ERDC/CRREL TR-07-5

Cold Regions Research and Engineering Laboratory

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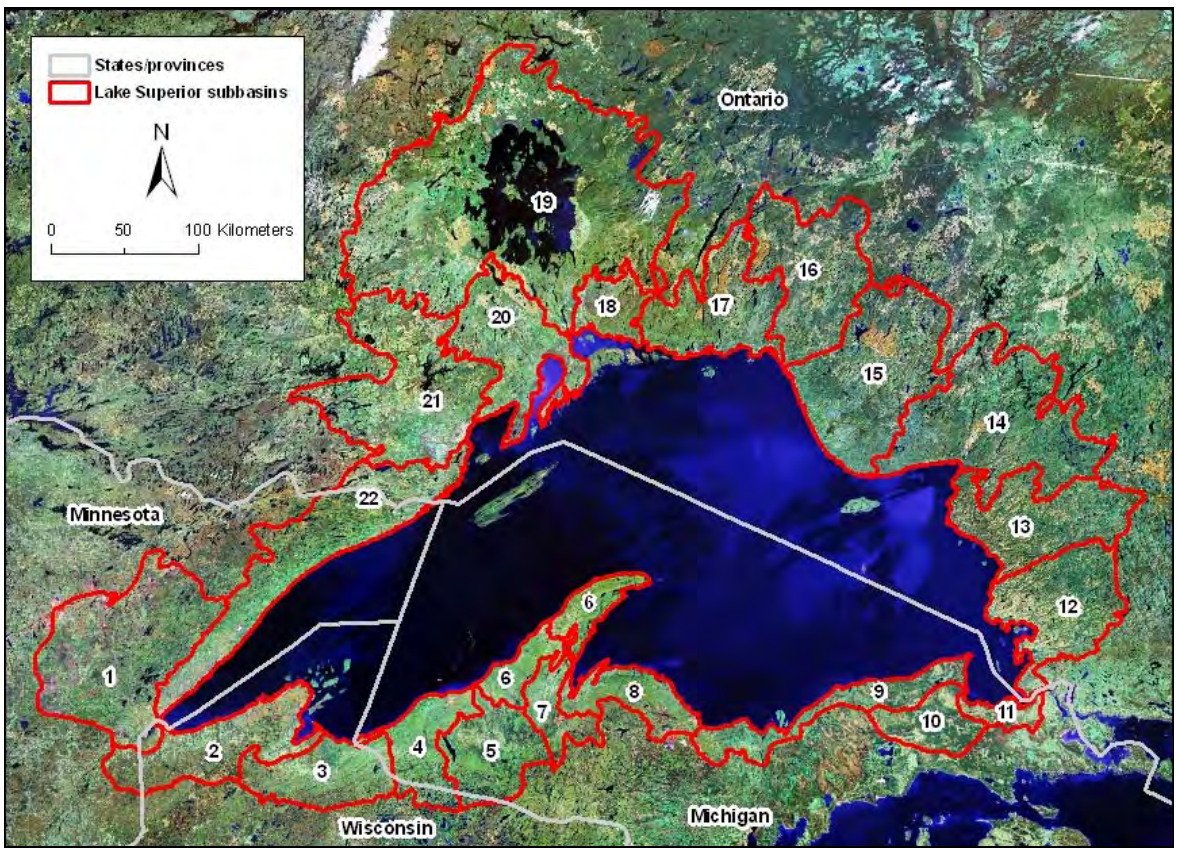
Analysis of the Lake Superior Watershed Seasonal Snow Cover

Steven F. Daly, Timothy B. Baldwin, and Patricia Weyrick

May 2007



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Final report

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Prepared for Detroit District, U.S. Army Corps of Engineers

Abstract: Daily estimates of the snow water equivalent (SWE) distribution for the period from 1 December through 30 April for each winter season from 1979–80 through 2002–03 were calculated for the entire Lake Superior watershed. The calculations were based on numerous ground-based daily observations collected and compiled by the National Weather Service in the United States and by the Meteorological Service of Canada in Canada. The daily estimates of SWE were then used to determine the annual accumulation and melt period characteristics of the Lake Superior watershed, along with the annual series of maximum SWE volume and the incremental accumulated SWE volume. Selected results are also shown for the individual sub-basins. Maps were also prepared of the mean SWE distributions on the 1st and 15th day of each winter month.

Contents

Figures and Tables

Figures

Tables

Preface

This report was prepared by Dr. Steven F. Daly, Timothy B. Baldwin, and Patricia Weyrick of the Remote Sensing/GIS and Water Resources Branch of Cold Regions Research and Engineering Laboratory, U.S. Army Engineer Research and Development Center. This work was supported by the Detroit District of the Corps of Engineers. The participation of Keith Kompoltowicz of the Detroit District is gratefully acknowledged. Steven Newman and Elke Ochs of CRREL provided insight into available remote sensing technology and analysis.

The report was prepared under the general supervision of Timothy Pangburn, Chief, Remote Sensing/GIS and Water Resources Branch; Dr. Lance Hansen, Deputy Director; and Dr. Robert E. Davis, Director, CRREL.

The Commander and Executive Director of ERDC is COL Richard B. Jenkins. The Director is Dr. James R. Houston.

1 Introduction

This report is an investigation of the historical spatial and temporal distribution of snow water equivalent (SWE) in the Lake Superior watershed. Lake Superior, the most upstream and largest of the Great Lakes, is an important water resource shared by Canada and the United States. The terrestrial and aquatic environments of the watershed, and the hydrology of the lake itself, are affected by the distribution of SWE and the rate of snow accumulation and ablation. Information on the volume of snowmelt inflow into Lake Superior is especially important in managing this valuable water resource. Snowmelt forms a portion of the total watershed runoff, which in turn, is a significant component of the total inflow into the lake, second only to the over-lake precipitation (Croley et al. 2001).

In this report we developed daily estimates of the SWE distribution each winter season from the winter of 1979–80 through the winter of 2002–03 for the entire Lake Superior watershed. Each winter season covered the period from 1 December through 30 April. These estimates were based on numerous ground-based daily observations collected and compiled by the National Weather Service (NOAA 2001, 2005) in the United States and compiled by the Meteorological Service of Canada in Canada (MSC 2000). The large majority of the observations were daily measurements of snow depth and not SWE. To make maximum use of the available snow observations, the SWE at each of these stations was estimated based on the observed snow depth and an estimated snow density. Different procedures were used to estimate the snow density in the U.S. and in Canada because of the very different observation protocols that were followed in each country. In both cases, if no observations of snow density were available within a specified distance and window of time around the snow depth observation, the long term monthly snow density was used. The long-term monthly snow density was estimated based on the historical data included in this study. Once the daily SWE had been estimated at every station the results could be interpolated throughout the Lake Superior watershed using inverse distance weighting. The end result was a series of gridded estimates of the daily SWE distribution covering the period of the study.

These gridded estimates of SWE were then used to estimate the total volume of SWE for each of the Lake Superior sub-basins and the entire watershed for each day between 1 December and 30 April for the years 1980 through 2003. These results were then used to analyze the Lake Superior watershed seasonal snow cover. Results include the determining the annual accumulation and melt period characteristics, the annual series of maximum SWE volume, and comparing the annual maximum SWE volume with the incremental accumulated SWE volume. Selected results are also shown for the individual sub-basins. Maps were also prepared of the mean SWE distributions on the 1st and 15th day of each month.

2 Lake Superior Watershed

Lake Superior is the largest of the Great Lakes, with a surface area of 83,400 km^2 and a volume of approximately 12,100 km^3 of water. This makes it the largest freshwater lake in the world by surface area and the third largest freshwater lake by volume. The Lake Superior watershed has an area of 211,400 km^2 with 128,000 km^2 of land surface (Fig. 1). The watershed covers portions of the province of Ontario, Canada, and portions of the states of Michigan, Wisconsin, and Minnesota in the United States. The Detroit District has conceptually divided the Lake Superior Watershed into 22 sub-basins with approximately half the sub-basins in each country. The area of each sub-basin is listed in Table 1.

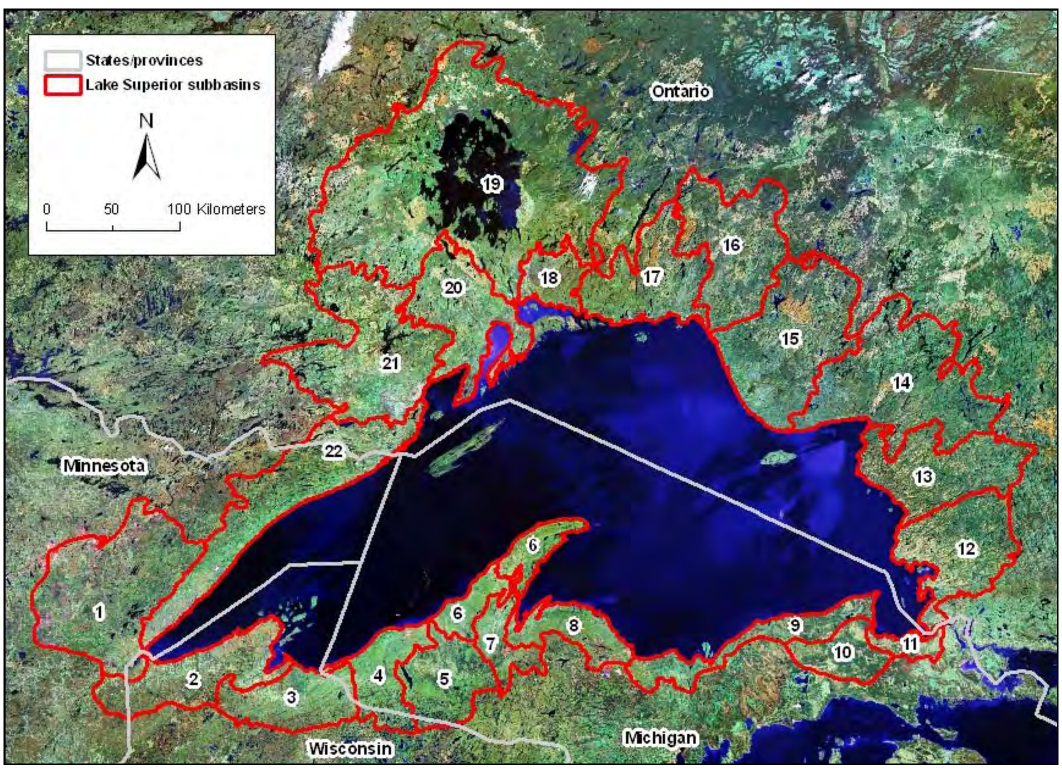


Figure 1. Lake Superior watershed.

The controlled outflow from Lake Superior is at the eastern end of the lake through the St. Marys River. The outflow from Lake Superior is controlled under stringent regulation plans agreed upon by Canada and the United States through the offices of the International Joint Commission (IJC). Other components of the Lake Superior water balance, such as runoff, groundwater inflow, over-lake precipitation, and evaporation are not controlled (Neff and Nicholas 2004). The variations in these uncontrolled components, especially runoff, over-lake precipitation, and evaporation cause corresponding variations in the Lake Superior water levels. The record of monthly water levels for Lake Superior for the period from 1918 to the present is displayed in Figure 2. The water level of Lake Superior experiences short term, annual and long term changes. The short term changes, on the order of a few minutes to a few days, are caused by wind, waves, and seiches. The annual cycle is the result of the annual balance of inflows, outflows, and evaporation. The long term changes, on the order of years, result from the long term variations in the total precipitation, including snow fall, over the Lake Superior watershed (Croley et al. 2001).

Table 1. Lake Superior sub-basin areas and maximum SWE values.

Sub-Basin Number	Area (km^2)	Average Annual Total Max. SWE Volume x 10^8 (m^3)	Average Annual Max. SWE (mm)
1	9602	10.9	113.7
2	4880	5.3	109.0
3	3709	5.0	135.6
4	2977	5.2	176.0
5	3664	6.1	165.8
6	2887	5.7	198.1
7	1775	3.5	200.0
8	2543	5.4	212.8
9	3076	6.5	212.9
10	2137	3.8	176.6
11	842	1.4	166.9
12	5299	11.5	217.7
13	5579	12.0	215.4
14	9516	18.1	190.3
15	8350	12.1	145.2
16	6439	8.8	136.4
17	5079	6.8	133.2
18	1894	2.4	126.5
19	25601	32.3	126.0
20	5389	5.8	107.2
21	8775	10.1	115.3
22	8011	10.6	132.2

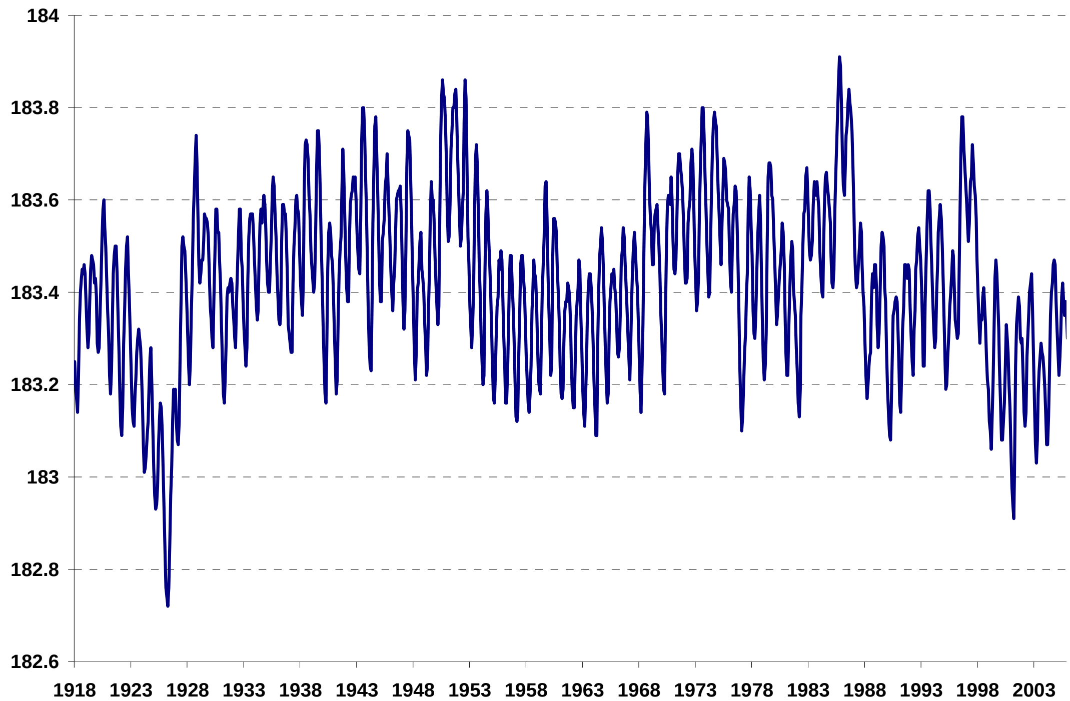


Figure 2. Lake Superior monthly water levels in meters from 1918 to 2005 (International Great Lakes Datum 1985).

The International Lake Superior Board of Control, with members from both countries, was established by the IJC in 1914 to control and regulate the outflow of Lake Superior through the St Marys River. The regulations acknowledge the needs of various interest groups on Lake Superior and the St. Marys River, including navigation, hydropower, and riparian owners. As described by the Board:

> "The main objective of the present regulation plan is to determining (sic) a flow that will bring the levels of Lake Superior and Lakes Michigan and Huron to nearly the same relative position within their respective ranges of actual historic levels. At the same time, the plan tries to prevent the level of Lake Superior from rising above or falling below certain water levels specified in the Order. The plan also contains provisions to safeguard against high levels in the harbor below the locks, provides a fixed minimum release, limits winter flows, and employs a forecast of future water supply conditions" (IJC 2006).

3 Data Sources

The total daily volume of SWE for the Lake Superior watershed was determined based on the observed snow data for the years 1979 through 2004. Canadian data were actually only available up to 2003 and determined the last year for which the total SWE for Lake Superior could be estimated. Data for the United States were collected and compiled by the NWS (NOAA 2001, 2005). Data for Canada was available from the Canadian Snow Data CD-ROM (MSC 2000). The overwhelming majority of U.S. and Canadian stations included in this study reported only a daily snow depth. These snow depths observations were used to estimate the corresponding daily SWE at each station by multiplying the observed snow depth by an estimated snow density. The procedure used to estimate the snow density is described in the next section. Once the daily SWE had been estimated at all the stations for which data were available in the Lake Superior watershed, the distribution of SWE over the entire Lake Superior watershed was estimated by interpolating the observed and estimated SWE data. The GIS coverages used in the interpolation process are described in this section and the GIS procedures used are described in a following section.

NWS Data

The NWS snow data (NOAA 2001, 2005) consisted of daily observations of snow depths at COOP stations and daily observations of snow water equivalent (SWE) and snow depth at the two first order stations located in the Lake Superior watershed (Fig. 3). This study included all COOP stations located within the Lake Superior watershed and within 60 km of the watershed boundary. The NWS stations used in this study are listed in Appendix A and Appendix B. Descriptive data available for each station included the latitude, longitude, elevation and period of record. The number of COOP stations providing snow depth data varied from day to day and year to year as shown in Figure 4. In general, more stations provided snow observation data in the winter than in the summer. The summer observations, when available, were uniformly zero depth, as expected. The number of stations providing data on any one day ranged from a maximum of about 100 to a low of about 65. The number of COOP stations providing useable snow depth observations dropped sharply in the winter of 2001–02. The number of stations recovered somewhat by the winter of 2003–04.

