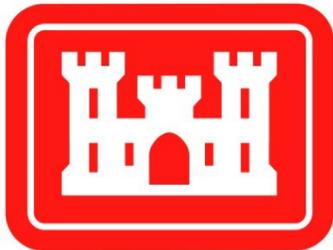


**Kinnickinnic River, Wisconsin  
Hydraulic and Hydrologic Analysis  
River Falls Hydroelectric Project  
Planning Assistance to States (PAS)**

January 2021



**US Army Corps  
of Engineers ®**

Prepared by:  
U.S. Army Corps of Engineers  
St. Paul District  
180 Fifth Street East, Suite 700  
St. Paul, Minnesota 55101-1678

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DQC – District Quality Control (U.S. Army Corps of Engineers)  
EIT – Engineer In Training  
MVP – St. Paul District (U.S. Army Corps of Engineers)  
PE – (Registered) Professional Engineer  
USACE – U.S. Army Corps of Engineers

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## Plates

Plate 1: Kinnickinnic River Watershed Overview Map (Attached)

## Appendices

Appendix 1: Climate Change Analysis (Attached)

# 1 Purpose and Scope of Work

## 1.1 Background

The City of River Falls Municipal Utilities (RFMU) currently owns and operates two hydroelectric dams along the Kinnickinnic River in River Falls, WI. Known as Junction Falls and Powell Falls, these hydroelectric dams are licensed by the Federal Energy Regulatory Commission (FERC) under the River Falls Hydroelectric Project (License No. 10489). RFMU is currently going through the relicensing process with FERC, as this license expires on August 31, 2023, (Reference 1). Both Junction Falls and Powell Falls are included in the National Inventory of Dams (NID) under NID IDs WI00021 and WI00079, respectively, (Reference 2).

When declaring their Notice of Intent to relicense the River Falls Hydroelectric Project, RFMU proposed only relicensing Junction Falls, while decommissioning Powell Falls and removing the dam, (Reference 1). Declaring the Notice of Intent began the relicensing process, which resulted in the development and filing of a Proposed Study Plan, which responded to additional information requests, proposed certain studies, and provided a rationale for why RFMU did not propose certain studies requested by stakeholders. Following a stakeholder comment period, RFMU submitted a Revised Study Plan (RSP). (Much greater detail on the development of the RSP is available in the document itself, (Reference 2)).

Section 6 of the RSP outlines the individual studies proposed by RFMU to analyze the potential effects of the continued operation of Junction Falls dam and the proposed decommissioning and removal of Powell Falls dam. Section 6.1 specifically describes the proposed Hydrologic and Hydraulic Analyses, with the objective of developing an analytical tool and hydrologic inputs that can be used to predict streamflow characteristics under the proposed project conditions. The goal for this study is that it will better inform stakeholders interested in balancing floodplain risk management with the beneficial use of the Kinnickinnic's riparian resources. The study will also help River Falls in meeting Wisconsin's floodplain management regulations, as they require floodplain zoning to be consistent with the existing hydraulic geometry in an area. Dams, for example, are a significant feature in a river's hydraulic geometry that affect how water flows through its channel; removing one would change the river's geometry, and potentially alter how water moves through the system. Additionally, as a participant in the National Flood Insurance Program, the City will eventually need to provide technical analysis supporting a Letter of Map Revision (LOMR) when Powell Falls dam is removed, (Reference 1).

## 1.2 Previous Studies

The Federal Emergency Management Agency's (FEMA) Flood Insurance Study (FIS) for Pierce County, WI, (where River Falls is located), outlines the results of hydrologic and hydraulic analyses conducted in 2002 to support floodplain zoning in the City of River Falls. The FIS, published in 2011, lists flow rates associated with the 10%, 1%, and 0.2% annual exceedance

probability (AEP) floods, and presents water surface elevation profiles associated with each of those flood events for the reach of the Kinnickinnic River that flows through River Falls. At the time that the RSP was developed, the location of the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) model, (used to support the hydrologic analysis for the FIS), was unknown.

