APPENDIX K

Lake Superior Navigation Project Referenced to IGLD85—Ontonagon Harbor, Michigan (Detroit District)

K-1. Purpose. This appendix contains an example of a Detroit District harbor project in Lake Superior (Figure K-1) that has been adequately referenced to the current NSRS orthometric datum and to the local reference water level datum in Lake Superior (IGLD85). The project consists of two breakwaters that have established reference baselines with local control on an IGLD85 vertical datum that is tied to a "Dynamic Height" reference plane used in the Great Lakes region—see Figure K-2. NOAA water level gages and bench marks in the Great Lakes are referenced to both orthometric heights (NAVD88) and dynamic heights (IGLD85). An overview on the establishment of IGLD85 and a list of IGLD reference datums throughout the Great Lakes and Connecting Waterways is at the end of this appendix.

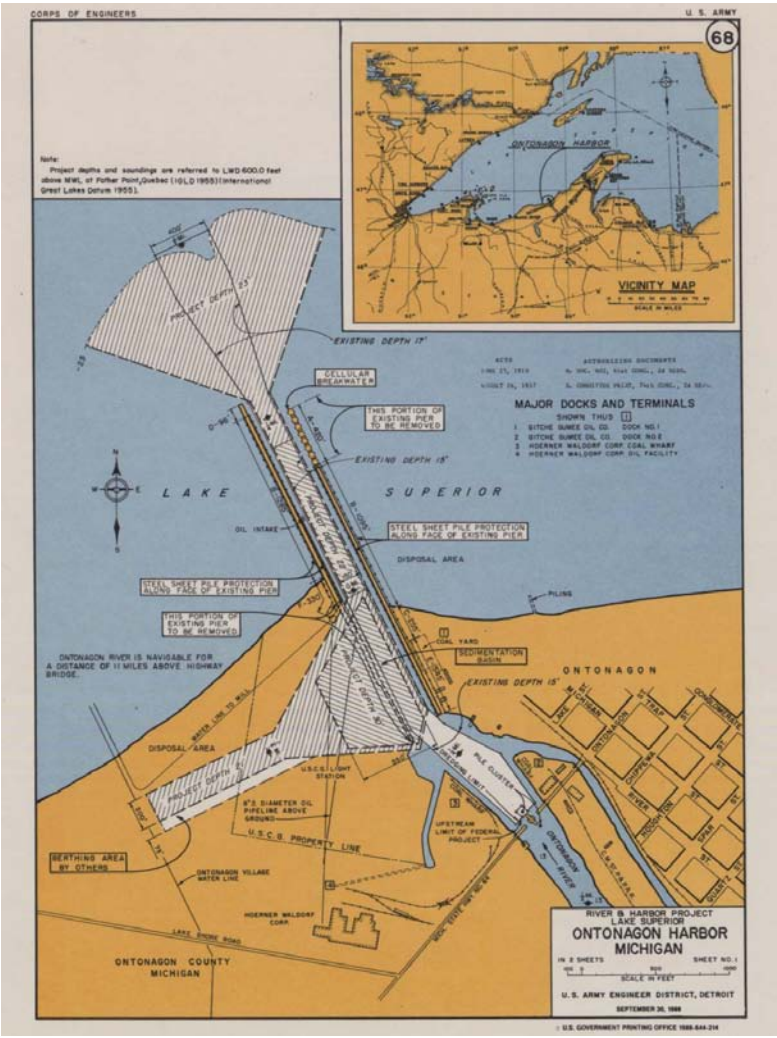

Figure K-1. Ontonagon Harbor, Michigan – Project Map.

K-2. Project Description.

ONTONAGON HARBOR, MICHIGAN

CONDITION OF IMPROVEMENT 30 SEPTEMBER 1986

EXISTING PROJECT: Authorized by the R&H Acts of 2 March 1867, 23 June 1874, 13 June 1902, 2 March 1907, 3 March 1909, 26 August 1937 and Act of 1962. Earlier authorizations (1910 and 1937) provide for a flared lake approach channel about 850 feet long to deep water and 16 feet deep with depths narrowing from 400 feet at the outer end to 150 feet opposite the outer end of the west pier; a channel between the piers 150 feet wide, 17 feet deep in the outer 250 feet, and 15 feet deep in the inner 2,200 feet; an inner basin 12 feet deep and 900 feet long, extending between lines 50 feet from the existing wharves on each side of the river, the maximum width being 200 feet; and the maintenance of this channel, the basin, and the east and west entrance piers which are 2,315 feet and 2,563 feet long, respectively.

