Establishment of Relationship of Great Lakes Vertical Datum using Dynamic Heights, Hydraulic Correctors and Accepted Datum Offset

Procedure Number: SOP #3.2.3.5 (E25)
Created: April 22, 2011
Created By: Cary Wong, Andrew Wehrli, and Derrell Lorthridge
Approved By: Steve Gill, Manoj Samant, Tom Landon, Jeff Oyler
Approved on: September 1, 2011
Modified March 11, 2016
By Cary Wong and Adam Grodsky
Approved By: Manoj Samant and Michael Michalski
Approved on: April 4, 2016

1. **Title:** Establishment of the relationship of International Great Lakes Datum 1985 (IGLD 1985) using North American Vertical Datum 1988 (NAVD 1988)/Dynamic Heights and Hydraulic Correctors to compute IGLD 1985) elevations (Accepted Datum Offset) at the water level gauge/data collection platform (DCP) as the datum reference.

2. **Purpose:**

The purpose of this document is to provide a brief background/history of IGLD, Dynamic Heights, Hydraulic Correctors (HC) and Accepted Datum Offset; and their calculation and application to reference IGLD (1985) elevations within the Great Lakes and their connecting channels.

3. **Background/History**

The first 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 on Great Lakes Basic Hydraulic and Hydrologic Data (CCGLBHHD or CC) formed in 1953. In establishing this datum, the committee agreed that the Great Lakes, their connecting channels and the St. Lawrence River system would be considered as a unit with datum and reference surfaces based on the 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 approximated mean sea level, and d) it had been connected to the remainder of the system via the connecting channels by first-order leveling and in between the connecting channels (lakes) utilizing water level transfer methodologies. For IGLD (1985) the zero reference location was moved from Pointe-au-Pere to Rimouski and became the zero reference point for the North American Vertical Datum of 1988 (NAVD88).

While IGLD (1955) was a much improved datum over the earlier datums, it was recognized that a new datum would be necessary approximately every 25-30 years due to movement of the earth's crust in the Great Lakes region. The CC pursued the development of IGLD (1985) based on the development of NAVD 1988. The requirement within the entire Great Lakes basin was to provide an accurate measurement of the potential hydraulic head, and to determine the hydraulic gradient of the connecting channels between the Great Lakes. This method, like IGLD (1955), requires the use of "Dynamic Heights" which gives an accurate measure of the potential hydraulic head between selected points. Dynamic heights are basically geopotential numbers scaled by a constant of 980.6199 gals, normal gravity at sea level at 45^{o} latitude. Consequently points that have the same geopotential number have the same dynamic height.

The current IGLD reference is IGLD (1985) and the development of which involved optical survey leveling observations between the years 1965 to 1986 and the analysis of Mean Water Level (MWL) data, water level comparisons and water level transfers for the period 1982 through 1988. These efforts involved level lines, consisting of 78 loops and 1,119 benchmarks, connecting 80 water level stations with 25 cross connections between the U.S. and Canada. The accumulative difference, adjustment from Pointe-au- Pere/Rimouski to the west end of Lake Superior was approximately 7 cm. Data for the four months June through September, 1982 through 1988 were used to calculate a dynamic MWL at each master station on a lake and each subordinate station on the same lake. The dynamic MWL at each water level station was treated as a benchmark the same as if holding a dynamic height on the stations primary benchmark (PBM). Since water surfaces of the Great Lakes are considered to be geopotentially equal, therefore on any particular lake, at the time a vertical datum is established, all dynamic MWL values for a water level station around the lake are theoretically the same as what was measured at the master lake station. The difference in the dynamic MWL heights from a subordinate station compared to the master station is known as the hydraulic corrector difference. Each subordinate station's hydraulic corrector difference is applied to the water level readings at that gauge, bringing all lake gauges at the time of establishment into the same reference system. These hydraulic correctors, once applied, reference IGLD (1985). This enables one Low Water Datum (LWD) value, also referred to as Chart Datum, to be held for a lake chart.

On Great Lakes connecting channels/rivers dynamic height equals IGLD (1985). This is true because water levels on a connecting channel or river can be considered to have a single point in its reference plane where as a lake will have several points on the lake datum plane (see example below).

Interconnecting Channel (River) Reference St. Clair River Chart

- **PLANE OF REFERENCE OF THIS CHART (Low Water Datum). Depths are referred to the sloping surface of the river when Lake Huron is at elevation 577.5 feet and Lake St. Clair is at elevation 572.3 feet.**

- **“Dynamic Heights equal IGLD 1985 in the sloping surface/rivers”**

See section.6.1 for list of Master Stations. Appendix A has a listing of the existing IGLD (1985) HC for operating Great Lakes Stations. Note that HC are not applied to stations located within the interconnecting waterways as explained above.

