Navigating Change: Understanding and Updating the International Great Lakes Datum

Introduction (00:14)

Slide 1 (00:14)

Hello, and welcome to this training session brought to you by NOAA's Center for Operational Oceanographic Products and Services, commonly known as CO-OPS.

As a program office operating under the National Ocean Service, CO-OPS is the go-to authority in the United States for data related to tides, water levels, currents, and other vital coastal oceanographic and meteorological conditions.

Slide 2 (00:39)

CO-OPS follows its Congressional mandate as well as legal precedents to maintain and update water level datums within the U.S. Specifically, CO-OPS is responsible for updating the National Tidal Datum Epoch and, together with partners in Canada, the International Great Lakes Datum and the associated Low Water Datum.

Slide 3 (00:59)

The International Great Lakes Datum, or IGLD, is the official vertical datum that is used for denoting water level measurements in the Great Lakes and St. Lawrence River region. This region spans eight U.S. states (Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, plus Vermont in the St. Lawrence watershed) and two Canadian provinces (Ontario and Quebec). Across this area stretch the five Great Lakes themselves: Superior, Huron, Michigan, Erie, and Ontario, as well as Lake St. Clair, Lake Champlain, Lake Winnebago, and the St. Lawrence Seaway. The lakes are connected by a series of channels, rivers, and lock systems, so water flows between them. This means that a common frame of reference for the water level among each of the lakes is needed, and this frame of reference is the International Great Lakes Datum.

Slide 4 (01:57)

The IGLD allows people who use these bodies of water to manage Great Lakes waterways using the same frame of reference. This is crucial for applications like navigation, water level regulation, hydrographic surveying, charting, and shoreline use planning and restoration. The Great Lakes have significant environmental, cultural, and economic value for the U.S. and Canada, and support recreation, hydroelectric power plants, and trade in the region. Knowing Great Lakes water levels is therefore critical to support their sustainable use.

Slide 5 (02:33)

Although the Great Lakes are linked by channels, each one has distinctive geomorphological features, circulation, and ecology. Each lake also varies in depth. Because of this, the U.S. and Canada have also established a Low Water Datum for each of the Great Lakes and Lake St. Clair. Low Water Datum is a set point below which water levels will seldom fall. For this reason, it is the datum used for safe navigation, is notated on navigation charts for the Great Lakes, and is sometimes referred to as "Chart Datum." The Low Water Datum for each lake is unique and

can only be applied to that body of water. The exceptions to this are Lakes Michigan and Huron. Since these lakes are connected by the Straits of Mackinac rather than a sloping river, they are treated as one body of water and share the same Low Water Datum value. In this training, we'll touch only briefly on the concept of Low Water Datum. For more information, including when, how, and why it's periodically reevaluated, please see our supplemental training on Low Water Datum.

Slide 6 (03:41)
This training will cover the basics of the upcoming IGLD update, which is formally called IGLD (2020). To start, we'll take a look at CO-OPS' role in the update, followed by the importance of reference frames and datums in observing and communicating water levels. We'll briefly discuss datum updates generally, then look at IGLD specifically, including why it needs to be updated, previous iterations of IGLD, and how the U.S. and Canada are working together to deliver a binationally-coordinated update. We'll also talk about the technical processes involved in updating IGLD. Finally, we'll go over some potential impacts of the new datum and the expected timeline for the completion of the update.

CO-OPS' Role in the International Great Lakes Datum Update (04:28)
Slide 8 (04:32)
CO-OPS supports the creation of water level products nationwide, including the process of updating IGLD, by maintaining a system of water level stations across the United States and within its territories in the Pacific and Caribbean. The backbone of CO-OPS' water level system is called the National Water Level Observation Network, or NWLON.

Slide 9 (04:53)
The NWLON is a network of approximately 210 continuously-operating water level observation stations spanning the U.S. ocean coastline and the Great Lakes. NWLON stations are equipped with instruments that operate at very precise, high standards to ensure that the resulting data are accurate and can reliably generate products such as tide and tidal current predictions, maps and charts, sea level trends, forecast models, and water level datums.

Slide 10 (05:22)
The NWLON includes a number of permanent gauges located on the Great Lakes, with data collection going as far back as the 1800s in some locations. Data from these gauges and Canadian gauges are used to create water level products that are specific to the region. For example, data are used to produce daily means of Great Lakes water levels, which are used by both countries to uphold legal requirements of water level regulation through the Boundary Waters Treaty of 1909. The data are also used to build models that provide forecasts of lake levels. Other government agencies, for example, the U.S. Army Corps of Engineers, use lake water level data to create their own products, such as lakewide mean water levels.

Slide 11 (06:05)
CO-OPS also has a program called the Physical Oceanographic Real-Time System®, or PORTS®. PORTS® engages in partnerships with communities to collect data that promote

safe navigation and improve the efficiency of U.S. harbors. There are three PORTS® partnerships currently operating in the Great Lakes: Soo Locks, Port of Toledo, and the Cuyahoga River.

Slide 12 (06:29)
Together, the NWLON and PORTS® programs include 52 permanent water level gauges in the Great Lakes that collect data to serve CO-OPS' three mission areas: safe navigation, coastal hazard preparedness, and accurate mapping and charting. CO-OPS also collaborates with Canada to monitor the water levels in the Great Lakes and uses this data to periodically update IGLD and Low Water Datum so that the lakes can be properly regulated.

Slide 13 (06:56)
This collaboration relies on additional data collected by the Canadian equivalent of CO-OPS, the Canadian Hydrographic Service. Through the Permanent Water Level Network, the Canadian Hydrographic Service operates around 130 gauges covering Canada's ocean coastline, the Great Lakes, and the St. Lawrence River. An archive of historical water level data is also maintained and available to the public.

