

# Morphometric data for Lake Manitoba

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using data digitized from Canadian Hydrographic Services charts

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This folder contains files associated with the area at selected water levels, and the bathymetry of Lake Manitoba as determined using satellite images and Canadian Hydrographic Services data (CHS 1986).

Table 1. File list and descriptions of contents.

File name	File type	Contents
LMB_area&bathymetry(2023)	pdf	Figures, tables and methods (this file)
LMB_bathymetry(CEOS,UM,2023)	rst & rdc	Idrisi raster file set containing georeferenced bathymetric data, where pixel values = depths below 247.2 m
LMB_bathymetry(CEOS,UM,2023)	tif	Geotiff version of bathymetric map converted from the Idrisi raster files, where pixel values = depths below 247.2 m
LMB_bathymetry(CEOS,UM,2023)COLOUR	jpg	colour rendition of bathymetry, not georeferenced
LMB_bathymetry(CEOS,UM,2023)GREYtone	jpg	greystone rendition of bathymetry showing 1-m isobaths, not georeferenced
LMB_depths(CHS,UTM14n)	xlsx	coordinates and depths abstracted from the CHS hydrographic chart
LMB_Landsat5TM_20110525_wl_2485	tif	georeferenced raster map of surface area at w.l. = 248.5 m
LMB_Landsat5TM_20110813_wl_2489	tif	georeferenced raster map of open water surface area at w.l. = 248.9 m
LMB_Landsat5TM_20110813_wl_2489	kml	georeferenced raster map of open water surface area at w.l. = 248.9 m
LMB_Sentinel2_20180519_wl_2474	tif	georeferenced raster map of open water surface area at w.l. = 247.4 m
LMB_Sentinel2_20190916_wl_2472	tif	georeferenced raster map of open water surface area at w.l. = 247.2 m
LMB_Sentinel2_20190916_wl_2472	kml	georeferenced raster map of open water surface area at w.l. = 247.2 m
LMB_Sentinel2_20210727_wl_2470	tif	georeferenced raster map of open water surface area at w.l. = 247.0 m
LMB_Sentinel2_20220831_wl_2477	tif	georeferenced raster map of open water surface area at w.l. = 247.7 m

## *Bathymetric map*

Figures 1 and 2 show the bathymetric map of Lake Manitoba in colour, and in grey tones with 1-m isobaths respectively. Tables 2–4 report morphometric data, derived from the bathymetric map and from maps derived from satellite data recorded at several water levels, including high water during the 2011 flood. The lake has been subdivided into three major basins (south, northeast and northwest) connected by narrow or very shallow straights (Figure 3). The Northwest Basin is further subdivided into sub-sub-basins divided by a similar shallow straight. Table 2 reports areas and volumes for only Lake Manitoba itself. For purposes of water and water chemistry modelling, Tables 3 and 4 include, in addition, areas and volumes of connected lakes and coastal wetlands that share water with Lake Manitoba during setup and seiche events, and by flooding during periods of high discharge from the watershed. Figure 4 displays area and cumulative volume data in the form of hypsometric curves.

At a surface elevation of 247.2–247.4 m above sea level (the normal range) the surface area of Lake Manitoba is about 4600 km<sup>2</sup> (Table 2). One early investigator reported essentially the same area (4597 km<sup>2</sup>, Bajkov, 1930). Recently, it has been most frequently reported as “about 4700” km<sup>2</sup> although few authors identify their source. Those who do cite either Crowe (1972) or Last (1980) who reported the lake area to be 4680 km<sup>2</sup> and 4690 km<sup>2</sup> respectively, although Last cites several earlier studies which reported a similar area (and a few that are quite different). Neither Crowe nor Last mention whether they include the area of Ebb and Flow Lake, which is about 100 km<sup>2</sup> in this study (Table 4). Since Ebb and Flow Lake freely exchanges water with Lake Manitoba, it may be that both Crowe and Last included it as an integral part of the larger lake.

