US Army Corps of Engineers®
St. Paul District

Appendix F: Long-term Hydrometeorological Hazard Assessment

UPPER ST. ANTHONY FALLS LOCK AND DAM

SECTION 216 DISPOSITION STUDY

REVISED DRAFT INTEGRATED DISPOSITION STUDY AND ENVIRONMENTAL ASSESSMENT

June 2025

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1 Purpose

The purpose of this analysis is to assess exposure to dynamic weather-related threats and hazards tied to hydrologic processes. Per the U.S. Army Corps of Engineers (USACE) Engineering Construction Bulletin (ECB) 2018-14 (revised August 2024), this assessment provides qualitative information on how hydrometeorological variables have changed in the observed records and how they may respond to changes in the future. Specifically, this assessment focuses on potential for changing hydrology at Upper St. Anthony Falls (USAF) Lock and Dam.

The integrated disposition study and environmental assessment of USAF Lock and Dam evaluates if USAF Lock and Dam should be deauthorized and if the lands and improvements should be disposed. The USAF Lock was ordered closed to navigation by Section 2010 of the Water Resources Reform and Redevelopment Act of 2014 (WRRDA 2014), but USAF Lock and Dam has not been deauthorized as a federal project.

USAF Lock and Dam provides additional benefits for recreation, hydropower, water supply and upstream erosion protection in the vicinity of the project. These benefits are the result of the presence of the dam and do not create additional operational costs regardless of river condition. A potential future USAF Lock and Dam owner would not benefit financially from these services that the structure passively provides. While USAF Lock and Dam is not authorized for flood risk management, flood mitigation operations of the Tainter gate are implemented during high flows to mitigate the effects of the structure. Although USACE would not require a new owner to operate the Tainter gate, USACE anticipates a new owner would do so unless the lock and dam is modified to make such operations unnecessary. Changes in flow conditions may impact the frequency of flood mitigation operations; therefore, flood mitigation operations are the focus of this analysis.

2 Project Background

The USAF Lock and Dam is located on the right descending bank of the Mississippi River in Minneapolis, Minnesota, at river mile 853.9. It is located in the Hydrologic Unit Code (HUC) 0701 watershed. HUC 0701 lies within the larger Upper Mississippi Region (HUC 07); this is indicated by the purple outline in Figure 2-1. The USAF Lock and Dam is located upstream of Lock and Dam 1 and downstream of the U.S. Geological Survey (USGS) gage at the Highway 610 Bridge in Brooklyn Park, Minnesota (USGS 05288500), as indicated in Figure 2-1.