In order for the U.S. and Canadian datasets to be used for joint management, all of the data from the Great Lakes has to be related to a common reference, or datum.

Datums (07:30)
Slide 15 (07:36)
A geodetic datum is a reference surface that is used to relate the location of objects to one another. For physical orientation applications, geodetic agencies provide a definition of a datum and the tools to access it, and users of the datum are responsible for mapping their observations onto the datum. Chances are you've used datums in your own life, perhaps without even realizing it.

Slide 16 (07:59)
Here's a common example: your height. Imagine that someone asks how tall you are, and you tell them that you're 6 feet tall. Most likely, you and the person you are telling both instinctively understand that you are using the ground as the reference surface for this number. In other words, when you tell someone you are 6 feet tall, you mean that you are 6 feet tall as measured from the ground you're standing on.

However, you can measure yourself from *any* reference surface, *as long as* everyone understands and agrees on what this surface is. This means that if everyone understands the reference surface to be the top of a table that you are standing next to, then you might say you are actually 3 feet tall.

Slide 17 (08:41)
Similarly, when you say that a certain body of water is reporting a value of 20 feet, this information is only useful if you've defined the reference surface from which you are measuring

this height. Ultimately, all reference surfaces are arbitrarily determined, but that doesn't mean they are random. Good reference surfaces are easily maintainable, relatable to the location of another reference surface, logical, understandable, and documentable. And to make horizontal and vertical distances useful, everyone has to be on the same page about where the reference surface is, and how it is defined.

Slide 18 (09:19)
Datums are the reference surfaces from which distances, heights, and depths are measured. The most common datums are given unique names.

Slide 19 (09:27)
In our previous height example, you might say that you are 6 feet tall above “Ground Datum,” but 3 feet tall above “Table Datum.”

Slide 20 (09:36)
In general, there are horizontal datums and there are vertical datums. Horizontal datums provide the ability to define latitude and longitude coordinates, which can help when measuring distances across Earth, while vertical datums allow for measurements of heights and depths. At CO-OPS, we develop vertical water level datums, including tidal datums, such as Local Mean Sea Level. CO-OPS and the Canadian Hydrographic Service together define the location of water levels in the Great Lakes. The U.S. and Canadian geodetic agencies then define a height for this based on a broader geodetic vertical datum. Through this process, water level heights are assigned on IGLD.

Slide 21 (10:18)
While CO-OPS uses IGLD and Low Water Datum to measure water heights and depths in the Great Lakes, tidal datums are used to measure and relate water levels in coastal areas with tides.

The process of updating each of these tidal datums results in the National Tidal Datum Epoch, or NTDE. To learn more about this update, please see our training video online at tidesandcurrents.noaa.gov.

The International Great Lakes Datum (10:43)
Slide 23 (10:49)
Updating IGLD is different from updating the NTDE, because the NTDE is based around the tidal cycle, and the Great Lakes are primarily meteorologically driven and not considered tidal. Because of this, each Great Lakes station does not have a set of tidal datums like each ocean coastal station does. Instead, IGLD is *one* water level datum that is used across *all* of the Great Lakes.

Slide 24 (11:15)
If you view a Great Lakes station on CO-OPS’ Tides and Currents map, you will see a water level value referenced to IGLD (1985). This reference point is the same across all Great Lakes

water level stations, meaning that the different values you see at different stations denote a height above that one reference plane.

Slide 25 (11:35)
Although water levels in the Great Lakes are variable to a degree, an updated IGLD does not mean that water levels themselves are changing. Rather, the point from which the water levels are being *referenced* is updated. A new IGLD establishes new reference heights for water levels, which results in a change in datum values, not in the height of the water itself.

Slide 26 (11:57)
Because the Great Lakes span both the U.S. and Canada, IGLD is developed and used jointly between the two countries. Prior to the first iteration of IGLD, each country used a different datum for water level measurements. The lack of a coordinated system made navigation and water resource management difficult. The establishment of the first joint datum, IGLD (1955), allowed for Great Lakes water levels to be measured, monitored, and managed on one common vertical reference that could be used by both the U.S. and Canada, making regulation of the Great Lakes easier and more collaborative.

Slide 27 (12:32)
IGLD is based on a network of permanent water level gauges maintained by the U.S. and Canadian governments, with associated gauges from states and other partners. This network comprises the Great Lakes, their connecting rivers and channels, and the St. Lawrence Seaway. CO-OPS has 52 permanent gauges in the region, while the Canadian Hydrographic Service has 54 permanent gauges west of Rimouski.

Slide 28 (12:58)
Each permanent gauge on a lake is considered either a master station or a subordinate station. A master station is a “control” station that is used as a reference for water level heights. Each lake has its own, except for Lakes Huron and Michigan, which share one. All of the current master stations are located in the U.S. and maintained by CO-OPS, but a Canadian site could be used if a new location needs to be chosen. Current master stations are located at Oswego for Lake Ontario; Fairport Harbor for Lake Erie; St. Clair Shores for Lake St. Clair; Harbor Beach, for Lake Huron and Lake Michigan; and Marquette for Lake Superior.

All other stations on the lakes are considered subordinate stations. They are referenced to the water level heights of their master station using something called hydraulic correctors, which are mathematical offsets that are applied to assume a uniform surface across each lake. We will cover more on hydraulic correctors in a few moments.

Slide 29 (13:57)
The Great Lakes region also includes the rivers that connect the lakes. Water level gauges that are located on the rivers are not considered master or subordinate. Since a river is a sloping surface, and therefore not treated as a flat surface as the Lakes are, the water level data from these gauges do not need to be hydraulically corrected.