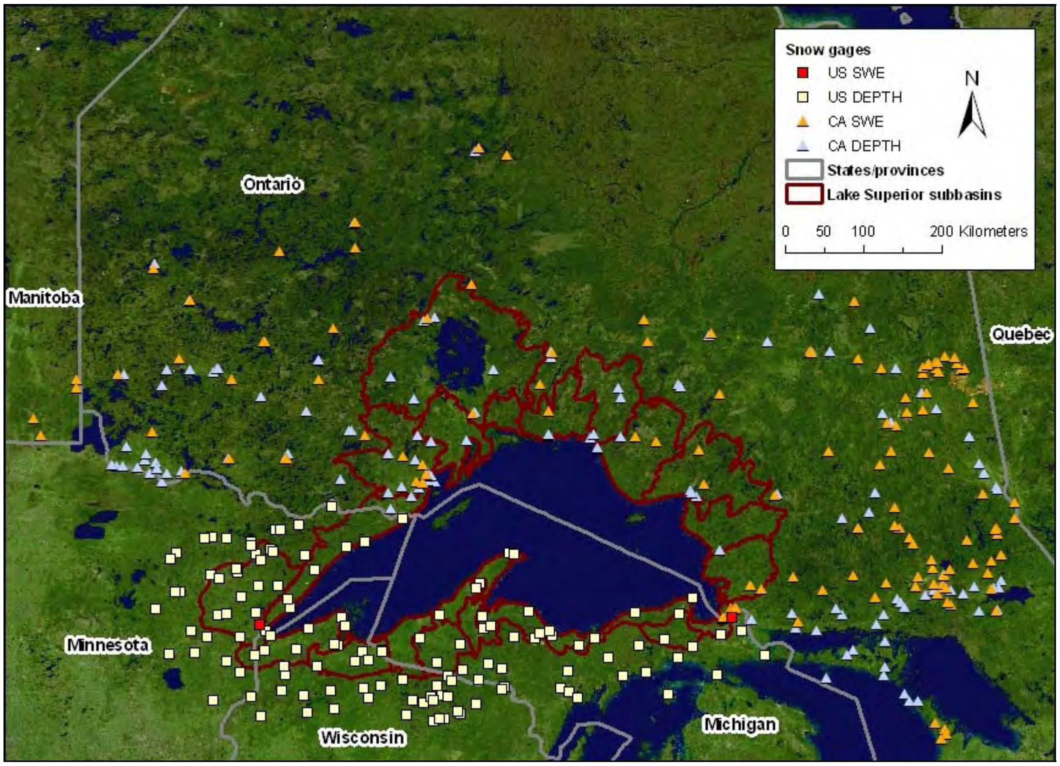


Figure 3. Stations providing snow information in the Lake Superior watershed.

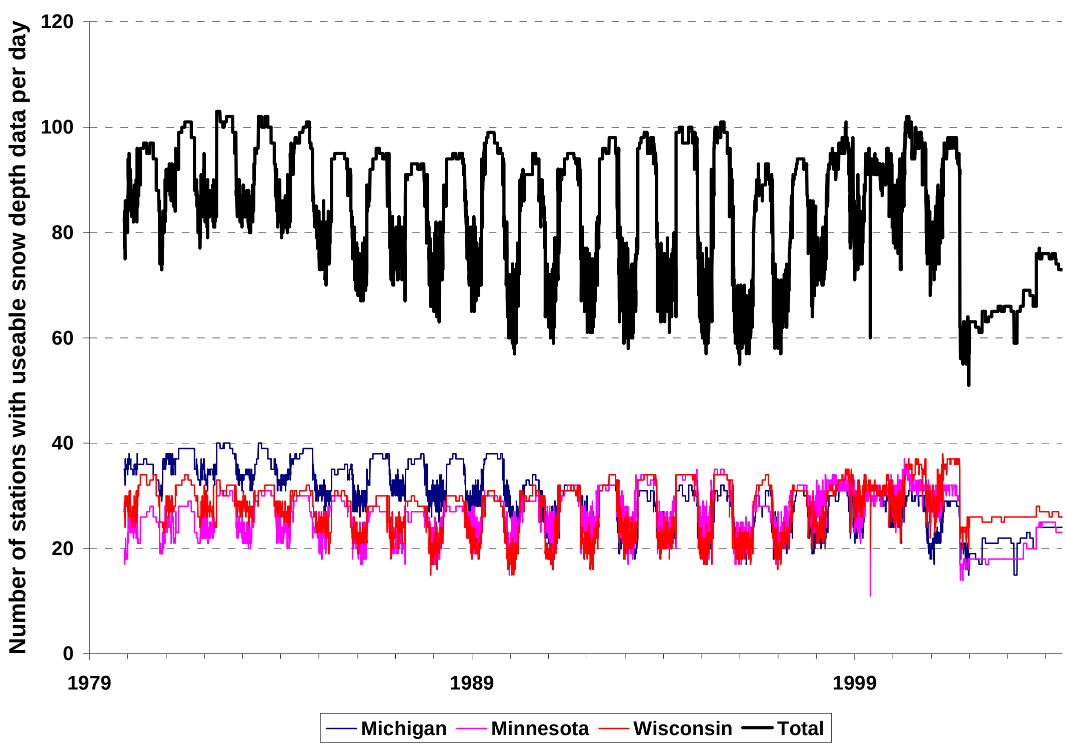


Figure 4. Number of observations stations reporting snow depth in the Lake Superior watershed and vicinity in Michigan, Minnesota, Wisconsin

Canadian Data

The Canadian Snow Data CD-ROM included the Canadian Daily Snow Depth Database and the Canadian Snow Water Equivalent Database (MSC 2000). The Daily Snow Depth Database consists of daily and weekly snow depth observations taken by the Meteorological Service of Canada. The Snow Water Equivalent Database contains SWE and snow depth measurements from snow surveys taken by more than 20 agencies weekly, biweekly or monthly. It also contains biweekly SWE estimates at Meteorological Service of Canada snow depth observing stations. Descriptive data available for each station in both databases included the latitude, longitude, elevation, and period of record. This study included all snow depth and SWE observations located within the Lake Superior watershed and within 300 km of the watershed boundary (Fig. 5). The Canadian stations used in this study are listed in Appendix C and Appendix D. The number of snow depth observations varied from day to day and year to year, as shown in Figure 5. The number of daily observations reported declined steadily since the early 1980s. The snow observations included in the Snow Water Equivalent Database were generally not made daily but rather on the 1st and 15th day of each winter month (Fig. 6).

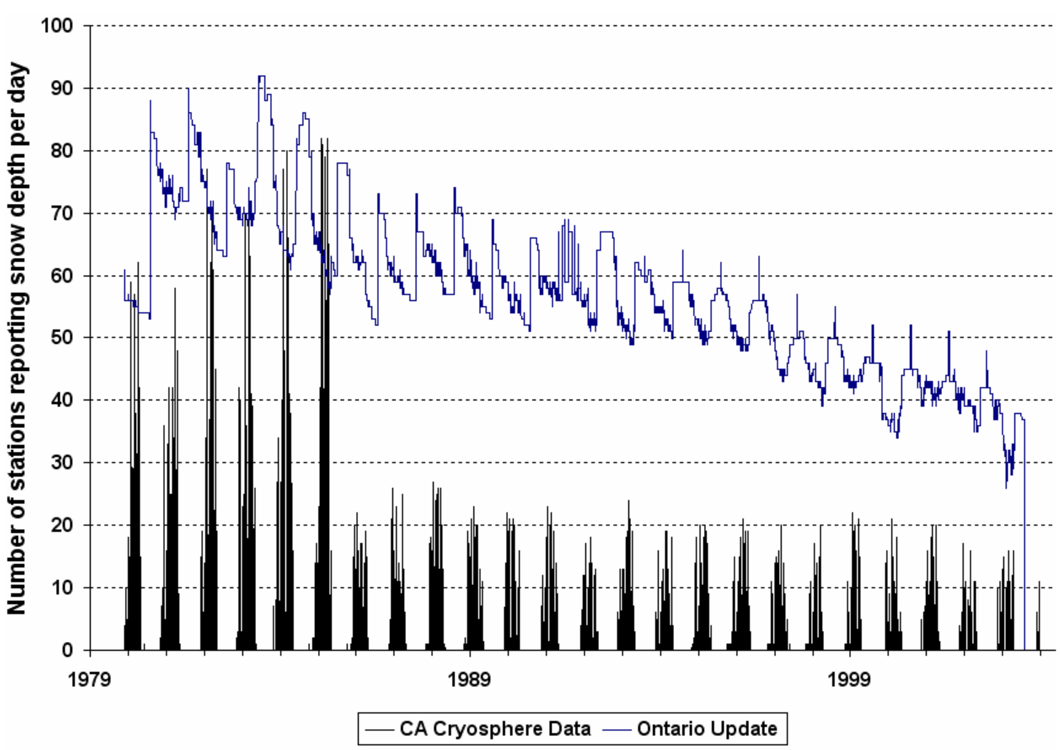


Figure 5. Number of stations reporting snow information in the Lake Superior watershed and vicinity in Ontario, Canada.

GIS Data

The two main GIS layers that were used in the analysis were a gage layer and a sub-basin layer. A gage GIS layer was created from the latitude and longitude values that came with the Canadian and United States gage snow observation data. On the US side, gages were only used if they were located within 60 km of the Lake Superior Basin. For the Canadian side, gages were kept if they were within 300 km of the basin. The gage layer was used to interpolate values across the study area.

The second GIS layer used in computations represented the 22 sub-basins in the Lake Superior basin. This sub-basin layer was obtained from U.S. Army Engineer District, Detroit. It was used to clip the interpolated SWE grids that were created to the Lake Superior basin boundary. Additionally, it was used to calculate the total SWE in each sub-basin for each day that was run.

In addition to the layers used in the GIS analysis itself, additional background data were used in the figures and maps that were created. Most of these layers came from ESRI (ESRI 2005). In addition to the ESRI data, a political boundaries layer of North America was used that was downloaded from the USGS (USGS 2006).

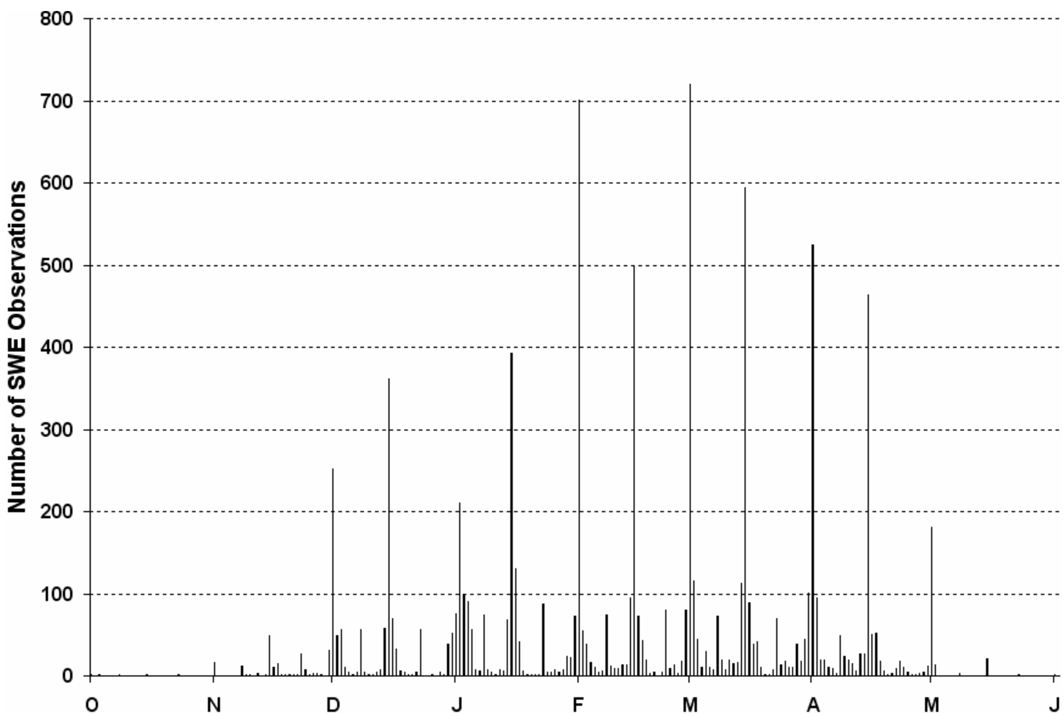


Figure 6. Number of SWE observations by day of year in the Lake Superior watershed and vicinity in Ontario, Canada.

4 Estimating SWE based on Snow Depth

The large majority of observations included in this study were of snow depth and not SWE. Estimations of SWE can be made based on snow depth if the snow density can be estimated. Snow density (the ratio of the snow mass to volume) can vary widely and it is not appropriate to use a fixed value. The density of new-fallen snow depends on the air temperature, humidity, and wind speed. Once on the ground, the density of snow increases via crystal metamorphism, settlement, and wind packing. Snow density can also vary with depth, with snow near the bottom of snowpacks tending to be denser than that near the top. Daily estimates of the depth-averaged snow density can be made at observation stations that report both the snow depth and SWE based on the conservation of total water

$$\bar{\rho}_s = \rho_w \frac{SWE}{d_s} \quad (1)$$

where

$\bar{\rho}_s$ = depth-averaged snow density

ρ_w = water density

SWE = observed SWE depth

d_s = snow depth.

Table 2. Average monthly SWE (kg/m^3).

Month	Duluth, MN	Sault Ste. Marie, MI	Canadian Data
NOV	150	110	180
DEC	170	130	180
JAN	160	190	190
FEB	190	240	210
MAR	280	330	250
APR	350	430	300

The monthly average snow densities, based on all years of record, for Duluth, Sault Ste. Marie, and Canada are listed in Table 2. The observed snow density at all the stations where SWE and snow depth observations were available are shown in Figures 7, based on the day of the winter. A histogram of the distribution of snow density values throughout the year is shown in figure 8. In general, the observations of SWE at Duluth and Sault Ste. Marie in the U.S. and at all the Canadian observation stations are consistent. All show a general increase throughout the winter.

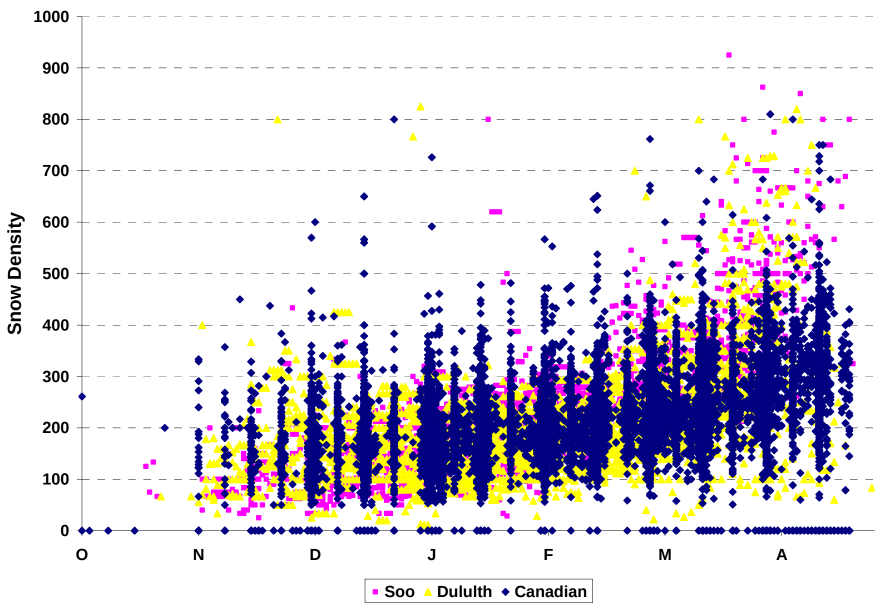


Figure 7. Snow density (kg/m³) by day of year at Sault Ste Marie (Soo), Duluth, and in the Lake Superior watershed and vicinity in Ontario, Canada.

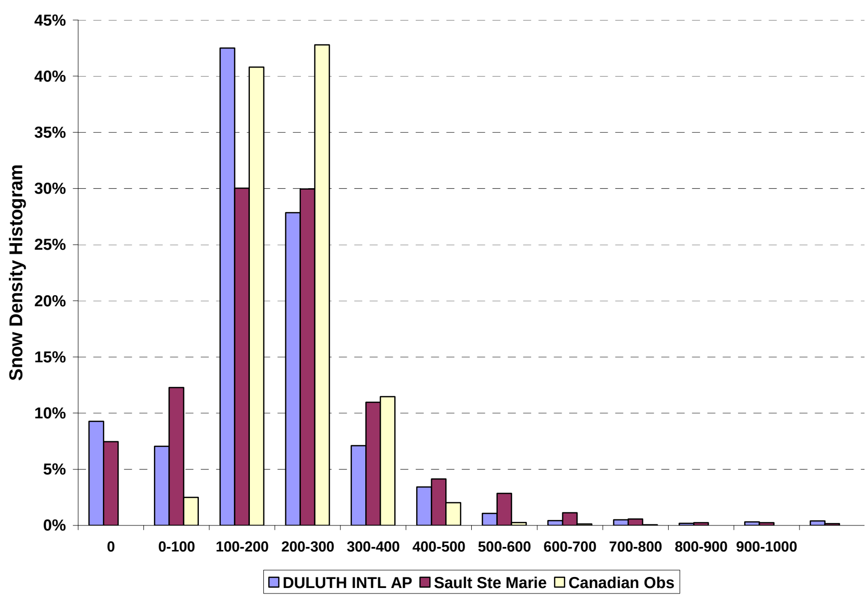


Figure 8. Snow density histogram (kg/m³) for Sault Ste Marie (Soo), MI; Duluth, MN; and in the Lake Superior watershed and vicinity in Ontario, Canada.

The following procedure was followed to estimate SWE at all the gages where snow depth observations were available.

NWS COOP Stations

The SWE at the NWS COOP stations was estimated by assuming that the snow density at each COOP station could be approximated by the observed snow density at the closer of the two U.S. NWS stations where SWE was observed on the same date. To start, the distance between each COOP station and the two U.S. NWS stations where SWE was observed, Duluth or Sault Ste. Marie, was calculated and the closest station selected. Then the SWE at a COOP station number *k* on day *j*, $SWE_{\mathrm{j}}^{\mathrm{k}}$, was estimated by rearranging eq 1 for SWE and then substituting the observed snow density

$$SWE_{\mathrm{j}}^{\mathrm{k}} = d_{\mathrm{s\,j}}^{\mathrm{k}} \frac{\overline{\rho}_{\mathrm{s\,j}}^{\mathrm{k}}}{\rho_{\mathrm{w}}} = d_{\mathrm{s\,j}}^{\mathrm{k}} \frac{SWE_{\mathrm{j}}}{d_{\mathrm{s\,j}}} \qquad (2)$$

where

$d_{\mathrm{s\,j}}^{\mathrm{k}}$ = snow depth observation at COOP station number *k* on day *j*

$\overline{\rho}_{\mathrm{s\,j}}^{\mathrm{k}}$ = unknown snow density at COOP station number *k* on day *j*

d_{sj} = snow depth at the closer SWE observation station, either Duluth or Sault Ste. Marie, on day *j*

SWE_{j} = SWE at the closer SWE observation station, either Duluth or Sault Ste. Marie, on day *j*.

