US Army Corps of Engineers
Detroit District

Great Lakes Update

Volume 200: Frequently Asked Questions about Water Levels

Current Conditions

All of the Great Lakes are above their long term average monthly mean water levels. Figure 1 shows water levels on each of the Great Lakes from 1918 to 2017, which is the period of record for which monthly mean water levels have been coordinated between U.S. and Canadian federal agencies. During this period, all of the Great Lakes have experienced multiple periods of high and low water levels. From December of 2017 to March 2018, Lake Superior water levels were the second highest on record (higher levels were seen in 1985 and 1986), but after very dry conditions in March and April, a dramatic decline in level brought the April monthly mean water level to the 9th highest on record. The Lake Michigan-Huron water level in April was the 16th highest April level on record, and the highest April water level since 1998. These high water levels stand out, in part because they follow an extended period of low water levels that occurred from the late 1990's to the early 2010's. In this Great Lakes Water Level Update, frequently asked questions about Great Lakes water levels, especially questions related to the currently high water levels, are addressed.

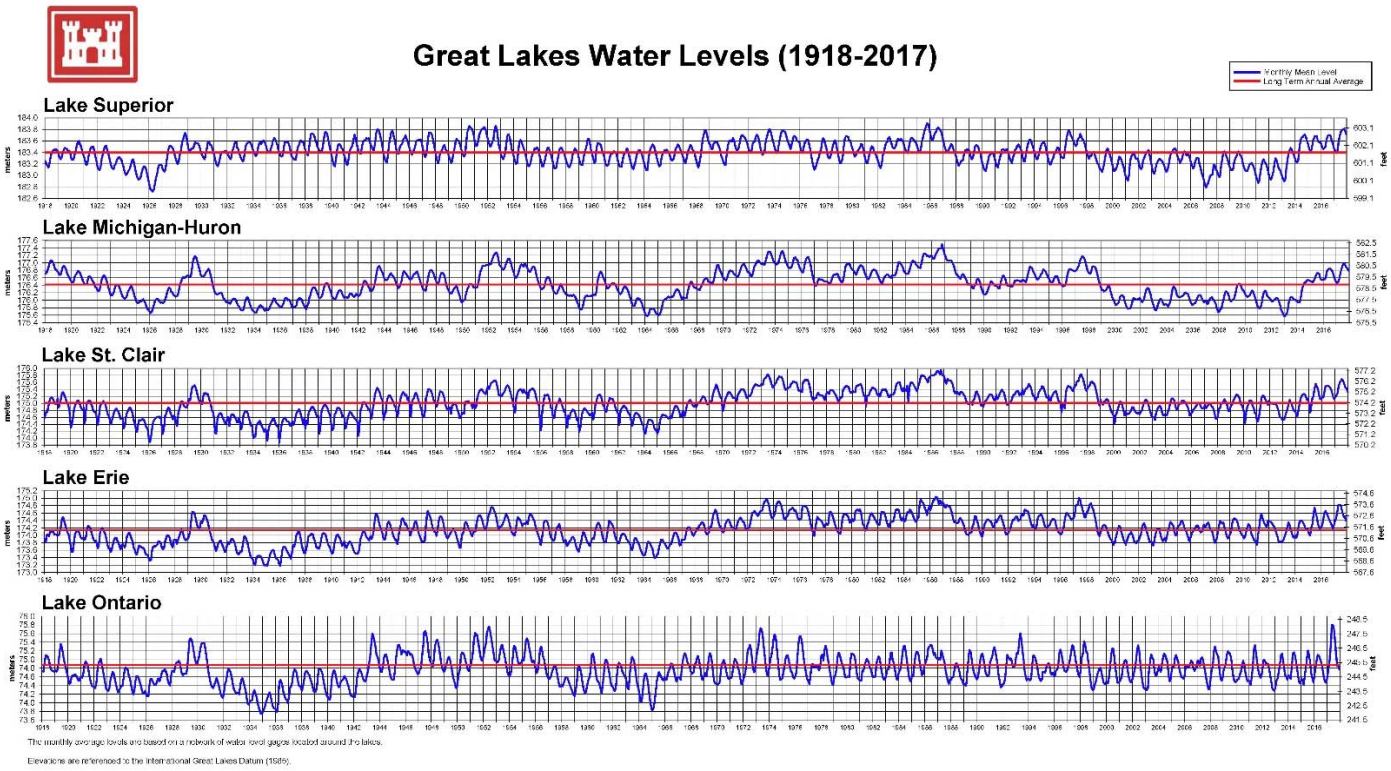

Figure 1. Historical Great Lakes water levels. This image can be downloaded as a pdf with higher resolution from www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Water-Levels/Historical-Data

How are water levels determined?

