

Present-day tilting of the Great Lakes region based on water level gauges

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ABSTRACT

By using monthly mean water levels at 55 sites around the Great Lakes, a regional model of vertical crustal motion was computed for the region. In comparison with previous similar studies over the Great Lakes, 15 additional gauge sites, data from all seasons instead of the 4 summer months, and 8 additional years of data were used. All monthly water levels available between 1860 and 2000, as published by the U.S. National Ocean Survey and the Canadian Hydrographic Service, were used. For each lake basin, the vertical velocities of the gauge sites relative to each other were simultaneously computed, using the least-squares adjustment technique. Our algorithm solves for and removes a monthly bias common to all sites, as well as site-specific biases. It also properly weighs the input water levels, resulting in a realistic estimation of the uncertainties in tilting parameters. The relative velocities obtained for each lake were then combined to obtain relative velocities over the entire Great Lakes region. Finally, the gradient of the relative rates for the regional model was found to agree best with the ICE-3G global isostatic model of Tushingham and Peltier, whereas the ICE-4G gradients were too small around the Great Lakes.

Keywords: Great Lakes, postglacial rebound, water level gauges, least-squares analysis, trend surface analysis, water management.

INTRODUCTION

The Earth's crust north of the Great Lakes in Canada was pressed down by as much as 3 km of ice in some areas during the last glacial era. When the ice began melting some 10,000 yr ago, the crust started rebounding. This phenomenon is called *postglacial rebound* (PGR)

and is still ongoing today. While the land north of the Great Lakes is rising, that south of the Great Lakes is subsiding to maintain equilibrium. Hence, residents on the south shores of the Great Lakes have noticed water levels rising slowly over time, while those on the north shores have noticed declining water levels.

Improving our knowledge of PGR over the Great Lakes and central Canada is important for shore industries and inhabitants to help in charting and mapping, management of water, shore constructions, shore erosion, shipping, hydroelectric dams, basins, power generation, flooding (such as along the Red River), environmental changes, groundwater resources (their quantity and pollution), as well as in determining crustal stress in earthquake-prone regions.

The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (hereinafter referred to as the Coordinating Committee) has the mandate to "review and update as necessary the apparent vertical crustal and other movement rates between water level gauge sites in the Great Lakes–St. Lawrence River System, and report coordinated findings" (Coordinating Committee, 1995b). Following are these findings, i.e., rates of movement, which are coordinated between the United States and Canada.

An important reason for refining PGR models is to improve the definition of the reference system for heights around the Great Lakes. Whereas the current International Great Lakes Datum (IGLD) of 1985 (Coordinating Committee, 1995a) was established using geodetic spirit leveling, the future reference system is expected to be defined by a geoid model and realized using global positioning system (GPS) techniques (Mainville et al., 1992) combined with a PGR model. This may also be the case for a future vertical reference system covering the whole of Canada. A PGR model helps to predict and manage geographical coordinate changes both vertically and horizontally.

A precise estimation of PGR is achieved here by studying water level records from 55 water level gauges around the Great Lakes in

the United States and Canada. Previous studies of PGR in the Great Lakes region from 1898 to 1977 are summarized in a report by the Coordinating Committee (1977).

Recently, in addition to the Coordinating Committee's 1977 report, Tait and Bolduc (1985), Carrera et al. (1991), and Tushingham (1992) used basically the same method, each using additional years of water level data to compute the rates of movement between pairs of gauges. In comparison with these studies over the Great Lakes, 15 additional sites and 8 additional years of data are used here. In addition, whereas only summer months (June to September) were used in previous studies, data from all 12 months are also used here. Finally, an improved mathematical model is applied that provides more realistic accuracy estimates.

Our estimates of the vertical velocities of each of the 55 gauges relative to each other are compared with previous studies and with the global PGR models ICE-3G (Tushingham and Peltier, 1991) and ICE-4G(VM1) and ICE-4G(VM2) (Peltier, 1994, 1995, 2001). A contour map combining our gauge-derived vertical velocities with ICE-3G velocities indicates the current tilting of the land over the Great Lakes. It is hoped that our solution can be used by PGR modelers to calibrate their global models.

DATA

The data used here to determine the vertical movement of the crust at each gauge are monthly mean water levels. The water levels, relative to IGLD 1985, are recorded at 55 gauge sites on the Great Lakes going back to 1860 and are published by the U.S. National Ocean Service and the Canadian Hydrographic Service.

A map of the gauge locations is shown in Figure 1, and the sites are listed in Table 1 together with the years in which water levels were recorded. When a gauge was moved within a harbor, the data from both gauges were merged as if they were the same gauge. Figure 1 also indicates the number of years of recorded data available and used at each gauge site.

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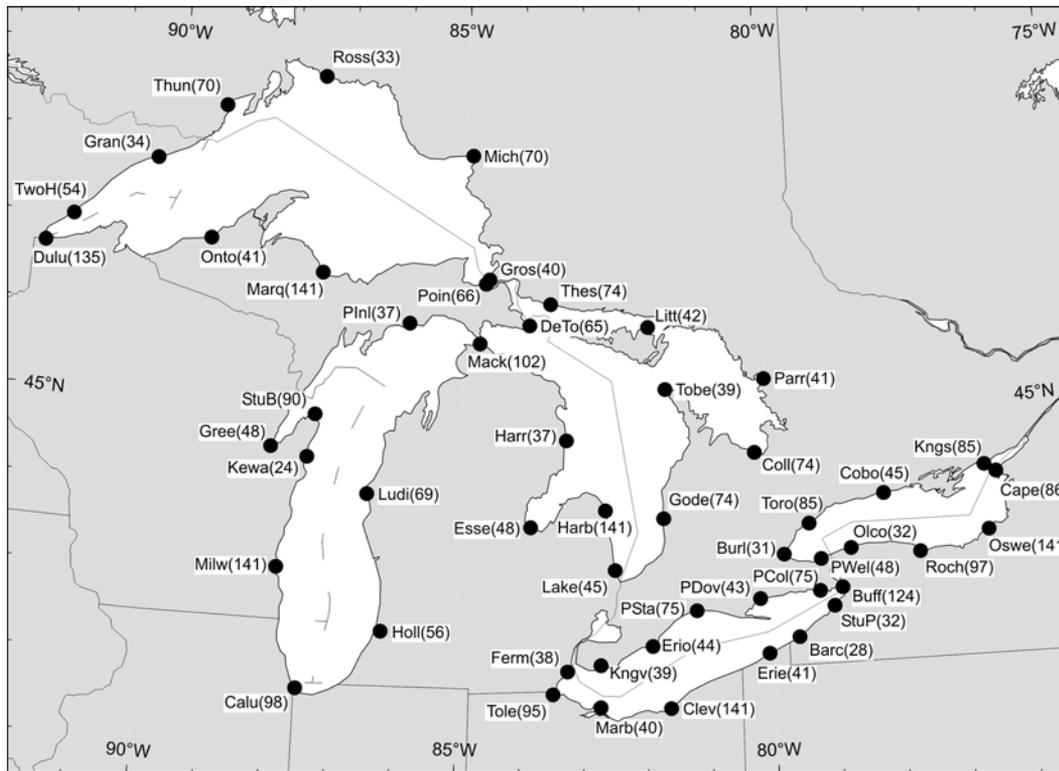


Figure 1. Locations of water level gauging stations. Stations BarP, Fair, and Monr on Lake Erie are not used in our final postglacial rebound (PGR) model. Shown in parentheses is the number of years of recorded water levels at each gauge.

Table DR1¹ indicates the years for which data are not available. See Coordinating Committee (2001, their Fig. 11) for graphs of monthly mean water levels at all 55 gauge sites.

ESTIMATING VERTICAL VELOCITIES

After recording the water level at two lake gauges for many years, the apparent vertical movement of a gauge site relative to the others can be computed. Relative water levels are needed to remove the seasonal water fluctuations common to all sites on each lake (the common bias cancels when differencing between gauges). The relative movement is represented by the linear trend on a plot of the water level differences with respect to time. This is the basic method used by previous studies, which we call Method 1.

¹GSA Data Repository item 2005107, Table DR1: Years when no data are available, i.e., when no monthly water level averages are available per gauge site; Tables DR2–DR5: Comparison of relative vertical velocities and their standard deviation in cm/century between gauges on Lakes Ontario (DR2), Erie (DR3), Michigan-Huron (DR4), and Superior (DR5); Table DR6: Count of outliers (i.e., monthly lake level averages) rejected during this study, per month and per gauge site, for each lake, are available on the Web at <http://www.geosociety.org/pubs/ft2005.htm>. Requests may also be sent to editing@geosociety.org.

An example is provided in Figure 2 for Calumet Harbor, Michigan, relative to Parry Sound, Ontario, using monthly mean water level data from 1960 to 2000. The difference in monthly mean water level is taken as Calumet Harbor minus Parry Sound. The linear trend (solid line) in Figure 2 is 0.32 m per century. Hence, Calumet Harbor is seen to be subsiding 32 cm/century relative to Parry Sound. Such relative movements were computed for all 391 possible pairs of water gauges on all Great Lakes (Fig. 1).

Owing to random errors in the data, the rates obtained on a pair-wise basis as described previously are not consistent among any three stations. For example, Calumet Harbor is subsiding by 10 cm/century relative to Lakeport, and Lakeport is subsiding by 25 cm/century relative to Parry Sound, the sum of which is different than the 32 cm/century rate of Calumet Harbor relative to Parry Sound, just discussed. In previous studies, the Coordinating Committee (1977), Tait and Bolduc (1985), Carrera et al. (1991), Tushingham (1992), and Tackman et al. (1999) published their rates with this inconsistency among stations. Given below is the least-squares adjustment technique of Mikhail (1976), which takes into account this inconsistency to obtain more precise results.

The least-squares adjustment method can be applied to this pair-wise analysis of gauges, here called Method 2. It uses the following observa-

tion, equation 1, for each gauge pair, which accounts for the inconsistency between pairs of gauges by using a residual error.

$$\Delta v_{ij}^{\text{obs}} + r_{ij} = v_i - v_j. \quad (1)$$

Here, $\Delta v_{ij}^{\text{obs}}$ is the “observed” yearly average relative velocity of point j relative to point i , computed using Method 1. The other variables are the output of the least-squares adjustment: v_i and v_j are the yearly velocities at gauge site i and j , respectively; r_{ij} are the residual errors in the observed relative velocities $\Delta v_{ij}^{\text{obs}}$. The $\Delta v_{ij}^{\text{obs}}$ are weighted a priori according to the number of years used to compute them. The a posteriori standard errors obtained from this method were too optimistic and unrealistic, however. The problem lies in the fact that data from some gauges are used in more than one of the estimates of the “observed” velocities. This so-called mathematical correlation between velocities needs to be taken into account, which is not easy to do. Craymer and Beck (1992) devised a method of overcoming this problem for a similar situation encountered in GPS baseline processing. However, this method is correct only when the same amount of data is collected at each site at the same times, which is not the case here.

To get around these problems, we formed a more fundamental observation equation on the basis of the actual observations themselves: the

TABLE 1. LIST OF 55 WATER LEVEL GAUGE SITES AND THEIR PERIOD OF RECORD USED IN THIS STUDY

Gauge name	Abbr.	ID	Years	Period of record [†]
<u>Lake Ontario</u>				
Burlington	Burl	13150	31	1970–2000
Cape Vincent	Cape	02000	86	1898–2000, exception
Cobourg	Cobo	13590	45	1956–2000
Kingston	Kngs	13988	85	1916–2000
Olcott	Olco	02076	32	1967–2000, exception
Oswego	Osw	02030	141	1860–2000
Port Weller	PWel	13030	48	1929–2000, exception
Rochester	Roch	02058	97	1860–2000, exception
Toronto	Toro	13320	85	1916–2000
<u>Lake Erie</u>				
Barcelona	Barc	03032	28	1960–1987
Bar Point	BarP	12005	35	1966–2000
Buffalo Harbor	Buff	03020	124	1860–2000, exception
Cleveland	Clev	03063	141	1860–2000
Erie	Erie	03038	41	1958–2000, exception
Erieau	Erio	12250	44	1957–2000
Fairport Harbor	Fair	03053	26	1975–2000
Fermi Power Plant	Ferm	03090	38	1963–2000
Kingsville	Kngv	12065	39	1962–2000
Marblehead	Marb	03079	40	1959–2000, exception
Monroe	Monr	03087	14	1975–1988
Port Colborne	PCol	12865	75	1926–2000
Port Dover	PDov	12710	43	1958–2000
Port Stanley	PSta	12400	75	1926–2000
Sturgeon Point	StuP	03028	32	1969–2000
Toledo	Tole	03085	95	1877–2000, exception
<u>Lake Huron</u>				
Collingwood	Coll	11500	74	1927–2000
De Tour	DeTo	05098	43	1896–1983, exception
De Tour Village		05099	23	1977–2000
De Tour Village	DeTo3 [‡]		65	1896–2000
Essexville	Esse	05034	26	1953–1978
Essexville		05035	24	1977–2000
Essexville	Esse3 [‡]		48	1953–2000
Goderich	Gode	11860	74	1927–2000
Harbor Beach	Harb	05014	141	1860–2000

continued

TABLE 1. LIST OF 55 WATER LEVEL GAUGE SITES AND THEIR PERIOD OF RECORD USED IN THIS STUDY (continued)

Gauge name	Abbr.	ID	Years	Period of record [†]
<u>Lake Huron</u>				
Lakeport	Lake	05002	45	1955–2000, exception
Little Current	Litt	11195	42	1959–2000
Mackinaw City	Mack	05080	102	1899–2000
Parry Sound	Parr	11375	41	1960–2000
Thessalon	Thes	11070	74	1927–2000
Tobermory	Tobe	11690	39	1962–2000
<u>Lake Michigan</u>				
Calumet Harbor	Calu	07044	98	1903–2000
Green Bay	Gree	07078	29	1953–1981
Green Bay		07079	22	1979–2000
Green Bay	Gree3 [‡]		48	1953–2000
Holland	Holl	07031	56	1894–1997, exception
Kewaunee	Kewa	07068	24	1974–1997
Ludington	Ludi	07023	69	1895–2000, exception
Milwaukee	Milw	07058	110	1860–1969
Milwaukee		07057	31	1970–2000
Milwaukee	Milw3 [‡]		141	1860–2000
Port Inland	PInl	07096	37	1964–2000
Sturgeon Bay C.	StuB	07072	90	1905–2000, exception
<u>Lake Superior</u>				
Duluth	Dulu	09064	135	1860–2000, exception
Grand Marais	Gran	09090	34	1966–2000, exception
Gros Cap	Gros	10920	40	1961–2000
Marquette	Marq	09016	121	1860–1980
Marquette C.G.		09018	21	1980–2000
Marquette C.G.	Marq3 [‡]		141	1860–2000
Michipicoten	Mich	10750	70	1931–2000
Ontonagon	Onto	09044	41	1959–2000, exception
Point Iroquois (Brimley)	Poin	09004	66	1930–2000, exception
Rosport	Ross	10220	33	1967–2000
Thunder Bay	Thun	10050	70	1931–2000
Two Harbors	TwoH	09070	54	1887–1988, exception

[†]Records are mainly up to December 2000. See Table DR1 (see footnote 1) for periods for which data are not available.

