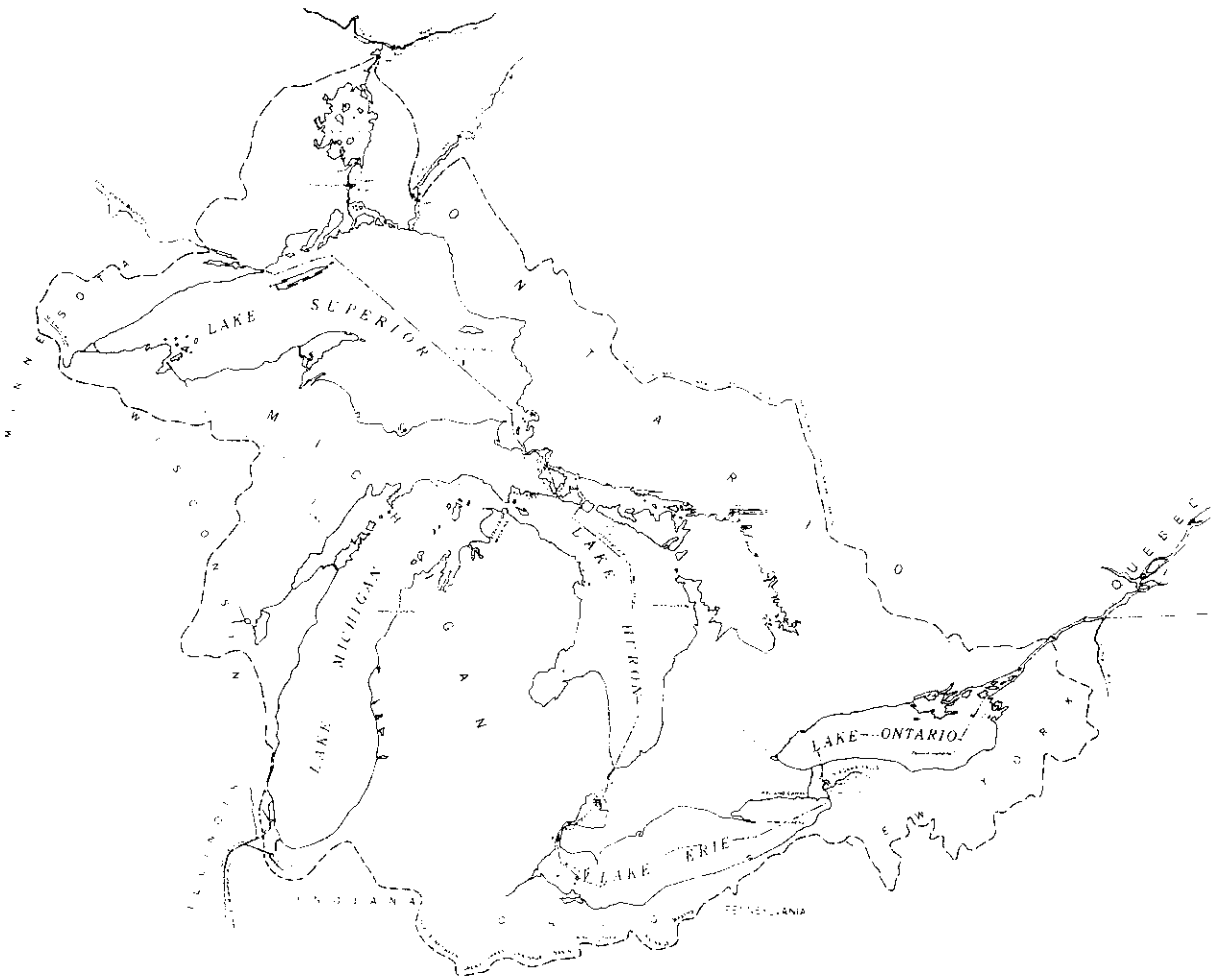
ESTABLISHMENT OF INTERNATIONAL GREAT LAKES DATUM (1985)



by
The Coordinating Committee
on
Great Lakes Basic Hydraulic and Hydrologic Data
December 1995

ESTABLISHMENT OF INTERNATIONAL GREAT LAKES DATUM (1985)

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ESTABLISHMENT OF INTERNATIONAL GREAT LAKES DATUM (1985)

INTERIM REPORT

INTRODUCTION

1. *Requirement for Internationally Coordinated Hydraulic and Hydrologic Data*. The Great Lakes-St. Lawrence River system extends some 3,200 km from the headwaters of streams tributary to Lake Superior to the Gulf of St. Lawrence. The system drains a great interior basin of about 775,000 square km to the outlet of Lake Ontario, reaches almost halfway across the North American continent, and borders upon eight states of the United States and two provinces of Canada. This vast series of lakes and rivers is shared by the United States and Canada. The joint use of these waters poses numerous international problems for which the solution requires using coordinated basic data.

2. Prior to 1953 data pertaining to the hydraulic and hydrologic factors of the Great Lakes and the St. Lawrence River were collected and compiled independently by the responsible federal agencies in Canada and the United States, with only superficial and informal coordination of some of the data. As a consequence, the data in many instances were developed on different bases and datums and were divergent in other respects.

3. *Establishment of International Study*. International problems were greatly increased by the advent of extremely high lake levels in 1952 and by the imminent power and navigation development in the St. Lawrence River. Recognizing that continued independent development of the basic data was illogical under the circumstances and that early agreement upon the hydraulic and hydrologic factors was of paramount importance, the Corps of Engineers, United States Army, and the Departments of Transport, Mines and Technical Surveys, and Resources and Development, Canada, opened negotiations early in 1953 to establish a basis for the development and acceptance of identical data by both countries. The negotiations culminated in a meeting of representatives of the interested agencies at Ottawa on 7 May 1953.

4. At the meeting the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data was formed to study the problem and to establish a basis of procedure. Recommendations of this committee were to be advisory to the agencies of the United States and Canada which are charged with the responsibility for collecting and compiling the Great Lakes hydraulic and hydrologic data. The committee was constituted as follows:

Canada	United States
T. M. Patterson, Water Resources Division, Department of Resources and Development, Chairman	Gail A. Hathaway, Office, Chief of Engineers Department of the Army, Chairman
J. E. R. Ross, Geodetic Survey of Canada, Department of Mines and Technical Surveys	Edwin W. Nelson, Great Lakes Division, Corps of Engineers, U.S. Army
D. M. Ripley, Special Projects Branch, Department of Transport	W. T. Laidly, U.S. Lake Survey Corps of Engineers, U.S. Army

The present membership of the Coordinating Committee is as follows:

Canada	United States
P. P. Yee, Water Issues Division, Environment Canada, Chairman	J. W. Kangas, Corps of Engineers, Department of Army, Chairman
P. D. Richards, Canadian Hydrographic Service, Department of Fisheries and Oceans	P. C. Morris, National Oceanic and Atmospheric Administration, Department of Commerce
C. Southam, Inland Waters Directorate, Environment Canada, Secretary	R. E. Wilshaw, Corps of Engineers, Department of Army, Secretary

Messrs. C. M. Cross, A. T. Prince, R. H. Smith, D. F. Witherspoon, B. J. Tait, and J. Robinson have also served as Canadian members of the Committee while Messrs. L. D. Kirshner, F. F. Snyder, H. F. Lawhead, F. A. Blust, B. G. DeCooke and C. I. Thurlow have served as United States members of the Committee.

5. Four working groups, designated the River Flow Subcommittee, the Vertical Control Subcommittee, the Lake Levels Subcommittee and the Physical Data Subcommittee, were formed to assist the Coordinating Committee in its work. These subcommittees were directed to conduct the required technical studies through the collaboration of the appropriate agencies of Canada and the United States. In November 1988 the

"Hydrometeorology and Modelling Subcommittee" was formed to explore the coordination of hydromet and hydraulic/hydrologic response models. In September 1969, the "Vertical Control and the Lake Levels Subcommittees" were combined into one body known as the Vertical Control-Water Levels Subcommittee. The Subcommittee was normally composed of three members from Canada and three from the United States. The following persons served as members of Vertical Control Water Level Subcommittee at various times during the progress of the work reported herein:

Canada	United States
G. C. Dohler	B. G. DeCooke
W. D. Forrester	C. F. Feldscher
L. P. Robertson	G. E. Ropes
B. E. Russell	C. F. Ellingwood
E. A. MacDonald	R. M. Berry
J. M. Murakami*	D. R. Rondy
M. H. Quast	E. P. Kulp
B. J. Tait	H. A. Lippincott
F. W. Young	R. E. Wilshaw*
D. A. St. Jacques	C. T. Whalen
W. M. Archer*	D. B. Zilkoski*
P. A. Bolduc	P. C. Morris*
R. G. Sandilands*	J. A. Oyler*

*Current Members

6. *Authority*. The Vertical Control-Water Levels Subcommittee of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data was instructed to provide an International Great Lakes Datum which would be acceptable to all agencies concerned. The following subjects were determined to be within the purview of the subcommittee:

a. Establishment of a reference zero near the mouth of the St. Lawrence River,

b. First-order leveling from reference zero to Lake Ontario and between the lakes,

c. Crustal movement in the Great Lakes area, and

d. Establishment of elevations for bench marks and reference surfaces in the Great Lakes-St. Lawrence River system.

The establishment of the International Great Lakes Datum (1955), or IGLD (1955), was one of the first major accomplishments of the Coordinating Committee. Accordingly the reference zero point was established at Point-au-Père, Quebec and first-order leveling begun in 1953 was completed in 1961. The established bench mark elevations were published in September 1961 (A second edition was also published with some revisions in December 1979). The result of this effort was International Great Lakes Datum (1955). This datum was implemented January 1, 1962, and used for the following 30 years, until the effects of crustal movement, the development of a common datum between Canada, the United States, and Mexico, new surveying methods, and the deterioration of the zero reference point gauge location made it desirable to revise the datum. The Vertical Control-Water Levels Subcommittee undertook the revision of IGLD (1955) beginning in 1976 and this effort has resulted in International Great Lakes Datum (1985).

7. *Purpose and Scope*. The purpose of this report is to document the continued work of the Vertical Control-Water Levels Subcommittee in the development and establishment of International Great Lakes Datum (1985) (IGLD (1985)) and to record the new datum elevations of bench marks at water level gauging stations located throughout the Great Lakes basin.