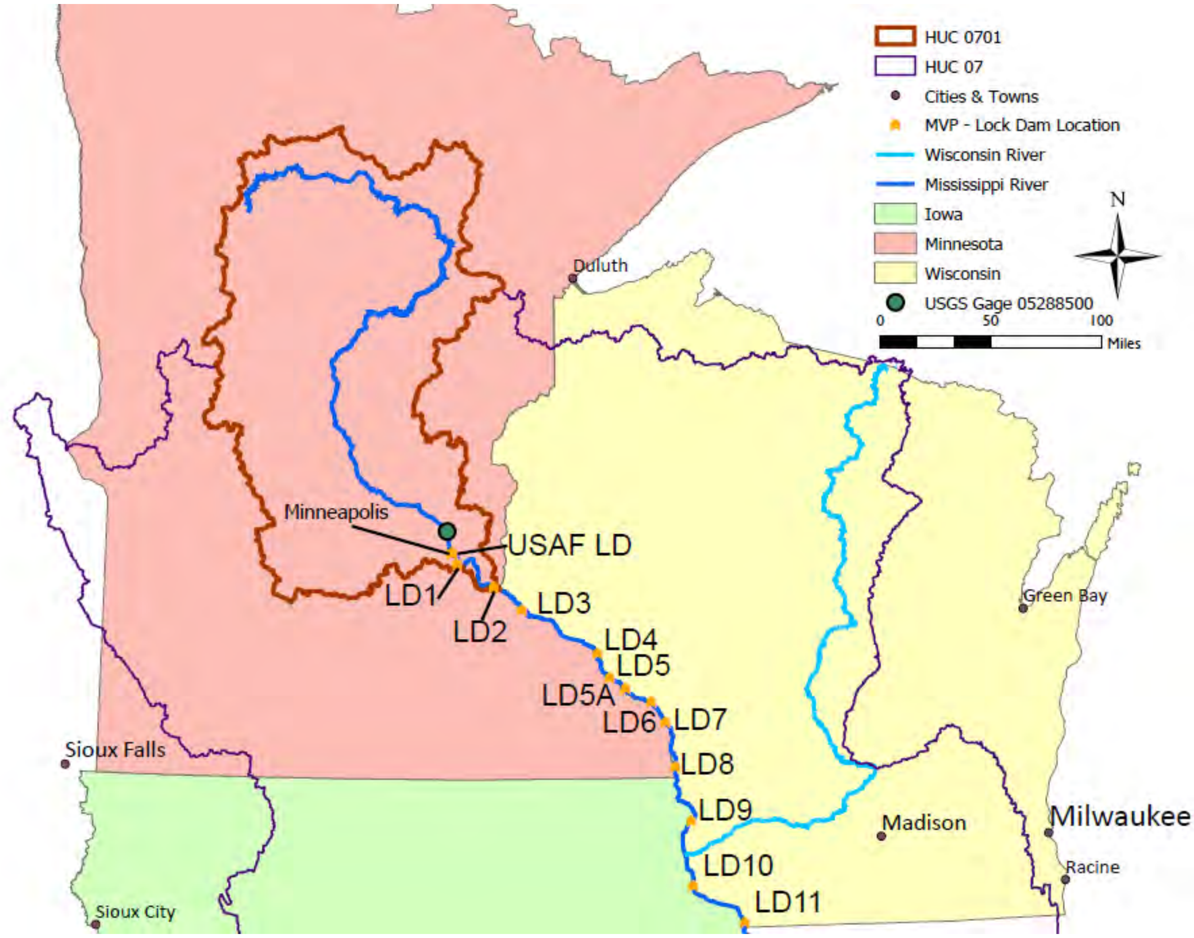

Figure 2-1. Project Location and Watershed Map

3 Literature Review

Temperature and precipitation have been measured since the late 1800s and provide insight into how the hydrometeorological conditions have changed over the past century. Coupled Model Intercomparison Project Phase 5 (CMIP5) meteorological models are used in combination with different radiative forcings to project future temperature and precipitation conditions. Those projected temperature and precipitation results can be transformed to regional and local scales (a process called downscaling) for use as inputs in hydrologic models (Graham, Andreasson, and Carlsson 2007). Long-term continuous streamflow gages have been collecting daily measurements since the late 1800s and can be used to determine trends over time. Global- and national-scale studies attempt to project future changes in hydrology through a combination of CMIP5 models, regional models and macroscale hydrologic models.

Uncertainty is inherent to modeling meteorological conditions due to the large scale of the models and the many variables needed to create future scenarios of temperature and precipitation (USGCRP 2017). Plus, hydrologic models introduce an additional layer of uncertainty. However, these methods represent the best available science to make future scenarios about hydrometeorological variables.

Many researchers use multiple models in their studies to understand how various model assumptions impact results (Gleckler et al., 2008).

3.1 Temperature

Based on observed temperature records, the annual average air temperature between 1986 and 2016 for the Midwest has increased by 1.26°F from the 1901-1960 annual average temperature (USGCRP 2017). Increased temperatures can accelerate snowmelt and lengthen the frost-free season (Carelton and Hsiang 2019; Liu, Goodrick, and Stanturf 2013; Woodward, Perkins, and Brown 2010). Many studies indicate a change in the seasonality in the region marked by increasing winter temperatures and early spring melt (Schwartz, Ault, and Betancourt 2013; Wang et al. 2009; Wolter et al. 2015; Westby, Lee, and Black 2013).

In Minnesota, winter has warmed 13 times faster than summer and nights have warmed 55% faster than days since 1970. The frequencies of -35°F readings in northern Minnesota and -25°F readings in the south have fallen by up to 90%. The minimum temperature for Minnesota during the winter months of December-February has increased 0.49°F per decade since the 1890s (MN DNR 2019). Specifically, in the Twin Cities, annual average temperatures have warmed by 3.2°F from 1951-2012. The frost-free season (growing season) lengthened by 16 days between 1951 and 2012. Most of this change has been due to an earlier spring thaw (GLISA 2019).

Although conditions will vary from year to year, in Minnesota, observed increases in temperature are projected to continue throughout the 21st century. Future scenarios for the Midwest show a statistically significant increase in both annual average temperature and the number extreme heat days over the next century (Vavrus and Behnke 2014). There is a high degree of uncertainty associated with temperature estimates in large part due to modeling complexity, the natural variability of temperature, and radiation forcing scenario. Regardless of future scenario, unprecedented warming is projected for Minnesota by the end of the 21st century (Runkle et al. 2017).

3.2 Precipitation

On a national scale, average annual precipitation has increased approximately 4% over the 1901-2015 period (USGCRP 2017). Average annual precipitation in the Midwest region has increased by 5% to 15% from the first half of the last century (1901-1960) as compared to present day (1986-2015). The amount of rain falling in extreme rain events (1% Annual Exceedance Probability Storm Events) has increased by 42% from 1958 to 2016 (USGCRP 2018). According to the Minnesota Department of Natural Resources (MN DNR), on average, Minnesota became 3.4 inches wetter between 1895 and 2017 (MN DNR 2019). Between 1895 and 2014, the wettest five year period was 1982-1986 (Runkle et al. 2017). Not only is Minnesota receiving more precipitation, but high-intensity 1-inch and 3-inch rains have become more common. The volume of the heaviest annual rainfall has increased (MN DNR 2019; Runkle et al. 2017).

In Minneapolis and St. Paul, the magnitude and frequency of precipitation has increased at a rate similar to the rest of the state. Annual precipitation increased by 5.5 inches in the Twin Cities from 1951 to 2012. Most of the increases in precipitation are occurring in the fall and spring. The number of heavy precipitation days (precipitation > 1% Annual Exceedance Probability Storm Event) has increased 58.3%, from 36 between 1951 and 1980 to 57 between 1981 and 2010 (GLISA 2019).

Future scenarios indicate that winter and spring precipitation in the Midwest could increase by up to 30% by the end of the century. It is notable that the largest observed springtime increases in the continental U.S. are projected to occur in Minnesota (Runkle et al. 2017). The MN DNR analysis, based on data collected by the National Centers for Environmental Information (NCEI), also indicates that annual average precipitation in Minnesota is projected to increase, with increases most likely occurring in the winter and spring (MN DNR 2019; NCEI 2020). Since winter and spring precipitation are important to flood risk, future increases in precipitation are important for planning. Precipitation increases of 10-15% are projected in winter and spring for HUC 07 from 2070-2099 relative to 1986-2015. However, in the summer and fall, future precipitation amounts are not expected to significantly change. A northward shift in the rain-snow transition zone in the central and eastern U.S. is projected by end of the 21st century, causing large areas that are currently snow-dominated in the cold season to be rainfall-dominated (USGCRP 2017; Ning and Bradley 2015).