[‡]Records from two gauges at same location were merged for this study.

independent monthly mean water level measurements. This method, here called Method 3, is similar to that used by Walcott (1972, p. 871) and avoids altogether the inconsistencies encountered in the previous two methods. The observation equation is of the following form for gauges $i = 1, \dots, n$ and epochs $j = 1, \dots, m$:

$$w_{ij}^{obs} + r_{ij} = (w_{i0} + a_i) + b_j + v_i(t_j - t_0). \quad (2)$$

Here, w_{ij}^{obs} are the observed monthly mean water levels given at each gauge $i = 1, \dots, n$, and for each epoch $t_j, j = 1, \dots, m$, w_{i0} is the water level at gauge i at a given reference epoch t_0 , a_i is a site dependent bias, b_j is an epoch dependent bias for each monthly mean water level observation and is common to all gauges on a lake, v_i is the velocity at each gauge site, r_{ij} are the residuals (errors in each month's water levels). Because w_{i0} and a_i are both site dependent, they

cannot be separately estimated. Hence, the combination of both is computed, i.e., $\alpha_i = (w_{i0} + a_i)$, one for each gauge site. The reference epoch used here was $t_0 = 1985.5$, which corresponds to the reference water level of IGLD 1985.

Finally, we weighted each monthly mean water level equally, which effectively results in sites with more monthly levels receiving greater weight, as would normally be desired. The a posteriori standard errors obtained with this method were found to be more realistic and meaningful than those with the other methods and are presented later. The summary statistics for the adjustment of each lake are provided in Table 2.

LAKEWIDE PGR RESULTS

Because the water level of each lake varies independently, each lake is adjusted individually, following each of the three methods described

previously. The adjustment in Method 3 computes the monthly biases, site biases, velocities, and residuals by minimizing the sum of the square of the residuals. If a residual r_{ij} is three times larger than the average residual, the corresponding monthly mean water level is removed and the adjustment repeated. This process is iterated until no more outliers remain. The final adjusted velocities and their standard deviations are listed in Table 3 and presented in Figure 3. Note that the velocities are given relative to a gauge at the lake outlet, because the mathematical model requires that we fix the velocity of one gauge.

Figure 3 illustrates uplift in the northeast and subsidence in the south, indicating a pattern of land tilting upward to the northeast. The flattening of the velocities in the southern parts of Lakes Michigan and Erie may suggest that these parts of the lakes are on or are approaching the subsiding forebulge of the PGR. However, our

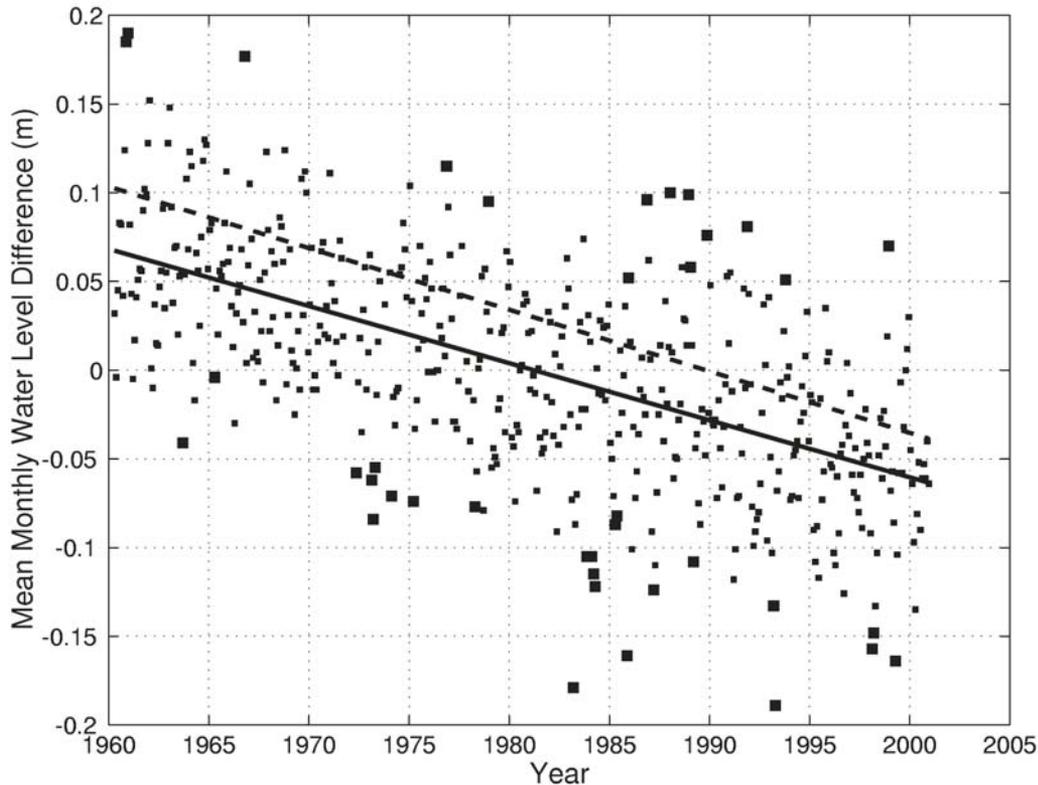


Figure 2. Example of vertical movement of Calumet Harbor, Michigan, relative to Parry Sound, Ontario, as determined from the difference between the monthly mean lake levels recorded at both gauges, from 1960 to 2000. The solid straight line is the linear trend obtained by regression from the data in the plot taken out of context of the other gauges (Method 1). The dashed straight line is the linear trend obtained from a simultaneous least-squares adjustment that takes into account all gauges on the lake (Method 3). The large squares are outliers rejected by the least-squares adjustment process.

results are not significant enough to actually support this claim.

The relative velocities between each pair of gauges can be derived simply, using the estimated velocities in Table 3. They are listed in Tables DR2–DR5 (see footnote 1) in column 7 together with the relative velocities (trends) computed using Method 1 (column 6) and the results of previous studies by the Coordinating Committee (1977), Tait and Bolduc (1985), Carrera et al. (1991), and Tushingham (1992).

Although the standard deviations tabulated in these tables represent the uncertainty with a 68% confidence level, uncertainty estimates for 95% confidence can be obtained by multiplying the standard deviation by 1.96, and for 99% confidence, by 2.58.

The lake-adjusted velocities from Method 3 indicate that Calumet Harbor is subsiding by 35 ± 1.2 cm/century relative to Parry Sound, instead of 32 cm/century as determined by Method 1. In Figure 2, the adjusted velocity (linear trend) from Method 3 is the dashed line, and the velocity from Method 1 is the solid line. See Coordinating Committee (2001, their Fig. 12) for plots of velocity trends for all the gauge pairs.

In addition to the trends, the adjustment computes three other useful values: monthly biases, site biases, and residuals. Each month there is a

different bias in the water level of a lake, resulting from such causes as precipitation, evaporation, barometric pressure, wind, snow melt, and water level regularization at dams. The Method 3 adjustment computes one bias b_j per month common to all gauges on the lake. It indicates the average level of the water after removing the trend and the site biases. It is a time-varying basinwide bias, which relates to the lowering or raising of lakewide water. Hydrologists and hydraulic engineers of the Great Lakes study how well this quantity correlates from basin

to basin. The mean monthly values obtained by using Method 3 are more precise than those usually used and may help in this analysis.

The site bias is specific to each gauge site. It may be used to improve future datum definitions: i.e., adding the site bias to the height relative to IGLD 1985 would provide a height at each gauge site that would match heights established using GPS and a very accurate geoid height. The biases and their estimated standard deviations are listed in Table 3 and plotted in Figure 4. They are small in magnitude, mostly

TABLE 2. STATISTICS ON THE LEAST-SQUARES ADJUSTMENT FOR EACH LAKE

Lake	Ontario	Erie	Mich.-Huron	Superior
No. of gauge sites	9	16	20	10
No. of velocities and no. of site biases solved for	8	15	19	9
No. of monthly average water levels inputted	7693	10,399	15,542	7979
No. of monthly water level rejected	269	516	331	147
No. of residuals	7424	9883	15211	7832
No. of monthly biases solved for	1627	1680	1683	1668
RMS of residuals (cm)	0.9	2.4	1.7	1.2
σ_0 a priori (mm)	3.1	5.1	4.3	3.7
σ_0 a posteriori (mm)	3.1	5.1	4.3	3.7

below 1 cm, which indicates the stability of the local datum at each gauge and the quality of the water level data.

The residuals represent the random errors in the data (monthly mean water levels) left after removing the monthly biases, the trends (i.e., the vertical movement of the crust at each gauge), and the site biases. The residuals are fairly small in magnitude: below 3, 7, 5, and 4 cm for Lakes Ontario, Erie, Michigan-Huron, and Superior, respectively. This indicates the quality of the data to be very good. Many outliers have been rejected for two of the four lakes. Statistically, up to 5% are allowed when using a 95% confidence interval to detect outliers. There are 3.6% rejections by adjustment for Lake Superior, 4.3% for Lakes Michigan-Huron, 9.9% for Lake Erie, and 7.0% for Lake Ontario. Systematic trends and unexplained outliers in the residuals have not been further investigated and may point to errors in the data that could have an impact on the accurate determination of the movement rates. Specifically, the residuals at Port Weller, Rochester, De Tour, Ludington, and Rosspport show undesirable systematic trends. Hence the data at these sites should be investigated in later studies.

Some monthly mean water levels were rejected as outliers by the adjustment process. When a residual, as explained earlier, was larger than three times the root mean square of all the residuals, its water level was automatically rejected. The number of outliers for each gauge and for each month are listed for each lake in Table DR6 (see footnote 1). For more details about the outliers, see Coordinating Committee (2001, their Table 3e-h and Figs. 11, 12, and 14).

Previous studies used only the four summer months (June to September) because winter months were found to be noisy. As seen in Table DR6 (see footnote 1), it is true that most outliers occur during the winter months, but nevertheless, 95% of the data from October to May contributed to our solution.

The small magnitude of the estimated standard deviations and residuals demonstrated for the first time the consistency of all gauges over each lake in measuring the same phenomenon of a tilting of the land resulting from PGR.

