Appendix A: Hydrology and Hydraulics

Mississippi River, Dubuque County, Iowa
CAP Section 14 Emergency Streambank Protection

Dubuque Forced Sewer Main

Doc Version: Final Feasibility Report
July 2021

Table of Contents

1. HYDROLOGIC AND HYDRAULIC CONDITIONS A-1
2. VELOCITY AND DEPTH PROFILES A-1
3. FLOW FREQUENCY A-3
4. RIPRAP A-3
5. 50% EXCEEDANCE DURATION ELEVATION A-4
6. FLOODPLAIN IMPACT ANALYSIS A-4
7. QUALITATIVE ASSESSMENT OF CLIMATE CHANGE IMPACTS A-4
8. REFERENCES A-21

FIGURES

Figure A-1. Approximated Velocities (ft/sec) Near Project Location A-1

Figure A-2. Depth (ft) Grid Near Project Location A-2

Figure A-3. CHANLPRO Input and Output A-3

Figure A-4. Flowchart for Incorporating Climate Change Impacts to an Inland Hydrologic Analysis A-5

Figure A-5. Annual Temperature Anomalies for the Midwest Region from the CRUTEM3 Data Set A-6

Figure A-6. Linear trends in Annual Precipitation, 1895 – 2009, Percent Change Per Century A-7

Figure A-7. Summary and Literature Consensus of Observed and Projected Trends in Important Meteorologic Variables Potentially Impacted by Climate Change A-8

Figure A-8. Project Area and HUC 4 Locations A-9

Figure A-9. Increasing Trend in Observed Annual Peak Instantaneous Streamflow for Mississippi River at Mcgregor, IA A-11

Figure A-10. Increasing Trend in Observed Annual Peak Instantaneous Streamflow for Mississippi River at Clinton, IA A-12

Figure A-11. Projected Annual Maximum Monthly Streamflow for the Mississippi River at Mcgregor, IA A-13

Figure A-12. Projected Annual Maximum Monthly Streamflow for the Mississippi River at Clinton, IA A-14

Figure A-13. Mean Projected Annual Maximum Monthly Streamflow for the Mississippi River at Mcgregor, IA A-15

Figure A-14. Mean Projected Annual Maximum Monthly Streamflow for the Mississippi River at Clinton, IA A-16

Figure A-15. Projected Vulnerability for the Upper Mississippi with Respect to Flood Risk Reduction A-18

TABLES

Table A-1. Velocity at Cross-section 578.02 for Different Flow Frequencies from UMRSFFS ... A-2

Table A-2. Discharge-Frequency Relationships for the Mississippi River near Green Valley, IL A-3

Table A-3. Projected Vulnerability with respect to Flood Risk Reduction A-19

Table A-4. Comparison of Different Indicators for the Upper Mississippi HUC-0706 .... A-19

Table A-5. Comparison of Different Indicators for the Upper Mississippi HUC-0708 .... A-20

1. HYDROLOGIC AND HYDRAULIC CONDITIONS

Previous modeling efforts were utilized for hydraulic analysis of the Section 14 Dubuque Forced Sewer Main Project. The Mississippi River CWMS Lock and Dam 10 to Lock and Dam 22 hydraulic modeling effort was completed in 2018 (USACE 2018). In 2019, Rock Island District applied discharges from the 2004 Upper Mississippi River System Flow Frequency Study (UMRSFFS) to the CWMS model geometry, producing updated hydraulic profiles for each annual chance of exceedance event. (USACE, 2004).

2. VELOCITY AND DEPTH PROFILES

Figure A-1 shows the approximate velocities for 100-year unsteady flow simulation near the project location. Table A-1 shows main channel and right overbank velocities for various flow frequencies from UMRSFFS. Table A-1 indicates that the flow velocity near the project area increases as discharge increases.

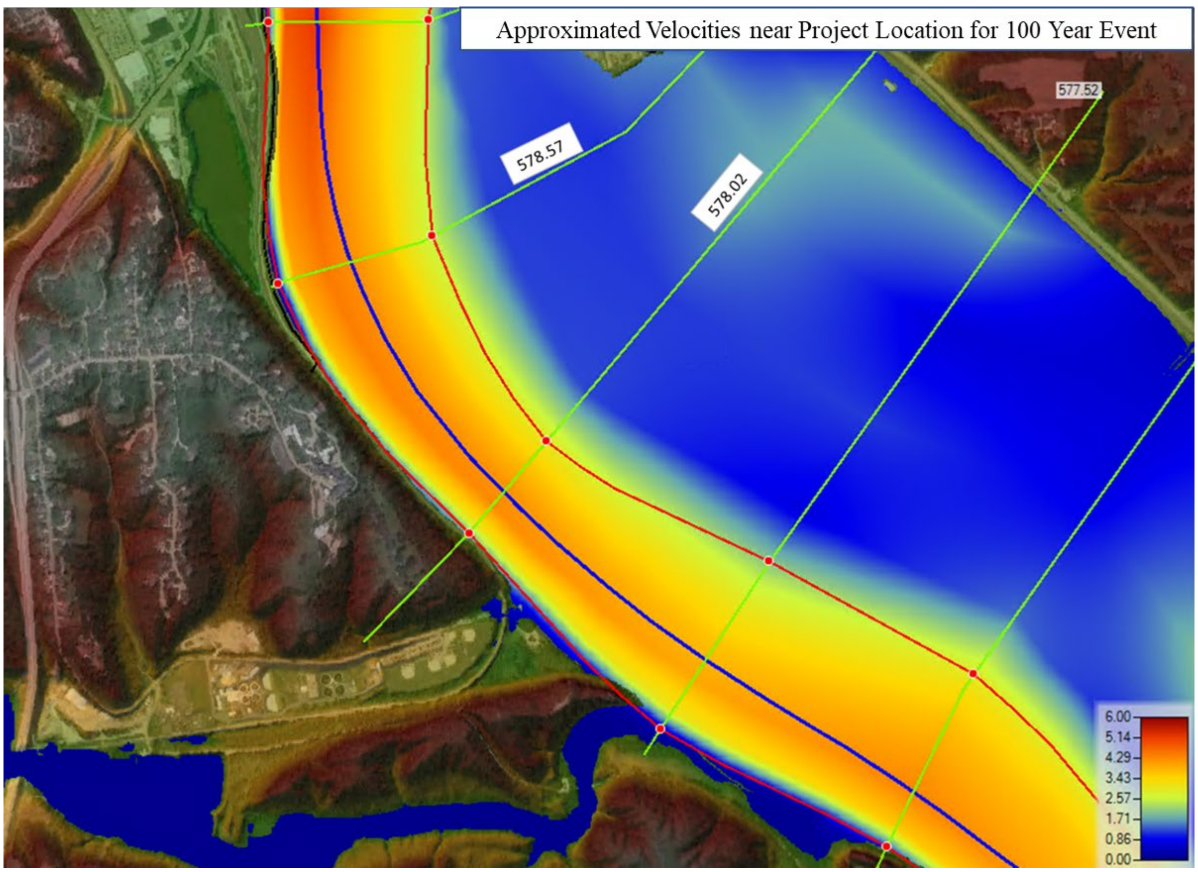

Figure A-1: Approximated Velocities (ft/sec) Near Project Location

Table A-1: Velocity at Cross-section 578.02 for Different Flow Frequencies from UMRSFFS

Frequency	Channel Velocity (ft/sec)	Right Overbank Velocity (ft/sec)
0.5 ACE (2 year)	3.21	0.20
0.2 ACE (5 year)	3.42	0.46
0.1 ACE (10 year)	3.59	0.56
0.04 ACE (25 year)	3.78	0.66
0.02 ACE (50 year)	3.90	0.72
0.01 ACE (100 year)	4.02	0.79
0.005 ACE (200 year)	4.14	0.82
0.002 ACE (500 year)	**4.29**	**0.88**

