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A COMPILATION OF THE AVERAGE DEPTHS
OF LAKE MICHIGAN AND LAKE ONTARIO
ON A TWO-MINUTE GRID

T. H. Hughes, G. E. Birchfield,
and M. T. Matthies

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T. H. Hughes, G. E. Birchfield,*
and M. T. Matthies

Applied Mathematics Division

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January 1972

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A COMPILATION OF THE AVERAGE DEPTHS OF LAKE MICHIGAN AND
LAKE ONTARIO ON A TWO-MINUTE GRID*

by

T. H. Hughes, G. E. Birchfield, and M. T. Matthies

ABSTRACT

Average depths for Lake Michigan and Lake Ontario are estimated at each two minutes of latitude and two minutes of longitude. Sounding data are used from the navigation charts and field sheets of the U. S. Corps of Engineers and the Canadian Hydrographic Office. The average at a point is taken to be the arithmetic mean of all soundings appearing in a circle of radius one minute of latitude centered at the point without consideration of the sounding's position relative to the point. For those locations with fewer than three soundings in such a circle, the circle is enlarged until three soundings appear within the circle. Final tabulation of the averages with contours is in blocks thirty minutes latitude by thirty minutes longitude. The averages are available on punched cards.

* Work performed in part under the auspices of the U. S. Atomic Energy Commission and National Science Foundation, Atmospheric Sciences Section, Grant No. GA-25992.

INTRODUCTION

The rapidly developing interest in the numerical solution of problems concerned with the hydrodynamics of the Great Lakes has created the need for a representation of the bottom topography in a form readily accessible to a computer. What is usually required is the average value of the basin depth at regularly spaced locations. For the Great Lakes there is a large amount of bathymetric data available. However, because of the irregular topography, it is often a difficult task to 'average by eye.' It is thus desirable to automate as much as possible the conversion of this data into a form suitable for computer usage. A major aspect of this study is the use of a simple precisely-defined set of rules for the estimation of the average depths.

THE COMPILATION PROCEDURE

For Lake Michigan, navigation charts #73-77 (scale 1:120,000) were used as a source of soundings for the southern and central portions and charts #701-706 and 60 (scale 1:80,000) for the northern portion. U. S. Corps of Engineers charts #21-25 (scale 1:80,000) provided soundings for the U. S. portion of Lake Ontario and Canadian Hydrographic Office charts #2058 and #2060-2064 (various scales all approximately 1:80,000) were used for the Canadian portion. Unfortunately there are gaps between these charts in the central lake areas and also no soundings are printed in legend areas. To close these gaps copies of the field sheets from

which the published charts are drawn were obtained from the U. S. Corps of Engineers in Detroit. For Lake Michigan, field sheets #1955-1960 (scale 1:120,000) were used. Ideally the field sheets should be used for the entire lake; but due to the number of soundings, particularly in the shore regions, the effort required was found prohibitive. For Lake Ontario field sheets #2078-2083 (scale 1:80,000) were used for most of the lake, navigation charts being used only in the near-shore regions. Because of the number and variety of sources it was found most convenient to work with longitude and latitude coordinates rather than to use a somewhat arbitrary square reference grid drawn on a polyconic projection of the whole lake. Additional lines were drawn directly on each chart to produce the complete two minute by two minute grid.

The average at each grid point is taken to be the arithmetic mean of all soundings appearing in a circle of radius one minute of latitude centered at the point. The position of the sounding within the circle is not considered. Nearly all locations have at least three soundings in such a circle. For those locations with fewer data, the circle is enlarged until three soundings appear within the circle. In only a couple of cases in the southern basin of Lake Michigan was a circle of area greater than three times the one minute circle required. In the case of Lake Ontario the soundings are sufficiently uniform and dense that the one minute circle is adequate for all locations. In the central portion of both lakes the soundings lie along the tracks of the survey ship spaced roughly one and one-half to two miles apart. The two minute grid size was chosen to be consistent with this spacing and the method of estimating the average depths. Average depths at a finer or coarser grid can be found using an interpolation-smoothing routine. At nearshore points where the circle overlaps land area,

the estimated average depth determined according to the rules above was reduced by the estimated fraction of land area appearing in the circle. An approximate shoreline was drawn on the charts and the land area to the water side of this artificial coastline, including small islands, is ignored in estimating the fraction of land area in the circle. The soundings were recorded by having one person of a team read off the soundings to a second person who entered the values into a WANG 700 calculator which was programmed to calculate and print the average and the standard deviation. Each point was processed twice and checked for consistency.

In order to make full use of the information on the charts to estimate area averages some type of distance weighted interpolation (e.g., the interpolation procedures used in objective analysis of weather data) or least squares surface fitting would be required. However, averages are required at about 7,500 points with an average of about eight soundings per point so the amount of work required for such procedures proved to be excessive. Dishon (1964) published averaged depths on a one degree grid of the world oceans for which he chose only a single value nearest to a grid point and used an interpolation-smoothing routine to fill in the many vacant locations. Kozlov (1969) used a procedure such as the one used in this report to produce a five degree grid map of the average depth for the Pacific Ocean. (He used a rectangle rather than a circle but we found a circle more convenient.) If the soundings are numerous and uniformly distributed, then the averaging procedure can be justified and the standard deviation of the soundings will be a good measure of the roughness of the bottom topography. In the cases where the standard deviation is small, choosing the single closest value is probably adequate. However, where the standard deviation is large, the averaging procedure is clearly better.