4. Scope/Applicability

This SOP is applicable to all the work done by OD (DT, DPT) and ED (COET).

5. Main Processes

(1) The Datums Team (DT) will calculate the HC one of three following ways for out-year calculations as listed below.

A. The primary bench mark (PBM) from a newly installed lake station (subordinate station) has a NGS published data sheet based on the June 1991 adjustment.

1. Identify the out-year station PBM and obtain the PBM PID.
2. Access the NGS datasheet page and enter PID to download PBM datasheet
3. Confirm that the orthometric height adjustment for the PBM is from the June 1991 adjustment
4. Copy the NAVD 88 orthometric height and Lat/Long position
5. Access the NGS Geodetic Tool Kit and select the “IGLD 85” (http://www.ngs.noaa.gov/TOOLS/program_descriptions.html#IGLD85)
6. Click on the ”IGLD 85” option
7. Click on the “To interactively compute an IGLD 85 height for a NAVD 88 benchmark” link
8. Input the Lat/Long, NAVD88 orthometric height and optional station name into the dialog box, be sure that the NAVD 88 to IGLD 85 button is selected
9. Retrieve the dynamic and IGLD85 heights
10. Calculate HC by using the following formula:

    HC = Dynamic Height – IGLD (1985) Height

11. Result is a model generated HC on IGLD (1985) datum reference
12. Proceed to section 5.2 to apply HC to the data in the database.

B. The new lake subordinate station does not have a NGS PBM published data sheet based on the June 1991 adjustment. The DT will calculate the HC value from the four summer months spanning June through September for a 7 year out-year period at the subordinate water level station and the corresponding master station (See section 3.2.3.5.6.1 for list of master stations). The four month period from June through September are selected because these months are ice free and are affected by wind the least. A seven year average period is used to reduce effects of abnormal weather patterns but not so long as to be overly affected by glacial isostatic adjustment.

1. Retrieve recent 7 years of monthly mean (MM) water level (WL) data for the master station and new subordinate station
2. Extract the 4 summer months of WLs (Jun-Sep)
3. If the subordinate station has data that has a HC already incorporated in to the WL value, then retrieve the published HC for the new station (retrieve from Station Parameters in PowerBuilder)
   a. Add the published HC to MM WL values of the subordinate station to convert MM WL to dynamic heights
4. Average MM WL data for master station (already on dynamic height) and newly calculated dynamic heights for the subordinated station
5. To calculate the Hydraulic Corrector subtract the MWL at the Master Station (MWL_{Master}) from the $MWL_{(dynamic)}$ at the Subordinate station (MWL_{Sub}).

$$HC = (MWL_{Sub}) - (MWL_{Master}) \quad (1)$$

where:

HC = Hydraulic Corrector for Subordinate Station. (Please note that the Hydraulic Corrector can be a positive or negative value.

MWL_{Sub} = Mean Water Level at Subordinate Station on a lake for the summer months (June – September) of the 7 year IGLD update period, MWL is referenced from the Subordinate Station Primary Bench Mark Dynamic Height.

MWL_{Master}= Mean Water Level at Lake Master Station for the summer months (June – September) of the 7 year IGLD update period. MWL is referenced from the Master Station Primary Bench Mark Dynamic Height.

The water level elevation ($WL_{Hydraulic\ corrected}$) is obtained by subtracting HC from the Dynamic Water Level Elevation ($WL_{Dynamic}$).

$$WL_{Hydraulic\ corrected} = (WL_{Dynamic}) - (HC) \quad (2)$$

where:

$WL_{Hydraulic\ corrected}$ = Water Level elevation (water level values stored in WALI on IGLD for the selected Water Level station.

WLDynamic = Water Level elevation referenced to Dynamic Height.

HC = Hydraulic Corrector for a selected Water Level station (The value may be positive or negative).

6. Calculated new HC - [subordinate station average dynamic MWL] – [master station average MWL] = HC based on current 7 year summer months
7. Proceed to section 5.2 to apply HC to the data in the database.

C. The newly installed lake subordinate station does not have a NGS PBM published data sheet based on the June 1991 adjustment. Calculate HC using current summer months with less than 7 years of data.