3.3 Hydrology

Observed hydrologic trends are strongly influenced by precipitation, temperature and other factors, including land use and land cover in a region, groundwater dynamics, drainage patterns, channel geomorphology and regulation. In the Upper Mississippi Region, multiple studies have identified increasing trends in the observed annual average streamflow (Novotny and Stefan 2007; Mauget 2004; Small, Islam, and Vogel 2006) and in the observed annual mean/median baseflow (Juckem et al. 2008; Xu et al. 2013). Seasonally, the studies have reported increasing annual minimum 7-day low flows in the fall (Small, Islam, and Vogel 2006) and annual average 7-day low flows in the fall and winter (Novotny and Stefan 2007). Annual peaks have increased in the spring and summer (Novotny and Stefan 2007). There is little to no consensus in the literature regarding changes in future streamflow in the Upper Mississippi Region.

3.4 Summary

Within the literature reviewed, there is strong evidence through consensus that temperature, precipitation and streamflow have increased over the observed period of record within the Upper Mississippi Region HUC 07. Future conditions show strong consensus on increases in future temperature and moderate consensus on increases in precipitation. There is little to no consensus related to trends in future streamflow. The 2015 USACE Civil Works Technical Report CWTS-2015-13 provides a visual summary of the trends in observed and future hydrometeorological variables; this is presented in Figure 3-1 below (USACE 2015).

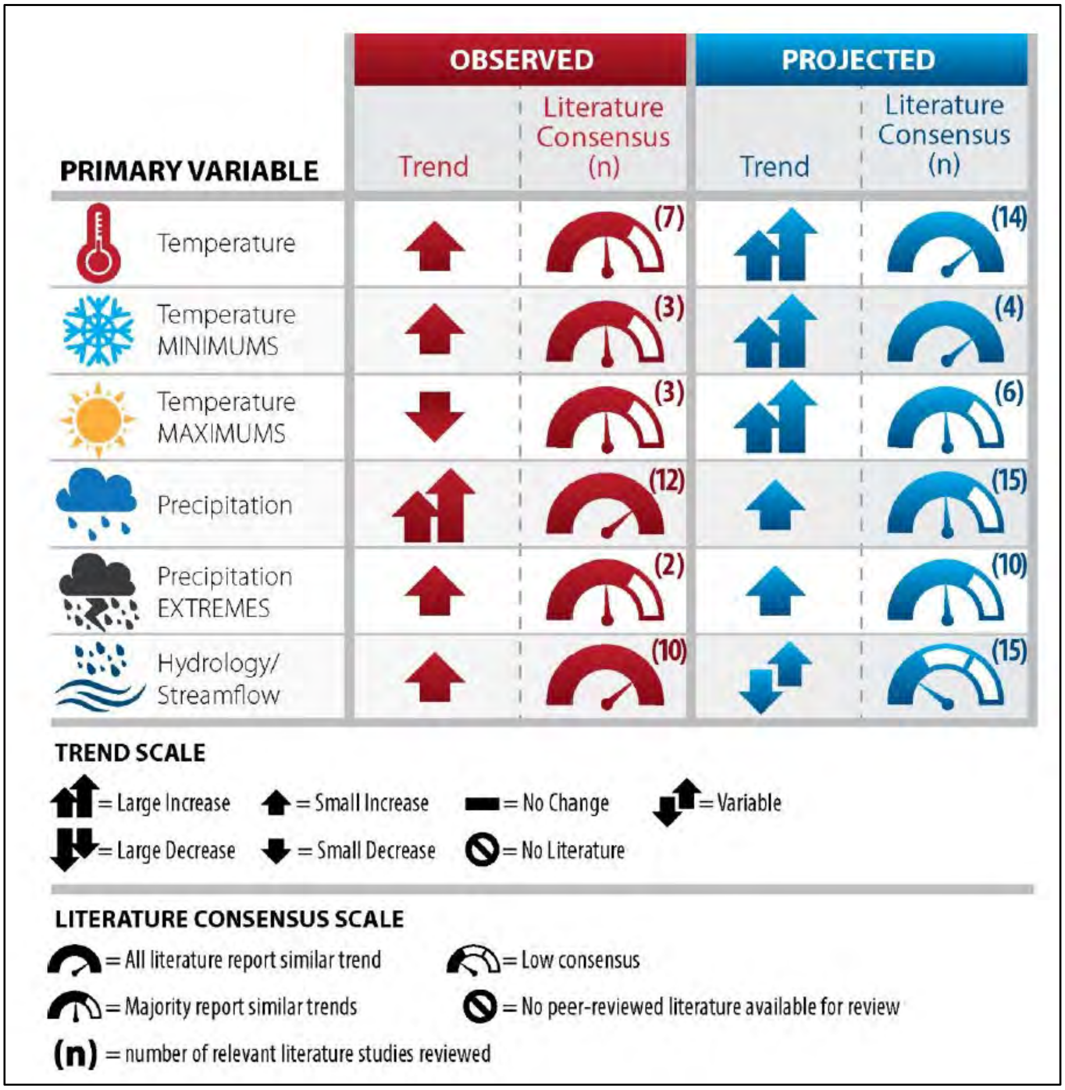

Figure 3-1. Summary matrix for the Upper Mississippi River Region HUC 07

4 Nonstationarity Detection and Trend Analysis

Many traditional hydrologic analyses assume hydrologic timeseries are stationary in time. The assumption can be tested using the techniques in the USACE Engineer Technical Letter (ETL) 1100-2-3, Guidance for Detection of Nonstationarities (2017). Stationarity is the assumption that the statistical characteristics of hydrologic time series data are constant through time. It implies that natural systems fluctuate within an unchanging range and that a given variable — for example, annual peak flow — is assumed to be relatively unchanging in time. Stationarity enables the use of well-accepted statistical methods in water resources planning and design in which the characterization of future conditions relies primarily on the observed record (USACE 2017).

Under USACE (2024) guidance, the stationarity of records is assessed by applying 12 statistical tests to an observed record. Ten of these tests look for an abrupt shift, while two smooth tests look for a gradual change over time. USACE has developed the Nonstationarity Detection (NSD) Tool now called the Time Series Toolbox (TST) to support these analyses (USACE 2025).