8. *Acknowledgements*. The Coordinating Committee acknowledges and expresses its appreciation of the high caliber of service which its Vertical Control-Water Levels Subcommittee rendered in the development of the results presented herein. It recognizes and appreciates also, that other personnel and facilities of the Canadian Hydrographic Service, Department of Fisheries and Oceans; the Geodetic Survey of Canada, Department of Natural Resources Canada; and the National Ocean Service (prior to 1970, the operation and records of Great Lakes water level gauging stations were the responsibility of the U. S. Lake Survey, Corps of Engineers), National Oceanic and Atmospheric Administration, Department of Commerce were employed throughout the study. The individual efforts of Rick Sandilands, Fred Young, David Zilkoski, Emery Balazs, and Harry Lippincott and other staff in their respective agencies are gratefully acknowledged by the committee in collecting and analyzing of historical data, developing the concept for the new datum, applying the mathematical adjustment, and compiling the information for preparing this report.

NEED FOR NEW DATUM

9. As in the establishment of IGLD (1955), there continues to be two principal reasons why it is highly desirable to establish an entirely new datum. One reason is that it will correct for changes in elevation caused by crustal movement prior to the date of the new datum. Because the crust of the Earth in the Great Lakes region is moving with respect to sea level, and because the

rate of movement is not uniform throughout the area and because of local marker instability, the elevations of bench marks are changing; with respect to each other and with respect to sea level. The other reason is to provide a common datum which could be used by all agencies interested in vertical control on the Great Lakes-St. Lawrence River system.

10. There have been several vertical datums which can be identified in the Great Lakes that have been used by the two governments, the most notable of which are the Canadian Geodetic Datum (CGD) of 1928, the Georgian Bay Ship Canal Datum, the National Geodetic Vertical Datum of 1929 (NGVD (1929)), the U.S. Lake Survey 1903 Datum, the U.S. Lake Survey 1935 Datum, and the IGLD (1955). While IGLD (1955) was a much improved datum over the earlier datums, it was recognized that a new datum would be necessary in approximately 25-30 years due to movement of the earth's crust in the Great Lakes region.

DESCRIPTION OF HISTORICAL DATUMS

11. As stated, prior to 1900 there were numerous datums used on the Great Lakes as references for water levels, charting, and river and harbor improvements. In 1903 the U.S. Coast and Geodetic Survey (now National Ocean Service) made an adjustment without the use of the orthometric correction based on level lines and tide gauge records in the United States east of the Mississippi. This adjustment was available at a number of places on the Great Lakes and provided the basis for the U.S. Lake Survey 1903 Datum. This datum was extended to all major harbors around the lakes, along the connecting rivers, and down the St. Lawrence River to Cornwall, Ontario, by the U.S. Lake Survey and the Canadian Hydrographic Service through water level transfers and leveling height differences. The latter agency made use of leveling height differences supplied by the Geodetic Survey of Canada.

12. The Georgian Bay Ship Canal Datum was in effect an extension of the U.S. Lake Survey 1903 Datum, and was established by leveling differences and water level transfers. The leveling for this datum was done by the Canadian Department of Public Works in the years 1904 to 1908, and consisted of level lines from Rouses Point, New York, through Montréal, Quebec, and North Bay, Ontario, to French River, Ontario, on Georgian Bay, and from Toronto, Ontario, to North Bay, Ontario, with a connection to Collingwood, Ontario. Water level transfers were made from U.S. Lake Survey gauges to French River, Collingwood and Toronto. Elevations on Georgian Bay Ship Canal Datum were determined after adjustment around the several loops in the system. Instrumental elevations were released before the adjustment was made, so that a distinction was necessary between the adjusted and unadjusted elevations in the system. The Georgian Bay Ship Canal Datum was not in general use since the Geodetic Survey of Canada took over the Public

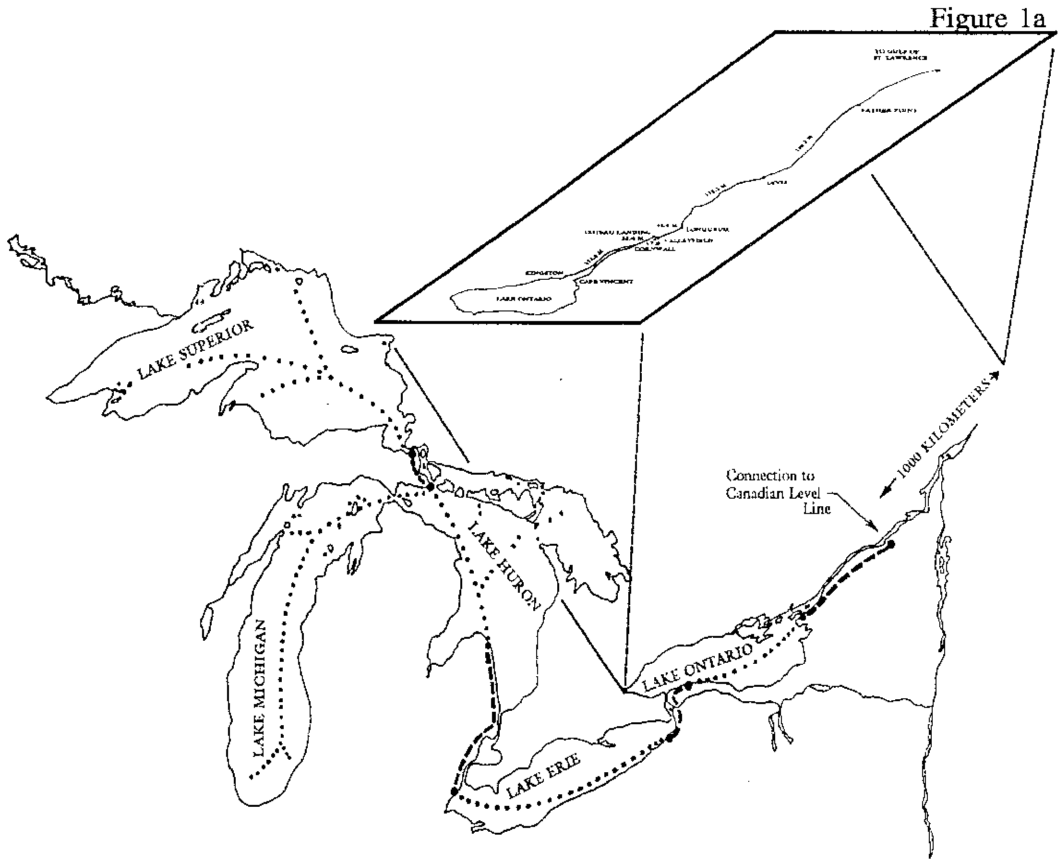


Figure 1
IGLD (1955) LEVEL LINES

Works leveling and adjusted it to the Canadian Geodetic Datum of 1928. However, it did survive locally in some areas, notably along the St. Lawrence River between Summerstown, Ontario, and Montréal, Quebec, where it was employed as a reference for water level gauges of the Canadian Hydrographic Service, and along the Trent Canal System, where it was employed as a reference datum by the Canal Services Branch of the Department of Transport. It has been replaced by IGLD and CGD.

13. By 1935, differential movement in the earth's crust was causing gauges at harbors on the same lake to show appreciable differences in water surface elevations, and the U.S. Lake Survey reopened the study of datums. A control point was chosen on each lake; Oswego, New York, on Lake Ontario; Cleveland, Ohio, on Lake Erie; Harbor Beach, Michigan, on Lake Michigan/Huron and Point Iroquois, Michigan, on Lake Superior. The bench mark elevations at the control points were adopted as given on U.S. Lake Survey 1903 Datum except for Point Iroquois, where elevations were derived

from Harbor Beach by water level transfer and leveling of 1934, between Lake Huron and Lake Superior. Bench mark elevations at other sites on the United States side of the Great Lakes were computed from these control points by water level transfers supplemented by local leveling. These resulting elevations were referred to as U.S. Lake Survey 1935 Datum. In other words, the elevations derived were the elevations of the bench marks as of 1935 with respect to their particular control point. The Canadian Hydrographic Service continued to use U.S. Lake Survey 1903 Datum.

14. The IGLD (1955) was an entirely new datum developed and established as the culmination of the international study under the charge and authority of the Coordinating Committee formed in 1953. In establishing this datum, the committee agreed that the Great Lakes-St. Lawrence River system would be considered as a unit with datum and reference surfaces based on mean water level at the outlet of the system in the Gulf of St. Lawrence. Pointe-au-Père, Quebec was chosen as the site for the new reference zero because: a) it was the outlet of the system, b) the tide gauge at that location had a long period of reliable record, c) the mean water level at that point approximates mean sea level, and d) it had been connected to the remainder of the system by first-order levels. When a new datum is established, it brings the elevations of all bench marks in the system into harmony -- that is, the assigned elevations are measurements of their respective places in the vertical. An analysis of the many miles of first-order levels and many months of gauge records used to determine the new datum indicated the year 1955 to be the best year for adoption. IGLD (1955) is a dynamic height system. For more information on IGLD (1955), readers are referred to the report by the Coordinating Committee dated December 1979, and entitled "Establishment of IGLD (1955), Second Edition".

DEVELOPMENT OF INTERNATIONAL GREAT LAKES DATUM (1985)

15. _Reference Zero_. The committee again agreed that the Great Lakes-St. Lawrence River system should be considered as a unit with datum and reference surfaces based on mean water level at the outlet of the system in the St. Lawrence River. The gauge at Pointe-au-Père, Quebec was used as the reference for IGLD (1955). Due to the deterioration of the wharf at Pointe-au-Père, the gauging station at the site was discontinued in 1984 and moved approximately five kilometers upstream to Rimouski, Quebec. The reference zero for IGLD (1985) was transferred to the new site at Rimouski, Quebec.

16. _Reference Year_. Because crustal movement causes bench marks to shift in position, it becomes very important to show the year in which the assigned elevations are true. Extensive crustal movement studies have shown that rates of movement are small enough to be negligible over a span of three to five years, and in most instances it is not necessary to make an over-all

adjustment of elevations more often than once every 25-30 years. An analysis of the gauging data used to determine the new international datum has shown the year 1985 to be the best date to adopt for the period 1982-1988.

17. *Network Concept*. The development of IGLD (1985) coincided with the development of a new North American Vertical Datum of 1988 (NAVD (1988)). This datum was to include vertical control networks of the U.S., Canada, and Mexico. Early discussions of the Coordinating Committee considered the inclusion of Great Lakes datum data in the network with the exceptions that for the Great Lakes the reference zero would remain at Pointe-au-Père, Quebec, or near the mouth of the St. Lawrence River, and the elevations would be published in the Dynamic height system, very similar to IGLD (1955). In determining the appropriate network for IGLD (1985) three separate adjustments were performed, the U.S. Network, the Canadian Network, and the U.S.- Canadian Network (combined). The U.S.-Canadian Network concept containing 78 loops of leveling and connecting to over 80 water level gauging stations in the basin was adopted for IGLD (1985).