In concluding this section, the estimated velocities provide a direct measurement of the relative movement of the Earth's crust. For example, over 100 yr, the land at Calumet Harbor became 10 cm lower than the land at Lakeport, and 35 cm lower than the land at Parry Sound. Again, these velocities are relative to one gauge site on each lake and thus are listed lake-by-lake in Table 3 and Tables DR2-DR5 (see footnote 1). The steps in determining relative

TABLE 3. GAUGE VERTICAL VELOCITY AND SITE BIAS

Gauge	Latitude (°N)	Longitude (°W)	Vertical velocity (cm/century)	Site bias (mm)	Comment
<u>Lake Ontario—Relative to Cape Vincent</u>					
Burlington	43°20'20"	79°46'08"	-20.0 ± 0.7	4 ± 0.7	
Cape Vincent	44°07'48"	76°19'47"	0	0	Outlet
Cobourg	43°57'28"	78°09'54"	-7.7 ± 0.4	6 ± 0.7	
Kingston	44°13'01"	76°31'01"	2.5 ± 0.2	3 ± 0.7	
Olcott	43°20'24"	78°43'48"	-11.3 ± 0.6	5 ± 0.7	
Oswego	43°27'36"	76°30'36"	-4.5 ± 0.2	7 ± 0.7	
Port Weller	43°14'13"	79°13'11"	-14.7 ± 0.3	5 ± 0.7	
Rochester	43°15'35"	77°37'47"	-10.2 ± 0.2	6 ± 0.7	
Toronto	43°38'24"	79°22'51"	-12.1 ± 0.2	12 ± 0.7	
<u>Lake Erie—Relative to Buffalo</u>					
Barcelona	42°19'47"	79°35'59"	-1.3 ± 2.1	-1 ± 3.1	
Bar Point	42°02'59"	83°06'39"	-16.1 ± 1.4	-17 ± 1.8	Rejected
Buffalo Har.	42°53'24"	78°53'24"	0	0	Outlet
Cleveland	41°31'48"	81°38'24"	-9.8 ± 0.3	-8 ± 1.6	
Erie	42°08'59"	80°04'47"	-12.1 ± 1.2	8 ± 1.9	
Erieau	42°15'35"	81°54'54"	-9.6 ± 1.1	-11 ± 1.8	
Fairport Ha.	41°45'35"	81°17'24"	-21.7 ± 2.2	6 ± 2.1	Rejected
Fermi Pow.	41°58'00"	83°15'00"	-9.6 ± 1.3	-16 ± 1.8	
Kingsville	42°01'37"	82°44'05"	-10.3 ± 1.2	-14 ± 1.8	
Marblehead	41°32'59"	82°43'48"	-8.4 ± 1.2	-17 ± 1.9	
Monroe	41°53'59"	83°21'35"	-16.0 ± 5.9	-16 ± 3.2	Rejected
Port Colbor.	42°52'26"	79°15'10"	-5.7 ± 0.5	2 ± 1.8	
Port Dover	42°46'51"	80°12'07"	-1.8 ± 1.1	1 ± 1.8	
Port Stanley	42°39'32"	81°12'46"	-7.4 ± 0.5	1 ± 1.8	
Sturgeon P.	42°40'47"	79°01'48"	2.1 ± 1.6	-2 ± 1.9	
Toledo	41°42'00"	83°28'48"	-8.6 ± 0.4	-9 ± 1.8	
<u>Lakes Huron—Michigan—Relative to Lakeport</u>					
Collingwood	44°30'18"	80°13'01"	16.6 ± 0.7	-5 ± 1.3	
De Tour	46°00'00"	83°54'00"	17.3 ± 0.8	-3 ± 1.3	
Essexville	43°38'59"	83°50'59"	-1.3 ± 0.9	-1 ± 1.4	
Goderich	43°44'45"	81°43'44"	-1.5 ± 0.7	-1 ± 1.3	
Harbor	43°51'00"	82°39'00"	0.1 ± 0.7	6 ± 1.3	
Harrisville	44°40'12"	83°16'48"	8.0 ± 1.1	-3 ± 1.4	
Lakeport	43°08'59"	82°30'00"	0	0	Outlet
Little Current	45°58'51"	81°55'40"	27.0 ± 1.0	-3 ± 1.3	
Mackinaw	45°46'48"	84°43'11"	10.0 ± 0.7	-3 ± 1.3	
Parry Sound	45°20'16"	80°02'09"	24.3 ± 1.0	-8 ± 1.4	
Thessalon	46°15'10"	83°33'07"	20.8 ± 0.7	0 ± 1.3	
Tobermory	45°15'32"	81°39'57"	16.7 ± 1.0	5 ± 1.3	
Calumet	41°42'00"	87°30'00"	-10.4 ± 0.7	7 ± 1.3	
Green Bay	44°30'00"	88°05'59"	-6.2 ± 0.9	0 ± 1.4	
Holland	42°23'59"	86°12'00"	-7.9 ± 0.8	7 ± 1.4	
Kewaunee	44°23'59"	87°30'00"	-8.5 ± 1.8	-1 ± 1.5	
Ludington	44°00'00"	86°30'00"	-12.2 ± 0.8	-1 ± 1.3	
Milwaukee	43°06'00"	87°54'00"	-14.4 ± 0.7	0 ± 1.3	
Port Inland	46°00'00"	85°54'00"	9.4 ± 1.1	-4 ± 1.4	
Sturgeon	44°53'59"	87°24'00"	-3.8 ± 0.7	-2 ± 1.3	
<u>Lake Superior—Relative to Point Iroquois</u>					
Duluth	46°40'12"	92°05'59"	-25.3 ± 0.3	-18 ± 0.9	
Grand Mara.	47°45'00"	90°19'47"	-7.6 ± 0.8	-3 ± 1.0	
Gros Cap	46°31'44"	84°35'05"	1.6 ± 0.7	-8 ± 1.0	
Marquette	46°32'59"	87°23'24"	-12.2 ± 0.3	2 ± 0.9	
Michipicoten	47°57'43"	84°54'03"	23.3 ± 0.3	-4 ± 1.0	
Ontonagon	46°52'11"	89°18'36"	-18.7 ± 0.7	-8 ± 1.0	
Point Iroqu.	46°28'47"	84°38'24"	0	0	Outlet
Rosspport	48°50'02"	87°31'11"	27.5 ± 0.8	-6 ± 1.0	
Thunder B.	48°24'32"	89°13'01"	2.4 ± 0.3	-9 ± 1.0	
Two Harb.	47°00'35"	91°40'12"	-21.2 ± 0.5	-2 ± 1.0	

Note: Vertical velocity standard error in cm/century, relative to each lake outlet. Site bias and its standard error in mm, also relative to the outlet.

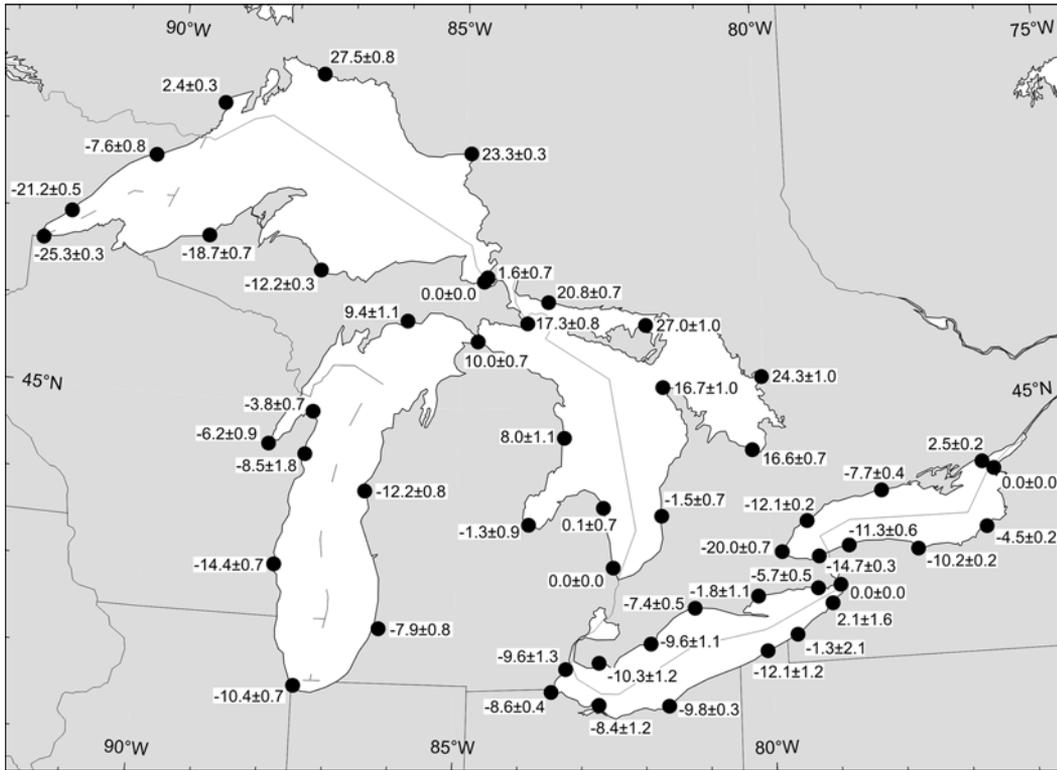


Figure 3. Vertical velocity and standard error relative to each outlet: Cape Vincent for Lake Ontario, Buffalo for Lake Erie, Lakeport for Lakes Michigan-Huron, Point Iroquois for Lake Superior, in centimeters per century.

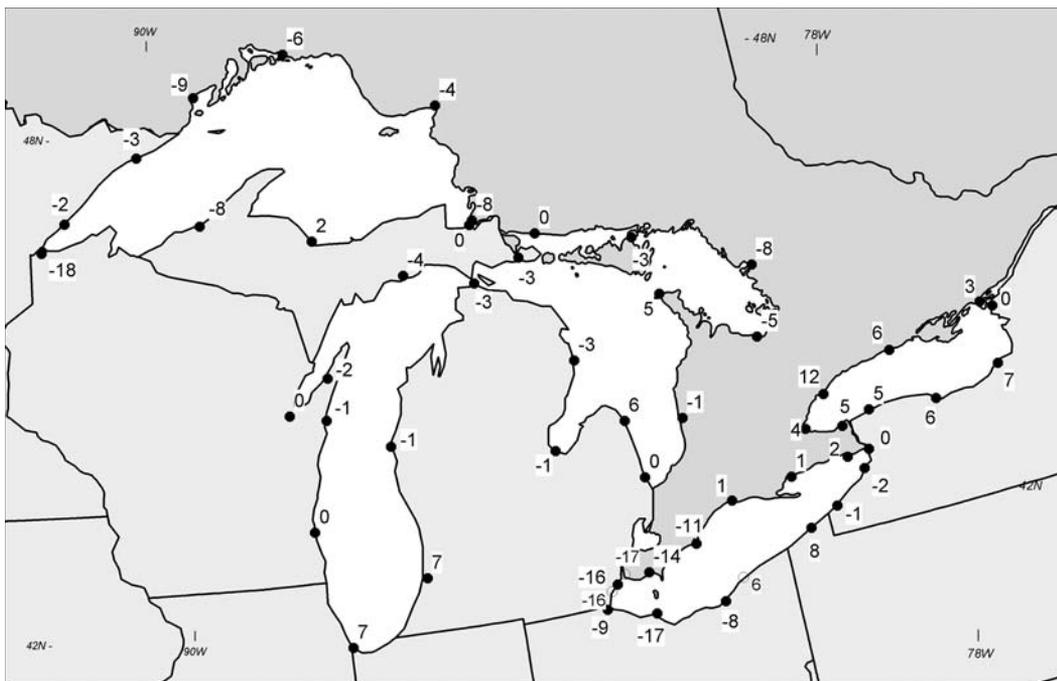


Figure 4. Site biases (in millimeters) relative to reference gauge near each lake outlet.

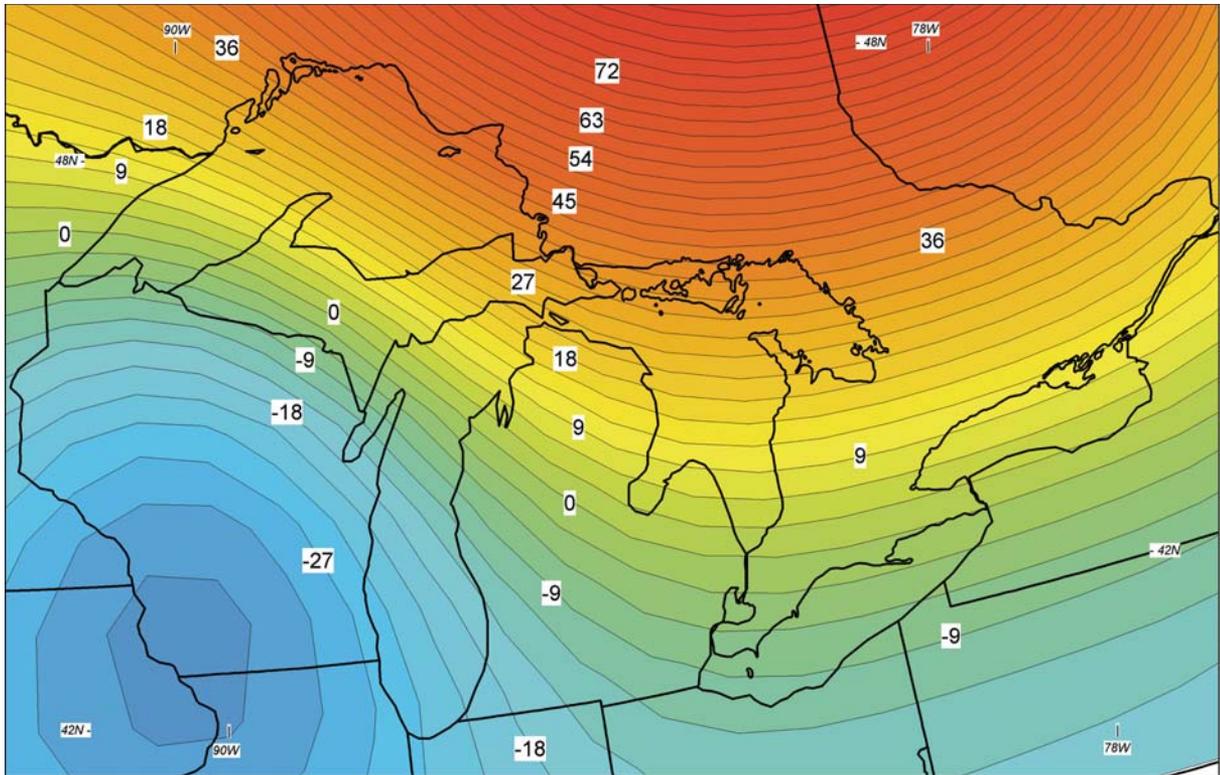


Figure 6. Contour map of ICE-3G global postglacial rebound-derived velocities in the Great Lakes area. Contour interval—3 cm/century.