Figure K-2. Ontonagon Harbor Michigan – Structure and federal navigation channel.

K-3. Connections to NSRS and Tidal Datum References. The Tidal BM established for the project is BM "D 135" as shown on Figure K-3. This point is published in the NSRS and has observed NAD83/GRS80 ellipsoid height observations, as excerpted from the NGS datasheet in Figure K-3.

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RL0728  CBN         -  This is a Cooperative Base Network Control Station.
RL0728  DESIGNATION -  D 135
RL0728  PID         -  RL0728
RL0728  STATE/COUNTY-  MI/ONTONAGON
RL0728  USGS QUAD   -
RL0728
RL0728                        *CURRENT SURVEY CONTROL
RL0728  ___________________________________________________________________
RL0728* NAD 83(2007)-  46 52 20.23258(N)    089 19 19.44724(W)     ADJUSTED
RL0728* NAVD 88     -       186.877  (meters)     613.11   (feet)  ADJUSTED
RL0728  ___________________________________________________________________
RL0728  EPOCH DATE  -        2002.00
RL0728  X           -      51,683.527 (meters)                     COMP
RL0728  Y           -  -4,367,861.008 (meters)                     COMP
RL0728  Z           -   4,632,183.750 (meters)                     COMP
RL0728  LAPLACE CORR-          -4.82  (seconds)                    USDV2009
RL0728  ELLIP HEIGHT-         155.401 (meters)          (02/10/07) ADJUSTED
RL0728  GEOID HEIGHT-         -31.44  (meters)                     GEOID09
RL0728  DYNAMIC HT  -         186.907 (meters)     613.21  (feet)  COMP
RL0728
RL0728  ------- Accuracy Estimates (at 95% Confidence Level in cm) --------
RL0728  Type    PID    Designation                       North   East  Ellip
RL0728  ------------------------------------------------------------------
RL0728  NETWORK RL0728 D 135                              1.55   1.12   5.21
RL0728  ------------------------------------------------------------------
RL0728  MODELED GRAV-     980,770.6   (mgal)                      NAVD 88
RL0728
RL0728  VERT ORDER  -  FIRST     CLASS II
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Figure K-3. Ontonagon Harbor Michigan – Tidal NGS BM D 135 Datasheet.

The 613.11 ft NAVD88 elevation of D135 is based on adjusted leveling observations. The estimated 95% confidence of the ellipsoid height is about 5 cm. Thus, this is an excellent point for use as an NOS gaging station from which all supplemental surveys can be referenced.

a. Local PBM and TBM control. Figure K-4 lists the local reference PBMs and TBMs that are used to control structure cross-section monitoring. All USACE monuments are run in level differential levels loops to the two known tidal bench marks. All elevation measurements were relative to BM"D 135" on the NAVD88 reference datum. All reported elevations on design surveys and channel depth surveys are referenced to IGLD85 datum.

b. IGLD85. IGLD85 is expressed as a dynamic height. Informally, this could also be considered as a height equivalent above mean sea level, based on work required to raise a unit mass. IGLD85 is also based on an adopted elevation at Point Rimouski/Father's Point. And, IGLD85 is realized as mean water levels at a set of master water level stations on the Great

Lakes. Due to various observational, dynamical, and satiric effects, there will be slight departures between a dynamic height and an IGLD85 height. These departures are known as hydraulic correctors, and are part of the NAVD88/IGLD85 datum transformation.

c. Conversion from NAVD88 Dynamic Height to IGLD85. The survey specifications required that structure profile data and all topographic be referenced on IGLD85, reported as true elevations. However soundings are reported as negative numbers in relationship to the datum of IGLD85 601.1 ft for Lake Superior. Thus, a (-) 26.5 ft depth reported on a condition survey is equal to an IGLD85 elevation of (601.1 - 26.5) = 574.6 ft.

(1) 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.