The standard deviations were computed but have not been analysed in detail. In the southern basin of Lake Michigan and most of Lake Ontario the standard deviation is roughly 5% to 15% of the average but there are irregular regions nearshore and in northern Lake Michigan where the standard deviation is often of the same order of magnitude as the average. No information was available to estimate the error in the soundings themselves. On the navigation charts, however, there is some bias toward the plotting of the shallowest values in a region since the charts are primarily intended for navigation. Also in the shallow regions near shore and islands there are many soundings but they often tend to be clustered around special features. In the central portion of the lake the soundings are fairly uniform but more sparse.

The construction of the approximate shoreline shown in the figures and used in estimating the nearshore depths is a more subjective activity. The general idea is to approximate the coastline of the lake by straight line segments approximately two minutes of latitude in length or longer. The approximate shoreline was drawn directly on the navigation charts using the following criteria: (1) at least one shore coordinate must fall on a 2' grid line, (2) the change in the land and water area should balance so that the total lake area is conserved, (3) the minimum segment length is one minute of latitude, (4) when a line segment would fall closer than $\frac{1}{2}'$ to a grid point, the line is moved to the grid point or farther away, (5) an island is ignored if its area is less than 2' by 2' latitude area, and (6) bays of 'depth' greater than 2' latitude with entrance 'width' less than 2' latitude are ignored. The coordinates of the junctions of the line segments for Lakes Michigan and Ontario are tabulated

in Tables II, III, and IV. The origin of coordinates for Lake Michigan is at $41^{\circ} 30'N$, $88^{\circ}W$ and $43^{\circ}N$, $80^{\circ}W$ for Lake Ontario; the units are minutes of longitude increasing eastward and minutes of latitude increasing northward. Nine islands are included for Lake Michigan and all islands in Lake Ontario are ignored.

RESULTS FOR LAKE MICHIGAN AND LAKE ONTARIO

The results of the averaging procedure are presented in blocks of data covering an area of $30'$ of latitude by $30'$ of longitude. The index for these data blocks for Lake Michigan is shown in Figure 1 and for Lake Ontario in Figure 6. The individual blocks are displayed in Appendix A and Appendix B. The average depths are also available on punched cards by writing to any one of the authors. The depth contours displayed on the figures were drawn by computer using routines described in Wessel (1970). These routines produce contour lines from a regular array of data by drawing straight line segments between points along the four sides of the rectangle defined by four data points. The location of the intersection of the contour lines with the sides of the rectangle are determined by linear interpolation. In order to provide smoother contours than permitted by the two-minute grid, the two-dimensional interpolation program SYMAP (Ref. 6) was used to produce a regular one-minute data field from the average depths. Since SYMAP can handle irregularly located data, it was also possible to include in the interpolation values along the irregular shoreline. The interpolation algorithm used by SYMAP is complex and for details the reader is referred to Shepard (1968). While the contours are not as smooth as

those drawn by a draftsman, they do give a reasonably accurate and objective picture of the lake bottom as represented by the average depths.

The complete bottom topography of Lake Michigan based upon the average depths is shown in Figure 2 and of Lake Ontario in Figure 7. Three sections of Lake Michigan are shown in greater detail in Figures 3, 4, and 5. These five figures contain contours using linear interpolation from the two-minute data and were not processed by SYMAP. The plus (+) marks scattered throughout the figures are the intersections of 30' parallels and 30' meridians and correspond to the corners of the 30' by 30' data blocks. The map projection used in these figures is the Sinusoidal or Mercator Equal-Area projection (Deetz & Adams, 1945). In this equal-area projection the parallels and the central meridian are straight and longitudinal distances are scaled by the cosine of the latitude. A number of characteristics of the two lakes have been calculated using the averaged depths and are recorded in Table I. The volume is calculated by a simple method in which the area of each 2' by 2' rectangle is multiplied by the average of the four depths at the corners. These elemental volumes are summed over all 2' rectangles having at least one non-zero value at a corner. The area of the lake is calculated as the sum (over all 2' rectangles having at least one non-zero corner value) of one-fourth the 2' by 2' area times the number of corners with non-zero values. This calculation of the lake area is equivalent to using a new approximate rectangular shoreline close to the shoreline shown in the tables and appendices. The mean depth is the lake volume divided by the lake area. The average slopes were found by taking the average over the lake of the first difference of the depths in feet divided by the appropriate length interval also in feet. The values computed for the areas of the two lakes are somewhat less than the values commonly quoted because in drawing the shoreline small bays and channels were neglected.

ACKNOWLEDGMENT

The navigation chart preparation, programming of the data handling routines, and production of the computer graphic displays were performed at Argonne National Laboratory. The reading of the sounding data and the recording of the values on the WANG 700 calculator were carried out at Northwestern University under support of National Science Foundation Grant No. GA-25992.

We wish to thank Northwestern University students Joan McLauflin and Nancy Birnbaum for their help in the tedious chart work.

Fig. 1. Index of 30' by 30' Data Blocks for Lake Michigan.

Fig. 2. Averaged Bottom Topography of Lake Michigan
(isobaths in intervals of twenty fathoms).
The shoreline of the islands has been omitted.

Fig. 3. Averaged Bottom Topography of the Southern Basin of Lake Michigan (isobaths in tens of fathoms).

Fig. 4. Averaged Bottom Topography of the Northern Basin of Lake Michigan (isobaths in intervals of twenty fathoms).

Fig. 5. Averaged Bottom Topography of the Northern Part of Lake Michigan (isobaths in intervals of twenty fathoms).

Fig. 6. Index of 30' x 30' Data Blocks for Lake Ontario.

Fig. 7. Averaged Bottom Topography of Lake Ontario
(isobaths in intervals of twenty fathoms).