If the snow depth observation at the COOP station was missing, the corresponding SWE observation was set as missing as well. If either the SWE observation or the snow depth observation was missing at the SWE observation station, or if the ratio of SWE to snow depth was greater than 0.8 at the SWE observation station, the appropriate monthly mean snow density at the snow observation station (Table 2) was used to estimate $SWE_{\mathrm{j}}^{\mathrm{k}}$ as

$$SWE_{\mathrm{j}}^{\mathrm{k}} = d_{\mathrm{s\,j}}^{\mathrm{k}} \frac{\overline{\rho}_{\mathrm{s\ monthly}}}{\rho_{\mathrm{w}}}\,. \qquad (3)$$

Canadian Stations

The Canadian observations differed from the U.S. observation in that there were many more stations that measured SWE directly, but almost all of these SWE observations were done bi-monthly or monthly and not daily. These stations are included in the Canadian Snow Water Equivalent Database did not need to have SWE estimated because the SWE had been measured in the field. These measurements also included snow depth and, as a result, these data could be used to estimate the depth-averaged snow density using eq 1. The density could be estimated on each day that measurements had been made, generally once or twice a month. Only at the stations where snow depth alone was measured was it necessary to estimate SWE. These stations are included in the Canadian Daily Snow Depth Database and the large majority of these stations had daily observations of snow depth.

The following procedure was used to estimate SWE. First, the distances between each snow depth station and all the stations where SWE had been measured were calculated and the three closest SWE stations selected. Each of the three closest SWE stations generally provided only one or two estimates of snow density a month, and usually the measurements were not made at all three stations on the same day. A centered 15-day moving average of SWE and snow depth for each of these stations was used to compensate for the sparseness in time of the measurements and the lack of synchronicity between stations. These three averaged SWE and snow depths were then used to estimate the snow density at each snow depth station. The snow density on day *j* at the snow depth observation station *k*, $\rho^{\mathrm{k}}_{\mathrm{snow\ j}}$, was estimated using inverse distance squared weighting

$$\rho^{\mathrm{k}}_{\mathrm{snow\ j}} = \rho_{\mathrm{w}} \frac{\sum_{m=1}^{n} \frac{1}{L^2_{\mathrm{k\text{-}m}}} \frac{SWE^{\mathrm{m}}_{\mathrm{15\ j}}}{d^{\mathrm{m}}_{\mathrm{15\ j}}}}{\sum_{m=1}^{n} \frac{1}{L^2_{\mathrm{k\text{-}m}}}} \tag{4}$$

where

$L_{\mathrm{k\text{-}m}}$ = distance from the snow depth observation station *k* to SWE observation station *m*

$SWE^{\mathrm{m}}_{\mathrm{15\ j}}$ = 15-day moving average SWE at station *m* on day *j*

$d^{\mathrm{m}}_{\mathrm{15\ j}}$ = 15-day moving average snow depth at station *m* on day *j*

n = the number of SWE observation stations with valid information ($0 \le n \le 3$).

The snow density was not allowed to change by more than 0.05 from one day to the next. The SWE was then estimated as

$$SWE_{\mathrm{j}}^{\mathrm{k}} = d_{\mathrm{s\,j}}^{\mathrm{k}} \frac{\rho_{\mathrm{snow\,j}}^{\mathrm{k}}}{\rho_{\mathrm{w}}} = d_{\mathrm{s\,j}}^{\mathrm{k}} \frac{\sum_{m=1}^{n} \frac{1}{L_{\mathrm{k\text{-}m}}^{2}} \frac{SWE_{15\,\mathrm{j}}^{\mathrm{m}}}{d_{15\,\mathrm{j}}^{\mathrm{m}}}}{\sum_{m=1}^{n} \frac{1}{L_{\mathrm{k\text{-}m}}^{2}}} \tag{5}$$

Once the snow density had been calculated, it was assumed to hold for 32 days, unless another valid snow density was estimated. After 32 days or if no valid snow densities had been estimated, the appropriate Canadian monthly mean snow density (Table 2) was used to estimate $SWE_{\mathrm{j}}^{\mathrm{k}}$ as

$$SWE_{\mathrm{j}}^{\mathrm{k}} = d_{\mathrm{s\,j}}^{\mathrm{k}} \frac{\rho_{\mathrm{s\,monthly}}}{\rho_{\mathrm{w}}} \tag{6}$$

As with the U.S. stations, if the daily snow depth observation was missing, the corresponding SWE observation was set as missing as well. If either the 15-day moving average SWE observation or the 15-day moving average snow depth observation was missing at the SWE observation station, or if the ratio of 15-day moving average SWE to 15-day moving average snow depth was greater than 0.8 at the SWE observation station, then the SWE observation was set to missing.

5 GIS Analysis of SWE over the Lake Superior Watershed

After the SWE had been calculated for all stations that only had snow depth measurements, the next step was to interpolate the SWE for these stations along with the stations that directly measured SWE across the study area. The GIS software used to perform the GIS analysis was ESRI's ArcGIS software package, version 9.1. The projection that was used for this study was an Albers equal area projection that ESRI refers to as "USA_Contiguous_Albers_Equal_Area_Conic_USGS_version." The parameters of this projection are as given in Table 3.

Table 3. GIS projection parameters.

Projection	Albers Equal Area
Units	meters
Parameters	
First standard parallel	29° 30′ 0.0″
Second standard parallel	45° 30′ 0.0″
Central meridian	–96° 0′ 0.00″
Latitude of origin	23° 0′ 0.00″
False easting (m)	0.00
False northing (m)	0.00
Datum:	NAD83

Interpolation

Once the SWE had been calculated for all sites using the procedures described above, the SWE was interpolated over the study area (Ochs 2005). The interpolation resulted in an Albers equal-area SWE grid with 1-km grid cells covering a rectangular area encompassing all of the stations that were used in the study (Fig. 9). The SWE in each grid cell was estimated using an inverse distance weighting (IDW) procedure. In this case the square of the distance was chosen as the weighting parameter:

$$\overline{SWE}_{\mathrm{m}} = \frac{\sum_{i=1}^{5} \frac{1}{d_{\mathrm{m\_i}}^{2}} \left(SWE_{\mathrm{i}} \right)}{\sum_{i=1}^{5} \frac{1}{d_{\mathrm{m\_i}}^{2}}}$$

where $\overline{SWE}_{\mathrm{m}}$ is the SWE in the m^{th} grid cell; $d_{\mathrm{m\_i}}$ is the distance to the i^{th} station where SWE information is available; and SWE_{i} is the SWE estimated or observed at the i^{th} station. . A grid containing the interpolated SWE values in millimeters was created for every day between December 1 and April 30 for the winter of 1979–1980 to the winter of 2002–2003. After the interpolations, the grids were than clipped to the Lake Superior watershed and the SWE values for each grid cell were rounded to the nearest whole millimeter. The end result was a grid with approximately 128,000 cells with SWE values (Fig. 10). This interpolation process took about one and a half hours of computer processing time for each winter period on a 3.4 GHz PC.

Total SWE

Once the SWE had been interpolated for each of the grid cells, the water volume over the entire watershed and each sub-basin was calculated. First, the grids were clipped to the Lake Superior basin. The interpolated SWE values for each grid cell were then rounded to the nearest whole millimeter (Fig. 9 and 10). The volume over the entire watershed was found as

$$Vol_{\mathrm{watershed}} = \sum_{i=1}^{n} \overline{SWE}_{\mathrm{i}} \cdot Area_{\mathrm{i}}$$

where n is the number of grid cells in a watershed; $Area_{\mathrm{i}}$ is the area of the grid cell. The total SWE in cubic meters for each sub-basin was found in this way for every day between 1 December and 30 April for the winter of 1979–1980 to the winter of 2002–2003.

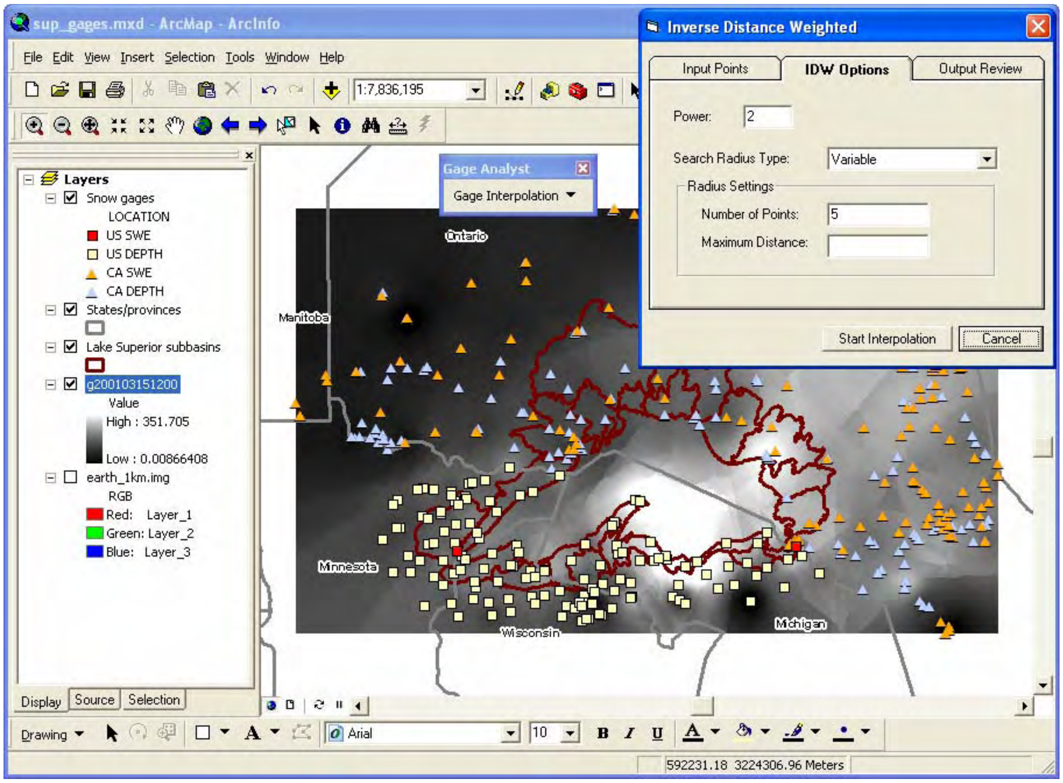


Figure 9. ArcMap and the Gage Analyst extension were used to interpolate the March 15, 2001 SWE grid displayed in a grey-scale color ramp.

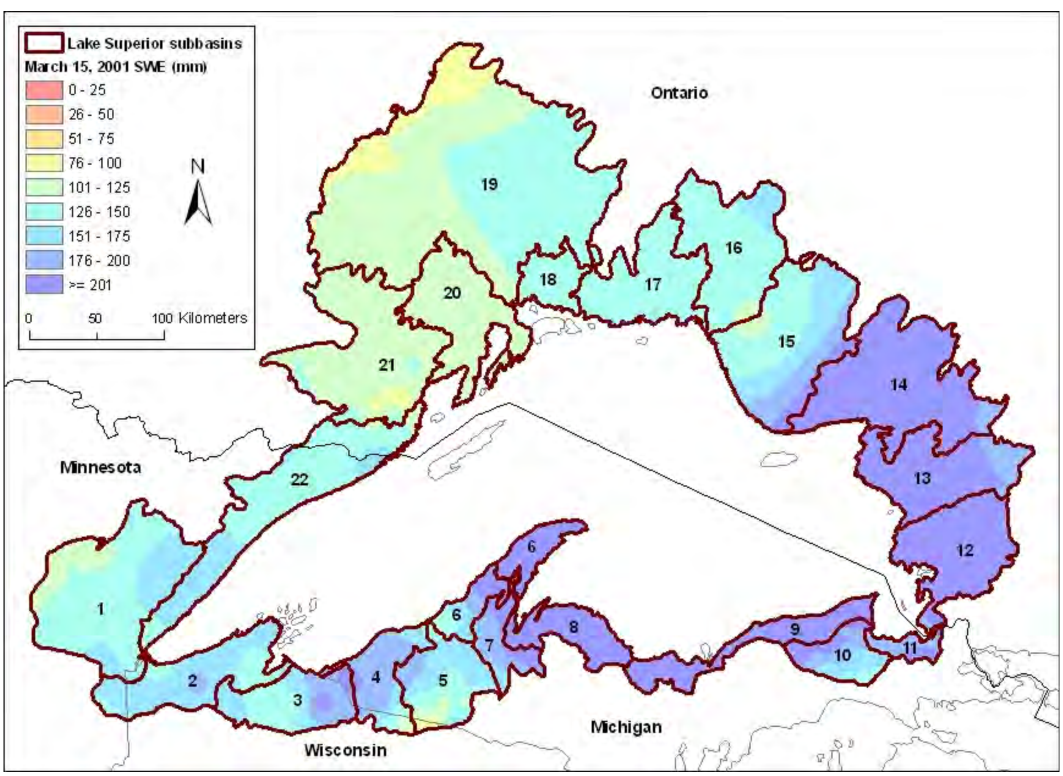


Figure 10. Map showing SWE grid that is clipped to the Lake Superior watershed for 15 March 2001.

6 Results

Total Lake Superior Watershed

In this section we will concentrate on the results for the total Lake Superior watershed. The calculations described above resulted in an estimate of the total volume of SWE for each of the 22 sub-basins of the Lake Superior watershed for each day between 1 December and 30 April starting in 1979 through 2003. Figure 11 displays the daily time series of the total SWE volume for the Lake Superior watershed for the period of record found by summing the daily totals of the 22 sub-basins. As can be seen, while the SWE volume displays some variation from winter to winter, there is a consistent form to the seasonal variation of SWE. To focus in on this characteristic form, the statistics of the SWE volume were calculated for each day of the winter season between 1 December and 30 April for the entire Lake Superior watershed. For each day of the winter season, Figure 12 displays the average SWE volume, the average plus and minus the standard deviation, and the maximum and minimum SWE volume. This information can be used to describe the characteristics of the SWE volume of the watershed. First, the winter season in can be divided into two distinct periods: a snow accumulation period characterized by increasing SWE, and a snow melt (ablation) period characterized by decreasing SWE; these are separated by the day of the seasonal maximum SWE volume. That day generally occurred in early March, although there was considerable year-to-year variation. The actual day varied between the middle of February and early April; the later in the winter season that the day of the seasonal maximum SWE volume occurred, the larger the value of the SWE maximum tended to be (Fig. 13).

On 1 December, the starting day of the calculations for each winter season, the volume of SWE was greater than zero for all the years of the study, with an average volume of SWE of 2.53×10^9 m^3. This SWE was probably accumulated in the preceding November, indicating a consistent accumulation prior to 1 December. On 30 April, the final day of the calculations for each winter season, the volume of SWE was greater than zero for 17 years of the study period and had reached zero for 7 years. The average volume of SWE on 30 April was 1.01×10^9 m^3 for the non-zero years.

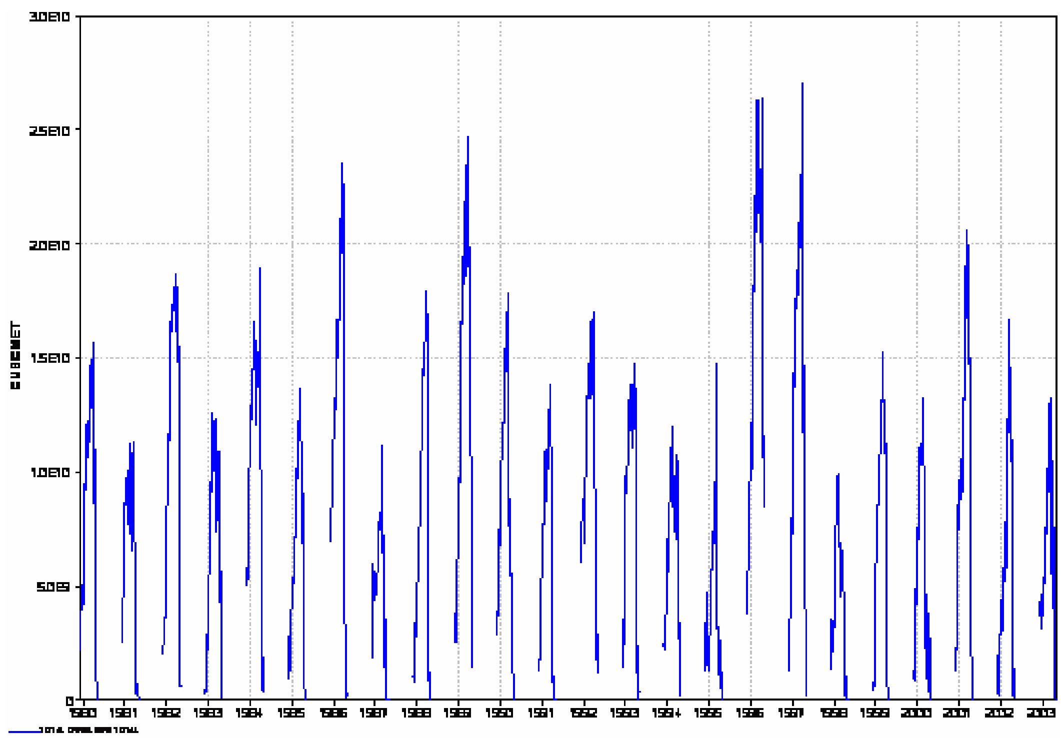


Figure 11. Daily SWE volume for the entire Lake Superior watershed.

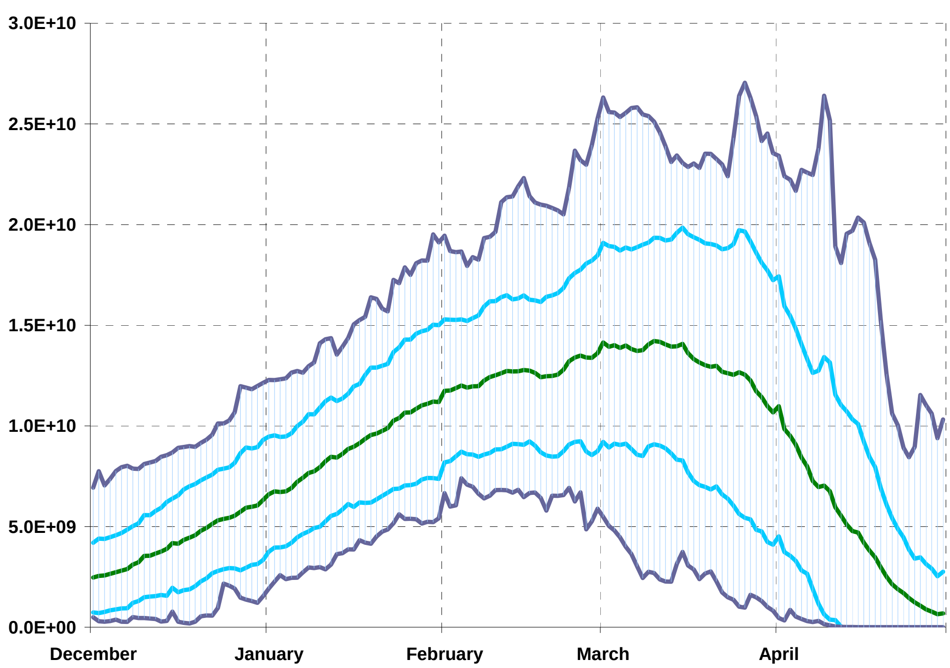


Figure 12. Daily SWE statistics for the entire Lake Superior watershed. Shown are the daily average (green), daily average plus and minus one standard deviation (blue), and the daily historical maximums and minimums.