18. *Dynamic values*. The surveying and mapping community uses several different heights systems. Two systems, orthometric and dynamic heights, are relevant to the establishment of IGLD (1985) and NAVD (1988). The geopotential numbers for individual bench marks are the same in both height systems. The requirement in the Great Lakes basin to provide an accurate measurement of potential hydraulic head is the primary reason for adopting dynamic heights. It should be noted that dynamic heights are basically geopotential numbers scaled by a constant of 980.6199 gals, normal gravity at sea level at 45 degrees latitude. Therefore, dynamic heights are also an estimate of the hydraulic head. Consequently points that have the same geopotential number have the same dynamic height.

19. Following are some of the advantages of dynamic heights:

a. In crustal movement studies, differences in the dynamic elevation of bench marks from lake to lake can be compared regardless of the route along which the leveling is done. This is also possible in the orthometric height system and with geopotential numbers.

b. Difference in dynamic heights and in geopotential numbers give an accurate measure of the potential hydraulic head between selected points. This is not true of orthometric heights.

c. If the mean surfaces of the lake are indeed level, every point on the lake surface will have the same dynamic elevation or geopotential numbers. If the lake surfaces are not level, the use of dynamic heights will make it easier to detect their departure from level.

20. The foregoing reasons define the decision to use dynamic heights in establishing IGLD (1985).

METHOD OF COMPUTATION OF DYNAMIC HEIGHTS

21. _General._ For determining a vertical control network in the Great Lakes region, the latest leveling data and water level transfer observations in the U.S. and Canada were made available. The primary network consisted of 78 loops based on the latest leveling data. Also, the network connected to over 80 U.S. and Canadian water level gauging stations. Additionally, 25 connections were made between the U.S. and Canadian national vertical control networks.

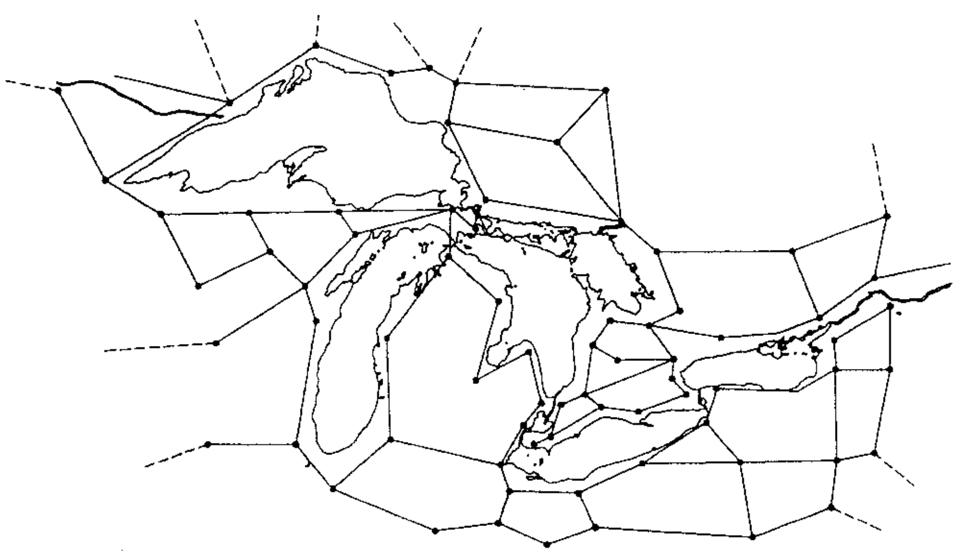


Figure 2
NAVD LEVELING LOOPS - NETWORK

22. Most of the leveling data involved were observed between the years 1965 and 1986. For the water level transfers, data for the four months June to September for the seven year period 1982-1988 were used to calculate a mean water level (MWL) at each permanent gauging station.

23. Corrections applied to the U.S. leveling observations were rod scale, rod temperature, level collimation, astronomic refraction and magnetic effects. These corrections to observed leveling data are to minimize the effects of known systematic errors. Approximately one-half of the vertical control network was generated from Canadian leveling data and this data in turn was corrected for rod scale, astronomic, refraction, and magnetic effects.

24. As stated earlier in paragraph 18, geopotential numbers relate dynamic heights and orthometric heights. A geopotential number (C) of a bench mark is the difference in potential measured from the reference surface to the equipotential surface passing through the mark. It is the amount of work required to raise a unit mass of 1 kg against gravity through the orthometric height to the mark. A geopotential difference is a difference in potential which can indicate hydraulic head.

25. An orthometric height of a mark is the distance from the reference surface to the mark, measured along the line perpendicular to every equipotential surface in between. Equipotential surfaces can be used to represent the gravity field. One of these equipotential surfaces is specified as the reference system from which orthometric heights are measured. The surfaces defined by the gravity field are not parallel because of the rotation and shape of the Earth as well as gravity anomalies in the gravity field. Two points, therefore, could have the same potential, but may have two different orthometric heights. The value of the orthometric height at a point depends on all the equipotential surfaces beneath that point.

26. The orthometric height (H) and the geopotential number (C) are related through the following equation:

$$C = G * H,$$

where G is the mean gravity value between the point and the reference surface, estimated for a particular system. Height systems are called different names depending on the G selected. When G is computed using the Helmert height reduction formula (Helmert 1890), the heights are called Helmert orthometric heights: when G is computed using the international formula for normal gravity, the heights are called normal orthometric heights: when G is equal to normal gravity at 45 degrees latitude, the heights are called dynamic heights. The elevations published in appendix A and published with respect to the IGLD (1985) are dynamic heights. Dynamic heights should be visualized as geopotential numbers. A dynamic height is a geopotential number simply scaled by a factor close to unity to transform the units of kgal•m to m for user convenience. Therefore, the data used to define the IGLD (1985) are:

One height (Pointe-au-Père transferred to Rimouski)
Water level transfers used to connect leveling across the Great Lakes
Geopotential numbers - observed leveling differences converted to geopotential differences using Earth's gravity values.
Dynamic heights

$H_{dyn} = C/G_o$; G_o = 980.6199 gals (0.980 619 9 kgal)
(Normal gravity at 45 degrees latitude as defined in 1984, DMA tR 8350.2, September 30, 1987)

ESTABLISHMENT OF REFERENCE ZERO AT POINTE-AU-PÈRE/RIMOUSKI

27. The original reference zero for IGLD (1955) was chosen as the mean water level at the Canadian Hydrographic Service gauging station at Pointe-au-Père, Quebec. Mean water level was calculated as the arithmetic mean of eleven yearly means between 1941 and 1956. The primary bench mark, 1248-G, had an elevation of 3.794 metres (12.447 feet) on IGLD (1955). Because of the deterioration of the Pointe-au-Père wharf and gauge, a new gauge was built in 1984 in the harbour at Rimouski, about five kilometers upstream. Both gauges were to be kept in operation for a period of time to compare the water level data and to facilitate the transfer of the reference zero to the new gauge at Rimouski. However, the data recorded at Pointe-au-Père were affected by the deterioration of the structure and a comparison was not possible. Therefore, the reference zero had to be transferred by first-order leveling to bench mark 1250-G at Rimouski.

28. In 1983, the Geodetic Survey of Canada (GSC) releveled the line between Rimouski and Pointe-au-Père and determined an elevation of 6.263 metres IGLD (1955) for bench mark 1250-G. This elevation is identical to the original IGLD (1955) elevation (20.549 feet, 6.263 metres) assigned to bench mark 1250-G. Since there is no appreciable difference in the character of the tide between Pointe-au-Père and Rimouski and there is good agreement in the first-order level line results, bench mark 1250-G can be used to define the reference zero for IGLD (1955). To determine the reference zero for IGLD (1985), mean water level was computed as the arithmetic mean of the daily mean water levels as recorded at Pointe-au-Père from 1970 to 1983 and at Rimouski from 1984 to 1988. The data set for this period was 87.3 percent complete. The arithmetic mean of the daily means for the period was -0.010 metres IGLD (1955) or 0.010 metres below the IGLD (1955) reference zero. Since the reference zero at Rimouski for IGLD 1955 is 6.263 metres below bench mark 1250-G, the reference zero for IGLD (1985) is defined as 6.273 metres below GSC bench mark 1250-G at Rimouski, Quebec.

29. The reference zero was calculated from the water level data recorded at the Pointe-au-Père and Rimouski gauging stations between 1970 and 1988. This period was chosen: (1) to use a nineteen year period of water level data (one tidal epoch), (2) to use as much data as possible form the new gauging station at Rimouski, (3) to include the time period of new land leveling up the St. Lawrence River (1978-82), and (4) to include the time period (1982-88) used for the water level transfers between gauging stations on the Great Lakes. In addition, selecting a period near the date of the datum adjustment, minimizes the effect of crustal movement or long-term fluctuations in mean water level on the establishment of the reference zero.

ESTABLISHMENT OF INTERNATIONAL GREAT LAKES DATUM (1985)

30. A special study was undertaken to compile a U.S. and Canadian primary vertical control network using the latest leveling data available in the Great Lakes region. Analyses of these networks proved helpful in determining the effects of datum constraints, the magnitude of height changes from IGLD (1955), and confirmed the validity of using the "Network Concept" in establishing IGLD (1985).

31. The network is comprised of leveling loops starting at the mouth of the St. Lawrence River and included leveling lines which surrounded the Great Lakes (see Figure 2). For ease in data computation, all U.S. and Canadian leveling data was merged and compiled in a data base at the Vertical Network Branch, National Geodetic Survey, a Division of the Coast and Geodetic Survey, National Ocean Service, National Oceanic and Atmospheric Administration (Zilkoski et al. 1989).

32. The network formed leveling loops for which misclosures were computed and checked against allowable closure tolerances. Heights of bench marks were computed using a least squares adjustment. The adjustments performed were minimum-constraint least squares adjustments holding fixed the geopotential number of a bench mark, referenced to a zero value of the local mean water level at Pointe-au-Père/Rimouski. Data outliers were detected and removed during this analysis. The resulting primary network consisted of 78 loops containing 1,119 bench marks. Each loop is composed of links based on the latest leveling connecting the junctions of loops. The network connected to over 80 water level gauging stations along the Great Lakes. In addition, 25 connections were made between the U.S. and Canadian vertical control networks.

33. Additionally, water-level transfer data, see paragraph 22, (Coordinating Committee 1979) from U.S. and Canadian gauging stations were included in each adjustment. These differences were used to generate observed height differences from the primary bench mark at the gauge site to

the mean water level (MWL) surface. The MWL surface at each station was treated as if it were a bench mark. In this way, the data were used to estimate geopotential numbers at all water level stations.

34. Three separate adjustments were performed. Each adjustment held the elevation of a bench mark referenced to local mean water level fixed at Pointe-au-Père/Rimouski. First, all U.S. data (known as U.S. Network) were combined into a network and adjusted. Second, the Canadian data (known as Canadian Network) was formed and adjusted. Lastly, the U.S. and Canadian data (U.S. - Canadian Network) were combined and adjusted. A comparison of the U.S. Network adjusted heights and Canadian Network adjusted heights showed good overall agreement. The difference between the adjusted heights using independent leveling data from Pointe-au-Père/Rimouski to the west end of Lake Superior is approximately 7 cm. This supports the importance of using a leveling network concept instead of single-route leveling to estimate the heights of bench marks for IGLD (1985).

