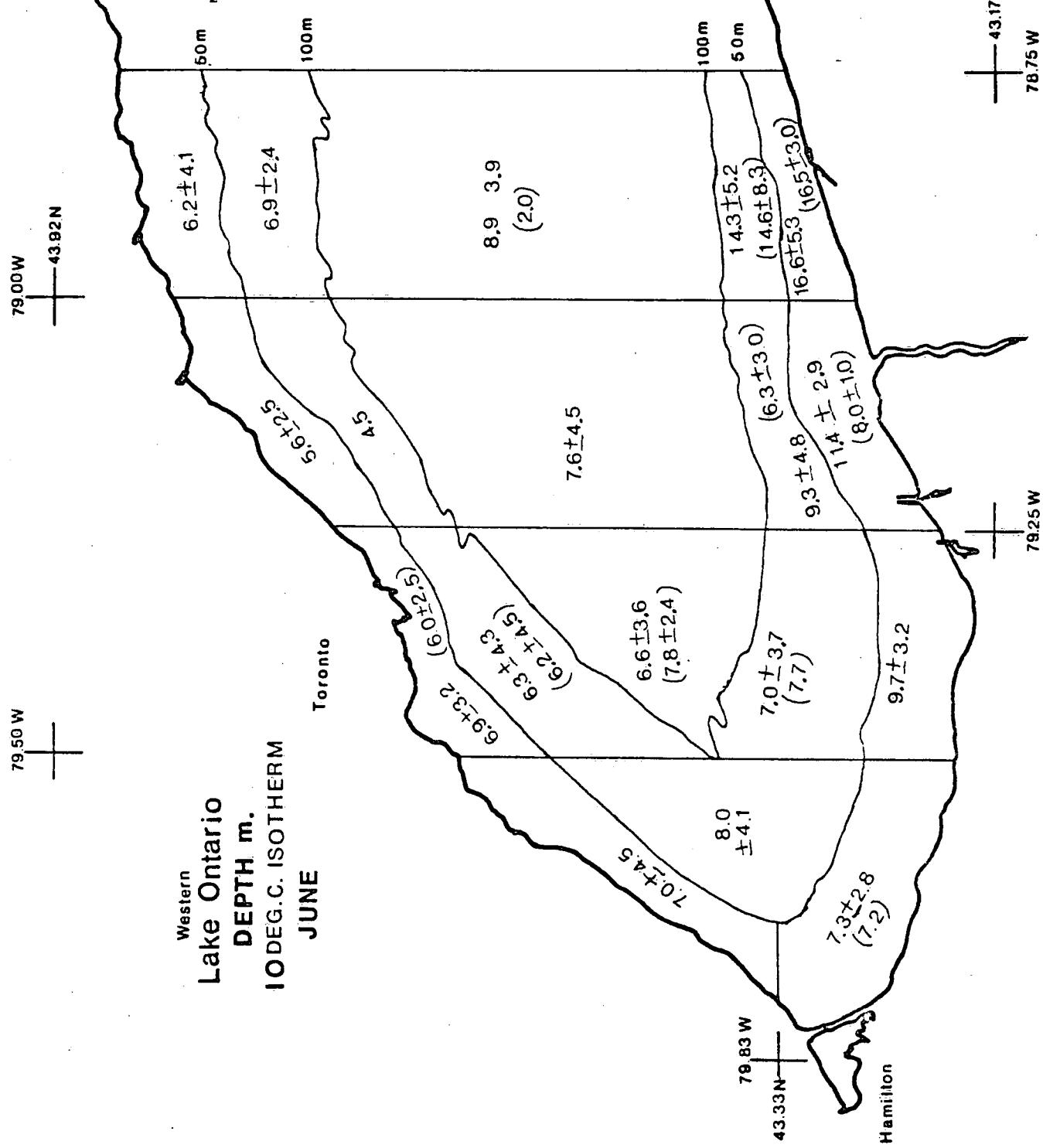
ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
2	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
3	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
4	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
5	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
6	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
7	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
8	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
9	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
10	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
11	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
12	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
13	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
14	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
15	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
16	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
17	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										
18	NO. OF OBS.											
	MEAN DEPTH(M)	ST.DEV.										