Lakewide average water levels of the Great Lakes are determined by averaging data from a network of gages operated and maintained by the U.S. National Oceanic and Atmospheric Administration (NOAA) and the Canadian Hydrographic Service (CHS), shown in Figure 2. Monthly mean water levels and beginning-of-month water levels are computed by the Detroit District's Great Lakes Hydraulics and Hydrology Office from data provided by these gages, and these levels are routinely coordinated with Canada.

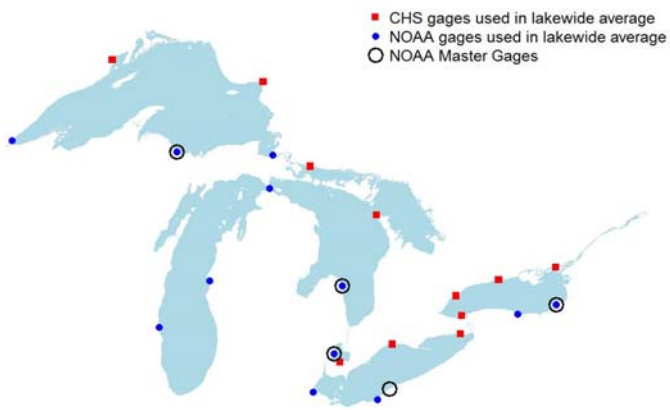

Figure 2. Great Lakes Water Level Gages.

What is the International Great Lakes Datum of 1985 (IGLD 85)?

The International Great Lakes Datum of 1985 is the common height reference system by which Great Lakes water levels are measured. The IGLD 1985 has its zero base at Rimouski, Quebec near the mouth of the St. Lawrence River (approximately sea level). The IGLD must be adjusted every 25 to 30 years, because of the movement of the earth's crust. The last adjustment was conducted in the 1990's, with 1985 as the central year of the period during which water level information was collected for the datum revision (1982-1988). Work is currently underway by federal agencies in the U.S. and Canada to conduct the next revision to the IGLD.

What is chart datum?

Chart Datum, also commonly referred to as Low Water Datum, is a vertical plane of reference used to measure water depth. There is a distinct Chart Datum for each lake which is determined from historical water level records. These datum planes have fixed elevations relative to the International Great Lakes Datum of 1985 (IGLD 1985). Water levels are referenced to chart datum in order to agree with navigation charts. According to the Canadian Hydrographic Service, "Chart datum is selected so that the water level will seldom fall below it and only rarely will there be less depth available than what is portrayed on the chart."

Why is Lake Michigan-Huron considered to be one lake?

Geographically speaking, Lake Michigan-Huron is often referred to as two lakes: Lake Michigan and Lake Huron. However, hydrologically speaking, these two bodies of water are referred to as one lake: Lake Michigan-Huron. This is because Lake Huron and Lake Michigan are hydraulically connected via the Straits of Mackinac, and as a result, they rise and fall together as one lake. For example, precipitation over Lake Michigan causes both Lake Michigan and Lake Huron to rise.

What causes water levels to change?

Water levels on the Great Lakes can change at different timescales, depending on different natural drivers. Large fluctuations in lake levels from one location on a lake to another can occur on the order of hours to days, and are the result of meteorological conditions. For example, a seiche occurs when there is a rapid change in atmospheric pressure that causes water to be pushed from one side of a lake to the other (Figure 3). This occurs

frequently on Lake Erie, owing to its shallow depth and southwest-to-southeast alignment. While most seiche events are relatively small in magnitude, in extreme cases the water levels at Toledo and Buffalo can differ by more than 10 feet.