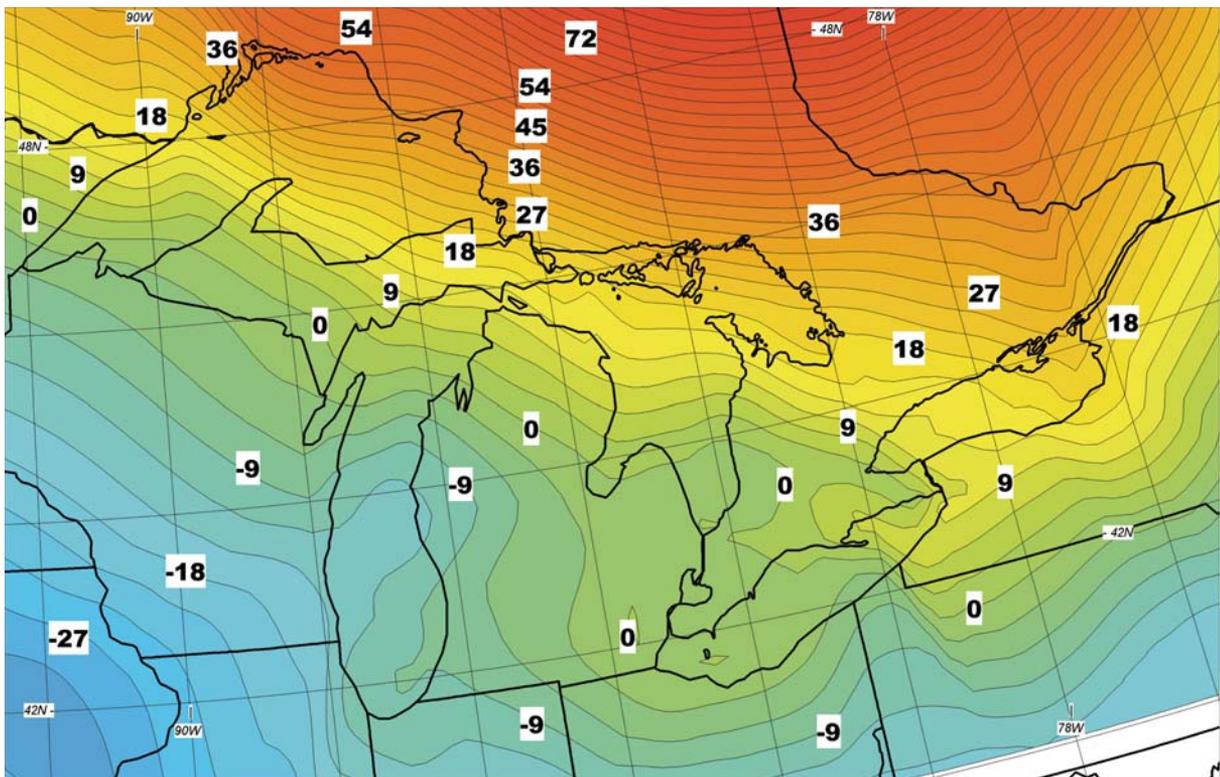


Figure 7. Contour map of vertical velocities derived from water level gauges over the Great Lakes surrounded with ICE-3G-derived velocities. Contour interval—3 cm/century.

± 1.2 cm/century (Tables 3 and DR2–DR5 [see footnote 1]). However, the relative velocity between sites on two different lakes likely has a standard deviation on the order of ± 6 cm/century. This increased standard deviation is due to the large uncertainty in interpolating the relative velocities between different lakes.

COMPARISON WITH ICE-4G PGR MODELS

As stated previously, the ICE-4G-derived velocities were tested against the gauge-derived velocities. First, Figure 8A displays ICE-3G-derived velocities in dashed lines, overlaid by the gauge-derived regional PGR model (solid lines). Similar maps were produced for ICE-4G(VM1)- and ICE-4G(VM2)-derived velocities also with the gauge-derived velocities overlaid (Fig. 8B, C, respectively). ICE-4G uses a different ice thickness and distribution than ICE-3G. ICE-4G(VM2) has a different viscosity model for the mantle as well as a different lithosphere thickness than ICE-4G(VM1). One can see visually in Figure 8C that the ICE-4G(VM2) contour gradient is too small in

comparison with the gauge-derived contours. In Figure 8B, the ICE-4G(VM1) contour gradient agrees better with the gauge-derived contours but not as well as ICE-3G in Figure 8A. The spacing between contour lines is the same for all models. In addition, maps similar to Figure 7 were produced using ICE-4G(VM1) and ICE-4G(VM2), again observing that ICE-4G gradients are too small around the Great Lakes. The ICE-3G contours in Figure 8A therefore agree best with the gauge-derived velocities.

CONCLUSIONS

The relative movements between 55 Canadian and U.S. lake level gauges on the Great Lakes were computed and are listed in Tables DR2–DR5 (see footnote 1), together with their uncertainties. These vertical velocities and standard deviations are summarized in Table 3 and Figure 3 as velocities relative to a reference gauge at each lake outlet. The relative velocity over the whole region was also derived and is shown in Figure 7.

The relative velocities between sites on the same lake have a standard deviation on the order

of ± 1 cm/century. However, the relative velocities between sites on different lakes is expected to be large because of the interpolation used to connect the velocities from different lakes.

The gauge-derived relative velocities were compared with the global PGR models ICE-3G and two versions of ICE-4G, using viscosity models VM1 and VM2. The agreement was found to be best with ICE-3G.

Note that the global PGR models do not provide standard deviations for their velocities. Hence the rates provided by our PGR model in Figure 7 do not have standard deviations assigned. One must therefore exercise caution when using these velocities.

Systematic trends in the residuals and outliers from our estimation model have not been adequately investigated and may point to errors in the data that could have some influence on the accurate determination of the movement rates. Specifically, more than 5% of the observations on Lakes Erie and Ontario were rejected as outliers, whereas the residuals at Port Weller, Rochester, De Tour, Ludington, and Rossport show undesirable systematic trends. Hence, the data from these sites should be investigated further.

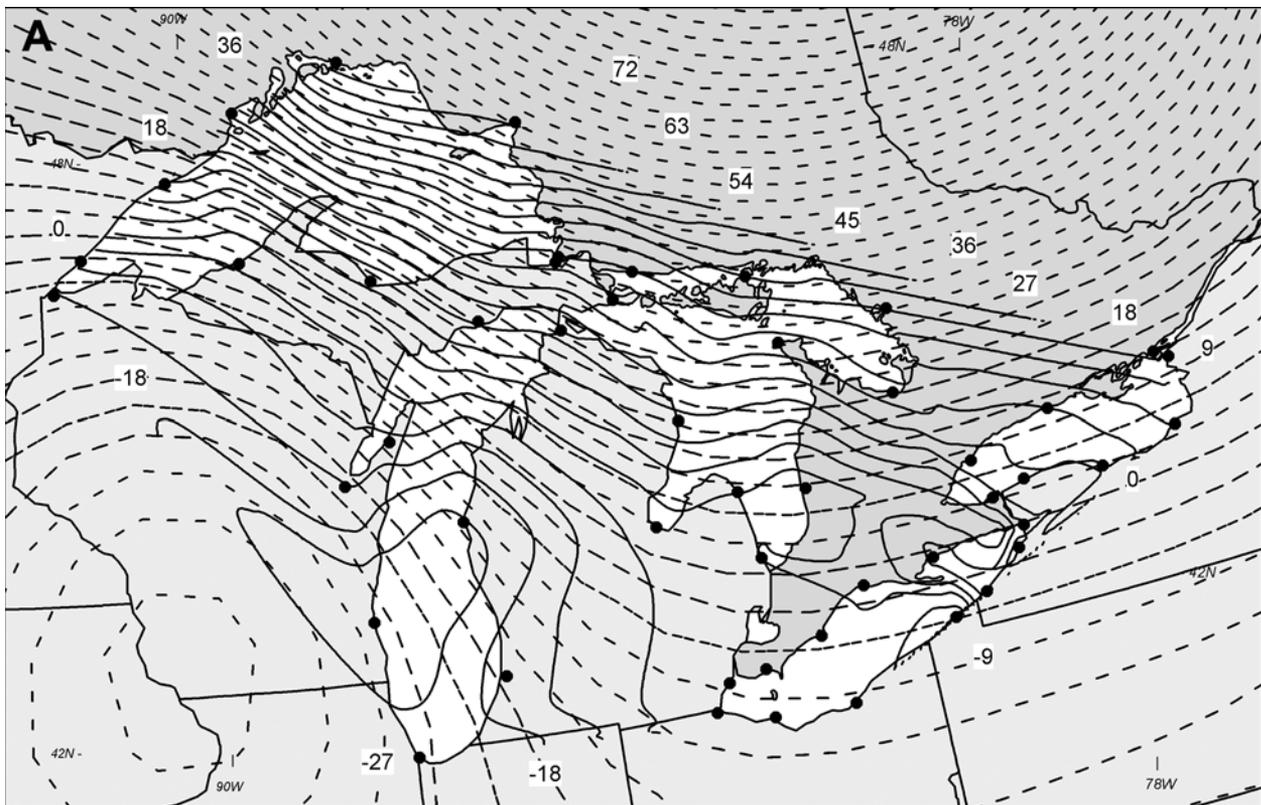


Figure 8. Overlaid contour maps comparing vertical velocities derived from water level gauges (solid contour lines) and those derived from (A) the ICE-3G postglacial rebound model, (B) the ICE-4G(VM1) model, and (C) the ICE-4G(VM2) model. Contour interval—3 cm/century. (Continued on following page).

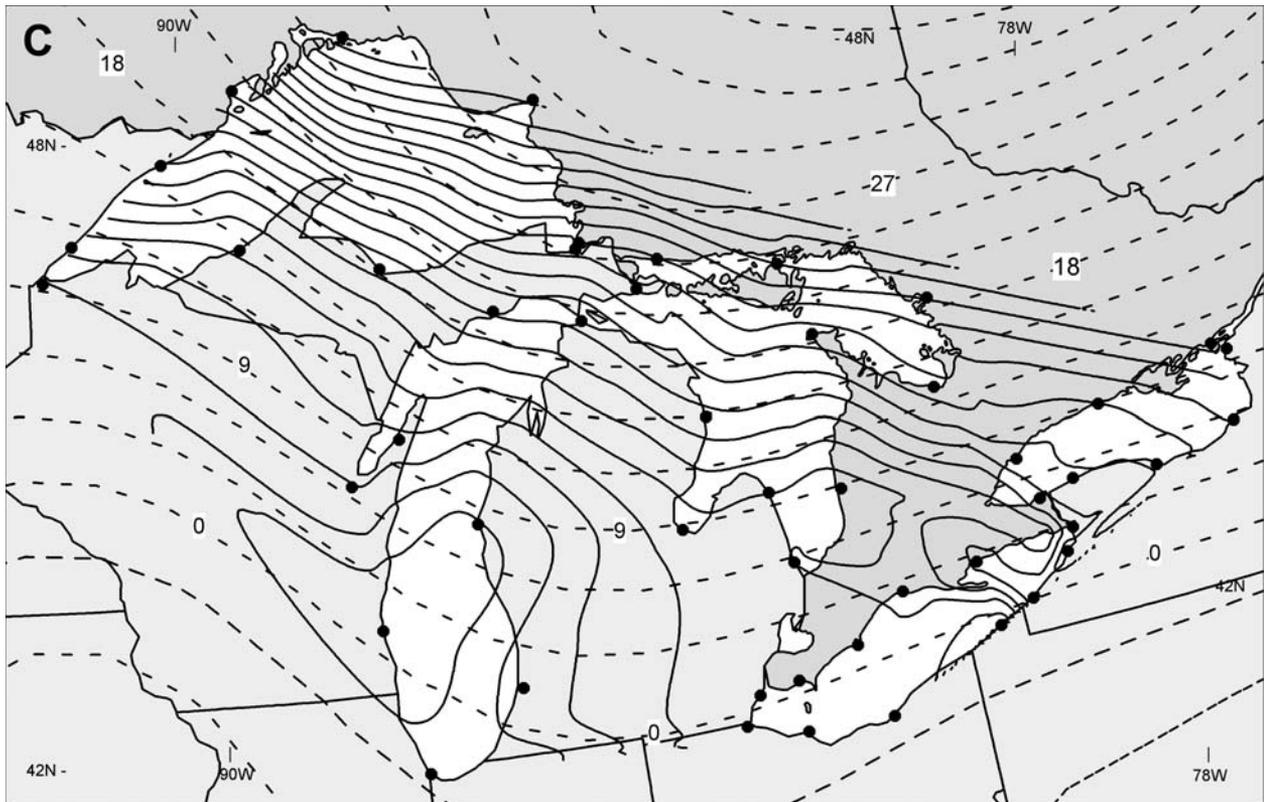
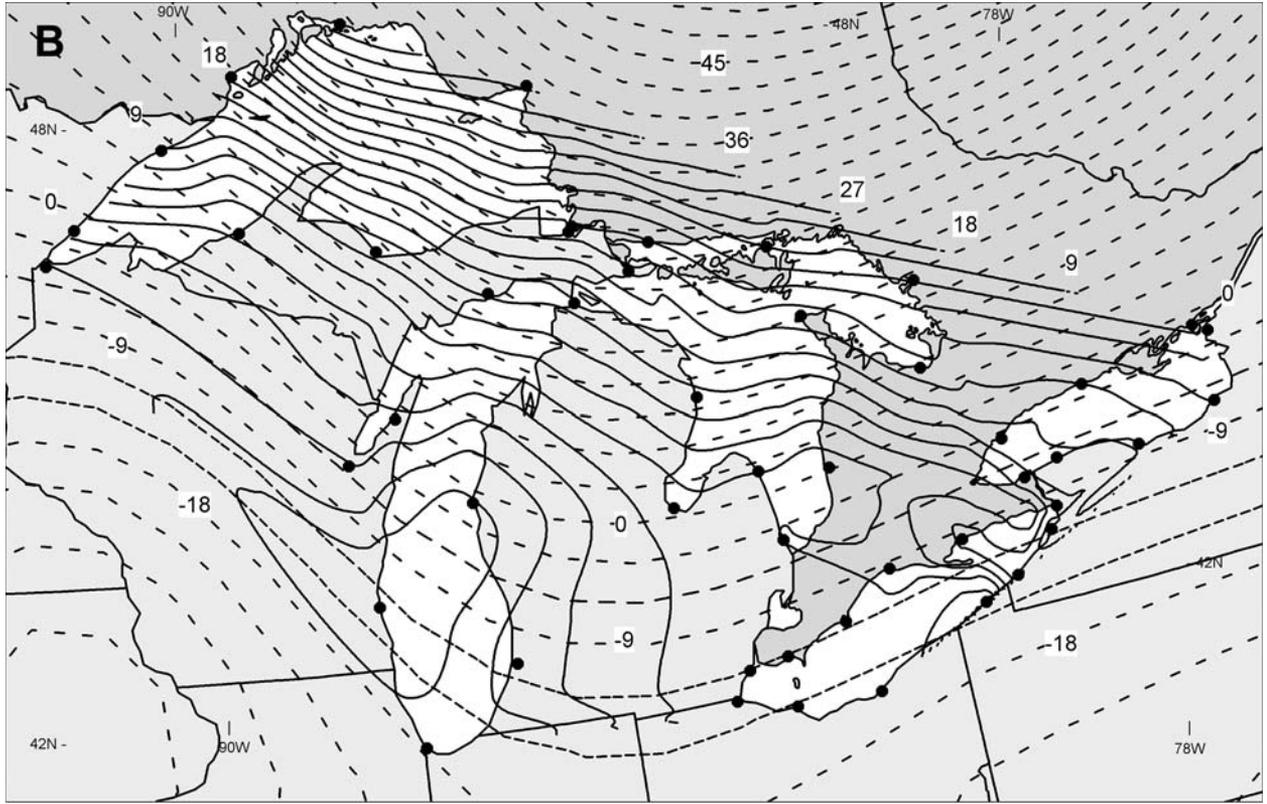