35. *International Great Lakes Datum (1985) and North American Vertical Datum (1988)*. The development of the NAVD (1988), as mentioned in paragraph 17, was to include vertical control networks of the U.S., Canada and Mexico, as well as International Great Lakes Datum data. For NAVD (1988), a minimum-constraint adjustment was performed also holding fixed the primary bench mark at Pointe-au-Père/Rimouski. Therefore, IGLD (1985) and NAVD (1988) are one and the same. The only difference between IGLD (1985) and NAVD (1988) is that the IGLD (1985) bench mark elevations are published as dynamic heights and the NAVD (1988) elevations are published as Helmert orthometric heights (Zilkoski et al. 1989). Geopotential numbers for individual bench marks are the same in both height systems.

36. *HYDRAULIC CORRECTOR*. The water surfaces of the Great Lakes are considered to be geopotentially equal. Therefore, on any particular lake, at the time a new vertical datum is established, all Mean Water Level (MWL) values for gauging stations around the lake should coincide. The MWL is the average water surface for the summer months (June - September) for the years 1982-1988 referenced to the gauging station Primary Bench Mark dynamic height (paragraph 18). As indicated in paragraph 33, the MWL at each gauging station was treated as a bench mark in the network adjustment. Following the adjustment (paragraph 32), the MWL values at each gauging station on a lake were slightly different. The differences are due to cumulative differences in the leveling adjustments. The Committee decided to apply a Hydraulic Corrector so each gauge on a lake has the same MWL as the Master Station for the lake. This is accomplished by holding the Master Station

as the controlling value and comparing all other gauging stations to it. The Master Stations for each lake are:

Lake Ontario	-	Oswego, New York
Lake Erie	-	Fairport, Ohio
Lake St. Clair	-	St. Clair Shores, Michigan
Lake Huron	-	Harbor Beach, Michigan
Lake Michigan	-	Harbor Beach, Michigan
Lake Superior	-	Marquette, Michigan

37. The Hydraulic Corrector (HC) was obtained by subtracting the MWL at the Master Station (MWL_{Master}) from the MWL at the subordinate gauging station in question (MWL_{Sub}). The answer retains its arithmetic sign. The Hydraulic Corrector may be positive or negative and is subtracted algebraically.

$$HC = MWL_{Sub} - MWL_{Master}$$

where:

HC — Hydraulic Corrector for Subordinate Gauge

MWL_{Sub} — Mean Water Level at Subordinate Gauging Station on a lake for the summer months (June - September) of 1982 - 1988. The MWL is referenced to the Subordinate Gauging Station Primary Bench Mark Dynamic Height.

MWL_{Master} — Mean Water Level at Lake Master Station for the summer months (June - September) of 1982 - 1988. The MWL is referenced to the Master Station Primary Bench Mark Dynamic Height.

38. The water surface elevation ($WS_{IGLD\ 1985}$) is obtained by subtracting the Hydraulic Corrector (HC) from the Dynamic Water Surface Elevation ($WS_{Dynamic}$).

$$WS_{IGLD\ 1985} = WS_{Dynamic} - HC$$

where:

$WS_{IGLD\ 1985}$ — Published Water Surface Elevation on IGLD (1985) for a selected gauging station. The value may be an instantaneous value, or a daily, monthly or annual mean.

$WS_{Dynamic}$ — Water Surface elevation referenced to Dynamic Height.

HC — Hydraulic Corrector for a selected gauging station. The value may be positive or negative.

39. The water surfaces of all connecting channels and other rivers on the Great Lakes are considered to be sloping surfaces. Therefore, their Hydraulic Corrector is zero.

40. Example of computations for Kingston, Ontario daily mean for July 1, 1994.

$$HC = MWL_{Sub} - MWL_{Master}$$
$$HC = 74.986 - 74.982$$
$$HC = 0.004$$

$$WS_{IGLD1985} = WS_{Dynamic} - HC$$
$$WS_{IGLD1985} = 75.054 - 0.004$$
$$WS_{IGLD1985} = 75.050$$

41. Example of computations for Point Iroquois, Michigan daily mean for July 4, 1994.

$$HC = MWL_{Sub} - MWL_{Master}$$
$$HC = 183.498 - 183.598$$
$$HC = -0.100$$

$$WS_{IGLD1985} = WS_{Dynamic} - HC$$
$$WS_{IGLD1985} = 183.344 - (-0.100)$$
$$WS_{IGLD1985} = 183.444$$

42. The Hydraulic Corrector at each gauge site on the lake has been incorporated into the data retrieval and storage process. As such, water level information stored at the site mechanically or electronically, at the National Oceanic and Atmospheric Administration (NOAA) or the Department of Fisheries and Oceans (DFO) computers, or in printed form, are in IGLD (1985) and do not require any further adjustment.

43. Hydraulic Correctors for primary gauges are shown in Appendix A.

44. *Dynamic Elevations on International Great Lakes Datum (1985)*. The dynamic elevation of the primary bench mark at each water level gauging station is shown in Appendix A.

45. *Differences IGLD (1985) to IGLD (1955)*. To obtain the Water Level Elevation on IGLD (1955), subtract the DIFF. 85-55 value in Appendix A from the Water Level Elevation on IGLD (1985).

46. *Descriptions of Bench Marks*. Appendix B lists the addresses where bench mark descriptions can be obtained.

47. _Public Information_. Appendix B lists address where general information can be obtained.

RECOMMENDATIONS TO RESPONDING AGENCIES

48. The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data considers and recommends that the establishment of IGLD (1985) along the Rivers and Lakes of the Great Lakes system satisfies the requirements for a new datum in this area. The responsible data collecting and publishing agencies in the United States and Canada implemented its use in January 1992.

49. The advantages of IGLD (1985), leading to the Coordinating Committee recommendations, may be summarized as follows:

a. Elevations, consistent with one another as of a recent date (1985), are provided for bench marks throughout the Great Lakes-St. Lawrence River system, with the reference zero at Pointe-au-Père/Rimouski.

b. The elevations given on this datum are based on the dynamic principle, and are therefore more suitable for hydraulic studies. Elevations on this new datum will greatly facilitate hydraulic, hydrographic and other engineering studies.

50. To ensure that the advantages of having this new datum in general use may be fully exploited, the committee provided its new datum values to all agencies interested in water levels on the Great Lakes-St. Lawrence River system adopt IGLD (1985) as set forth in this report.

REFERENCES

Zilkoski, D.B., Balazs, E.I., and Bengston, J.M., 1989, Datum Definition Study for the North American Vertical Datum of 1988 (NGS unpublished technical report), National Ocean Service, Rockville, MD., 20852.

Zilkoski, D.B., Balazs, E.I., Bengston, J.M., 1989, Analyses Performed by the National Geodetic Survey in Support of the Readjustment of the International Great Lakes Datum (NGS unpublished technical report), National Ocean Service, Rockville, MD., 20852.

Coordinating Committee, 1979, Establishment of International Great Lakes Datum (1955), Second Edition, Coordinating Committee of Great Lakes Basic Hydraulic and Hydrologic Data, Chicago, IL., and Ottawa, ON.

Apparent Vertical Movement over the Great Lakes Report - The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, July 1977, printed by Detroit District Corps of Engineers

U.S. National Geodetic Glossary, National Geodetic Survey, September 1986, Rockville, MD

APPENDIX A

TABULATION OF PRIMARY BENCH MARK ELEVATIONS AT GAUGE SITES

INTERNATIONAL GREAT LAKES DATUM (1985)

Tabulation of Primary Bench Mark, Dynamic Elevation[1], Hydraulic Corrector[2], and Difference IGLD (1985) to IGLD (1955)[3], in Metres

CANADA

STATION NAME / BENCH MARK / ELEVATION	H.C. / DIFF. 85-55
ST. LAWRENCE RIVER, QUEBEC	
RIMOUSKI	
1250-G	n/a
6.273	0.010
SAINT-JOSEPH-DE-LA-RIVE	
1049-B	n/a
7.253	0.038
SAINT-FRANÇOIS	
69L159	n/a
24.513	0.054
GROS CACOUNA	
3-1982	n/a
4.972	0.032
QUÉBEC (LAUZON)	
3162	n/a
5.960	0.060
NEUVILLE	
1-1958 NEUV	n/a
7.884	0.053
PORTNEUF	
MMMCLIII	n/a
5.314	0.072
GRONDINES	
GRON 1-1958	n/a
4.331	0.051
CAP À LA ROCHE	
3-1963 CAPA	n/a
5.763	0.036
BATISCAN	
CROWSFOOT	n/a
8.250	0.051
CHAMPLAIN	
MMMCXXX	n/a
10.974	0.050
TROIS-RIVIÈRES	
3 RIV 1-1958	n/a
8.814	0.056
PORT-SAINT-FRÂNÇOIS	
2598	n/a
8.678	0.053
LAC SAINT-PIERRE	
87L9200	n/a
9.980	0.030
SOREL	
DBM 69L058	n/a
13.488	0.056

n/a = not applicable

[1]Hydraulic Corrector not applied.

[2]See paragraph 36-43.

[3]See paragraph 45.