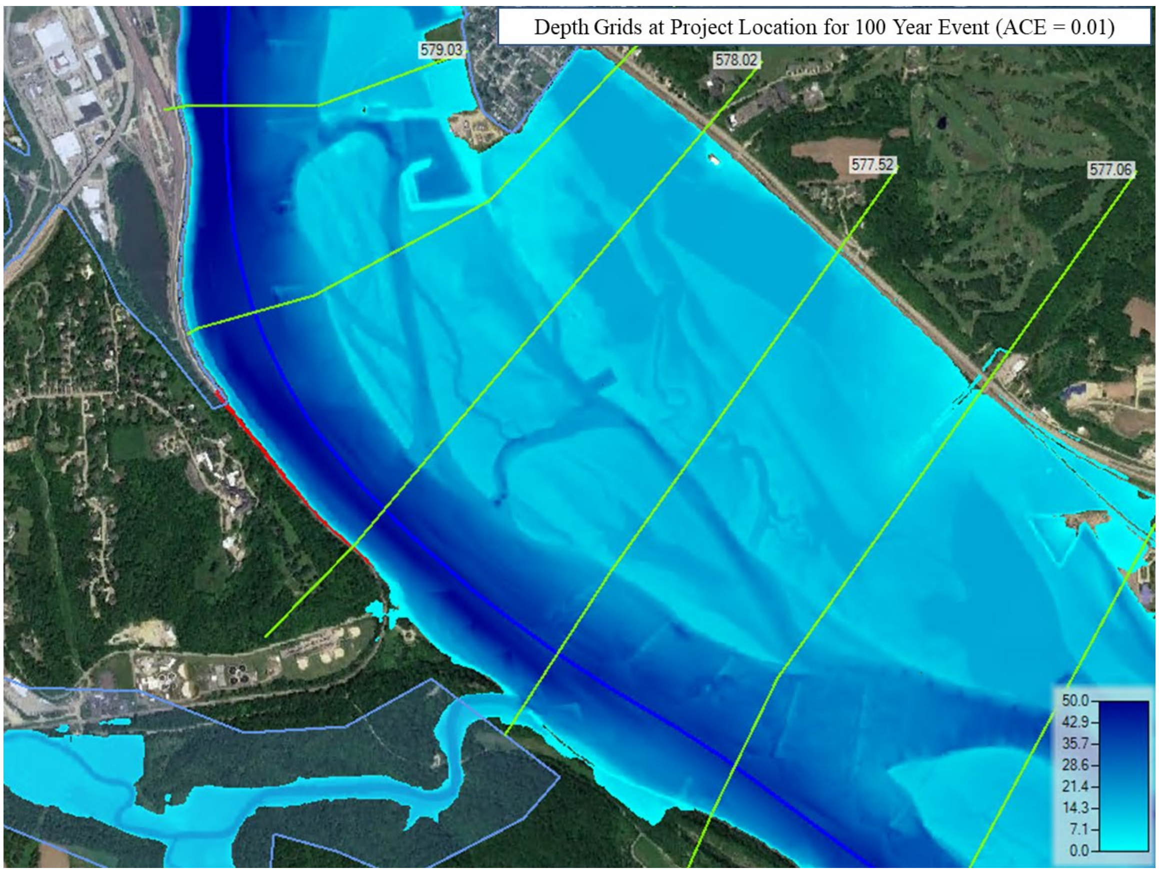

Figure A-1: Depth (ft) Grid Near Project Location

Figure A-2 shows the depth grids for 100-year unsteady flow simulation near the project location. Velocity and depth (thalweg) grids indicate that the project area is more susceptible for erosion during high flow events. Sediments are eroded from the outside (convex) side of the bend and deposited on the inside (concave) side. At a bent of meandering river, natural erosion continues until the flow encounter a protection layer (rocks or floodwall) or a natural equilibrium is formed. These conclusions are based on basic river geomorphology only.

3. FLOW FREQUENCY

Discharge-frequency relationships for the Mississippi River near Dubuque, IA (at River Mile 578.6) are shown in Table A-2. Flow frequency relationships were obtained from UMRSFFS.

Table A-1: Discharge-Frequency Relationships for the Mississippi River near Green Valley, IL (UMRSFFS)

Annual Chance Exceedance (ACE)	50% (2-yr)	20% (5-yr)	10% (10-yr)	4% (25-yr)	2% (50-yr)	1% (100-yr)	0.5% (200-yr)	0.2% (500-yr)
Discharge (cfs), 2004 FFS (RM 578.6)	127,000	169,000	195,000	228,000	251,000	274,000	297,000	326,000

4. RIPRAP

The riprap sizing computer program CHANLPRO was used to calculate the appropriate riprap gradation for this repair. Maximum Mississippi River channel velocity in the vicinity of the project location (RM 578) is about 5 ft/s (Table A-1). A local average depth of 20 feet, specific weight of stone of 165 lbs/ft^2 and a factor of safety of 1.3 are used in this project. A maximum stone size requirement of 36 pounds was computed (Figure 1). Riprap gradation of IA DOT Class E or higher is recommended. For the sensitivity test, specific stone weight of 155 lb/ft^3, higher safety factors (1.4 and 1.5) as well as higher velocities (6 and 7 ft/sec) were tested in CHANLPRO. Recommended riprap gradation of IA DOT Class E or higher will satisfy all scenarios for this repair.

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PROGRAM OUTPUT FOR A CHANNEL WITH A KNOWN LOCAL
    DEPTH AVERAGED VELOCITY, STRAIGHT REACH
               INPUT PARAMETERS
SPECIFIC WEIGHT OF STONE,PCF              165.0
LOCAL FLOW DEPTH,FT                        20.0
CHANNEL SIDE SLOPE,1 VER: 1.50 HORZ
LOCAL DEPTH AVG VELOCITY,FPS               5.00
SIDE SLOPE CORRECTION FACTOR K1            0.71
CORRECTION FOR VELOCITY PROFILE IN BEND    1.00
RIPRAP DESIGN SAFETY FACTOR                1.30


                       SELECTED STABLE GRADATIONS
                              ETL GRADATION

NAME    COMPUTED D30(MIN)  D100(MAX)  D85/D15  N=THICKNESS/   CT  THICKNESS
         D30 FT     FT         IN                 D100(MAX)            IN
 1        0.11     0.37       9.00       1.70       1.00       1.00     9.0

D100(MAX)        LIMITS OF STONE WEIGHT,LB          D30(MIN)  D90(MIN)
   IN          FOR PERCENT LIGHTER BY WEIGHT           FT        FT
                100           50            15
 9.00       36     15     11      7      5      2    0.37      0.53