Slide 30 (14:17)
In addition to the permanent gauges, a network of seasonal gauges were installed in both the U.S. and Canada. Typically, these gauges collected data from June to September, when the lakes are usually ice free. The period of overall data collection was from 2014 to 2024, however due to varying resource availability, each country didn't install gauges during each year. The data from these seasonal stations are used for hydraulic corrector calculations, to fill gaps between the permanent gauges, for model validation, and to help the public reference non-federal data to IGLD.

Components of the International Great Lakes Datum (14:54)
Slide 32 (14:59)
In addition to the physical water level stations, IGLD requires four theoretical components in order to be updated: a defined reference zero, a reference surface, a reference epoch, and dynamic height values. Let's explore each of these in more detail.

Slide 33 (15:18)
First is a defined reference zero, which represents the baseline from which heights and depths are measured. The reference zero for IGLD (2020) is a value denoting mean sea level as agreed upon by international working groups and closely matching water level measurements taken from around the coasts of North America.

Slide 34 (15:37)
Next is the reference surface. This is an equipotential or "level" surface, which means that water on this surface would lay still and not flow one way or another. The IGLD reference surface extends the reference zero height across the entire Great Lakes region. In past IGLD updates, the reference surface was extended from a coastal tide gauge inland via extensive survey leveling networks. However, this process is costly, time consuming, arduous, and introduces systematic error. To avoid these issues, the U.S. and Canada are using a geoid model to extend this reference surface for IGLD (2020). We'll touch more on this later in the training.

Slide 35 (16:20)
The third component is the reference epoch, which is the center of the time period from which water level observations are taken to compute the final datum. IGLD typically uses an observation period of at least 7 years, which is statistically long enough to mitigate impacts of extreme and seasonal events, such as unusually dry or wet years. The middle year of this period is the reference epoch, and it's this year that provides the name for the datum, for example, IGLD (2020). However, data from outside this 7-year period are often used to validate other parts of IGLD, such as hydraulic correctors.

Slide 36 (16:59)
Finally, IGLD requires dynamic height values. Dynamic heights represent constant gravity potential. To better understand dynamic heights, let's first talk about why orthometric heights alone are not sufficient for IGLD.

An orthometric height is defined as a height as measured from the geoid, a reference surface representative of global mean sea level. Orthometric heights are used in most engineering applications to define elevation.

Slide 37 (17:29)
Dynamic heights, by comparison, are based on geopotential numbers. A geopotential number represents the measure of potential energy at a point of interest. When two points have different geopotential values, water will flow between them.

Slide 38 (17:46)
As you move toward the poles, the ellipsoidal shape of the Earth means that surfaces having the same potential begin to converge. As a result, orthometric heights may not be constant along a level surface like a lake, making it difficult to judge how water will flow. CO-OPS and the Canadian Hydrographic Service leverage dynamic height values in the Great Lakes region, allowing one dynamic height to be applied across the entire lake surface. This allows for better water level management.

Slide 39 (18:16)
Dynamic heights are also important in the Great Lakes because they are a direct indication of hydraulic head. Hydraulic head is a measure of the potential energy that can be generated at a dam, and it’s a critical value to know for proper water management and power generation.

However, although each Great Lake is considered to be geopotentially equal across its surface, we know that a lake’s surface isn't truly flat. In reality, the dynamic height of the surface changes across the lake.

To account for these variations and water level differences caused by atypical weather effects (like strong prevailing winds), and to some degree, for errors introduced during the leveling process, scientists use hydraulic correctors.

Slide 40 (18:59)
Hydraulic correctors are mathematical offsets that are applied to the height data to “flatten” any differences in long-term lake levels. They are the differences in the long-term height averages between a particular point and a master station on the Great Lake. Hydraulic correctors are applied to observed water level heights at subordinate stations to make their level match those of the master station when viewed over the long-term. They can be updated as more data are collected. Hydraulic correctors ensure that decisions, such as outflow adjustments at control structures, are based on comparable measurements across the lakes. Because they are a critical part of IGLD, hydraulic correctors are also being evaluated for a potential update. One thing to remember is that when you are looking at a water level height value on IGLD (1985), you are seeing a dynamic height with a hydraulic corrector added.

Great Lakes Water Level Fluctuations (19:52)
Slide 43 (19:58)

If the Great Lakes don't have tides, and they aren't affected by changes in sea level, why do their water levels need to be monitored and the IGLD updated?

Water levels in the Great Lakes respond very minimally to the movements of the Moon and Sun, but these effects are very small and barely noticeable. The Great Lakes *do* experience changes in water levels as a result of other factors. In fact, water levels can vary quite rapidly, not just seasonally or from year to year, but even from hour to hour in some instances. Lake levels have been known to fluctuate by a range of about six and a half feet.

Great Lake levels fluctuate seasonally mainly due to two factors: meteorology, and seasonal changes in the hydrologic cycle. Let's look at these in more detail.

Slide 44 (20:48)
Meteorologically-driven changes are changes due to weather. Strong storms can cause storm surge in the lakes just as they can at the ocean coast. The Great Lakes are also susceptible to seiches, which are standing waves that oscillate in a closed body of water.

Slide 45 (21:05)
Seiches can occur as a result of strong winds combined with changes in atmospheric pressure. This combination pushes water from one end of a body of water to the other, and the water rebounds and oscillates back and forth until it stabilizes again. Think of this process as similar to creating waves in a bathtub. This causes staggered high water and low water at either end of the lake that can look like an astronomical tide, especially because the time between these highs and lows can last for hours.

