Appendix H: Climate Change
For
Chicago Area Waterway Systems (CAWS)
Dredged Material Management Plan (DMMP)

August 2020
Climate Change Appendix

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1.0 Literature Review

USACE is undertaking its climate change preparedness and resilience planning and implementation in consultation with internal and external experts using the best available — and actionable — climate science. As part of this effort, the USACE has developed concise reports summarizing observed and projected climate and hydrological patterns, at a HUC2 watershed scale cited in reputable peer-reviewed literature and authoritative national and regional reports. Trends are characterized in terms of climate threats to USACE business lines. The reports also provide context and linkage to other agency resources for climate resilience planning, such as downscaled climate data for sub-regions, and watershed vulnerability assessment tools.

The USACE literature review report focused on the Great Lakes Region was finalized in April 2015 (USACE, April 2015). The Dredged Material Management Plan (DMMP) encompasses the Calumet River, Chicago River, Cal-Sag Channel and the Chicago Sanitary and Ship Canal (CSSC) and is located in the Great Lakes Region. Figure 1 portrays the 4th National Climate Assessment’s (NCA) reported summary of the observed change in very heavy precipitation for the U.S., defined as the amount of precipitation falling during the heaviest 1% of all daily events. The NCA results indicate that 42% more precipitation is falling in the Great Lakes Region now as compared with the first half of the 20th century, and that the precipitation is concentrated in larger events.

![Figure 1 - Percent changes in precipitation falling in the heaviest 1% of events from 1958 to 2016 for each region (Easterling et al., 2017).](image-url)
The USACE literature review document summarizes and consolidates several studies which have attempted to project future changes in hydrology. Based on a review of four studies, the projected total annual precipitation is expected to have a small increase when compared to the historic record and the precipitation extremes are projected to see a large increase. It is noted that consensus between the studies is low, and although most studies indicate an overall increase in observed average precipitation, there is variation in how these trends manifest both seasonally and geographically. Figure 2, taken from the USACE Climate Change and Hydrology Literature Reviews, summarizes observed and projected trends for various variables reviewed.

![Figure 2 - Great Lakes Region - Summary matrix of observed and projected climate trends and literary consensus. (USACE, 2015)](image)

For the Great Lakes Regions, increase in temperatures have been observed and additional increases in temperature are predicted for the future. In addition, for the Great Lakes Region, “nearly all studies note an upward trend in average temperatures, but generally the observed change is small. Some studies note seasonal differences with possible cooling trends in fall or winter.” There is a strong consensus within the literature that temperatures are projected to continue to increase over the next century.
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Extreme heat wave temperatures are projected to increase by 2 to 5 °C in the Great Lakes Region when compared to the baseline period (2001 – 2004). The projected duration of heat waves is projected to increase by 0 – 2 days per event throughout the region and the projected frequency of heat wave events is projected to increase by 4 – 8 days per year.

Similar to the USACE literature review documents, several studies reviewed as part of the 4th National Climate Assessment indicate that increase in temperatures have been observed and additional increases in temperature are predicted for the future. The 4th NCA states that warm-season temperatures are projected to increase more in the Midwest than any other region of the United States and that by the middle of this century (2036–2065), 1 year out of 10 is projected to have a 5-day period that is an average of 13°F warmer than a comparable period at the end of last century (1976–2005).

Pryor et al. (2009) performed statistical analysis on 20th century rainfall data to investigate for trends across a range of precipitation metrics. They used data from 643 stations scattered across the continental U.S. This study reports an increasing trend of precipitation at stations throughout the Great Lakes Region. It also shows an increase in the number of precipitation days per year and, correspondingly, a decrease in the average precipitation on a precipitation day, i.e. total annual precipitation has gone up due to a larger number of smaller events.

Kunkel et al. (2012) reported that the multi-model mean change in the number of days with precipitation greater than one inch from the nine North American Regional Climate Change Assessment Program (NARCCAP) simulations varies from little or no change in the southeastern and eastern portion of the Midwest region to an over 30% increase in the northern portion of the region by mid-century. The percentage increases in frequency are projected to be larger for more extreme precipitation events (e.g., precipitation rates greater than one inch, two inches, three inches, and four inches). More generally, Schoof et al. (2010) found that, based on downscaled climate projections from ten Global Climate Models (GCMs), intense precipitation events in the Midwest are likely to either continue at their current frequency or increase in frequency, regardless of the sign of the change in total precipitation. Increases in streamflow have been observed and projections for streamflow rates are variable. For the Great Lakes region, trends in low and annual streamflow were variable, with slight streamflow increases observed at some gages but other gages showing no significant changes. “Significant uncertainty exists in projected runoff and streamflow, with some models projecting increases and other decreases. Changes in runoff and streamflow may also vary by season. Projections of water levels in the Great Lakes also have considerable uncertainty, but overall lake levels are expected to drop over the next century.”