(2) The "Hydraulic Corrector" at each gage site on the lake has been incorporated into the data retrieval and storage process. As such, water level information is stored mechanically or electronically, at the NOAA CO-OPS or the Canadian Department of Fisheries and Oceans (DFO). Water elevations are referenced to IGLD85 and do not require any further adjustment.

(3) Hydraulic Correctors for several harbors in Lake Superior are listed below in Table K-1. IGLD85 vertical datum is based on calculated and interpolated corrections to be applied to Dynamic Heights for the Great Lakes region.

Table K-1. Lake Superior Hydraulic Correctors for IGLD85 (in meters).

PROJECT	LOCATION	HC	IHC
Duluth-Superior MN-WI	Lake Superior	0.3	--
Ontonagon Harbor MI		0.2	--
Grand Travis Bay MI		--	0.1
Saxon Harbor WI		--	0.2

IHC = Interpolated from established Hydraulic Correctors
HC = Hydraulic Correctors from “Establishment of International Great Lakes Datum” December 1995

INTERNATIONAL GREAT LAKES DATUM (1985)
Tabulation of Primary Bench Mark,
ONTONAGON

Primary PBM NO 2		Hydraulic Corrector	0.049 m
IGLD85 elev	185.443 m	Diff IGLD85-IGLD55	0.323 m

d. NOAA gage Ontonagon. The NOAA CO-OPS station data for the Ontonagon gage is shown in Figures K-4 and K-5.

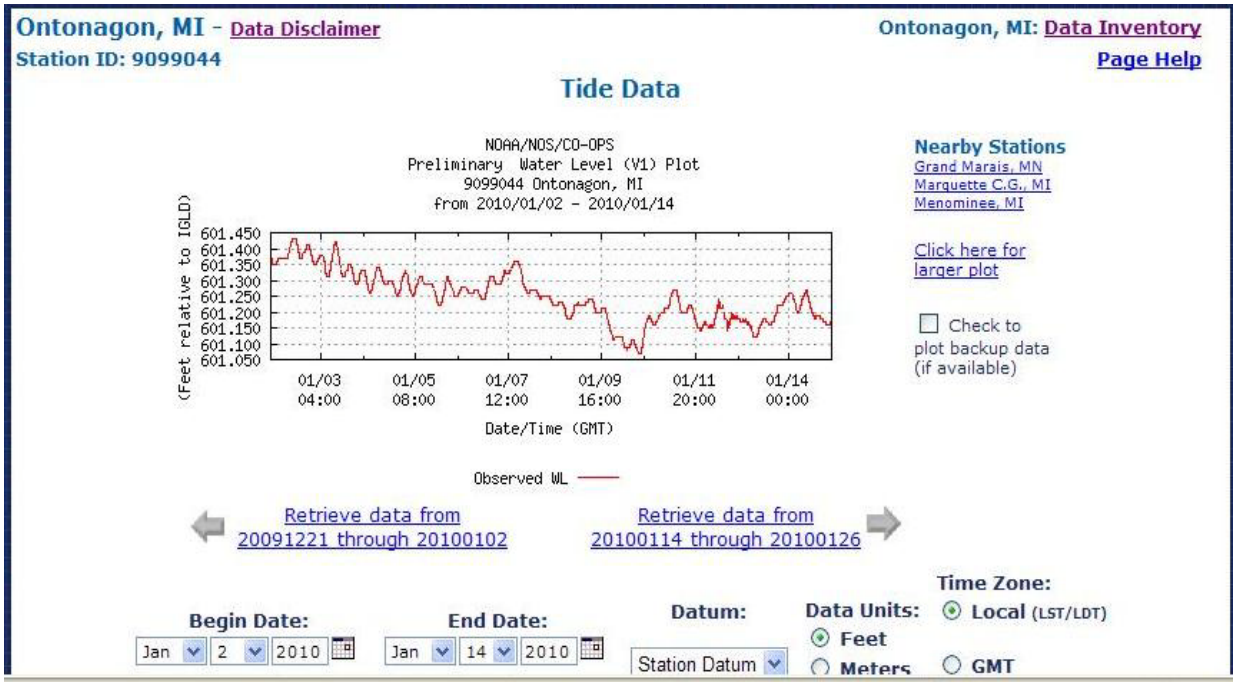

Figure K-4. Published NOAA/CO-OPS gage data in IGLD85 per CO-OPS web site.