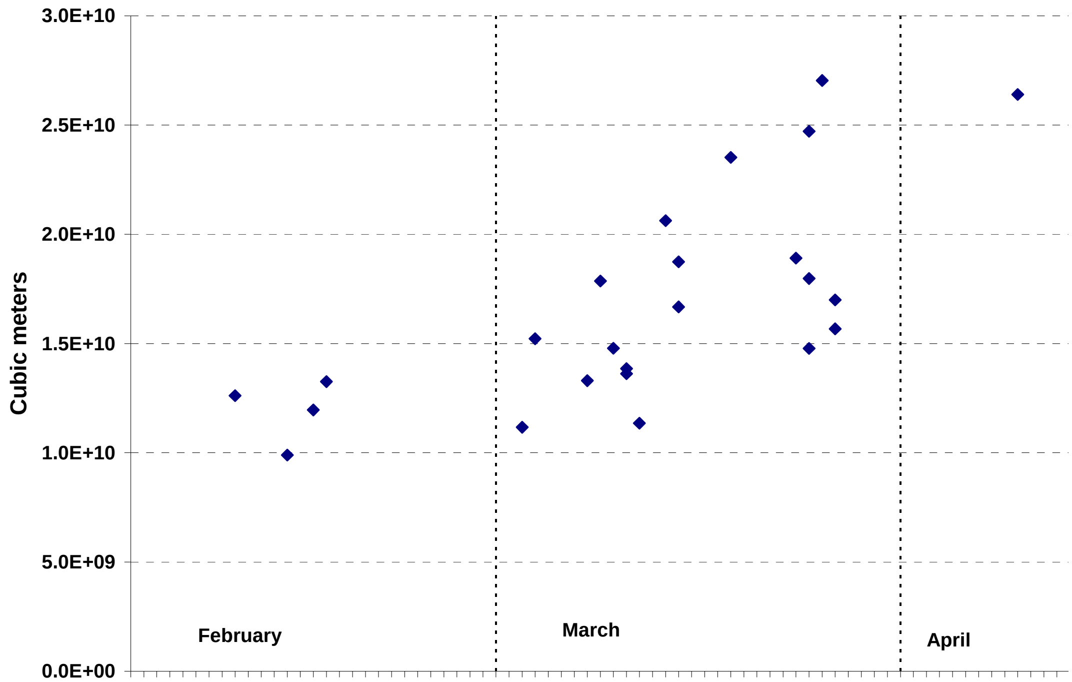


Figure 13. Maximum volume of SWE for the total Lake Superior watershed and the day of year when the maximum occurred.

The snow accumulation and melt periods are times when the overall trend is for either accumulation or melt, but there was not a monotonic increase during the accumulation period or a monotonic decrease during the snow melt period in any year. In fact, episodes of accumulation and melt occurred during each period. These periods can be complex, as snow can accumulate on one portion of the watershed on the same day it is melting in another portion. However, if we take the Lake Superior watershed as a whole, and ignore these sub-watershed spatial variations, we can roughly estimate the total snow accumulation that occurred prior to the day of the maximum SWE volume. The accumulated total SWE volume on each day can be estimated as the seasonal sum of the incremental change in the daily SWE volume, SWE_j, when the change is positive, as

$$SWE_{\mathrm{acc\,i}} = \sum_{j=2}^{i} \left(SWE_{\mathrm{j}} - SWE_{\mathrm{j-1}} \right) \quad \text{only when} \quad \left(SWE_{\mathrm{j}} \geq SWE_{\mathrm{j-1}} \right)$$

where $SWE_{\mathrm{acc\,i}}$ is the total accumulated snowfall on day i of the winter season. The calculations are started on 1 December of each year, with the total on that date taken as the accumulation in the previous months. $SWE_{\mathrm{acc\,i}}$ increases monotonically throughout the winter season and reaches a maximum on or before 30 April, the last day for which daily volumes are available. It is clear that $SWE_{\mathrm{acc\,imax}} \geq SWE_{\mathrm{imax}}$, where $imax$ is the day on which the seasonal maximum SWE volume occurs. If SWE_j were a monotonically increasing with time, then $SWE_{acc\ imax}$ would be identical to SWE_{imax}. However, in the case of the Lake Superior watershed, the seasonal maximum SWE volume is related to, but always less than, the accumulated total SWE volume that occurred on the day of the seasonal maximum. In fact, SWE_{imax} is equal to 68% of $SWE_{acc\ imax}$ on average, indicating that, typically, there was considerable melting during the accumulation periods. Figure 14 plots SWE_{imax} against $SWE_{acc\ imax}$ for each year and SWE_{imax} against $SWE_{acc\ 30Apr}$, the accumulated total seasonal SWE volume on 30 April for year. The 30 April accumulated total can used to represent the accumulated total SWE volume for the entire winter season. The results are presented in terms of SWE depth in millimeters, found by dividing the total volume of SWE in cubic meters by the land area of the Lake Superior watershed.

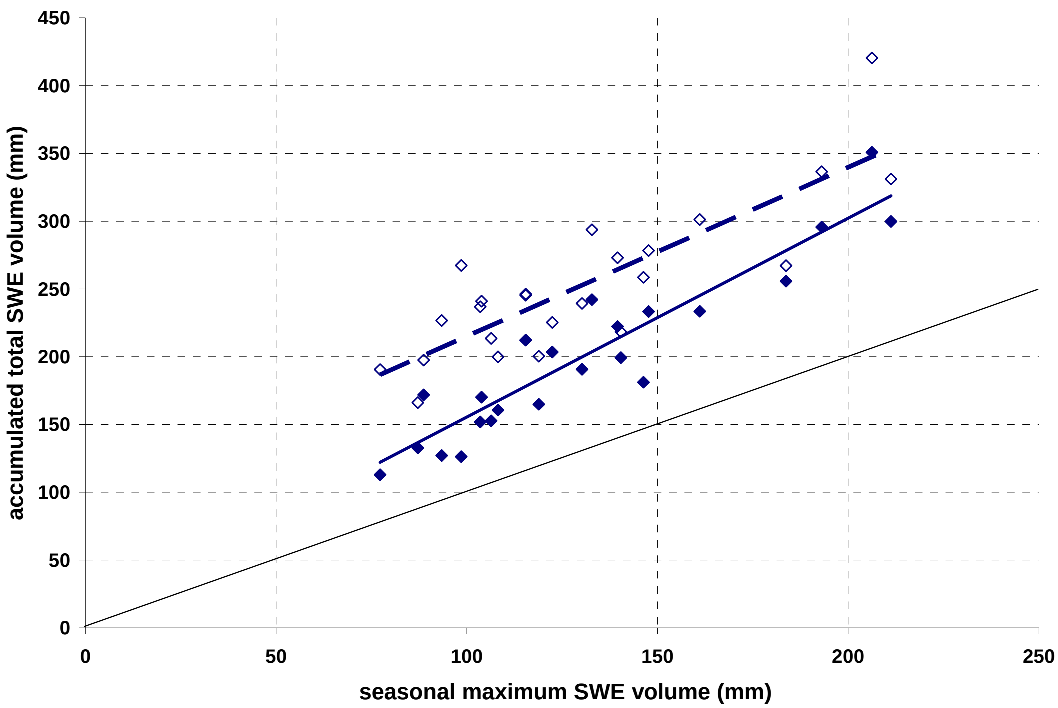


Figure 14. Accumulated SWE volume on the day of the maximum SWE volume (solid diamonds), and accumulated SWE volume on 30 April (open diamonds) plotted against the seasonal maximum SWE volume for each year.

The annual series of the seasonal maximum SWE is shown in Figure 15, along with the total snow accumulation that occurred up to and including the day of the maximum SWE volume, and the accumulated total seasonal SWE volume on 30 April each year. It can be seen that there is no overall trend in these values. The largest SWE volumes occurred in 1996 and 1997.

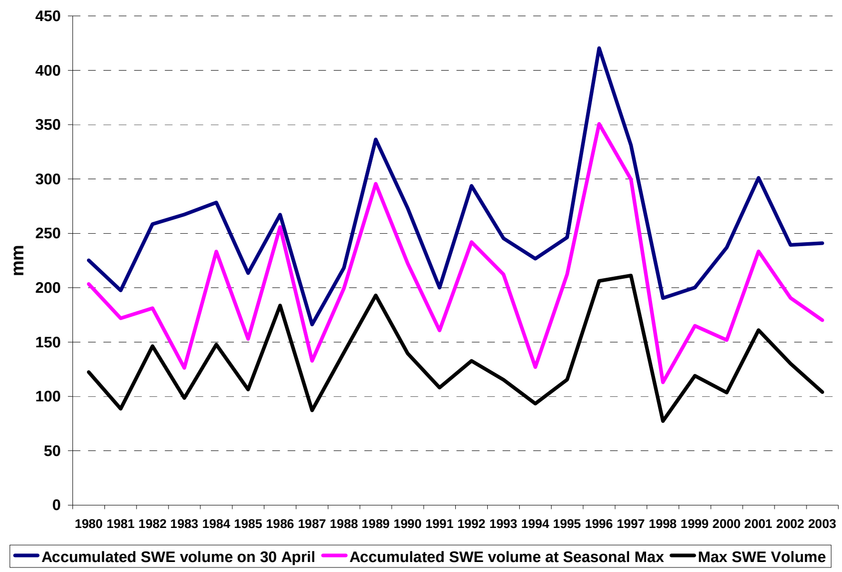


Figure 15. Maximum SWE volume, accumulated SWE volume on the day of the maximum SWE volume, and accumulated SWE volume on 30 April.

Lake Superior Sub-basins

Figure 16 displays the daily time series of SWE volume for the 22 Lake Superior sub-basins. The annual maximum SWE volume for each sub-basin for each year of the study is listed in Table 4a and b. The average annual maximum SWE volume and the average annual SWE depth for each sub-basin are listed in Table 1.

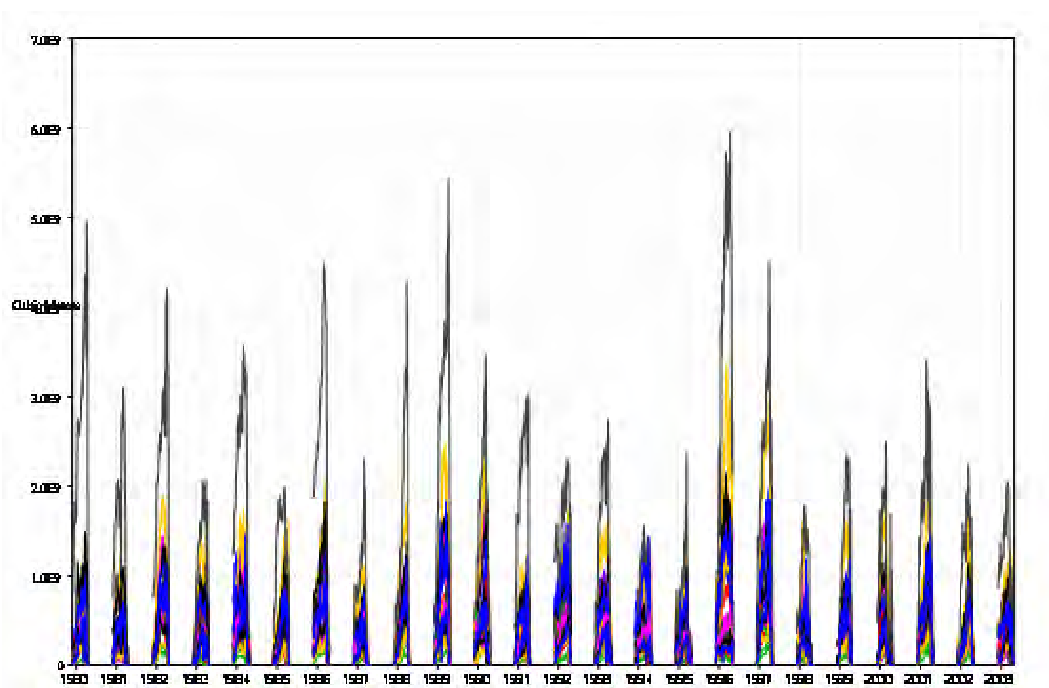


Figure 16. Daily SWE volume for the Lake Superior sub-basins.

Table 4. Total Lake Superior and sub-basins annual maximum. SWE × 10^8 (m^3) (maximum year in POR is in bold).

a. Sub-basins 1–11

Year	Basins											
	Total	1	2	3	4	5	6	7	8	9	10	11
1980	156.73	9.02	3.45	3.43	4.02	4.49	5.41	2.24	4.25	5.69	3.63	1.19
1981	113.53	3.78	1.79	2.40	3.98	4.43	3.74	2.06	4.22	7.24	4.13	1.59
1982	187.33	13.06	5.83	4.91	4.85	6.79	5.97	3.29	6.28	9.33	5.74	1.83
1983	126.14	12.55	6.31	6.25	5.15	5.87	5.29	3.79	4.70	4.58	1.93	0.85
1984	189.08	13.07	6.41	5.87	5.95	7.57	**9.76**	4.37	**11.23**	**14.61**	4.33	1.19
1985	136.17	8.59	3.86	4.44	5.46	6.61	6.05	4.39	6.00	8.39	4.92	1.76
1986	235.16	12.08	5.75	5.27	6.06	7.54	6.35	4.28	8.24	9.29	5.15	2.01
1987	111.61	6.32	2.78	3.18	2.94	3.51	2.82	1.84	2.55	3.44	2.39	0.87
1988	179.76	9.01	5.60	6.30	5.68	6.46	6.91	5.00	6.69	8.98	5.35	1.42
1989	247.15	**22.24**	**9.61**	**8.20**	**7.63**	8.87	7.26	4.42	5.85	6.44	4.86	1.79
1990	178.62	6.09	3.39	3.85	4.96	5.28	4.62	2.84	3.76	5.21	3.97	1.74
1991	138.49	9.55	5.71	5.58	5.31	4.44	4.22	2.91	3.48	5.26	2.58	0.71
1992	169.99	15.87	6.79	5.53	7.29	7.40	6.04	4.34	5.67	4.82	3.57	1.49
1993	147.76	10.55	4.35	3.87	4.11	5.22	5.89	3.39	4.98	4.79	4.04	1.03
1994	119.59	13.43	5.01	4.22	5.09	5.73	6.03	2.85	2.67	3.51	2.91	0.85
1995	147.79	9.65	4.57	3.55	4.11	4.67	3.85	2.52	3.48	3.49	2.14	1.68
1996	263.97	16.29	6.90	6.78	4.78	5.81	6.48	4.31	4.11	2.77	1.74	1.22
1997	**270.44**	19.58	9.18	7.51	6.30	8.16	7.59	**5.19**	8.33	10.81	**6.38**	**2.23**
1998	98.92	7.60	3.03	2.86	3.03	3.90	3.14	1.97	3.59	3.51	1.97	0.92
1999	152.22	6.80	4.33	4.21	5.61	6.90	5.66	3.64	5.86	6.50	2.92	1.32
2000	132.55	5.02	3.90	4.21	3.96	4.66	3.69	2.58	4.09	4.98	2.93	1.19
2001	206.21	14.30	7.95	6.52	7.51	6.92	7.61	4.71	7.03	8.94	4.60	1.70
2002	166.71	11.62	7.53	7.87	7.37	**8.92**	7.14	5.09	7.78	7.45	3.82	1.50
2003	133.02	5.87	3.57	3.91	4.60	5.63	5.72	3.18	5.03	7.11	4.58	1.64

b. Sub-basins 12–22.

Year	Basins										
	12	13	14	15	16	17	18	19	20	21	22
1980	9.91	7.52	11.56	10.19	10.23	8.05	3.78	49.51	7.48	14.93	8.76
1981	12.57	10.04	12.58	7.44	4.15	3.06	1.34	30.97	3.58	10.98	5.47
1982	14.30	14.46	19.18	13.38	9.66	10.37	2.97	42.17	5.73	11.16	11.37
1983	8.83	8.45	14.65	11.18	8.98	6.70	1.70	22.76	3.90	8.91	8.97
1984	13.90	12.49	17.47	11.30	8.61	7.52	2.45	35.77	4.67	8.20	8.97
1985	10.18	8.78	16.29	12.37	7.51	5.22	1.53	24.72	4.04	7.55	8.61
1986	**18.76**	16.16	20.34	18.27	12.82	**10.61**	3.54	44.84	10.35	16.10	10.39
1987	6.46	6.88	11.33	8.98	8.13	3.37	1.39	23.09	3.43	4.96	5.15
1988	10.38	12.20	18.02	13.77	11.96	8.69	2.80	42.90	4.45	5.77	7.69
1989	15.40	16.51	24.70	16.99	12.66	9.69	3.78	54.29	9.47	16.12	16.84
1990	16.94	16.63	23.22	17.94	**14.06**	9.57	3.42	34.67	6.53	9.04	7.12
1991	9.36	9.27	12.24	9.99	7.59	5.74	2.69	30.36	6.58	8.58	12.06
1992	11.40	11.78	17.14	12.09	9.97	6.82	1.08	23.04	3.99	11.43	15.82
1993	8.73	10.32	16.76	12.46	9.11	7.73	2.76	27.46	5.75	9.69	8.85
1994	10.51	12.94	13.68	6.33	3.97	3.55	1.40	15.58	3.68	6.89	14.28
1995	9.15	11.63	16.38	11.07	7.82	6.20	1.55	23.73	4.75	10.77	9.34
1996	16.63	**19.74**	**33.54**	**19.51**	12.28	9.85	**4.79**	**59.68**	**13.16**	**21.46**	16.68
1997	13.96	17.57	29.47	15.94	10.56	8.73	3.51	45.05	9.14	14.15	**18.59**
1998	8.23	10.82	16.04	5.05	3.13	2.63	1.17	17.86	3.49	6.13	11.98
1999	10.20	10.41	16.03	9.50	6.41	5.40	1.81	23.57	5.49	10.14	11.74
2000	9.42	11.44	21.15	12.12	7.93	6.55	2.17	25.03	4.64	6.49	5.49
2001	11.20	13.57	23.95	13.70	9.76	8.13	2.91	34.02	7.46	12.38	14.54
2002	9.50	10.36	16.45	11.46	6.55	3.98	1.57	22.47	3.84	5.93	9.54
2003	10.89	8.52	12.37	9.91	6.97	4.24	1.35	20.46	3.01	5.07	5.95

Figure 17 displays the annual maximum SWE volume converted to a depth in millimeters, and shows that the range of annual maximums depths can vary from year to year. It is interesting to note that the years of maximum SWE for the Lake Superior basin, 1996 and 1997, do not necessarily have the maximum SWE depths for the sub-basins. The maximum years are 1996 and 1997 because nearly all the sub-basins had large SWE values but only twelve sub-basins had record high values in those two years. In absolute terms, 1984 had the largest sub-basin SWE depths on record, but in that year only three sub-basins had record values and many had relatively modest SWE depths.