At the median of daily mean surface elevations recorded over the decade 2013 through 2022, 247.4 m above sea level, Lake Manitoba has a volume of about 16 km<sup>3</sup> (Table 2). This is considerably less than the 20 km<sup>3</sup> reported by the International Garrison Diversion Study Board (1976; attributed to J. Crowe, by pers. comm.) or the 23 km<sup>3</sup> reported by Page [2011; attributed to Last (1980) although I was not able to find this value in Last’s thesis]. Too little information has been retained from these earlier studies to assess their results<sup>1</sup>. However, the investigators did not have access to the extensive and numerous depth soundings reported by the CHS (1986). It seems reasonable to accept the lower volume reported here as the better supported result.

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<sup>1</sup> Last (1980) reported a volume of 14.1 km<sup>3</sup> for the South Basin—*i.e.* 23 % greater than the 11.5 km<sup>3</sup> reported here (Table 2). The difference is not explained by the difference in reference surface elevation. Last adjusted depths to the long term mean surface elevation of 247.5 m, only 0.1 m higher than value used here, which would account for about 0.5 km<sup>3</sup> greater volume. Likewise, including or excluding the volume of Ebb and Flow Lake cannot account for the difference. The volume of Ebb and Flow Lake is only roughly estimated here to 0.11 km<sup>3</sup> (Table 4); it would require a clearly unrealistic mean depth of over 25 m to explain the 2.5 km<sup>3</sup> difference between the volumes reported for the South Basin.