Table I

PARAMETERS BASED UPON AVERAGE DEPTHS AND APPROXIMATE SHORELINE

	<u>Lake Michigan</u>	<u>Lake Ontario</u>
Reference Level	576.8 ft.	242.8 ft.
Area	21,826 sq. mi.	6,963 sq. mi.
Volume	1,150 cu. mi.	397 cu. mi.
Mean Depth	278 ft.	301 ft.
Average Slope: North-South	.00235	.00493
Average Slope: East-West	.00379	.00186
Depth Frequencies:		
1 to 100 ft.	1448	385
101 to 200	872	285
201 to 300	1049	265
301 to 400	915	278
401 to 500	629	254
501 to 600	363	241
601 to 700	194	91
701 to 800	169	15
801 to 900	84	0
901 to 1000	<u>0</u>	<u>0</u>
Total Averaged Depth Values	5723	1814

Table II

THE APPROXIMATE SHORELINE OF LAKE MICHIGAN.

Each pair of numbers is the location (eastward coordinate before northward coordinate, see text for origin and units) of a junction of straight line segments approximating the lake shoreline. Read table left to right, top to bottom.

42.0	7.1	44.0	7.2	46.0	7.4	48.0	7.7
50.0	8.0	52.0	8.9	54.0	9.1	56.0	9.7
60.0	11.1	62.4	12.0	64.0	12.7	66.0	13.7
68.0	14.5	71.4	16.0	74.0	17.4	76.0	18.6
78.0	20.0	80.0	21.3	82.0	22.8	84.0	25.0
84.8	26.0	85.8	28.0	86.6	30.0	88.0	32.0
89.2	34.0	90.0	35.4	90.4	36.0	92.0	38.0
96.0	42.0	98.0	44.4	99.2	46.0	100.3	48.0
102.0	51.0	103.0	54.0	104.0	56.0	104.8	58.0
105.2	60.0	105.5	62.0	106.0	64.0	106.4	66.0
106.3	68.0	107.1	70.0	107.5	72.0	107.5	74.0
107.4	76.0	107.3	80.0	107.4	82.0	107.1	84.0
106.9	86.0	106.7	88.0	106.3	90.0	105.7	92.0
104.9	94.0	104.3	96.0	103.2	98.0	102.0	100.0
100.8	102.0	98.0	106.0	95.7	110.0	93.7	114.0
92.4	118.0	91.7	120.0	90.6	122.0	90.0	122.9
89.3	124.0	88.0	126.0	87.5	128.0	87.6	130.0
89.4	132.0	90.0	132.6	92.0	134.5	93.1	136.0
94.0	138.0	94.3	140.0	93.6	142.0	93.2	144.0
92.8	146.0	92.0	148.0	91.1	150.0	90.0	151.2
89.2	152.0	89.1	154.0	90.0	154.6	92.0	155.7
94.0	156.9	95.0	158.0	96.4	160.0	98.0	162.0
99.0	164.0	100.4	166.0	101.6	168.0	103.5	170.0
104.4	172.0	104.9	174.0	105.2	176.0	104.9	178.0
105.6	180.0	106.3	182.0	106.8	184.0	106.5	186.0
105.1	188.0	104.5	190.0	104.9	192.0	108.0	192.8
110.0	193.5	114.0	194.0	115.5	196.0	115.5	198.0
116.0	200.0	115.6	202.0	116.0	204.0	118.0	204.9
120.0	204.0	122.0	205.0	122.0	206.0	124.0	208.0
126.0	208.0	128.0	206.4	130.0	206.5	132.0	207.5
133.4	210.0	134.5	212.0	136.0	213.7	138.0	214.4
139.3	216.0	140.0	218.0	142.0	220.0	146.0	222.0
148.0	222.0	148.0	220.0	144.0	216.0	146.0	214.0
146.0	212.7	144.0	212.0	144.0	210.0	144.0	208.0
144.0	206.0	142.0	204.0	141.0	202.0	140.9	200.0
142.0	198.0	145.0	198.0	146.0	200.0	147.3	202.0
146.5	204.0	148.0	206.0	148.8	208.0	150.0	210.0
152.0	210.0	152.0	208.0	150.6	206.0	150.6	204.0
150.0	202.0	148.0	200.0	146.3	198.0	146.0	196.0
148.0	195.1	150.0	196.0	150.0	198.0	154.0	202.0
156.0	206.0	156.9	208.0	157.3	210.0	157.2	212.0
158.0	214.0	158.0	216.0	156.8	222.0	156.7	224.0
157.5	226.0	160.0	228.0	162.0	229.1	164.0	229.4
168.0	231.7	172.0	232.4	174.0	232.0	178.0	232.0
180.0	232.3	182.0	232.6	185.2	234.0	184.0	235.5
180.0	235.8	178.0	236.0	175.2	238.0	174.0	240.0
173.3	242.0	172.8	244.0	174.0	246.0	176.0	248.0
180.0	250.0	182.9	252.0	183.2	254.0	182.0	254.6
180.0	255.5	182.0	255.5	184.0	255.6	186.0	255.1
188.0	255.2	190.0	254.8	192.0	256.0	194.0	257.4
196.0	257.4						