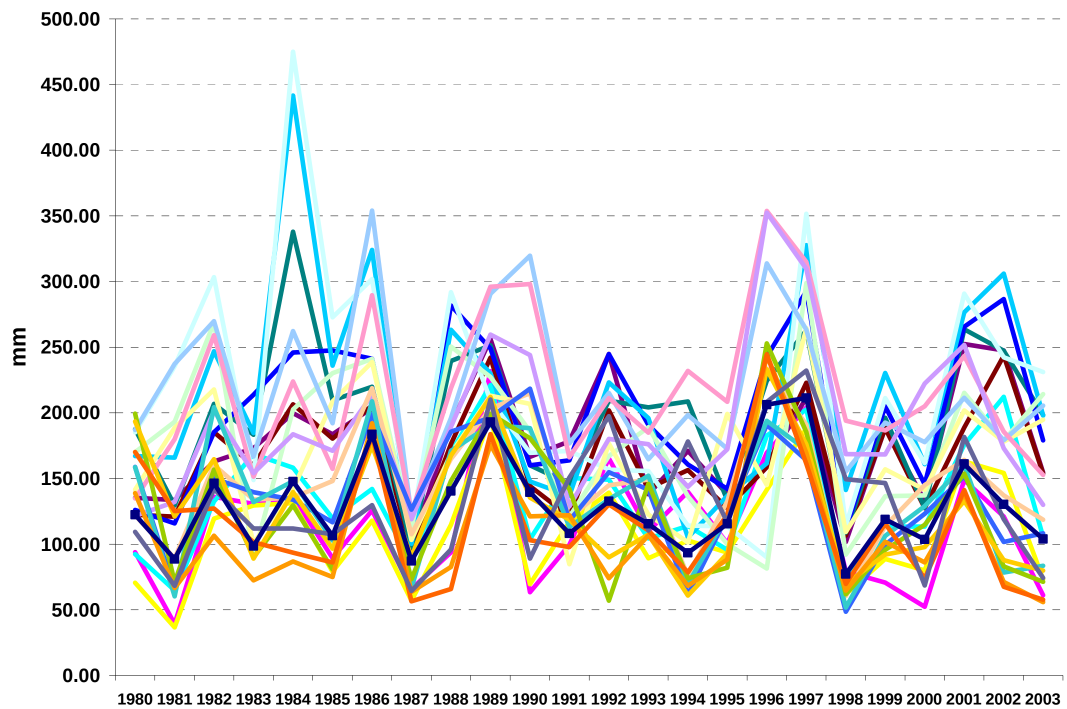


Figure 17. Maximum SWE volume in mm for all 22 Lake Superior sub-basins. The line with rectangular markers is for the entire Lake Superior watershed.

The average SWE depth for each sub-basin is displayed in Figures 18 and 19, along with the standard deviation of the SWE depths. Sub-basins 6, 7, 8, and 9 along the south coast of Lake Superior in Michigan's Upper Peninsula have the largest average SWE depths along with sub-basins 12 and 13, which are at the eastern end of Lake Superior in Ontario, Canada, with sub-basin 12 abutting the United States. Lake effect snows probably account for the larger average SWE depths in all cases. The average day of year when the maximum SWE volume occurs is generally in early to mid-March for all the sub-basins, with the most northern basins—16, 17, and 18—occurring later. There is also a tendency for sub-basins located in the western end of the watershed to reach their maximums earlier in the winter.

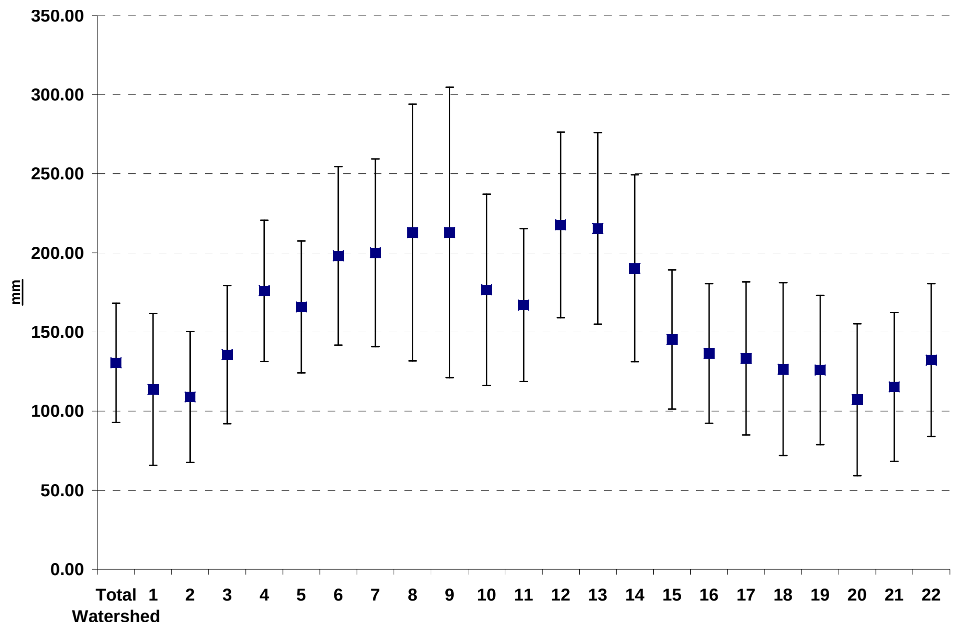


Figure 18. Average and standard deviation of the maximum volume of SWE for the total Lake Superior watershed and the 22 sub-basins.

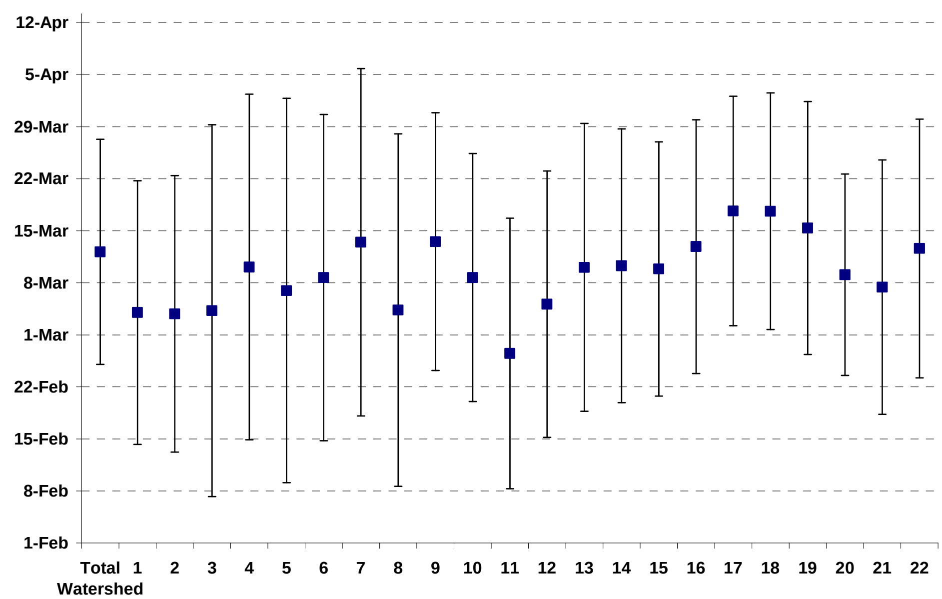
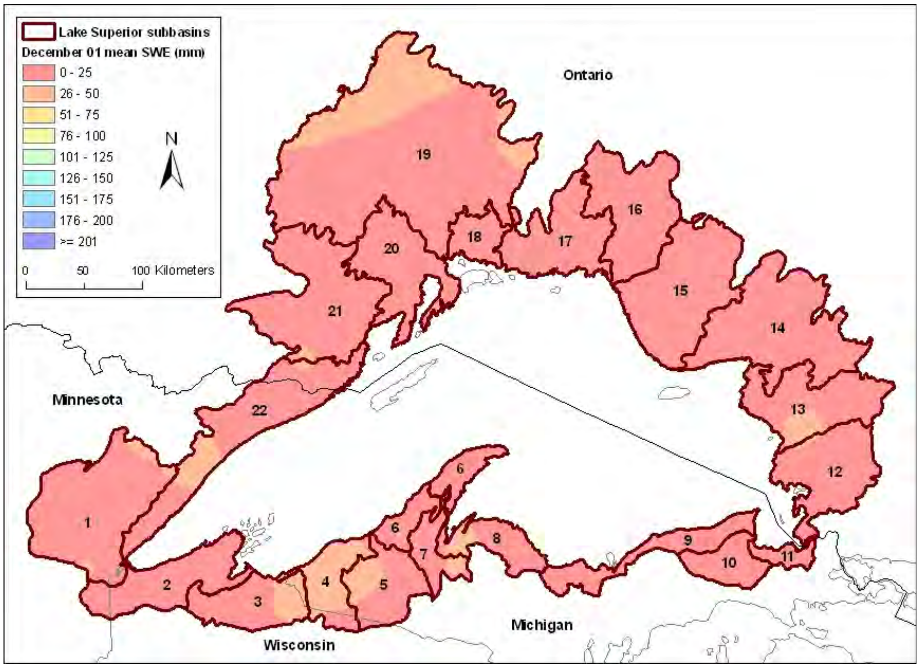


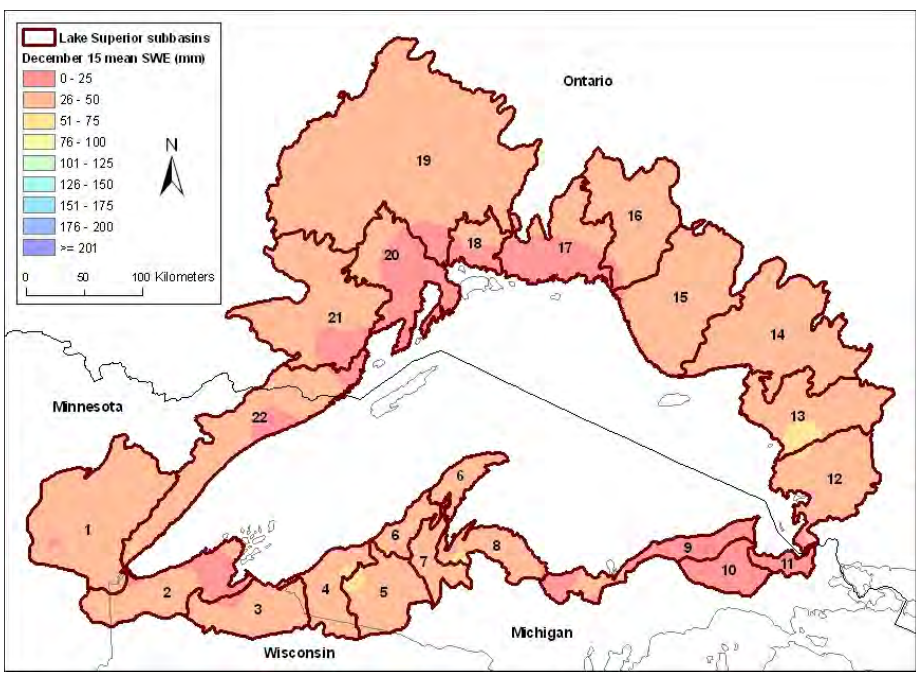
Figure 19. Average day of year and standard deviation of the maximum volume of SWE for the total Lake Superior watershed and the 22 sub-basins.

Mean SWE Maps

To estimate the areal distribution of SWE throughout the winter, a grid representing the mean SWE for the 1st and 15th of each winter month was calculated. First all the daily grids that represented 1 December of each year were collected from 1979-2002 and then were averaged on a cell by cell basis. A map was then created to present the final mean results. This process was then repeated for the 15th of December, 1st of January (using the years 1980-2003), etc, through the 15th of April. The end result was a series of maps displaying the mean SWE for the 1st and 15th of each month. (Fig. 20).

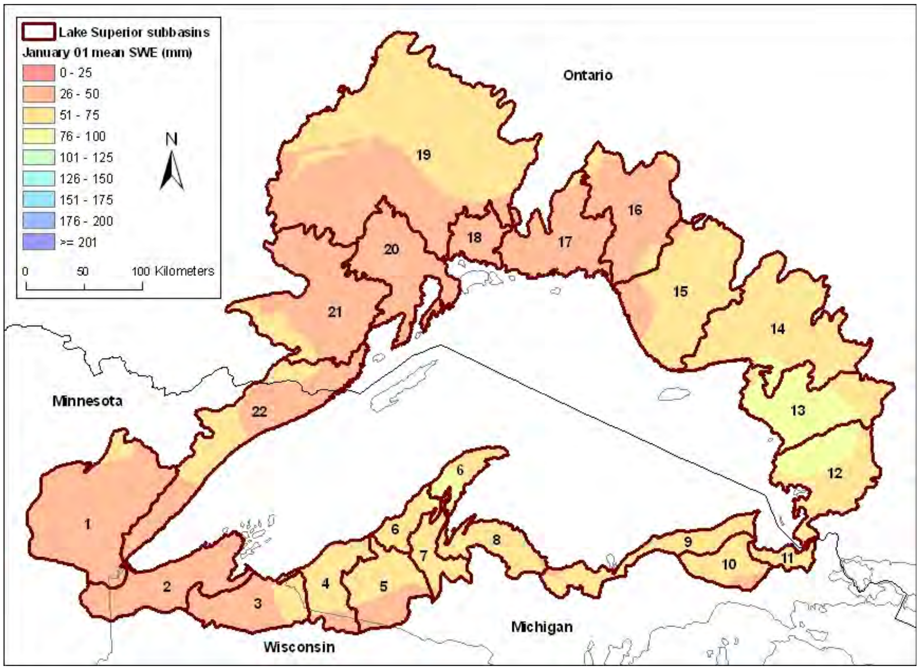


a. 1 December.

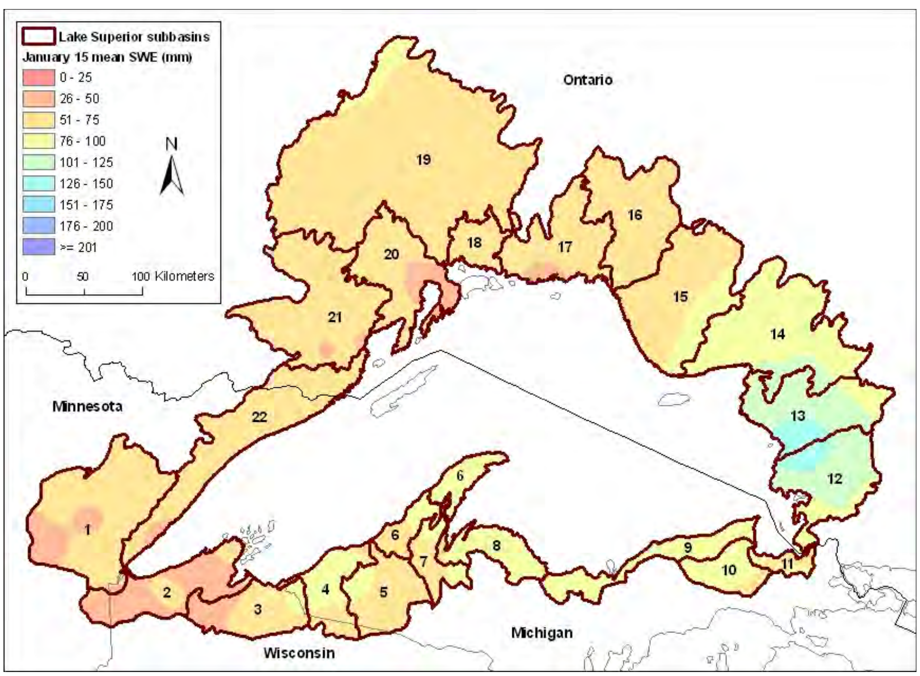


b. 15 December.

Figure 20. Mean SWE Distribution for the entire Lake Superior watershed for the 1st and 15th of each month throughout the winter season.

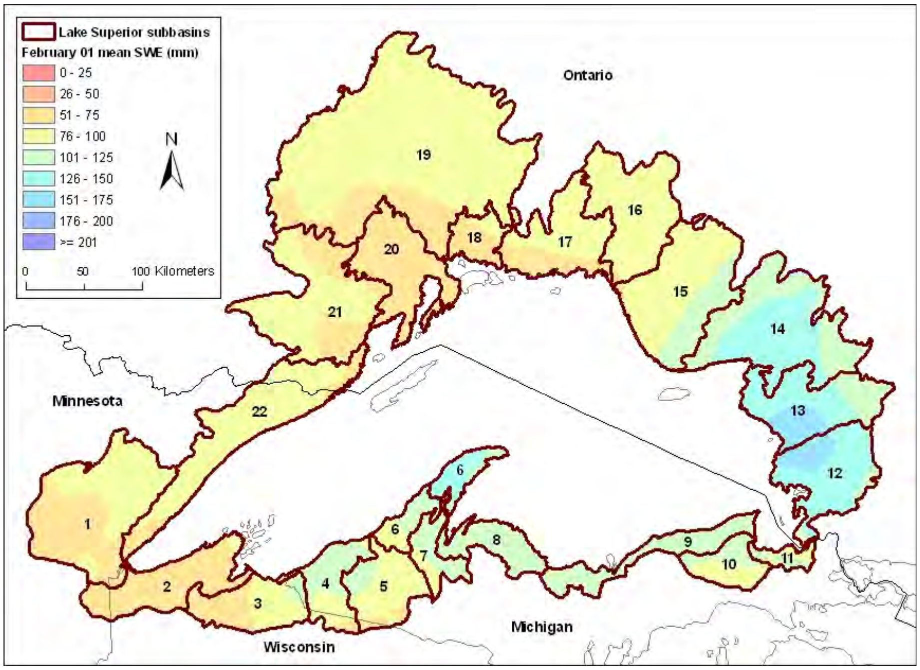


c. 1 January.