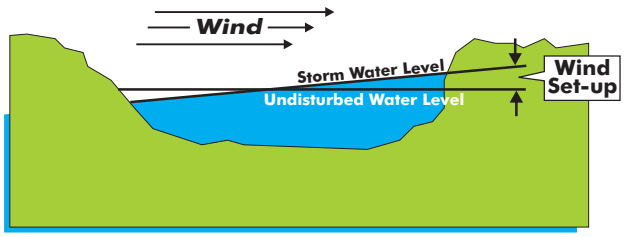

Figure 3. A seiche is an atmospherically driven fluctuation in lake levels across a lake, and occurs on the order of hours to days.

Monthly and seasonal fluctuations are the result of changes in the amount of water flowing into and out from the lakes. While human influences have a small impact on these inflows and outflows (see FAQs related to Lake Superior regulation and Great Lakes Diversions in this article), these inflows and outflows are primarily determined by regional climatic conditions, which influence the Net Basin Supply (NBS) of water to each lake (Figure 4). NBS represents the net influence of precipitation over the lake, runoff from a lake's watershed into the lake, and evaporation from the lake's surface.

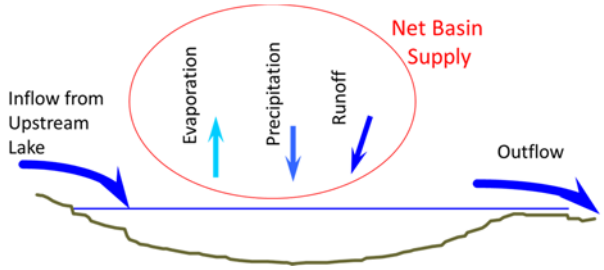

Figure 4. Inflows and outflows driving monthly to seasonal changes on the Great Lakes.

Why is there a seasonal cycle to water levels?

The water levels of the Great Lakes follow a seasonal cycle in which water levels rise in the spring and early summer, and then decline in the late summer and fall. The processes that drive the seasonal cycle are shown in Figure 5. During the winter, snow falls and accumulates in snowpack, limiting the amount of precipitation that becomes runoff into the lakes. Then, in the spring, as the snow melts and rainfall becomes runoff, water levels increase. During the summer, the lakes warm, and in the fall, when cold air comes into the region and passes over the lake, evaporation from the lake surface increases.

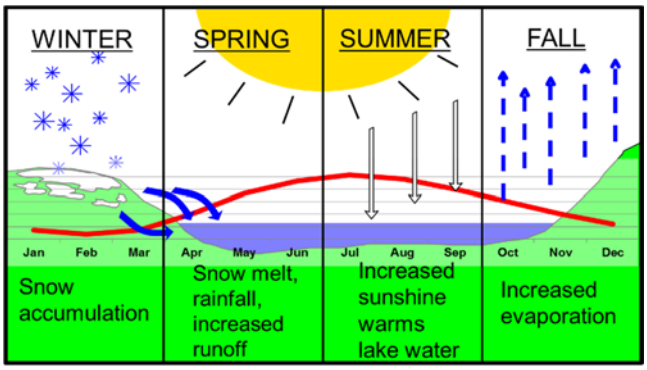

Figure 5. Seasonal cycle of water levels.

What is the influence of aquifer recharge on water levels?

Water that recharges aquifers does not typically directly factor into the computation of the water budget of the Great Lakes. It is, however, indirectly accounted for in models that simulate the translation of precipitation to runoff, and the climatic conditions that lead to a high groundwater table would also lead to higher lake levels. It is common practice to assume that groundwater movement into the lakes is negligible, relative to other components of the water cycle.

Why are the water levels high?

Over the past several years, annual NBS has, more often than not, been above average on all lakes. On Lake Superior and Michigan-Huron, the extremely high 2013, 2014, and 2017 NBS were especially noticeable, and were accompanied by a record-

setting 2-year rise in 2013-2014. This dramatic rise in water levels came on the heels of a decade of mostly below average NBS that resulted in an extended period of low water levels and culminated in a record low water level on Lake Michigan-Huron in January 2013. On Lake Ontario, record high NBS during the spring of 2017 contributed to a rapid rise, resulting in record high water levels in May, June, and July of 2017. Figure 6 shows the annual NBS over the past decade for each lake, as well as water levels for the same period.

