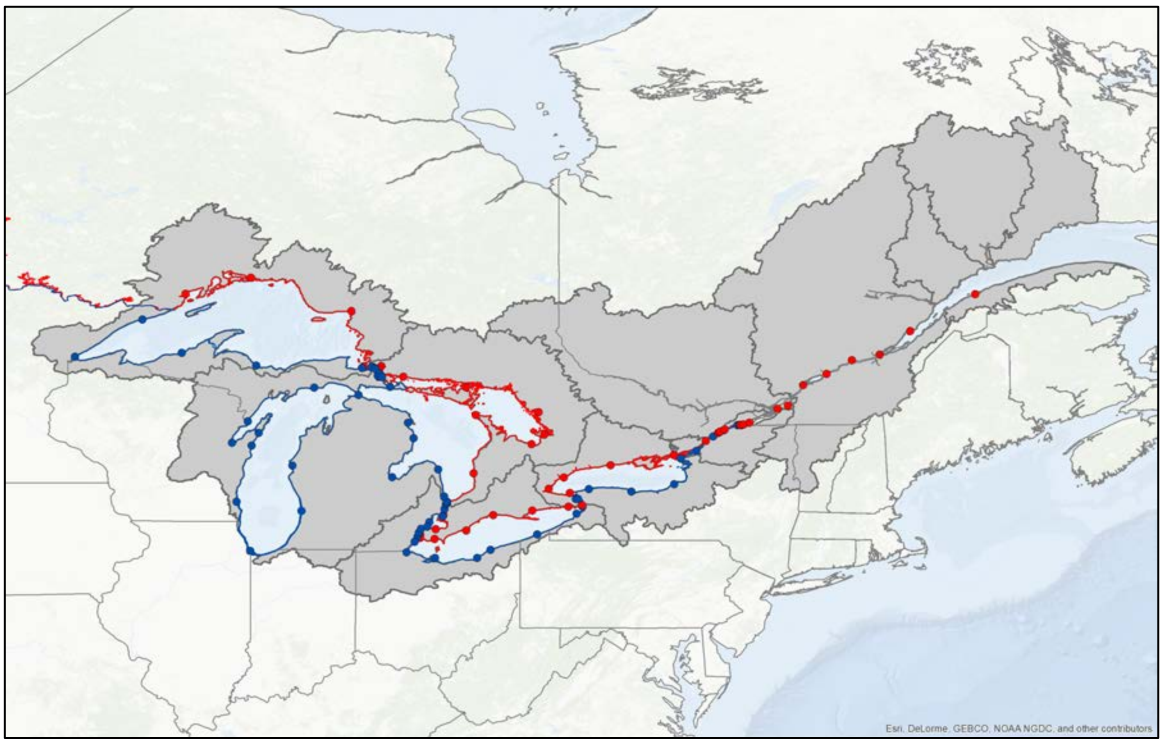
Coordinating Committee on Great Lakes
Basic Hydraulic & Hydrologic Data

Updating the International Great Lakes Datum (IGLD)

Executive Summary



Prepared by the
Vertical Control – Water Levels Subcommittee
on behalf of the
Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data

September 2017

The Great Lakes – St. Lawrence River system is one of the world's greatest freshwater resources and has important environmental, cultural, and economic value for Canada and the United States. The Great Lakes have long been an economic driver for both nations ($180 billion in Canada-U.S. trade). An analysis found that more than 1.5 million jobs are directly connected to the Great Lakes, generating $62 billion in annual wages. The Midwest has recently suffered economic hardships but, thanks to the Great Lakes, the region still generated 27% of the U.S. gross domestic product and 24% of the country's exports in 2009. It is estimated that marine shipping on the Great Lakes moves 164 million metric tons of essential raw materials and finished products annually. A slight decrease in the depth of a waterway means that a vessel must decrease its draft (i.e., reduce the amount of cargo that it's carrying). The Great Lakes Information Network estimates that a 1,000-foot vessel will need to reduce its cargo by about 270 tons for each inch decrease in its draft (a 300-m vessel needs to reduce its cargo by 100 tons for each centimeter decrease in draft).