In addition to requiring the application of tests to evaluate records for nonstationarities, ECB 2018-14 requires that hydrometeorological records relevant to the project area and purpose be analyzed for the presence of trends (USACE 2024). The TST allows the user to evaluate the datasets of interest for monotonic trends using the Spearman Test and the Mann-Kendall Test. Monotonic trends represent consistent increases or decreases in a variable over the period of record. Unlike linear trends, for monotonic trends, the change over time does not have to be defined by a straight line. When evaluating datasets for the presence of linear trends or applying the selected monotonic trend tests, p-values below 0.05 provide a reasonable basis for statistical significance and allow the user to assume that some variable (outside of randomness) is causing a change.

4.1 Mississippi River at Highway 610 in Brooklyn Park, Minnesota (USGS Gage 05288500)

USGS gage 05288500 has a period of record extending from 1931 to present and is located at Highway 610 in Brooklyn Park, Minnesota. This gage location was previously published as the USGS gage near Anoka, Minnesota. It captures flows from 19,100 square miles of drainage area. The USGS water year summary (Figure 4-1) states that flows are slightly regulated by the six reservoirs in the headwaters of the Upper Mississippi River. However, based on previous analysis, it is determined that the effects of the headwater reservoirs on peak flows are negligible at USGS gage 05288500 (USACE 2018).

05288500 MISSISSIPPI RIVER AT HWY 610 IN BROOKLYN PARK, MN

LOCATION - Lat 45°07'36", long 93°17'48" referenced to North American Datum of 1927, in SW 1/4 sec.12, T.119 N., R.21 W., Hennepin County, MN, Hydrologic Unit 07010206, on right bank 0.27 mi downstream from Coon Creek, 1.3 mi downstream from Coon Rapids dam at Coon Rapids, 6.5 mi downstream from Anoka, at downstream side of Hwy 610 bridge, and at mile 864.8 upstream from Ohio River.

DRAINAGE AREA - 19,100 mi^2.

SURFACE-WATER RECORDS

PERIOD OF RECORD - June 1931 to current year. Prior to October 1931 published as "at Coon Rapids, near Anoka."

GAGE - Water-stage recorder. Datum of gage is 804.739 ft above sea level (NAVD 88). Prior to June 14, 1932, at site 1.2 mi upstream at different datum.

REMARKS - Flow slightly regulated by six reservoirs on headwaters; total usable capacity, 1,640,600 acre-ft. Diurnal regulation caused by Coon Rapids dam 1.3 mi. above station.

Records good except those for estimated days, which are poor.

EXTREMES FOR PERIOD OF RECORD - Minimum discharge, 529 ft^3/s, Aug. 29, 1976, due in part to regulation.

Figure 4-1. USGS Gage Summary 05288500

4.1.1 Annual Peak Streamflow

During high flow conditions, the gates at USAF Lock and Dam are operated to mitigate the effects of the structure on upstream water surface elevation, preventing upstream flood damages in the vicinity of the project. Consequently, operational costs increase with increases in the frequency of occurrence of high flow conditions. According to the St. Anthony Falls Water Control Manual, if forecasted flows at USAF, as measured by the USGS gage 05288500, are expected to exceed 52,000 cfs, the Tainter gate at

USAF should be opened to pass flow (UASCE 2004). Peak streamflow can be used to represent future trends in the need for flood operations at USAF Lock and Dam and is thus the primary focus of this assessment.

The observed data at USGS gage 05288500 shows insufficient statistical evidence of a linear trend in the annual peak streamflow record (p-value = 0.13 > 0.05) from 1931-2014and similarly no evidence of monotonic trends across the period of record (1931-2019). As shown in Figure 4-2, peak flows have exceeded 52,000 cfs six times in the 89-year period of record. Exceedances are distributed throughout the period of record and are not concentrated within the most recent portion of the period of record.