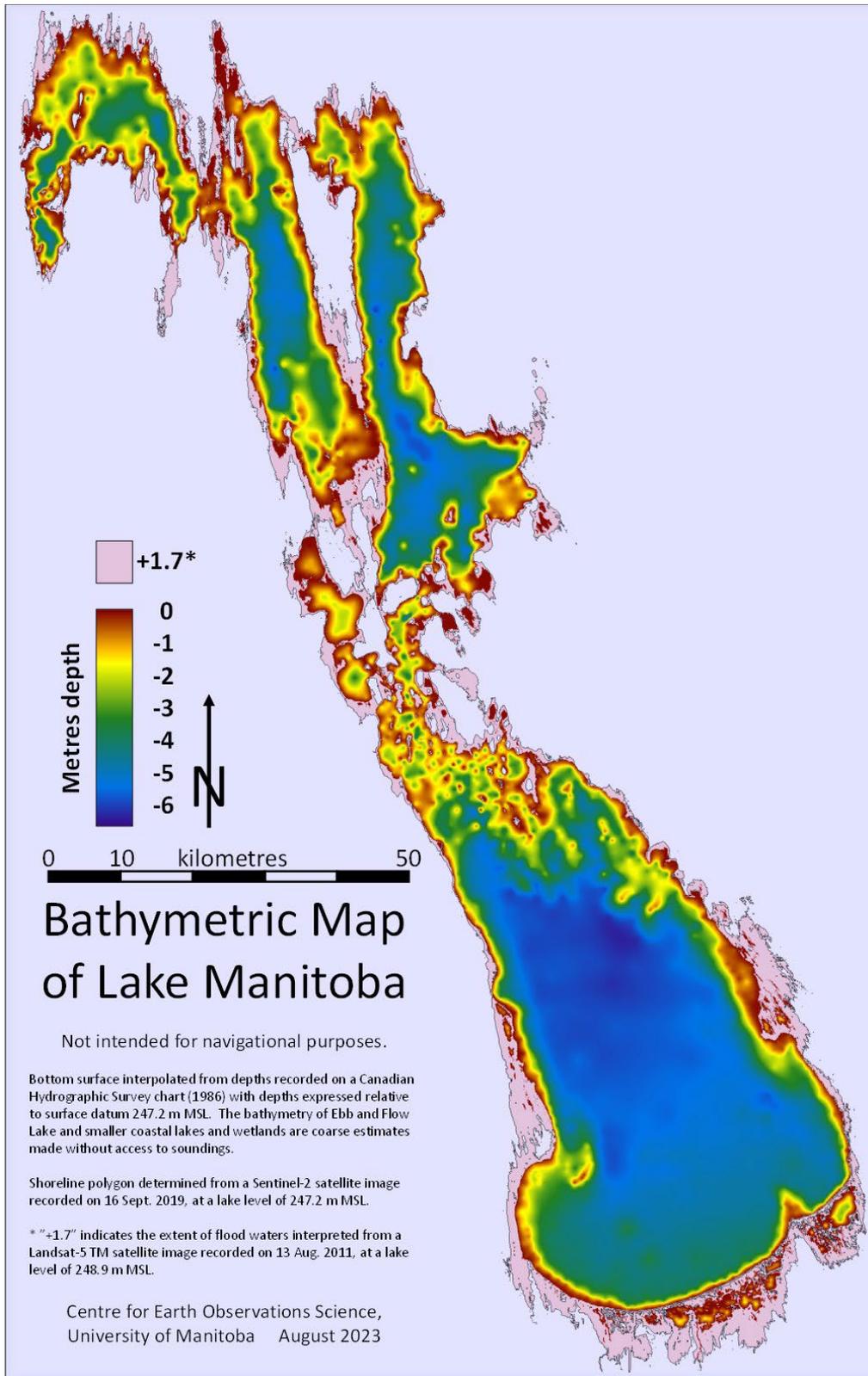


Figure 1. Bathymetric map of Lake Manitoba with connected lakes and coastal wetlands, including the adjacent area flooded in 2011. UTM Zone 14N projection.