The RSP, (Reference 2), made a point to mention that the hydrologic and hydraulic models used in FEMA’s FIS for River Falls would not include current estimates of rainfall frequency, the river geometry associated with the dam removal, or comparisons to known peak streamflows at the downstream U.S. Geological Survey (USGS) gage on the Kinnickinnic River near River Falls, WI, (USGSG gage 05342000). The gage along the Kinnickinnic currently has 24 years of data, with a systematic period of record that includes October 1916 to September 1921 and July 2002 to present, (Reference 5).

The engineering consulting firm Short, Elliot, and Hendrickson (SEH) conducted a hydraulic analysis of the Kinnickinnic River with hypothetical, post-removal conditions in conjunction with the dam removal feasibility studies. When conducting the analysis, however, SEH assumed that both Powell Falls dam and Junction Falls dam would be removed; this is reflected in their Hydrologic Engineering Center – River Analysis System (HEC-RAS) model and their technical memo on the study, (Reference 6). SEH also included updated precipitation frequency values using the National Oceanic and Atmospheric Administration’s (NOAA) *Atlas 14*, (Reference 7), and updated channel geometry near both dams, informed by sediment studies conducted by another engineering consulting firm, Inter-Fluve, in 2016, (Reference 8). In their study, however, SEH opted to use flood frequency flows outlined in FEMA’s FIS for Pierce County. This was primarily due to a lack of an adequate hydrologic model at the time.

### 1.3 Hydrologic Analysis Scope of Work

The hydrologic analysis proposed within the Revised Study Plan (RSP), (Reference 2), focuses on developing an updated flood frequency analysis for the Kinnickinnic River through the use of a variety of methods. These methods include:

- Applying the methods outlined within the USGS’s *Guidelines for Determining Flood Flow Frequency – Bulletin 17C*, (Reference 9), to develop a flood frequency curve for the USGS on the Kinnickinnic River, 05342000, located 4.8 miles downstream from Powell Falls dam, (Reference 5).
- Retrieving, (if possible), the HEC-HMS model used for FEMA’s FIS for the Kinnickinnic River, (Reference 4). The HEC-HMS model would then be used in conjunction with the 24-hour, 1% AEP precipitation depth specified in the National Oceanic and Atmospheric Administration’s (NOAA) *Atlas 14* and using the MSE-3 distribution, (Reference 7).
- Applying the 2019 USGS flood frequency regression equations for WI, (Reference 10).

#### 1.4 Hydraulic Analysis Scope of Work

The hydraulic analysis proposed within the RSP, (Reference 2), focuses on reviewing and refining the HEC-RAS model developed by SEH in their 2017 study, (Reference 6). To approximate the water surface profiles for the channel and overbank areas following the hypothetical removal of Junction Falls and Powell Falls dams, the model incorporates the refusal area identified by Inter-Fluve in their 2016 sediment assessment, (Reference 7). The RSP outlined how the HEC-RAS model would need to be updated and reviewed, including:

- Adding Junction Falls dam back into the model. (SEH's study assumed that both dams were removed).
- Reviewing the model's input geometry data and site conditions to determine whether a topographic survey of the channel and bedrock near Powell Falls, prior to dam removal, will support significant model improvements.
- If judged to be beneficial during the step above, conducting a topographic and bathymetric survey on the downstream side of Powell Falls dam and incorporating the survey geometry into the HEC-RAS model.

Once complete, the HEC-RAS model will be used to calculate water surface elevations, velocities, depths, and wetted top widths for several flow conditions, including: a typical summer low flow, and the 50%, 10%, and 1% AEP floods. The information generated by this model will be utilized in submittals related to floodplain zoning and the National Flood Insurance Program (NFIP). The submittal of this information will be deferred until the decommissioning process is underway though, which is expected to occur in 2025 or 2026.

During initial coordination on this project between the Project Management and Hydraulic & Hydrologic Engineering Branches of the U.S. Army Corps of Engineers' (USACE) St. Paul District, it was determined that current funding levels would not allow for topographic and bathymetric surveying of the downstream side of Powell Falls dam. Due to this, this task was not conducted as part of this study, but may be recommend as part of a future analysis.

#### 1.5 Climate Change Assessment

Although not included in the scope of work outlined in the RSP, (Reference 2), USACE guidance requires qualitative climate change assessments to be included with every hydrologic analysis that supports planning and engineering decisions that have an extended decision time frame. Due to this, the USACE has included a climate assessment with this analysis, Appendix 1.