STRAITS OF MACKINAC

196.0	260.8	194.0	260.8	192.0	262.0	190.0	262.4
189.0	264.0	184.9	266.0	184.0	267.1	182.0	268.8
180.4	270.0	180.0	270.3	178.0	270.9	174.0	272.0
172.0	272.8	170.0	272.9	168.0	272.9	166.0	273.6
164.0	274.0	160.0	275.6	158.0	274.9	156.0	275.8
154.0	275.8	152.0	275.6	150.0	275.9	148.0	275.1
144.0	272.0	142.4	270.0	142.0	269.5	140.0	268.0
138.0	267.7	136.0	268.0	134.0	268.3	132.0	268.8
130.0	268.0	126.0	268.0	124.0	265.6	122.0	266.5
120.0	267.2	118.0	267.6	116.0	268.0	114.0	268.0
112.0	267.6	110.0	267.4	108.0	267.8	106.0	266.9
104.0	266.6	102.0	265.4	100.6	264.0	100.0	262.0
99.3	260.0	99.0	258.0	98.0	257.3	96.0	257.8
94.0	256.0	90.0	255.2	88.0	253.0	85.0	252.0
84.8	250.0	82.7	250.0	82.8	248.0	83.5	246.0
83.0	244.0	82.0	242.4	80.0	244.0	78.0	246.0
78.0	248.0	76.9	250.0	78.0	251.4	80.0	252.0
80.0	253.4	82.0	255.2	82.0	256.9	85.4	258.0
86.9	260.0	88.0	260.9	88.0	263.0	86.0	264.0
84.0	262.6	82.0	262.0	82.0	260.5	80.0	260.0
78.0	260.6	76.0	261.0	75.2	262.0	74.0	262.0
73.1	260.0	73.2	258.0	70.8	256.0	69.5	254.0
68.0	252.6	66.0	252.4	64.0	252.0	62.0	250.0
61.0	252.0	61.3	254.0	61.1	256.0	60.7	258.0
60.0	260.0	58.0	260.0	56.5	258.0	56.7	256.0
57.0	254.0	56.0	252.4	54.0	251.1	52.0	250.5
50.0	250.0	46.0	245.4	44.9	244.0	44.0	242.0
42.6	240.0	40.0	236.8	40.0	235.2	38.0	233.3
36.4	232.0	35.6	230.0	34.0	229.0	34.0	228.0
30.0	224.0	28.0	222.0	26.0	220.9	24.9	220.0
23.6	218.0	24.0	216.0	26.0	214.0	23.1	214.0
22.4	212.0	22.5	210.0	22.0	208.7	20.0	208.4
18.0	208.4	16.0	208.0	14.0	208.0	12.0	207.4
10.0	206.0	10.0	202.8	8.0	200.5	6.7	200.0
5.0	198.0	4.0	196.0	2.0	194.0	0.9	192.0
0.0	190.0	0.0	187.0	1.0	186.0	2.0	182.0
4.0	182.0	5.7	184.0	6.0	185.0	8.0	186.8
11.0	188.0	14.0	188.6	15.2	190.0	16.8	192.0
17.3	194.0	19.1	196.0	21.3	198.0	22.9	200.0
26.0	201.2	29.1	202.0	30.0	202.0	31.6	202.0
34.0	203.5	36.0	205.0	37.8	208.0	39.2	210.0
40.7	212.0	44.0	214.7	44.4	216.0	45.0	218.0
46.0	220.0	49.6	220.0	50.0	221.0	52.9	222.0
52.9	224.0	54.0	225.5	55.4	226.0	56.0	228.0

58.0	227.2	60.0	228.0	62.0	227.0	61.1	226.0
61.2	224.0	60.0	222.8	58.0	222.0	57.1	220.0
58.0	218.8	56.9	216.0	56.0	214.0	52.0	212.0
52.0	211.1	50.0	210.0	48.6	208.0	50.0	206.0
48.0	205.1	47.4	204.0	47.1	202.0	44.0	200.8
42.0	198.0	40.7	196.0	40.0	195.2	39.7	194.0
38.7	192.0	36.0	188.0	33.7	186.0	32.6	184.0
31.6	182.0	31.0	180.0	30.4	178.0	30.0	176.0
29.1	174.0	28.8	172.0	27.6	170.0	27.5	168.0
28.5	166.0	29.6	164.0	29.5	162.0	28.0	160.0
26.0	158.5	24.0	158.0	22.0	156.8	21.0	156.0
20.8	154.0	19.6	152.0	18.5	150.0	18.0	148.0
16.9	146.0	16.4	144.0	16.0	142.0	16.8	138.0
18.0	136.0	17.4	134.0	18.0	132.0	17.2	130.0
14.0	126.0	12.7	124.0	12.4	122.0	12.4	120.0
12.0	118.0	10.3	116.0	8.4	114.0	7.4	112.0
6.4	108.0	5.5	106.0	5.5	104.0	6.4	102.0
7.1	100.0	6.0	98.0	7.3	96.0	8.0	94.0
6.0	92.0	6.8	90.0	8.0	89.1	9.3	88.0
9.4	86.0	9.3	84.0	9.6	82.0	10.7	80.0
12.0	78.7	14.0	77.0	13.5	76.0	12.9	72.0
11.7	70.0	11.0	68.0	11.1	66.0	11.3	64.0
11.3	62.0	12.0	60.0	12.0	54.0	11.0	52.0
10.3	50.0	10.0	48.0	10.4	46.0	12.0	42.5
14.0	40.0	15.3	38.0	17.0	36.0	19.6	34.0
20.0	32.0	20.6	30.0	21.6	28.0	22.0	26.0
23.0	24.0	24.0	20.0	25.0	18.0	26.0	16.5
28.0	15.0	29.0	12.0	30.0	11.5	32.0	10.4
34.0	11.1	35.6	10.0	36.0	8.3	38.0	7.7
42.0	7.1						

Table III

THE APPROXIMATE SHORELINE OF THE NINE LARGEST ISLANDS
IN LAKE MICHIGAN

See Table II for explanation of numbers

S. MANITOU ISLAND

110.7	210.0	111.0	212.0	112.0	212.8	114.0	212.8
115.2	212.0	114.0	210.0	110.7	210.0		