STATION NAME	
BENCH MARK	H.C.
ELEVATION	DIFF. 85-55

ST. LAWRENCE RIVER, QUEBEC

Station / Bench Mark / Elevation	H.C. / Diff. 85-55
LAVALTRIE	
2644	n/a
13.253	0.082
CONTRECOEUR	
70L810	n/a
12.907	0.051
VERCHÈRES	
2567	n/a
9.601	0.050
VARENNES	
DBM 69L042	n/a
13.557	0.054
POINTE AUX TREMBLES	
79L012	n/a
12.567	0.081
MONTRÉAL, RUE FRONTENAC	
3153	n/a
15.236	0.076
MONTRÉAL, JETTY NO. 1	
MOKE 6	n/a
13.259	0.060
SAINT-LAMBERT BELOW	
DBM 69L029	n/a
13.599	0.060
SAINT-LAMBERT ABOVE	
CXLI	n/a
15.091	0.054
LA PRAIRIE	
SLSC 47	n/a
23.277	0.055
CÔTE-STE-CATHERINE	
COSC 1-58	n/a
23.797	0.069
LACHINE	
LACH 2-1958	n/a
22.714	0.072
POINTE-CLAIRE	
CCCCIII	n/a
25.646	0.082
SAINTE-ANNE-DE-BELLEVUE	
CCCCXI	n/a
26.487	0.091
POINTE-DES-CASCADES	
CASC 3-1958	n/a
24.153	0.082
BEAUHARNOIS BELOW	
LOBE 1-1958	n/a
24.014	0.073
BEAUHARNOIS ABOVE	
UPBE 4-1959	n/a
48.125	0.070
COTEAU-DU-LAC	
CCCCXXVII	n/a
48.332	0.068
COTEAU-LANDING	
68L003	n/a
48.260	0.078

ST. LAWRENCE RIVER, ONTARIO

Station / Bench Mark / Elevation	H.C. / Diff. 85-55
SUMMERSTOWN	
2616	n/a
50.738	0.093
CORNWALL	
H.S. 2-1958	n/a
52.993	0.102
IROQUOIS BELOW	
H.S. L2	n/a
76.010	0.119

STATION NAME BENCH MARK ELEVATION	H.C. DIFF. 85-55
ST. LAWRENCE RIVER, ONTARIO	
IROQUOIS ABOVE	
H.S. 2	n/a
76.616	0.119
BROCKVILLE	
68U339	n/a
86.673	0.145
LAKE ONTARIO	
KINGSTON	
75U502	0.004
76.649	0.176
COBOURG	
67U057	0.002
77.493	0.131
TORONTO	
579-F	0.034
77.013	0.132
BURLINGTON	
60U3327	0.064
76.799	0.083
PORT WELLER	
H.S. 3	0.040
78.629	0.137
LAKE ERIE	
PORT COLBORNE	
71U032	-0.024
175.921	0.191
PORT DOVER	
MMDCCXXX	-0.020
175.797	0.220

STATION NAME BENCH MARK ELEVATION	H.C. DIFF. 85-55
PORT STANLEY	
POST JW-1975	-0.002
175.764	0.191
ERIEAU	
H.S. 2-1958	0.012
175.360	0.176
KINGSVILLE	
KING 3-1961	0.012
176.357	0.181
BAR POINT	
3016	0.021
176.744	0.176
DETROIT RIVER	
AMHERSTBURG	
71U117	n/a
175.750	0.203
LA SALLE	
MMMDXLVIII	n/a
176.716	0.190
TECUMSEH	
TECU 2-1959	n/a
176.310	0.183
LAKE ST. CLAIR	
BELLE RIVER	
BELLE 1-1961	-0.008
176.606	0.215
ST. CLAIR RIVER	
PORT LAMBTON	
POLA 1-1959	n/a
176.918	0.196
POINT EDWARD	
PTED 1-1959	n/a
178.114	0.176

STATION NAME BENCH MARK ELEVATION	H.C. DIFF. 85-55

LAKE HURON

GODERICH	
72U108	0.002
184.277	0.195

TOBERMORY	
101 R2	-0.006
180.883	0.278

COLLINGWOOD	
DCLXIX	0.008
178.175	0.244

PARRY SOUND	
420 A 3	0.002
183.133	0.334

LITTLE CURRENT	
LICU 9-1965	0.021
178.725	0.340

THESSALON	
THES 2-1959	0.011
179.273	0.258

ST. MARY'S RIVER

SAULT STE MARIE BELOW	
MIDDLE SOO	n/a
186.662	0.273

SAULT STE MARIE ABOVE	
MIDDLE SOO	n/a
186.662	0.273

LAKE SUPERIOR

GROS CAP	
GROS 3-1963	-0.097
185.942	0.384

MICHIPICOTEN	
698	-0.018
191.326	0.439

STATION NAME BENCH MARK ELEVATION	H.C. DIFF. 85-55

ROSSPORT	
70U652	0.012
205.609	0.464

THUNDER BAY	
346-E	0.045
185.321	0.383

INTERNATIONAL GREAT LAKES DATUM (1985)

Tabulation of Primary Bench Mark, Dynamic Elevation[1], Hydraulic Corrector[2], and Difference IGLD (1985) to IGLD (1955)[3], in Metres

UNITED STATES
PRIMARY STATIONS

STATION NAME / BENCH MARK	ELEVATION	H.C.	DIFF. 85-55
ST. LAWRENCE RIVER			
OGDENSBURG / A	84.614	n/a	0.113
ALEXANDRIA BAY CG / LAND	86.171	n/a	0.152
LAKE ONTARIO			
CAPE VINCENT / CAPE	77.071	0.008	0.170
OSWEGO / LAKE	77.487	0.000	0.158
ROCHESTER / SUB	76.804	0.006	0.147
OLCOTT / WEST	77.492	0.008	0.137
NIAGARA RIVER			
ASHLAND AVENUE / POOL	111.428	n/a	0.160
AMERICAN FALLS / FRONTIER	171.855	n/a	0.158
NIAGARA INTAKE / INTAKE	173.380	n/a	0.162
LAKE ERIE			
BUFFALO / MACHINE	176.555	-0.026	0.203
STURGEON POINT / WATER	197.551	-0.023	0.204
ERIE / Y 13	175.445	-0.025	0.191

[1]Hydraulic Corrector not applied.

[2]See paragraph 36-43.

[3]See paragraph 45.

n/a = not applicable

STATION NAME	
BENCH MARK	H.C.
ELEVATION	DIFF. 85-55

LAKE ERIE

FAIRPORT	
K 321	0.000
175.918	0.175

CLEVELAND	
G 321	0.010
177.731	0.182

MARBLEHEAD	
Z 317	-0.006
177.238	0.178

TOLEDO	
NAVAL	-0.005
175.459	0.180

FERMI POWER PLANT	
POWER	0.023
177.589	0.189

DETROIT RIVER

GIBRALTAR	
M 234	n/a
176.630	0.206

WYANDOTTE	
CHIEF	n/a
176.119	0.196

FORT WAYNE	
RAMP	n/a
175.232	0.191

WINDMILL POINT	
D 2	n/a
177.780	0.188

LAKE ST. CLAIR

ST. CLAIR SHORES	
FOOD	0.000
176.970	0.191

STATION NAME	
BENCH MARK	H.C.
ELEVATION	DIFF. 85-55

ST. CLAIR RIVER

ALGONAC	
TREAT	n/a
176.868	0.188

ST. CLAIR SP	
A 237	n/a
176.591	0.178

DRY DOCK	
Z 236	n/a
180.760	0.189

MOUTH BLACK RIVER	
Z 43	n/a
178.932	0.181

DUNN PAPER	
3060	n/a
179.121	0.185

FORT GRATIOT	
RETAINING WALL	n/a
179.553	0.181

LAKE HURON

LAKEPORT	
BURTCH	0.013
178.796	0.202

HARBOR BEACH	
E 237	0.000
179.732	0.214

ESSEXVILLE	
CON	-0.002
179.173	0.213

HARRISVILLE	
K 306	-0.003
184.766	0.240

STATION NAME BENCH MARK	H.C.
ELEVATION	DIFF. 85-55
LAKE HURON	
MACKINAW CITY	
J 299	0.043
179.608	0.232
DE TOUR VILLAGE	
L 293	0.005
179.704	0.253
ST. MARY'S RIVER	
U.S. SLIP	
C 293	n/a
184.301	0.272
S.W. PIER	
V 295	n/a
186.090	0.274
LAKE MICHIGAN	
LUDINGTON	
J 318	0.087
177.983	0.150
HOLLAND	
W 319	0.090
177.577	0.190
CALUMET HARBOR	
COM	0.104
178.065	0.166
MILWAUKEE	
NAVY	0.106
182.949	0.156
KEWAUNEE	
ROD	0.114
177.968	0.181
STURGEON BAY CANAL	
DWELLING A	0.106
178.580	0.187

STATION NAME BENCH MARK	H.C.
ELEVATION	DIFF. 85-55
GREEN BAY	
WIS	0.114
179.656	0.197
PORT INLAND	
POLE	0.046
180.945	0.212
LAKE SUPERIOR	
POINT IROQUOIS	
A 293	-0.100
187.799	0.377
MARQUETTE	
U 329	0.000
189.933	0.345
ONTONAGON	
NO 2	0.049
185.443	0.323
DULUTH	
BAR	0.079
184.432	0.285
GRAND MARAIS, MN	
SCOTT	0.046
184.985	0.356

INTERNATIONAL GREAT LAKES DATUM (1985)

Tabulation of Primary Bench Mark, Dynamic Elevation, in Metres

UNITED STATES
SEASONAL

STATION NAME BENCH MARK	ELEVATION
ST. LAWRENCE RIVER	
ALEXANDRIA BAY	
SL 7	77.401
CLAYTON	
C	79.322
LAKE ONTARIO	
SACKETS HARBOR	
MILITIA	75.333
PORT ONTARIO	
LIGHT	75.995
LITTLE SODUS BAY	
WL 132	79.986
SODUS BAY	
WL 131	80.931
OAK ORCHARD	
HOTEL	77.743
WILSON	
HARBOR	80.385
FORT NIAGARA	
PIT	75.888
NIAGARA RIVER	
LA SALLE YACHT CLUB	
LA SALLE YACHT CLUB	173.233
TONAWANDA ISLAND	
N 19	176.207
HUNTLEY STATION	
N 15	175.426
BEAVER ISLAND S.P.	
ROCK	173.101
ONTARIO STREET	
SUN	175.584
PEACE BRIDGE	
N 6	174.859
LAKE ERIE	
LACKAWANNA	
POWER NO 5	178.863
DUNKIRK	
WL 119	183.290
BARCELONA	
C 471	177.041
CONNEAUT	
WL 116 A	177.330
ASHTABULA	
WL 114	178.679
MENTOR HARBOR	
F RANGE 12	175.143

N/A= not available

STATION NAME BENCH MARK	ELEVATION

LAKE ERIE

STATION NAME / BENCH MARK	ELEVATION
ROCKY RIVER	
COD	175.518
LORAIN	
BRIDGE	176.486
VERMILION	
BANK	182.655
HURON	
POWER	176.439
CEDAR POINT	
GATE	N/A
SANDUSKY	
EXPRESS	177.953
KELLEYS ISLAND	
CABIN	N/A
PUT IN BAY	
O.S.F.H.	N/A
EAST HARBOR	
EAST	N/A
WEST HARBOR	
COTTAGE	N/A
PORT CLINTON	
WL 106	176.833
TURTLE CREEK	
SHED	N/A
COOLEY CREEK	
LAMP	N/A
BOLLES HARBOR	
FENCE	N/A
MONROE	
REAR RANGE	176.406

STATION NAME BENCH MARK	ELEVATION

LAKE ST. CLAIR

STATION NAME / BENCH MARK	ELEVATION
NORTH CHANNEL	
McCULLOUGH	N/A
ST. CLAIR FLATS	
BEYSTER	175.577
DICKINSON ISLAND	
SNOW	N/A
MINNICH DOCK	
DRIVEWAY	176.001