Figure 8 (continued).

The GPS satellite positioning technique is seen as the technology for determining the absolute velocities of the Earth's crust around the Great Lakes. Having gauge sites on each lake that are permanently equipped with GPS receivers will allow us, after several years, to accurately link the relative rates of all five lakes (as well as Lake Saint Clair, between Lakes Huron and Erie) and eventually achieve absolute rates of vertical movement over the region. Obtaining absolute velocities is important in view of linking the area to ocean level and upgrading the vertical datum, hydraulic and hydrologic studies, bathymetry, charts, and navigational safety.

The resulting velocities will provide important constraints on future PGR analyses. Crustal tilting rates are key for future safe navigation on the Great Lakes. Precise positioning obtained by GPS will require corrections for crustal tilting, and thus such models, as developed here, are becoming necessary.

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TABLE DR1. LIST OF YEARS WITH NO DATA AVAILABLE (I.E., WITH NO MONTHLY AVERAGE).

Lake	Abbr.	No. of Years	Periods with no data available
<i>Ontario</i>			
	Cape	16	1899 - 1913, 1915
	Olco	2	1998- 99
	PWel	24	1932- 55
	Roch	44	1908- 34, 1936- 52
<i>Erie</i>			
	Buff	17	1870 - 1886
	Erie	2	1998- 99
	Marb	2	1998- 99
	Tole	27	1878 - 1903, 1909- 10
<i>Huron</i>			
	DeTo	40	1897- 98, 1900, 1904- 33, 1937- 43
	Lake	2	1998-99
<i>Michigan</i>			
	Holl	49	1898, 1901- 02, 1904, 1909- 34, 1936- 40, 1943- 55, 1957- 58
	Ludi	38	1898- 99, 1901- 02, 1907, 1909- 34, 1938, 1940- 43, 1948- 49
	StuB	6	1920- 21, 1923- 24, 1926, 1998
<i>Superior</i>			
	Dulu	6	1974- 79
	Gran	1	1998
	Onto	1	1998
	Poin	5	1945- 49
	TwoH	48	1888- 98, 1901- 29, 1932- 34, 1936- 40

TABLE DR2. COMPARISON OF RELATIVE VERTICAL VELOCITIES AND THEIR STANDARD DEVIATION IN CM/CENTURY BETWEEN GAUGES ON LAKE ONTARIO.

Gauge pair		Coordinating Com., 1977	Tait and Bolduc, 1985	Carrera et al, 1991	Tushingam, 1992	This Study Method 1	This Study Method 3
Burl	Cape					18.8 ± 1.8	20.0 ± 0.7
Burl	Cobo					13.5 ± 1.2	12.3 ± 0.8
Burl	Kngs					18.5 ± 1.7	22.5 ± 0.7
Burl	Olco					8.9 ± 0.9	8.7 ± 0.9
Burl	Oswe					13.9 ± 1.6	15.5 ± 0.7
Burl	PWel					4.4 ± 0.9	5.3 ± 0.8
Burl	Roch					13.3 ± 1.2	9.8 ± 0.7
Burl	Toro				21.2 ± 2.0	11.2 ± 1.0	7.9 ± 0.7
Cape	Cobo				-11.5 ± 1.9	-8.2 ± 1.5	-7.7 ± 0.4
Cape	Kngs	5.8 ± 0.6			-4.5 ± 2.2	2.4 ± 1.1	2.5 ± 0.2
Cape	Olco				-14.7 ± 2.6	-11.0 ± 1.4	-11.3 ± 0.6
Cape	Oswe	-2.1 ± 0.6			-2.8 ± 0.4	-4.8 ± 1.2	-4.5 ± 0.2
Cape	PWel				-12.2 ± 2.4	-14.9 ± 1.7	-14.7 ± 0.3
Cape	Roch				-7.7 ± 1.1	-8.2 ± 1.3	-10.2 ± 0.2
Cape	Toro	-11.6 ± 0.9			-11.2 ± 0.7	-12.1 ± 1.7	-12.1 ± 0.2
Cobo	Kngs				9.1 ± 2.3	7.9 ± 1.5	10.2 ± 0.4
Cobo	Olco				1.5 ± 2.4	-3.7 ± 0.9	-3.6 ± 0.7
Cobo	Oswe				6.8 ± 1.6	2.9 ± 1.4	3.2 ± 0.4
Cobo	PWel				-7.4 ± 3.1	-9.2 ± 1.0	-7.0 ± 0.5
Cobo	Roch				3.3 ± 1.3	0.2 ± 1.1	-2.5 ± 0.4
Cobo	Toro			-1.3 ± 1.0	-1.5 ± 1.6	-3.3 ± 1.0	-4.4 ± 0.4
Hami	Toro			0.8 ± 6.4			
Kngs	Olco				-7.4 ± 2.6	-10.0 ± 1.2	-13.8 ± 0.6
Kngs	Oswe	-7.9 ± 0.6	-7.6 ± 0.4	-7.5 ± 0.2	-1.2 ± 1.5	-7.4 ± 1.0	-7.0 ± 0.3
Kngs	PWel				-19.9 ± 2.8	-15.5 ± 1.6	-17.2 ± 0.4
Kngs	Roch				-6.0 ± 1.5	-7.7 ± 1.1	-12.7 ± 0.3
Kngs	Toro	-17.4 ± 0.9	-16.4 ± 0.6		-8.9 ± 2.2	-14.5 ± 1.6	-14.6 ± 0.3
Olco	Oswe				4.9 ± 1.6	5.2 ± 1.0	6.8 ± 0.6
Olco	PWel				-6.6 ± 2.8	-5.6 ± 0.7	-3.4 ± 0.7
Olco	Roch				4.0 ± 1.5	5.1 ± 0.7	1.1 ± 0.6
Olco	Toro			6.6 ± 1.5	3.9 ± 1.7	3.0 ± 0.7	-0.8 ± 0.6
Oswe	PWel				-9.5 ± 2.0	-9.9 ± 1.4	-10.2 ± 0.4
Oswe	Roch			-3.8 ± 0.5	-6.1 ± 0.4	-5.6 ± 1.6	-5.7 ± 0.3
Oswe	Toro	-9.4 ± 0.9	-8.8 ± 0.7	-8.5 ± 0.5	-11.3 ± 0.9	-7.2 ± 1.5	-7.6 ± 0.3
PDal	Toro			1.3 ± 0.6			
PWel	Roch				11.6 ± 2.4	9.0 ± 1.1	4.5 ± 0.4
PWel	Toro			-0.6 ± 0.7	-1.3 ± 2.0	2.7 ± 1.0	2.6 ± 0.4
Roch	Toro				-5.5 ± 0.8	-3.5 ± 1.1	-1.9 ± 0.3

TABLE DR3. COMPARISON OF RELATIVE VERTICAL VELOCITIES AND THEIR STANDARD DEVIATION IN CM/CENTURY BETWEEN GAUGES ON LAKE ERIE.

Gauge pair		Coordinating Com., 1977	Tait and Bolduc, 1985	Carrera et al, 1991	Tushingham, 1992	This Study Method 1	This Study Method 3
Barc	BarP					-8.0 ± 4.2	-14.8 ± 2.5
Barc	Buff					6.3 ± 2.0	1.3 ± 2.1
Barc	Clev					-9.1 ± 3.3	-8.5 ± 2.1
Barc	Erie					-7.3 ± 1.6	-10.8 ± 2.4
Barc	Erio			3.8 ± 2.1		-9.3 ± 3.4	-8.3 ± 2.4
Barc	Fair					2.9 ± 2.5	-20.4 ± 3.0
Barc	Ferm					-9.7 ± 4.8	-8.3 ± 2.5
Barc	Kngv					-7.6 ± 4.2	-9.0 ± 2.4
Barc	Marb					-8.3 ± 4.6	-7.1 ± 2.4
Barc	Monr					-14.2 ± 5.1	-14.7 ± 6.3
Barc	PCol					-1.2 ± 1.8	-4.4 ± 2.2
Barc	PDov					-0.4 ± 1.5	-0.5 ± 2.4
Barc	PSta			4.6 ± 2.3		-9.4 ± 2.4	-6.1 ± 2.2
Barc	StuP					16.7 ± 1.9	3.4 ± 2.6
Barc	Tole					-7.8 ± 4.9	-7.3 ± 2.1
BarP	Buff				19.8 ± 5.9	18.7 ± 4.8	16.1 ± 1.4
BarP	Clev				7.0 ± 3.7	9.0 ± 2.3	6.3 ± 1.4
BarP	Erie				6.2 ± 4.9	-0.2 ± 4.1	4.0 ± 1.8
BarP	Erio				6.8 ± 4.9	7.3 ± 2.2	6.5 ± 1.8
BarP	Fair					-1.4 ± 2.8	-5.6 ± 2.6
BarP	Ferm					6.7 ± 1.7	6.5 ± 1.9
BarP	Kngv			2.0 ± 2.5	0.6 ± 6.0	5.6 ± 1.6	5.8 ± 1.8
BarP	Marb				6.6 ± 3.2	7.0 ± 1.9	7.7 ± 1.8
BarP	Monr					8.6 ± 2.3	0.1 ± 6.1
BarP	PCol					13.1 ± 4.6	10.4 ± 1.5
BarP	PDov				14.6 ± 5.0	14.5 ± 4.3	14.3 ± 1.8
BarP	PSta				6.7 ± 3.7	5.5 ± 3.6	8.7 ± 1.5
BarP	StuP				14.5 ± 7.9	19.1 ± 4.8	18.2 ± 2.1
BarP	Tole			2.7 ± 2.7	4.7 ± 3.0	4.7 ± 2.2	7.5 ± 1.5
Buff	Clev	-5.8 ± 1.2			-9.0 ± 0.5	-9.9 ± 4.5	-9.8 ± 0.3
Buff	Erie				-8.8 ± 2.1	-11.5 ± 2.1	-12.1 ± 1.2
Buff	Erio				-7.2 ± 3.0	-9.5 ± 3.8	-9.6 ± 1.1
Buff	Fair					-21.9 ± 2.9	-21.7 ± 2.2
Buff	Ferm					-12.3 ± 5.3	-9.6 ± 1.3
Buff	Kngv				-8.9 ± 4.3	-11.8 ± 4.6	-10.3 ± 1.2
Buff	Marb				-7.3 ± 2.7	-9.1 ± 4.9	-8.4 ± 1.2
Buff	Monr					-26.1 ± 5.5	-16.0 ± 5.9
Buff	PCol	-6.4 ± 0.9		-5.8 ± 0.4		-5.1 ± 1.3	-5.7 ± 0.5
Buff	PDov				-3.1 ± 2.7	-2.5 ± 1.9	-1.8 ± 1.1
Buff	PSta	-0.3 ± 1.5			-0.5 ± 0.9	-6.1 ± 3.3	-7.4 ± 0.5
Buff	StuP				-0.1 ± 1.6	1.5 ± 1.1	2.1 ± 1.6
Buff	Tole				-4.5 ± 1.0	-7.8 ± 5.7	-8.6 ± 0.4
Clev	Erie				-1.2 ± 1.5	-3.2 ± 3.0	-2.3 ± 1.2
Clev	Erio				-0.1 ± 2.2	0.0 ± 1.4	0.2 ± 1.1
Clev	Fair			-6.9 ± 3.6		-16.6 ± 1.4	-11.9 ± 2.2
Clev	Ferm					-2.4 ± 2.6	0.2 ± 1.3
Clev	Kngv				-0.5 ± 2.8	-2.7 ± 1.9	-0.5 ± 1.2
Clev	Marb			0.6 ± 1.3	0.8 ± 1.3	-0.3 ± 2.2	1.4 ± 1.2
Clev	Monr					-12.0 ± 2.9	-6.2 ± 5.9
Clev	PCol	-0.6 ± 1.2	0.3 ± 0.9			3.8 ± 4.0	4.1 ± 0.6
Clev	PDov				6.2 ± 2.1	6.8 ± 3.0	8.0 ± 1.1
Clev	PSta	5.5 ± 1.5	4.9 ± 1.1	4.1 ± 0.5	5.8 ± 0.9	2.4 ± 2.2	2.4 ± 0.6
Clev	StuP				10.2 ± 3.2	8.7 ± 3.5	11.9 ± 1.6
Clev	Tole			2.1 ± 0.7	1.8 ± 0.7	0.1 ± 3.1	1.2 ± 0.5
Erie	Erio				1.0 ± 2.9	2.5 ± 2.9	2.5 ± 1.6
Erie	Fair					-5.0 ± 2.2	-9.6 ± 2.5
Erie	Ferm					4.8 ± 4.8	2.5 ± 1.8
Erie	Kngv				2.6 ± 3.0	3.7 ± 4.0	1.8 ± 1.7
Erie	Marb				2.5 ± 2.2	4.0 ± 4.3	3.7 ± 1.7
Erie	Monr					-2.0 ± 4.8	-3.9 ± 6.0
Erie	PCol					6.9 ± 1.9	6.4 ± 1.3
Erie	PDov				5.3 ± 2.6	9.6 ± 1.4	10.3 ± 1.6
Erie	PSta			1.1 ± 2.1	0.2 ± 2.2	1.9 ± 1.9	4.7 ± 1.3
Erie	StuP				10.7 ± 4.2	15.4 ± 1.8	14.2 ± 2.0