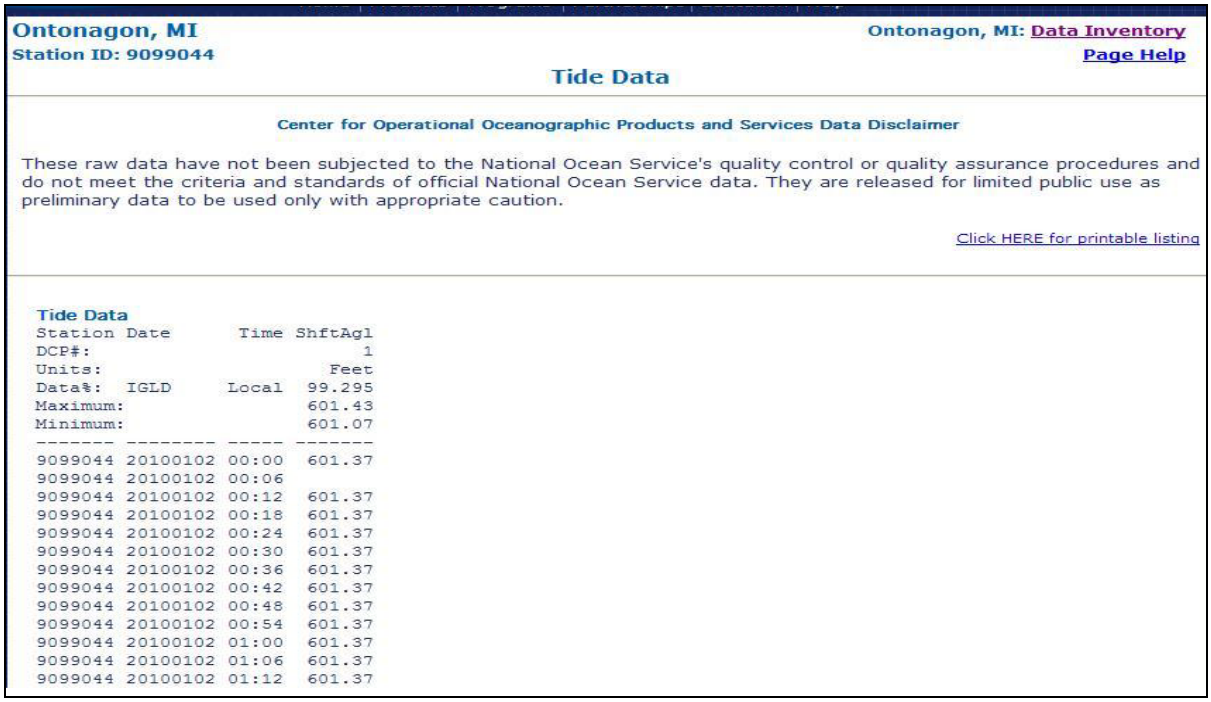

Figure K-5. Published NOAA/CO-OPS gage data in IGLD85 per WEB site in IGLD85 in Local Standard Time (LST) in six-minute intervals.

e. Sounding corrections. Based on the gage data in Figure K-5 for the date shown (2 Jan 10), the water level at Ontonagon is 0.27 ft above IGLD85 (601.1 ft). To correct all sounding data observed on 2 Jan 10 to the IGLD85 depth, one would subtract 0.27 ft from all observed soundings. The difference between NAVD88 and IGLD85 is assumed the same throughout this small project site. Figure K-6 illustrates survey depths referenced to IGLD85 on a Project Condition Survey of Ontonagon Harbor. Figures K-7a and K-7b are examples of design placement grades on the IGLD85 reference datum.