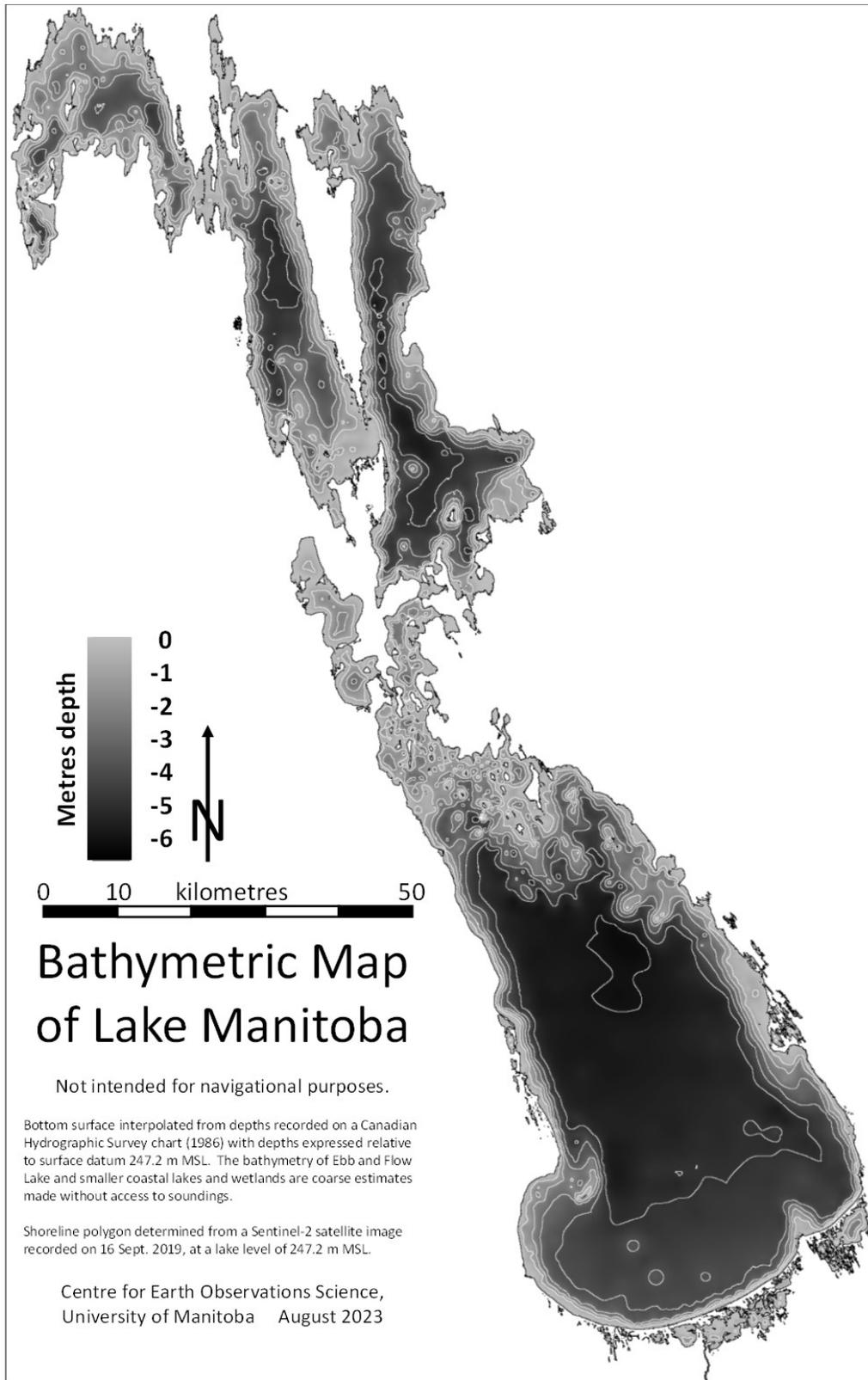


Figure 2. Grey tone rendition of bathymetric map of Lake Manitoba with connected lakes and coastal wetlands. Isobaths are at 1 m intervals. UTM Zone 14N projection.

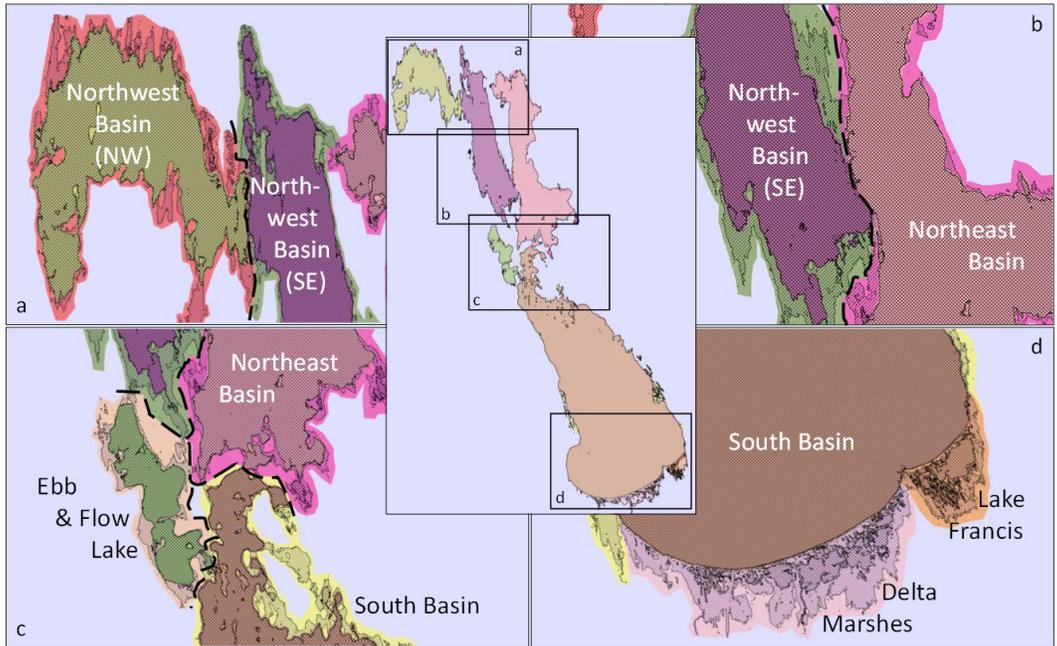


Figure 3. Boundaries of sub-basins of Lake Manitoba, extended to include adjacent lakes and coastal wetlands connected by flooding in 2011. Colours discriminate basins, and wetlands or flooded area connected to each basin. Dashed lines in enlarged insets show inter-basin boundaries in more detail. Cross-hatching indicates Lake Manitoba and open water in attached lakes and coastal wetlands on 16 Sept 2019, at a water level of 247.2 m above sea level, determined from a Sentinel-2 satellite image. Single hatching marks the area flooded on 13 Aug 2011 at a water level of 248.9 m, determined from a Landsat TM image.

Table 2. Morphometric data for Lake Manitoba, *excluding* connected lakes and coastal wetlands. The lake surface areas at 247.4 m above sea level (the median of daily mean water levels recorded from 2013 through 2022) and at 247.2 m [the “low water” datum to which sounding depths were adjusted on the CHS hydrographic chart of the lake (1986)] were determined using Sentinel-2 satellite images recorded on 19 May 2018 and 16 September 2019. Volumes below each isobath were calculated from a digital elevation model of the lake bottom derived from soundings reported on the CHS chart.