1. Follow method outlined in section 5.1.b using recent data from 1 to 6 years as appropriate.

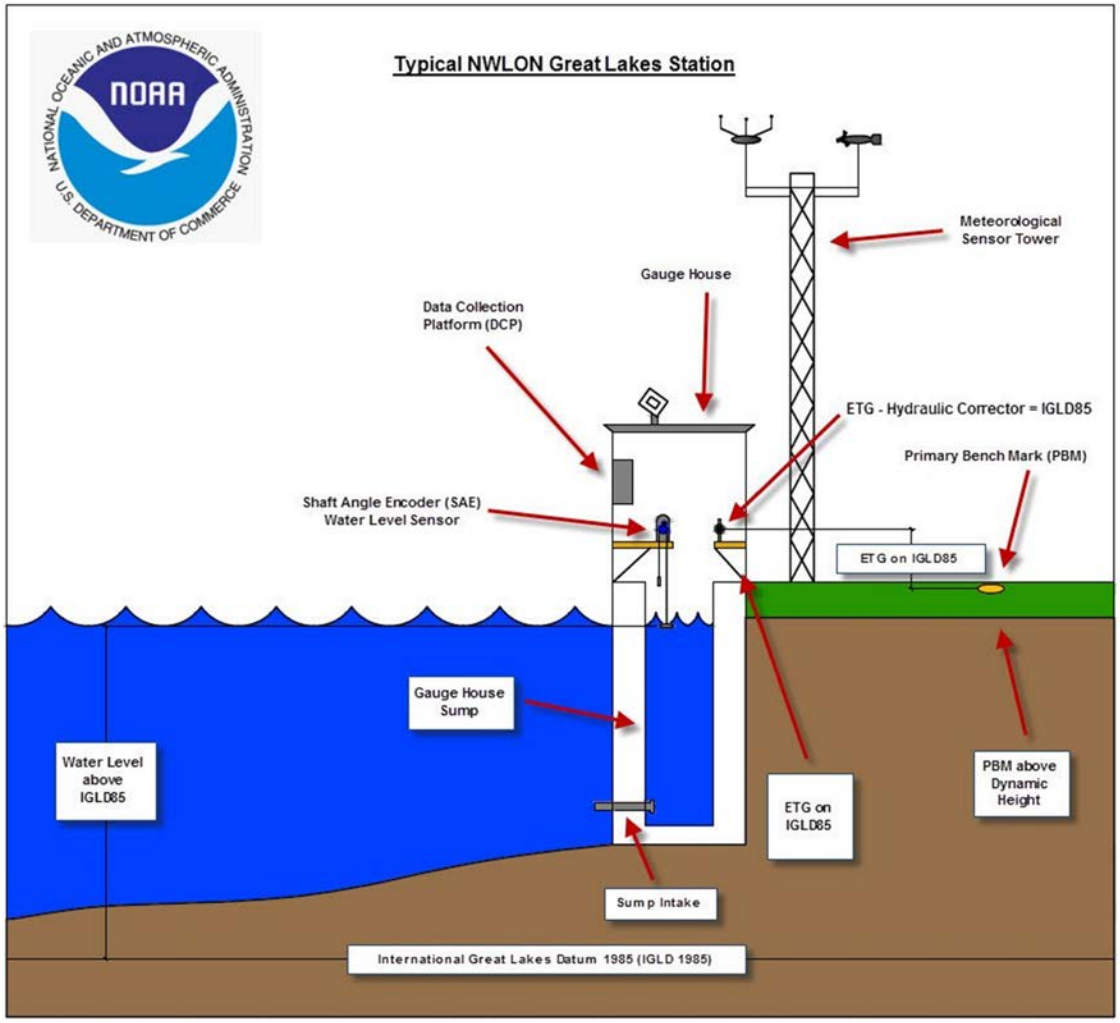
(2) Accepted Datum offset (ACCEPT_DATUM_OFFSET) is a sensor parameter stored in the Data Management System PowerBuilder (DMS PB) by the Configuration and Operational Engineering Team (COET). Accepted Datum Offset is defined as follows:

ACCEPT_DATUM_OFFSET =
IGLD (1985) elevation = (Measured elevation of ETG) – HC *(3)*

Thus the HC value is algebraically subtracted from the Electronic Tape Gauge (ETG) elevation to determine the Accepted Station Datum (IGLD (1985) as listed in equation 3. Then the Raw Water Level reading value provided by the Shaft Angle Encoder (SAE) is subtracted from the Accepted Datum Offset to determine the water level above IGLD (1985) also known as Station Datum (SD) as follows:

WL on IGLD 1985 (SD) = (ACCEPT_DATUM_OFFSET) - (Raw WL) *(4)*

Raw water level values from SAE = dynamic height water level values



Above: diagram depicting a typical NWLON Great Lakes station and associated elevations.

