GREAT LAKES VERTICAL CONTROL

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ABSTRACT. The Vertical Control Reference System on the Great Lakes is reviewed from its historical beginning over 140 years ago through the establishment of International Great Lakes Datum (IGLD) in 1955. Elevations above mean sea level were determined in 1877, 1903, and 1955. In 1935, differences in elevation between the lakes were determined although no connection was made to sea level. The elevation determination in 1955 was an internationally coordinated effort between the United States and Canada and resulted in the entire Great Lakes-St. Lawrence River system being completely covered by a single uniform vertical control network. The discussion will include the development of the early vertical control system, the concept of water level transfers, the various adjustments which provided bench mark elevations referenced to a common datum, the crustal movement phenomenon, the International Great Lakes Datum (IGLD) 1955, the relationship between IGLD and the National Geodetic Vertical Datum (NGVD) of 1929, and the current status of the IGLD update.

INTRODUCTION

Over one hundred and forty years ago (1841) the U.S. Congress appropriated funds for the "Survey of the Northern and Northwestern Lakes". At that time, the Great Lakes area was the Northern and Northwestern lakes of a rapidly expanding young country. The U.S. Lake Survey was established, under the Corps of Topographical Engineers of the U.S. Army, to carry out the surveys. In the early 1840's, the meager population of the Great Lakes was concentrated in the southern and eastern sections, public transportation was in its infancy,and control for surveys did not exist. One of the first tasks facing this new survey organization was the development of a vertical control reference system. Vertical control, to engineers and surveyors, consists of a network of stable points called "bench marks" whose elevations above or below a reference zero, are known.

EARLY VERTICAL CONTROL

Although surveys were in progress and water level gages were providing data on the relative fluctuations of each of the Great Lakes by 1860, the elevations of the lakes above sea level were not established until 1877. In 1875, levels were run from Greenbush (now Rensselaer), N.Y. on the Hudson River, westerly along the Erie Canal, wagon roads and, the New York and Oswego Midland Railroad to Oswego, N.Y. on Lake

Ontario. This leveling established elevations in Oswego Harbor referred to sea level at New York City. Additional leveling in 1875 provided the land connections between Lakes Ontario and Erie and Lakes Erie and Huron. An important concept introduced at this time was a procedure called "water level transfer". Working on the theory that a mean water surface of any body of water will be at an equal elevation throughout, the sea level elevations at Oswego were transferred to the mouth of the Niagara River and using the land level lines mentioned above, and including a water transfer across Lake Erie, a continuous sequence of measurements were provided for basis of assigning a sea level elevation at the Escanaba, Michigan gage on Lake Michigan.

In 1876, the final line of levels, extending from Escanaba on Lake Michigan to Marquette on Lake Superior, for the determination of sea level elevations in the Great Lakes was completed. Adjustment of this leveling resulted in the "Levels of 1877." Further leveling in the Great Lakes includes a 1898 line of levels from Hogansburg, New York to St. Regis and up the St. Lawrence River to Tibbetts Point, a 1898-99 line of levels between Gibraltar and Lexington, 1901 level lines between both Olcott and Buffalo and Detour and Point Iroquois, and a 1902 line of levels rerun between Greenbush and Oswego.

WATER LEVEL TRANSFERS OVER LARGE BODIES OF WATER

Since 1875, the procedure called "Water Level Transfer" has been used to establish vertical datum on each of the Great Lakes. This concept assumes that the mean water surface at any location on each lake wilt be at an equal elevation during a period of time. A water level transfer (Figure 1) involves a technique where the elevation from a permanent bench mark at one location on a lake is transferred through averaged gage readings to the water level surface and inturn through averaged gage readings at a different location on the same lake to a permanent bench mark at that location. The longer the time period used in the transfers, and the more values averaged, results in greater precision of elevations determined.

Historically, the geodetic community has been reluctant to accept the results based on the concept of water level transfers. However, after familiarity with the concept, many individuals inside and outside the community, past and present, have accepted this procedure as a valuable tool for establishing hydraulically acceptable reference elevations and for monitoring vertical changes in the earth.