Image date	Depth (m)	Water level (m above sea level)	Northwest basin (NW & SE sub-basins)	Northeast basin	South basin	Lake Manitoba
<b>Isobath area (km<sup>2</sup>)</b>						
2018 May 19	0.2	247.4	992 (430, 562)	812	2792	4596
2019 Sep 16	0	247.2	996 (432, 564)	812	2791	4599
	-1	246.2	667 (274, 393)	644	2511	3823
	-2	245.2	473 (181, 292)	527	2276	3276
	-3	244.2	294 (94, 199)	425	2023	2742
	-4	243.2	133 (16, 117)	301	1733	2168
	-5	242.2	33 (0.2, 33)	81	1058	1173
	-6	241.2	0.03 (0.01, 0.01)	0.03	64	64
<b>Cumulative volume (km<sup>3</sup>)</b>						
2018 May 19	0.2	247.4	2.3 (0.9, 1.4)	2.5	11.5	16.3
2019 Sep 16	0	247.2	2.1 (0.8, 1.3)	2.4	10.9	15.3
	-1	246.2	1.2 (0.4, 0.8)	1.6	8.3	11.1
	-2	245.2	0.7 (0.2, 0.5)	1.0	5.9	7.6
	-3	244.2	0.3 (0.1, 0.2)	0.6	3.7	4.6
	-4	243.2	0.1 (0.01, 0.1)	0.2	1.8	2.1
	-5	242.2	0.01 (0.00009, 0.01)	0.03	0.5	0.5
	-6	241.2	0.000002 (0.000001, 0.000001)	0.00	0	0
<b>Mean depth (m)*</b>			2.3 (2.0, 2.5)	3.1	4.1	3.5
<b>Maximum depth (m)*</b>			6.9 (6.9, 6.3)	6.3	6.5	6.9

\* Mean and maximum depths relative to water level = 247.4 m above sea level.

Table 3. Areas at, and cumulative volumes below the surface and 1-m isobaths for the northern regions of Lake Manitoba. Between-basin boundaries are shown in Figure 3. NW (NW) and NW (SE) indicate the northwestern and southeastern sub-basins of the Northwest Basin, respectively. NE = the Northeast Subbasin. The suffix "W" indicates connected lakes and coastal wetlands, for which volumes were calculated based on estimated depths. Inter-basin boundaries are shown in Figure 3. Surface areas were derived from cloud-free Landsat TM5 (2011) or Sentinel-2 (2018, 2019 and 2022) satellite images. Volumes were calculated from a digital elevation model constructed using soundings reported by the CHS (1986).

	Elevation (m above sea level)	NW (NW)	NW (NW) W	NW (SE)	NW (SE) W	NE	NE W
<b>Area (km<sup>2</sup>)</b>							
2011 Aug 13	248.9	453	86	589	115	846	95
2011 May 25	248.5	449	66	587	91	842	76
2022 Aug 31	247.7	439	16	573	9	825	16
2018 May 19	247.4	430	3	562	3	812	9
2019 Sep 16	247.2	432	3	564	4	812	9
	246.2	274		393		644	
	245.2	181		292		527	
	244.2	94		199		425	
	243.2	16		117		301	
	242.2	0.2		33		81	
	241.2	0.01		0.01		0.03	
<b>Cumulative volume (km<sup>3</sup>)</b>							
2011 Aug 13	248.9	1.52	0.06	2.28	0.08	3.77	0.08
2011 May 25	248.5	1.34	0.03	2.05	0.04	3.43	0.04
2022 Aug 31	247.7	0.98	0.004	1.58	0.004	2.76	0.01
2018 May 19	247.4	0.85	0.001	1.41	0.002	2.52	0.005
2019 Sep 16	247.2	0.77	0.001	1.30	0.001	2.36	0.003
	246.2	0.42		0.82		1.63	
	245.2	0.19		0.48		1.04	
	244.2	0.06		0.24		0.57	
	243.2	0.01		0.08		0.21	
	242.2	0.0001		0.01		0.03	
	241.2	0.000001		0.000001		0.000002	

Table 4. Areas at, and cumulative volumes below the surface and 1-m isobaths for the South Basin of Lake Manitoba. "S" = South Basin; "S W" = small lakes and wetlands exchanging water with the south basin, excepting "LF" = Lake Francis, "DM" = Delta Marsh, "E&F L" = Ebb and Flow Lake and "E&F L W" = wetlands bordering Ebb and Flow Lake. Inter-basin boundaries are shown in Figure 3. Surface areas were derived from cloud-free Landsat TM5 (2011) or Sentinel-2 (2018, 2019 and 2022) satellite images. The South Basin volumes were calculated from a digital elevation model constructed using soundings reported by the CHS (1986). Volumes of connected lakes and coastal wetlands area based on estimated depths.