Above, left: outdoor ETG reference point from station 9052000 Cape Vincent, NY.
Above, right: indoor ETG reference point (with tape and weight visible) from station 9087088 Menominee, WI.

Please refer to Appendix B for examples of stick diagrams showing the relationship between Dynamic Heights, Hydraulic Correctors and IGLD elevations (Accepted Datum Offset).

(3) Apply the hydraulic corrector to the station data

A. COET will enter the calculated hydraulic corrector into the HYDRO_CORRECTION parameter in DMS PBLogistics Control-Station-Parameters option. The value entered into Power Builder will serve as the historical record of the hydraulic corrector for a particular station.
B. COET will note the six minute time interval that the new corrector is applied to new ingested data and provide the time range to DPT for historical data correction.
C. DPT will adjust all data in the database for the time range provided by COET from step b. in WALI to account for the shift in vertical reference resulting from the hydraulic corrector using the following steps.
    1. DPT will verify that the new hydraulic corrector and sensor/datum offsets provided by COET match what is stored in the database.
    2. Verifier unmarks all data that will have a new corrector applied (six- min (W1), hourly (W2), daily mean (W4), monthly mean (W5) and annual mean (W6)).
    3. Apply corrector adjustment in WALI using the "add a constant" tool. Include comment such as "updated hydraulic corrector" (note that the audit trail only has a 27 character limit for comments section). Check data and audit trail to make sure that the corrector was applied.
    4. Once the hydraulic corrector is applied to the new station as a continuity check, plot the new station water level values against at least two nearby stations and the master lake station to make sure that the stations show similar plots characteristics.
        a. Use WALI to plot simultaneous station plots.
        b. Use WALI-Analyze Water Level and Environmental Data-Compare-Direct to generate plots of differences and histogram of differences between the new station and master/adjacent stations to see if there are any abnormal trends.
    5. Use WALI-Compare-Direct to generate basic statistics to quantify variability (average difference, min/max difference, standard deviation and 95% confidence interval) of differences between the new station and the master/adjacent stations.
    6. Remark all data types (W1, W2, W4, W5, W6) complete.
    7. Processor informs a verifier that constants have been applied and data is re-marked complete.
    8. A verifier checks to see that the corrector was applied and all data are adjusted properly.
    9. Verifier marks all data types verified.
    10. Place all documentation and emails pertaining to corrector update in to station package. Print out new verified hourly heights, daily means, monthly means, and annual means reports for time frame of corrected data to replace reports in station package.

(4) For a new permanently operating lake station, at the end of each summer season, for a total of 7 years of comparisons/computations perform a check comparing the cumulative four summer monthly mean water levels between the Subordinate lake station and the Master lake station. If the cumulative summer monthly mean water level between these two stations exceeds 3 mm in difference, a new hydraulic corrector for the Subordinate lake station shall be recomputed using the procedures stated in section 5.

(5) For establishing a hydraulic corrector for Seasonal lake stations a comparison of the Subordinate lake station four summer monthly means with the appropriate Master lake station is sufficient. However, if the Subordinate lake station is in continuous operation for multiple summer month years, the method of calculating a hydraulic corrector will follow the procedure used for a permanently operating Subordinate lake station for the years that the Seasonal station is in continuous summer month operation.

(6) If a Seasonal lake station is installed with a previously established IGLD (1985) hydraulic corrector, computed during the same reference period as the permanent stations, the accepted hydraulic corrector will be used for that Seasonal lake station.

6. <u>Detailed Sub-Processes/Checklists</u>

1) List of Master Stations by lake:
    1. Lake Ontario - 9052030 Oswego, New York
    2. Lake Erie - 9063053 Fairport, Ohio
    3. Lake St. Clair - 9034052 St. Clair Shores, Michigan
    4. Lake Huron - 9075014 Harbor Beach, Michigan
    5. Lake Michigan- 9075014 Harbor Beach, Michigan
    6. Lake Superior - 9099018 Marquette, Michigan

2) See Appendix A for list of existing IGLD (1985) Hydraulic Correctors for each operating station.

7. <u>Quality Assurance/Control</u> The Datums team is responsible for establishing a hydraulic corrector and COET is responsible for ensuring the hydraulic corrector is applied properly in DMS PB for data ingestion.