        EQUIVALENT SPHERICAL DIAMETERS IN INCHES
D100(MAX)  D100(MIN)  D50(MAX)  D50(MIN)  D15(MAX)  D15(MIN)
  9.0        6.6        6.0       5.3       4.8       3.6
```

Figure A-2: CHANLPRO Input and Output

5. 50% EXCEEDANCE DURATION ELEVATION

Based on Mississippi River Duration Curves Analysis (1980-2012), 50% exceedance duration elevation of 593.46 feet NAVD88 was determined at this Mississippi River repair site (RM 578). It will be included in the Project plan set.

6. FLOODPLAIN IMPACT ANALYSIS

H&H PDT member will perform Floodplain Impact Analysis after 65% of the design review to ensure that the project meets local and state floodplain ordinances.

7. QUALITATIVE ASSESSMENT OF CLIMATE CHANGE IMPACTS

7.1 Background

Recent Scientific evidence shows that in some places and for some impacts relevant to USACE operations, climate change is shifting the climatological baseline about which that natural climate variability occurs and may be changing the range of that variability as well. This is relevant to the USACE because the assumptions of stationary climatic baselines and fixed range of natural variability, as captured in the historic hydrologic record, may no longer be appropriate for long-term projections of flood risk.

Climate Change impacts on the hydrology of Upper Mississippi River (in HUC 0706 and 0708), are evaluated in accordance with USACE Engineering and Construction Bulletin (ECB) 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs and Projects (USACE, 2018), and USACE Engineering Technical Letter (ETL) 1100-2-3 *Guidance for Detection of Nonstationarities in Annual Maximum Discharges* (USACE,2018). A flowchart indicating the requirements for a quantitative climate assessment is displayed in Figure A-4.

The USACE's current policy is to interpret and use climate change information for hydrologic analysis through a qualitative assessment of potential climate change threats and impacts relevant to the USACE project for which the hydrologic analysis is being performed. As indicated in Figure A-4, qualitative analysis required includes consideration of both past (observed) changes, as well as potential future (projected) changes to relevant hydrologic inputs.

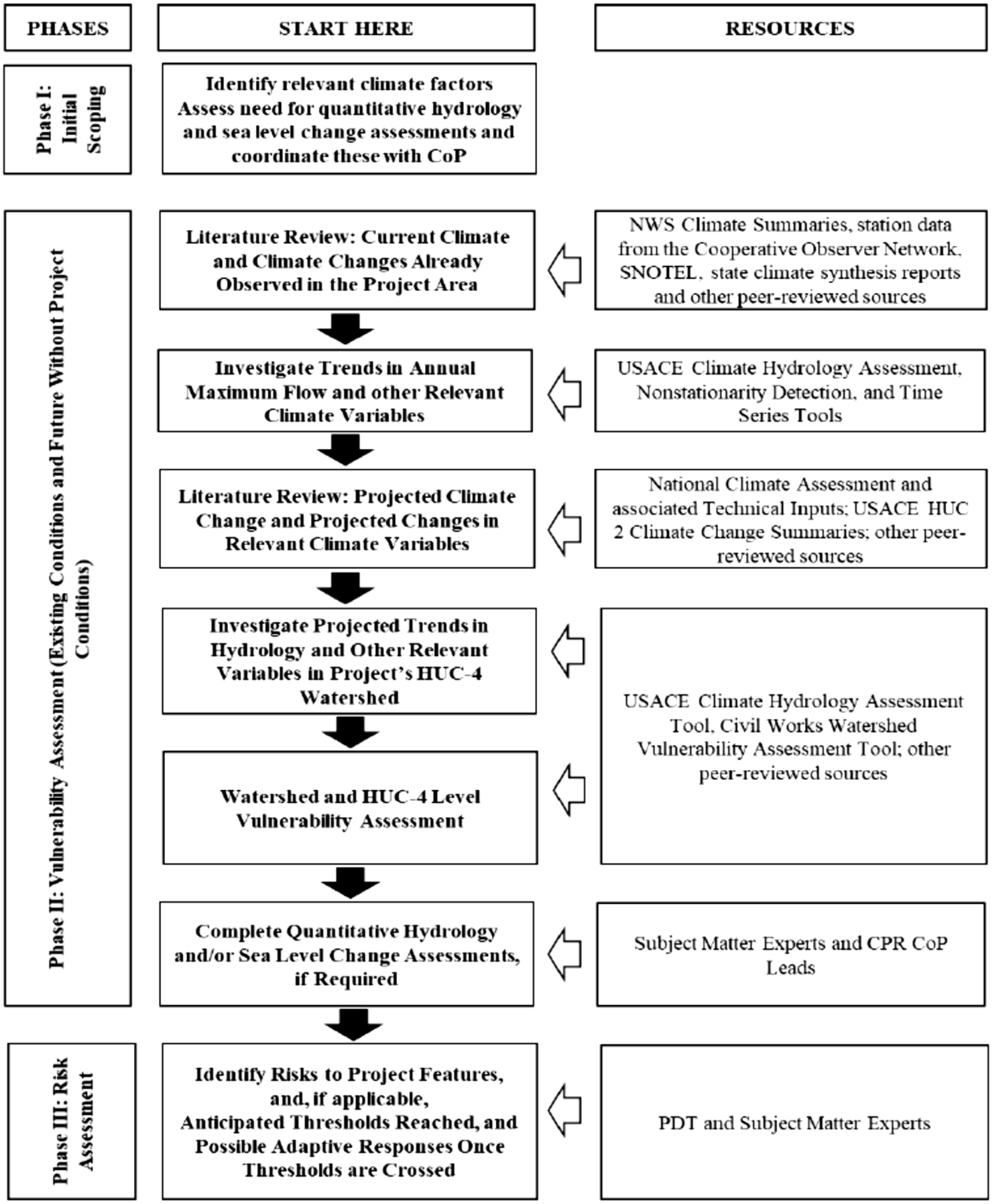

Figure A-3: Flowchart for Incorporating Climate Change Impacts to an Inland Hydrologic Analysis (USACE, 2018)

7.2 Literature Review, Regional Climate Change Trends