	Elevation (m above sea level)	S	S W	LF	DM	E&FL	E&FL W
<b>Area (km<sup>2</sup>)</b>							
2011 Aug 13	248.9	2850	252	63	205	109	36
2011 May 25	248.5	2841	190	34	175	108	26
2022 Aug 31	247.7	2800	33	29	57	102	1
2018 May 19	247.4	2792	20	29	54	100	1
2019 Sep 16	247.2	2791	20	25	52	101	1
1981-1983	246.2	2511	0.4	6	2	36	
1981-1983	245.2	2276		2		7	
1981-1983	244.2	2023				0.4	
1981-1983	243.2	1733					
1981-1983	242.2	1058					
1981-1983	241.2	64					
<b>Cumulative volume (km<sup>3</sup>)</b>							
2011 Aug 13	248.9	15.71	0.19	0.08	0.21	0.27	0.02
2011 May 25	248.5	14.57	0.10	0.06	0.14	0.22	0.009
2022 Aug 31	247.7	12.31	0.02	0.03	0.05	0.14	0.001
2018 May 19	247.4	11.47	0.01	0.03	0.03	0.11	0.000
2019 Sep 16	247.2	10.91	0.01	0.02	0.02	0.09	0.0002
1981-1983	246.2	8.26	0.0001	0.005	0.001	0.02	
1981-1983	245.2	5.87		0.001		0.003	
1981-1983	244.2	3.72				0.0001	
1981-1983	243.2	1.85					
1981-1983	242.2	0.47					
1981-1983	241.2	0.004					