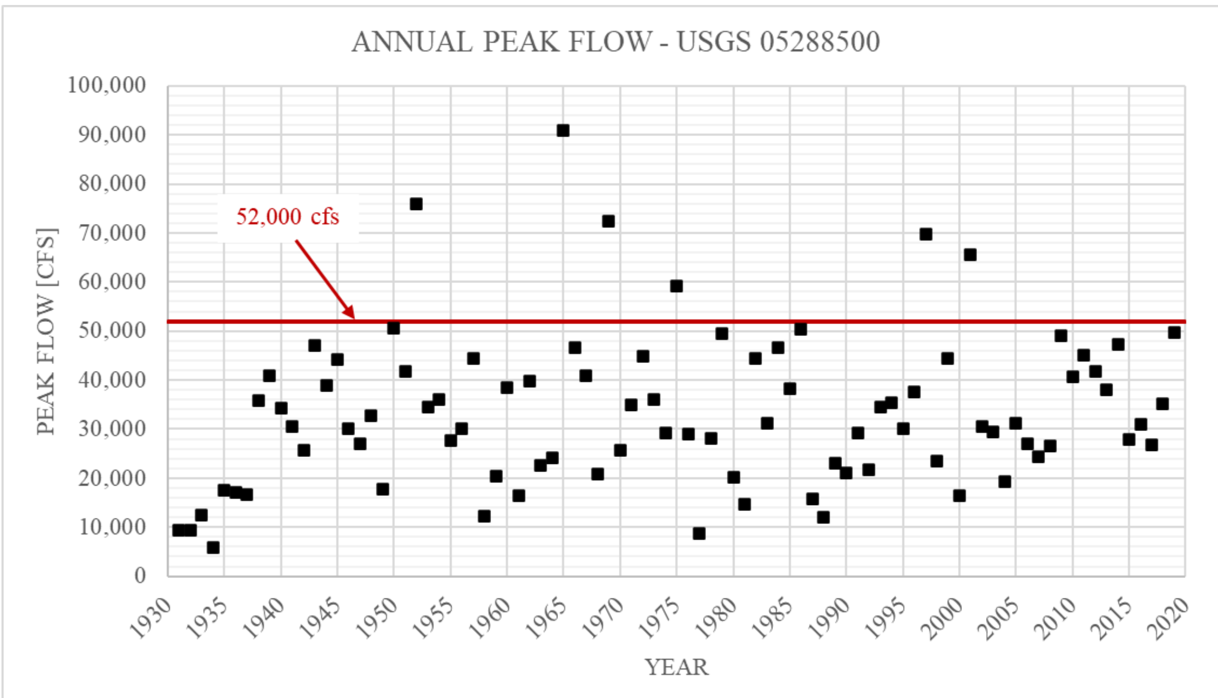

Figure 4-2. USGS Gage 05288500 — Annual Instantaneous Peak Flow: 1931-2019

In the USACE TST tool, USGS gage 05288500 has strong evidence of a nonstationarity at water year 1937 (see Figure 4-3). A strong nonstationarity is one that demonstrates a degree of consensus, robustness and a significant increase or decrease in the sample mean and/or variance. The 1937 nonstationarity is identified by multiple tests targeted at identifying a change in the overall statistical distribution (see blue bars in Figure 4-3), indicating consensus. The 1937 nonstationarity can be considered robust because tests targeted at identifying nonstationarities in different statistical properties indicate a change in overall distribution (blue bars), mean (red bar) and variance (orange bar) in Figure 4-3. The magnitude of the mean annual peak flow almost tripled from 12,600 cfs between 1931 and 1936 to 35,200 cfs between 1938 and 2019.

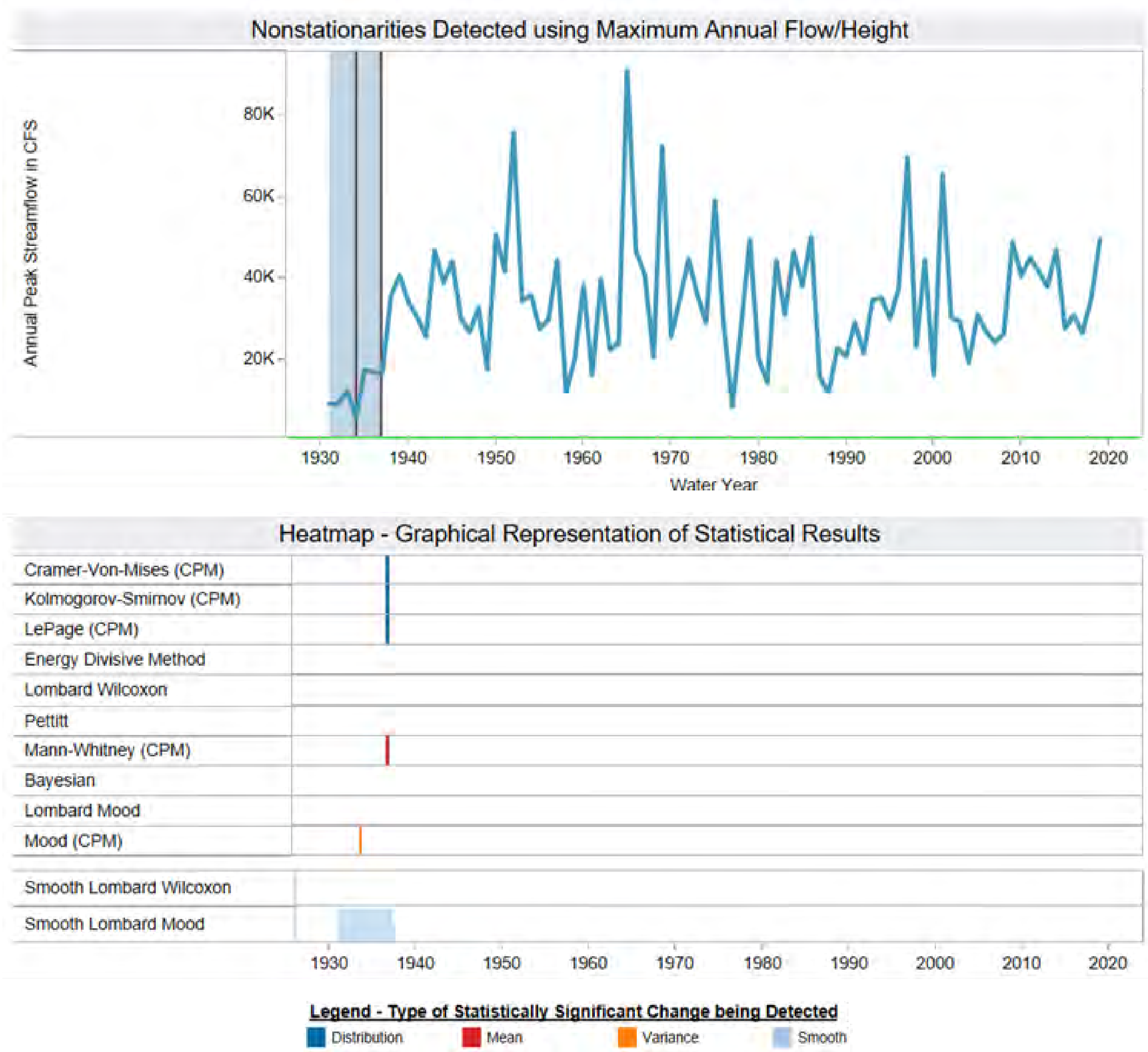

Figure 4-3. Nonstationarity Results for USGS Gage 05288500: 1931-2019

A strong nonstationarity indicates that it could be beneficial to analyze the data as two subsamples. Analyzing the subset of record from 1938-2019 resulted in no statistically significant monotonic trends nor additional nonstationarities. The subset from 1931-1938 does not have enough data to be reasonably analyzed.