DEPTH(M) OF THE 14.0 DEG.C. ISOTHERM

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1 NO. OF OBS.	12	25	28	17	10.01	15.25						
1 MEAN DEPTH(M)	3.36	5.31	5.51	10.05	10.01	15.50						
2 NO. OF OBS.	12	17	12	3.3	5.3	5.63						
2 MEAN DEPTH(M)	2.86	3.75	6.59	10.87	11.12	10.56						
3 NO. OF OBS.	13	24	4.16	1.66	5.72	3.52						
3 MEAN DEPTH(M)	1.79	6.79	7.93	10.2	10.2	15.24						
4 ST. DEV.	1.70	5.73	3.90	6.05	8.38	4.09						
4 NO. OF OBS.	13	10	18	31	17.17	2.2						
4 MEAN DEPTH(M)	2.06	4.61	7.51	9.39	17.84	9.80						
5 ST. DEV.	1.49	2.27	5.30	4.44	10.59	1.46						
5 NO. OF OBS.	12	5	32	5.2	36							
5 MEAN DEPTH(M)	0.97	5.60	4.12	9.09	16.54	8.77						
6 ST. DEV.	1.10	4.05	3.22	4.36	8.77	7.34						
6 NO. OF OBS.	10	21	43	6.1	6.6							
6 MEAN DEPTH(M)	1.10	5.29	6.45	10.21	14.03	15.11						
7 ST. DEV.	3	3.10	2.71	5.30	5.75	5.17						
7 NO. OF OBS.	3	21	58	6.69	6.69	1.1						
7 MEAN DEPTH(M)	2.58	4.66	7.18	9.30	13.91	15.92						
8 ST. DEV.	1.69	2.6	2.69	4.31	5.34	9.05						
8 NO. OF OBS.	12	17	29	10.25	10.17	9.9						
8 MEAN DEPTH(M)	1.75	5.54	7.03	10.20	10.64	9.64						
9 ST. DEV.	1.75	2.35	3.93	3.45	5.92	4.94						
9 NO. OF OBS.	12	4	12	2.21	1.1							
9 MEAN DEPTH(M)	2.50	5.70	7.01	9.12	15.99	11.19						
10 ST. DEV.	1	2.62	2.62	4.46	4.46	3.70						
10 NO. OF OBS.	1	1	1	4.41	3.13	1.77						
10 MEAN DEPTH(M)	0.41	8.35	9.97	13.71	15.12							
11 ST. DEV.	1.21	2.85	3.24	3.87	4.60	6.09						
11 NO. OF OBS.	12	22	36	6.0	7.1							
11 MEAN DEPTH(M)	1.21	6.56	9.74	14.05	17.56	16.34						
12 ST. DEV.	2	3.26	3.05	5.18	19.09	7.07						
12 NO. OF OBS.	7.09	4.81	5.36	3.45	3.5							
12 MEAN DEPTH(M)	6.55	6.57	9.36	10.60	10.07	11.35						
13 ST. DEV.	5.03	8.27	9.36	10.60	10.97	12.97						
13 NO. OF OBS.	3	3.45	2.96	3.88	17.97	2.91						
13 MEAN DEPTH(M)	3.33	3.2	2.9	2.20	1.1							
14 ST. DEV.	5.03	6.57	3.96	7.82	12.25	14.82						
14 NO. OF OBS.	3	3.3	2.10	3.46	4.67	3.32						
14 MEAN DEPTH(M)	3.33	2.10	3.23	3.36	2.26							
15 ST. DEV.	1.81	7.21	6.93	10.05	14.29	16.29						
15 NO. OF OBS.	1	1	1	1.41	2.97	3.34						
15 MEAN DEPTH(M)	1.81	7.21	6.21	6.21	7.2	2.27						
16 ST. DEV.	2	3.26	3.20	6.2	1.21	2.21						
16 NO. OF OBS.	7.09	4.81	5.36	6.93	11.18	15.60						
16 MEAN DEPTH(M)	6.55	6.57	9.33	3.89	4.31	8.75						
17 ST. DEV.	1.21	3.28	2.28	2.25	4.0	1.6						
17 NO. OF OBS.	1	1	1	1.21	2.25	1.25						
17 MEAN DEPTH(M)	1.21	3.28	2.28	2.25	2.25	1.25						
18 ST. DEV.	0.40	10.80	11.72	15.87	15.90	9.11						
18 NO. OF OBS.	1	33	33	28	28	31						
18 MEAN DEPTH(M)	0.40	10.80	11.72	15.87	15.90	9.11						
18 ST. DEV.	6.29	12.89	12.89	6.61	6.61	3.78						

APPENDIX B

Figures identical to Figure 7 for the depths of the 10, 11,
13 and 14°C isothermal surfaces.