## 2 Watershed Information

### 2.1 General Information

The Kinnickinnic River (Kinni) watershed is located in west central Wisconsin, approximately 30 miles east from the center of the Minneapolis-St. Paul metro area. The watershed drains 172 square miles across Pierce and St. Croix Counties, and encompasses the entirety of the USGS's Hydrologic Unit Code (HUC)-10 watershed 0703000511, (Reference 11). The watershed is dominated by agriculture (57%), grassland (22%), and forest (17%), with approximately 2% of the watershed consisting of wetlands and lakes, (Reference 12). The Kinni begins its journey as the culmination of flows from several intermittent, spring-fed streams, approximately 16 miles northeast of River Falls, WI. The Kinni then flows 26 miles southwest, through the center of River Falls, discharging as the last major tributary to the St. Croix River at Kinnickinnic State Park, approximately halfway between Prescott, WI and Hudson, WI. The average slope of the Kinni is approximately 10 feet/mile with middle portions of the river being flatter. Elevations in the watershed vary from 1,205 feet NAVD 88, in the upper portions of the watershed, to 680 feet NAVD 88 at its confluence with the St. Croix. The Kinni is classified as a Class I trout stream and is very popular for fishing and kayaking. Plate 1 shows the location of the Kinnickinnic River.

### 2.2 Geodesy used in Study

The North American Vertical Datum (NAVD) 88 was used as the vertical datum throughout the study. The North American Datum (NAD) 83 was used throughout the study as the horizontal datum, with the Central Zone of Wisconsin's State Plane Coordinate (SPC) system 83 used as the projection for mapping and calculating areas.

### 2.3 Geomorphological Setting

The Kinni is located in a unique geomorphological setting for Wisconsin, containing the only true prairie potholes in the state, (Reference 12). The Environmental Protection Agency's Level IV Ecoregions map of the United States highlights the watershed's distinctiveness, showing it as falling entirely within the small and only portion of Wisconsin that is defined as ecoregion 47g, the Prairie Pothole Region, or the Lower St. Croix and Vermillion Valleys of the Western Corn Belt Plains, (Reference 13). This ecoregion is characterized by,

“Smooth to undulating topography, productive prairie soils, and loess- and till-capped dolomite bedrock. The potential natural vegetation is predominantly tall grass prairie with a gradual transition eastward to more mixed hardwoods, distinguishing 47g from the greater concentration of mixed hardwoods of both 51a to the north and 51b to the east, and the mixed prairie and oak savanna of 52b to the south,” (Reference and 14).

The geology of the Kinnickinnic River basin consists of loess and glacial till deposited as moraines during the Quaternary Period. The soil overlies Ordovician bedrock, with the depth to

bedrock ranging from 0 to 50 feet. The glacial till consists of unstratified clay, silt, sand, gravel, and boulders. The uppermost bedrock units include Galena Dolomite, Decorah Shale, and Platteville Limestone ranging from 0 to 115 feet thick. Below these units lies St. Peter Sandstone, ranging in thickness from 0 to 200 feet, (Reference 15).

## 2.4 Climatological Setting

Most of the Kinnickinnic River basin is located within the warm summer, humid continental Köppen climate type, characterized by warm summers with ample rainfall, and cold to frigid winters with moderate snowfall, (Reference 16). Average monthly temperatures in River Falls, WI vary from a minimum of 13.3 degrees Fahrenheit (°F) in January to a maximum of 70.3 °F in July. Average monthly precipitation ranges from a minimum of 0.7 inches in January to a maximum of 4.75 inches in August, (Reference 17). Figure 2-1 below shows a climatograph depicting typical monthly temperatures and average cumulative precipitation depths for River Falls. Precipitation that falls during the months of November through March is typically snow. However, snow has the potential to begin accumulating as early as October and fall as late as April. The closest snow recording station to River Falls is located in Baldwin, WI, (USC00470486), where average annual snowfall is 44.8 inches, (Reference 18).