The Doctoral Thesis by Herbert W. Stoughten (1980), "Investigation of the Accuracy of Water Level Transfer to Determine Geodetic Elevations in Lake Ontario", further concludes that "From An Engineering Viewpoint, The Water Level Transfer Employing Dynamic Heights Derived From Uncorrected Four Month Mean Lake Level Readings Is At Least As Accurate As First-Order, Class I Geodetic Leveling".

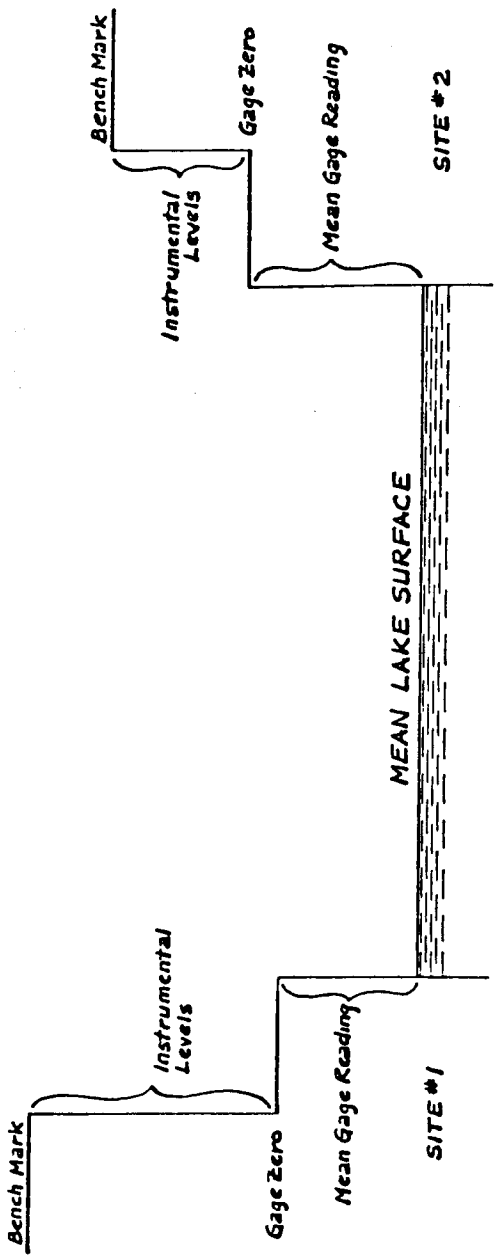

Figure 1 : WATER LEVEL TRANSFER

VARIOUS ADJUSTMENTS REFERENCED TO COMMON DATUMS

Adjusted Levels of 1903

By 1902 all level lines between the lakes had been rerun, and the U.S. Coast and Geodetic Survey had extended its level network westward past the Mississippi River. As

the Coast and Geodetic Survey work progressed through the Great Lakes area, the U.S. Lake Survey level lines were incorporated into the national system, and in 1903, these lines were included in the adjustment of all leveling east of the Mississippi. This 1903 adjustment of levels incorporated several series of U.S. Lake Survey water level transfers.

Elevations resulting from this adjustment, which were known as the "Adjusted Levels of 1903", were adopted by the U.S. Lake Survey. Through additional instrumental leveling and water level transfers, elevations on the new datum were determined for a11 remaining bench marks in the Great Lakes network. This new network soon became known as U.S. Lake Survey 1903 Datum or simply "The 1903 Datum".

Adjustment of 1935

By 1930 it was obvious from the increasing differences in water surface elevations that a reevaluation of bench mark elevations would soon be necessary. In 1933 water level gages were installed in practically every U.S. harbor on the Great Lakes. In view of the new information available from water level transfers and the releveled land connections between lakes, an adjustment of all U.S. Lake Survey elevations was approved early in 1936. This adjustment was to be called the "Adjustment of 1935" or simply "The 1935 Datum".