Slide 46 (21:34)
Of all the Great Lakes, Lake Erie is particularly prone to seiches. This graph shows the impact of a seiche event that occurred in 2015. As a result of this event, waters rose to almost 176 meters, or about 577 feet, referenced to IGLD (1985) in Toledo, Ohio. At the same time, they were dropping proportionately to almost 174 meters, or about 570 feet, in Buffalo, New York on the opposite side of the lake. If you imagine the shape of Lake Erie with Toledo on one side and Buffalo on the other, you can see how the seiche mimicked a huge sloshing wave in a bathtub. For this event, it took multiple days for water levels to settle back to their typical levels.

Slide 47 (22:19)
The second factor that causes lake levels to fluctuate is seasonal changes in the lakes and the related changes in the hydrologic cycle. In late fall and early winter, when air temperatures are colder and water surface temperatures are warmer, energy exchange between the water and air leads to higher rates of evaporation than at other times of the year. Conversely, the Sun's warming effect in the region leads to lower evaporation during the summer.

Slide 48 (22:45)
Rainfall and snowfall both contribute to higher water levels. Precipitation that doesn't fall directly into the lakes can still reach them through runoff or snowmelt. In winters with less snow, there is

less runoff into the lakes, which results in a lower rebound of water levels in the spring.

Slide 49 (23:03)
The lakes are also impacted by the larger scale seasonal effects brought on by El Niño and La Niña. El Niño years are typically warmer and drier, resulting in greater rates of evaporation, which tends to lower lake levels. Conversely, La Niña years are typically cooler and wetter, which can raise lake levels.

Slide 50 (23:23)
Because meteorology and hydrologic cycle changes happen over seasonal timescales, they change lake levels temporarily, but not long-term, so they are not the primary reason that updating IGLD is crucial. Great Lakes water levels are more dramatically impacted by a phenomenon called glacial isostatic adjustment, or GIA.

Slide 51 (23:44)
During the last ice age, huge sheets of ice covered large parts of the Northern Hemisphere. This ice settled for thousands of years, creating a tremendous amount of pressure, which compressed the Earth's crust and forced the land downward. Meanwhile, the land on the edges of the ice sheets rose up in response, deforming the Earth's crust into a bowl shape. After these ice sheets melted, the Earth began to rebound to its original position, with the land where the ice sheets once were now rising up, and the land on the perimeter of this area slowly sinking.

Slide 52 (24:19)
The Great Lakes region is located on this perimeter. The result, which is visualized in this model, is that the northern part of the lakes is experiencing uplift, while the southern part is experiencing subsidence, and this change impacts water level measurements. As a result of GIA, there is a tilting across the entire basin in the range of about 5 to 7 millimeters per year, or around a quarter of an inch. Over a 30 year period, this adds up to a tilted difference of about 21 centimeters, or about 8 and a quarter inches.

Slide 53 (24:52)
This tilting is visible in the water level record, and needs to be tracked through continuous observations. The plot on the screen shows water level measurement differences between Lake Superior's master gauge and other subordinate gauges on the lake across each IGLD epoch. You can see that over time and following the adoption of each new epoch, the tilting signal resulting from GIA is picked up in the water level observations. When IGLD (1985) replaced IGLD (1955), the water levels "snapped" back to equilibrium with an updated datum. On this second plot, these water levels have been "corrected" by applying a crustal motion model that removes the effect of this tilt. This model will also be applied to IGLD (2020) values, which will streamline future updates to the datum.

Slide 54 (25:41)
Another reason that IGLD should be regularly updated is to make sure that water level reference values are up-to-date in case of extreme high and low water events.

Slide 55 (25:50)
If such an event does occur, having an accurate IGLD elevation means communities can conduct shoreline maintenance, restore coastal zones, prevent erosion, and update building codes and permits with the knowledge that this work is all being referenced to an accurate datum.

Slide 56 (26:06)
An IGLD update is especially relevant now, because there is an opportunity to bring the reference system for the lakes and their connecting waterways in line with updates to the National Spatial Reference System, which connects on-shore, near-shore, and offshore positioning data. We'll discuss this more later, including information on the North American-Pacific Geopotential Datum of 2022, and the benefits of updating IGLD in tandem with it.

Who is responsible for updating the International Great Lakes Datum? (26:33)
Slide 58 (26:39)
With CO-OPS responsible for maintaining the water level gauges on the U.S. side of the Great Lakes, and Canada responsible for maintaining those on the Canadian side, the process of updating IGLD is a true binational partnership. The U.S. and Canada work together to update IGLD through the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

Slide 59 (27:00)
The origins of the Coordinating Committee can be traced back to 1909, when the Boundary Waters Treaty was signed by the U.S. and Canada. At this time, one of the main lake datums in use was the U.S. Lake Survey 1903 Datum. The treaty outlines the joint management of the waters shared between the two countries, and established a governing body known as the International Joint Commission to carry out its duties. The Commission is in charge of recommending solutions for issues that come up concerning boundary waters, and approves projects that affect water levels and flows across the boundary.

Between 1909 and the 1950s, three more datums came into use: the Canadian Geodetic Datum of 1928, the National Geodetic Vertical Datum of 1929, and the U.S. Lake Survey 1935 Datum. These were sometimes replacements of each other and sometimes used concurrently by the two countries.

By the 1950s, the International Joint Commission recognized the need for accurate and consistent water level data in order to properly regulate the Great Lakes and their outflows to connecting waterways, such as the St. Marys, Niagara, and St. Lawrence Rivers. The data that influenced decisions were not formalized or standardized between the U.S. and Canada. Furthermore, prior to 1953, each country was still calculating and maintaining their own water level reference datums without coordination with each other. This caused problems across the region because datums did not connect to each other on the same reference plane, making them difficult to use in tandem and requiring extra work to determine heights across international

boundaries.