ST. CLAIR RIVER

STATION NAME / BENCH MARK	ELEVATION
ROBERTS LANDING	
LANDING	177.264
MARINE CITY	
BELLE	177.715
MARYSVILLE	
MARY	178.419

LAKE HURON

STATION NAME / BENCH MARK	ELEVATION
LEXINGTON	
LEXINGTON NO 3	189.461
PORT SANILAC	
GIDDINGS	181.956
FORESTVILLE	
WILLIE	192.689
GRINDSTONE CITY	
WHALEN	181.911
PORT AUSTIN	
OVAL	179.265
CASEVILLE	
PIGEON	178.028

STATION NAME BENCH MARK	ELEVATION
LAKE HURON	
BAY PORT	
RUINS	178.781
SEBEWAING	
DUTCHER	177.680
BAY CITY	
HL MON 44	178.791
AU GRES	
GATE	178.636
POINT LOOKOUT	
STIEHL	N/A
EAST TAWAS	
ETFP	178.123
OSCODA	
MARINA	177.504
BLACK RIVER	
JAHR	N/A
ALPENA	
ALPENA	N/A
PRESQUE ISLE	
PRESQUE ISLE	179.358
CALCITE	
POWER	N/A
ROGERS CITY	
MONUMENT	178.622
HAMMOND BAY	
SPA	179.349
CHEBOYGAN	
RANGE	179.081
MACKINAC ISLAND	
S 11 E	N/A

STATION NAME BENCH MARK	ELEVATION
ST. IGNACE	
IGNATIUS	189.718
CEDARVILLE	
INN	179.965
DE TOUR DOCK	
ROAD A	178.510
ST. MARY'S RIVER	
FRECHETTE POINT	
FRECHETTE	178.903
LITTLE RAPIDS	
LITTLE RAPIDS	178.524
LAKE MICHIGAN	
ST. JAMES	
BOOTH	N/A
CROSS VILLAGE	
POLE	N/A
PETOSKEY	
DEPOT	180.764
CHARLEVOIX	
WL 218	179.573
ELK RAPIDS	
POWER	N/A
TRAVERSE CITY	
CEDAR CREEK	182.921
SUTTONS BAY	
BURKE	N/A
NORTHPORT	
CULVERT	N/A
LELAND	
E 88	N/A

LAKE MICHIGAN

STATION NAME	BENCH MARK	ELEVATION
SOUTH MANITOU ISLAND	PUMP	N/A
PLATTE RIVER	POLE	N/A
FRANKFORT	WL 215	N/A
ARCADIA	POLE	N/A
PORTAGE LAKE	WALK	N/A
MANISTEE	STEPKA	178.041
PENTWATER	LAWN	178.424
WHITE LAKE	PIPE	N/A
MUSKEGON	YARD	179.690
GRAND HAVEN	A 7	180.546
SAUGATUCK	KONING	N/A
SOUTH HAVEN	POST	N/A
ST. JOSEPH	WL 236	179.179
NEW BUFFALO	POLE	179.304
MICHIGAN CITY	WL238	181.391
BURNS WATERWAY	BURNS	183.675
GARY	SUPPORT	181.045
INDIANA HARBOR	H 18	180.075
CHICAGO HARBOR	N. PIER	179.210
GREAT LAKES	PAINT	N/A
WAUKEGAN	OIL	181.521
KENOSHA	KENOSHA LIGHT	184.114
RACINE	SHOP	180.368
PORT WASHINGTON	WORKS	179.472
SHEBOYGAN	WL 250	179.498
MANITOWOC	ARCADE	180.723
TWO RIVERS	OFFICE	178.335
ALGOMA	WL 256	178.168
STURGEON BAY VILLAGE	ACE	184.186
BAILEYS HARBOR	7074 D	N/A
DETROIT HARBOR	TANK	N/A

STATION NAME	
BENCH MARK	ELEVATION

LAKE MICHIGAN

Station Name / Bench Mark	Elevation
JACKSON HARBOR	
SHED	N/A
BIG SUAMICO RIVER	
FONT	177.147
PENSAUKEE	
SWAER	178.589
OCONTO	
VANDERBUSH	177.400
MENOMINEE	
CCC	179.384
CEDAR RIVER	
CEDAR	177.790
ESCANABA	
OWEN	180.597
KIPLING	
RUINS	179.938
MANISTIQUE	
S.P.	N/A
NAUBINWAY	
OUTCROP	178.615

LAKE WINNEBAGO

Station Name / Bench Mark	Elevation
NEENAH	
FLAG POLE	229.680
OSHKOSH	
IRVING	228.498
FOND DU LAC	
POWER	228.152
CALUMET HARBOR	
CONSERVATION	N/A

STATION NAME	
BENCH MARK	ELEVATION

LAKE SUPERIOR

Station Name / Bench Mark	Elevation
WHITEFISH POINT	
3 A	N/A
LITTLE LAKE	
STEEL PILE	N/A
GRAND MARAIS, MI	
WL 301	N/A
MUNISING	
ALGER	N/A
PRESQUE ISLE	
ANCHOR NUT	185.266
BIG BAY	
BIG BAY	N/A
KEWEENAW, LOWER END	
WL 311	N/A
HOUGHTON-HANCOCK	
NO 3	N/A
GRAND TRAVERSE BAY	
WEST	N/A
LAC LA BELLE	
OLD LIGHT	N/A
COPPER HARBOR	
HIP	N/A
EAGLE HARBOR	
NO 2	N/A
KEWEENAW, UPPER END	
COAST GUARD	N/A
BLACK RIVER	
CONGLOMERATE	N/A
SAXON HARBOR	
PILING	N/A

STATION NAME	
BENCH MARK	**ELEVATION**

LAKE SUPERIOR

ASHLAND	
REISS	193.552
BAYFIELD	
NORTHERN	N/A
MADELINE ISLAND	
SQUARE	N/A
CORNUCOPIA	
CHURCH	N/A
PORT WING	
NO 2	N/A
KNIFE RIVER	
LEDGE ROCK	184.450
TWO HARBORS	
ORE DOCK	186.902
BEAVER BAY	
MATTSON	186.142
LUTSEN	
COURT	190.238
ROCK HARBOR, ISLE ROYALE	
ROYALE	N/A
WASHINGTON HARBOR, ISLE ROYALE	
SINGER	N/A

APPENDIX B

SOURCES OF BENCH MARK DESCRIPTIONS AND PUBLIC INFORMATION

BENCH MARK DESCRIPTIONS

To obtain descriptions of bench marks in Canada write to the:

Regional Tidal Officer
Canadian Hydrographic Service
Fisheries and Oceans Canada
Canada Centre for Inland Waters
867 Lakeshore Road
Burlington, Ontario L7R 4A6

To obtain descriptions of bench marks in the United States write to the:

National Ocean Service
Office of Ocean and Earth Sciences
Measurement Branch
Great Lakes Section
SSMC4, N/OES211, Sta. 7523
1305 East-West Highway
Silver Spring, Maryland 20910-3281

PUBLIC INFORMATION

To obtain information on IGLD (1985) write to:

Great Lakes Water Level
Communications Centre
Environment Canada
Canada Center for Inland Waters
867 Lakeshore Road
Burlington, Ontario L7R 4A6

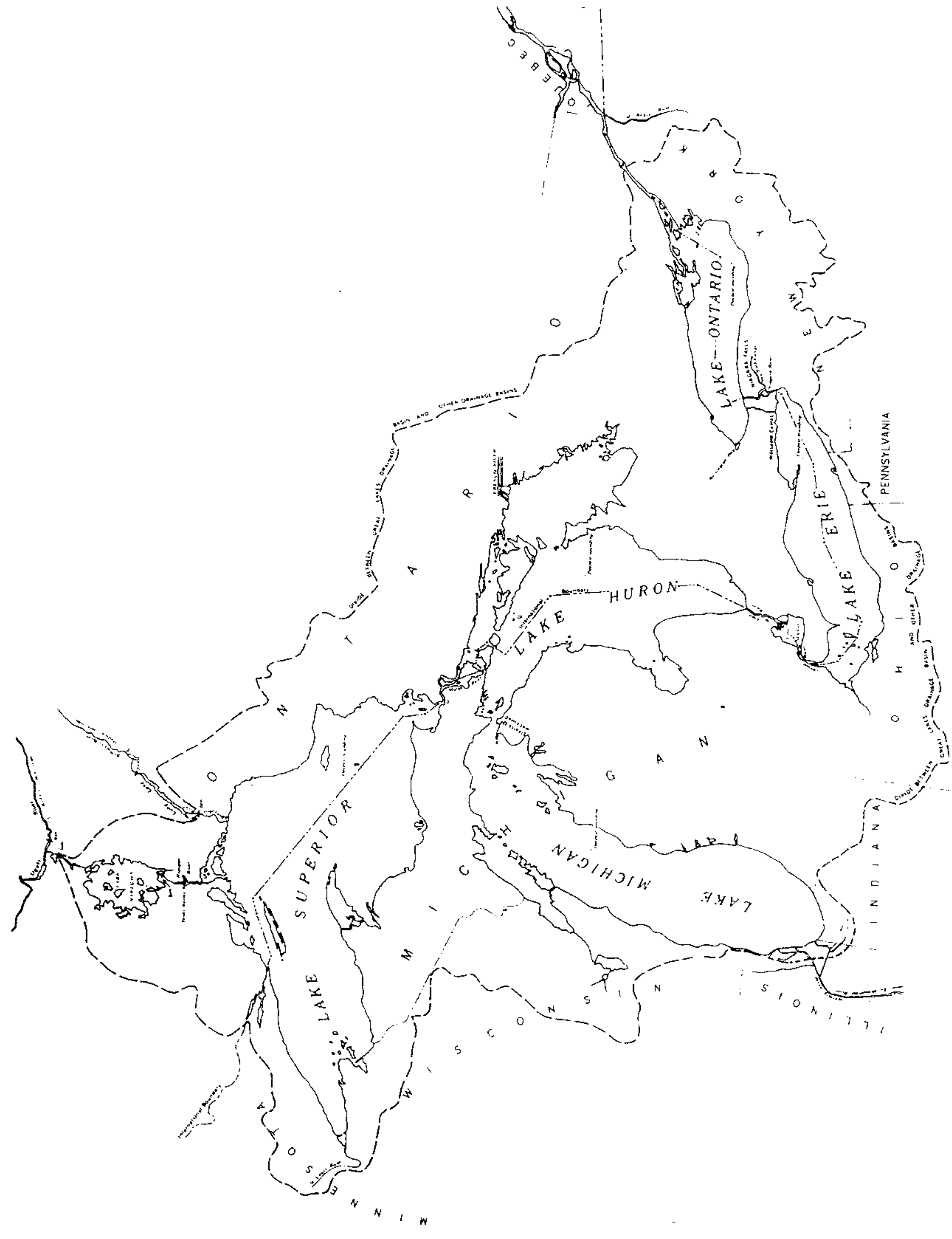
Geodetic Survey of Canada
Natural Resources Canada
615 Booth Street
Ottawa, Ontario K1A
0E9