Since a new sea level connection had not been made, it was decided for this adjustment to hold existing elevations, based on the 1903 adjustment, for the bench marks at one control harbor on each lake and compute new elevations for marks at all other harbors on the lake by water level transfers. Therefore, at Oswego, Cleveland and Harbor Beach, bench mark elevations were held fixed and were adopted as 1935 Datum elevations. The exception to the above were elevations on Lake Superior, which were determined by water level transfer from Harbor Beach to DeTour and instrumental leveling to Point Iroquois. Then, new elevations for the bench marks in all other Lake Superior harbors were computed from 1935 gage records. Therefore, elevations of all bench marks in the Great Lakes area were in harmony as related to the 1935 Datum.

CRUSTAL MOVEMENT PHENOMENON

Through knowledge obtained from measurement of the crustal movement phenomenon during the 1903-1935 period, it was realized at the time of the establishment of 1935 Datum, that future adjustment of elevations would be necessary. It was clear that releveling between the lakes and additional adjustments of elevations would be required, approximately every 20-30 years in the Great Lakes basin. This was because of the natural phenomenon, termed in the Great Lakes area, "crustal movement". As time progressed, computations of mean lake levels from records of gages that had been set in 1903 to record the same elevations showed different values. These values differed by increasing amounts with time and it was first thought to be the result of differential vertical movement occurring at one or more of the gage sites. Leveling

between gage zeros and nearby bench marks showed stability for the immediate area surrounding the gage. This indicated the movement was not of the gage itself, but of some other reason, possibly movement in the earth's crust or overburden. Comparisons for other gage readings showed the phenomenon to be present on all the lakes, being the greatest on Lakes Superior and Michigan.

Mr. G. K. Gilbert of the U.S. Geological Survey proposed in 1898 to use a three gage network on Lakes Michigan and Huron to check the premise of crustal tilt in the Great Lakes Basin. Subsequent investigators as; (Gutenberg 1941), (Moore 1948), and (MacLean 1961) have provided credulity to Gilbert's proposal.

A recent report "Apparent Vertical Movement Over the Great Lakes", prepared by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (1977), lists results of crustal tilt based on the water level transfer procedure.

INTERNATIONAL GREAT LAKES DATUM (IGLD)

A brief examination of vertical control in Canada is introduced to provide a background of the international coordination entailed in the establishment of the International Great Lakes Datum.

In 1935, Canadian government agencies were operating approximately a dozen water level gages along the Canadian shore of the Great Lakes. These gages had been set to record water surface elevations based on the 1903 Datum by making water level transfers from the nearest United States gages. When the 1935 Datum was adopted by the Corps of Engineers, the Canadian government decided to continue using the 1903 Datum values. As a result, lake level data published by agencies of the two governments were not identical for the same lakes and rivers.

These differences were not great and considered insignificant until the advent of international power development on the St. Lawrence River. At this time it became very important for basic hydraulic and hydrologic data pertaining to the Great Lakes System be the same in both countries.

In 1953 the U.S. Lake Survey and its counterpart agencies in Canada began a program of coordinating basic hydraulic and hydrologic data, and one of the many results of this coordination and a high point of U.S.-Canadian cooperation, was the development and establishment of International Great Lakes Datum (1955) or simply IGLD (1955).

In establishing this new international datum, it was necessary to meet certain basic requirements:

1) The datum had to be acceptable to both governments, so that previous, uncoordinated datum references could be abandoned. This requirement meant the new datum had to include bench marks along the entire St. Lawrence River, thus the requirement for the reference zero somewhere in the Gulf of

St. Lawrence.

2) It had to incorporate an adjustment of a11 elevations to compensate for changes caused by differential vertical earth movement to the date of datum establishment, and to correct any errors that may have existed because of inconsistencies in the original work. Therefore, it was necessary to make a timely and complete new elevation determination throughout the Great Lakes area by rerunning the first-order lines between the lakes and operating many special water level gages to obtain data for water level transfers across the lakes since resources were not available to run the additional hundreds of miles of first-order level lines around the lakes.

3) It had to provide elevations suitable for use in resolving the many involved hydraulic and hydrologic problems existing on the Great Lakes System. The prime reason for adopting dynamic elevations for the new datum was to provide a means of accurate measure of potential hydraulic head between points.