To address this issue and support the International Joint Commission, in 1953 the U.S. and Canada formed the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, and with it the requirement to establish a common water level reference system, which would be called the International Great Lakes Datum.

Slide 60 (29:01)
The Coordinating Committee includes four subcommittees that support management of the Great Lakes watershed. The Coordinated Regulation and Routing Model Update Subcommittee works on improving a hydrologic routing model that is used in the lakes and on the St. Lawrence River. The Hydraulics Subcommittee regulates the methods that are used to conduct hydraulic discharge in the lakes. The Hydrology Subcommittee reviews and coordinates water level data and other hydrological variables such as precipitation. Finally, the Vertical Control - Water Levels Subcommittee updates IGLD, standardizes a system for water level data processing across Canada and the U.S., and maintains the water level and Global Navigation Satellite System (or GNSS) reference station networks. This is the subcommittee most directly involved in the IGLD update. However, water level data from the U.S.'s National Water Level Observation Network and Canada's Permanent Water Level Network are foundational to the work of all the subcommittees.

Slide 61 (30:03)
The Vertical Control - Water Levels Subcommittee is made up of federal experts from both countries. From the U.S., this includes NOAA, specifically CO-OPS and the National Geodetic Survey; the U.S. Geological Survey; and the U.S. Army Corps of Engineers. From Canada, this includes Fisheries and Oceans Canada, specifically the Canadian Hydrographic Service; Natural Resources Canada, specifically the Canadian Geodetic Survey; and Environment and Climate Change Canada. Other partners involved in the update are the New York Power Authority, the Great Lakes St. Lawrence Seaway System, and Ontario Power Generation.

Today, the data and recommendations put forth by the Coordinating Committee are used by the International Joint Commission's three Great Lakes Boards of Control for water level regulation decision-making.

How is the International Great Lakes Datum updated? (30:57)
Slide 63 (31:02)
To understand how IGLD (2020) will be updated, we should first understand how its previous iterations were updated.

There have been two versions of IGLD. The first version was called IGLD (1955). It was established using water level observations from the 7-year period of 1952 - 1958, and named for its average reference epoch of 1955. The next update, and the one currently in use, is known as IGLD (1985). It was established from observations in the years 1982 - 1988, with a reference epoch of 1985.

Slide 64 (31:43)
IGLD (1955) was established by first identifying a reference tide gauge at a place called Pointe-au-Pére at the mouth of the St. Lawrence River that was representative of mean sea level. Then, surveyors conducted geodetic leveling along the St. Lawrence River and around each of the Great Lakes and their connecting channels. This process established a series of bench marks with highly accurate geodetic elevations. The elevations from these bench marks were then transferred via leveling to water level gauges that were located along the shores of each lake and their connecting channels.

Slide 65 (32:19)
IGLD (1985) was established using a similar process as IGLD (1955) with a few key differences.

First, it was defined in connection with the North American Vertical Datum of 1988 (or NAVD88), the official vertical datum in the U.S. Also, the leveling network for the updated datum included a greater number of bench marks than was used in 1955. This resulted in more accurate access to the IGLD throughout the Great Lakes region. However, this leveling used procedures that were unfortunately affected by a systematic error that resulted in a significant 35 centimeter, or almost 14 inch, tilt of the datum. This is one of the reasons for needing to update IGLD (1985). IGLD (1985) also used a new reference bench mark established at the Rimouski tide gauge, which is located on the Gulf of St. Lawrence in Quebec. This change was partially a result of the deterioration of the original tide gauge at Pointe-au-Père, 3 miles from Rimouski. The tide gauge at Rimouski also represents mean sea level on the Atlantic coast of North America.

Slide 66 (33:29)
IGLD historically has been updated every 25-30 years in order to capture changes in vertical land motion as a result of glacial isostatic adjustment. The new update, which will be known as IGLD (2020), is primarily based on water level data collected from 2017 through 2023, and will have a central reference epoch of 2020.

Slide 67 (33:52)
This update coincides with the implementation of a new geodetic vertical datum for the United States and its territories, the North American-Pacific Geopotential Datum of 2022, or NAPGD2022. NAPGD2022 represents a departure from its predecessor, NAVD 88, primarily due to the fact that it relies on an Earth model called a “geoid” for its implementation, as opposed to thousands of miles of arduous leveling. NAPGD2022 also utilizes Global Navigation Satellite Systems, or GNSS, for positioning, which makes it accessible everywhere and not just at locations that have bench marks. These changes also mean that IGLD (2020) will be able to more seamlessly connect to NAPGD2022 through its reference zero and reference surface.

Let’s dive into how these two systems are related.

Connecting the International Great Lakes Datum with the World (34:48)
Slide 69 (34:54)
Earlier we mentioned that there are horizontal datums and there are vertical datums, and that

they are used to relate the location of objects to one another. At CO-OPS, we are typically concerned with tidal or water level datums - the vertical datums that tell you the height of water levels in relation to the Earth.

Slide 70 (35:12)
There is also an office at NOAA called the National Geodetic Survey, and an office of the Canadian government called the Canadian Geodetic Survey, that specialize in the field of geodesy. Geodesy is the science of accurately measuring and understanding the Earth's geometric shape, orientation in space, and gravity field. The National Geodetic Survey and the Canadian Geodetic Survey perform the work that yields other horizontal and vertical datums, which provide reference frames that are typically used in on-shore areas.