The State of Illinois Department of Natural Resources released a report for the Urban Flooding Awareness Act in June 2015 (IDNR, 2015). The report discusses statewide trends associated with changing climate. The following is a discussion which relates temperature changes to precipitation changes from this report.

“There are a number of factors contributing to more precipitation and more heavy rain events in recent decades. First is that temperatures in the U.S. have warmed by about 1.5 to 1.9 degrees (depending on the calculation used) over the last century. Meanwhile, temperatures in Illinois have warmed by about 1.0 degree over the last century. Warmer air has the ability to hold more water vapor. This ability increases by almost 4% with each degree increase. This means that on average storms have slightly more water available for precipitation. It is also possible that the characteristics of storms are changing.

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as the U.S. gets warmer. For example, a longer warm season increased the opportunity for thunderstorms. Additional work in Illinois suggests that the increasingly intense agricultural practices of the Midwest (more acreage and more plants per acre) have elevated summer humidity levels as well (Chagnon, Sandstrom, & Bentley, 2007).

With respect to local climate change in the DMMP project region, the Chicago Metropolitan Agency for Planning (CMAP) has prepared a document titled *Primary Impacts of Climate Change in the Chicago Region* (June 2013), that provides additional information with regards to temperature trends in northeastern Illinois. This document was prepared in cooperation with the University of Illinois, Illinois State Water Survey, Illinois-Indiana Sea Grant, and Midwestern Regional Climate Center.

Based on data collected at Chicago O’Hare Airport, approximately 25 miles outside of the study area, annual trends for minimum, mean and maximum temperature in Chicago have exhibited a slight warming trend since the late 1970’s, refer to Figure 3 below. The trend of warming overnight, low temperatures and increasing daytime maximum temperatures is not only evident in Chicago, but also at other locations in the Midwest (CMAP, 2013).

![Figure 3: Average annual temperature trends for maximum temperature (red), mean temperature (green), and minimum temperature (blue) for Chicago O’Hare. The dots represent the average annual temperature and the black dotted line represents the 11-year centered mean.](image)

Consistent with global projections, climate model studies for Chicago and surrounding regions are in general agreement that it is very likely annual temperatures will increase by mid-century and later. However, the degree of warming can differ substantially from one study to the next. Compiling information from several studies for Chicago and surrounding regions, a majority of studies project annual temperatures to be 5-9°F higher than they are today by the end of the 21st century. Some studies project slightly lower warming of only 2-5°F by the end of the century while some project higher, on the order of 9-13°F. In the near future (2010-2039), Hayhoe et al. (2010) estimates annual temperatures in Chicago may rise by 2-3.5°F and by mid-century (2040-2069) by 2.5-9°F.
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Additional information presenting an analysis of data collected at precipitation gages within or near the DMMP project area is included in the Literature Review section.

Climate changes can have a direct impact on dredging. Increased precipitation and flooding causes higher erosion rates, sediment transport rates, and combined sewer overflows. Dredging will continue to be an important activity in the future to maintain commercial waterways and it is possible that dredging requirements may increase as a result of increased flooding and erosion resulting in increased sedimentation. Changes in water levels also could impact dredging requirements. Higher levels could potentially reduce dredging needs while lower levels could increase the need for dredging. Lake levels would have a direct impact on the Calumet Harbor and River but levels on the Chicago River, CSSC and Cal-Sag channel are all maintained at a specific elevation through the use of lakefront controlling works and downstream sluice gate operations. Table 1 below contains a couple features that may be impacted by climate changes.

Table 1: Climate Risk Register

<table>
<thead>
<tr>
<th>Feature or Measure</th>
<th>Trigger</th>
<th>Hazard</th>
<th>Consequence</th>
<th>Qualitative Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment deposition dredging</td>
<td>Increased precipitation from larger storms</td>
<td>Future increases in flood volumes</td>
<td>Higher erosion rates, increased sediment transport rates, increases in combined sewer overflows. Increases in sediment deposition and frequency and/or depth of dredging</td>
<td>Likely</td>
</tr>
<tr>
<td>Rubble Mound protecting Chicago CDF perimeter</td>
<td>Increased precipitation from larger storms</td>
<td>Higher Lake Michigan levels</td>
<td>Record lake levels may result in need for maintenance/repair of rubble mound to protect against higher stage wave action</td>
<td>Possible</td>
</tr>
</tbody>
</table>