79.50 W
43.92 N

Western
Lake Ontario
DEPTH m.
10 DEG.C. ISOTHERM
JULY

79.00 W
43.82 N

50m

100m

8.9 ± 5.0

9.5 ± 3.0

100m

50m

13.3 ± 4.3

11.1 ± 3.1

100m

50m

9.5 ± 3.0
 (11.3 ± 1.4)

11.2 ± 4.3

100m

50m

16.5 ± 3.8
 (20.8 ± 5.5)

11.7 ± 2.8
 (10.2 ± 2.9)

100m

50m

9.9 ± 2.9

10.7 ± 5.0

100m

50m

9.1 ± 3.6

100m

50m

43.17 N
78.75 W

79.25 W
43.82 N

79.83 W
43.33 N

Hamilton

79.50 W
+-----+

Lake Ontario
DEPTH m.
10 DEG.C. ISOTHERM
AUGUST

79.00 W
+-----+
43.92 N

50m

100m

12.3 ± 4.8

13.2 ± 4.6

14.1 ± 5.1
(12.2)

12.8 ± 4.5
(8.9)

100m
50m

22.0 ± 5.6
(20.0 ± 2.3)

16.6 ± 7.4
(14.9)

11.3 ± 4.2

78.25 W
+-----+
43.17 N

14.1 ± 5.2

14.2 ± 4.0

13.4 ± 6.0
(1.9)

12.8 ± 6.4
(2.2 ± 9.4)