Slide 71 (35:44)
To do this, geodesists have traditionally relied on geodetic leveling to create or extend a network of bench marks around the country. Most often, these are bronze disks or other markers on which known height can be established that can then be transferred to other points of interest, such as water level sensors. Surveying across a bench mark network allows you to create what is essentially a coordinate system in which any point can be easily referenced to something else. This is the process that was used to establish IGLD (1955) and (1985).

Slide 72 (36:19)
Though CO-OPS, the National Geodetic Survey, and the Canadian Geodetic Survey still use physical bench marks for establishing and preserving a height at desired locations, advances in GNSS and gravity modeling technology have helped geodesists create models of the Earth. These models enable vertical positioning through GPS observations and a gravity model, removing the need to tie directly to these physical bench marks. This makes the work of realizing a vertical reference frame and relating objects within it more straightforward and less time consuming.

Slide 73 (36:52)
When we refer to "Earth models" in this context, we mean mathematical models that represent the shape of Earth for measurement and positioning purposes. These models help us measure distances, heights, gravity, and depths theoretically. There are a few different ways to model Earth, and each one takes its own approach to representing the Earth's shape.

Slide 74 (37:15)
As a first approximation, the Ellipsoid is a mathematical shape in which Earth is represented by a smooth surface resembling a sphere that is slightly squashed in at the poles. Though the Earth looks almost perfectly round from space, in reality its shape is not so straightforward. The Earth bulges outward at the equator, and we also know that uneven terrain, such as mountains and ocean trenches, results in a more irregular shape than our eye perceives from a distance. This irregularity is even reflected in sea level. Variations in gravity result in hills and valleys on the ocean itself. The Ellipsoid model smooths out these irregularities and imagines Earth's surface as being a constant, simple shape. Ellipsoidal datums are used worldwide for mapping

and planning applications, and the Ellipsoid model informs GPS because it defines latitude and longitude on Earth. This is a very useful model, but it does not fully account for the effects of gravity. Therefore, heights referenced from the Ellipsoid, which are called ellipsoidal heights, cannot tell you which way water flows.

Slide 75 (38:24)
For determining true heights, a more detailed model of Earth is needed. Geoid models were created to account for this need. They take into account the variation of gravity across Earth's surface while removing the effects of tides and currents. Since water is responsive to gravitational forces, with a Geoid model you end up with an irregularly shaped but smooth surface that appears more bulbous in areas where the influence of gravity is weaker, and has valleys where the influence of gravity is stronger. The Geoid's surface defines zero elevation for geodesists, and this elevation can be extended over Earth using math and gravity data.

Slide 76 (39:05)
Geodesists use these different Earth models when establishing datums. As of 2025, the North American Vertical Datum of 1988, or NAVD 88, is the official *vertical* datum of the U.S., and the North American Datum of 1983, or NAD 83, is the official *horizontal* datum of the U.S.

Slide 77 (39:27)
Together, these datums and others form the National Spatial Reference System. This is the official coordinate system in the U.S. that defines height, latitude and longitude, orientation, scale, gravity, and the national shoreline. Although water level datums like the IGLD are not officially part of the National Spatial Reference System, they depend on it and can be integrated into it using bench marks. This is useful for relating water levels in IGLD to other points in the System.

Slide 78 (39:58)
At the same time that CO-OPS and the Canadian Hydrographic Service are updating IGLD, the National Geodetic Survey and Canadian Geodetic Survey are working to modernize the National Spatial Reference System by replacing some of its older elements. Of particular note is the development of the North American Pacific Geopotential Datum of 2022, or NAPGD2022, a geoid-based vertical datum that will replace NAVD 88. Meanwhile, the NAD 83 horizontal datum is being replaced with the North American Terrestrial Reference Frame of 2022, or NATRF2022. Both new datums are tied to global models that are internationally accepted, meaning that heights in the US and Canada, including IGLD heights, will be connected to the global system.

In order to understand why NAPGD2022 is an improvement, and why it's relevant to IGLD (2020), we should first learn how it was created.

Slide 79 (41:00)
As mentioned previously, technological advances have helped geodetic agencies move away from systems based purely on physical bench marks, to Earth models that are based on GNSS and other satellite technology. GNSS is a term for any network of satellites that provides

positioning, navigation, and timing services on a global scale. GPS is a common example. GNSS works by a satellite sending a signal to Earth, where the signal is picked up by a receiver. The receiver determines the distance between itself and the satellite based on the time difference between when the satellite broadcasts the signal and when the receiver picks it up. When at least four satellites are picked up by the receiver, this provides the positioning reading.

Slide 80 (41:48)
GNSS data are collected continuously at 18 of the permanent gauges on the Great Lakes. Additionally, shorter term GNSS survey campaigns were conducted in 1997, 2005, 2010, 2015, and 2022 on bench marks at *all* permanent gauges (as well as the seasonal gauges during the 2022 campaign) to prepare for the IGLD (2020). The data collected provide vertical positioning information that verifies the heights of water level gauges and bench marks in the network.

Slide 81 (42:23)
However, GNSS provides only an ellipsoid height, which tells you the difference between a point on Earth's surface - the point to which you are measuring - and a point on the ellipsoid. But an ellipsoid height does not give you enough information to know how water will flow from a certain location. For that, you need a geoid model.

Slide 82 (42:44)
The first step in creating a geoid model that will give you information on meaningful heights that reflect water flow is to apply a gravity field to the ellipsoid model. Through complicated math, this results in a model of geoid heights across the region.