Use of Great Lakes freshwater resources by the people of Canada, the United States, First Nations and Native Americans, requires knowledge and measurement of water levels, depths, volumes and flows throughout the region. The joint, harmonious use of these waters requires international coordination of many aspects of their management. The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (Coordinating Committee) is an *ad hoc* committee of experts from Federal agencies of the United States and Canada that is responsible for coordinating the collection, compilation, use, and dissemination of data related to hydraulics, hydrology, vertical control and water levels for the Great Lakes – St. Lawrence River System. A fundamental requirement for coordinated management is a common height reference system or "vertical datum" by which water levels can be measured and meaningfully related to each other. The first such common datum was the International Great Lakes Datum of 1955 (IGLD (1955)), later updated to IGLD (1985). To ensure that the vertical datum can provide sufficiently accurate heights, it must be adjusted every 25-30 years to account for the effects of glacial isostatic adjustment (GIA) described below.

Presently the Coordinating Committee is undertaking the development of the next IGLD, referred to here as IGLD (2020). This document outlines the scope of work involved. The Vertical Control-Water Levels Subcommittee of the Coordinating Committee is overseeing this important work. Unlike the previous two IGLDs, this datum update will use a geoid-based vertical datum that will be accessible using global navigation satellite systems (GNSS) such as the Global Positioning System (GPS). The same GNSS used for diverse applications that include navigation of ships, aircraft, spacecraft, and ground vehicles, is employed to monitor millimeter-level shifts of the Earth's surface. GNSS technology will also provide the capability for millimeter-level measurements of water levels in support of safe navigation, regulation, lake level forecasting, international cooperative treaties and agreements, riparian interests, hydroelectric power generation, construction, dredging, litigation, and many other environmental, water resources management and development activities. The water level datum (IGLD) and gauge infrastructure are key components to both nations' transportation and logistics network information. A reliable port and inland waterway system ensures that commercial goods can move quickly, affordably, and safely to facilitate trade and benefit the economies of both countries.

The International Great Lakes Datum update will consist of four main attributes:

- Reference Zero: The reference zero for a vertical datum is usually some determination of mean sea level. For IGLD (2020) the Coordinating Committee has adopted the same reference zero that the U.S. and Canada have adopted for the new geoid-based North American vertical datum expected to be implemented in 2022.
- Reference Surface (Equipotential Surface): For both IGLD (1955) and IGLD (1985), the reference surface was determined from elevations on bench marks established using a network of geodetic leveling loops anchored to the reference zero at Pointe-au-Père, Québec. Although geodetic leveling remains very precise locally, it cannot achieve the accuracy required for present and expected future applications on regional and national scales. Distortions in IGLD (1985) arise from systematic errors in the NAVD 88 leveling network that accumulate in a tilting of the datum of about 35 cm over the entire network from Pointe-au-Père to Thunder Bay (see Figure 1). Furthermore, geodetic leveling is cost prohibitive, time consuming, laborious, and error prone. Consequently, Canada and the U.S. are redefining their national vertical reference systems using a geoid as a reference surface for the datum. The geoid is a stable surface that can be determined both consistently and accurately across the entire continent. It is defined in relation to a reference ellipsoid, making it more compatible with space-based positioning technologies such as GNSS and satellite radar altimetry. Use of modern GNSS measurement techniques is far more efficient in terms of cost, effort, and accuracy. Canada has already adopted a geoid for their Canadian Geodetic Vertical Datum of 2013. The U.S. is expected to adopt a North American geoid for their new vertical datum in 2022 and Canada is expected to update their datum to the new N.A. geoid. It is recommended to adopt the same N.A. geoid as the reference surface for the new IGLD (2020) to maintain consistency with the national vertical datum in both Canada and the U.S.