21.6 ± 7.1

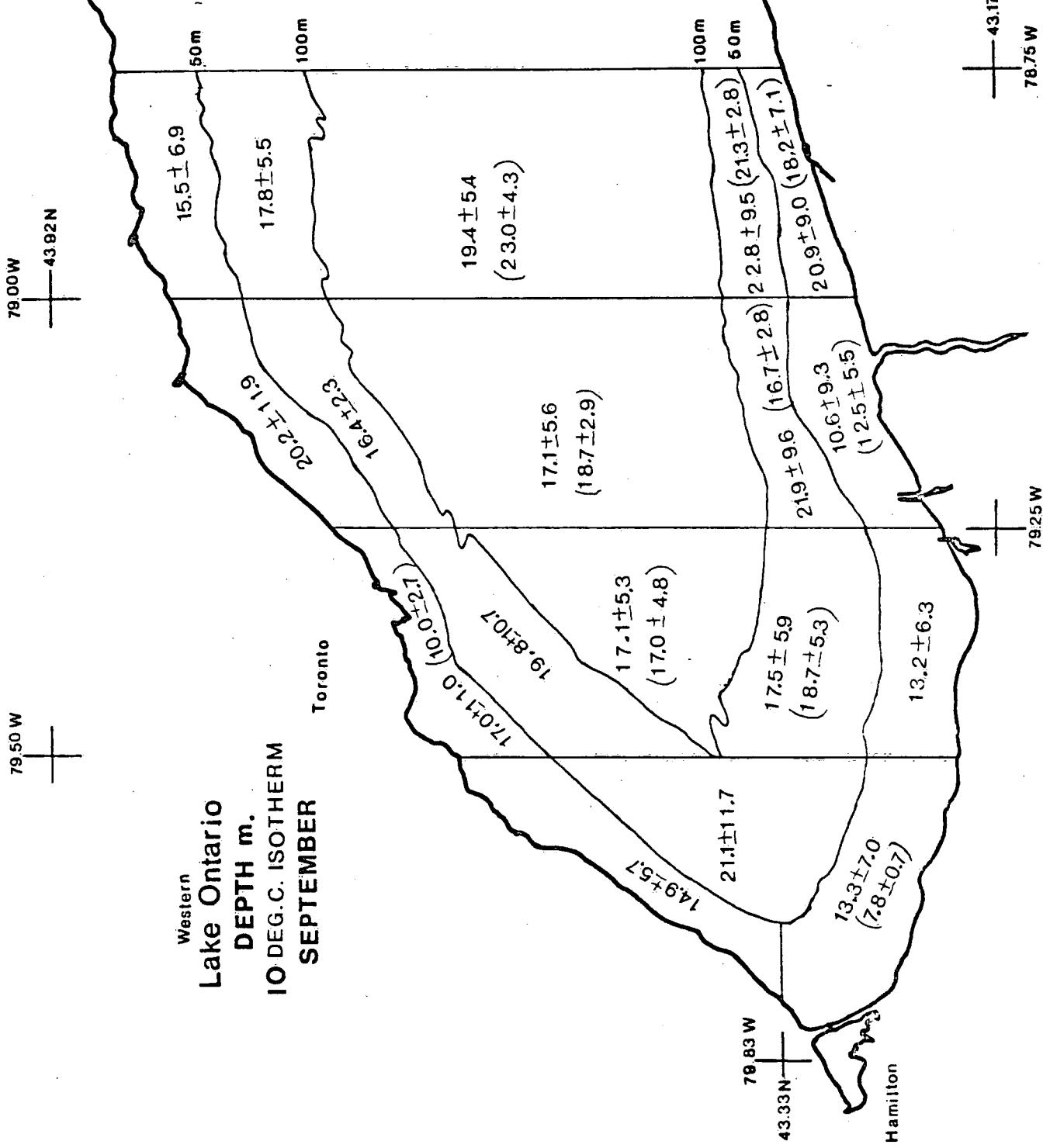
78.83 W
+-----+