The new datum was established during the period 1952-1958 by first-order leveling along the St. Lawrence River from Point-au-Pere (Father Point), Quebec in the Gulf of St. Lawrence to Kingston, Ontario at the easterly end of Lake Ontario. A parallel line along the United States side of the river was connected with the main Canadian level line at Cornwall, Ontario, at the St. Lawrence Power Dam, at the Iroquios Dam, and at the Thousand Islands Bridge. Water level transfers were made from Kingston to all gage sites on Lake Ontario, where sufficient water level data for the period 1952-1958 were available, and the new datum was established at other locations by using first-order level lines between transfer points.

The new datum was extended to the easterly end of Lake Erie by firstorder levels run along the Wetland Canal in Canada and along the Niagara River in the United States, and to other sites on Lake Erie by water level transfer supplemented with some short first-order leveling ties. This same procedure extended elevations to Lake Superior. Figure 2 shows the network of level lines and water level transfers used in establishing International Great Lakes Datum (1955).

THE RELATIONSHIP BETWEEN IGLD AND NGVD

International Great Lakes Datum (IGLD), 1955 is the present vertical control reference system in the Great Lakes Basin. An international study between agencies for the development and acceptance of identical elevation data for the Great Lakes and the St. Lawrence River System was completed in 1961. IGLD was the outgrowth of that study. A report prepared by the Coordinating Committee on Great Lakes Hydraulic and Hydrologic data on the "Establishment of International Great Lakes Datum (1955). Second Edition, December 1979,

describes the datum establishment and the reader is referred there for an in-depth explanation.