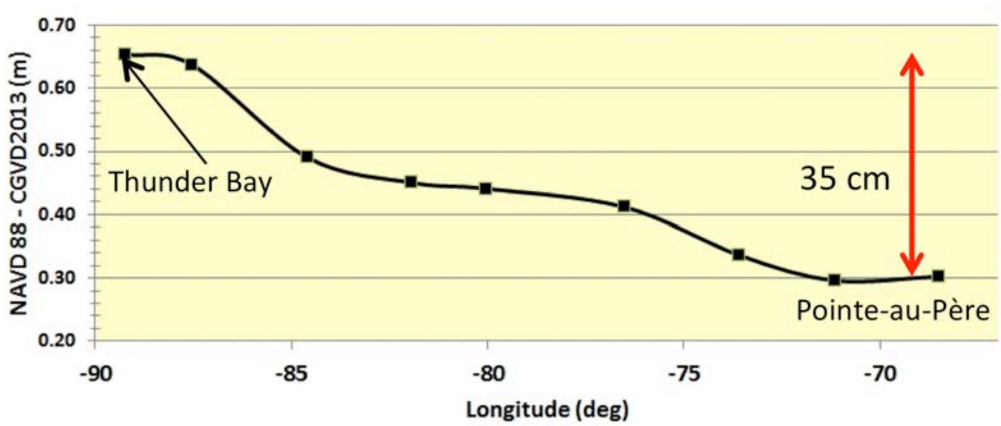


Figure 1. Errors in NAVD 88 heights as determined from comparisons with heights in the geoid-based CGVD2013 datum along a leveling profile from Pointe-au-Père, QC to Thunder Bay, ON.

- Reference Epoch: IGLD (2020) will use a base water level observational period of 2017–2023 with a central water level reference epoch of 2020. In addition to a reference epoch for water levels, heights in the new IGLD (2020) will also need to be referenced to a common epoch because of the effects of crustal motion. It is expected the same 2020 epoch will be used.
- Dynamic Heights: Knowledge of the hydraulic head in the Great Lakes system is critical for water level management and power generation. Traditional orthometric heights do not provide a measure of hydraulic head while dynamic heights do (see Figures 2 and 3). Dynamic heights therefore need to be used on all large bodies of water in the Great Lakes Basin, their connecting channels, and the St. Lawrence River. Dynamic heights are geopotential numbers scaled by a constant value of gravity, allowing them to be expressed in units of distance proportional to the geopotential and providing a direct indication of hydraulic head between locations. It needs to be ascertained how accurately dynamic heights can be determined in a geoid-based datum. Because gravity values are used in the process of determining dynamic heights, it also needs to be determined if new surface gravity measurements will be required or if the interpolation of existing gravity measurements will be sufficiently accurate.

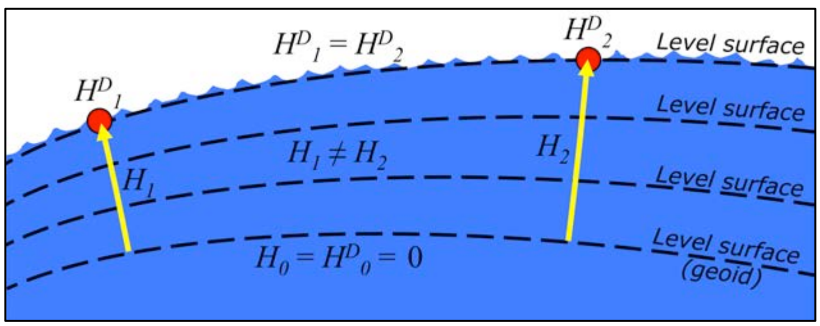


Figure 2. Illustration of dynamic (H^D) vs. orthometric heights (H) on an equipotential surface such as an undisturbed lake. Dynamics heights are proportional to the geopotential and thus constant. Orthometric heights represent the physical distance from the reference geoid, which changes because of convergence of the equipotential surfaces (and increasing value of gravity) as one proceeds north and closer to the center of mass of the Earth due to the flattening of the shape of the Earth at the poles.

Figure 3. Orthometric heights (lower green line) versus dynamic heights (upper blue line) of Lake Superior water surface along a straight line profile from Duluth, Minnesota to Marathon, Ontario, illustrating that orthometric heights are not constant along a level water surface, while dynamic heights are.

In addition, the following issues related to the development and implementation of a new IGLD need to be resolved:

Hydraulic Correctors: The water surfaces within each of the Great Lakes are considered geopotentially equal and, therefore, the dynamic height of the mean water level on a particular lake should be the same everywhere. However, due to variations in lake topography and errors in leveling, this is not the case in practice (see Figure 4). Hydraulic correctors are used to account for these variations and errors by adjusting the observed water level heights at gauging stations on a lake so they agree with each other over a given time period. Errors in height are expected to be much smaller for a more accurate, geoid-based vertical datum, resulting in hydraulic correctors that will be both smaller and more representative of actual lake topography than they have been in the past. Whether or not hydraulic correctors are still required for IGLD (2020) needs to be determined. This will require water level observations at additional (seasonal) gauges, the location and number of which also needs to be determined.