43.33 N

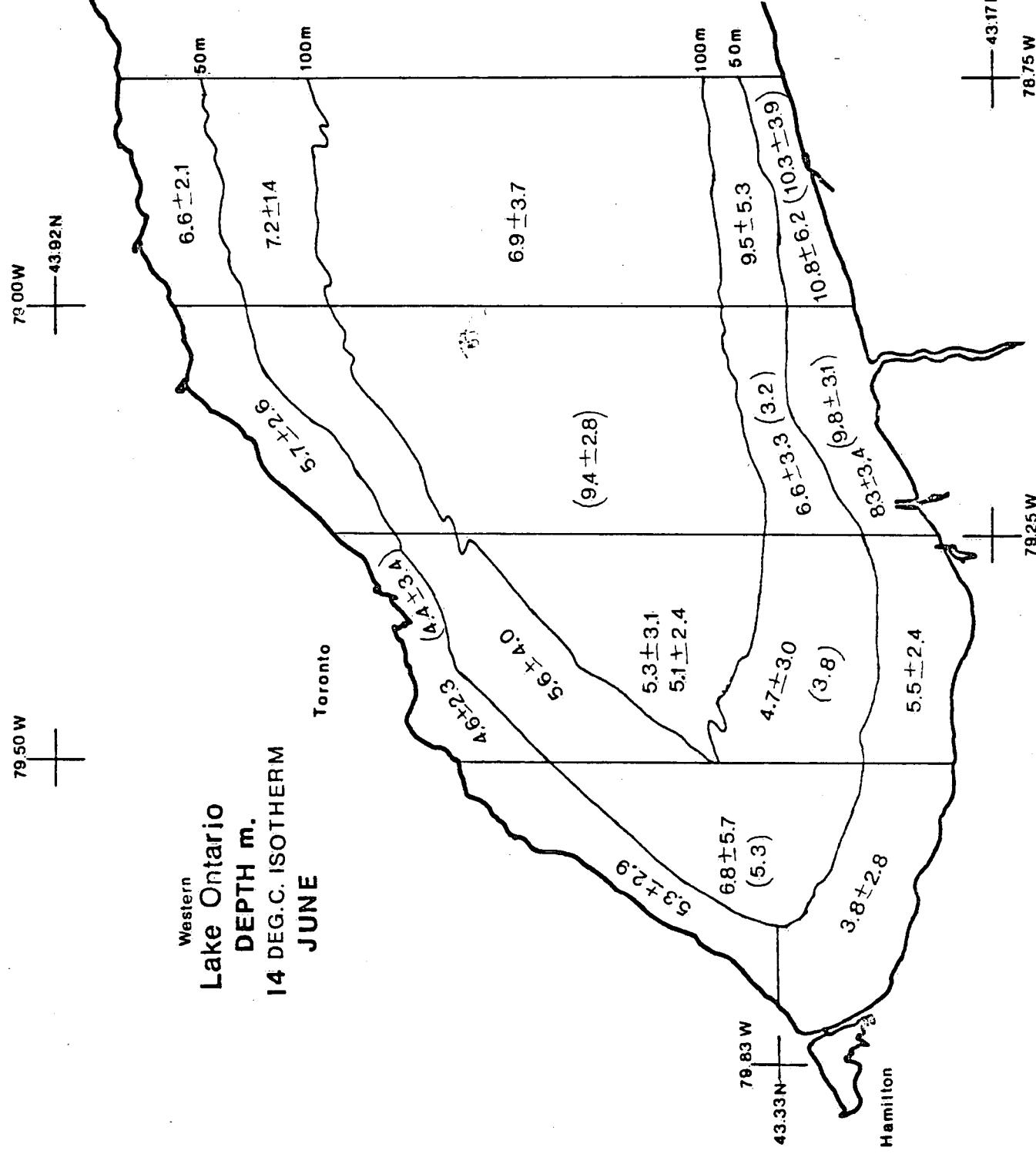
14.0 ± 4.5
(21.1 ± 0.6)