USACE (2015) summarized a number of studies focused on observed trends in historical as well as projected climate variables both in regional and national scales. This report is part of a series of twenty one (21) regional climate syntheses prepared by the USACE under the leadership of the Response to Climate Change Program at the scale of the 2-digit U.S. Geological Survey (USGS) Hydrologic Unit Codes (HUC) across the continental United States, Alaska, Hawaii, and Puerto Rico. The report for Water Resources Region 07 focuses the Upper Mississippi River (UMR) basin.

Most of the studies summarized in USACE (2015) show consensus in statistically significant increases in trends in average annual temperature and total annual precipitation. In Figure A-5, the trends calculated from the CRUTEM3 data set show a 0.06°C (0.11°F) per decade increase in annual mean temperature over the Midwest during the 1900-2010 period. When the trend is calculated over the period of 1950-2010, it increases to 0.12°C (0.22°F) per decade, and 0.26°C (0.47°F) per decade for the period of 1979-2010, showing an increased rate of warming in the recent time period (Kunkel et al., 2010).

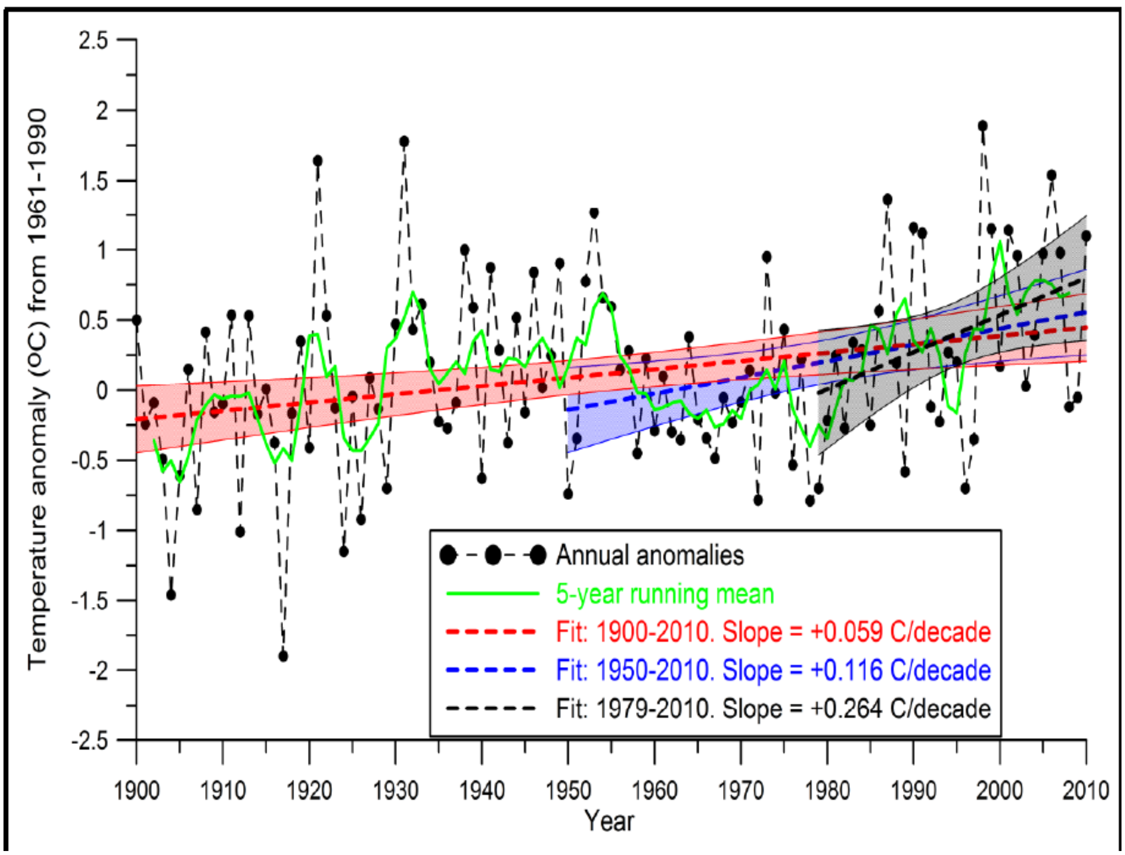

Figure A-4: Annual Temperature Anomalies for the Midwest region from the CRUTEM3 Data Set. (Figure 13 of Kunkel et al., 2010)

McRoberts and Nielsen-Gammon (2011) did the comparison of long-term trends of annual precipitation. They analyzed the linear trends of annual precipitation for all 344 U.S. climate divisions for the period1895–2009 (Figure A-7). The trends are expressed as a percentage change per century relative to the 1895–2009 mean precipitation. The percentage change per century relative to the 1895–2009 mean precipitation for UMR is within red oval in Figure A-7.

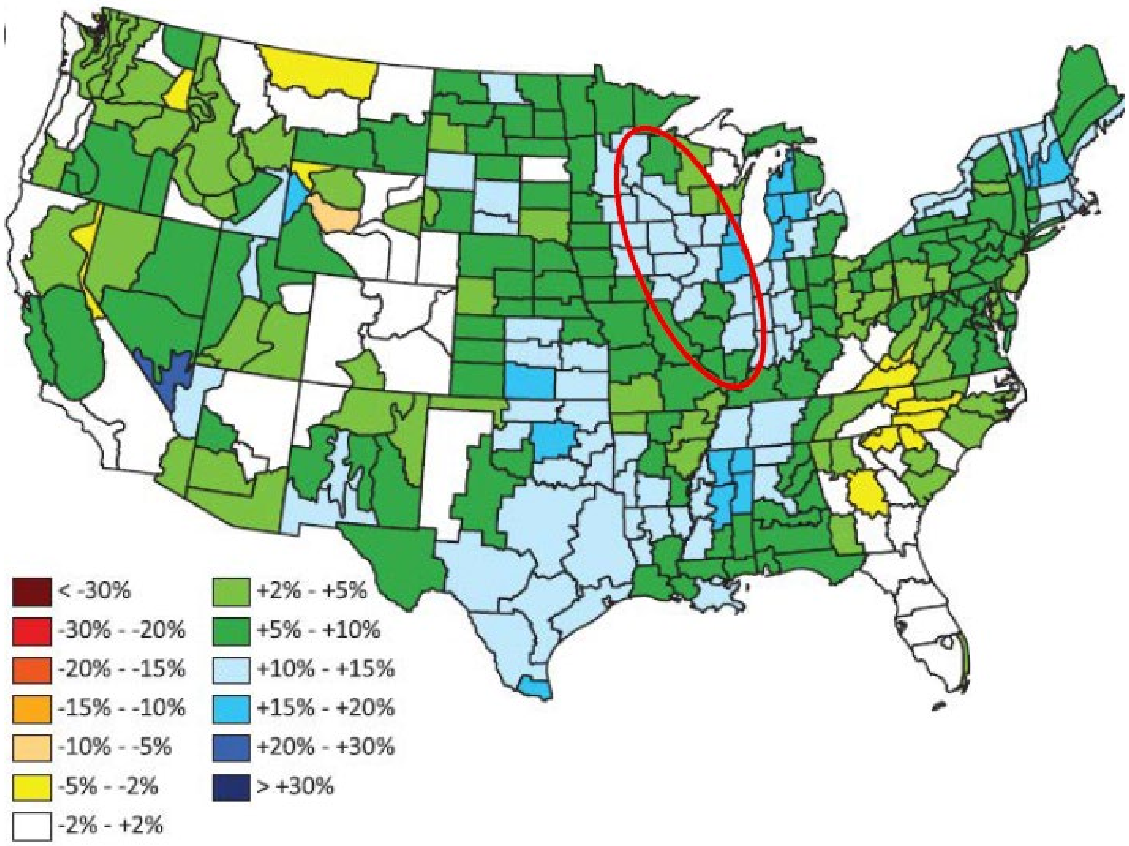

Figure A-5: Linear Trends in Annual Precipitation, 1895 – 2009, Percent Change Per Century. The UMR is within the red oval (McRoberts and Nielsen-Gammon (2011), USACE (2015).

There is strong consensus that air temperatures will increase in the UMR, with studies generally agreeing on an increase in mean annual air temperature of approximately 2 to 6 ºC (3.6 to 10.8 ºF) by the latter half of the 21st century. A reasonable consensus is also seen on projected increases in extreme temperature events. This includes more frequent, longer, and more intense summer heat waves in the long-term future compared to the recent past.

Most of the precipitation projections in the studies forecast an increase in both annual precipitation and in the frequency of large storm events. Seasonally, though, some studies indicate a potential for drier summers despite the overall increase in annual precipitation totals. As a result of increased air temperature and evapotranspiration rates, droughts are also projected to increase in the UMR.