S. FOX ISLAND

130.0	232.6	130.6	234.0	129.3	236.0	127.1	236.0
130.0	232.6						

HIGH ISLAND

138.0	252.0	138.0	254.8	140.0	254.8	141.0	254.0
140.0	252.0	138.0	252.0				

HOG ISLAND

158.0	256.0	159.0	258.0	158.0	259.3	156.0	256.6
158.0	256.0						

GARDEN ISLAND

150.0	256.5	152.0	256.4	152.7	258.0	150.0	259.6
148.0	259.8	148.0	258.0	150.0	256.5		

BEAVER ISLAND

150.0	246.0	150.8	248.0	150.0	250.0	150.4	252.0
150.0	254.0	150.0	255.4	148.0	255.3	146.0	255.7
146.0	254.0	144.0	251.6	143.4	250.0	143.1	240.0
142.3	246.0	144.0	244.6	146.0	244.4	148.0	244.7
150.0	246.0						

WASHINGTON ISLAND

64.0	235.4	63.1	234.0	62.9	232.0	63.2	230.0
66.0	228.0	68.0	230.0	70.0	234.0	68.0	234.8
66.0	234.5	64.0	235.4				

CHAMBERS ISLAND

40.0	222.9	37.2	222.0	38.0	220.0	40.0	219.6
40.0	222.9						

N. MANITOU ISLAND

120.0	213.3	122.0	214.0	121.1	216.0	121.5	218.0
120.0	219.3	118.0	219.6	116.0	218.0	116.5	216.0
120.0	213.3						

Table IV

THE APPROXIMATE SHORELINE OF LAKE ONTARIO
See Table II for explanation

12.0	19.2	12.3	18.0	14.0	15.5	16.0	14.5
18.0	14.2	20.0	13.7	22.0	13.6	24.0	12.8
26.0	12.4	28.0	11.7	30.0	11.7	32.0	11.8
34.0	11.9	36.0	11.8	38.0	11.0	40.0	10.9
42.0	11.6	44.0	12.3	46.0	13.2	48.7	14.0
52.0	15.5	56.0	15.8	56.7	14.0		
NIAGARA RIVER							
57.1	14.0	56.7	16.0	58.0	16.3	60.0	16.7
62.0	16.9	64.0	17.5	66.0	18.0	70.0	19.0
72.0	19.5	74.0	19.8	76.0	20.3	78.0	20.5
82.0	21.5	84.0	21.7	86.0	22.0	88.0	22.3
90.0	22.5	92.0	22.4	96.0	22.6	98.0	22.6
100.0	22.4	104.0	22.4	106.0	22.2	108.0	22.3
110.0	22.5	112.0	22.6	114.0	22.6	118.0	22.0
120.0	22.0	122.0	22.0	128.0	21.0	132.0	20.5
134.0	20.4	136.0	20.0	138.0	18.5	140.0	17.2
142.8	16.0	146.0	14.3	148.0	14.1	150.0	15.0
152.0	15.5	154.0	16.0	156.0	16.4	158.0	16.7
160.0	16.8	162.0	16.7	164.0	16.6	166.0	16.9
172.0	17.2	174.0	17.2	176.0	16.8	178.0	16.3
180.0	16.4	182.0	16.4	184.0	16.8	186.0	17.7
188.0	17.7	190.0	18.4	192.0	18.5	194.0	19.1
195.3	20.0	196.0	20.7	198.0	20.7	200.0	22.0
201.3	24.0	202.0	24.7	204.0	25.5	206.0	26.8
208.8	28.0	210.0	28.2	212.4	30.0	214.0	30.8
216.0	31.6	218.0	31.4	220.0	30.8	222.0	30.9
224.0	31.3	226.0	32.0	227.8	34.0	228.0	36.0
228.3	38.0	227.4	44.0	227.0	46.0	226.4	48.0
224.0	49.6	222.0	50.4	222.5	52.0	224.0	52.8
226.0	53.2	228.0	52.0	232.0	54.0	232.0	56.0
230.0	56.7	228.0	58.0	224.0	58.0	223.3	60.0
220.0	62.0	218.0	62.0	218.0	66.0	222.0	70.0
ST. LAWRENCE RIVER - SOUTH PASSAGE							
220.0	70.0	214.0	66.0	212.0	66.0	210.0	68.0
208.0	69.0	208.0	70.5	210.0	71.3	212.0	72.0
ST. LAWRENCE RIVER - NORTH PASSAGE							
212.0	74.0	210.0	73.3	208.0	72.7	206.0	72.5
204.0	71.6	200.0	68.8	198.0	66.4	196.0	66.0
192.8	66.0	192.0	67.0	189.5	66.0	188.0	64.6
186.9	64.0	186.0	63.4	186.0	62.0	184.0	61.3
182.0	60.0	182.0	59.2	180.0	58.6	178.0	57.3
178.0	56.3	180.0	56.2	182.0	56.3	184.0	56.0
188.0	56.9	188.4	56.0	186.0	55.3	184.0	55.1
180.0	53.6	176.0	52.8	172.0	50.6	170.0	50.6
168.0	51.4	166.0	51.4	166.0	54.0	163.4	54.0
160.0	56.8	158.0	56.7	156.0	56.0	152.0	55.6
150.0	55.6	148.0	57.7	146.4	58.0	144.0	60.0
142.0	61.2	140.0	61.1	139.4	60.0	138.0	59.3
138.0	59.3	136.0	59.3	136.0	60.0	134.0	60.5
130.0	60.0	128.0	58.9	126.0	58.7	124.0	58.3