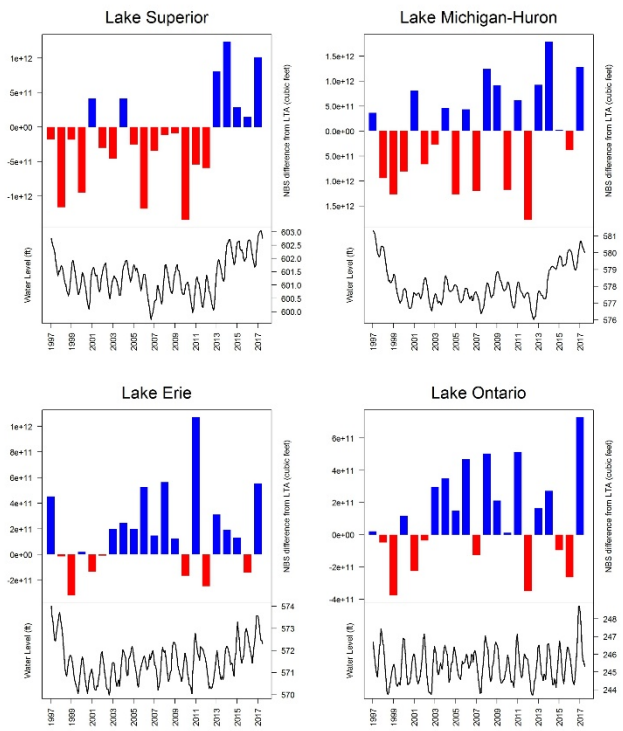

Figure 6. Difference from long term average annual NBS in cubic feet per year (top panels) and monthly mean water levels in feet over the past decade (bottom panels).

Have water level trends changed in recent years, relative to the past?

Great Lakes water levels vary significantly from year to year and can swing from above to below average water levels within a few years (see Figure 1). While it is difficult to find long term trends in lake levels using the coordinated period of record (1918-2017), the past 5 years have changed the water level story dramatically from one of persistently low levels, especially on Lakes Superior and Michigan-Huron to a story of high water levels. In fact, Lakes Superior and Michigan-Huron both experienced a record setting 2-year rise in 2013 and 2014. Over the long term, however, there is no indication that this recent trend will continue.

How do high water levels influence shoreline erosion?

Variation in lake levels, whether short or long term, have little effect on the creation of waves, the primary erosion agent. Most waves are generated far offshore in deep water where such relatively small water level variations are insignificant. As long as the long-term meteorological and hydrographic factors that determine wave energy remain the same, the long-term erosion rate would remain essentially unchanged. The lake level does, however, have an effect on where wave energy is dissipated on the beach profile, and thus may affect bluff recession rates over short time periods.

The lake level is only one of many factors influencing coastal erosion and recession. To date, the relative importance of lake level compared to the other influencing factors has not been fully quantified. Observations suggest that along much of the coast, storm duration and return frequency, and sediment supply have much more influence on coastal erosion and recession than higher lake levels do.

How do diversions into or out from the Great Lakes impact water levels?

There are five locations around the Great Lakes where water is diverted using hydraulic structures. These include the Long Lac Diversion, the Ogoki

Diversion, the Chicago Diversion, the Welland Canal Diversion, and the New York State Barge Canal Diversion. These diversions have a small influence on Great Lakes water levels, relative to the climatically driven NBS on each lake.

Figure 7. Great Lakes diversions.