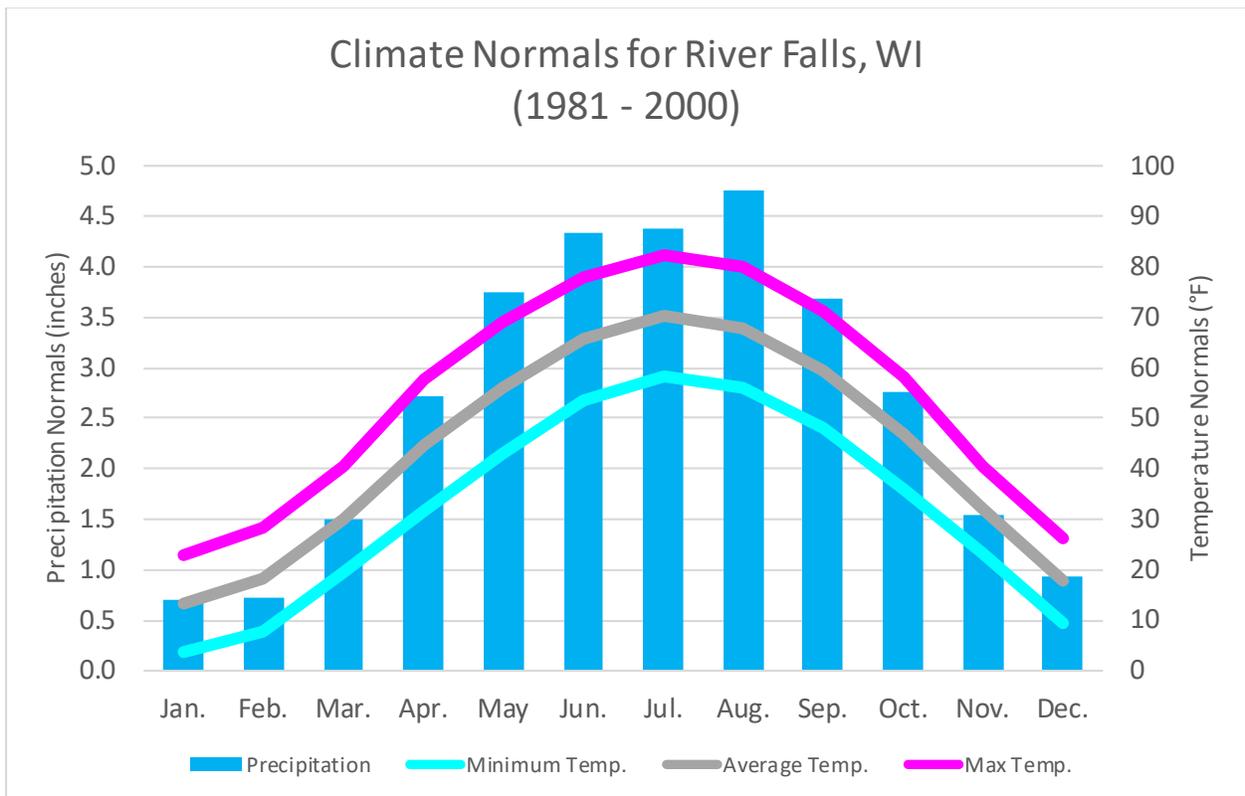


Figure 2-1. Climate Normals for River Falls, WI, (Reference 17)

NOAA's *Atlas 14* provides precipitation depth-duration-frequency curves for the entire United States. Figure 2-2 depicts the depth-duration-frequency curves for River Falls for the full ranges of storm durations, precipitation depths, and corresponding annual percent chance exceedance probabilities included in *Atlas 14*. Table 2-1 summarizes the estimated precipitation depths associated with the 24-hour storm and several annual percent chance exceedance probabilities.