122.0	58.4	120.0	58.0	114.7	58.0	112.0	57.4
108.0	57.3	106.0	57.1	104.0	57.1	102.0	56.5
100.0	56.3	96.0	55.2	94.0	54.7	92.0	54.0
90.0	54.0	88.0	53.8	82.0	53.8	80.0	53.3
77.0	52.0	72.0	52.0	70.0	51.6	66.0	50.9
64.0	51.1	60.0	49.5	58.0	48.9	56.0	48.6
54.0	48.5	50.2	46.0	47.3	44.0	44.0	40.7
42.0	40.0	40.0	37.5	38.0	37.0	36.0	36.8
35.5	38.0	31.7	38.0	30.0	35.7	28.0	35.2
24.0	32.0	23.7	30.0	19.5	26.0	18.0	24.0
16.0	22.0	14.0	20.4	12.0	19.2		

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APPENDIX A: AVERAGE DEPTHS FOR LAKE MICHIGAN

The average depths for Lake Michigan on a two minute grid are displayed on the following forty-four pages. These figures are reproduced directly from the 35mm film produced by an IBM 2280 film display-recorder unit. Block 24 is missing because it contains only a short piece of shoreline, which is shown in block 25. Block 46 has been omitted since it contains only one point, which is shown on block 45. The coordinates in degrees latitude and degrees longitude at the lower left corner of each figure are the location of the lower left corner of the particular 30' by 30' block. Each number (or symbol L or S) is the average depth at the grid point located at the lower right corner of the number. The symbol L represents a grid point on land and S denotes a grid point on the approximate shoreline. An approximate Sinusoidal map projection is used for the placement of the number and location of the contours. The distance between meridians is uniform over each individual block and is correct at a point halfway up the block. The error in the horizontal length at the top and bottom of each figure is about .3% which is probably less than the errors in the computer graphic equipment and the various reproduction procedures. The contour interval is fifty feet and the reference water level for all blocks is shown in Table I. The contour lines are not labeled, but their values should be clear from the neighboring numbers.

L	L	L	L	L	L	S	43	82	133	168	201	231	250	277	301
L	L	L	L	L	L	S	40	92	135	164	196	224	256	269	327
L	L	L	L	L	L	S	50	91	126	151	192	228	245	272	288
L	L	L	L	L	L	S	58	92	110	142	180	219	238	256	276
L	L	L	L	L	L	L	22	58	84	112	150	174	208	236	267
L	L	L	L	L	L	L	28	60	79	107	129	146	190	225	244
L	L	L	L	L	L	S	30	52	73	93	117	135	155	179	221
L	L	L	L	L	L	L	28	45	63	83	104	121	136	163	197
L	L	L	L	L	L	L	7	33	51	70	88	102	126	138	157
L	L	L	L	L	L	L	L	26	35	47	63	80	94	112	128
L	L	L	L	L	L	L	S	28	39	47	62	92	108	140	160
L	L	L	L	L	L	L	L	18	34	42	48	51	80	106	139
L	L	L	L	L	L	L	L	L	18	25	36	55	66	90	117
L	L	L	L	L	L	L	L	L	L	13	28	40	53	62	84
L	L	L	L	L	L	L	L	L	L	S	23	28	47	61	75
L	L	L	L	L	L	L	L	L	L	L	19	23	36	51	64

(42.0°, 88.0°) L MICHIGAN BLOCK 4

(42.0°, 87.0°) L. MICHIGAN BLOCK 6

L	L	L	L	24	40	70	100	144	172	194	217	243	262	282	301
L	L	L	L	L	20	58	68	118	153	180	196	228	261	284	313
L	L	L	L	L	18	41	67	89	111	148	165	200	243	291	316
L	L	L	L	L	21	30	53	74	88	130	152	184	232	285	301
L	L	L	L	L	18	38	53	64	82	76	140	176	237	266	309
L	L	L	L	L	L	34	47	56	71	81	116	164	207	255	288
L	L	L	L	L	L	L	33	40	66	86	104	141	188	241	274
L	L	L	L	L	L	L	18	39	65	76	100	146	205	243	271
L	L	L	L	L	L	L	19	35	63	75	101	145	214	247	270
L	L	L	L	L	L	L	28	48	63	88	129	169	221	251	276
L	L	L	L	L	L	L	18	36	48	60	110	165	198	245	280
L	L	L	L	L	L	L	30	41	53	80	138	174	198	251	269
L	L	L	L	L	L	L	24	43	54	120	146	180	212	255	279
L	L	L	L	L	L	L	24	44	68	124	150	190	229	253	275
L	L	L	L	L	L	L	26	46	89	135	170	193	217	251	279
L	L	L	L	L	L	L	9	43	82	133	168	201	231	250	277

(42.5°, 88.0°)

L. MICHIGAN

BLOCK 8

301 309 309 311 272 283 289 298 296 283 256 257 260 253 270 280
 313 320 317 313 308 303 300 306 307 298 285 278 275 270 277 285
 316 320 320 321 315 306 307 314 318 315 307 298 286 303 310 288
 301 316 325 324 328 333 330 344 365 381 379 378 365 362 371 396
 309 319 325 325 327 351 363 371 394 412 433 420 410 432 431 419
 288 318 328 328 334 353 369 398 416 444 464 472 484 486 486 488
 274 297 324 330 339 370 391 415 426 446 472 490 494 496 504 512
 271 303 327 334 352 379 420 454 465 477 487 496 502 509 522 527
 270 288 322 346 375 407 435 454 469 484 492 501 505 517 524 529
 276 315 343 372 387 420 443 455 468 482 494 506 510 517 525 531
 306 346 367 378 403 416 432 456 469 477 489 492 502 518 526 533
 298 332 359 372 398 421 433 450 469 480 490 500 506 509 516 533
 309 336 356 373 392 412 426 443 458 474 482 491 497 505 511 519
 300 328 352 372 389 405 420 440 454 471 485 489 497 506 510 527
 301 324 341 361 373 389 410 428 451 461 477 475 480 486 490 504
 301 318 338 356 376 390 405 433 453 458 458 464 464 473 496 506
 (42.5°, 87.5°) L. MICHIGAN BLOCK 9