Regarding streamflow and hydrology projections, there is no clear consensus in the literature. Projections generated by coupling GCMs with macro scale hydrologic models in some cases indicate a reduction in future streamflow, but in other cases indicate a potential increase in streamflow. Figure A-8 summarizes the trends and literary consensus of observed and projected primary variables of temperature, temperature extremes, precipitation, precipitation extremes, and streamflow (hydrology).

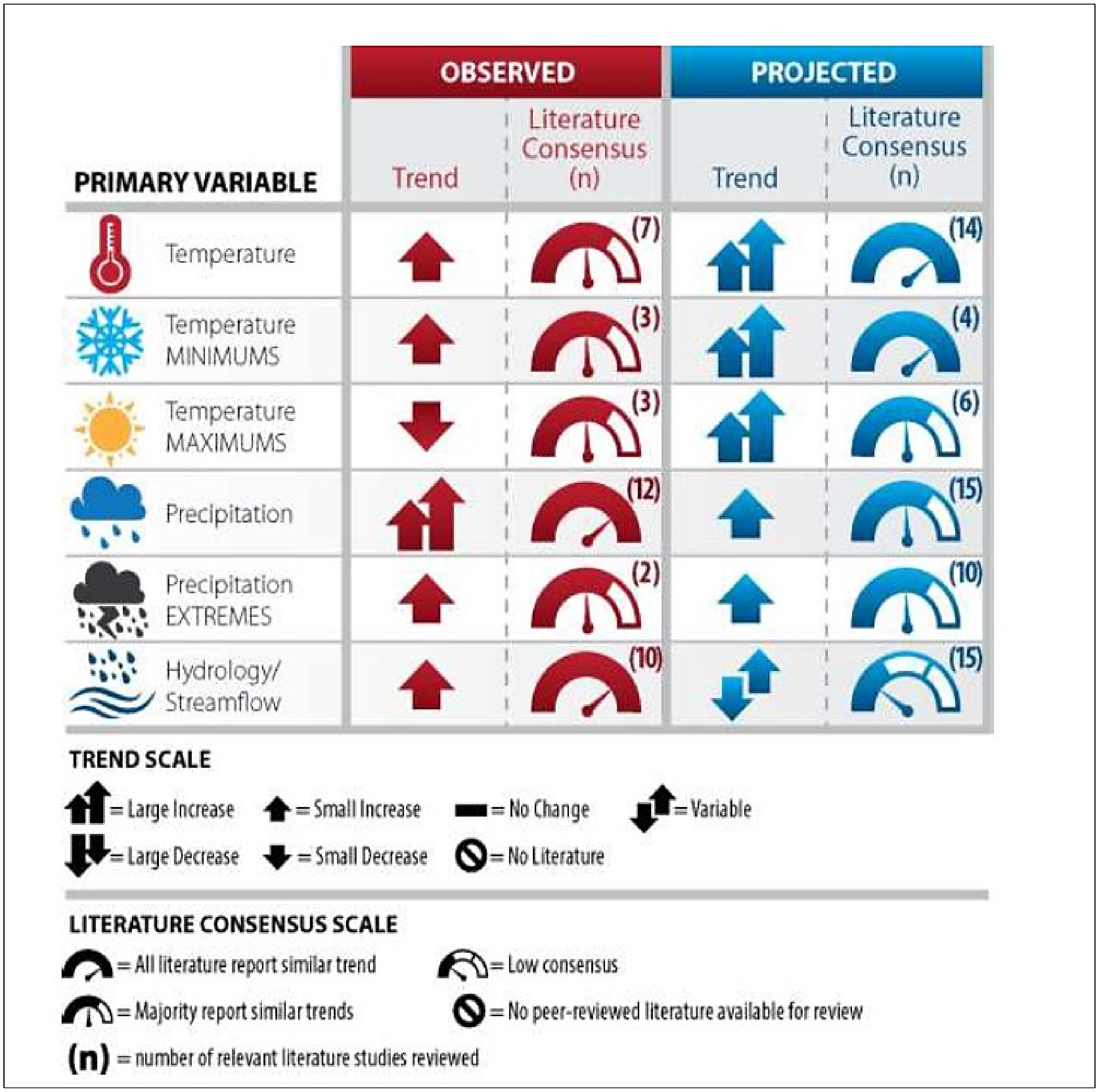

Figure A-6: Summary and Literature Consensus of Observed and Projected Trends in Important Meteorologic Variables Potentially Impacted by Climate Change (USACE, 2015)

7.3 Regional Scale Trends in Streamflow and Climate Change – Climate Hydrology Assessment Tool

To evaluate projects trends in hydrology for the Project area, the USACE Climate Hydrology Assessment Tool (CHAT) was used to analyze streamflow for the Upper Mississippi-Maquoketa-Plum (HUC 0706), Mississippi River at McGregor, IA and Upper Mississippi-Iowa-Skunk-Wapsipinicon (HUC 0708) Mississippi River at Clinton, IA. The Climate Hydrology Assessment Tool provides qualitative information at the HUC 4 watershed level about future climate conditions and allows the Corps to produce repeatable analytical results using consistent information.

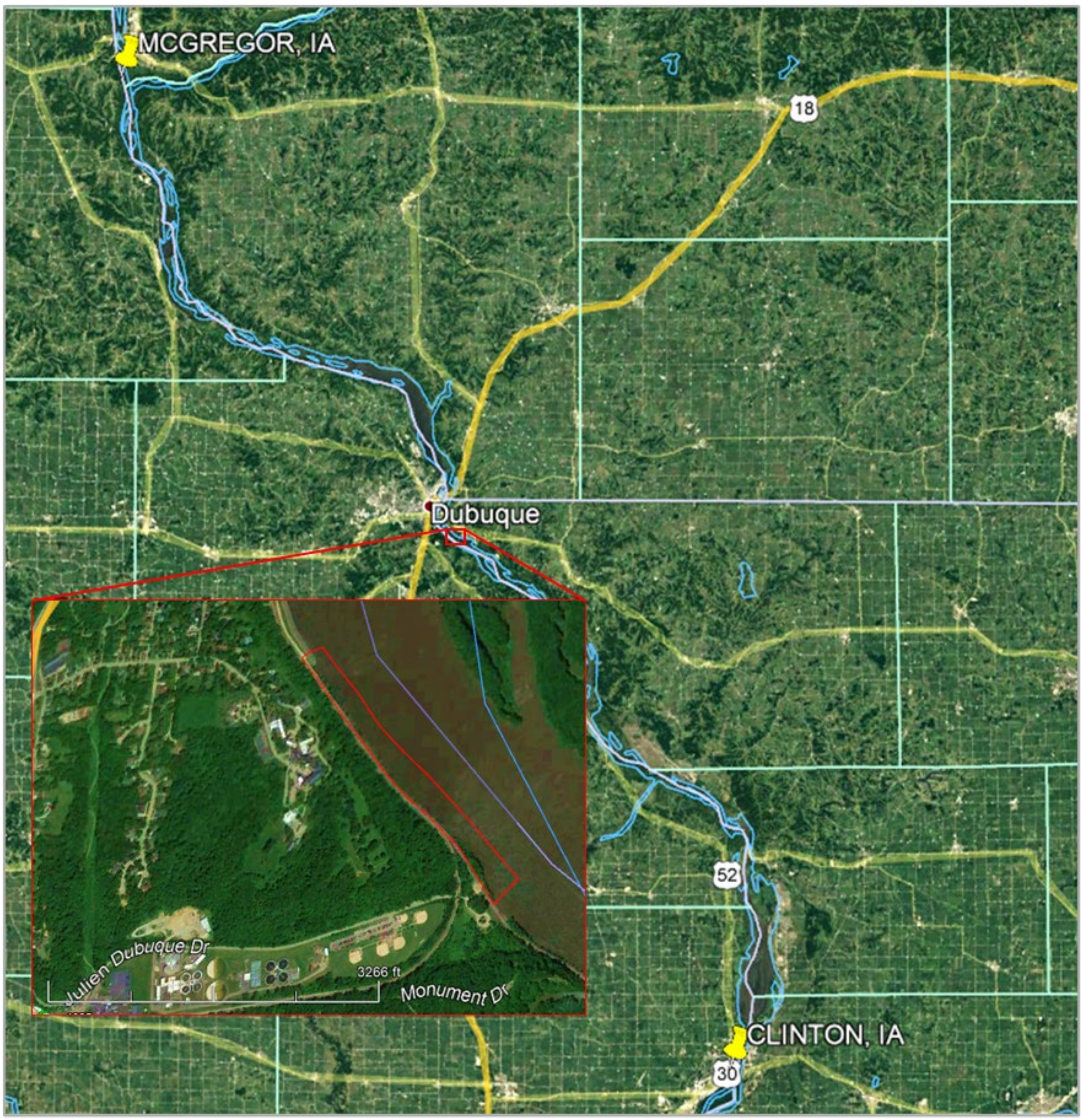

Figure A-7: Project Area and HUC 4 Locations

Observed trends in annual peak instantaneous streamflow for the Mississippi River at McGregor, IA (USGS gage 05389500) and at Clinton, IA (USGS gage 05420460) were evaluated using CHAT. These gages were chosen because they are respectively the nearest gage upstream and downstream from the project (see Figure A-8). Figure A-9 and A-10 respectively show observed peak streamflow in Mississippi River at McGregor (1937-2014) and Clinton Iowa (1874-2014). These analysis of observed peak streamflow indicates a steadily increasing trend in annual peak instantaneous streamflow for the period of records, but at both locations the increasing trends are not statistically significant with p-values of 0.1490 and 0.1330 respectively for McGregor and Clinton.

Projected hydrology under future climate conditions is generated using a hydrologic model with precipitation and temperature input parameters derived from GCM output. The range in projected annual maximum monthly streamflow is computed based on 93 different climate hydrologic model simulations for the 1950-2099 period (Figure A-11 and A-12).