The Chicago diversion is the only structural diversion that moves water outside the Great Lakes basin, and annual flow in the Chicago Diversion is limited to 91 m^3/s (3,200 cfs) by a Supreme Court decree. Relative to the average annual NBS (112,700 cfs), average annual inflows from the St. Marys River (74,900 cfs), and outflows from the St. Clair River (183,300 cfs), this 3,200 cfs diversion is very small and has very little influence on Great Lakes water levels. The Long Lac and Ogoki diversions collectively add roughly 5,300 cfs into Lake Superior, which is small, relative to the average annual NBS (roughly 71,300 cfs) and average annual outflow through the St. Marys River (74,900 cfs). The Welland Canal diversion transfers an average of about 8,000 cfs from Lake Erie to Lake Ontario, which is small, relative to the Niagara River, which averages roughly 204,100 cfs annually, and NBS of Lake Erie, which averages 21,900 cfs annually. The New York State Barge Canal Diversion presently diverts water from the Niagara River watershed and returns it to Lake Ontario, and its flows are accounted for within the Niagara River flows.

Where are flows in the Great Lakes regulated?

Regulation of connecting channel flows in the Great Lakes occurs at three locations: the St. Marys River, the Niagara River, and the St. Lawrence River. Oversight of regulation at these three control structures is provided by the International Joint Commission. Unlike regulation at the St. Marys and St. Lawrence Rivers, regulation at the Niagara River has no influence on the total outflow of Lake Erie, and therefore no influence on the level of Lake Erie or Lake Ontario. Regulation of Niagara River flows is determined by the 1950 Niagara Treaty, which specifies the minimum amount of water that must flow over the Niagara Falls at different times.

How is Lake Superior outflow regulated?

Regulation of Lake Superior outflows is the responsibility of the International Lake Superior Board of Control, under the authority of the International Joint Commission. Plan 2012 is the current regulation plan for Lake Superior that provides a set of rules used to determine Lake Superior outflows each month. These rules begin with a "pre-project" flow relationship, which determines the flow that would occur if the infrastructure that controls flow in present times did not exist. This relationship is based on flows prior to 1887. Then, a balancing principle is applied. This balancing principle adjusts flow based on the level of each lake relative to seasonal targets based on average conditions. These adjusted flows are subject to physical and operational limits. Finally, the flow is allocated among municipal and industrial uses, navigation (via the locks), hydropower, and the St. Marys rapids. The end result of the operation of Plan 2012 is a determination of the Lake Superior outflow and the gate setting. Note, however, that because of the lack of ability to control or predict NBS, the

ability to regulate Lake Superior outflow does not mean that full control of Lake Superior (or Lake Michigan-Huron) water levels is possible. For more information, see the resources available on the International Lake Superior Board of Control website:
http://www.ijc.org/en_/ilsbc/International_Lake_Superior_Board_of_Control.

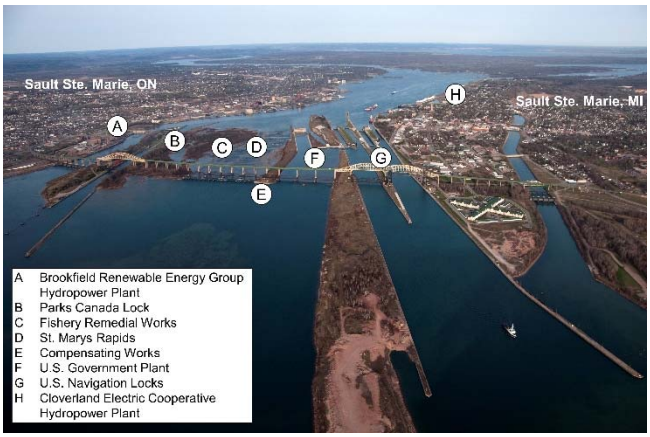

Figure 8. St. Marys River, looking downstream. Operation of Plan 2012 results in a determination of the coming month's Lake Superior outflow and flow through the St. Marys Rapids (via the Compensating Works).

To what degree does regulation impact Lake Superior water levels?

The ability to control Lake Superior's outflow does not mean that full control of lake levels is possible. This is because major factors that affect the water supply to the Great Lakes are over-lake precipitation, runoff, and evaporation (together known as net basin supply). These components of net basin supply can vary dramatically from month to month and cannot be controlled, nor can they be accurately predicted in the long term. The NBS, St. Marys River discharge, and inflow from the Long Lac and Ogoki Diversions, which collectively comprise the Lake Superior water budget, are shown in terms of their influence over Lake Superior water levels in Figure 9. The month-to-month and interannual variability in NBS shown in Figure 9 is the main factor in limiting the ability of regulation to control Lake Superior water levels.