TABLE DR3. COMPARISON OF RELATIVE VERTICAL VELOCITIES AND THEIR STANDARD DEVIATION IN CM/CENTURY BETWEEN GAUGES ON LAKE ERIE (CONTINUED...)

Gauge pair		Coordinating Com., 1977	Tait and Bolduc, 1985	Carrera et al, 1991	Tushingham, 1992	This Study Method 1	This Study Method 3
Erie	Tole				2.4 ± 2.4	1.8 ± 4.8	3.5 ± 1.3
Erio	Fair					-14.1 ± 1.4	-12.1 ± 2.5
Erio	Ferm					-1.7 ± 2.7	0.0 ± 1.7
Erio	Kngv				2.9 ± 4.0	-1.7 ± 2.0	-0.7 ± 1.6
Erio	Marb				-0.3 ± 1.9	-0.3 ± 2.4	1.2 ± 1.6
Erio	Monr					-4.3 ± 3.0	-6.4 ± 6.0
Erio	PCol					5.5 ± 3.7	3.9 ± 1.2
Erio	PDov				6.1 ± 4.4	7.3 ± 3.0	7.8 ± 1.6
Erio	PSta			5.5 ± 2.0	2.2 ± 3.2	-0.5 ± 2.1	2.2 ± 1.2
Erio	StuP				10.7 ± 4.2	10.3 ± 3.5	11.7 ± 1.9
Erio	Tole				-0.5 ± 2.6	-2.7 ± 3.1	1.0 ± 1.2
Fair	Ferm					14.1 ± 3.3	12.1 ± 2.6
Fair	Kngv					10.1 ± 2.6	11.4 ± 2.5
Fair	Marb					13.8 ± 3.0	13.3 ± 2.5
Fair	Monr					-8.0 ± 3.7	5.7 ± 6.3
Fair	PCol					15.8 ± 3.0	16.0 ± 2.3
Fair	PDov					19.9 ± 2.4	19.9 ± 2.5
Fair	PSta					12.9 ± 1.4	14.3 ± 2.3
Fair	StuP					22.3 ± 2.9	23.8 ± 2.7
Fair	Tole					13.0 ± 3.6	13.1 ± 2.2
Ferm	Kngv					-0.4 ± 1.4	-0.7 ± 1.8
Ferm	Marb					1.4 ± 1.3	1.2 ± 1.8
Ferm	Monr					-2.7 ± 1.1	-6.4 ± 6.0
Ferm	PCol					6.6 ± 5.2	3.9 ± 1.4
Ferm	PDov					7.6 ± 4.9	7.8 ± 1.7
Ferm	PSta					-0.8 ± 4.1	2.2 ± 1.4
Ferm	StuP					10.5 ± 5.2	11.7 ± 2.1
Ferm	Tole			1.6 ± 1.3		-1.4 ± 1.3	1.0 ± 1.4
Kngv	Marb				3.1 ± 2.3	1.6 ± 1.4	1.9 ± 1.7
Kngv	Monr					5.2 ± 1.7	-5.7 ± 6.0
Kngv	PCol					7.2 ± 4.6	4.6 ± 1.3
Kngv	PDov				8.8 ± 3.8	8.6 ± 4.1	8.5 ± 1.6
Kngv	PSta				-4.8 ± 3.6	-0.3 ± 3.4	2.9 ± 1.3
Kngv	StuP				11.0 ± 6.6	12.6 ± 4.5	12.4 ± 2.0
Kngv	Tole				4.7 ± 2.6	-0.7 ± 2.1	1.7 ± 1.3
Marb	Monr					-5.5 ± 1.5	-7.6 ± 6.0
Marb	PCol					4.6 ± 4.9	2.7 ± 1.3
Marb	PDov				5.4 ± 3.0	6.2 ± 4.5	6.6 ± 1.6
Marb	PSta				-1.0 ± 2.7	-1.3 ± 3.8	1.0 ± 1.3
Marb	StuP				7.4 ± 3.5	9.0 ± 4.9	10.5 ± 2.0
Marb	Tole				0.0 ± 1.1	-2.0 ± 1.8	-0.2 ± 1.3
Monr	PCol					7.2 ± 5.5	10.3 ± 5.9
Monr	PDov					11.0 ± 5.0	14.2 ± 6.0
Monr	PSta					6.8 ± 4.4	8.6 ± 5.9
Monr	StuP					24.1 ± 5.3	18.1 ± 6.1
Monr	Tole			6.6 ± 4.3		3.6 ± 1.4	7.4 ± 5.9
PCol	PDov					1.9 ± 1.5	3.9 ± 1.2
PCol	PSta	6.1 ±	4.6 ± 1.2	3.8 ± 0.6		-1.0 ± 2.9	-1.7 ± 0.7
PCol	StuP			4.6 ± 2.4		4.6 ± 0.9	7.8 ± 1.7
PCol	Tole					-2.3 ± 5.4	-2.9 ± 0.6
PDov	PSta			-7.0 ± 2.3	-5.7 ± 3.1	-8.1 ± 1.8	-5.6 ± 1.2
PDov	StuP				8.0 ± 3.5	4.6 ± 1.4	3.9 ± 1.9
PDov	Tole				4.7 ± 3.7	-8.5 ± 4.9	-6.8 ± 1.2
PSta	StuP				11.4 ± 3.3	12.0 ± 2.3	9.5 ± 1.7
PSta	Tole				-2.8 ± 1.3	-2.2 ± 4.0	-1.2 ± 0.6
StuP	Tole				-10.3 ± 4.5	-12.2 ± 5.5	-10.7 ± 1.6

TABLE DR4. COMPARISON OF RELATIVE VERTICAL VELOCITIES AND THEIR STANDARD DEVIATION IN CM/CENTURY BETWEEN GAUGES ON LAKE MICHIGAN-HURON.

Gauge pair		Coordinating Com., 1977	Tait and Bolduc, 1985	Carrera et al, 1991	Tushingham, 1992	This Study Method 1	This Study Method 3
Calu	Coll	31.7 ± 2.1			29.1 ± 1.5	26.7 ± 3.9	27.0 ± 1.0
Calu	DeTo3					27.0 ± 3.2	27.7 ± 1.1
Calu	Esse3				10.5 ± 2.0	8.0 ± 2.1	9.1 ± 1.1
Calu	Gode	10.4 ± 2.4			8.9 ± 1.0	8.5 ± 3.5	8.9 ± 1.0
Calu	Gree3				5.0 ± 2.3	3.0 ± 2.1	4.2 ± 1.1
Calu	Harb	12.5 ± 1.8			13.2 ± 1.1	11.7 ± 2.9	10.5 ± 1.0
Calu	Harr				13.3 ± 3.2	16.1 ± 2.9	18.4 ± 1.3
Calu	Holl				3.6 ± 1.6	3.2 ± 1.9	2.5 ± 1.1
Calu	Kewa					-0.9 ± 1.8	1.9 ± 1.9
Calu	Lake				11.0 ± 1.9	9.6 ± 2.6	10.4 ± 0.7
Calu	Litt					34.3 ± 3.9	37.4 ± 1.2
Calu	Ludi				-5.3 ± 1.8	-3.0 ± 2.4	-1.8 ± 1.1
Calu	Mack	20.1 ± 2.1			22.1 ± 1.1	20.5 ± 3.3	20.4 ± 1.0
Calu	Milw3	-4.9 ± 1.2		-4.5 ± 0.7	-2.4 ± 1.0	-5.1 ± 1.8	-4.0 ± 1.0
Calu	Parr				29.2 ± 3.7	32.2 ± 4.0	34.7 ± 1.2
Calu	Plnl				17.0 ± 3.9	16.7 ± 2.7	19.8 ± 1.3
Calu	StuB	7.6 ± 1.8			10.5 ± 1.4	6.9 ± 2.3	6.6 ± 1.0
Calu	Thes	31.4 ± 2.1			29.4 ± 1.3	31.1 ± 3.4	31.2 ± 1.0
Calu	Tobe				15.3 ± 5.0	24.5 ± 3.8	27.1 ± 1.2
Coll	DeTo3					3.0 ± 1.8	0.7 ± 1.1
Coll	Esse3				-13.7 ± 2.1	-15.1 ± 3.1	-17.9 ± 1.1
Coll	Gode	-20.4 ± 1.5	-20.6 ± 1.6	-18.9 ± 0.4	-18.7 ± 0.7	-18.2 ± 1.5	-18.1 ± 1.0
Coll	Gree3				-17.1 ± 2.2	-20.2 ± 3.9	-22.8 ± 1.1
Coll	Harb	-19.2 ± 0.6			-15.8 ± 0.4	-14.5 ± 1.6	-16.5 ± 1.0
Coll	Harr				-4.2 ± 2.8	-6.0 ± 1.6	-8.6 ± 1.3
Coll	Holl				-19.8 ± 3.0	-23.8 ± 3.2	-24.5 ± 1.1
Coll	Kewa					-22.1 ± 3.5	-25.1 ± 1.9
Coll	Lake				-11.7 ± 2.1	-14.0 ± 2.0	-16.6 ± 0.7
Coll	Litt					14.9 ± 1.9	10.4 ± 1.2
Coll	Ludi				-31.8 ± 2.0	-30.7 ± 3.0	-28.8 ± 1.1
Coll	Mack	-11.3 ± 1.2			-7.2 ± 0.7	-5.9 ± 2.1	-6.6 ± 1.0
Coll	Milw3	-36.3 ± 1.8			-31.4 ± 0.8	-32.4 ± 3.7	-31.0 ± 1.0
Coll	Parr			12.0 ± 1.2	12.2 ± 1.9	11.0 ± 1.1	7.7 ± 1.2
Coll	Plnl				-0.6 ± 3.6	-3.0 ± 2.7	-7.2 ± 1.3
Coll	StuB	-24.1 ± 1.5			-19.1 ± 0.8	-20.8 ± 3.3	-20.4 ± 1.0
Coll	Thes	0.0 ± 0.9		1.8 ± 0.6	1.7 ± 0.7	4.1 ± 1.7	4.2 ± 1.0
Coll	Tobe			4.2 ± 1.8	4.3 ± 2.9	3.4 ± 1.3	0.1 ± 1.2
DeTo3	Esse3					-19.3 ± 2.7	-18.6 ± 1.2
DeTo3	Gode					-21.0 ± 1.9	-18.8 ± 1.1
DeTo3	Gree3					-24.3 ± 3.1	-23.5 ± 1.2
DeTo3	Harb					-15.3 ± 1.6	-17.2 ± 1.1
DeTo3	Harr					-9.9 ± 1.3	-9.3 ± 1.4
DeTo3	Holl					-26.2 ± 2.4	-25.2 ± 1.1
DeTo3	Kewa					-27.6 ± 2.6	-25.8 ± 2.0
DeTo3	Lake					-17.9 ± 2.0	-17.3 ± 0.8
DeTo3	Litt					9.9 ± 1.7	9.7 ± 1.3
DeTo3	Ludi					-34.2 ± 2.1	-29.5 ± 1.1
DeTo3	Mack					-6.1 ± 1.1	-7.3 ± 1.1
DeTo3	Milw3					-31.8 ± 2.9	-31.7 ± 1.1
DeTo3	Parr					6.5 ± 1.7	7.0 ± 1.3
DeTo3	Plnl					-9.0 ± 1.5	-7.9 ± 1.4
DeTo3	StuB					-22.4 ± 2.4	-21.1 ± 1.1
DeTo3	Thes			3.2 ± 0.8	2.7 ± 1.1	3.5 ± 1.1	3.5 ± 1.1
DeTo3	Tobe					-1.4 ± 1.5	-0.6 ± 1.3
Esse3	Gode				-3.3 ± 2.9	-1.6 ± 2.9	-0.2 ± 1.1
Esse3	Gree3				-4.9 ± 1.4	-5.0 ± 2.2	-4.9 ± 1.3
Esse3	Harb			1.7 ± 1.9	3.7 ± 1.3	4.5 ± 2.2	1.4 ± 1.1
Esse3	Harr				8.4 ± 2.3	10.8 ± 2.4	9.3 ± 1.4
Esse3	Holl				-7.8 ± 1.9	-6.2 ± 2.1	-6.6 ± 1.2
Esse3	Kewa					-6.3 ± 2.1	-7.2 ± 2.0
Esse3	Lake				1.1 ± 1.4	1.4 ± 1.9	1.3 ± 0.9
Esse3	Litt					30.5 ± 3.3	28.3 ± 1.3
Esse3	Ludi				-16.5 ± 1.7	-14.8 ± 2.4	-10.9 ± 1.2
Esse3	Mack				12.7 ± 1.8	14.4 ± 2.7	11.3 ± 1.1
Esse3	Milw3				-15.3 ± 1.8	-13.5 ± 2.2	-13.1 ± 1.1
Esse3	Parr				25.8 ± 3.4	27.3 ± 3.4	25.6 ± 1.3
Esse3	Plnl				10.7 ± 3.1	12.5 ± 2.5	10.7 ± 1.4
Esse3	StuB				-4.7 ± 1.6	-3.4 ± 2.0	-2.5 ± 1.1
Esse3	Thes				16.7 ± 2.4	22.6 ± 2.9	22.1 ± 1.1
Esse3	Tobe				16.4 ± 4.0	20.3 ± 3.2	18.0 ± 1.3