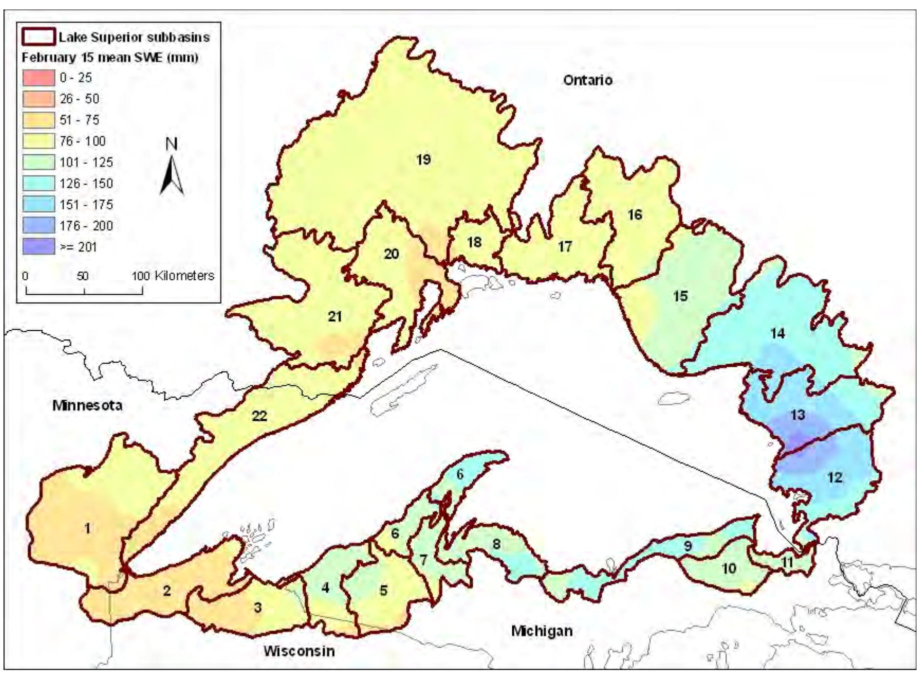


d. 15 January.

Figure 20 (cont'd). Mean SWE Distribution for the entire Lake Superior watershed for the 1st and 15th of each month throughout the winter season.

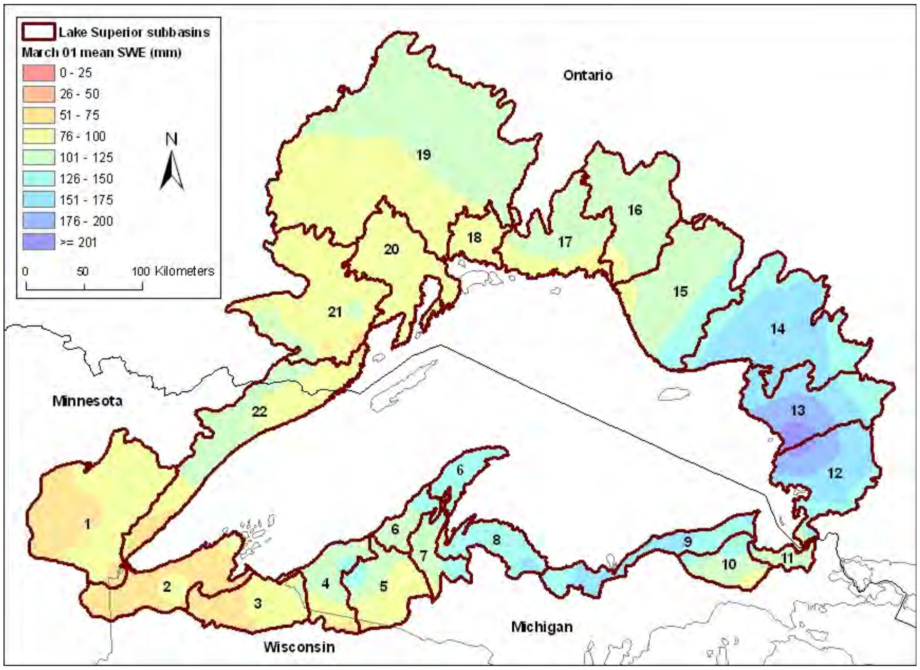


e. 1 February.

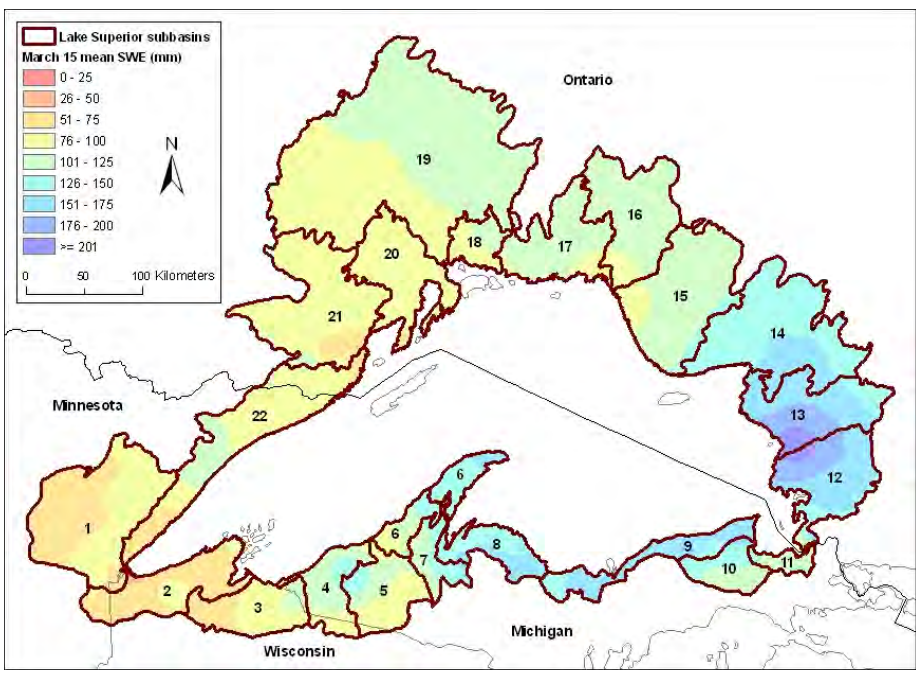


f. 15 February.

Figure 20 (cont'd). Mean SWE Distribution for the entire Lake Superior watershed for the 1st and 15th of each month throughout the winter season.

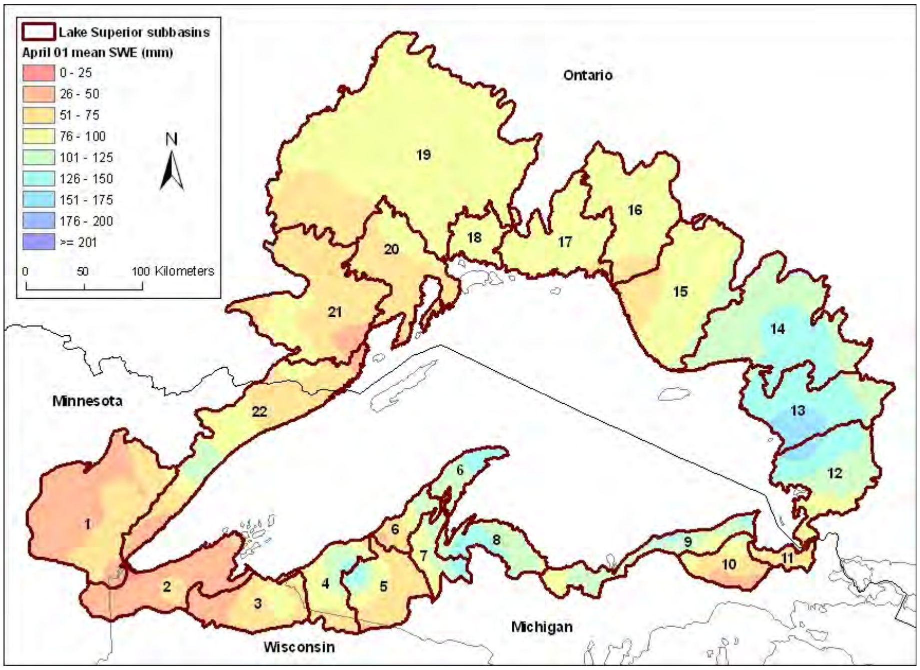


g. 1 March.

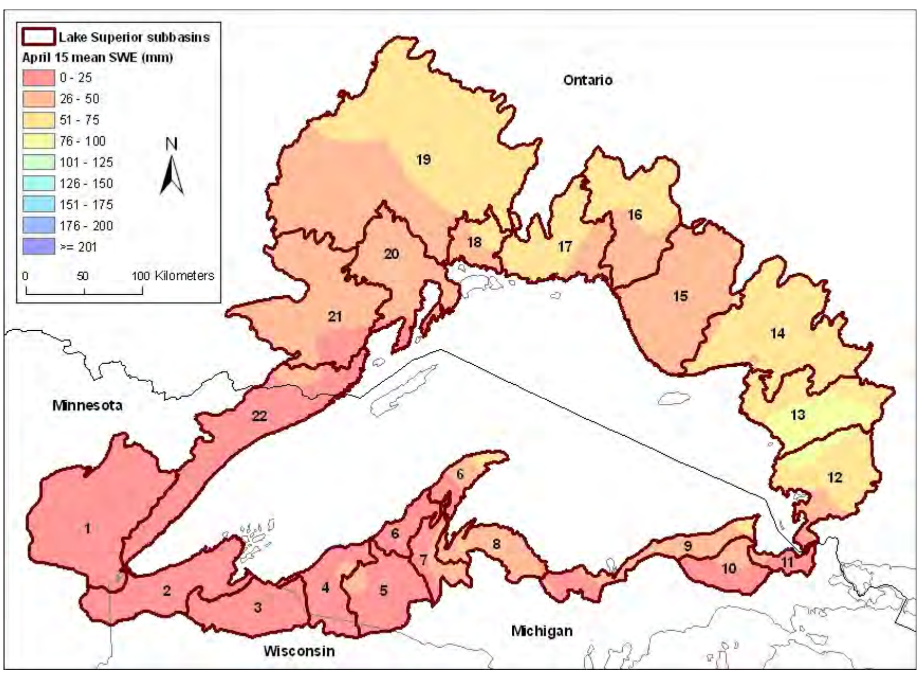


i. 15 March.

Figure 20 (cont'd). Mean SWE Distribution for the entire Lake Superior watershed for the 1st and 15th of each month throughout the winter season.



j. 1 April.



k. 15 April.

Figure 20 (cont'd). Mean SWE Distribution for the entire Lake Superior watershed for the 1st and 15th of each month throughout the winter season.

7 Summary

This report investigated the historical spatial and temporal distribution of snow water equivalent (SWE) in the Lake Superior watershed using ground based measurements and GIS techniques. This report covers the winter seasons from the 1979–80 through 2002–03. Each winter season covered the period from 1 December through 30 April. These estimates were made on the basis of numerous ground-based daily observations collected and compiled by the National Weather Service (NOAA 2001, 2005) in the United States and compiled by the Meteorological Service of Canada (MSC 2000). The large majority of the observations were daily measurements of snow depth and not SWE. To make maximum use of the available snow observations, the SWE at each of these stations was estimated from the observed snow depth and an estimated snow density. Different procedures were used to estimate the snow density in the U.S. and in Canada because of the very different observation protocols that were followed in each country. In both cases, if no observations of snow density were available within a specified distance and window of time around the snow depth observation, the long term monthly snow density was used. The long-term monthly snow density was estimated on the basis of historical data included in this study. Once the daily SWE had been estimated at every station, the results could be interpolated throughout the Lake Superior watershed using inverse distance weighting. The end result was a series of gridded estimates of the daily SWE distribution covering the period of the study.

These gridded estimates of SWE were then used to estimate the total volume of SWE for each of the Lake Superior sub-basins and the entire watershed for each day between 1 December and 30 April for 1980 through 2003. These results were then used to analyze the Lake Superior watershed seasonal snow cover. Results include determining the annual accumulation and melt period characteristics, the annual series of maximum SWE volume, and comparing the annual maximum SWE volume with the incremental accumulated SWE volume. Selected results are also shown for the individual sub-basins. Maps were also prepared of the mean SWE distributions on the 1st and 15th day of each month.

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APPENDIX A: SWE Stations in the U.S.

STATION ID	STATION NAME	START YEAR	END YEAR	LAT	LONG	ELEV (m)
207366	SAULT STE MARIE WSO	1979	1994	46.487	−84.403	220.1
212248	DULUTH INTL AP	1979	2004	46.837	−92.183	436.8

APPENDIX B: Snow Depth Stations in the U.S.

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
200089	ALBERTA FORD FOR CEN	1957	1997		46.650	–88.483	399.3
200197	AMASA 1 W	1999	2004		46.235	–88.454	448.1
200485	BARAGA	1967	1987	*	46.783	–88.483	195.1
200647	BEECHWOOD 7 WNW	1949	1990		46.183	–88.883	506.0
200718	BERGLAND DAM	1948	2004		46.587	–89.548	396.2
200770	BIG BAY 2 SE	1965	1999		46.798	–87.707	198.1
201439	CHAMPION VAN RIPER P	1949	2004		46.519	–87.986	487.4
201484	CHATHAM EXPERIMENT F	1948	1988		46.350	–86.933	268.2
201486	CHATHAM EXP FARM 2	1987	2004		46.347	–86.929	265.2
201777	COPPER HARBOR 3 WNW	1979	1984		47.483	–87.950	192.0
201780	COPPER HARBOR FT WIL	1948	2004	*	47.468	–87.867	190.5
201800	CORNELL 4 WSW	1963	1991		45.883	–87.300	268.2
201802	CORNELL 5 SE	1991	2004		45.827	–87.159	243.5
201922	CRYSTAL FALLS 6 NE	1948	1989	*	46.167	–88.233	414.5
202094	DETOUR VILLAGE	1948	2004		45.998	–83.901	181.4
202298	DUNBAR FOREST EXP ST	1948	1990		46.317	–84.233	182.9
202626	ESCANABA	1948	2004	*	45.750	–87.033	180.1
203319	GRAND MARAIS 2 E	1948	2004		46.667	–85.950	190.2
203639	HARVEY	2002	2004		46.491	–87.355	missing
203744	HERMAN	1968	2004		46.667	–88.350	530.4
203908	HOUGHTON FAA AIRPORT	1952	2000		47.168	–88.489	327.4
203917	HOUGHTON MTU	1993	2003		47.117	–88.550	259.1
204104	IRONWOOD	1948	2004		46.467	–90.183	435.9
204127	ISHPEMING	1948	1987		46.483	–87.650	438.9
204328	KENTON	1948	2002	*	46.483	–88.883	355.7
205073	MANISTIQUE	1948	2004		45.951	–86.251	189.0
205178	MARQUETTE	1948	2004		46.550	–87.383	202.7
205184	MARQUETTE WSO AP	1959	2004	*	46.531	–87.549	431.3
205637	MOTT ISLAND ISLE ROY	1948	2004	*	48.100	–88.550	185.9
205690	MUNISING	1948	2004		46.412	–86.663	207.3
205759	NAUBINWAY 6 E	2000	2000		46.091	–85.322	179.5
205816	NEWBERRY 3 S	1948	2004		46.313	–85.511	259.1
206220	ONTONAGON 6 SE	1977	2004		46.833	–89.200	240.8
206686	PORT INLAND	1953	1989		45.967	–85.867	185.9
207068	ROCK 1 E	1948	1990		46.067	–87.150	286.5
207190	RUDYARD 4N	1978	2004		46.296	–84.576	229.8

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
207274	ST IGNACE MACKINAC B	1974	2004		45.849	–84.723	181.4
207277	ST JAMES 4SSW BEAVER	1952	2004	*	45.691	–85.546	204.8
207364	SAULT STE MARIE	1998	2004		46.487	–84.403	192.0
207366	SAULT STE MARIE SNDR	1948	2000	*	46.479	–84.357	220.1
207515	SENEY WILDLIFE REFUG	1961	2000		46.283	–85.950	216.4
207812	STAMBAUGH 2 SSE	1948	2004		46.056	–88.628	442.0
207880	STEUBEN	1948	1989		46.183	–86.467	225.6
208043	TAHQUAMENON FALLS ST	1968	2004		46.601	–85.224	227.1
208293	TROUT LAKE 2 WNW	1948	2004	*	46.199	–85.073	265.5
208680	WATERSMEET 5 W	1948	1999		46.289	–89.284	495.3
208920	WHITEFISH POINT	1952	2004		46.753	–84.979	184.4
210059	AITKIN 2E	1948	2004		46.534	–93.703	370.3
210387	BABBITT	1999	2004		47.710	–91.944	454.8
210390	BABBITT 2 SE	1948	1986		47.683	–91.917	192.0
210754	BIGFORK 5 ESE	1948	1980	*	47.700	–93.550	430.1
210989	BRIMSON 1E	1948	2004	*	47.285	–91.858	461.8
211074	BRUNO 7ENE	1990	2004		46.301	–92.541	257.6
211630	CLOQUET	1949	2004		46.705	–92.525	385.6
211771	COOK	1999	2004		47.851	–92.693	413.0
211773	COOK 12 W	1997	1999		47.879	–92.933	399.9
211776	COOK 18 W	1959	1995		47.867	–93.067	400.8
211840	COTTON	1962	2002		47.170	–92.467	405.1
212246	DULUTH HARBOR STA	1960	1997		46.768	–92.090	185.9
212248	DULUTH INTL AP	1948	2004		46.837	–92.183	436.8
212543	ELY	1997	2004		47.924	–91.859	421.2
212555	ELY 25 E	1998	2004		47.975	–91.456	425.2
212576	EMBARRASS	1994	2004		47.658	–92.196	426.7
212645	EVELETH WASTE WATER	1986	2004		47.458	–92.530	440.4
212842	FLOODWOOD 3 NE	1986	2004		46.973	–92.870	384.0
213282	GRAND MARAIS	1948	2004		47.739	–90.361	186.5
213296	GRAND PORTAGE RNG ST	1958	2004	*	47.971	–89.691	222.5
213303	GRAND RAPIDS FORESTR	1948	2004		47.244	–93.498	399.3
213417	GUNFLINT LAKE 10 NW	1961	2004	*	48.160	–90.877	443.5
213727	HIBBING POWER SUBSTN	1948	1981	*	47.433	–92.967	467.0
213730	HIBBING FAA AIRPORT	1962	2000		47.387	–92.839	410.6
213793	HINCKLEY	1948	2004		45.992	–92.993	315.5
213921	HOYT LAKES 5 N	1958	1984		47.583	–92.133	463.9
214068	ISABELLA 1 W	1957	2004	*	47.618	–91.375	612.6
214096	ISLAND LAKE RESERVOI	1948	1995	*	46.983	–92.233	418.2
214918	LUTSEN 3NNE	1986	2004		47.698	–90.666	396.2