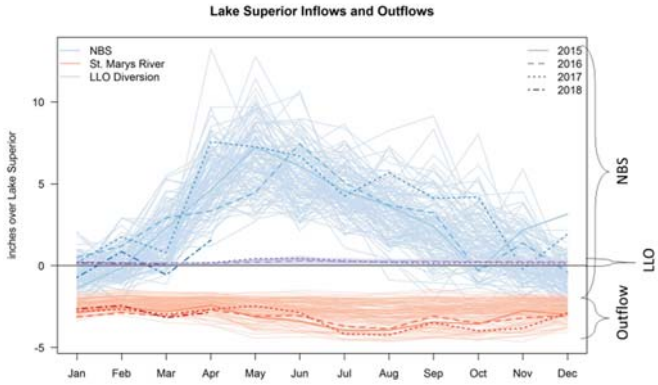

Figure 9. NBS, inflow (Long Lac and Ogoki Diversion, or LLO), and outflow (St. Marys River) for each year of the historical record, in terms of inches over Lake Superior. Note that outflows are shown as having a negative effect on Lake Levels, so higher St. Marys River discharge is plotted lower on the y-axis.

Why isn't more water being sent through the St. Marys River?

The International Lake Superior Board of Control utilizes Lake Superior Regulation Plan 2012 to determine the amount of water to release from Lake Superior and balance the impacts to Lake Superior, Lake Michigan-Huron, and the St. Marys River. As described above and in Figure 9, the ability to control water levels via regulation is small, relative to natural influences on lake levels.

How would adding or removing an inch of water over Lake Superior via the St. Marys River change the water level on Lake Michigan-Huron?

Lake Michigan-Huron's surface area is about 43% larger than Lake Superior (45,300 square miles, compared with 31,700 square miles, shown overlapping in Figure 10). Accordingly, if the volume of water contained in an inch of water over

Lake Superior's surface was added or removed from Lake Superior, it would result in a 0.7 inch rise or fall on Lake Michigan-Huron (if there were no outflow through the St. Clair River).

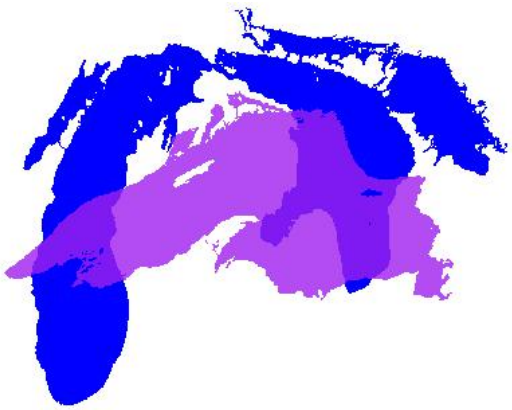

Figure 10. Lake Superior's surface area is roughly 67% of Lake Michigan-Huron's surface area.

What was the variability in lake levels prior to regulation?

Regulation of Lake Superior began with the Order of Approval of 1914, with full control of the current 16-gate structure being achieved in 1921. Regulation has had little impact on the variability of water levels of Lake Superior, as can be seen in Figure 11. Looking back prior to the 1920s, water levels are determined using a single master gage on each lake (Figure 2 shows the location of these gages). Monthly mean water levels from 1860 to present are shown in Figure 11. Prior to 1921, the highest monthly mean water level occurred in 1876 (603.58 ft) and the lowest monthly mean water level occurred in 1866 and 1911 (600.07 ft). Subsequent to 1921, the highest water level occurred in 1985 (603.38 feet) and the lowest water level occurred in 1926 (599.48 ft).

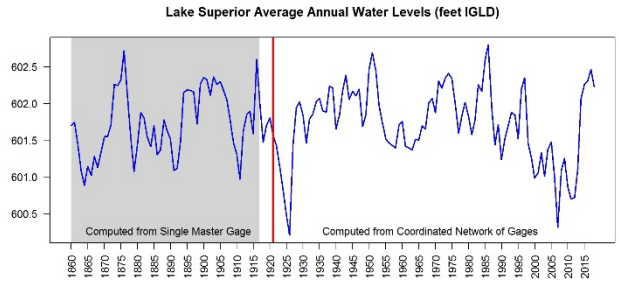

Figure 11. Monthly mean water levels on Lake Superior. The vertical line is drawn at 1921, when full regulation of the St. Marys River began.