These analyses indicate no trends across both the full period of record (1931-2019) and the subset from 1938-2019. One strong nonstationarity was identified within the annual peak streamflow record in 1937. In the Midwest, the 1930s are considered the Dust Bowl, a time of severe drought (Heim 2018); therefore, it is not surprising for a nonstationarity to be detected in 1937. The severe drought decreases the average peak flow from 1931-1937 in comparison to the average peak flow from 1938-2019.

5 Future Hydrology and Vulnerability

To understand potential future conditions, USACE developed several tools to project future streamflow and assess vulnerability to changing conditions at a regional scale up to water year 2099. These tools are used to investigate projected changes to basin hydrology. HUC 0701, the Mississippi Headwaters area shown in Figure 2-1, encompasses USAF Lock and Dam and was used for this assessment.

5.1 Comprehensive Hydrology Assessment

Version 1.0 of the Comprehensive Hydrology Assessment Tool (CHAT) was used to investigate potential future trends in streamflow for the Mississippi Headwaters (HUC 0701) up to water year 2099. Hydrologic model outputs are generated using meteorological inputs derived based on 93 different combinations radiative forcings and CMIP5 models (USACE 2023). As expected, there is considerable variability in the future annual maximum monthly flows for the Mississippi Headwaters Basin (HUC 0701) across the 93 future scenarios. This is shown by the yellow shading in Figure 5-1. This spread is indicative of the high degree of uncertainty associated with future hydrology.

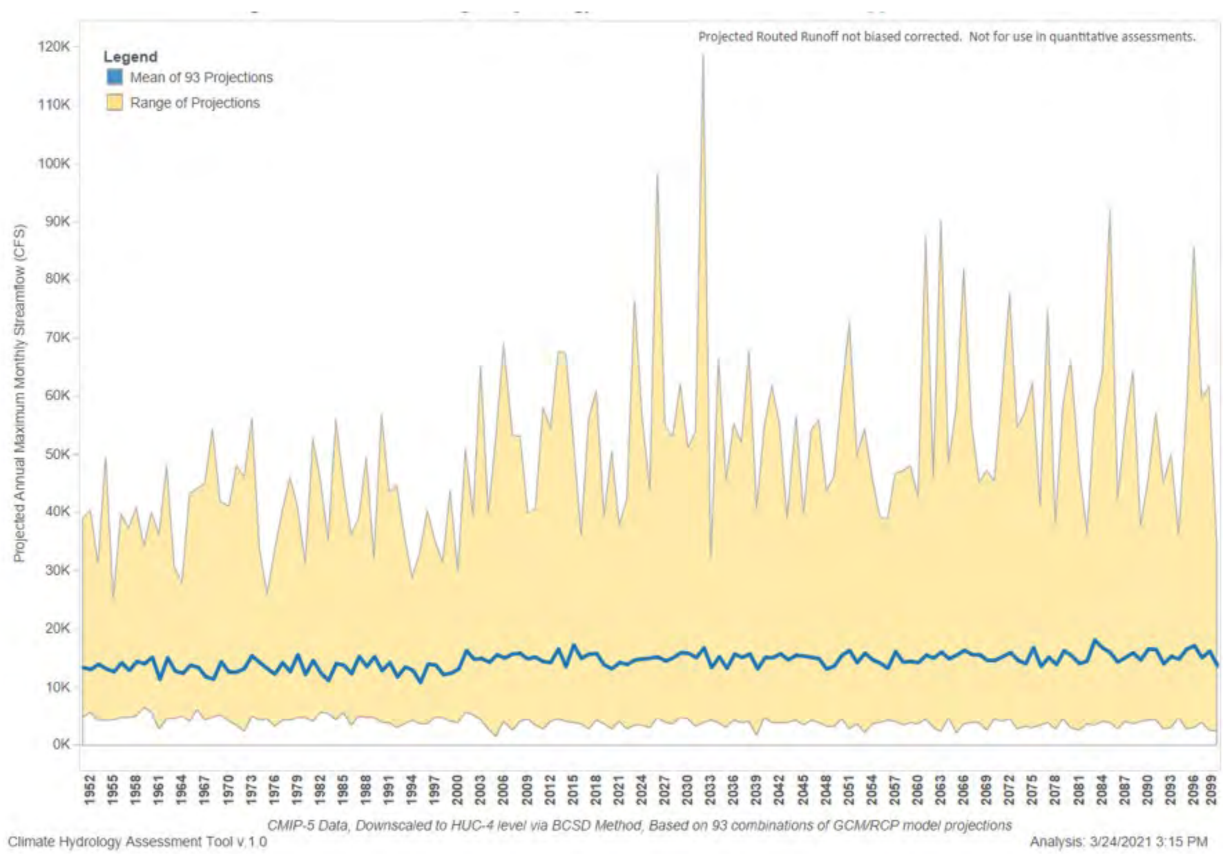

Figure 5-1. Modeled Annual Maximum Monthly Streamflow in HUC 0701

For the Mississippi Headwaters (HUC 0701), there is no statistically significant linear trend for the mean of future annual maximum monthly streamflow between 2000 and 2099 (p-value = 0.09>0.05; dashed blue line shown in Figure 5-2). Therefore, neither the future hydrology data nor the observed peak flow data investigated on the mainstem of the Mississippi River at the Highway 610 Bridge downstream of Anoka, Minnesota, have linear trends.