Overall increasing trends captured by the best-fit line ranges from approximately 10 cfs/year for HUC 0706 (Figure A-13) to 40 cfs/year for HUC 0708 (Figure A-14). Over the 50-year project life cycle flows are only projected to increase in a range of 500 cfs to 2000 cfs. This trend, while indicative of increasing flows over time, is not substantial given the scale of discharges on the Mississippi River. Between 1936 and 2013 the average annual discharge for USGS gage 05389500, Mississippi river at McGregor, IA is 37,700 cfs. The lowest annual mean daily flow is 17,400 cfs (1977) and between 1874 and 2014, the average annual discharge and lowest annual mean daily flow at Clinton, IA are 40,700 cfs and 12,180 cfs (2015) respectively.

This result is qualitative only.

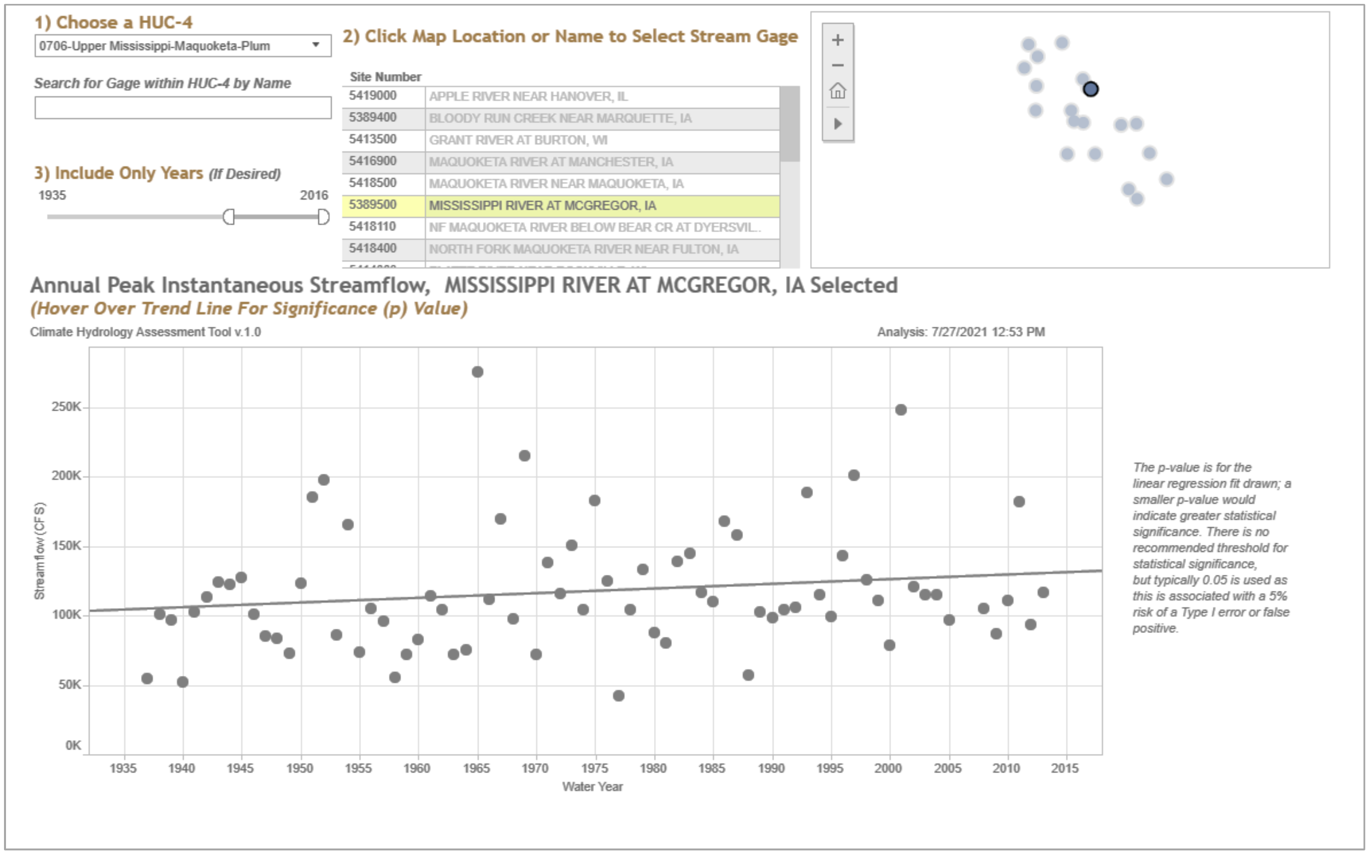

Figure A-8: Increasing Trend in Observed Annual Peak Instantaneous Streamflow for Mississippi River at McGregor, IA (p-value=0. 1490) (HUC 0706) (CHAT)

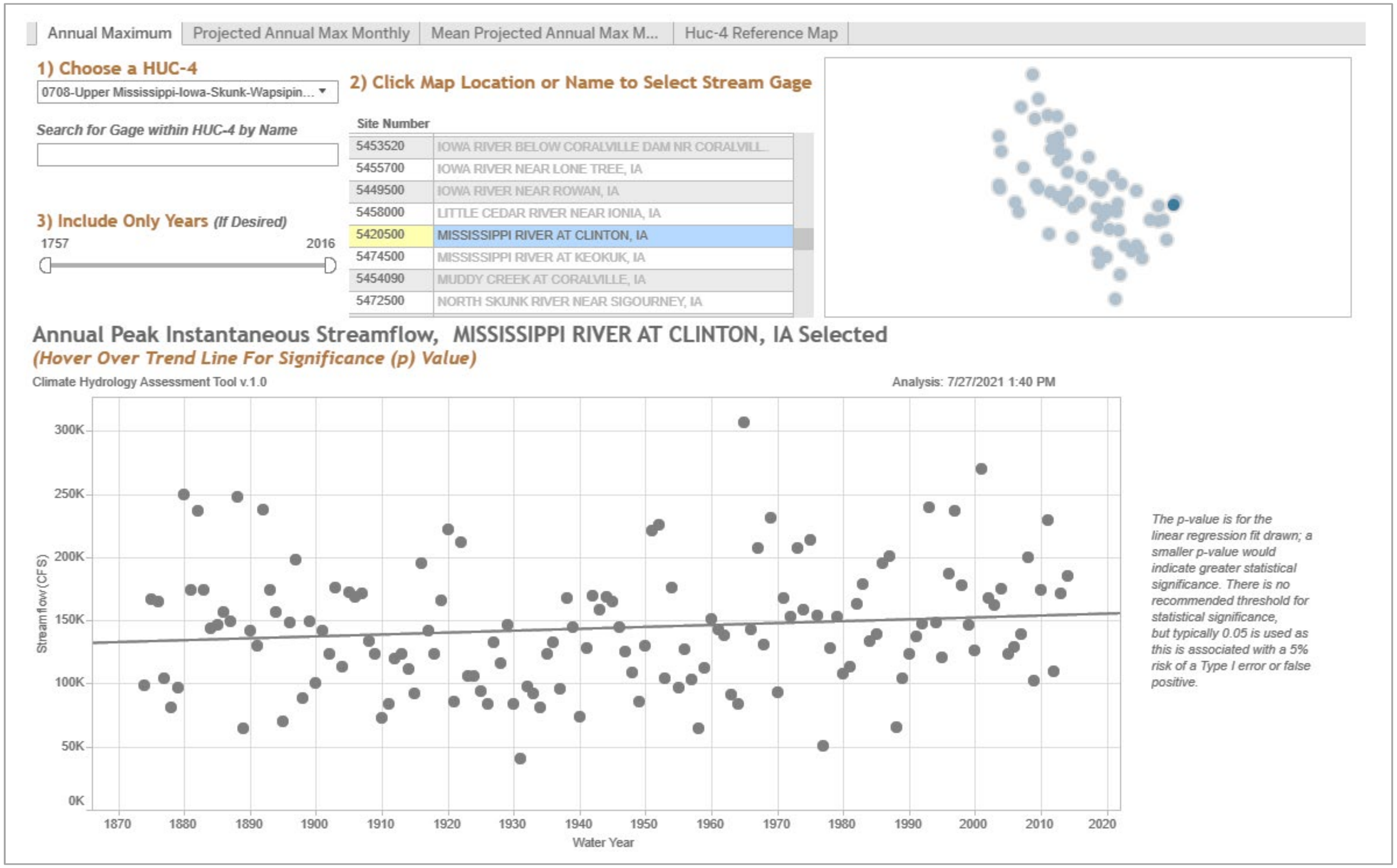

Figure A-9: Increasing Trend in Observed Annual Peak Instantaneous Streamflow for Mississippi River at Clinton, IA (p-value=0. 1330) (HUC 0708) (CHAT)

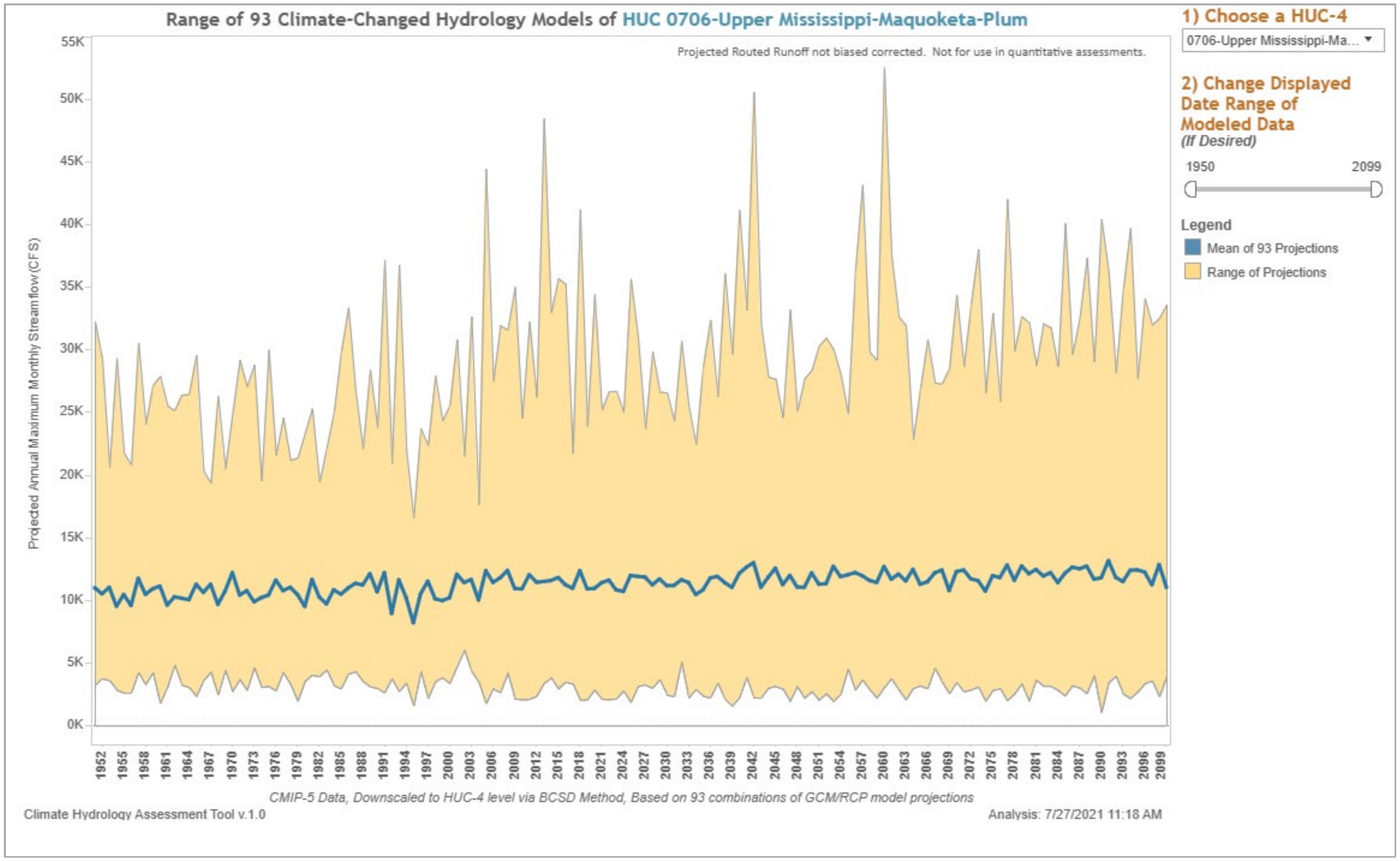

Figure A-10: Range in Projected Annual Maximum Monthly Streamflow for the Mississippi River at McGregor, IA (HUC 0706) (CHAT)

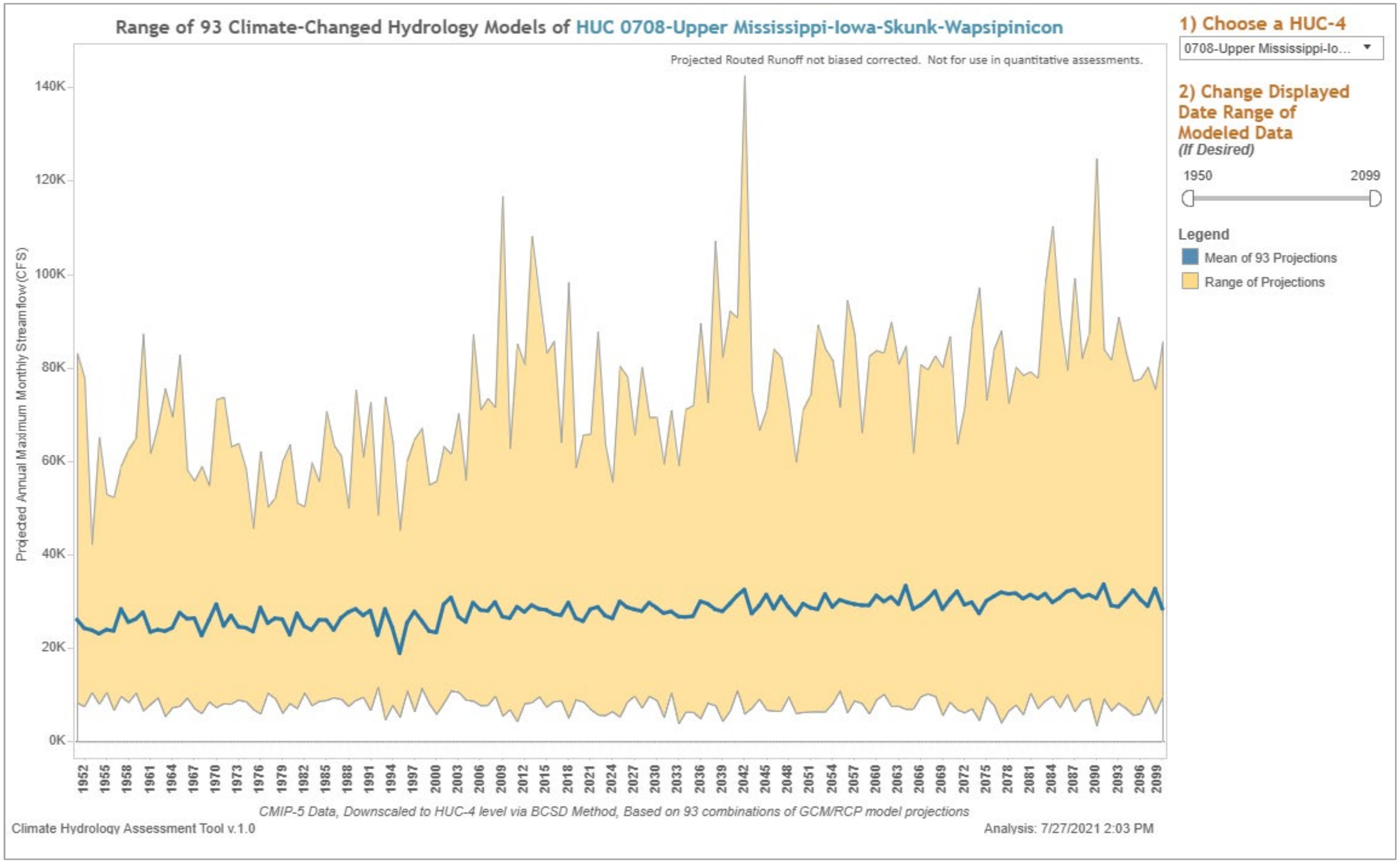

Figure A-11: Range in Projected Annual Maximum Monthly Streamflow for the Mississippi River at Clinton, IA (HUC 0708) (CHAT)

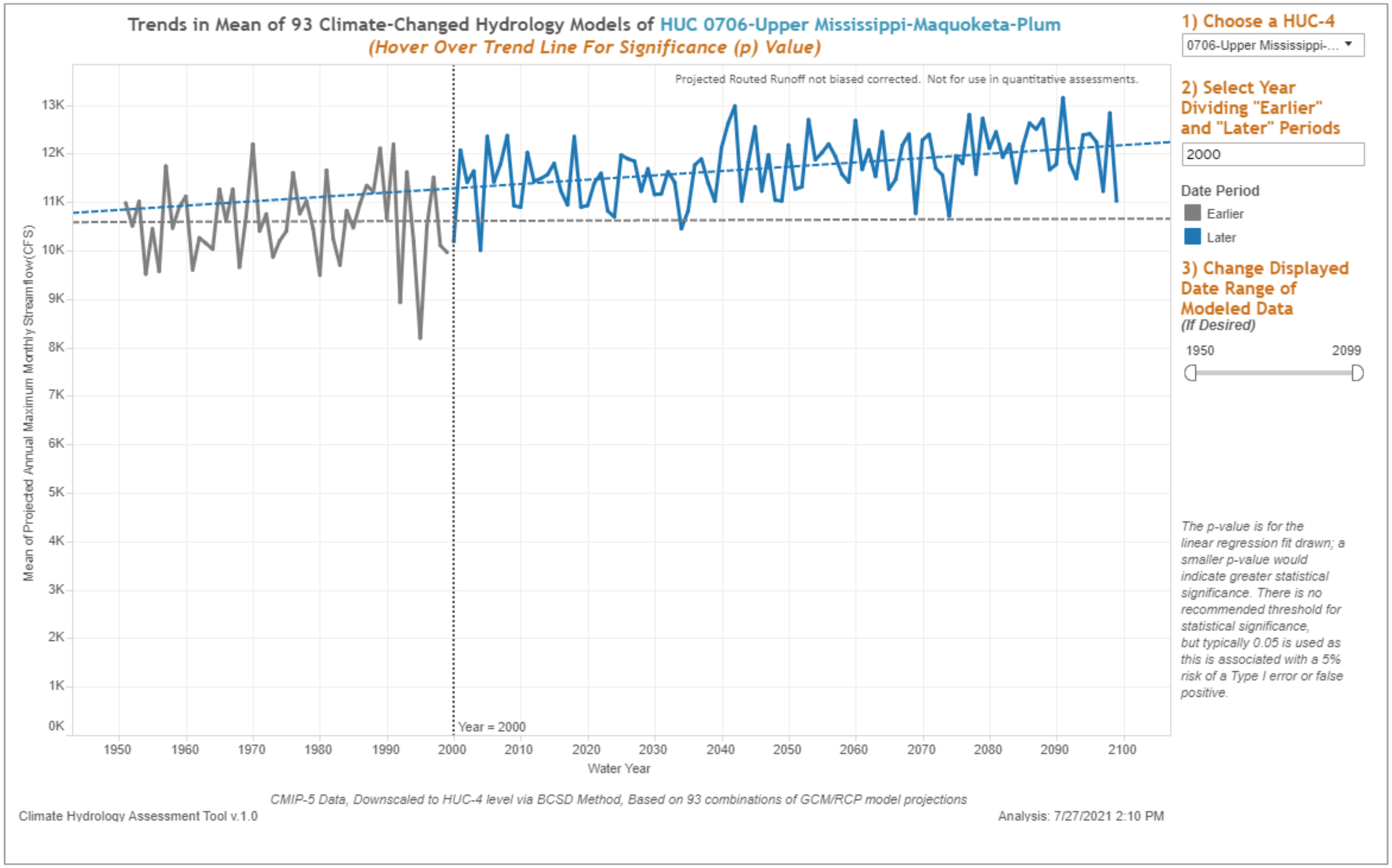

Figure A-12: Mean Projected Annual Maximum Monthly Streamflow for the Mississippi River at McGregor, IA (HUC 0706)

Trendline Equation: Q = 8.91178*[Water Year] – 6542.32, $p < 0.0001$ (CHAT)

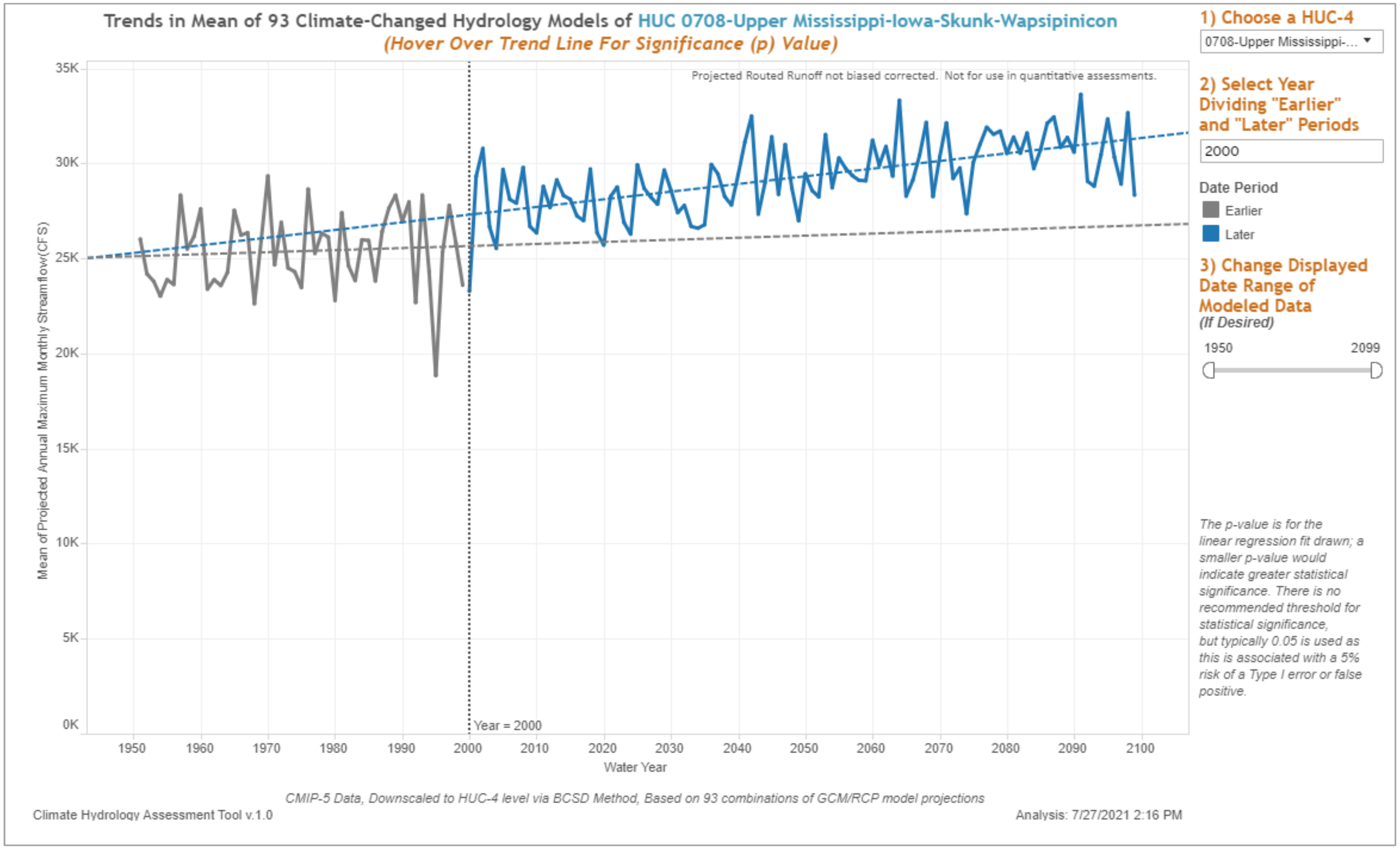

Figure A-13: Mean Projected Annual Maximum Monthly Streamflow for the Mississippi River at Clinton, IA (HUC 0708)

Trendline Equation: $Q = 40.3183*[\text{Water Year}] - 53326.3$, $p < 0.0001$ (CHAT)

7.4 SCREENING LEVEL VULNERABILITY ASSESSMENT TO CLIMATE CHANGE IMPACTS.