2.0 First Order Statistical Analysis & Nonstationarity Analysis

There are three stream gages in close proximity to the project area which have periods of record well in excess of 30 years. All are found within the Upper Illinois HUC 0712, Upper Illinois which also contains the dredging project area within the DMMP. The gages are 05536290 - Little Calumet River at South Holland, IL, 05536275 – Thorn Creek at Thornton, IL and 05536195 – Little Calumet River at Munster, IN. The drainage area for 05536290 - Little Calumet River at South Holland, IL is 208.0 square miles. The drainage area for 05536275 – Thorn Creek at Thornton, IL is 104.0 square miles. The drainage area for 05536195 – Little Calumet River at Munster, IN is 90.0 square miles.
2.1 Climate Hydrology Assessment Tool

As outlined in ECB No. 2018-14, an investigation of the trends in the annual maximum flow gage data was performed to qualitatively assess impacts of climate change within the watershed using the USACE Climate Hydrology Assessment Tool. Figure 4 below shows the observed, instantaneous peak streamflow obtained from the USGS website for stream gage 05536290 - Little Calumet River at South Holland, IL. The figure depicts a decreasing trend in annual peak streamflow for the period of record with a p-value of 0.412893. Gages that have a p-value smaller than 0.05 (the generally accepted threshold for significance) indicates that the trends are statistically significant. The P-value associated with this gage is well above that threshold indicating an insignificant downward trend in annual peak streamflow.

![Figure 4: Annual Peak Streamflow Time Series, Little Calumet River at South Holland, IL](image)

The p-value is for the linear regression fit drawn; a notable p-value would indicate greater statistical significance. There is not recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a type I error or false positive.

Figure 5 shows the observed, instantaneous peak streamflow obtained from the USGS website for stream gage 05536275 – Thorn Creek at Thornton, IL. The figure depicts an increasing trend in annual peak streamflow for the period of record with a p-value of 0.0601987. Gages that have a p-value smaller than 0.05 (the generally accepted threshold for significance) indicates that the trends are statistically significant. The P-value associated with this gage is slightly above that threshold indicating a moderate upward trend in annual peak streamflow.

![Figure 5: Annual Peak Streamflow Time Series, Thorn Creek at Thornton, IL](image)
Figure 6 shows the observed, instantaneous peak streamflow obtained from the USGS website for stream gage 05536195 – Little Calumet River at Munster, IN. The figure depicts a slight increasing trend in annual peak streamflow for the period of record with a p-value of 0.632205. The P-value associated with this gage is slightly well above that threshold indicating an insignificant upward trend in annual peak streamflow.
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Figure 6 displays the projected annual, maximum monthly trends from the USACE Climate Hydrology Assessment Tool for HUC 0712, Upper Illinois. As expected for this type of qualitative analysis, there is a considerable, but consistent spread in the projected annual maximum monthly flows. This spread is indicative of the uncertainty associated with climate changed hydrology. The trend in the mean projected annual maximum monthly streamflow indicates an increase over time. This increasing trend for the Upper Illinois watershed HUC-4, which encompasses the DMMP study area, is statistically-significant (p-value < 0.0001) and suggests the potential for future increases in flow relative to current conditions.
2.2 Nonstationarity Detection Tool

Stationarity, or the assumption that the statistical characteristics of hydrologic time series data are constant through time, enables the use of well-accepted statistical methods in water resources planning and design in which the definition of future conditions relies primarily on the observed record. However, recent scientific evidence shows that in some locations climate change and human modifications of watersheds are undermining this fundamental assumption, resulting in nonstationarity (Milly et al., 2008, Friedman, et. al, 2016). An assessment of historic gage records was performed to determine if nonstationarity exists within the DMMP watershed by carrying out a nonstationarity detection analysis using the USACE’s Nonstationarity Detection Tool, which uses twelve nonparametric and parametric tests to identify abrupt or smooth changes in distribution, mean, and variance of annual flood time series data. Using the web-based Nonstationarity Detection Tool, the same three stream gages with close proximity to the project area with a period of record of 30 years or more were investigated for nonstationarities. There are no nonstationarities or statistically significant monotonic trends detected in the peak streamflow record observed at stream gage 05536290 - Little Calumet River at South Holland, IL. Refer to Figure 8 and Figure 9 below. There are no nonstationarities or statistically significant monotonic trends detected in the peak streamflow record observed at stream gage, 05536275 – Thorn Creek at Thornton, IL. Refer to Figure 10 and Figure 11 below. There are no nonstationarities or statistically significant monotonic trends detected in the peak streamflow record observed at stream gage 05536195 – Little Calumet River at Munster, IN. Refer to Figure 12 and Figure 13 below.
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Figure 8: Nonstationarity Analysis, Little Calumet River at South Holland, IL
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Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.527.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.548.