TABLE DR4. COMPARISON OF RELATIVE VERTICAL VELOCITIES AND THEIR STANDARD DEVIATION IN CM/CENTURY BETWEEN GAUGES ON LAKE MICHIGAN-HURON (CONTINUED...).

Gauge pair		Coordinating Com., 1977	Tait and Bolduc, 1985	Carrera et al, 1991	Tushingam, 1992	This Study Method 1	This Study Method 3
Gode	Gree3				-0.8 ± 3.5	-3.4 ± 3.8	-4.7 ± 1.1
Gode	Harb	1.5 ± 1.2	3.7 ± 1.4	2.3 ± 0.4	2.3 ± 0.6	3.7 ± 1.4	1.6 ± 1.0
Gode	Harr				8.6 ± 4.9	9.8 ± 1.6	9.5 ± 1.3
Gode	Holl				-4.9 ± 3.8	-5.9 ± 2.9	-6.4 ± 1.1
Gode	Kewa					-3.4 ± 3.2	-7.0 ± 1.9
Gode	Lake			2.8 ± 1.6	3.8 ± 2.7	2.3 ± 1.9	1.5 ± 0.7
Gode	Litt					30.5 ± 2.3	28.5 ± 1.2
Gode	Ludi				-14.6 ± 2.4	-13.4 ± 2.9	-10.7 ± 1.1
Gode	Mack	9.4 ± 1.5	11.7 ± 1.5		11.6 ± 0.7	12.4 ± 2.2	11.5 ± 1.0
Gode	Milw3	-14.9 ± 1.8	-13.1 ± 1.6		-12.7 ± 0.9	-14.3 ± 3.3	-12.9 ± 1.0
Gode	Parr				26.8 ± 3.6	27.0 ± 1.9	25.8 ± 1.2
Gode	Plnl				8.7 ± 5.8	11.9 ± 2.7	10.9 ± 1.3
Gode	StuB	-3.0 ± 1.5			-1.4 ± 0.8	-2.6 ± 3.1	-2.3 ± 1.0
Gode	Thes	20.7 ± 1.2	21.5 ± 1.6		20.8 ± 0.9	22.4 ± 1.9	22.3 ± 1.0
Gode	Tobe				16.9 ± 5.8	19.0 ± 1.9	18.2 ± 1.2
Gree3	Harb				8.1 ± 1.4	9.7 ± 3.1	6.3 ± 1.1
Gree3	Harr				13.1 ± 2.2	15.5 ± 3.1	14.2 ± 1.4
Gree3	Holl				-3.5 ± 1.5	-1.7 ± 2.0	-1.7 ± 1.2
Gree3	Kewa					1.3 ± 1.7	-2.3 ± 2.0
Gree3	Lake				6.1 ± 1.7	6.8 ± 2.9	6.2 ± 0.9
Gree3	Litt					33.6 ± 3.8	33.2 ± 1.3
Gree3	Ludi				-11.5 ± 1.3	-10.0 ± 2.1	-6.0 ± 1.2
Gree3	Mack				18.0 ± 2.1	19.4 ± 3.0	16.2 ± 1.1
Gree3	Milw3				-11.0 ± 1.7	-8.7 ± 1.8	-8.2 ± 1.1
Gree3	Parr				29.1 ± 2.7	31.7 ± 4.1	30.5 ± 1.3
Gree3	Plnl				14.3 ± 2.8	16.0 ± 2.4	15.6 ± 1.4
Gree3	StuB			-1.7 ± 1.7	0.0 ± 1.6	1.3 ± 1.6	2.4 ± 1.1
Gree3	Thes				21.5 ± 2.4	27.5 ± 3.2	27.0 ± 1.1
Gree3	Tobe				17.9 ± 3.2	23.7 ± 3.8	22.9 ± 1.3
Harb	Harr			4.7 ± 1.2	4.9 ± 1.2	5.2 ± 0.9	7.9 ± 1.3
Harb	Holl				-11.9 ± 1.5	-8.7 ± 2.3	-8.0 ± 1.1
Harb	Kewa					-11.0 ± 2.6	-8.6 ± 1.9
Harb	Lake				-2.5 ± 1.1	-3.2 ± 0.9	-0.1 ± 0.7
Harb	Litt					24.8 ± 2.0	26.9 ± 1.2
Harb	Ludi				-20.2 ± 1.1	-13.6 ± 2.6	-12.3 ± 1.1
Harb	Mack	7.6 ± 1.2			9.1 ± 0.4	8.9 ± 1.8	9.9 ± 1.0
Harb	Milw3	-17.1 ± 1.5			-13.7 ± 0.4	-14.5 ± 2.9	-14.5 ± 1.0
Harb	Parr				21.7 ± 1.8	21.9 ± 1.8	24.2 ± 1.2
Harb	Plnl				7.1 ± 2.3	6.8 ± 2.1	9.3 ± 1.3
Harb	StuB	-5.2 ± 1.2			-3.3 ± 0.6	-5.3 ± 2.5	-3.9 ± 1.0
Harb	Thes	19.2 ± 1.2			17.5 ± 0.6	18.7 ± 1.6	20.7 ± 1.0
Harb	Tobe				11.2 ± 2.6	14.2 ± 1.6	16.6 ± 1.2
Harr	Holl				-16.1 ± 2.1	-17.0 ± 2.3	-15.9 ± 1.4
Harr	Kewa					-15.9 ± 2.6	-16.5 ± 2.1
Harr	Lake				-6.8 ± 2.3	-8.1 ± 1.4	-8.0 ± 1.1
Harr	Litt					17.7 ± 1.7	19.0 ± 1.5
Harr	Ludi				-21.0 ± 2.1	-23.2 ± 2.2	-20.2 ± 1.4
Harr	Mack				6.9 ± 2.2	5.9 ± 1.5	2.0 ± 1.3
Harr	Milw3				-19.2 ± 2.8	-21.7 ± 2.8	-22.4 ± 1.3
Harr	Parr				17.5 ± 2.3	17.6 ± 1.7	16.3 ± 1.5
Harr	Plnl				2.6 ± 2.6	1.4 ± 1.9	1.4 ± 1.6
Harr	StuB				-10.0 ± 2.1	-11.9 ± 2.4	-11.8 ± 1.3
Harr	Thes				11.3 ± 3.4	13.6 ± 1.5	12.8 ± 1.3
Harr	Tobe				6.6 ± 2.9	8.8 ± 1.6	8.7 ± 1.5
Holl	Kewa					-0.4 ± 1.4	-0.6 ± 2.0
Holl	Lake				10.3 ± 1.7	8.1 ± 2.3	7.9 ± 0.8
Holl	Litt					35.5 ± 3.2	34.9 ± 1.3
Holl	Ludi				-5.5 ± 1.4	-3.2 ± 1.5	-4.3 ± 1.1
Holl	Mack				24.7 ± 2.4	18.1 ± 2.4	17.9 ± 1.1
Holl	Milw3			-14.7 ± 1.3	-2.8 ± 1.4	-7.3 ± 1.6	-6.5 ± 1.1
Holl	Parr				32.8 ± 2.8	33.1 ± 3.4	32.2 ± 1.3
Holl	Plnl				19.1 ± 2.6	18.2 ± 1.9	17.3 ± 1.4
Holl	StuB				5.8 ± 1.4	4.2 ± 1.4	4.1 ± 1.1
Holl	Thes				26.5 ± 2.9	30.2 ± 2.5	28.7 ± 1.1
Holl	Tobe				21.3 ± 3.7	25.5 ± 3.0	24.6 ± 1.3

TABLE DR4. COMPARISON OF RELATIVE VERTICAL VELOCITIES AND THEIR STANDARD DEVIATION IN CM/CENTURY BETWEEN GAUGES ON LAKE MICHIGAN-HURON (CONTINUED).

Gauge pair	Coordinating Com., 1977	Tait and Bolduc, 1985	Carrera et al, 1991	Tushingam, 1992	This Study Method 1	This Study Method 3
Kewa Lake					6.9 ± 2.5	8.5 ± 1.8
Kewa Litt					31.0 ± 3.4	35.5 ± 2.1
Kewa Ludi					-5.2 ± 1.5	-3.7 ± 2.0
Kewa Mack					20.1 ± 2.4	18.5 ± 1.9
Kewa Milw3					-8.1 ± 1.3	-5.9 ± 1.9
Kewa Parr					31.7 ± 3.7	32.8 ± 2.1
Kewa Plnl					17.0 ± 1.9	17.9 ± 2.1
Kewa StuB			14.5 ± 3.3		4.9 ± 1.0	4.7 ± 1.9
Kewa Thes					34.1 ± 2.8	29.3 ± 1.9
Kewa Tobe					32.0 ± 3.5	25.2 ± 2.1
Lake Litt					28.2 ± 2.5	27.0 ± 1.0
Lake Ludi				-17.1 ± 1.9	-16.2 ± 2.4	-12.2 ± 0.8
Lake Mack				12.9 ± 2.0	13.9 ± 2.2	10.0 ± 0.7
Lake Milw3				-16.2 ± 1.8	-14.9 ± 2.5	-14.4 ± 0.7
Lake Parr				22.8 ± 2.5	24.9 ± 2.3	24.3 ± 1.0
Lake Plnl				9.9 ± 3.1	10.6 ± 2.3	9.4 ± 1.1
Lake StuB				-5.7 ± 1.6	-5.0 ± 2.4	-3.8 ± 0.7
Lake Thes				16.4 ± 2.8	21.5 ± 2.2	20.8 ± 0.7
Lake Tobe				11.7 ± 3.9	16.5 ± 2.2	16.7 ± 1.0
Litt Ludi					-41.6 ± 3.0	-39.2 ± 1.3
Litt Mack					-13.3 ± 1.8	-17.0 ± 1.2
Litt Milw3					-39.3 ± 3.7	-41.4 ± 1.2
Litt Parr					-3.2 ± 1.6	-2.7 ± 1.4
Litt Plnl					-14.4 ± 2.3	-17.6 ± 1.5
Litt StuB					-30.5 ± 3.3	-30.8 ± 1.2
Litt Thes			-20.4 ± 2.4		-4.4 ± 1.7	-6.2 ± 1.2
Litt Tobe					-8.2 ± 1.5	-10.3 ± 1.4
Ludi Mack				29.1 ± 1.4	23.7 ± 2.3	22.2 ± 1.1
Ludi Milw3			-2.6 ± 1.5	0.9 ± 1.5	-3.6 ± 2.1	-2.2 ± 1.1
Ludi Parr				38.7 ± 2.3	39.2 ± 3.2	36.5 ± 1.3
Ludi Plnl				22.0 ± 1.6	23.0 ± 1.4	21.6 ± 1.4
Ludi StuB			11.6 ± 0.7	11.5 ± 0.9	10.3 ± 1.4	8.4 ± 1.1
Ludi Thes				34.2 ± 1.5	37.1 ± 2.2	33.0 ± 1.1
Ludi Tobe				28.4 ± 2.9	31.1 ± 2.9	28.9 ± 1.3
Mack Milw3	-24.7 ± 1.5			-24.2 ± 0.6	-25.3 ± 2.9	-24.4 ± 1.0
Mack Parr				8.2 ± 2.7	10.0 ± 2.0	14.3 ± 1.2
Mack Plnl			-6.8 ± 1.8	-4.3 ± 2.1	-4.3 ± 1.4	-0.6 ± 1.3
Mack StuB	-12.8 ± 1.2		-13.9 ± 0.6	-12.0 ± 0.6	-14.0 ± 2.5	-13.8 ± 1.0
Mack Thes	11.6 ± 1.2		9.2 ± 0.5	9.4 ± 0.8	10.1 ± 1.3	10.8 ± 1.0
Mack Tobe				2.6 ± 3.6	3.1 ± 1.8	6.7 ± 1.2
Milw3 Parr				35.3 ± 3.6	37.2 ± 3.9	38.7 ± 1.2
Milw3 Plnl				23.2 ± 3.4	22.9 ± 2.2	23.8 ± 1.3
Milw3 StuB	12.2 ± 1.2			12.5 ± 0.5	11.8 ± 1.7	10.6 ± 1.0
Milw3 Thes	36.0 ± 1.5			34.5 ± 1.1	36.8 ± 3.0	35.2 ± 1.0
Milw3 Tobe				22.8 ± 4.6	30.2 ± 3.6	31.1 ± 1.2
Parr Plnl				-15.1 ± 2.7	-14.3 ± 2.6	-14.9 ± 1.5
Parr StuB				-27.2 ± 2.5	-28.0 ± 3.5	-28.1 ± 1.2
Parr Thes				-4.2 ± 2.2	-2.4 ± 1.7	-3.5 ± 1.2
Parr Tobe				-10.1 ± 3.2	-8.5 ± 1.3	-7.6 ± 1.4
Plnl StuB				-14.9 ± 1.8	-13.1 ± 1.6	-13.2 ± 1.3
Plnl Thes				10.2 ± 2.9	13.2 ± 1.7	11.4 ± 1.3
Plnl Tobe				9.0 ± 3.7	7.8 ± 2.4	7.3 ± 1.5
StuB Thes	24.4 ± 1.2			23.7 ± 0.8	25.0 ± 2.6	24.6 ± 1.0
StuB Tobe				16.2 ± 3.9	20.1 ± 3.2	20.5 ± 1.2
Thes Tobe				-2.6 ± 2.9	-5.5 ± 1.4	-4.1 ± 1.2