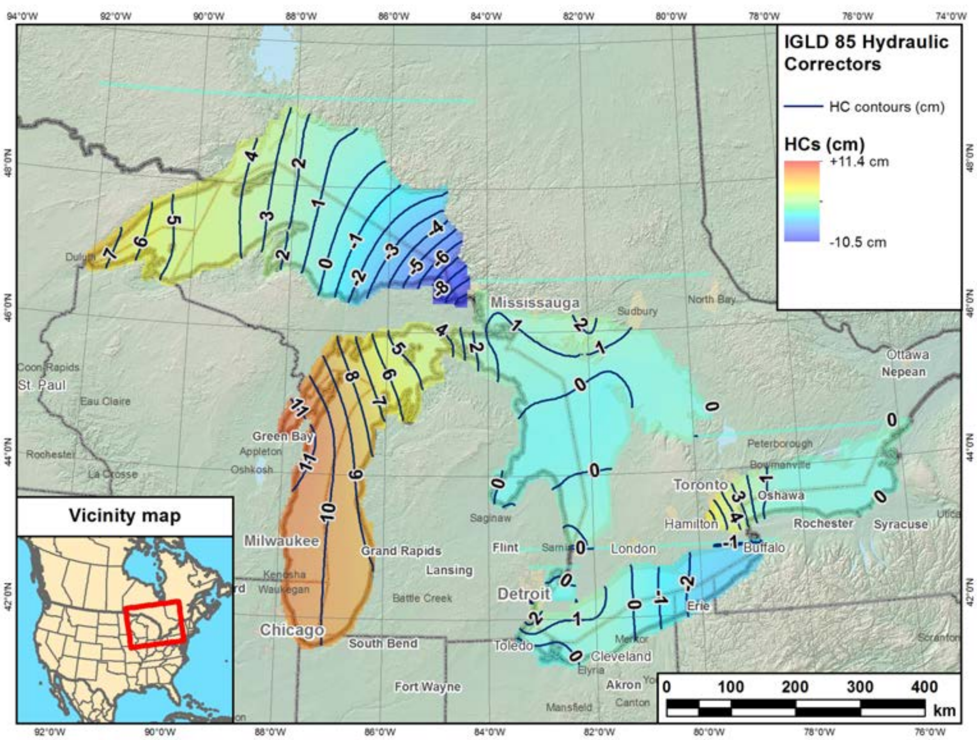


Figure 4. IGLD (1985) hydraulic corrector model developed and implemented in the VDatum transformation tool.

Crustal Motions and Their Effect on Heights: It is a well-documented fact that crustal movement due to GIA affects the Great Lakes region (see Figure 4). The northern parts of the Great Lakes Basin are uplifting while the southern parts are subsiding, representing an overall north-south tilting of the entire basin of about 5–7 mm/yr (see Figure 5). After a few decades height differences become out of date by as much as 21 cm over the entire basin, thereby necessitating a redefinition of the heights and IGLD in general. To determine these movements, permanent GNSS stations (referred to as Continuously Operating Reference Stations (CORS) in the U.S. and Canadian Active Control Stations (CACS) in Canada) have been installed at key permanent water level gauging stations. Realizing that it takes several years to obtain an accurate estimate of the vertical motion, such new sites should be installed in targeted locations at the earliest opportunity to obtain accurate velocity estimates as soon as possible to improve the modeling of GIA. To determine GIA movements at all of the other permanent water level gauges, specially designed, high-accuracy GPS campaign-style surveys have been performed in 1997, 2005, 2010, and 2015. A new GNSS survey is planned for 2020 to coincide with the central epoch of the new IGLD. Comparing repeated, high-accuracy, GNSS-derived ellipsoid heights can provide further estimates of crustal movement (velocities) at the reference bench marks. Using the velocity estimates from the CORS, CACS and campaign surveys, it will be possible to model the crustal motion and propagate heights to an adopted common reference epoch. It will also be possible to update the heights to future reference epochs to keep pace with the crustal motion. This will require the development of procedures and algorithms for using vertical rates of movement for projects that require high-accuracy heights.