8. <u>Management/Responsibility</u> COET and DT are responsible for making sure that the hydraulic corrector is applied and maintained correctly. The CO-OPS Coordinating Committee representative is responsible with coordinating related activities with the International Coordinating Committee on Great Lakes basic Hydraulic and Hydrologic Data. DPT is responsible for processing and verification of the water level values and monitoring for data gaps in the hourly height values. DT is responsible for establishing and checking the dynamic height and hydraulic corrector calculations for each station. COET is responsible for entering and maintaining the hydraulic corrector in DMS PB tables for data ingestion

9. References

Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (1995). *Establishment of International Great Lakes Datum* (1985). Report by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. Chicago, IL and Cornwall, ON, December 1995.

NGS International Great Lakes Datum of 1985, Tool Kit: NAVD88 – IGLD85 Height Conversion at: http://www.ngs.noaa.gov/cgi-bin/IGLD85/IGLD85.prl

Hydraulic Corrector definition (unpublished) at: http://intranet.nos-tcn.noaa.gov/media/wikidocs/Great_Lakes/Glossary/Hydraulic_Corrector.pdf

Appendix A

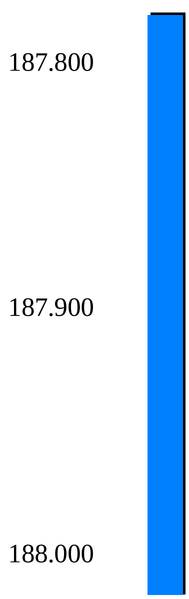
Below is a list of existing IGLD (1985) Hydraulic Correctors for each permanent operating station in the Great Lakes. Please note that correctors are not applied to stations located within the interconnecting waterways. Master stations are listed in bold.

Station ID	Station Name, State	Hydraulic Corrector (m)
9052000	Cape Vincent, NY	0.008
9052030	**Oswego, NY**	**0.000**
9052058	Rochester, NY	0.006
9052076	Olcott, NY	0.008
9063020	Buffalo, NY	-0.026
9063028	Sturgeon Point, NY	-0.023
9063038	Erie, PA	-0.025
9063053	**Fairport, OH**	**0.000**
9063063	Cleveland, OH	0.010
9063079	Marblehead, OH	-0.006
9063085	Toledo, OH	-0.005
9063090	Fermi Power Plant, OH	0.023
9034052	St. Clair Shores, MI	0.000
9075002	Lakeport, MI	0.013
9075014	**Harbor Beach, MI**	**0.000**
9075035	Essexville, MI	-0.002
9075065	Alpena, MI	0.031
9075080	Mackinaw City, MI	0.043
9075099	De Tour Village, MI	0.005
9087023	Ludington, MI	0.087
9087031	Holland, MI	0.090
9087044	Calumet Harbor, IL	0.104
9087057	Milwaukee, WI	0.106
9087068	Kewaunee, WI	0.114
9087072	Sturgeon Bay Canal, WI	0.106
9087079	Green Bay, WI	0.114
9087088	Menominee, MI	0.124
9087096	Port Inland, MI	0.046
9099004	Point Iroquois, MI	-0.100
9099018	**Marquette C.G., MI**	**0.000**
9099044	Ontonagon, MI	0.049
9099064	Duluth, MN	0.079
9099090	Grand Marais, MN	0.046

Appendix B

EXAMPLE 1:

Elevation Information
PID: RJ0586
Designation: A 293
Station Name: Point Iroquois
Station ID: 9099004
Epoch used to compute the Hydraulic Corrector: IGLD 1982 - 1988

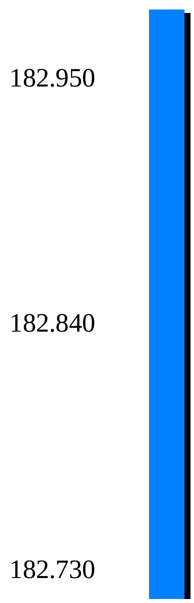


Dynamic Height	=	187.799 meters
Hydraulic Corrector	=	-0.100 meters
IGLD 85 Elevation	=	187.899 meters

Dynamic Height – Hydraulic Corrector = IGLD 85 Elevation
187.799 m – (-0.100 m) = 187.899 m

EXAMPLE 2

Elevation Information
PID: OL0278
Designation: NAVY
Station Name: Milwaukee, WI
Station ID: 9087057
Epoch used to compute the Hydraulic Corrector: IGLD 1982 – 1988



Dynamic Height	=	182.949 meters
Hydraulic Corrector	=	0.106 meters
IGLD 85 Elevation	=	182.843 meters

Dynamic Height – Hydraulic Corrector = IGLD 85 Elevation
182.949 m – 0.106 m = 182.843 m