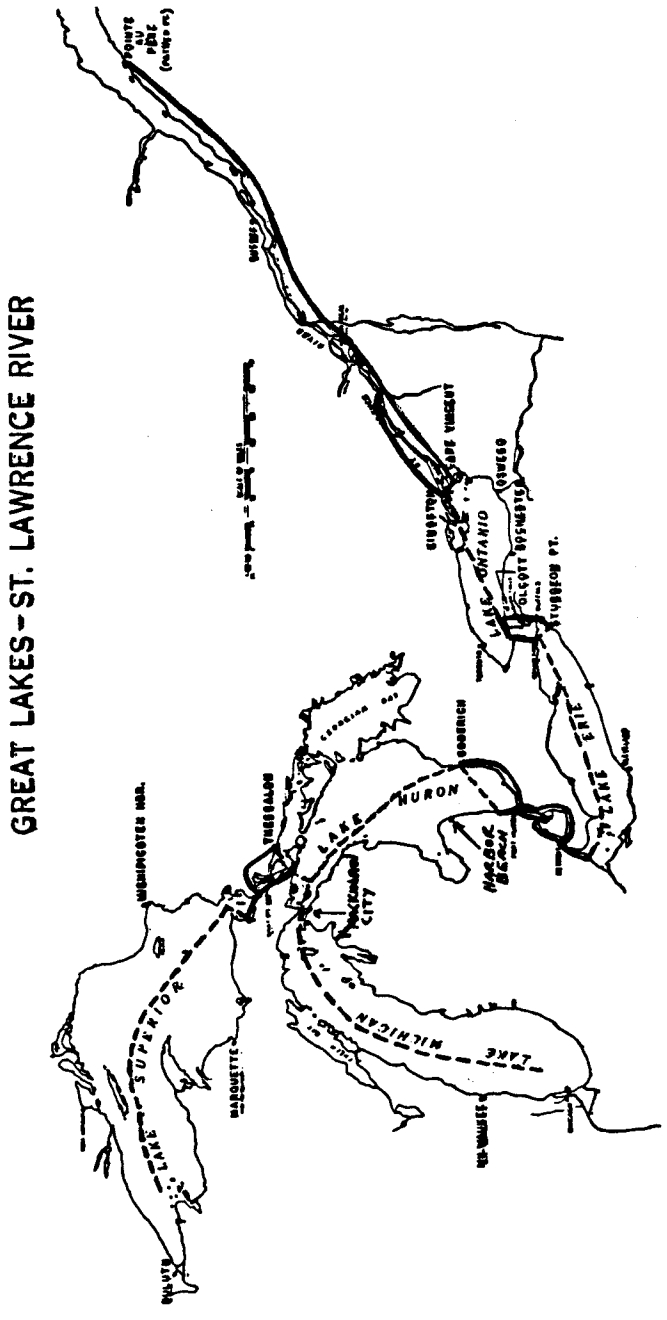

Figure 2 : LEVEL NETWORK, INTERNATIONAL GREAT LAKES DATUM

As previously stated, the new datum has its reference zero based on mean

water level surface at Point-au-Pere (Fathers Point), Quebec, with land leveling determining elevations at Kingston, Ontario on Lake Ontario, then by water level transfer to other points on Lake Ontario. A combination of land leveling and water level transfer then extends elevations throughout the remainder of the system to Lake Superior.

The National Vertical Control Network (NVCN) consists of a hierarchy of interrelated nets which span the Nation. Adjustments for each level net of the hierarchy provide bench mark elevations having equal or higher order accuracy. These primary and secondary nets provide a common reference system for user's needs. Bench mark elevations of the NVCN are currently being published as normal orthometric heights. These elevations are referenced to the National Geodetic Vertical Datum (NGVD) of 1929". The 1929 Datum was established by constraining the combined United States and Canada first-order leveling nets to conform to Mean Sea Level as determined at 26 long-term tide stations (21 in the United States and 5 in Canada).

Elevations on IGLD are adjusted in the dynamic number system in that the dynamic value of a bench mark is not a true linear elevation, but a serial number given to the level surface on which the mark lies, and it represents the work required to raise a mass of one pound against the force of gravity from the geoid to the level surface in question in foot-pounds. Some advantages of dynamic elevations are: 1) in vertical earth change or crustal movement studies, differences in the dynamic elevation of bench marks from lake to lake may be compared regardless of the route along which the leveling is done, 2) differences in dynamic elevations give an accurate measure of the potential hydraulic head between the points, and 3) if the mean surfaces of the lakes are indeed level, every point on that particular lake surface will have the same dynamic elevation. If the lake surfaces are sloped, the use of dynamic elevations make it easier to detect their departure from level. For these reasons it was decided to adopt dynamic elevations in establishing IGL (1955) for use in the Great Lakes Basin.

Elevations referenced to NGVD 1929 are unacceptable for use in resolving the involved hydraulic and hydrologic problems of the Great Lakes system. Primarily, the reasons are; 1) the reference zeros are not located within the system, and 2) that orthometric elevations are not a satisfactory solution for large bodies of water such as the Great Lakes. Orthometric elevations only represent heights above mean sea level. Gravitational forces are not considered and on account of this, no large body of water can be presented as an equipotential surface. Therefore, water level measurements obtained at both ends of a Lake and connected to the NGVD 1929 network would show some magnitude of a permanent northerly slope.

INTERNATIONAL GREAT LAKES DATUM UPDATE

While the subject matter of this text has been primarily a discussion or the historical vertical control system in the Great Lakes up to and including the present vertical control datum it also has shown the need for periodic reevaluation of any vertical control datum used in the Great Lakes. In 1976 the Coordinating Committee on Basic Hydraulic and HydroTogic Data approved a plan for reevaluation of IGLD. Field work to obtain the required data began in 1977 and was completed in December 1983. Field parties of both the National Geodetic Survey, NOS and the Geodetic Survey of Canada, Department of Energy, Mines and Resources completed over 2,000 kilometers of leveling for the update program. During the leveling, ties were made to water level stations operated by NOS and the Canadian Hydrographic Service. At present, the leveling results are being evaluated and placed in automated format, and gage data records are being evaluated for use in the water level transfer procedure. Once these evaluations are completed, the data will be merged to compute new bench mark elevations. These bench marks elevations will be adjusted and referred to the new vertical control datum. International Great Lakes Datum 1980. The target date for publication and distribution of adjusted elevations is October 1986.

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