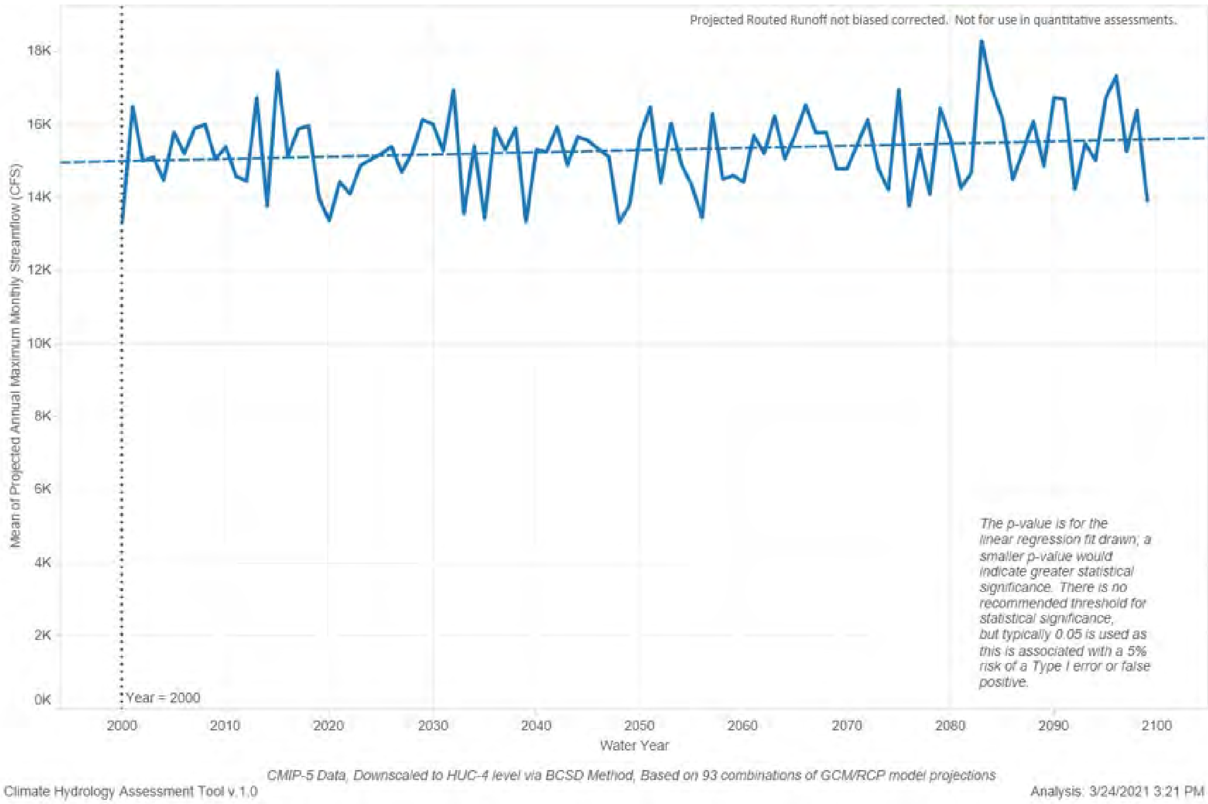

Figure 5-2. Trends in Modeled Annual Maximum Monthly Streamflow in HUC 0701

5.2 Vulnerability Assessment

The USACE Vulnerability Assessment (VA) Tool completes a screening-level assessment of vulnerability by comparing a selected watershed to all 4-digit HUC watersheds in the continental U.S. This tool is used to assess the relative vulnerability of a specific USACE business line within a watershed to changing conditions. Vulnerability is measured using the Weighted Order-Weighted Average (WOWA) method to compute a composite vulnerability score for each business line, time period (2050 or 2085 30-year epoch), and scenario (wet or dry). Each WOWA score is based on a set of standardized indicator variables which reflect stressors related to hydrometeorological conditions, demographic changes, ecological changes, and other factors (USACE 2016).

For this study, the Flood Risk Reduction business line is analyzed with the tool's default National Standard Settings. Indicators used to compute the Flood Risk Reduction WOWA score include the acres of urban area within the 500-year floodplain, the coefficient of variation in cumulative annual flow, runoff elasticity (ratio of streamflow runoff change to precipitation change), and two indicators of flood magnification (indicator of how much high flows are projected to change over time), one of which includes contributions from upstream watersheds, while the other focuses only on the change in flood frequency within the watershed of interest. Figure 5-3 and Table 5-1 display the vulnerability scores for the Mississippi Headwaters (HUC 0701) watershed for the Flood Risk Reduction business line. The Mississippi Headwaters is considered vulnerable in both the wet and dry scenarios in 2050 and in the dry scenario for 2085. Therefore, the Mississippi Headwaters ranks in the top 20% of watersheds in the U.S. with respect to Flood Risk Reduction vulnerabilities for three of the four scenarios considered by the tool. For the wet scenarios, the dominant indicator contributing 48% to the Mississippi Headwaters' vulnerability score is Flood Magnification. For the dry scenarios, the dominant indicator is Runoff Elasticity, contributing 43% to 44% of the score.

Table 5-1. HUC 4 Watershed Flood Risk Reduction Vulnerability Scores (WOWA) for HUC 0701

Year	2050	2050	2085	2085
Scenario	**Wet**	**Dry**	**Wet**	**Dry**
Mississippi Headwaters (0701)	58.14	51.85	58.37	52.90

To provide absolute context to the watersheds' vulnerabilities, cumulative flood magnification is projected to be above one for the Mississippi Headwaters' wet scenarios. Watersheds with flood magnification above one should anticipate higher flood flows in the future. Within the VA tool, flood flows are defined as the monthly flow magnitude that is exceeded 10% of the time (USACE 2016). At USAF Lock and Dam, the magnitude of the flow exceeded 10% of the time is less than 20,000 cfs. Therefore, while flows in excess of 20,000 cfs are expected increase over time, this will not necessarily require more frequent emergency operation of the Tainter gate. For the Mississippi Headwaters dry scenarios, the ratio of runoff change to precipitation change (elasticity) is expected to increase over time. For the dry scenarios, runoff elasticity is estimated to be 2.5 and 2.8 for 2050 and 2085, respectively. This means that for every 1% monthly increase in precipitation, runoff will increase by 2.5% and 2.8%, respectively.