National Ocean Service
Office of Ocean and Earth Sciences
Measurement Branch
Great Lakes Section
SSMC4, N/OES211, Sta. 7523
1305 East-West Highway
Silver Spring, Maryland 20910-3281

U.S. Army Corps of Engineers
Detroit District
P.O. Box 1027
Detroit, Michigan 48231-1027

APPENDIX C

GREAT LAKES BASIN


LAKE ONTARIO
LAKE ERIE
LAKE HURON
LAKE MICHIGAN
LAKE SUPERIOR
PENNSYLVANIA
O N T A R I O
M I C H I G A N
O H I O
I N D I A N A
I L L I N O I S
W I S C O N S I N
M I N N E S O T A
N E W Y O R K

APPENDIX D

GLOSSARY

GLOSSARY

ADR Gauge - Analog to Digital Recording water level gauge. A float or pressure actuated water level gauge that records the heights at regular time intervals in digital format.

air acoustic ranging sensor - A pulsed, acoustic-ranging device using the air column in a tube as the acoustic sound path. The fundamental measurement is the time it takes for the acoustic signal to travel form a transmitter to the water surface and then back to the receiver. The distance from a reference point to the water surface is derived from the travel time. A calibration point is set at a fixed distance from the acoustic transducer and is used to correct the measured distance using the calibrated sound velocity in the tube.

analog - A continuous measurement or a continuous graphic display of data. See ADR gauge and marigram.

annual inequality - Seasonal variation in water level or current, more or less periodic, due chiefly to meteorological causes.

anomaly - As applied to astronomy, the anomaly is the angle made at any time by the radius vector of a planet or moon with its line of apsides, the angle being reckoned form perihelion or perigee in the direction of the body's motion. It is called the true anomaly when referred to the actual position of the body, and mean anomaly when referred to a fictitious body moving with a uniform angular velocity equal to the average velocity of the real body and passing perihelion or perigee at the same time.

automatic water level gauge - An instrument that automatically registers the rise and fall of the water level. In some instruments, the registration is accomplished by recording the heights at regular time intervals in digital format; in others, by a continuous graph of height against time.

bench mark (BM) - A fixed physical object or mark used as reference for a vertical datum. A primary bench mark is the principal (or only) mark of a group of bench marks to which the staff or ETG and datums are referred. The standard bench mark is a brass, bronze, or aluminum alloy disk 3-1/2 inches in diameter containing the owners inscription together with other individual identifying information. Bench mark disks serve simultaneously to reference both dynamical and geodetic datums.

bench mark description - A published, concise description of the location, stamped number or designation, date established, and elevation of a specific bench mark.

chart datum - The datum to which soundings on a chart are referred. It corresponds to the low-water datum (LWD) elevation.

Coast and Geodetic Survey - A former name of the National ocean Service. The organization was known as: The Survey of the Coast from is founding in 1807 to 1836, Coast Survey from 1836 to 1878, Coast and Geodetic Survey form 1878 to 1970, and National Ocean Survey from 1970 to 1982. In 1982 it was named National Ocean Service. From 1965 to 1970, the Coast and Geodetic Survey was a component of the Environmental Science Services Administration (ESSA). The National Ocean Survey was a component of the National Oceanic and Atmospheric Administration (NOAA). NOAA became the successor to ESSA in 1970. The National Ocean Service is a component of NOAA, U.S. Department of Commerce.

control station - See primary control water level station.

current - Generally, a horizontal movement of water. Currents may be classified as tidal and nontidal. Tidal current are caused by gravitational interactions between the Sun, Moon, and Earth and are part of the same general movement of the sea that is manifested in their vertical rise and fall, called tide. Tidal current are periodic with a net velocity of zero over the particular tidal cycle. See tidal wave. Nontidal currents include the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from more pronounced meteorological variability. Current however, is also the British equivalent of our nontidal current.

data collection platform (DCP) - A microprocessor-based system that collects data from sensors, processes the data, stores the data in random access memory (RAM), and provides communication links for the retrieval or transmission of the data.

datum (vertical) - A base elevation used as a reference from which to reckon heights or depths. In order that they may be recovered when needed, such datums are referenced to fixed points known as bench marks. See chart datum.

Datum of 1983, North American - The horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980. this datum, designated as NAD 83, is the new geodetic reference system. It is scheduled for implementation in 1986 to replace the North American Datum of 1927, NAD 83 is based on the adjustment of 250,000 points including 600 satellite Doppler stations which constrain the system to a geocentric origin.

declination - Angular distance north or south of the celestial equator, taken as positive when north of the equator and negative when south. The Sun passes through its declinational cycle once a year, reaching its maximum north declination of approximately 23-1/2° about June 21 and its maximum south declination of approximately 23-1/2° about December 21. The Moon has an average declinational cycle of 27-1/3 days which is called a tropical month. Tides or tidal currents occurring near the times of maximum north or south declination of the Moon are called tropic tides or tropic currents, and those occurring when the Moon is over the Equator are called equatorial tides or equatorial currents. The maximum declination reached by the Moon in successive months depends upon the longitude of the Moon's node, and varies from 28-1/2" when the longitude of the ascending node is 0°, to 18-1/2" when the longitude of the node is 180°. The node cycle, or time required for the node to complete a circuit of 360° of longitude, is approximately 18.6 years. See epoch (2).

dynamic depth anomaly (ΔD)—The excess in geopotential difference over the standard geopotential difference (at a standard specific volume at 35 parts per thousand (‰) and 0 degrees C) between isobaric surfaces. See geopotential and geopotential topography.

$$\Delta D = \int_{P_1}^{P_2} \delta dP$$

where p is the pressure and δ is the specific volume anomaly $(1/\rho) - (1/\rho_o)$. P_1 and P_2 are the pressures at two depths, ρ is the actual mean density of the water between those pressures, and ρ_o is the mean density of the homogeneous water column.

dynamic height - The value is computed by dividing the NAVD 88 geopotential number by the normal gravity value computed on the Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45 degrees latitude (G = 980.6199 gals.). See geopotential difference. (1) The value, assigned to a point, determined by dividing the geopotential number for that point by the value of gravity on the reference ellipsoid at 45° latitude, as calculated from a standard gravity formula. (2) The same as (1) above, except that the reference value of gravity may be calculated for any selected latitude. See also dynamic number.

Dynamic height is sometimes (unfortunately) used as a synonym for geopotential number.

dynamic metre (D) - The former practical unit for geopotential difference (dynamic depth), equal to 10 geopotentials (dynamic decimeters). See geopotential (dynamic depth) anomaly.

dynamic number - A distinction is sometimes made between dynamic number and dynamic height in that the latter has the dimension of heights, whereas the former is in dimensions of potential (or work per unit mass) scaled through division by the numerical value of normal gravity at 45° latitude. In this sense, the dynamic number is a scaled geopotential number. Numerically, dynamic number and dynamic height (1) are equivalent.

dynamic topography - the topography of a surface (usually isobaric) specified in terms of the dynamic height of that surface above a specified surface of reference.

electric tape gauge - A gauge consisting of a graduated Monel metal tape on a metal reel (with supporting frame), voltmeter, and battery. Heights can be measured directly by unrolling the tape into its stilling well. When contact is made with the water's surface, the circuit is completed and the voltmeter needle moves. At that moment the length of tape is read against an index mark, the mark having a known elevation relative to the bench marks.

equipotential surface - See geopotential surface.

extreme high water - The highest elevation reached by the water as recorded by a water level gauge during a given period. The National Ocean Service routinely documents monthly and yearly extreme high waters for its control stations.

extreme low water - The lowest elevation reached by the water as recorded by a water level gauge during a given period. The National Ocean Service routinely documents monthly and yearly extreme low water for its control stations.

float well - A stilling well in which the float of a float-actuated gauge operates. See stilling well.
Geodetic Heights - Unofficial terminology - see dynamic depth.

Geodetic Reference System 1980 (GRS-80) - The following set of values adopted in 1979 by the International Union of Geodesy and Geophysics:

a	6,378,137 m
GM	$398{,}600.5 \times 10^{9}\ m^{3}\ s^{-2}$
J_2	0.001 082 63
ω	$7{,}292{,}115 \times 10^{-11}$ rad s^{-1},

defined on the equipotential ellipsoid. Where a is its semimajor axis, ω its angular velocity, GM the product of the gravitational constant G by its mass, and J_2 its dynamical form factor. A complete description of Geodetic Reference System 1980 is contained in Bulletin Géodésique, vol. 54, no. 3 (1980), pp. 395-405, in particular the derived values:

f^{-1}	(reciprocal of flattening)	298.257
γ_e	(equatorial gravity)	978.0327 gal.

geopotential - The unit of geopotential difference, equal to the gravity potential of 1 metre squared per second squared, m^2/s^2, or 1 joule per kilogram, J/kg.

geopotential anomaly - See dynamic depth anomaly

geopotential difference—The work per unit mass gained or required in moving a unit mass vertically from one geopotential surface to another. See geopotential, geopotential anomaly, and geopotential topography.

geopotential number - (1) The quantity W given by the integral

$$W = \int_{P_O}^{P_N} g\,dh$$

where P_O is a point on the geoid, P_N is the point at which the geopotential number is wanted, the integration is carried out along the plumb line between P_N and P_O, and g is the actual value of gravity along that line.

(2) the sum, from i=1 to i=I, of the quantities $\Delta h_i g_i$ obtained in going from an equipotential surface of reference, through a sequence of equipotential surfaces from i = 1 to i = I - 1, to the equipotential surface through the point from which the equipotential number is wanted. Successive surfaces S_{i-1} and S_i are separated by the very small distance Δh_i, expressed in metres, and g_i is the average value of the acceleration of gravity, expressed in kilogals, along the distance h_i. The geopotential number at a point is approximately equal

numerically to the elevation of that point in metres because g_l in kilogals at the surface of the Earth is approximately unity.

geopotential (equipotential) surface - See surface, level

geopotential topography - see dynamic topography

gravity gradient - The rate of change of gravity with respect to position. It is expressed as a set of 9 second derivatives of the potential with respect to the 3 coordinates of position.

gravity gradiometer - An instrument for measuring the gradient of gravity, i.e. the rate of change of gravity with change of location.

high water (HW) - The maximum height reached by a rising water level. The high water is due to the periodic water level forces and the effects of meteorological, hydrologic, and/or lake conditions.

high water line - The intersection of the land with the water surface at an elevation of high water.

high water mark - A line or mark left upon water level flats, beach, or alongshore objects indicating the elevation of the intrusion of high water. The mark may be a line of oil or scum on alongshore objects, or a more or less continuous deposit of fine shell or debris on the foreshore or berm. This mark is physical evidence of the general height reached by wave runup at recent high waters.

hydraulic current - A current in a channel caused by a difference in the surface elevation at the two ends. Such a current may be expected in a strait connecting two bodies of water in which the tides differ in time or range. The current in the East River, New York, connecting Long Island Sound and New York Harbor, is an example.

hydrographic datum - A datum used for referencing depths of water and the heights of predicted tides or water level observations. Same as chart datum. See datum.

incremental shaft encoder - A component of a water level gauge for converting length to a shaft angle on a rotating disk. The position of the rotating disk is determined by a single or dual optical or magnetic sensors to provide an electrical output. No electro-mechanical components or gears are used, so extremely low torque is required to move the float wheel, wire, and float mechanism.