TABLE DR5. COMPARISON OF RELATIVE VERTICAL VELOCITIES AND THEIR STANDARD DEVIATION IN CM/CENTURY BETWEEN GAUGES ON LAKE SUPERIOR.

Gauge pair		Coordinating Com., 1977	Tait and Bolduc, 1985	Carrera et al, 1991	Tushingham, 1992	This Study Method 1	This Study Method 3
Dulu	Gran				22.3 ± 1.2	19.4 ± 1.2	17.7 ± 0.9
Dulu	Gros				29.5 ± 4.1	28.6 ± 2.5	26.9 ± 0.8
Dulu	Marq3	11.3 ± 0.9			11.7 ± 0.4	13.1 ± 2.5	13.1 ± 0.4
Dulu	Mich	52.1 ± 1.5	50.9 ± 1.0		47.1 ± 0.9	50.2 ± 2.5	48.6 ± 0.4
Dulu	Onto				8.0 ± 1.9	8.5 ± 1.8	6.6 ± 0.8
Dulu	Poin	23.5 ± 1.2			25.8 ± 0.8	26.9 ± 2.6	25.3 ± 0.3
Dulu	Ross					55.1 ± 2.2	52.8 ± 0.9
Dulu	Thun	29.0 ± 1.2	29.9 ± 0.9	30.8 ± 0.4	29.9 ± 0.6	29.4 ± 1.5	27.7 ± 0.4
Dulu	TwoH			5.9 ± 0.5		4.9 ± 0.9	4.1 ± 0.6
Gran	Gran				9.5 ± 14	7.2 ± 1.8	9.2 ± 1.1
Gran	Marq3				-2.7 ± 1.8	-0.7 ± 1.3	-4.6 ± 0.9
Gran	Mich				22.5 ± 2.8	29.6 ± 1.8	30.9 ± 0.9
Gran	Onto				-15.0 ± 2.5	-12.1 ± 1.3	-11.1 ± 1.1
Gran	Poin				9.6 ± 2.0	9.0 ± 1.8	7.6 ± 0.8
Gran	Ross					35.0 ± 1.8	35.1 ± 1.1
Gran	Thun			15.3 ± 2.2	15.3 ± 3.5	10.0 ± 1.2	10.0 ± 0.9
Gran	TwoH					-11.9 ± 0.8	-13.6 ± 0.9
Gros	Marq3				-14.4 ± 4.0	-10.7 ± 1.4	-13.8 ± 0.8
Gros	Mich				17.1 ± 4.2	18.9 ± 1.4	21.7 ± 0.8
Gros	Onto				-20.5 ± 11.0	-20.7 ± 2.0	-20.3 ± 1.0
Gros	Poin			3.4 ± 4.0	3.4 ± 9.7	-0.2 ± 1.2	-1.6 ± 0.7
Gros	Ross					27.2 ± 2.0	25.9 ± 1.1
Gros	Thun				0.6 ± 5.1	0.2 ± 2.1	0.8 ± 0.8
Gros	TwoH					-21.4 ± 2.3	-22.8 ± 0.9
Marq3	Mich	40.8 ± 0.9	39.4 ± 0.8	35.4 ± 0.5	33.7 ± 0.8	33.9 ± 1.3	35.5 ± 0.4
Marq3	Onto			-7.5 ± 2.1	-12.4 ± 1.8	-9.4 ± 1.5	-6.5 ± 0.8
Marq3	Poin	12.2 ± 0.6			11.1 ± 0.5	10.6 ± 1.1	12.2 ± 0.3
Marq3	Ross					35.7 ± 1.9	39.7 ± 0.9
Marq3	Thun	17.7 ± 1.2	17.5 ± 1.1	18.7 ± 0.5	16.9 ± 0.6	13.0 ± 1.8	14.6 ± 0.4
Marq3	TwoH					-9.0 ± 1.8	-9.0 ± 0.6
Mich	Onto				-36.7 ± 2.7	-39.1 ± 1.7	-42.0 ± 0.8
Mich	Poin	-29.0 ± 0.9		-25.4 ± 0.5	-25.3 ± 0.8	-23.3 ± 1.3	-23.3 ± 0.3
Mich	Ross					5.7 ± 2.0	4.2 ± 0.9
Mich	Thun	-23.2 ± 1.5	-21.0 ± 1.2		-17.3 ± 1.0	-20.9 ± 2.0	-20.9 ± 0.4
Mich	TwoH					-45.0 ± 2.3	-44.5 ± 0.6
Onto	Poin	23.5 ± 1.2			20.5 ± 2.0	19.2 ± 1.8	18.7 ± 0.7
Onto	Ross					46.3 ± 2.0	46.2 ± 1.1
Onto	Thun				26.8 ± 2.5	21.1 ± 1.5	21.1 ± 0.8
Onto	TwoH					1.2 ± 1.7	-2.5 ± 0.9
Poin	Ross					25.8 ± 2.1	27.5 ± 0.8
Poin	Thun	5.8 ± 1.2			5.8 ± 0.9	2.5 ± 2.2	2.4 ± 0.3
Poin	TwoH					-20.5 ± 2.3	-21.2 ± 0.5
Ross	Thun			-27.4 ± 3.2		-24.9 ± 1.7	-25.1 ± 0.9
Ross	TwoH					-57.7 ± 2.2	-48.7 ± 0.9
Thun	TwoH					-23.8 ± 1.4	-23.6 ± 0.6

TABLE DR6 - COUNT OF OUTLIERS (MONTHLY LAKE LEVEL AVERAGES REJECTED DURING THIS STUDY) PER MONTH AND PER SITE FOR EACH LAKE

Gauge	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	# of meas.	% of outliers
<i>Lake Ontario</i>															
Burl	2	0	0	1	0	2	0	0	0	1	3	1	10	349	3%
Cape	7	7	6	4	1	0	3	4	1	3	2	9	47	997	5%
Cobo	2	1	3	1	1	0	1	0	1	1	1	1	13	531	2%
Kngs	3	1	2	2	2	0	0	0	1	1	2	2	16	1019	2%
Olco	0	0	1	0	0	0	0	0	0	0	0	0	1	377	0%
Oswe	9	8	11	13	4	2	4	2	2	5	8	9	77	1692	5%
PWel	0	1	0	1	1	0	0	3	1	0	3	1	11	567	2%
Roch	4	7	9	12	3	2	4	2	2	5	8	8	66	1143	6%
Toro	7	3	3	4	0	0	0	2	3	2	2	2	28	1018	3%
Total	34	28	35	38	12	6	12	13	11	18	29	33	269		
<i>Lake Erie</i>															
Barc	6	1	0	0	0	0	0	0	1	0	3	5	16	306	5%
BarP	0	0	0	0	0	0	0	0	0	2	4	5	11	411	3%
Buff	23	2	3	1	0	0	0	0	0	5	33	37	104	1434	7%
Clev	5	2	0	0	0	0	0	0	0	0	10	9	26	1692	2%
Erie	5	1	0	0	0	0	0	0	0	4	8	18	18	475	4%
Erio	0	0	0	0	0	0	0	0	0	0	0	1	1	510	0%
Fair	0	0	0	0	0	0	0	0	0	0	0	0	0	304	0%
Ferm	4	2	0	1	0	0	0	0	0	1	6	6	20	447	4%
Kngv	0	0	0	0	0	0	0	0	0	2	5	7	7	456	2%
Marb	5	0	0	1	0	0	0	0	0	1	4	8	19	465	4%
Monr	0	0	0	0	0	0	0	0	0	2	2	3	7	157	4%
PCol	16	0	0	0	0	0	0	0	0	1	15	19	51	900	6%
PDov	7	1	0	2	1	1	0	0	0	0	3	9	24	490	5%
PSta	1	0	0	0	0	0	0	0	0	0	1	0	2	884	0%
StuP	13	0	0	0	0	0	0	0	0	1	11	14	39	383	10%
Tole	25	15	12	8	2	0	0	1	3	11	50	44	171	1085	16%
Total	110	24	15	13	3	1	0	1	4	24	148	173	516		
<i>Lake Michigan-Huron</i>															
Calu	8	8	11	9	2	1	1	1	5	2	10	12	70	1160	6%
Coll	1	0	1	0	0	0	0	0	2	1	7	2	14	886	2%
DeTo3	0	0	0	0	0	0	0	0	1	0	0	0	1	686	0%
Esse3	3	2	6	6	1	0	0	0	0	1	10	5	34	587	6%
Gode	0	3	0	1	1	1	1	0	0	0	2	4	13	884	1%
Gree3	3	2	6	8	6	1	0	0	1	3	12	10	52	588	9%
Harb	1	1	1	3	0	0	0	0	0	0	1	2	9	1692	1%
Harr	0	0	0	1	0	0	0	0	0	0	0	0	1	416	0%
Holl	1	0	1	1	0	1	0	0	0	0	0	0	4	528	1%
Kewa	1	0	1	1	0	0	0	0	0	0	2	0	5	286	2%
Lake	0	0	0	0	0	1	1	0	1	0	1	0	4	507	1%
Litt	3	0	1	0	0	1	4	4	3	3	3	3	25	497	5%
Ludi	1	0	0	1	0	2	0	0	0	0	0	2	6	669	1%
Mack	0	2	2	0	0	0	0	0	0	0	2	0	6	1213	0%
Milw3	4	5	6	5	0	0	0	0	1	0	4	7	32	1687	2%
Parr	1	1	2	1	1	0	0	0	0	2	4	1	13	485	3%
Plnl	0	1	0	0	0	0	0	0	0	0	0	1	2	431	0%
StuB	6	4	3	4	2	4	1	1	1	0	1	5	32	1016	3%
Thes	1	0	1	0	0	0	0	0	0	0	4	0	6	866	1%
Tobe	2	0	0	0	0	0	0	0	0	0	0	0	2	458	0%
Total	36	29	42	41	13	12	8	6	15	12	63	54	331		
<i>Lake Superior</i>															
Dulu	10	7	1	1	6	3	1	0	2	3	4	3	41	1571	3%
Gran	0	0	1	0	0	0	0	0	0	0	0	0	1	398	0%
Gros	7	1	0	2	2	2	2	2	3	0	2	4	27	454	6%
Marq3	6	2	1	1	5	3	1	0	1	2	3	1	26	1701	2%
Mich	2	0	0	0	1	1	1	0	0	1	2	3	11	834	1%
Onto	2	2	3	4	1	0	1	0	0	0	0	1	14	450	3%
Poin	8	1	0	0	0	0	0	0	0	1	2	1	13	768	2%
Ross	2	0	2	1	0	0	1	0	0	0	0	0	6	383	2%
Thun	0	0	1	0	0	0	0	0	0	0	0	0	1	839	0%
TwoH	1	2	0	0	1	0	1	0	0	1	0	1	7	581	1%
Total	38	15	9	9	16	9	8	2	6	8	13	14	147		