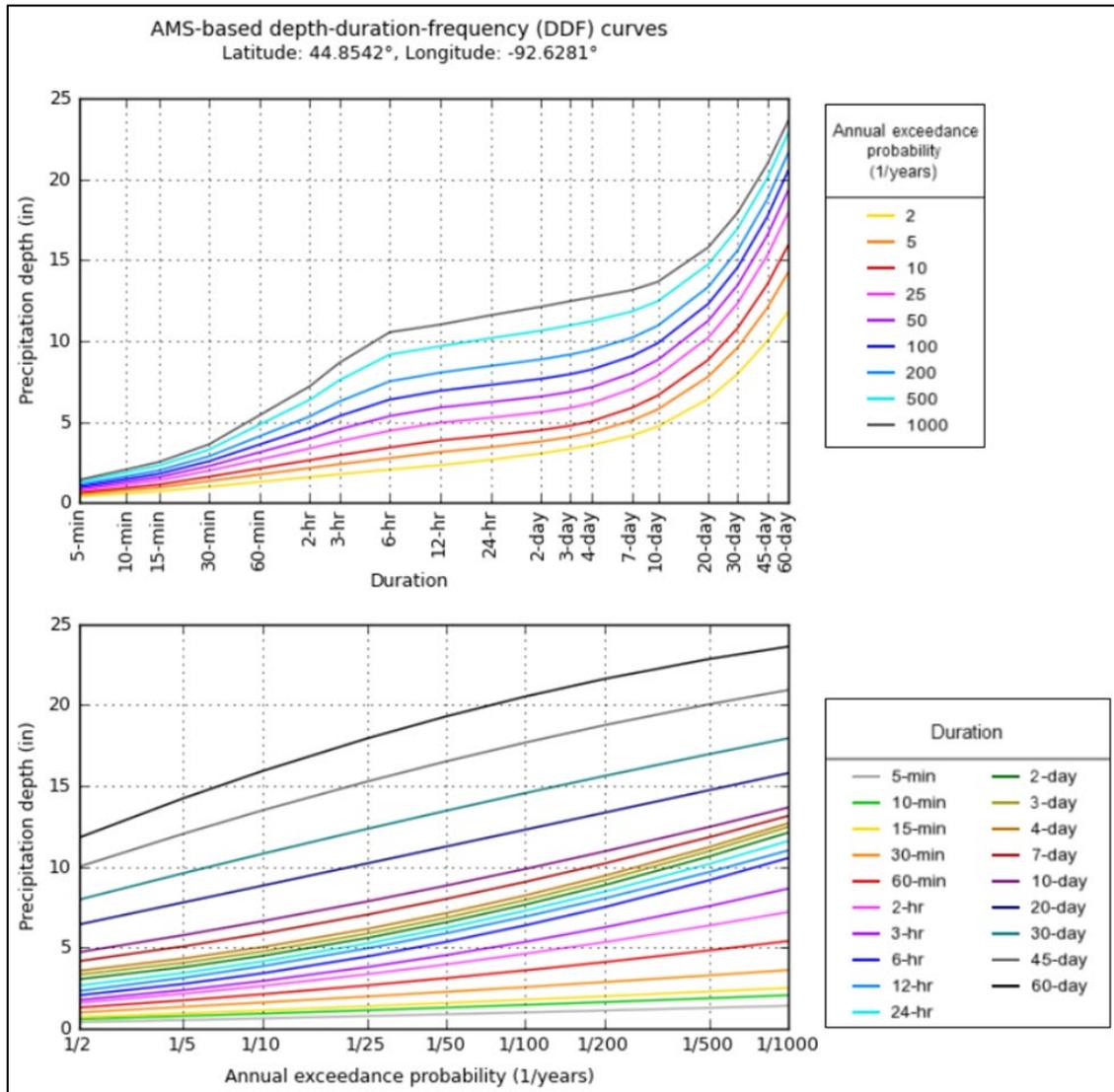


Figure 2-2. Annual Maximum Series-Based Depth-Duration-Frequency Curves for River Falls, WI, (Reference 7)

Table 2-1. Precipitation Depth Estimates for a 24-Hour Storm Duration for Varying Annual Percent Chance Exceedance Probabilities, (in inches), with 90% Confidence Intervals, (Reference 7).