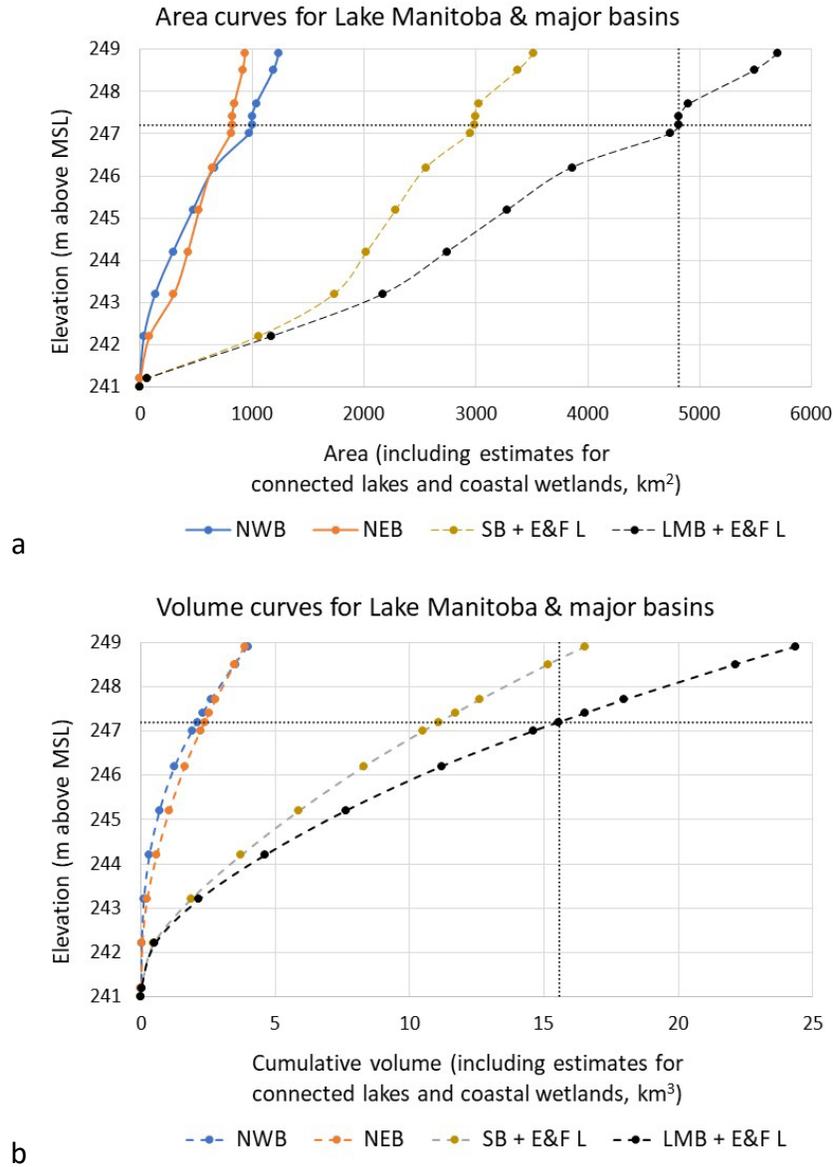


Figure 4. Hypsometric curves for the northwest, northeast and south basins of Lake Manitoba, including estimated volumes of connected small lakes and coastal wetlands which exchange water freely with the main basins. Dotted lines indicate the datum elevation for CHS soundings (247.2 m above sea level), and the surface area and cumulative volume at that datum (including connected lakes and open water in coastal wetlands = 4813 km<sup>2</sup> and 15.5 km<sup>3</sup>). Note the break in the area curve, where there is little difference between areas at the long term low water datum of 247.2 m (CHS, 1986) and the median water level of 247.4 m (2013–2022 m)>

## Data sources and methods

### Lake surface maps

Through the decade from 2013 through 2022, the 1<sup>st</sup> quartile, median and 3<sup>rd</sup> quartile water levels of Lake Manitoba (averaged between data at stations at Steep Rock near the lake outlet and near Westbourne at the south end of the lake) were 247.3, 247.5 and 247.7 m above sea level. The “low water” datum to which CHS soundings were adjusted is 247.2 m.

Maps of the open water areas of Lake Manitoba and connected small lakes and coastal wetlands within the typical range of lake levels were derived from Sentinel-2 satellite images (band 8 wavelength = 842 nm) recorded in 2018, 2019 and 2021 (Table 5). Maps showing open water surfaces extending into the same connected small lakes and coastal wetlands were derived from Landsat 5 Thematic Mapper satellite images (band 5, wavelength = 1650 nm) recorded during the flood of 2011. One additional map at an intermediate water level was derived from a Sentinel-2 satellite image (band 8) recorded in 2022.

In general, the procedure was to select a threshold reflectance below which pixels represented open water and above which pixels represented either mixed water and land or exclusively land.

Table 5. Raster images of lake surface at selected water levels. Filenames include 1) source satellite sensor, 2) image capture date (YYYYMMDD) and 3) water level (10X m above sea level).

Image date	Water level (m above sea level) <sup>*1</sup>	Satellite platform	Spatial resolution (m)	Filename
2011 Aug 13 <sup>*2</sup>	248.9	Landsat TM-5	30	LMB_Landsat5TM_20110813_wl_2489.tif
2011 May 25	248.5	Landsat TM-5	30	LMB_Landsat5TM_20110525_wl_2485.tif
2022 Aug 31	247.7	Sentinel-2	10	LMB_Sentinel2_20220831_wl_2477.tif
2018 May 19	247.4	Sentinel-2	10	LMB_Sentinel2_20180519_wl_2474.tif
2019 Sep 16	247.2	Sentinel-2	10	LMB_Sentinel2_20190916_wl_2472.tif
2021 July 27	247.0	Sentinel-2	10	LMB_Sentinel2_20210727_wl_2470.tif

<sup>\*1</sup> mean of daily levels reported at Steep Rock and near Westbourne

<sup>\*2</sup> In the Landsat images, some regions, especially in the Delta Marsh, appear as open water on 25 May 2011, but as land on 13 August, although the lake level was higher on the latter date. In the two images, cattail stands appeared greener in true colour renditions, and had higher NDVI values in general in August than the same beds appeared in May. The regions in question were green in the true colour image of 13 August, and displayed higher NDVI values. It is likely that senescent cattail beds were overtopped by flood waters in May, but had grown and stood above water by August. I assumed that such areas constituted flooded land in both cases. To correct the August flood map, I added any May flooded polygons that were 1) not water in August and 2) not outside the outer boundary of the August water polygon.