The USACE Watershed Climate Vulnerability Assessment (VA) Tool was used to compare the relative vulnerability of the Upper Mississippi HUC-0706 and HUC-0708, to climate change to the other 202 HUC 04 watersheds across the continental United States (CONUS). The tool facilitates a screening level, comparative assessment of how vulnerable a given HUC-4 watershed is to the impacts of climate change. The tool can be used to assess the vulnerability of a specific USACE business line such as 'Flood Risk Reduction' to projected climate change impacts. Assessments using this tool help to identify and characterize specific climate threats and particular sensitivities or vulnerabilities, at least in a relative sense, across regions and business lines.

The tool uses the Weighted Order Weighted Average (WOWA) method to represent a composite index of how vulnerable a given HUC-4 watershed (Vulnerability Score) is to climate change specific to a given business line. The HUC-4 watersheds with the top 20% of WOWA scores are flagged as being vulnerable. Indicators considered within the WOWA score for Flood Risk Reduction include change in flood runoff, long-term variability in hydrology, etc. (Table A-4).

When assessing future risk projected by climate change, the USACE Climate Vulnerability Assessment Tool makes an assessment for two 30-year epochs of analysis centered at 2050 and 2085. These two periods were selected to be consistent with many of the other national and international analyses. The tool assesses how vulnerable a given HUC 4 watershed is to the impacts of climate change for a given business line using climate hydrology based on a combination of projected climate outputs from the general climate models (GCMs) and representative concentration pathway (RCPs) resulting in 100 traces per watershed per time period. The top 50% of the traces is called "wet" and the bottom 50% of the traces is called "dry." Meteorological data projected by the GCMs is translated into runoff using the Variable Infiltration Capacity (VIC) Macroscale hydrologic model. For this assessment the default, National Standards Settings are used to carry out the vulnerability assessment.

Based on the results of the USACE Watershed Climate Vulnerability Assessment Tool presented in Figure A-15, relative to the other 202 HUC04 watersheds in the CONUS, the Upper Mississippi HUC-0706 and HUC-0708 are relatively less vulnerable to the impacts of climate change on Flood Risk Reduction. Only 2050 Epoch dry scenario is detected vulnerable based on this assessment tool.

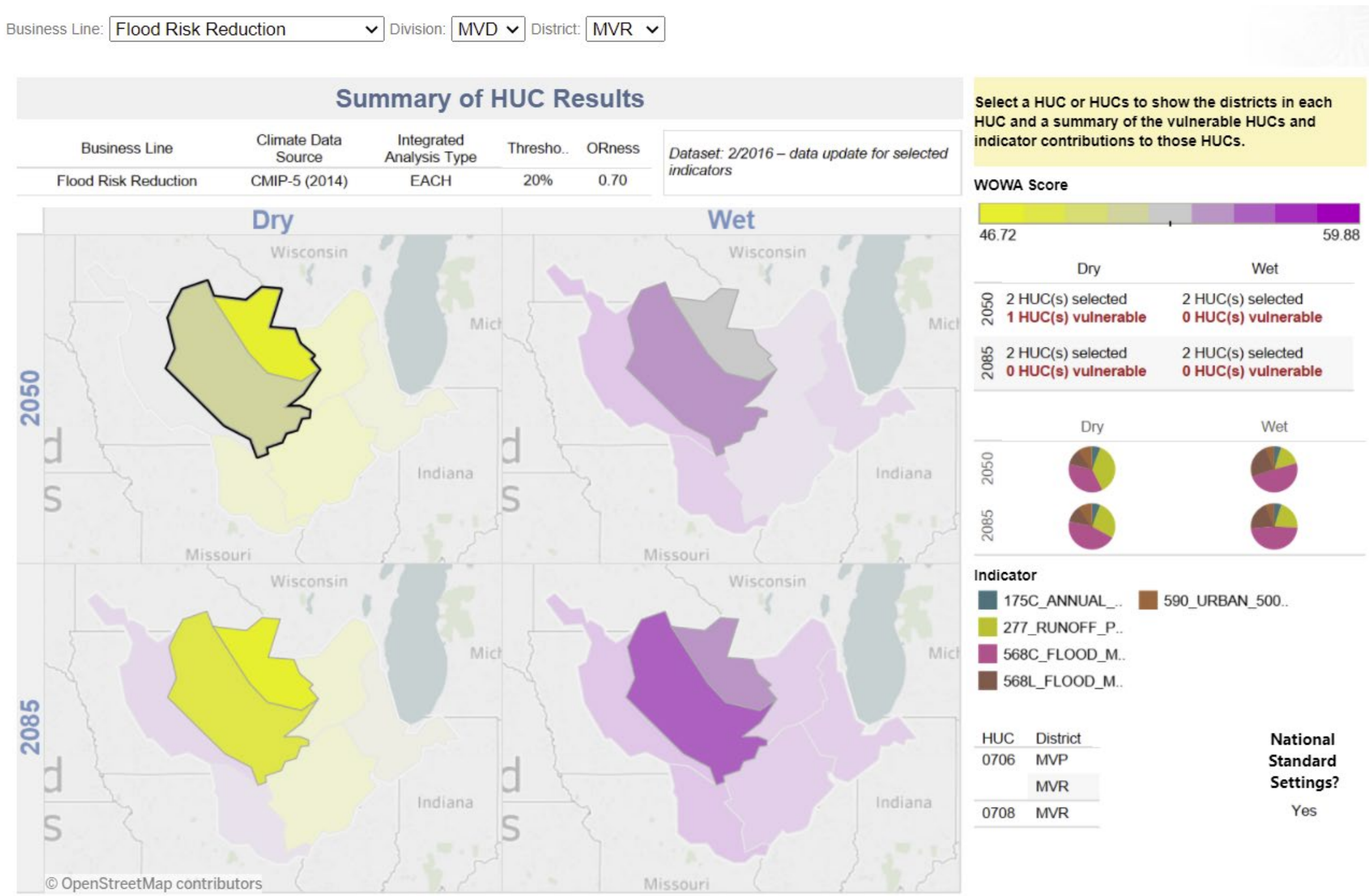

Figure 14: Projected Vulnerability for the Upper Mississippi (HUC- 0706 and HUC- 0708) with Respect to Flood Risk Reduction