International Great Lakes Datum (1985) (IGLD (1985)) - Mean water level at Rimouski/Pointe-au-Père, Quebec, on the Gulf of St. Lawrence over the period 1970 through 1988, from which geopotential elevations (geopotential differences) throughout the Great lakes region are measured. The term is often used to mean the entire system of geopotential elevations (geopotential differences) throughout the Great Lakes region are measured. Their term is often used to mean the entire system of geopotential elevations rather than just the referenced water level. See low water datum.

isobaric surface - A surface of constant or uniform pressure.

latitude - Angular distance in a great circle of reference reckoned from an accepted origin to the projection of any point on that circle. Latitude on the Earth's surface is measured on the meridian north and south of the Equator and is expressed in degrees.

level surface - See surface, level

longitude - Angular distance in a great circle of reference reckoned from an accepted origin to the projection of any point on that circle. Longitude on the Earth's surface is measured on the Equator east and west of the meridian of Greenwich and may be expressed either in degrees or in hours, the hour being taken as the equivalent of 15° of longitude. Celestial longitude is measured in the ecliptic eastward from the vernal equinox. The mean longitude of a celestial body moving in an orbit is the longitude that would be attained by a point moving uniformly in the circle of reference at the same average angular velocity as that of the body, with the initial position of the point so taken that its longitude would be the same as that of the body at a certain specified position in its orbit. With a common initial point, the mean longitude of a body will be the same in whatever circle it may be reckoned.

low water datum (LWD) - The geopotential elevation (geopotential difference) for each of the Great Lakes and the corresponding sloping surfaces of the St. Mary's, St. Clair, Detroit, Niagara, and St. Lawrence Rivers to which are referred the depths shown on the navigational charts and the authorized depths for navigation improvement projects. elevations of these planes are referred to IGLD (1985) and are Lake Superior - 183.2 metres, Lakes Michigan and Huron - 176.0 metres, Lake St. Clair - 174.4 metres, Lake Erie - 173.5 metres, and Lake Ontario - 74.2 metres.

low water line - The intersection of the land with the water surface at an elevation of low water.

magnetic azimuth - Azimuth reckoned from the magnetic north or magnetic south. See magnetic direction.

magnetic direction - Direction as indicated by a magnetic compass after correction for deviation but without correction for variation.

marigram - A graphic record of the rise and fall of the water. The record is in the form of a curve in which time is generally represented on the abscissa and the height of the water level on the ordinate.

Master Station - A water level station at which continuous observations have been made over a minimum of 19 years. Its purpose is to provide data for computing accepted values of the harmonic and nonharmonic constants essential to water level predictions and to the determination of tidal datums for charting and for coastal and marine boundaries. The data series from this station serves as a primary control for the reduction of relatively short series from subordinate water level stations through the method of comparison of simultaneous observations and for monitoring long-period sea level trends and variations. See water level station,

mean water level (MWL) - A tidal datum. The mean surface elevation as determined by averaging the heights of the water at equal intervals of time, usually hourly, over the National Tidal Datum Epoch. Mean water level is used in areas of little or no range in water level.

NAD 83 (Horizontal Datum) - See Datum of 1983, North American

NAVD 88 (Vertical Datum) - New referenced obtained by NGS, adopted as the fixed vertical reference in North America.

National Geodetic Vertical Datum of 1929 (NGVD (1929)) - A fixed reference adopted as a standard geodetic datum for elevations determined by leveling. The datum was derived for surveys from a general adjustment of the first-order leveling nets of both the United States and Canada. In the adjustment, mean sea level was held fixed as observed at 21 tide stations in the United State and 5 in Canada. The year indicates the time of the general adjustment. A synonym for Sea-level Datum of 1929, USGS Datum, and C&GS Datum. The geodetic datum is fixed and does not take into account the changing stands of sea level. Because there are many variable affecting sea level, and because the geodetic datum represents a best fit over a broad area, the relationship between the geodetic datum and local mean sea level is not consistent from one location to another in either time or space. For this reason, the National Geodetic Vertical Datum should not be confused with mean sea level.

National Water Level Observation Network (NWLON) - The network of tide and water level stations operated by the National Ocean Service along the marine and Great Lakes coasts and islands of the United States.

Next Generation Water Level Measurement System (NGWLMS) - A fully integrated system encompassing new technology sensors and recording equipment, multiple data transmission options, and an integrated data processing, analysis, and dissemination subsystem. System developed and used by the United States.

normal gravity - The pound force of gravity on a one pound mass at sea level at latitude 45° on foot-pounds or gals (G=980.6199 gals)

observed gravity - See gravity gradient/gravity gradiometer

orthometric height - The distance between the geoid and a point measured along the plumb line and taken positive upward from the geoid.

orthometric height difference - Is the difference of elevation between two neighboring points computed by curvature formula for total line length.

orthometric correction - The quantity added to the observed difference of elevation to correct for the error introduced when level surfaces at different elevations are not parallel. The equation used for the orthometric correction to the difference of elevation between two neighboring points is:

$$\text{Orthometric Correction} = - Chd\phi$$

where

- C is a function of latitude taken directly form prepared tables;
- h is the average elevation of the instrument between the points;
- dø is the difference of latitude in minutes, positive where the second point is north of the first.

Any unit of length may be used for the factor h. The adopted unit of length will determine the unit of the resulting orthometric correction.

pressure gauge - A water level gauge that is operated by the change in pressure at the bottom of a body of water due to the rise and fall of the water level. See gas purged pressure gauge.

pressure sensor - A pressure transducer sensing device for water level measurement. A relative transducer is vented to the atmosphere and pressure readings are made relative to atmospheric pressure. An absolute transducer measures the pressure at its location. The readings are then corrected for barometric pressure taken at the surface.

protective well - A vertical pipe with a relatively large opening (intake) in the bottom. It is used with the air acoustic ranging sensor and electronic processing (filtering) technique to minimize the nonlinear characteristics of the stilling well. Its purpose is also to shield the sensing element from physical damage and harsh environment. Unlike a stilling well, damping of high frequency waves is not a critical requirement. See stilling well.

real-time - Pertains to a data collecting system that controls an on-going process and delivers its outputs (or controls its inputs) not later than the time when these are needed for effective control.

reference station - A tide or current station for which independent daily predictions are given in the "Tide Tables" and "Tidal Current Tables", and from which corresponding predictions are obtained for subordinate stations by means of differences and ratios. See subordinate tide station (2) and subordinate current station (2).

seasonal station - Temporary water level stations used to collect water level lake data for a predetermined period.

seiche - A stationary wave usually caused by strong winds and/or changes in barometric pressure. It is found in lakes, semi-enclosed bodies of water, and in areas of the open ocean. The period of a seiche in an enclosed rectangular body of water is usually represented by the formula:

Period $(T)=2L/\ gd$

in which L is the length, d the average depth of the body of water, and g the acceleration of gravity. See standing wave.

shoreline (coastline) - The intersection of the land with the water surface. The shore line shown on charts represents the line of contact between the land and a selected water elevation. In areas affected by tidal fluctuations, this line of contact is the mean high water line. In confined coastal waters of diminished tidal influence, the mean water level line may be used. See coast line.

staff - A water level gauge consisting of a vertical graduated staff from which the height of the water level can be read directly. It is called a fixed staff when secured in place so that is cannot be easily removed. A portable staff is one that is designed for removal from the water when not in use. For such a staff a fixed support is provided. The support has a metal stop secured to it so that the staff will always have the same elevation when installed for use. See electric tape gauge.

standard time - A kind of time based upon the transit of the Sun over a certain specified meridian, called the time meridian, and adopted for use over a considerable area. With a few exceptions, standard time is based upon some meridian which differs by a multiple of 15° from the meridian of Greenwich. the United States first adopted standard time in 1883 on the initiative of the

American Railway Association, and at noon on November 18 of that year the telegraphic time signals from the Naval Observatory at Washington were changed to this system.

stilling well - A vertical pipe with a relatively small opening (intake) in the bottom. It is used in a gauge installation to dampen short period surface waves while freely admitting the long period waves; which can then be measured by a water level gauge sensor inside. See float well and protective well.

storm surge - A departure from a normal elevation of the sea due to the piling up of water against a coast by strong winds such as those accompanying a hurricane or other intense storm. Reduced atmospheric pressure often contributes to the departure in height during hurricanes. It is potentially catastrophic, especially in deltaic regions with onshore winds at the time of high water level and extreme wind wave heights.

submerged lands - Lands covered by water at any stage of the water level.

surface, level - An equipotential surface of the gravity field. The force of gravity is everywhere perpendicular to this surface. The surface of a body of still water is a level surface. The surface of the ocean, if disturbances caused by tides, currents, winds, atmospheric pressure, and so on, are not considered, is a level surface. The surface of the geoid is a level surface. With respect to the Earth, level surfaces are approximately ellipsoidal, the distance between any two level surfaces decreasing with increase of latitude. For example, a level surface which is 1000 m above the average surface of the sea at the Equator is 995 m above that surface at the poles.

tape gauge - See electric tape gauge.

telemetry - The capability of transmitting or retrieving data over long distance communication links, such as satellite or telephone.

thermistor - Temperature sensor.

universal time (UT) - Same a Greenwich mean time (GMT).

water level gauge - An instrument for measuring the rise and fall of the water level. See ADR gauge, automatic water level gauge, Next Generation Water Level Measurement System, electric tape gauge, pressure gauge, and staff.

water level station - The geographic location at which water level observations are conducted. Also, the facilities used to make water level observations. These may include a gauge house, water level gauge, staff, and bench marks. See master station.

water level elevation - The elevation of a particular point or small patch on the surface of a body of water above a specific point or surface, averaged over a period of time sufficiently long to remove the effects of short period disturbances.

water level transfer - The extension of leveling across a lake or between large bodies of water by assuming that the average position of the surface of each body, averaged over a suitable length of time, is a level surface.

zero electric tape gauge - A specific IGLD 85 elevation at each Great Lake Water Level Station to ensure correct water level measurements.