## *Bathymetric map*

The surface polygon for the bathymetric map of Lake Manitoba, including connected small lakes and coastal wetlands was derived from a Sentinel-2 satellite image (band 5) recorded on 16 Sept. 2019, when the mean daily water level was 247.2 m above sea level near Westbourne in the South Basin and the same near Steeprock in the Northeast Basin. A continuous digital elevation model of the bottom was constructed using the kriging routine in Surfer™ from soundings recorded by the Canadian Hydrographic Service (CHS) in 1982 and 1983 and reported on the CHS hydrographic charts of the lake (CHS, 1986). Depths on the charts were adjusted to the long term low water datum of 247.2 m. The CHS did not sound connected small lakes and coastal wetlands which exchange water with Lake Manitoba during set-up and seiche events and when the level fluctuates in response to varying discharge from the watershed. Depths of these water bodies were estimated.

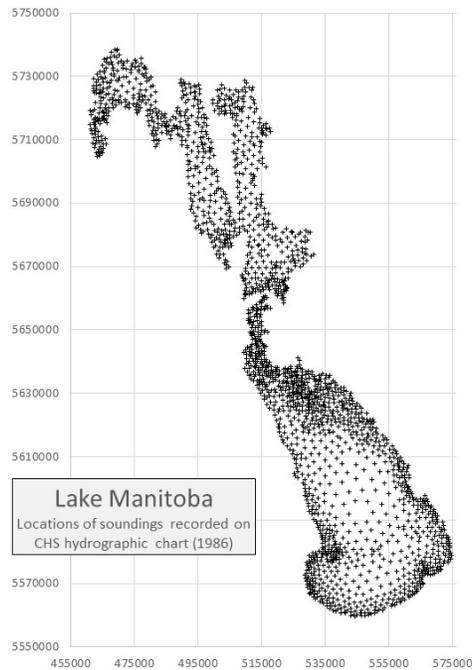


Figure 5. Locations of soundings recorded on the Canadian Hydrographic Survey hydrographic chart (published 1986). Note that no soundings were reported for Ebb and Flow Lake and smaller, attached lakes and coastal wetlands. All geographical coordinates and depths are stored in the accompanying file “LMBdepths(CHS,UTM14n).xlsx”.

The bathymetric map is stored as georeferenced raster data in Idrisi (.rst files, with metadata in .rdc files) and also in Geotiff (.tif file) format. Values in either format are depths in m; other properties of the files are reported in Table 6. High resolution colour and greytone renditions (i.e. Figures 1 and 2) are supplied in JPEG format.

Table 6. Properties of the raster images of the bathymetric map.

Parameter	Description
data type	real
file type	binary
columns	11901
rows	19040
ref. system	utm-14n (WGS84)
ref. units	m
pixel resolution	10 m
min. Easting	458995
max. Easting	578005
min. Northing	5550605
max. Northing	5741005
min. value	0
max. value	6.6902766

Surface area at selected water levels

## *References*

Bajkov, A. 1930. Biological conditions of Manitoba lakes. Contributions to Canadian Biology and Fisheries. New Series. P. 383–422. <https://cdnsiencepub.com/doi/10.1139/f30-012>

CHS. 1986 (reprint of 1985 edition). Lake Manitoba: Northern and Southern Portions. Canadian Hydrographic Service, Fisheries and Oceans Canada. <https://www.charts.gc.ca/charts-cartes/paper-papier/papertable-tablepapier-eng.asp>

Crowe, J. 1972. Lake Manitoba water Quality, 1966–1969. Manitoba Dept. of Mines, Resources and Environmental Management. Research Branch. MS Report No. 72-15. 22 p.

International Garrison Diversion Study Board. 1976. Report to the International Joint Commission. Appendix A: Water Quality Report. <https://legacyfiles.ijc.org/publications/ID573.pdf>

Last, W. M. 1980. Sedimentology and post-glacial history of Lake Manitoba. University of Manitoba thesis. xxi + 333 p. + appendices. <https://mspace.lib.umanitoba.ca/items/11647639-a5d0-498d-8a54-f0aa95dd87f5>