280	297	307	314	324	332	329	329	329	332	336	323	312	310	294	276
285	302	318	323	341	338	329	326	324	324	324	317	307	295	288	276
288	295	316	328	337	336	324	318	314	312	311	304	296	285	270	270
396	401	406	340	344	326	320	308	300	303	304	295	287	272	254	252
419	418	406	406	385	354	329	316	304	296	293	287	282	279	270	252
488	482	483	465	424	377	366	303	322	300	289	283	277	262	268	250
512	514	513	506	469	443	414	384	343	308	294	285	276	264	264	263
527	536	530	527	506	487	478	415	392	371	361	299	295	283	276	269
529	536	536	521	505	491	455	416	380	364	348	327	295	287	277	271
531	537	535	514	490	468	420	370	361	344	336	327	303	284	276	269
533	537	536	529	511	479	437	397	348	332	326	309	305	287	276	263
533	535	536	523	497	467	417	393	327	311	299	297	283	274	262	255
519	538	533	506	490	452	405	355	313	293	287	281	272	263	253	247
527	540	538	523	481	419	374	338	310	297	278	271	263	259	251	240
504	528	521	487	463	429	383	333	301	286	267	258	258	250	244	236
506	510	517	475	433	399	351	307	283	280	264	257	251	243	228	225

(42.5°, 87.0°) L. MICHIGAN BLOCK 10

276	265	251	231	210	167	127	61	16	L	L	L	L	L	L	L
276	261	240	218	206	176	126	65	27	L	L	L	L	L	L	L
270	254	240	223	201	169	146	86	29	L	L	L	L	L	L	L
252	242	233	223	198	173	126	80	35	L	L	L	L	L	L	L
252	244	234	209	189	172	138	87	42	L	L	L	L	L	L	L
250	247	245	229	204	182	129	94	46	L	L	L	L	L	L	L
263	258	252	236	228	197	139	77	55	L	L	L	L	L	L	L
269	264	258	236	220	188	138	70	41	L	L	L	L	L	L	L
271	266	260	241	212	175	124	84	52	L	L	L	L	L	L	L
269	262	258	226	200	170	117	75	50	L	L	L	L	L	L	L
263	258	250	225	203	174	115	74	38	L	L	L	L	L	L	L
255	250	242	222	191	162	118	49	20	L	L	L	L	L	L	L
247	239	230	203	177	147	94	63	30	L	L	L	L	L	L	L
240	236	223	203	169	137	88	53	S	L	L	L	L	L	L	L
236	226	207	188	148	115	90	43		L	L	L	L	L	L	L
225	211	190	166	138	110	73	48		L	L	L	L	L	L	L

(42.5°, 86.5°) L. MICHIGAN BLOCK 11

468 471 478 480 455 400 351 333 325 294 293 291 278 301 304 290
 471 487 477 470 465 399 349 325 299 274 273 265 257 276 298 302
 505 474 462 414 374 341 317 284 251 239 240 251 251 256 265 273
 496 442 422 343 350 327 311 261 197 191 189 210 213 212 239 272
 347 299 318 332 322 309 299 286 213 173 166 177 197 196 206 291
 279 282 298 315 313 313 306 293 263 176 152 151 185 253 294 347
 256 283 299 315 316 310 305 312 265 224 204 209 245 276 310 340
 262 287 296 298 299 307 317 324 304 255 241 240 276 293 324 345
 255 273 283 261 262 289 305 303 246 266 259 272 286 295 316 337
 239 255 252 238 233 265 276 278 272 267 261 275 283 294 310 327
 243 248 247 246 243 256 258 259 252 254 263 269 278 285 292 311
 252 215 244 264 251 253 267 268 262 256 269 265 274 281 288 301
 306 277 256 228 229 256 279 279 272 254 260 264 266 275 278 283
 307 312 228 210 196 254 280 263 280 270 259 252 254 265 264 274
 299 311 312 268 189 241 289 296 293 273 255 253 257 266 269 275
 301 309 309 311 272 283 289 298 296 283 256 257 260 253 270 280
 (43.0°, 87.5°) L. MICHIGAN BLOCK 13

290 301 347 388 438 420 412 406 377 335 309 295 258 215 164 61
 302 312 358 424 437 429 432 436 427 379 335 323 286 235 166 73
 273 304 390 420 431 427 432 425 408 396 365 328 285 237 174 116
 272 312 397 421 424 419 419 419 411 396 365 329 309 268 215 127
 291 381 404 411 420 418 407 407 401 387 357 341 317 265 223 169
 347 372 390 396 403 401 397 397 393 374 348 321 315 214 261 162
 340 374 386 391 389 399 395 391 394 384 370 348 330 300 248 161
 345 363 365 373 380 388 391 388 393 379 365 353 341 322 237 169
 337 337 349 356 360 366 367 374 383 382 371 365 363 347 296 218
 327 323 332 344 344 346 347 358 380 372 367 365 360 359 348 265
 311 305 306 315 322 326 330 338 372 363 356 356 353 354 354 298
 301 300 305 295 306 313 323 336 352 349 346 346 345 341 342 304
 283 286 288 293 311 315 320 341 351 346 346 337 341 336 317 309
 274 292 300 302 308 312 312 323 333 341 341 331 328 327 315 296
 275 293 301 311 317 322 321 324 328 333 335 322 315 310 291 283
 280 297 307 314 324 332 329 329 329 332 336 323 312 310 294 276
 (43.0°, 87.0°) L. MICHIGAN BLOCK 14