Slide 83 (43:01)
From the ellipsoid height and the geoid height, scientists and surveyors can derive an orthometric height and a dynamic height. Remember, we said earlier that orthometric heights are heights as measured from the geoid, and dynamic heights are based on geopotential numbers. Geopotential numbers represent the measure of potential energy between two points as a result of gravity, so if two areas have different geopotential values, water flows between them. Flat surfaces of water have a constant geopotential value over the entire surface. This is important in the Great Lakes because you can use dynamic heights to make a lake's surface look consistently flat.

Slide 84 (43:43)
So, all of the GNSS data collected from gauges around the lakes, along with a geoid model and gravity data, are being used to help realize NAPGD2022, the datum based on a more advanced model of Earth. To recap a very simplified version of this complicated process, this works as follows: heights are initially realized as ellipsoid heights in the datum NATRF2022 through GNSS readings. Once you have the ellipsoid heights, a geoid model is applied to get a NAPGD2022 orthometric height. From that height, you can apply a gravity model to get dynamic heights in NAPGD2022 and IGLD (2020).

Slide 85 (44:28)
NAPGD2022 has a few perks over NAVD 88. First, it will be able to be defined in areas outside of the North American continent, so it will be a *more* comprehensive and consistent reference frame, regardless of whether you are working on-shore, in the lakes, in the connecting channels, or even on the ocean. It also primarily uses GNSS to determine heights, instead of relying on leveling and physical bench marks (though some local leveling will still be needed). Additionally, it's more compatible with satellite positioning technologies like GNSS that many organizations are already using. Finally, NAPGD2022 is designed to work directly with new terrestrial reference frames, which are used for determining horizontal positions. It's also compatible with the Canadian Geodetic Vertical Datum of 2013, commonly called CGVD2013. These two datums use the same reference zero and the same Geoid model, which means they are "linked," and heights will be relatable between them. This will improve coordination between the U.S. and Canada and improve efficiency on future datum updates.

The New and Improved International Great Lakes Datum (45:42)
Slide 87 (45:48)
Unlike its predecessors, IGLD (2020) will be defined based on a geoid model instead of leveling observations. This, along with the ability to obtain IGLD (2020) heights through GNSS observations, will result in major accuracy and accessibility improvements for the datum.

For example, because NAPGD2022 is a geopotential datum that is created using gravity data that covers the entire region, it will be able to more accurately depict the flow of water over Earth. It will also be able to verify water level heights more easily because water flows according to changes in geopotential values. Since NAPGD2022 is accessed via satellite data rather than geodetic leveling, this removes systematic biases, resulting in smaller errors in heights over long distances. This will result in a more accurate datum. Additionally, the time and cost to determine heights is significantly reduced.

Slide 88 (46:50)
The replacement of NAVD 88 with NAPGD2022 also fundamentally changes how we update IGLD. Before, the datum was updated by completing leveling runs across the U.S. and Canada and assigning height values to all of the bench marks in the region. IGLD (1985) height values were generated using the same leveling adjustment that defined NAVD 88. Both datums have the same reference zero at Rimouski, and feature the same geopotential numbers and dynamic heights.

Rather than relying on this process to update the datum, IGLD (2020) is reliant on the development of NAPGD2022. When the National Geodetic Survey has finished updating the National Spatial Reference System, they will have produced a set of new reference heights for all the bench marks that support water level determination in the Great Lakes region based on a new reference zero. Scientists at CO-OPS and the Canadian Hydrographic Service will connect these new heights to all of the water level sensor elevations through very short geodetic leveling surveys, essentially bringing the water level network into NAPGD2022's reference framework. This will result in IGLD (2020), and it will also tie the new datum into the updated National

Spatial Reference System.

Slide 89 (48:13)
Since IGLD (2020) is so heavily dependent on NAPGD2022's implementation, there are several important facets of IGLD (2020) that still need to be determined. For example, since it is expected that the new datum will have fewer errors as a result of leveling, and since hydraulic correctors in part help account for these errors, hydraulic correctors may not be needed at all in order to implement IGLD (2020). And because subordinate stations exist in part to help generate hydraulic correctors, there may also be no need to continue distinguishing between the master and subordinate stations on the lakes.

With the introduction of NAPGD2022, it is also expected that updates to IGLD will be more streamlined in the future, because NAPGD2022 will be a time-dependent datum that will be regularly updated to take into account glacial isostatic adjustment and other changes. Any future IGLD updates can then be done more easily using the NAPGD2022 information. However, an update to NAPGD2022 does not necessarily mean another IGLD update will be required. This is a process that is being determined.

Slide 90 (49:31)
The trifecta of NAPGD2022, the Canadian Geodetic Vertical Datum of 2013, and IGLD (2020) will allow all of the datums in the Great Lakes region, across both countries, to work together in a more cohesive way.

Slide 91 (49:47)
For the most up-to-date information on decisions made about the IGLD (2020) update, please check the IGLD news page on our website.

Impacts of Updating IGLD: What You Should Know and How You Can Prepare (49:57)
Slide 93 (50:03)
After IGLD is updated, water level references for the Great Lakes will have changed. But remember that this does not mean that the *amount* of water changes.

Slide 94 (50:13)
Although levels in the Great Lakes vary seasonally due to weather effects, water regulation, and the hydrologic cycle, and experience long-term changes due to glacial isostatic adjustment, the Great Lakes are not subject to either astronomical forces or sea level change, and so their levels are relatively stable over time.

Slide 95 (50:33)
Therefore, the IGLD update does not represent a change in the amount of water in the lakes. Rather, the *reference value* that the water level depth is measured to is being updated, and as a result, water level height values will be updated to reflect this.