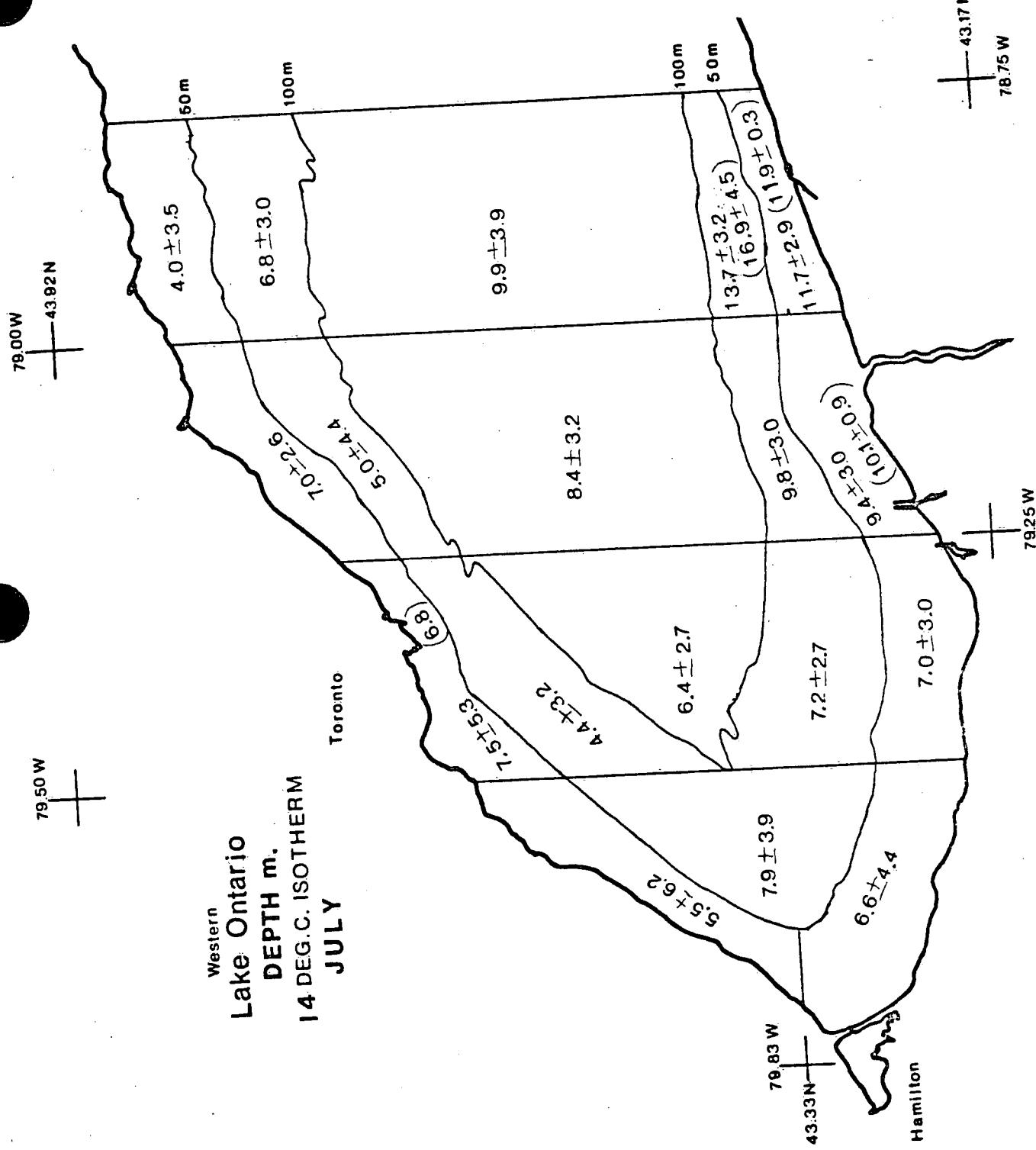
12.1 ± 4.0

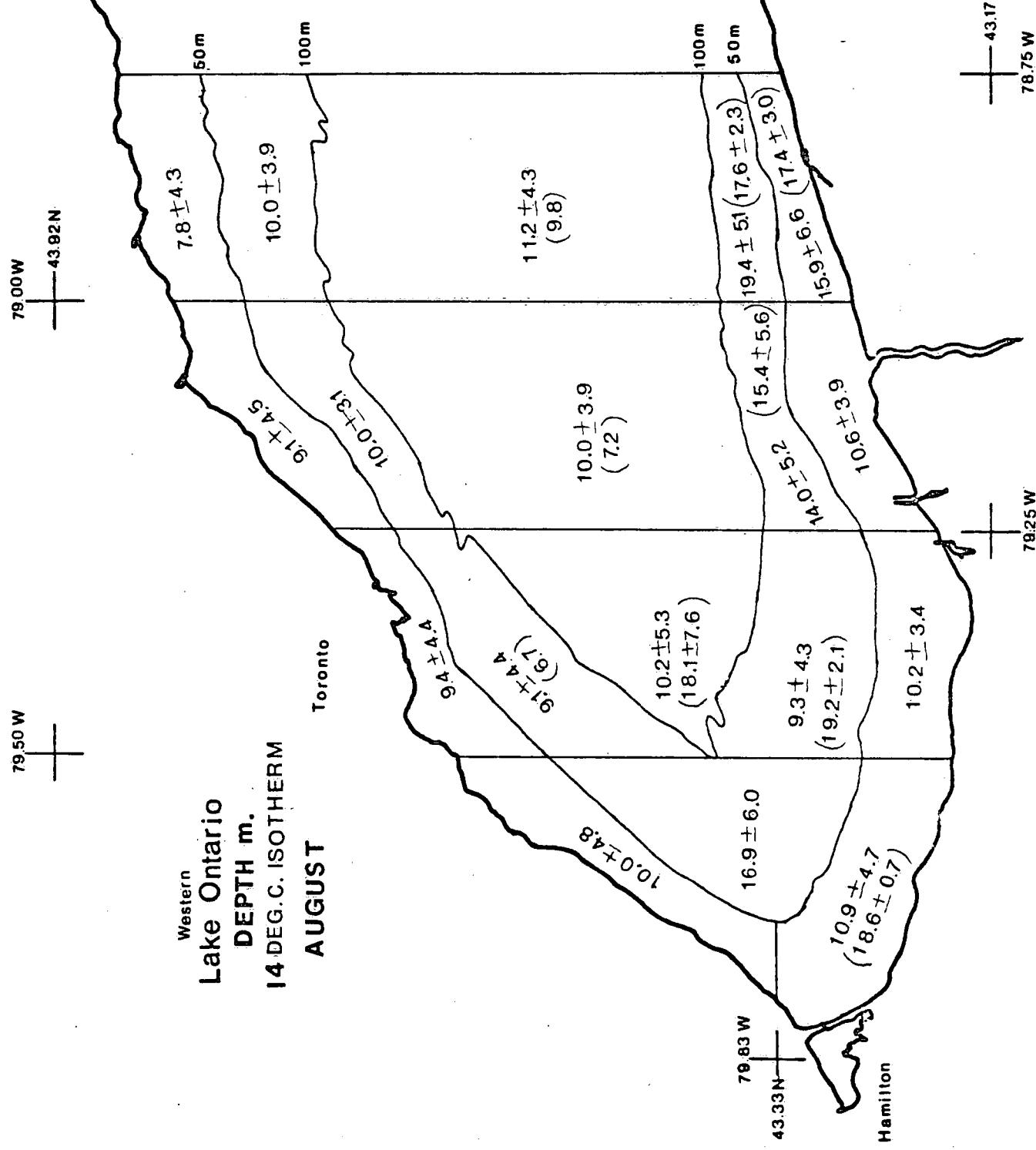
Toronto