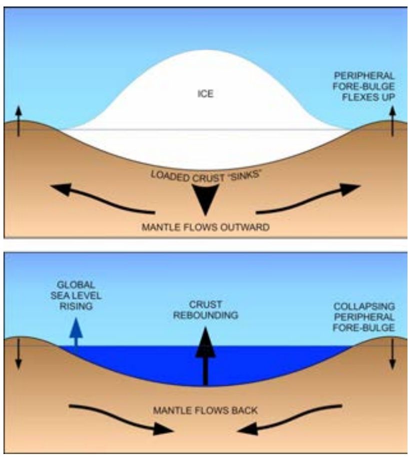


Figure 4. Process of glacial isostatic adjustment.

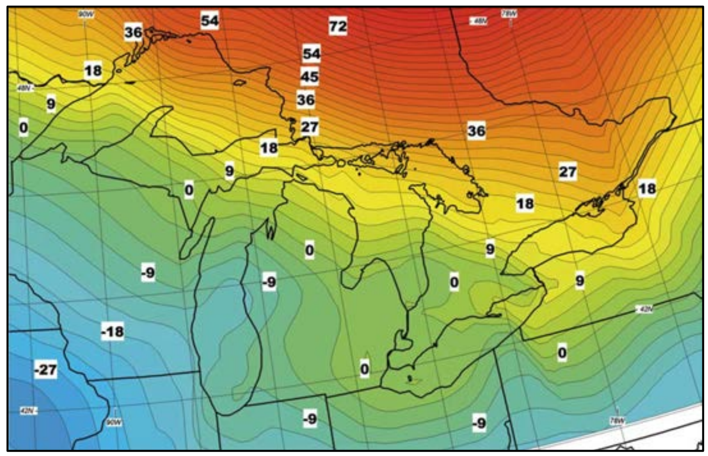


Figure 5. Contour map of crustal movement in cm/century derived from water level gauges. Contour interval: 3 cm/century (0.3 mm/year).

Determining Heights in a Geoid-Based Datum: GNSS-based height determination in a geoid-based datum has been widely used for many years and can provide high-accuracy heights and height differences in a more efficient and cost-effective manner than traditional geodetic spirit leveling. This enables one to achieve more consistent and accurate heights on water level gauges and their reference bench marks across the entire region. Permanent GNSS stations (CORS and CACS) have been installed at many key water level stations. Such stations are connected directly to the same structure as the gauge reference, enabling the accurate (millimeter-level) determination of the absolute heights of water levels without the adverse effects of any local movements of the reference bench mark network. They also provide more accurate estimates of crustal motion and enable more accurate GNSS-surveys at nearby gauges. The network of CORS and CACS will need to be maintained and further expansion needs to be considered. The heights on all permanent and seasonal water level gauges and their reference bench marks need to be determined using GNSS-style survey campaigns. Appropriate internationally coordinated survey methodologies also need to be determined to achieve the required accuracies in the new IGLD. In addition to GNSS surveys at the permanent water level stations, additional surveys will also be required for the seasonal water level stations. In future it is envisaged that all water level gauges will use permanent GNSS installations to determine the height of the gauge reference points (e.g., ETG or gnomon) in near real-time without the need for any reference bench mark network and its regular monitoring. It is expected this would reduce operational costs in the long term while enabling more accurate determinations of water levels, in addition to any crustal motion

Updating Low Water Datum: The LWD (or chart datum) is the geopotential elevation for each of the Great Lakes, their connecting channels, and St. Lawrence River to which the depths shown on navigational charts and the authorized depths for navigation improvements are referred. By definition, LWD is supposed to identify a surface so low that the water level will seldom fall below it. The historical record of water levels has not been reviewed in the context of re-evaluating LWD since their original determination in 1933. Since then, the Great Lakes region has experienced historically high and low water levels. Considerable changes to water level regulation plans, as well as hydraulic and hydrologic conditions, have left in question the suitability of the existing LWD determination for present-day and future use. Re-evaluating the determination of LWD on each lake is therefore recommended, along with the LWD steps along interconnecting channels and the St. Lawrence River.

Other Impacts of a New IGLD: In addition to updating the Low Water Datum the establishment and implementation of a new IGLD will have a significant impact on a great many other operations, products and services, including navigation, water level regulation, water management, shoreline use planning, surveying, and mapping (see the Great Lakes Commission Resolution on the IGLD Update in Appendix 1). A list of some of these impacts is given in Table 1 of Section 3.3. An outreach plan will need to be constructed to prepare for and mitigate the effects of an updated IGLD. Two of the most important impacts are the updating and determination of low water datum discussed above and the determination of IGLD (2020) heights at the many gauge references other than those operated by the National Oceanic and Atmospheric Administration and Canadian Hydrographic Service through their inclusion in the 2020 GNSS survey campaign.