Duration	Annual Percent Chance Exceedance Probability					
	50%	10%	2%	1%	0.5%	0.2%
24-hr	2.65 (2.20-3.23)	4.15 (3.41-5.07)	6.22 (4.86-8.01)	7.28 (5.48-9.52)	8.46 (6.09-11.3)	10.2 (7.02-13.8)

## 2.5 Flooding

Upon examining the annual maximum series of peak flows recorded by the USGS gage on the Kinnickinnic River, (05342000), it is apparent that there are at least two types of meteorological events that can result in flooding; intense rainfall brought by thunderstorms during the summer months and the rapid melting of snow during the spring. It is likely that rain on snow during the spring is another flood inducing event, but it is difficult to discern this from the streamgage record alone. Table 2-2 displays the annual peak streamflows recorded at the USGS's gage on the Kinni. Note that the annual maximum from 2020 was provided only as provisional data, subject to revision, at the time of this study; it is considered important to include in this study, however, as it would represent the largest flood ever recorded by this stream gage, and occurred after 6 inches of rain fell during a summer thunderstorm, (Reference 19).

The floods of 1894, 1934, and 1965 predate the installation of the USGS gage on the Kinnickinnic River, but are the most significant floods noted in the historical record. The flood of 1894 followed 8.0 inches of rainfall over 24 hours in mid-May. Thought to be the greatest flood ever recorded in the watershed, the 1894 flood washed out the Maple Street bridge, as well as the Prairie Mill dam and the Junction Falls dam, (Reference 20). Two floods occurred in 1934; the first in April when a rapid rise in temperature accompanied by 3.0 inches of rain quickly melted snow, and the second in September when 4.0 inches of rain fell in River Falls, with considerably more rain further up the watershed. 7.37 inches of rain fell in River Falls on June 1, 1965, with even more precipitation falling further up the watershed, (Reference 21).

Flow estimates for the three historical floods were made in a 1976 report by Roger Swanson, PhD, then an Associate Professor of Plant & Earth Science at the University of Wisconsin – River Falls, (Reference 21). Professor Swanson did this by calculating a flow-frequency curve for the County Road MM Bridge (Powell Avenue), and then equating the flood stages observed at that location to estimated discharges using that curve. In that report, he states that the 1934 and 1965 events were approximately 2% and 1% AEP events, and that the 1894 event “must have had a recurrence interval in excess of 200 years,” or had an AEP <0.5%, (Reference 21). As the 1976 report includes an estimate for the 0.2% event, it's assumed that flow for the 1894 event was above his estimate for the 0.5% event and below that of the 0.2% event.

The University Archives and Area Research Center at the University of Wisconsin – River Falls has additional information on these floods, including photographs. As the methods used for estimating the stage of these historical floods in the 1976 study are somewhat ambiguous, it may be possible to determine better estimates for the discharges associated with these floods by examining the photos and personal accounts available through the archives, and then correlating those to a hydraulic model. Conducting this thorough of an analysis of historical flooding of the Kinnickinnic River was outside the scope of this study, however. Figure 2-3 and

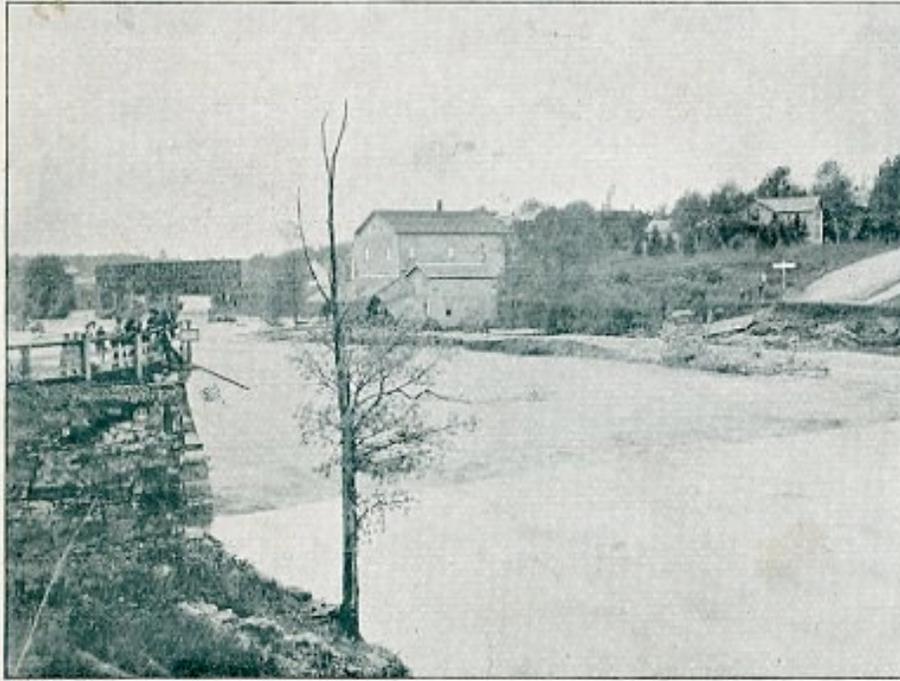
Figure 2-4 show photos taken of the 1894 and 1934 floods, respectively, that were available on the website for the University Archives and Area Research Center, (Reference 22).