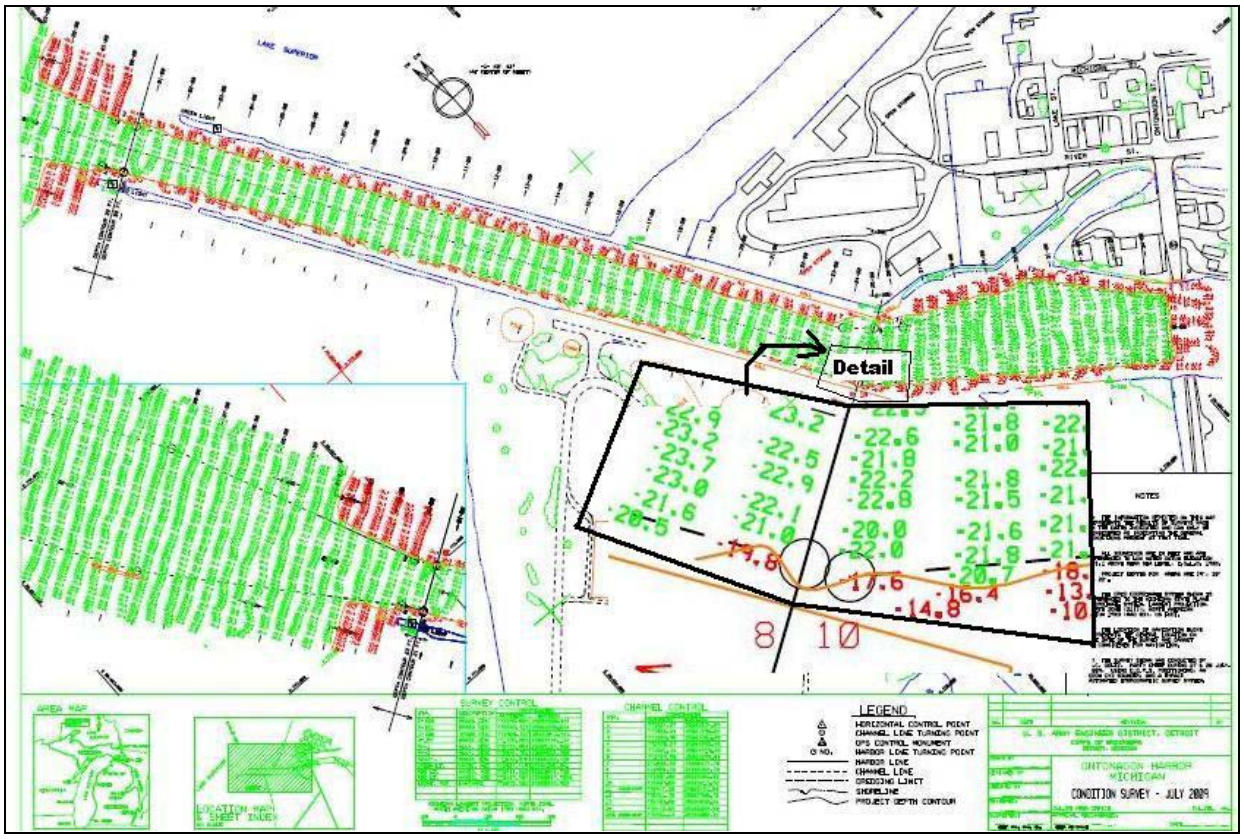

Figure K-6. Hydrographic condition survey of federal navigation channel with soundings referenced to IGLD85 (601.1 ft) Datum.