Transforming Between IGLD (2020) and Other Datums: There are many products using the older IGLD and other datums that will need to be updated to IGLD (2020). In many cases, it will not be possible to regenerate such products in the new datum without collecting new data. In cases where it is not possible to collect new data, transformation models and tools will be required to update these products to IGLD (2020). This task will require heights at common points in both the new and old datums in digital form.

Resource Requirements: A wide range of resources, knowledge, and skills will be needed to develop and implement IGLD (2020). These are identified in the body of the report for the activities involved and summarized in Table 1 below. GNSS data will need to be collected at all permanent and prioritized seasonal gauges. Additional funding may also be required to address some of the outstanding questions identified above. Personnel resources will be required from the geodetic and water management agencies in both countries to complete the analysis and research required for the update to IGLD (2020).

Outreach: A significant amount of coordinated outreach will be needed in relation to the update. Coordinating Committee member agencies will need to inform and educate stakeholders of the

IGLD update and its impact through such means as publications, webinars, etc. A collaborative outreach and communication strategy needs to be developed by the Coordinating Committee to ensure that these stakeholder groups are identified and included.

Table 1. IGLD (2020) project activities and milestones. Section number refers to the body of the report.

Activity	Target Date/Period	Recommended Responsible Agencies
Complete binational plan for IGLD (2020) and present to the Coordinating Committee for approval	Completed	Vertical Control – Water Levels Subcommittee
Choose and adopt a W_0 as the new IGLD reference zero (Section 2.1)	Completed	Coordinating Committee
Identify potential IGLD partners and users who can help develop and implement IGLD (2020) (Section 3.4)	2016-2023	Vertical Control – Water Levels Subcommittee
Digitize and archive old leveling information, as required	2016-2023	CO-OPS, NGS CHS, CGS
Perform annual maintenance and leveling ties at permanent water level gauges	2016-2024	CO-OPS, USACE CHS, ECCC & others
Perform analysis of permanent gauging requirements and prioritize new proposed gauges (Section 2.5)	2017	CO-OPS CHS
Adjust and publish 2015 GPS campaign survey results	2017	NGS CGS
Complete preparation of internationally coordinated methodologies for determining heights using GNSS surveys and local leveling ties at gauges (Section 2.7)	2017- 2018	NGS, CO-OPS, USGS, USACE CGS, CHS, ECCC
Complete preparation of international outreach and communication plan, and begin implementation (Section 5)	2017- 2018	Vertical Control – Water Levels Subcommittee
Review historic water level data for re-evaluation of LWD (Section 3.1)	2017-2018	CO-OPS, USACE CHS, ECCC
Reanalyze and compare all GPS campaign surveys from 1997, 2005, 2010, 2015 to estimate preliminary rates of movement (Section 2.6)	2017-2018	NGS CGS
Perform analysis of seasonal gauge requirements and prioritize locations (Section 2.5)	2017-2023	CO-OPS CHS
Begin annual installations of seasonal water level gauges with GPS and leveling ties (Section 2.5)	2017-2023	CO-OPS CHS
Perform 2020 GPS campaign survey in Great Lakes – St. Lawrence River system, including entity gauges (Section 2.6).	Summer 2020	NGS, CO-OPS CGS, CHS and others
Adopt N.A. geoid model for IGLD (2020) (Sections 2.1 and 2.2)	2022	Coordinating Committee with NGS & CGS
Create crustal movement models for the Great Lakes – St. Lawrence River system using all available GPS campaigns and CORS/CACS data (Section 2.6)	2023	NGS CGS
Complete seasonal water level gauging (Section 2.5)	2023	CO-OPS CHS
Determine hydraulic correctors (Section 2.4)	2024	NGS, CO-OPS CGS, CHS, ECCC
Determine new LWD on lakes and rivers with respect to IGLD (2020) (Section 3.1)	2024	CO-OPS, USACE CHS, ECCC
Determine and publish transformations between IGLD (2020) and other datums, including IGLD (1985) (Section 2.8)	2024	NGS CGS
Publish new IGLD (2020) datum	2025	Coordinating Committee