What type of trend was detected?
Using parametric statistical methods, no trend was detected.
Using robust parametric statistical methods (Sen’s Slope), no trend was detected.

Figure 9: Trend Analysis, Little Calumet River at South Holland, IL

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.
This gage has a drainage area of 104.5 square miles.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 38 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

**Heatmap - Graphical Representation of Statistical Results**

- Cramer-Von-Mises (CPM)
- Kullback-Leibler (CPM)
- Lempel (CPM)
- Energy Divisive Method
- Lombard Wilcoxon
- Pettit
- Mann-Whitney (CPM)
- Bayesian
- Lombard Mood
- Mood (CPM)
- Smooth Lombard Wilcoxon
- Smooth Lombard Mood

**Legend - Type of Statistically Significant Change being Detected**

- Distribution
- Variance
- Mean
- Smooth

**Mean and Variance Between All Nonstationarities Detected**

<table>
<thead>
<tr>
<th>Segment Mean (CFS)</th>
<th>3K</th>
<th>2K</th>
<th>1K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment Standard Deviation (CFS)</td>
<td>1000</td>
<td>500</td>
<td>0</td>
</tr>
<tr>
<td>Segment Variance (CFS Seared)</td>
<td>1000K</td>
<td>500K</td>
<td>0K</td>
</tr>
</tbody>
</table>

Figure 10: Nonstationarity Analysis, Thorn Creek at Thornton, IL
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Plot of Maximum Annual Flow/Height at Thorn Creek at Thornton, IL

Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.082.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.086.

What type of trend was detected?
Using non-parametric test, no trend was detected.
Using robust non-parametric test (Sen’s Slope), no trend was detected.

Figure 11: Trend Analysis, Thorn Creek at Thornton, IL
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Figure 12: Nonstationarity Analysis, Little Calumet River at Munster, IN

This page has a drainage area of 50.00 square miles.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

The figure presents a nonstationarity analysis for the Little Calumet River at Munster, IN, showing the nonstationarities detected using maximum annual flow/height. The analysis includes various methods such as Cramer-Von-Mises (CPM), Kolmogorov-Smirnov (CPM), LePaps (CPM), Energy Divisive Method, Lombard Wilcoxon, Pettit, Mann-Whitney (CPM), Bayesian, Lombard Mood, Mood (CPM), Smooth Lombard Wilcoxon, and Smooth Lombard Mood.

The heatmap graphically represents the statistical results of the nonstationarity analysis, with different colors indicating the type of statistically significant change detected (i.e., mean, variance, smooth). The legend at the bottom of the heatmap explains these colors.

The mean and variance between all nonstationarities detected are also shown in the figure, with key statistics such as segment mean, segment standard deviation, and segment variance (CFs Sealed).

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity analysis tool as part of their progress in climate preparedness and resilience and making it widely available.
3.0 Vulnerability Assessment Tool

The USACE Vulnerability Assessment Tool was applied for the 0712-Upper Illinois HUC-4 to assess the DMMP study area vulnerability to climate change impacts relative to the other 201 HUC-4 watersheds within the continental United States. The USACE Watershed Climate Vulnerability Assessment (VA) Tool facilitates a screening level, comparative assessment of the vulnerability of a given HUC 04 watershed to the impacts of climate change relative to a maximum of 202 (depending on which business line is specified) HUC04 watersheds within the continental United States (CONUS). Assessments using this tool identify and characterize specific climate threats and sensitivities or vulnerabilities, at least in a relative sense, across regions and business lines. Navigation is the primary business line being assessed as part of this DMMP study.
The Watershed Vulnerability tool uses the Weighted Order Weighted Average (WOWA) method to represent a composite index of how vulnerable (vulnerability score) a given HUC04 watershed is to climate change specific to a given business line by using a set of specific indicator variables which relate to a particular business line. The HUC04 watersheds with the top 20% of WOWA scores are flagged as vulnerable. All vulnerability assessment analyses were performed using the National Standard Settings.