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
215175	MARCELL 5 NE	1981	2004	*	47.631	–93.652	422.8
215298	MEADOWLANDS 9 S	1948	1985		46.983	–92.733	386.8
215598	MOOSE LAKE 1 SSE	1948	2004		46.438	–92.758	338.3
216612	POKEGAMA DAM	1948	2004		47.251	–93.586	390.1
216849	REMER NO 2	1957	2000	*	47.062	–93.915	410.0
216929	RICE LAKE NWR	1992	2004		46.538	–93.284	381.0
217460	SANDY LAKE DAM LIBBY	1948	2004		46.795	–93.321	376.1
218307	TOWER DNR	1994	2004		47.794	–92.279	432.8
218311	TOWER 3 S	1948	2004		47.755	–92.286	445.0
218419	TWO HARBORS	1948	2004		47.026	–91.665	190.5
218421	TWO HARBORS 7 NW	1998	2004		47.125	–91.707	413.0
218543	VIRGINIA	1948	1987	*	47.500	–92.550	438.9
218939	WHITEFACE RESERVOIR	1948	1995	*	47.283	–92.183	454.8
219101	WINTON POWER PLANT	1948	1995	*	47.933	–91.767	407.5
219134	WOLF RIDGE E L C	1993	2004		47.450	–91.217	426.7
219173	WRIGHT 4 NW	1961	2004		46.718	–93.070	394.7
470347	ASHLAND 3 S	1998	2004		46.552	–90.916	251.8
470349	ASHLAND EXP FARM	1948	2004		46.573	–90.971	198.1
470603	BAYFIELD 6 N	1948	2004		46.883	–90.817	249.9
471131	BRULE R S	1948	2004		46.538	–91.592	304.8
471139	BRULE ISLAND	1948	1989		45.950	–88.217	381.0
471155	BUCKATABON	1948	2004		46.023	–89.308	502.9
471249	BUTTERNUT 3 N	1997	2004		46.054	–90.522	474.6
471618	CLAM LAKE 10SW	1998	2004		46.046	–91.070	419.7
471847	COUDERAY 7 W	1948	2004	*	45.800	–91.459	396.2
471978	DANBURY	1948	2004		46.008	–92.370	281.9
472240	DRUMMOND	1948	2004	*	46.333	–91.267	408.4
472314	EAGLE RIVER	1948	2004	*	45.909	–89.253	501.4
472814	FLAMBEAU RESERVOIR	1948	1981		46.067	–90.233	478.8
472826	FLORENCE	1997	2004		45.925	–88.257	397.8
472889	FOXBORO	1963	2004	*	46.486	–92.288	284.1
473186	GORDON	1951	2004		46.245	–91.805	317.0
473332	GURNEY	1952	2004		46.474	–90.511	295.7
473511	HAYWARD RANGER STA	1948	2004		46.000	–91.508	365.8
473636	HILES	1999	2004		45.681	–88.960	497.7
473800	HURLEY	1987	2004		46.462	–90.193	295.7
474383	LAC VIEUX DESERT	1948	2004		46.121	–89.119	515.1
474829	LONG LAKE DAM	1948	2001		45.888	–89.139	496.8
474953	MADELINE ISLAND	1948	2004		46.783	–90.767	201.2
475286	MELLEN 4 NE	1948	2004		46.369	–90.642	396.2

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
475516	MINOCQUA DAM	1948	2004		45.875	–89.728	481.6
475525	MINONG 5 WSW	1961	2004	*	46.067	–91.867	327.7
475863	NEWALD 4 N	1959	1996		45.783	–88.700	469.4
476122	NORTH PELICAN	1948	2004		45.636	–89.242	490.7
476398	PARK FALLS DNR HQ	1948	2004		45.934	–90.451	464.8
476413	PATTISON STATE PARK	1998	2004		46.537	–92.119	335.3
476518	PHELPS	1948	2004		46.066	–89.076	541.3
476772	PORT WING	1948	2004	*	46.778	–91.386	198.4
476939	RAINBOW RSVR-LK TOMA	1948	1996		45.834	–89.549	487.7
477092	REST LAKE	1948	2004		46.121	–89.876	490.7
477113	RHINELANDER	1948	2004		45.622	–89.423	481.6
477115	RHINELANDER 4 NE	2001	2004		45.646	–89.305	483.1
477480	ST GERMAIN 2 E	1971	2004		45.907	–89.436	501.4
477892	SOLON SPRINGS	1948	2004		46.350	–91.817	329.2
478288	SUGAR CAMP	1948	2003		45.865	–89.382	489.2
478349	SUPERIOR	1948	2004		46.700	–92.017	192.0
478478	THREE LAKES 10 SE	1948	1997	*	45.713	–89.003	524.3
478750	UPSON	1998	2004		46.368	–90.412	456.3
479012	WEBSTER 9 SE	1998	2004		45.788	–92.233	306.3
479236	WILLOW RESERVOIR	1948	2004		45.709	–89.853	475.5
479304	WINTER	1948	2004		45.823	–91.014	425.8

*Indicates non-continuous record.

APPENDIX C: SWE Stations in Canada

STATION ID	STATION NAME	LAT	LONG	ELEV (m)	START YR	END YR		ACTUAL START	ACTUAL END
ONR-0608	ADAMSVILLE	44.8667	−81.1667	229.0	1981	1982		27-Nov-81	2-Apr-82
ONR-0609	COLPOY BAY 2	44.8000	−81.1667	213.0	1982	2003		1-Dec-82	16-Feb-04
ONR-1401	HAZELWOOD L	48.5833	−89.3000	442.0	1973	2003		9-Feb-73	16-Feb-04
ONR-1501	THUNDER BAY	48.4667	−89.2500	244.0	1973	2003		9-Feb-73	16-Feb-04
ONR-1601	ROSSLYN	48.3833	−89.4333	229.0	1973	2003		9-Feb-73	16-Feb-04
ONR-1701	FORT CREEK	46.5333	−84.3500	213.0	1973	1981		4-Feb-73	15-Apr-81
ONR-1702	SHERWOOD FOR	46.5500	−84.3500	229.0	1973	1980		4-Feb-73	15-Dec-80
ONR-1703	FOURTH LINE	46.5667	−84.3333	243.0	1980	2003		15-Dec-80	16-Feb-04
ONR-1801	RED PINE	46.5833	−84.2833	282.0	1973	2003		4-Feb-73	16-Feb-04
ONR-1802	WISHART PARK	46.5667	−84.2833	221.0	1973	1980		4-Feb-73	15-Dec-80
ONR-1901	W. CEMETARY	46.5667	−84.4000	229.0	1973	1980		6-Feb-73	1-Apr-80
ONR-1902	EAST KORAH	46.5500	−84.4000	221.0	1973	2003		18-Dec-73	16-Dec-03
ONR-1903	E.DAVIGON CR	46.5500	−84.3667	198.0	1980	1981		14-Dec-79	15-Apr-81
ONR-1904	BENNET CR	46.5333	−84.4000	191.0	1980	1981		14-Dec-79	15-Apr-81
ONR-1905	BRULE ROAD	46.5833	−84.3667	274.0	1980	2003		15-Dec-80	16-Dec-03
ONR-1906	LEIGH'S BAY	46.5500	−84.3667	198.0	1980	2003		15-Dec-80	2-Dec-03
ONR-1907	WALLS ROAD	46.5000	−84.5167	213.0	1980	2003		15-Dec-80	16-Dec-03
ONR-6001	MARTEN RIVER	46.7333	−79.8000	305.0	1980	2003		1-Mar-80	15-Apr-03
ONR-6002	AFTON	46.9667	−80.3333	351.0	1980	2003	*	14-Mar-80	15-Apr-03
ONR-6003	DANA TWP	46.7000	−80.2833	259.0	1981	2003	*	13-Jan-81	15-Apr-03
ONR-6004	FELIX	47.2333	−81.4000	411.0	1981	2003	*	2-Mar-81	15-Apr-03
ONR-6007	THOR LAKE	47.1000	−81.2667	427.0	1989	1989		1-Mar-89	1-May-89
ONR-6008	GIBBONS TWP	46.5500	−80.0667	256.0	1989	2003	*	3-Mar-89	15-Apr-03
ONR-6101	CHAUDIERE D	46.1167	−80.0333	198.0	1981	2003	*	15-Dec-81	16-Dec-03
ONR-6102	BURWASH	46.2667	−80.7500	241.0	1987	1989		16-Feb-87	1-May-89
ONR-6201	GORDON CHUTE	46.4833	−81.9667	366.0	1980	1986		4-Mar-80	14-Mar-86
ONR-6202	SEARCHMONT	46.8167	−84.0000	281.0	1983	2003		28-Feb-83	16-Dec-03
ONR-6203	RITCHIE FALL	46.7667	−82.2833	465.0	1985	1993		16-Dec-85	1-May-93
ONR-6301	TEMAGAMI	47.0500	−79.8167	298.0	1982	2003	*	15-Jan-82	15-Apr-03
ONR-6302	HERRIDGE	46.9833	−79.8000	321.0	1987	1988		15-Dec-87	15-Apr-88
ONR-6401	MCFARLANE LAKE	46.4167	−80.9500	230.0	1982	1993		1-Feb-82	30-Dec-93
ONR-6402	CAPREOL PARK	46.7167	−80.9500	310.0	1982	2003		14-Dec-82	1-Apr-03
ONR-6403	NIKLEDALE	46.5333	−80.9833	270.0	1982	1984		15-Dec-82	15-Apr-84
ONR-6404	OFFSET RD.	46.6500	−81.2167	270.0	1982	1997		15-Dec-82	16-Dec-97
ONR-6405	STOBIE DAM	46.5333	−81.2833	260.0	1982	2003		15-Dec-82	1-Apr-03
ONR-6406	ESTAIRE	46.3000	−80.8167	250.0	1991	2003	*	1-Mar-91	2-Jan-03

STATION ID	STATION NAME	LAT	LONG	ELEV (m)	START YR	END YR		ACTUAL START	ACTUAL END
ONR-6407	GARSON	46.5167	−80.8500	missing	1998	2003		3-Feb-98	1-Apr-03
ONR-6501	DUMP CAMP	46.6500	−82.8167	320.0	1980	1986		5-Mar-80	28-Feb-86
ONR-6502	COBRA LAKE	46.7667	−83.8333	412.0	1986	1996	*	1-Apr-86	28-Mar-96
SCD-MB170	VASSAR D-9	49.0833	−95.8333	360.0	1962	1985	*	14-Feb-62	12-Mar-85
SCD-MB184	WEST HAWK LAKE D-5	49.7333	−95.2167	335.0	1962	1985		12-Feb-62	11-Mar-85
SCD-MB186	WHITEMOUTH D-3	49.2833	−95.9500	287.0	1962	1985		12-Feb-62	11-Mar-85
SCD-ON001	ABITIBI CANYON	49.9167	−81.5667	229.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON003	ADAMSVILLE	44.8667	−81.1667	222.0	1976	1980		15-Dec-76	15-Apr-78
SCD-ON005	AFTON	46.9667	−80.3333	351.0	1980	1985		14-Mar-80	22-Apr-85
SCD-ON006	ALBERMARLE	44.8667	−81.1667	229.0	1981	1982		27-Nov-81	2-Apr-82
SCD-ON011	ARMSTRONG	50.2833	−89.0333	351.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON018	ATIKOKAN	48.7500	−91.6167	393.0	1956	1988		5-Jan-56	1-Apr-88
SCD-ON019	AUBREY FALLS	46.8500	−83.2833	396.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON036	BENNET CR	46.5333	−84.4000	191.0	1980	1981		15-Dec-80	15-Apr-81
SCD-ON041	BISCOTASING	47.3000	−82.1000	411.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON047	BOLANDS BAY	46.6333	−81.7667	305.0	1961	1985		1-Jan-63	15-Apr-85
SCD-ON049	BONIS EADES STATION	48.9333	−79.9333	269.0	1956	1985	*	31-Jan-56	1-Apr-85
SCD-ON061	BRULE ROAD	46.5833	−84.3667	274.0	1980	1985		15-Dec-80	16-Apr-85
SCD-ON065	CAMERON FALLS	49.1333	−88.3833	238.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON071	CAPREOL PARK	46.7167	−80.9500	310.0	1982	1985		1-Dec-82	15-Apr-85
SCD-ON077	CHALLIES WHITE WATER	49.1167	−80.1667	missing	1965	1985		3-Jan-85	1-Apr-85
SCD-ON078	CHAPLEAU	47.8167	−83.4000	427.0	1956	1985		1-Jan-56	15-Apr-85
SCD-ON079	CHAUDIERE DAM HARDY	46.1167	−80.0333	198.0	1981	1985		15-Dec-81	22-Apr-85
SCD-ON087	COLPOY BAY	44.8000	−81.1667	213.0	1976	1985	*	15-Dec-76	2-Apr-84
SCD-ON104	DINORWIC	49.7000	−92.5000	379.0	1956	1984	*	1-Mar-56	5-Mar-84
SCD-ON106	DOG LAKE DAM	48.7000	−89.6167	427.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON107	DUMP CAMP BRIDGE	46.6500	−82.8167	320.0	1981	1985		1-Feb-81	17-Mar-85
SCD-ON110	E DAVIGNON CR	46.5500	−84.3667	198.0	1980	1981		14-Dec-79	15-Apr-81
SCD-ON112	EAR FALLS	50.6333	−93.1833	366.0	1956	1985		1-Jan-56	15-Apr-85
SCD-ON113	EAST KORAH	46.5500	−84.4000	221.0	1973	1985		18-Dec-73	16-Apr-85
SCD-ON123	FELIX	47.2333	−81.4000	411.0	1981	1985		2-Mar-81	23-Apr-85
SCD-ON126	FIELD	46.3667	−80.0500	236.0	1956	1980	*	3-Mar-56	3-Mar-80
SCD-ON130	FOLEYET	48.2333	−82.4000	326.0	1956	1985		1-Jan-56	15-Apr-85
SCD-ON131	FORT CREEK	46.5333	−84.3500	213.0	1973	1981		4-Feb-73	15-Apr-81
SCD-ON132	FORT FRANCES	48.6167	−93.3500	341.0	1956	1984	*	3-Jan-56	1-Apr-84
SCD-ON134	FORTH LINE	46.5667	−84.3333	243.0	1980	1985		30-Nov-80	16-Apr-85
SCD-ON136	FREDERICKHOUSE DAM	48.7167	−80.9500	290.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON137	FREELE MILE 28	49.0667	−80.4667	312.0	1960	1985		1-Feb-60	1-Apr-85
SCD-ON145	GERALDTON	49.7667	−86.9167	335.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON146	GHOST RIVER	48.5333	−79.8333	381.0	1963	1985		1-Jan-63	1-May-85

STATION ID	STATION NAME	LAT	LONG	ELEV (m)	START YR	END YR		ACTUAL START	ACTUAL END
SCD-ON151	GORDON CHUTES	46.4833	–81.9667	366.0	1980	1985		4-Mar-80	15-Apr-85
SCD-ON155	HAWK JUNCTION	48.0500	–84.5667	366.0	1971	1985		1-Feb-79	15-Apr-85
SCD-ON157	HAZELWOOD LAKE	48.5833	–89.3000	442.0	1973	1985		9-Feb-73	17-Apr-85
SCD-ON158	HEARST	49.7833	–84.1167	259.0	1956	1985		1-Jan-56	2-May-85
SCD-ON169	HUNTA	49.1000	–81.3000	274.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON172	IGNACE	48.7500	–91.6333	452.0	1956	1984	*	1-Mar-56	5-Mar-84
SCD-ON173	INDIAN CHUTE	47.8333	–80.4333	299.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON176	KAPUSKASING	49.4167	–82.4500	225.0	1956	1985		1-Jan-56	15-Apr-85
SCD-ON177	KAPUSKASING A	49.4167	–82.4667	229.0	1962	1984	*	8-Jan-62	11-Dec-84
SCD-ON178	KAPUSKASING CDA	49.4000	–82.4333	218.0	1966	2001	*	23-Nov-66	9-Apr-01
SCD-ON183	KENORA	49.7833	–94.4833	335.0	1956	1985	*	1-Mar-56	1-Apr-85
SCD-ON190	KORAH	46.5500	–84.4000	229.0	1973	1980		6-Feb-73	29-Feb-80
SCD-ON193	LADY EVELYN LAKE	47.4667	–79.9333	290.0	1957	1985	*	1-Jan-57	15-Apr-85
SCD-ON194	LANSDOWNE HOUSE	52.2333	–87.8833	256.0	1965	1988		15-Nov-65	23-Dec-88
SCD-ON196	LEIGH'S BAY ROAD	46.5500	–84.3667	198.0	1980	1985		15-Dec-80	16-Apr-85
SCD-ON201	LONG LAKE CONTROL DA	49.0833	–87.0667	320.0	1956	1985	*	15-Jan-56	15-Apr-85
SCD-ON211	MARTEN RIVER	46.7333	–79.8000	305.0	1980	1985		1-Mar-80	15-Apr-85
SCD-ON213	MATTAGAMI DAM	48.0000	–81.5667	335.0	1956	1985		1-Jan-56	15-Apr-85
SCD-ON214	MCFARLANE LAKE	46.4167	–80.9500	230.0	1982	1985		1-Feb-82	15-Apr-85
SCD-ON221	MILNET	46.8167	–80.9500	335.0	1956	1985	*	1-Mar-56	15-Apr-85
SCD-ON223	MINE CENTRE	48.7667	–92.6000	366.0	1956	1984	*	1-Mar-56	5-Mar-84
SCD-ON225	MISTINIKON DAM	48.0500	–80.7167	320.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON244	NESTOR FALLS	49.1167	–93.9000	329.0	1956	1984	*	1-Mar-56	5-Mar-84
SCD-ON246	NICKEL OFFSET ROAD	46.6500	–81.2167	260.0	1982	1985		1-Dec-82	15-Apr-85
SCD-ON247	NICKELDALE RESERVOIR	46.5333	–80.9833	270.0	1982	1984		1-Dec-82	15-Apr-84
SCD-ON248	NIGHTHAWK	48.5500	–80.9667	290.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON256	OBA	49.0667	–84.1000	335.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON263	PAGWACHUAN	49.7667	–85.2333	213.0	1965	1985	*	1-Feb-79	15-Apr-85
SCD-ON271	PICKLE LAKE	51.4667	–90.2000	369.0	1967	2001	*	1-Mar-67	23-Apr-01
SCD-ON279	QUIBELL	49.9500	–93.4000	350.0	1956	1984	*	1-Mar-56	5-Mar-84
SCD-ON280	RAT RAPIDS	51.1667	–90.2167	375.0	1956	1985		1-Jan-56	1-May-85
SCD-ON281	RED CEDAR LAKE DAM	46.6833	–79.9833	259.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON282	RED LAKE	51.0167	–93.8167	381.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON283	RED PINE HIAWATHA	46.5833	–84.2833	282.0	1973	1985		4-Feb-73	16-Apr-85
SCD-ON285	REDROCK	46.3333	–83.3000	213.0	1956	1985	*	1-Jan-56	15-Apr-85
SCD-ON290	ROSSLYN	48.3833	–89.4333	229.0	1973	1985		9-Feb-73	14-Apr-85
SCD-ON293	SAULT STE MARIE A	46.4833	–84.5000	192.0	1971	1995	*	18-Dec-71	23-Apr-95
SCD-ON295	SAVANNE	48.9667	–90.2500	459.0	1956	1984	*	5-Jan-56	5-Mar-84
SCD-ON296	SAVANT LAKE	50.2333	–90.6833	439.0	1956	1984	*	1-Mar-56	5-Mar-84
SCD-ON299	SEARCHMONT	46.8167	–84.0000	281.0	1983	1985		5-Dec-83	9-Apr-85