Slide 96 (50:49)
To illustrate, let's return to our example from the beginning about your height. Suppose a new mandate was put into effect that everyone's height now *had* to be related to "Table Datum" as opposed to the original "Ground Datum." Now, everyone will have to give their height from a reference point that is three feet higher than it was before. This mandate does not change your physical height from the bottom of your feet to the top of your head, but it does change the zero point from which you measure yourself. Going forward, you now have to say you are three feet tall instead of six feet tall, but the amount of space you take up vertically stays exactly the same.

Slide 97 (51:25)
Similarly, when IGLD (2020) is implemented, this should not be interpreted as an indication that water levels have changed, even if the values of the heights have changed.

These changes will impact any field of work that references or uses heights related to IGLD (1985). Let's discuss a few more examples.

Slide 98 (51:46)
Commercial and recreational navigation will both be impacted by the new IGLD values. This will require updating water level references and chart datum on navigation charts and at ports and harbors.

Slide 99 (52:00)
Surveying and mapping efforts will also be impacted. Procedures for determining heights in the region will change, as long-distance geodetic leveling between water level gauges will typically be replaced with GNSS survey connections for the new datum and going forward.

Slide 100 (52:16)
IGLD (2020) will also become the new reference that is used to regulate outflow in the lakes. Entities that monitor outflow regulations will need to be aware of the update. In addition, adjusted water level reference heights may affect dam and lock operations.

Slide 101 (52:33)
There will also be impacts to coastal zone management and planning. When planning for shoreline erosion and flooding, the new IGLD should be used because the reference zero will have changed, causing the reference heights for these applications to shift.

Slide 102 (52:47)
Provincial and state transportation and emergency management agencies will need to update to IGLD (2020) for emergency planning and hazard mapping purposes.

Slide 103 (52:58)
New IGLD values will also require updates to engineering plans, as height values will need to be updated in order to support coastal infrastructure design, construction and maintenance, and other projects. New projects should be referenced to the new datum, and references on permits

will also need to be updated accordingly.

Slide 104 (53:17)
The datum update will also impact restoration projects, such as the Great Lakes Restoration Initiative. IGLD (2020) will need to be taken into account to support ongoing ecosystem restoration efforts and future management decisions.

Slide 105 (53:32)
Forecast modelers will need to use IGLD (2020) for future surface water modeling management. This will include updating existing modeling and decision-making tools, like the NOAA Lake Level Viewer. River management plans will also require updating.

Slide 106 (53:49)
The new IGLD may also necessitate the implementation of new legislation or the updating of existing legislation in the Great Lakes region to support all of these applications and more.

Slide 107 (54:00)
The implementation of IGLD (2020) and NAPGD2022 will also be followed by the release of transformation tools, such as the update to NOAA's VDatum program. These tools will allow practitioners to update data products that are currently on IGLD (1985) to IGLD (2020). CO-OPS and the Canadian Hydrographic Service plan to provide water level data referenced to IGLD (2020); however, users will still be able to obtain water level data on IGLD (1985) and reference height offsets between datum versions.

Slide 108 (54:36)
One of the best things you can do to prepare for the impacts of the updated IGLD is to make sure you are paying attention to the metadata of the datasets you are using, and document metadata when performing your own survey or water level work. Metadata is data about data. It tells you the details of when, where, and how data was collected and processed. For example, if someone wanted details about the water level value in Duluth, Minnesota, they would check the metadata to find information like the water level sensor specifications, leveling procedures and quality control methods used, bench mark information, units of measurement, and which realization of IGLD is being referenced. It's important to not just pay attention to the data you collect, but also to keep good notes about *how* they were collected, and to not make assumptions about the compatibility of multiple datasets.

Timeline (55:29)
Slide 110 (55:36)
IGLD (2020) is expected to be released in 2027, though this date might shift later into 2028. There are still a number of milestones to meet and decisions to make.

GNSS processing and the GEOID model for IGLD modernization are now complete. Next, scientists will make a final determination on whether or not hydraulic correctors will be implemented and if they should be updated. They will then work to determine preliminary

heights for NAPGD2022, IGLD (2020), and the associated bench marks. The bench mark heights will be used to determine offsets between themselves and the mean water level surface of each lake. Following the computation of these offsets, the U.S. and Canada will update products related to IGLD, which will go through user experience testing. Next, Canada and the U.S. will develop a long-term plan to maintain IGLD and its future updates. This plan will consider technological advances afforded by geoid models, as well as the requirements of those who rely on IGLD. Once a maintenance plan has been determined, IGLD (2020) water level reference heights will be formally rolled out and will officially replace those of IGLD (1985). Considering this timeline, IGLD (2020) is expected to be rolled out about one year after the acceptance and publication of the modernized National Spatial Reference System.

Closing (57:04)

Slide 111 (57:04)

The implementation of IGLD (2020) will represent a large-scale change in how water levels are referenced in the Great Lakes region. This may seem like a big adjustment, but now that you are more familiar with IGLD as a whole, we hope that you feel more prepared to adapt to the coming datum update, and will be able to navigate changes to IGLD with confidence.

Slide 112 (57:25)

This training was made possible through collaboration with our partners. NOAA CO-OPS would like to acknowledge and thank experts from NOAA's National Geodetic Survey, the Canadian Hydrographic Service, the Canadian Geodetic Survey, Environment and Climate Change Canada, the U.S. Army Corps of Engineers, and the NOAA Great Lakes Environmental Research Lab.

Slide 113 (57:48)

We hope that you have found this training informative and useful. If you will be impacted by the IGLD update, and have more questions or concerns, remember that we are here to help. For questions about more technical concepts that were not covered here, how you can specifically prepare for the IGLD update, or comments about this training, please email CO-OPS oceanographers at tide.predictions@noaa.gov.