*Table 2-2. Annual Peak Streamflow Measurements for Every Water Year on Record for the USGS's Gage on the Kinnickinnic River, (05342000), (Reference 5)*

Water Year	Date	Gage Height (feet)	Streamflow (cfs)
1917	Mar. 27, 1917	5.67	1,970
1918	Jun. 05, 1918	6.60	3,080
1919	Mar. 12, 1919	7.00	3,560
1920	Mar. 15, 1920	7.98	4,760
1921	Jun. 14, 1921	5.35	410
2002	Aug. 21, 2002	12.53	774
2003	Jun. 25, 2003	15.05	2,130
2004	Mar. 02, 2004	11.31	516
2005	Mar. 06, 2005	12.84	1,120
2006	Mar. 30, 2006	12.06	842
2007	Mar. 13, 2007	15.21	2,490
2008	Mar. 14, 2008	10.92	360
2009	Aug. 08, 2009	13.69	1,560
2010	Aug. 11, 2010	17.98	4,340
2011	Jun. 22, 2011	12.56	997
2012	Jun. 20, 2012	12.23	718
2013	Jun. 26, 2013	13.37	1,380
2014	Jun. 01, 2014	15.68	2,180
2015	Jul. 06, 2015	17.84	3,100
2016	Jul. 05, 2016	12.69	909
2017	May 29, 2017	13.32	1,230
2018	Aug. 24, 2018	12.24	745
2019	Apr. 17, 2019	18.02	3,160
2020	Jun. 29, 2020	21.00	6,300

*Table 2-3. Historical Flood Estimates for the Kinnickinnic River at River Falls, WI, (Reference 21)*

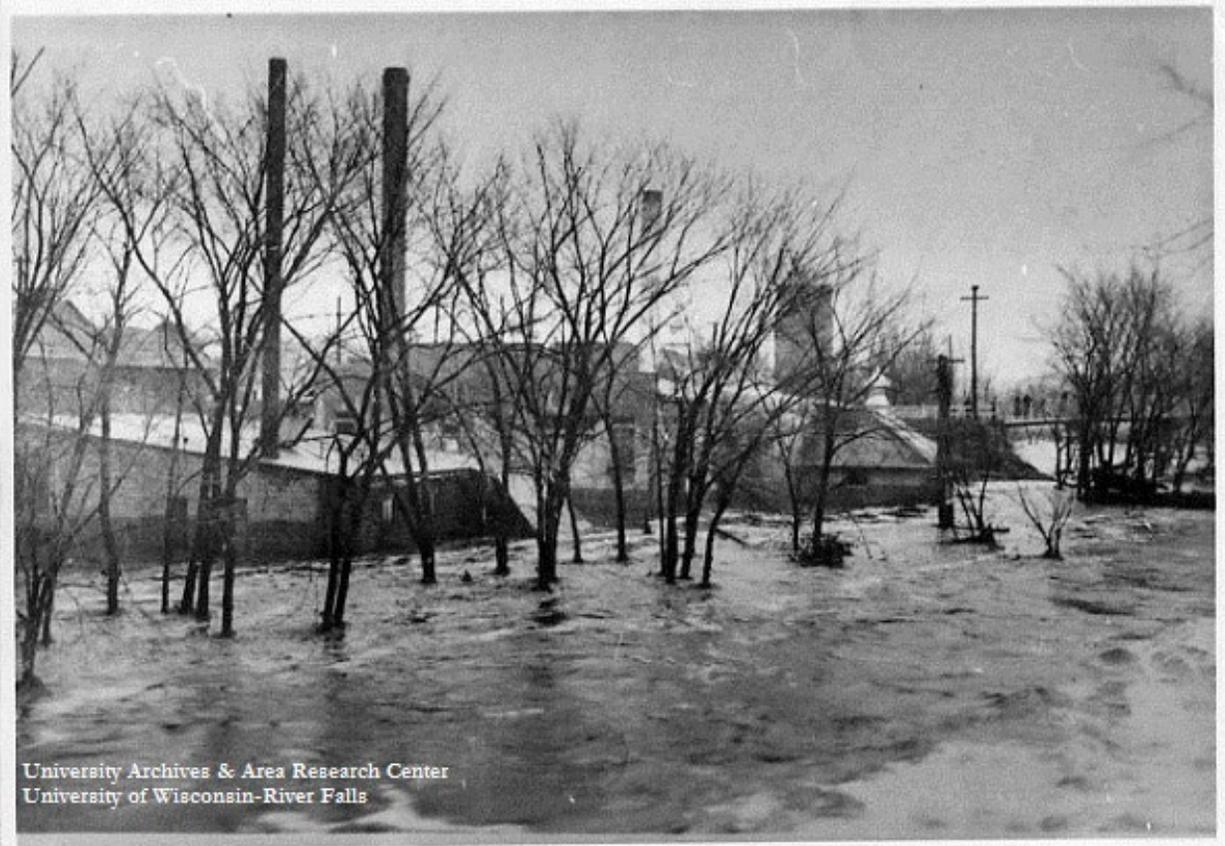
Flood	1976 AEP Estimates (%)	Discharge Estimate at County Road MM (cfs)
May 15, 1894	<0.5	8,900 – 9,900
April 5, 1934	1	8,600
June 1, 1965	2	7,200