STATION ID	STATION NAME	LAT	LONG	ELEV (m)	START YR	END YR		ACTUAL START	ACTUAL END
SCD-ON304	SHERWOOD FOREST	46.5500	−84.3500	213.0	1973	1980		4-Feb-73	15-Dec-80
SCD-ON305	SHILLINGTON	48.5500	−80.7000	290.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON306	SHININGTREE	47.4833	−81.4167	396.0	1957	1985	*	1-Jan-57	15-Apr-85
SCD-ON309	SIOUX LOOKOUT	50.1167	−91.9167	375.0	1956	1985		1-Jan-56	1-Apr-85
SCD-ON311	SIOUX LOOKOUT A	50.1167	−91.9000	390.0	1966	1985	*	15-Nov-66	23-Mar-85
SCD-ON313	SOUTH PORCUPINE	48.4167	−81.1833	305.0	1956	1985	*	1-Jan-56	1-May-85
SCD-ON324	STEELE MILE 50	49.0167	−79.9833	381.0	1960	1985		1-Feb-60	1-Apr-85
SCD-ON327	STIMSON DIAMOND	48.9667	−80.6000	294.0	1960	1985		1-Feb-60	1-Apr-85
SCD-ON330	STOBIE DAM	46.5333	−81.2833	260.0	1982	1985		1-Dec-82	15-Apr-85
SCD-ON335	SUDBURY A	46.6167	−80.8000	347.0	1965	1996		8-Dec-65	1-Apr-96
SCD-ON337	TANNIN	49.6500	−91.0000	448.0	1956	1984		1-Mar-56	5-Mar-84
SCD-ON341	TEESWATER	44.9500	−81.3167	300.0	1979	1985		15-Feb-79	15-Apr-85
SCD-ON342	TEMAGAMI	47.0500	−79.8167	298.0	1983	1985		15-Dec-83	1-May-85
SCD-ON343	TEMAGAMI	47.0500	−79.8333	305.0	1956	1985		1-Jan-56	1-May-85
SCD-ON347	THUNDER BAY	48.4667	−89.2500	244.0	1973	1985		9-Feb-73	1-Apr-85
SCD-ON348	THUNDER BAY A	48.3667	−89.3167	199.0	1969	1986		23-Nov-69	25-Mar-86
SCD-ON366	WALLS ROAD	46.5000	−84.5167	213.0	1981	1985		3-Dec-81	16-Apr-85
SCD-ON367	WANAPITEI	46.4667	−80.7833	259.0	1956	1980		5-Mar-56	3-Mar-80
SCD-ON373	WAWAITIN	48.4500	−81.3333	320.0	1956	1985		1-Jan-56	1-May-85
SCD-ON377	WHITE RIVER	48.6000	−85.2833	381.0	1962	1985		1-Jan-63	15-Apr-85
SCD-ON379	WIG LAKE	49.4000	−87.1833	381.0	1963	1985		1-Jan-63	15-Apr-85
SCD-ON386	WISHART PARK	46.5667	−84.2833	221.0	1973	1980		4-Feb-73	15-Dec-80
SCD-QC335	VILLE MARIE	47.3167	−79.4333	244.0	1956	1985		13-Jan-56	13-Apr-85

* Indicates gaps in data.

APPENDIX D: Snow Depth Stations in Canada

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
6012198	EAR FALLS	1930	1996	*	50.630	−93.220	360.9
6012199	EAR FALLS (AUT)	1999	2003		50.630	−93.220	362.6
6014350	LANSDOWNE HOUSE	1941	1989		52.230	−87.880	254.5
6014353	LANSDOWNE HOUSE (AUT	1993	2003		52.200	−87.940	253.4
6016525	PICKLE LAKE (AUT)	1930	1990	*	51.450	−90.220	390.8
6016527	PICKLE LAKE A	1990	2003		51.450	−90.220	386.2
6016975	RED LAKE A	1933	2003	*	51.070	−93.790	385.6
6020379	ATIKOKAN	1966	1988		48.750	−91.620	395.3
6020384	ATIKOKAN MARMION	1980	2003	*	48.800	−91.580	442.0
6020559	BARWICK	1979	2003		48.630	−93.970	335.0
6020727	BERGLAND	1980	1981		48.950	−94.350	363.9
6022010	DEVLIN	1979	1992		48.520	−93.750	335.0
6022011	DEVLIN BELLAMY	1979	1992		48.630	−93.670	347.2
6022475	FORT FRANCES	1892	1995	*	48.620	−93.420	343.2
6022476	FORT FRANCES A	1976	2003		48.650	−93.430	342.0
6025203	MINE CENTRE	1916	2003	*	48.770	−92.620	342.9
6026852	RAINY RIVER	1916	2003	*	48.720	−94.530	316.0
6027825	SLEEMAN	1964	1991		48.720	−94.420	335.3
6028125	STRATTON	1970	1986		48.780	−94.050	358.1
6028127	STRATTON ROEN	1979	1983	*	48.850	−94.020	347.2
6028128	STRATTON ROMYN	1979	2003		48.700	−94.170	366.1
6032117	DRYDEN	1914	1997	*	49.780	−92.830	371.9
6032119	DRYDEN A	1970	2003		49.830	−92.750	412.7
6032120	DRYDEN 'A' (AUT)	2000	2002		49.830	−92.740	412.7
6032192	EAGLE RIVER	1986	1988		49.820	−93.220	350.0
6033697	IGNACE TCPL 58	1970	1993		49.480	−92.000	473.0
6034075	KENORA A	1938	2003		49.790	−94.370	406.1
6034077	KENORA TCPL 49	1970	1990	*	49.780	−94.480	340.2
6035002	MARTIN TCPL 60	1970	1983		49.280	−91.230	470.6
6036904	RAWSON LAKE	1969	2003		49.650	−93.720	358.1
6037775	SIOUX LOOKOUT A	1938	2003		50.120	−91.900	383.4
6039136	VERMILION BAY TCPL 5	1970	1984		49.830	−93.630	385.0
6040010	ABITIBI CAMP 11	1978	1983	*	48.930	−89.350	442.0
6040011	ABITIBI CAMP 11	1983	1988		48.850	−89.120	491.0
6040020	ABITIBI CAMP 230	1970	1982		49.350	−89.370	457.2
6040022	ABITIBI CAMP 300	1978	1986		49.630	−89.750	426.7

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
6040325	ARMSTRONG (AUT)	1938	2002	*	50.290	−88.910	322.5
6040330	ARMSTRONG JELLIEN	1987	1992		50.250	−89.100	341.4
6040572	BEARDMORE	1974	1986	*	49.620	−87.950	304.8
6041109	CAMERON FALLS	1924	1998	*	49.150	−88.350	228.6
6041110	CAMERON FALLS (AUT)	1998	2003		49.150	−88.340	232.6
6041193	CARAMAT	1949	1983	*	49.270	−85.830	338.3
6041221	CARIBOU ISLAND	1935	1988	*	47.330	−85.830	186.5
6042067	DORION TCPL 70	1970	1984		48.820	−88.520	192.6
6042715	GERALDTON	1967	1981		49.700	−86.950	330.7
6042716	GERALDTON A	1981	2003		49.780	−86.930	348.7
6043452	HEMLO BATTLE MOUNTAI	1985	2001		48.700	−85.880	335.0
6044298	LAKEHEAD UNIVERSITY	1969	2002	*	48.430	−89.270	210.3
6044903	MANITOUWADGE	1956	1995		49.150	−85.800	332.2
6044959	MARATHON	1945	1983	*	48.720	−86.400	189.0
6044961	MARATHON A	1989	1999		48.760	−86.340	315.5
6045541	MYRT LAKE	1980	1985		48.470	−90.720	518.2
6045676	NOLALU SSW22	1979	1985		48.100	−89.880	349.9
6045781	ONE ISLAND LAKE	1992	1993		48.650	−89.420	457.2
6046767	PUKASKWA (AUT)	1996	2002		48.590	−86.290	207.6
6046770	PUKASKWA NATL PARK	1983	2003		48.600	−86.300	192.0
6046856	RAITH TCPL 64	1970	1984		48.730	−89.870	433.1
6047810	SLATE ISLAND	1967	1989		48.620	−87.000	185.9
6048145	STURGEON LAKE	1973	1994	*	49.880	−90.970	428.2
6048230	TERRACE BAY	1972	1999	*	48.800	−87.100	289.0
6048231	TERRACE BAY A	1996	2003		48.820	−87.100	289.6
6048261	THUNDER BAY A	1941	2003	*	48.370	−89.330	199.0
6048864	TRANQUILLO RIDGE	1991	2003		48.230	−89.520	335.3
6049095	UPSALA (AUT)	1993	2003		49.030	−90.470	488.5
6049098	UPSALA TCPL 62	1971	1985		49.030	−90.520	492.9
6049443	WELCOME ISLAND (AUT)	1967	2002	*	48.370	−89.120	211.4
6049466	WHITEFISH LAKE	1980	2003		48.280	−89.920	399.0
6050805	BLIND RIVER HYDRO CE	1982	1989		46.200	−83.020	189.0
6052259	ELLIOT LAKE A	1995	2003		46.350	−82.560	331.3
6052268	ELLIOT LAKE STANLEIG	1984	1997		46.420	−82.650	374.0
6053463	HIGH FALLS	1977	1989		47.920	−84.720	221.0
6053570	HORNEPAYNE	1917	1989	*	49.230	−84.800	329.2
6053575	HORNEPAYNE A	1990	1995		49.200	−84.770	335.0
6053803	IRON BRIDGE	1988	1991	*	46.270	−83.350	198.0
6055210	MISSISSAGI ONT HYDRO	1970	1997		46.430	−83.380	225.6
6055302	MONTREAL FALLS	1977	1999		47.270	−84.430	306.3

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
6057590	SAULT STE MARIE 2	1958	2002		46.530	–84.330	211.8
6057592	SAULT STE MARIE A	1945	2003	*	46.480	–84.510	192.0
6059409	WAWA	1970	1984		48.000	–84.800	297.2
6060070	AGNEW MINE	1978	1983		46.430	–81.620	305.1
6060773	BISCOTASING	1914	2000	*	47.300	–82.100	406.9
6061361	CHAPLEAU A	1978	2003		47.820	–83.350	446.5
6061850	CONISTON STP	1962	2002		46.480	–80.850	267.6
6062860	GOGAMA TREE NURSERY	1989	1992		47.680	–81.720	352.0
6064460	LIVELY	1981	1991		46.430	–81.150	282.0
6065006	MASSEY	1983	2003		46.180	–82.030	198.0
6065250	MONETVILLE	1963	2003		46.140	–80.310	221.0
6066873	RAMSAY	1973	1983		47.450	–82.330	429.8
6066877	RAMSEY 2	1984	1984		47.470	–81.870	402.0
6067308	ST CHARLES	1980	1984	*	46.370	–80.520	235.9
6068150	SUDBURY A	1955	2003		46.630	–80.800	347.5
6068158	SUDBURY SCIENCE NORT	1986	1996	*	46.470	–81.000	263.0
6068980	TURBINE	1914	1990	*	46.380	–81.570	205.7
6069165	WABAGISHIK	1978	1988	*	46.320	–81.520	213.4
6069197	WAHNAPITAE-STOKES	1990	1991		46.430	–80.720	750.0
6069428	WEBBWOOD	1983	1986		46.270	–81.880	196.0
6071712	COCHRANE	1910	1993	*	49.070	–81.030	274.9
6072183	DYMOND ONT HYDRO	1973	1998		47.520	–79.680	198.1
6072224	EARLTON AWOS	2001	2002		47.700	–79.850	243.4
6072225	EARLTON A	1938	2003		47.700	–79.850	243.2
6072325	ENGLEHART	1948	2000	*	47.820	–79.900	251.5
6073810	IROQUOIS FALLS	1913	1998		48.750	–80.670	259.1
6073840	ISLAND FALLS	1955	1996		49.580	–81.380	213.0
6073960	KAPUSKASING CDA	1918	2001		49.400	–82.430	217.9
6073975	KAPUSKASING A	1937	2003		49.410	–82.470	226.5
6073980	KAPUSKASING CDA ON	2000	2003		49.410	–82.440	218.0
6074209	KIRKLAND LAKE	1950	1996	*	48.150	–80.000	324.0
6074211	KIRKLAND LAKE CS	1997	2003		48.150	–80.000	324.0
6075013	MATHESON ONT HYDRO	1983	1992		48.530	–80.470	274.0
6075024	MATTICE TCPL	1967	1995		49.600	–83.170	233.2
6075543	NAGAGAMI (AUT)	1993	2003		49.750	–84.160	264.0
6075594	NEW LISKEARD	1924	1983	*	47.500	–79.670	194.2
6076572	PORCUPINE ONT HYDRO	1969	2001		48.470	–81.270	298.7
6077845	SMOKY FALLS	1934	1997		50.070	–82.170	182.9
6078285	TIMMINS A	1955	2003		48.570	–81.380	294.7
6081928	CRYSTAL FALLS	1922	1988	*	46.450	–79.870	227.1

STATION ID	STATION NAME	START YEAR	END YEAR		LAT	LONG	ELEV (m)
6082612	FRENCH R CHAUDIERE D	1970	2003		46.130	−80.020	198.1
6088144	STURGEON FALLS	1884	2002	*	46.370	−79.930	201.0
6092915	GORE BAY	1881	1983	*	45.920	−82.470	190.5
6092925	GORE BAY A	1947	2002		45.880	−82.570	193.5
6093004	GREAT DUCK ISLAND	1966	1985		45.650	−82.970	182.9
6094449	LITTLE CURRENT	1986	1989		45.970	−81.920	190.5
6097426	SANDFIELD	1998	2003		45.680	−81.980	229.0
6097915	SOUTH BAYMOUTH	1954	1993		45.580	−82.020	181.7
6121912	COVE ISLAND	1965	1985	*	45.330	−81.730	179.8
6121940	CYPRUS LAKE CS	1995	2003		45.230	−81.530	190.0
6128320	TOBERMORY	1888	1983	*	45.250	−81.670	182.9
6128323	TOBERMORY CYPRUS LAK	1988	1994		45.230	−81.530	190.0
6020LPQ	ATIKOKAN (AUT)	2000	2003		48.760	−91.630	389.3
602B300	EMO HOSKINS	1979	1993	*	48.750	−93.850	351.1
602FQ5L	RAINY RIVER-COOPER	1991	1993		48.730	−94.620	323.0
602K300	EMO RADBOURNE	1979	2002	*	48.680	−93.830	350.0
6042MJ7	FLINT	1979	2003		48.350	−89.680	274.0
6048K6J	THUNDER BAY MCS CENT	1980	1983	*	48.320	−89.380	231.6
604H26A	THUNDER BAY POMBER	1980	1987		48.500	−89.220	228.9
604HBFA	THUNDER BAY WPCP	1961	1989		48.400	−89.230	184.4
604HK61	THUNDER BAY PROVINCI	1990	1990		48.450	−89.170	184.4
604S003	THUNDER BAY A FIREHA	1995	1996		48.370	−89.320	199.0
6050NNP	BAR RIVER	1988	1992	*	46.430	−84.050	180.0
6059D09	WAWA A	1977	2003		47.970	−84.780	287.1
6069K90	WARREN	1987	1998		46.430	−80.320	212.0
6070QK6	BONNER LAKE	1990	2003		49.380	−82.120	245.0
608A06G	CACHE BAY	1981	1985		46.380	−80.020	198.1

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14. ABSTRACT
Daily estimates of the snow water equivalent (SWE) distribution for the period from 1 December through 30 April for each winter season from 1979–80 through 2002–03 were calculated for the entire Lake Superior watershed. The calculations were based on numerous ground-based daily observations collected and compiled by the National Weather Service in the United States and by the Meteorological Service of Canada in Canada. The daily estimates of SWE were then used to determine the annual accumulation and melt period characteristics of the Lake Superior watershed, along with the annual series of maximum SWE volume and the incremental accumulated SWE volume. Selected results are also shown for the individual sub-basins. Maps were also prepared of the mean SWE distributions on the 1st and 15th day of each winter month.

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