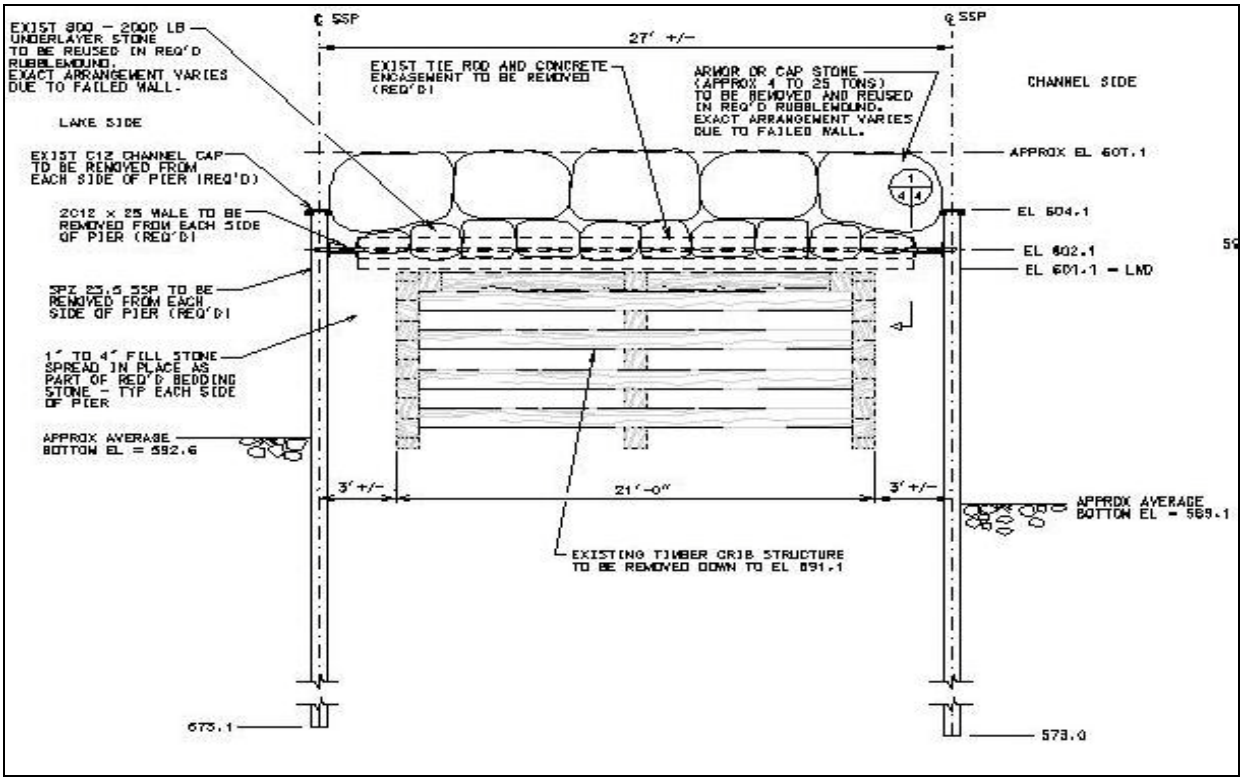

Figure K-7a. Timber crib design details referenced to IGLD85 (601.1) Datum.

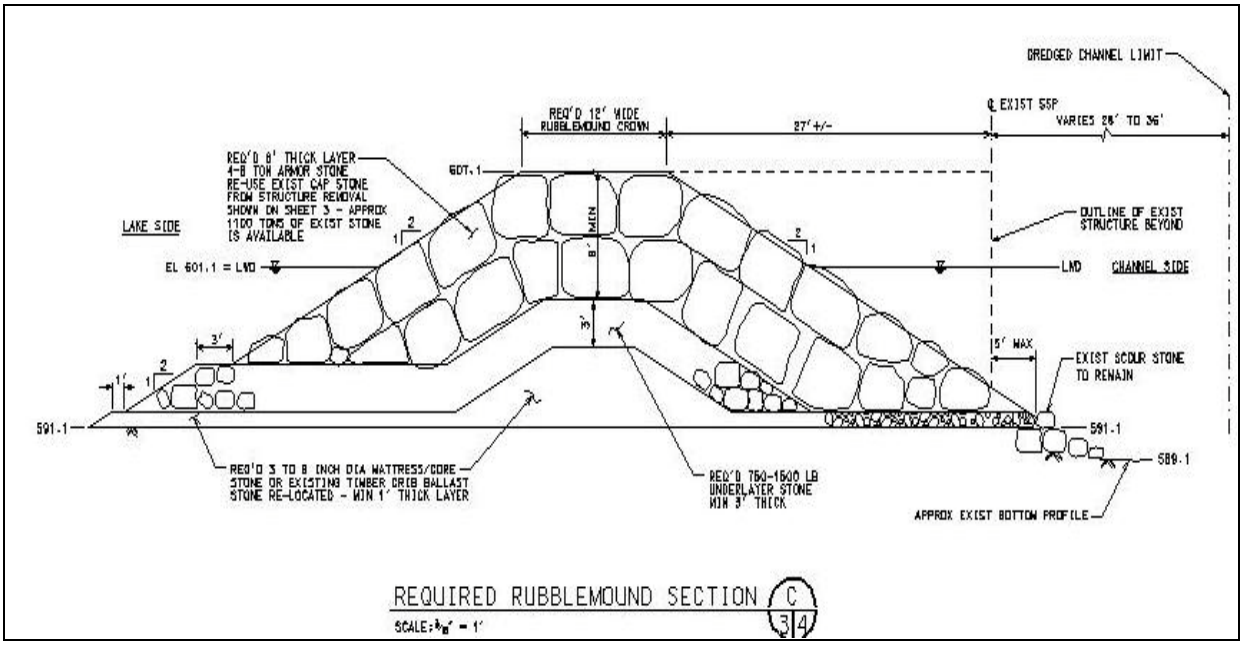

Figure K-7b. Rubblemound design details referenced to IGLD85 (601.1) Datum.