The USACE Climate Vulnerability Assessment Tool makes an assessment for two 30-year epochs centered at 2050 and 2085 to judge future risk due to climate change. These two epochs are selected to be consistent with many other national and international analyses related to climate. The Vulnerability tool assesses climate change vulnerability for a given business line using climate changed hydrology based on a combination of projected climate outputs from the general circulation models (GCM) and representative concentration pathway (RCPs) of greenhouse gas emissions resulting in 100 traces per watershed per time period. The top 50% of the traces is called “wet” and the bottom 50% of traces is called “dry.” Meteorological data projected by the GCMs is translated into runoff using the Variable Infiltration Capacity (VIC) macroscale hydrologic model. The VIC model applied to generate the results used by the Vulnerability Assessment Tool was developed by the U.S. Bureau of Reclamation and is configured to model unregulated basin conditions.

While there is a great deal of uncertainty with the climate changed hydrology given by the vulnerability assessment tool, it does allow a qualitative analysis of watershed-scale vulnerability for USACE business line and for individual contributing indicators to the business lines. Each of the inputs to the vulnerability assessment tool has uncertainty associated with it. The vulnerability tool relies on projected, climate changed hydrology. The uncertainty associated with projected hydrologic data includes error in temporal downscaling, error in spatial downscaling, errors in the hydrologic modeling, errors associated with emissions scenarios, and errors associated with GCMs. Some of the uncertainty associated with the tool can be visualized because the tool separates results for each of the scenarios (wet versus dry) and epochs (2050 versus 2085) combinations rather than presenting a single, aggregate result (USACE, 2014). The analysis also incorporates uncertainty inherent in the level of risk aversion selected (ORness factor) and the importance weights applied. Some users may elect to use a higher level of risk aversion while others may not. The importance weights of the indicator variables used to compute the WOWA (vulnerability) scores are subjective assessments of the expert users on a national basis (in the national standard view) and by local experts if a user-modified analysis is performed. The user should note that the uncertainty with climate changed hydrology projects may be high, but this uncertainty is ameliorated by using all of the available climate information and no prematurely downselecting to a small subset of models.

For the Navigation business line, the results show that the project is relatively vulnerable to climate change generally for the Dry scenarios within the Upper Illinois River HUC-4 region as shown in Figure 14 below, with increasing vulnerability over time for both wetter and dryer future conditions. For the dry scenario there was a +3.09% change and the wet scenario a +3.03% change in the WOWA scores computed for 2050 and 2085 for the HUC-4 Region with a Navigation business line as shown in Figure 15 and Figure 16 below.

The main indicator variables contributing to the dry WOWA scores are 570C 90PERC EXCEEDANCE, monthly runoff which is exceeded 90% of the time, and 700C LOW FLOW REDUCTION, the change in low runoff which is the ratio indicator 570C to 570C in the base period. The WOWA scores for the wet condition for 2050 and 2085 are 70.417 and 72.552, respectively. The main indicator variables
contributing to the wet WOWA scores are 568C FLOOD MAGNIFICATION, the change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time) to 571C in base period, and 570C 90PERC EXCEEDANCE. Additional information about each of these indicator variables and how they are used to determine a WOWA score is described in the Vulnerability Assessment User Manual.

Figure 14: Vulnerability Assessment Tool HUC-4: 0712 Upper Illinois
Figure 15: Vulnerability Score, Dry Scenario HUC-4: 0712 Upper Illinois

Figure 16: Vulnerability Score, Wet Scenario HUC-4: 0712 Upper Illinois
4.0 Conclusions

The Dredged Material Management Plan is specifically a 20-year plan for dredging of Calumet Harbor and the Calumet River with potential for minor dredging along the Cal-Sag channel. The three closest stream gages that were investigated that had long period of records did not show any significant trends. However the literature review revealed upward trends in temperature and precipitation. Precipitation increases can have a direct impact on dredging. Increased precipitation and flooding causes higher erosion rates, sediment transport rates, and combined sewer overflows. USACE Chicago District in cooperation with the Engineer Research and Development Center (ERDC) have concluded that the sediment sources are primarily from stormwater and combined sewer overflows, channel outlets, non-point sources and overland flow. Increases in overall precipitation along with more intense storms would lead to increases in sediment deposition in all of these sources.

Dredging will continue to be an important activity in the future to maintain commercial waterways and it is possible that dredging requirements may increase as a result of increased flooding and erosion resulting in increased sedimentation. Forecasted changes in water levels of Lake Michigan are inconclusive but would also have impacts on dredging requirements in both the Calumet Harbor and Calumet River. Lower levels would reduce navigable depths and could result in increased dredging frequency and depths while higher levels could potentially reduce dredging needs. Although lake levels would have a direct impact on the Calumet Harbor and River, levels on the Chicago River, CSSC and Cal-Sag channel are all maintained at a specific elevation through the use of lakefront controlling works and downstream sluice gate operations and consequently would not be affected by climate changes.
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References