For the Upper Mississippi watersheds, the major drivers of the computed vulnerability score are, "Change in flood runoff", and "deviation of runoff". Table A-3 shows the vulnerability scores for the two 30-year epochs and the scores are relatively constant between both epochs and but shows a significant change on their wet and dry subsets of traces. Additionally, Table A-3 and Table A-4 show the vulnerability score contributions of the different indicators for the 2050 epoch and 2085 epoch.

Table A-2: Projected Vulnerability with Respect to Flood Risk Reduction

	Ecosystem Reduction Vulnerability Score			
HUC 4 Watershed	**2050 Dry**	**2050 Wet**	**2085 Dry**	**2085 Wet**
Mississippi River (0706)	46.89	52.99	47.38	54.70
Mississippi River (0708)	52.41	55.00	49.56	55.69

Table A-3: Comparison of Different Indicators for the Upper Mississippi HUC-0706

HUC-0706	**2050 Epoch**		**2085 Epoch**	
Indicator	**Dry**	**Wet**	**Dry**	**Wet**
	Contribution to WOWA Flood Risk Reduction Vulnerability Score		Contribution to WOWA Flood Risk Reduction Vulnerability Score	
Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	3.52	3.28	3.48	3.51
Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	13.60	8.50	13.20	14.06
Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	21.23	26.60	21.96	26.74
Acres of urban area within the 500-year floodplain.	1.45	1.42	1.50	1.50
Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	6.99	13.18	7.24	8.90

Table A-4: Comparison of Different Indicators for the Upper Mississippi HUC-0708

HUC-0708	2050 Epoch		2085 Epoch	
Indicator	Dry	Wet	Dry	Wet
	Contribution to WOWA Flood Risk Reduction Vulnerability Score		Contribution to WOWA Flood Risk Reduction Vulnerability Score	
Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	2.43	2.12	2.21	2.27
Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	22.78	8.50	13.22	8.59
Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	14.30	26.19	21.97	26.05
Acres of urban area within the 500-year floodplain.	8.02	4.78	7.48	4.81
Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	4.89	13.41	4.69	13.98

7.5 CONCLUSION

Based on this qualitative assessment, which shows no significant signals specific to the HUC-06 and HUC-08 (Upper Mississippi Basin) towards climate change, so the recommendation is to treat the potential effects of climate change and long-term natural variability in climate as occurring within the uncertainty range calculated for the current hydrologic analysis.

8. REFERENCES

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USACE Non-Stationarity Detection Tool *http://corpsmapu.usace.army.mil/cm_apex/f?p=257:2:0::NO*

USACE Vulnerability Assessment Tool *https://maps.crrel.usace.army.mil/apex/f?p=201*