f. Geodetic and water level references and uncertainties. Based on the published data, the geodetic and "tidal datum" relationships at Tidal Bench Mark “D-135” could be tabulated as shown in Table K-2.

Table K-2. Elevations at Tidal Bench Mark “D-135.”

Datum	Elevation	Referenced From	Estimated Uncertainty	Relative to
NGVD29	613.22 ft	VERTCON transform	±0.3 ft	NSRS
IGLD85	613.01 ft	Tidal BM D-135	±0.2 ft	NGS
NAVD88	613.11 ft	NSRS	±0.1 ft	NSRS
Dynamic Ht	613.21 ft	Tidal BM D-135	±0.2 ft	NWLON

K-4. Background on Establishment of IGLD85. The following paragraphs provide additional background on the establishment of IGLD85 in the Great Lakes. They are excerpted from "*Establishment of International Great Lakes Datum (1985*)" (IJC 1995) by The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

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 the 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) ... The development of the NAVD (1988) ... 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 Geopotential numbers for individual bench marks are the same in both height systems.

Dynamic height 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. Following are some of the advantages of dynamic heights:

(1) 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.

(2) 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.

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 ... the MWL at each gauging station was treated as a bench mark In the network adjustment. Following the adjustment ..., 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*

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 M W' months (June - September) of 1982 - 1988. The MWL is referenced to the Master Station Primary Bench Mark Dynamic Height.

The water surface elevation ($WS_{IGLD1985}$) is obtained by subtracting the Hydraulic Corrector (HC) from the Dynamic Water Surface Elevation ($WS_{Dynamic}$).

$$WSI_{GlD1985} - WS_{Dynamic} - HC$$

where:

$WS_{IGLD1985}$ = 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

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

The advantages of IGLD (Ì985), leading to the Coordinating Committee recommendations, may be summarized as follows:

(1) 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.

(2) 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.

K-5. Tabulation of Great Lakes and Connecting Channels Water Level Datums (NOAA CO-OPS).

STATION NUMBER	LWD (Meters)	LWD (Feet)	STATION NAME, STATE & BODY OF WATER
ST. LAWRENCE RIVER (CHART DATUM/LWD - SEE STATION VALUE FOR SLOPING SURFACE)			
8311030	73.88	242.4	Ogdensburg, NY St. Lawrence River
8311062	74.07	243.0	Alexandria Bay, NY St. Lawrence River
LAKE ONTARIO (CHART DATUM/LWD 74.2 M - 243.3 FT.)			
9052000	74.2	243.3	Cape Vincent, NY Lake Ontario
9052030	74.2	243.3	Oswego, NY Lake Ontario
9052058	74.2	243.3	Rochester, NY Lake Ontario NY
9052076	74.2	243.3	Olcott, NY Lake Ontario
NIAGARA RIVER (NON NAVIGABLE WATERS)			
9063007	N/A	N/A	Ashland Ave., NY Niagara Falls-Below the falls
9063009	N/A	N/A	American Falls, NY Niagara Falls-Above the Falls
9063012	N/A	N/A	Niagara Intake, NY Niagara River – Power diversion water intakes
LAKE ERIE (CHART DATUM/LWD 173.5 M - 569.2 FT.)			
9063020	173.5	569.2	Buffalo, NY Lake Erie
9063028	173.5	569.2	Sturgeon Point, NY Lake Erie
9063038	173.5	569.2	Erie, PA Lake Erie
9063053	173.5	569.2	Fairport, OH Lake Erie
9063063	173.5	569.2	Cleveland, OH Lake Erie
9063079	173.5	569.2	Marblehead, OH Lake Erie
9063085	173.5	569.2	Toledo, OH Lake Erie
9063090	173.5	569.2	Fermi Power Plant, MI Lake Erie
DETROIT RIVER (CHART DATUM/LWD - SEE STATION VALUE FOR SLOPING SURFACE)			
9044020	173.58	569.5	Gibraltar, MI Detroit River
9044030	173.95	570.7	Wyandotte, MI Detroit River
9044036	174.08	571.1	Fort Wayne, MI Detroit River
9044049	174.34	572.0	Windmill Point, MI Detroit River

K-5 (Continued). Tabulation of Great Lakes and Connecting Channels Water Level Datums (NOAA CO-OPS).