What water level forecast products are available?

The Detroit District Office of Great Lakes Hydraulics and Hydrology publishes several forecast products that are available online at https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Water-Levels/Water-Level-Forecast. The Monthly Bulletin of Great Lakes Water Levels provides a forecast of monthly mean water levels 6-months out, and is updated at the start of each month. This forecast is produced through a coordinated process between the Detroit District and Environment and Climate Change Canada. In addition to the Monthly Bulletin, the District also publishes the Weekly Great Lakes Water Level Update, which is updated each week and provides a forecast of water levels 30 days out; and the Connecting Channels forecast, which is also updated weekly, and provides a forecast of depths in the St. Marys, St. Clair, Detroit, and St. Lawrence shipping channels for the next four weeks. In addition to these forecasts, the Detroit District also publishes a Great Lakes Water Level Outlook (also found on the forecast website listed above). Although this Water Level Outlook is not a forecast, it provides an indication of what the Great Lakes water levels could be under alternative scenarios of net basin supply conditions over the coming 12 months.

This scenario-based product is updated on a monthly basis. The National Oceanic and Atmospheric Administration provides nearer term forecasts of water levels at specific locations on the order of hours to days.

Why do water level forecasts change from month to month?

Each month, forecasts of water levels for the next 6 months are released through the Monthly Bulletin of Great Lakes Water Levels. As a new month begins, the actual starting level may be different from the water level that had been forecast during the previous month. Accordingly, the "most probable" forecast, as well as the forecast range is adjusted to reflect the actual starting levels. In some cases, this can result in a significant change in the forecast from on month to the next. See, for example, the difference in the forecast range between the forecast published in April of this year, compared with May (Figure 12). In this case, the NBS in April was very small, despite climatic outlooks that did not indicate particularly wet or dry conditions in April.

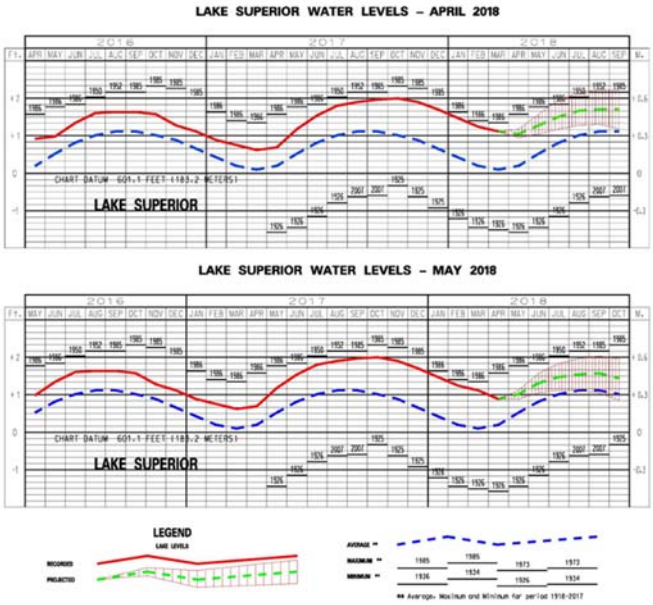

Figure 12. Lake Superior water level forecasts from April (top) and May (bottom) of 2018.

More Information

Like this article, future *Great Lakes Updates* will be included in various editions of the *Monthly Bulletin.* Topics will rotate between Great Lakes hydrology and lake levels and other less technical pieces relevant to the Great Lakes as a whole. February's *Monthly Bulletin* will typically include an annual summary from the prior year. All of our past Update Articles can be read online here:

https://www.lre.usace.army.mil/Missions/GreatLakesInformation/NewsandInformation/GreatLakesUpdateArticles.aspx

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The Detroit District also has a Facebook page which can be found here:

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