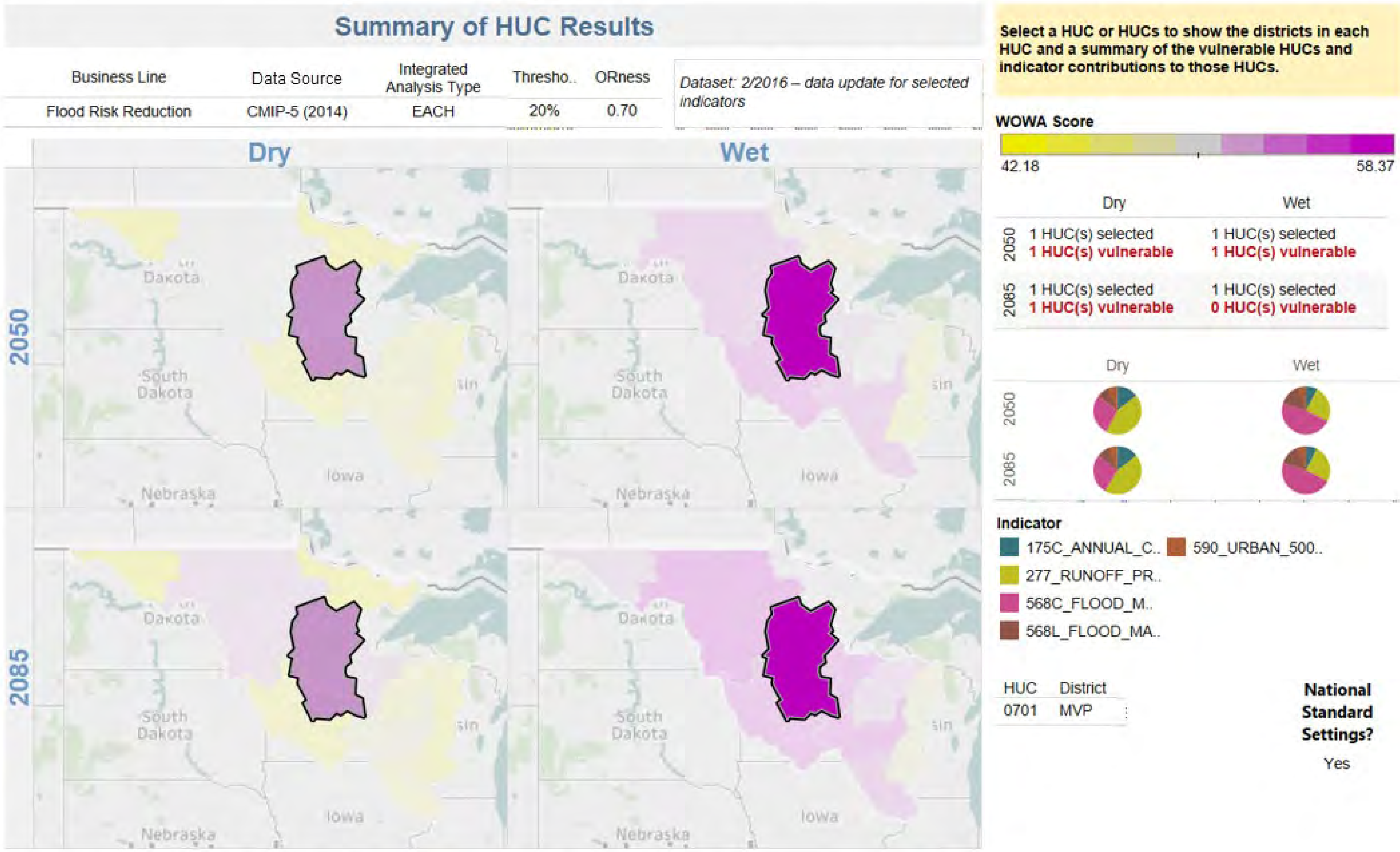

Figure 5-3. Future Vulnerability for Flood Risk Reduction in HUC 0701

6 Conclusion and Residual Risk

USAF Lock and Dam were originally authorized for navigation; however, due to the closure of the lock in 2015, USAF Lock and Dam can no longer serve the originally authorized purpose. While not authorized for flood risk management, emergency lock operations as part of the authorized navigation purpose are allowed during high flow conditions. If there are more frequent extreme events in the future, the need to open the gates would occur more frequently and result in increased operations and maintenance costs.

From the literature reviewed, warmer and wetter conditions are expected in the future. However, the literature did not contain much consistency on how the hydrology within the project area will change. Analysis of future annual maximum monthly streamflow data produced results consistent with the literature review findings (i.e., no statistically significant trends). While the vulnerability assessment indicates that Flood Risk Reduction in the Mississippi Headwaters (HUC 0701) is more vulnerable to the future changes relative to other watersheds in the continental U.S., this vulnerability is based on increasing flood flows (i.e., the monthly flow exceeded 10% of the time) and not the peak flows that require emergency operation.

Observed annual peak streamflow data from 1931 to 2019 was reviewed to support qualitative statements characterizing the potential future risks to USAF Lock and Dam. Neither the trend nor nonstationarity analysis indicated that the peak flow regime is changing; however, a nonstationarity was identified in water year 1937. Table 6-1 indicates potential residual risks along with a qualitative rating of how likely those residual risks are to occur.

Table 6-1. Residual Risks to Project Features: Phase III

Project Feature	Trigger	Hazard	Harm	Qualitative Likelihood Rating	Justification for Rating
Tainter Gate Operation	Projected increases in heavy precipitation events	Future flow may be larger than present, and floods may occur more frequently	Flood waters may require more frequent operation of the Tainter gate which will incur operation and maintenance costs	Low	Observed and projected precipitation data show increase over time; however, observed and projected hydrology does not show evidence of increasing flows, suggesting other variables are mitigating the impact of the flood

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