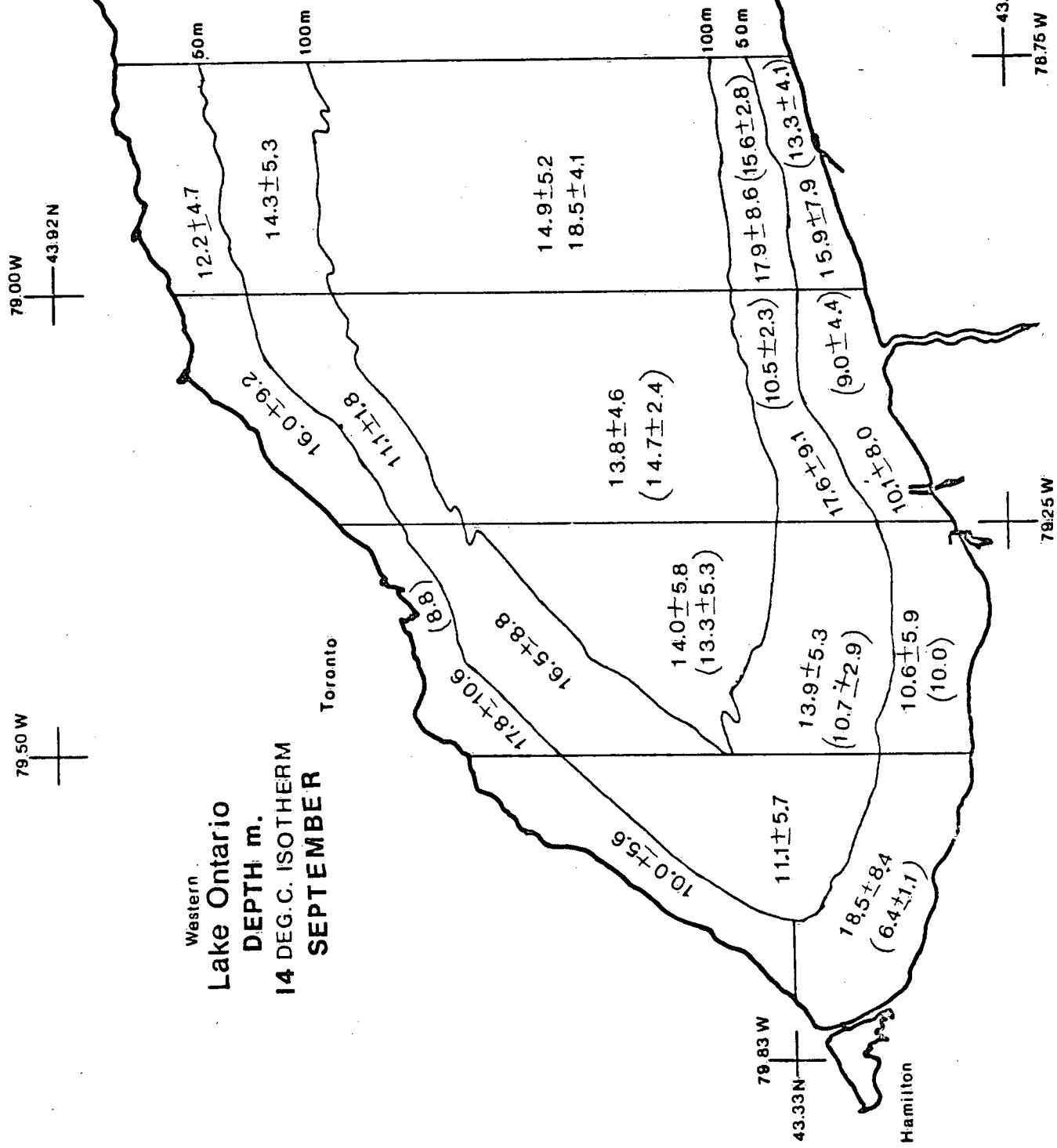
Hamilton











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