STATION NUMBER	LWD (Meters)	LWD (Feet)	STATION NAME, STATE & BODY OF WATER
LAKE ST. CLAIR (CHART DATUM/LWD 174.4 M - 572.3 FT.)			
9034052	174.4	572.3	St. Clair Shores, MI Lake St. Clair
ST. CLAIR RIVER (CHART DATUM/LWD - SEE STATION VALUE FOR SLOPING SURFACE)			
9014070	174.58	572.8	Algonac, MI St. Clair River
9014080	175.08	574.4	St. Clair State Police, MI, St. Clair River
9014084	175.35	575.3	Marysville, MI St. Clair River (in-active)
9014087	175.50	575.8	Dry Dock, MI St. Clair River
9014096	175.77	576.7	Dunn Paper, MI St. Clair River
9014098	175.93	577.2	Fort Gratiot, MI St. Clair River
LAKE HURON (CHART DATUM/LWD 176.0 M - 577.5 FT.)			
9075002	176.0	577.5	Lakeport, MI Lake Huron
9075014	176.0	577.5	Harbor Beach, MI Lake Huron
9075035	176.0	577.5	Essexville, MI Lake Huron
9075059	176.0	577.5	Harrisville, MI Lake Huron
9075065	176.0	577.5	Alpena, MI Lake Huron
9075080	176.0	577.5	Mackinaw City, MI Lake Huron
9075099	176.0	577.5	De Tour Village, MI Lake Huron
LOWER - ST. MARY'S RIVER (CHART DATUM/LWD-SEE STATION VALUE FOR SLOPING SURFACE)			
9076024	176.03	577.5	Rock Cut, MI St. Mary's River
9076024	176.12	577.8	West Neebish Island, MI
9076028	176.12	577.8	Lookout Station #4, MI St Mary's River
9076032	176.29	578.4	Little Rapids, MI St Mary's River
9076060	176.38	578.7	U.S. Slip, MI St. Mary's River
UPPER - ST. MARY'S RIVER (CHART DATUM/LWD - SEE STATION VALUE FOR SLOPING SURFACE)			
9076070	183.00	600.4	S.W. Pier, MI St. Mary's River

K-5 (Concluded). Tabulation of Great Lakes and Connecting Channels Water Level Datums (NOAA CO-OPS).

STATION NUMBER	LWD (Meters)	LWD (Feet)	STATION NAME, STATE & BODY OF WATER
LAKE MICHIGAN (CHART DATUM/LWD 176.0 M - 577.5 FT.)			
9087023	176.0	577.5	Ludington, MI Lake Michigan
9087031	176.0	577.5	Holland, MI Lake Michigan
9087044	176.0	577.5	Calumet Harbor, IL Lake Michigan
9087057	176.0	577.5	Milwaukee, WI Lake Michigan
9087068	176.0	577.5	Kewaunee, WI Lake Michigan
9087072	176.0	577.5	Sturgeon Bay Canal, WI Lake Michigan
9087079	176.0	577.5	Green Bay, WI Lake Michigan
9087088	176.0	577.5	Menominee, MI Lake Michigan
9087096	176.0	577.5	Port Inland, MI Lake Michigan
LAKE SUPERIOR (CHART DATUM/LWD 183.2 M - 601.1 FT.)			
9099004	183.2	601.1	Point Iroquois, MI Lake Superior
9099018	183.2	601.1	Marquette C.G. MI Lake Superior
9099044	183.2	601.1	Ontonagon, MI Lake Superior
9099064	183.2	601.1	Duluth, MN Lake Superior
9099090	183.2	601.1	Grand Marais, MN Lake Superior