61	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
73	28	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
116	38	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
127	68	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
169	89	26	L	L	L	L	L	L	L	L	L	L	L	L	L	L
162	98	45	L	L	L	L	L	L	L	L	L	L	L	L	L	L
161	105	72	29	L	L	L	L	L	L	L	L	L	L	L	L	L
169	143	93	58	9	L	L	L	L	L	L	L	L	L	L	L	L
218	143	111	77	40	L	L	L	L	L	L	L	L	L	L	L	L
265	191	148	112	62	33	L	L	L	L	L	L	L	L	L	L	L
298	233	191	136	94	57	9	L	L	L	L	L	L	L	L	L	L
304	264	224	182	125	85	39	L	L	L	L	L	L	L	L	L	L
309	295	265	215	152	94	59	19	L	L	L	L	L	L	L	L	L
296	284	268	250	188	116	69	37	L	L	L	L	L	L	L	L	L
283	269	260	243	201	126	90	44	L	L	L	L	L	L	L	L	L
276	265	251	231	210	167	127	61	16	L	L	L	L	L	L	L	L

(43.0°, 86.5°) L MICHIGAN BLOCK 15

L	L	L	L	L	L	L	L	L	L	24	65	122	149	170	191
L	L	L	L	L	L	L	L	L	S	37	95	136	162	188	195
L	L	L	L	L	L	L	L	L	20	58	107	155	182	182	190
L	L	L	L	L	L	L	L	L	30	73	120	158	184	194	209
L	L	L	L	L	L	L	L	S	43	91	139	174	195	211	232
L	L	L	L	L	L	L	L	L	35	86	142	169	195	232	249
L	L	L	L	L	L	L	L	L	25	74	131	164	219	246	273
L	L	L	L	L	L	L	L	L	5	57	119	169	231	263	283
L	L	L	L	L	L	L	L	L	25	57	108	142	250	286	291
L	L	L	L	L	L	L	L	L	S	64	108	187	261	295	316
L	L	L	L	L	L	L	L	L	40	99	159	227	284	327	381
L	L	L	L	L	L	L	L	L	23	75	127	197	244	332	363
L	L	L	L	L	L	L	S	65	112	172	242	302	362	441	458
L	L	L	L	L	L	L	L	47	94	157	205	254	330	410	456
L	L	L	L	L	L	L	L	66	132	185	209	335	396	424	442
L	L	L	L	L	L	L	L	66	168	247	258	340	401	429	468

(43.5°, 88.0°) L. MICHIGAN BLOCK 16

(43.5°, 87.0°) L. MICHIGAN BLOCK 18

(44.0°, 87.0°) L. MICHIGAN BLOCK 22

$(44.5^\circ, 88.0^\circ)$

(44.5°, 87.5°) L. MICHIGAN BLOCK 26

(44.5°, 87.0°) L. MICHIGAN BLOCK 27

(44.5°, 86.5°) L MICHIGAN BLOCK 28

(44.5°, 86.0°) L. MICHIGAN BLOCK 29

(45.0°, 86.5°) L. MICHIGAN BLOCK 34

(45.0°, 86.0°)

L. MICHIGAN

BLOCK 35

(45.0°; 85.5°)

L. MICHIGAN

BLOCK 36

168

159

32

(45.0°, 85.0°)

L. MICHIGAN

BLOCK 37

(45.5°, 87.0°)

(45.5°, 86.5°) L. MICHIGAN BLOCK 40

(45.5°, 85.0°)

L. MICHIGAN BLOCK 43

(46.0°, 85.5°) L. MICHIGAN BLOCK 45

APPENDIX B: AVERAGE DEPTHS FOR LAKE ONTARIO

The average depths for Lake Ontario on a two-minute grid are displayed on the following nineteen pages. Block 18 has been omitted since it does not contain any depths. For further information on the figures, see the introduction to Appendix A.

(43.0°, 80.0°)

L. ONTARIO

BLOCK 1

554 561 557 554 548 542 551 550 548 551 547 542 551 547 538 541

482 485 488 485 469 456 466 467 449 449 434 439 438 438 437 445

393 358 333 299 298 292 283 276 260 256 256 269 270 311 335 343

129 116 96 86 84 74 70 72 76 72 100 70 121 119 120 144

L L L L L L L L L L L L L L S S

L L L L L L L L L L L L L L L

L L L L L L L L L L L L L L L

L L L L L L L L L L L L L L L

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L L L L L L L L L L L L L L L

L L L L L L L L L L L L L L L

L L L L L L L L L L L L L L L

(43.0°, 78.5°) L. ONTARIO BLOCK 4

L. ONTARIO

BLOCK 8

(43.5°, 76.5°)

L. ONTARIO

BLOCK 16

BLOCK 17

(44.0°, 77.0°) L. ONTARIO BLOCK 19

L L L L L L L L L L L L L L L L

L L L L L L L L L L L L L L L L

L L L L L L L L L L L L L L L L

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L L L L L L L L L L L L L L L L

L L L L L L L L L L L L L L L L

S L L L L L L L L L L L L L L L

39 S L L L L L L L L L L L L L L

L L L L L S S L L L L L L L L L

S L L L L S L L L L L L L L L L

38 S S 51 S L L L L L L L L L L

71 45 57 77 S L L L L L L L L L

39 68 81 36 S S L L L L L L L L

108 115 66 82 62 33 20 L L L L L L L L L

(44.0°, 76.5°) L. ONTARIO BLOCK 20

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