The Flood of 1894,  
Site of Maple St. Bridge,  
River Falls, Wis.

CANT SAY  
the town  
has gone  
DRY  
now.

Figure 2-3. Photograph of the Former Site of the Maple Street Bridge during the 1894 Flood, (Reference 22)



University Archives & Area Research Center  
University of Wisconsin-River Falls

Figure 2-4. Photograph of an Unknown Location in Downtown River Falls during the 1934 Flood, (Reference 22)

## 3 Climate Change Analysis

### 3.1 Background

An underlying assumption in conducting a hydrologic analysis is that climatic conditions have remained stable within the watershed being analyzed for the duration of the period or record. Due to the existence of climate change, this assumption may or may not be true, and it is USACE policy to verify it by conducting a climate assessment. If the assumption of stationary hydrologic conditions is found to be false, then the hydrologic analysis is adjusted accordingly.

Two documents outline the USACE's current procedures for conducting a climate assessment: these include the USACE's Engineering and Construction Bulletin (ECB) 2018-14, *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects*, (Reference 23), and the USACE's Engineering Technical Letter (ETL) 1100-2-3, *Guidance for Detection of Nonstationarities in Annual Maximum Discharges*, (Reference 24). In accordance with these two documents, the USACE conducted a qualitative climate assessment of hydrologic conditions for the Kinnickinnic River watershed in conjunction with the main River Falls Hydroelectric study. The full climate assessment is included with this document as Appendix 1, with key points summarized in Section 3.2.

### 3.2 Summary

An extensive review of climate change literature demonstrates consensus among the scientific community that average temperatures have increased in the region encompassing the Kinnickinnic River watershed and that heavy precipitation events have become increasingly frequent and intense. These trends are projected to continue into the future. This same literature review, however, showed a lack of consensus on if and how peak streamflows have changed over the same period, and how they may change in the future.

A first order statistical analysis of observed annual peak streamflow records at two USGS gages in the vicinity of the Kinnickinnic River watershed found no statistically significant trends or nonstationarities. A third site analyzed exhibited evidence of nonstationarity, but the cause of what is driving the shifts in statistical properties there is unclear. Additionally, an analysis of projected, peak streamflows within the St. Croix River watershed did not show a statistically significant trend through the end of the 21<sup>st</sup> century. A screening level vulnerability assessment carried out for the St. Croix River watershed did not indicate that the area is particularly vulnerable to the impacts of climate change in terms of high flow conditions.

Taking the entirety of the climate assessment into account, the hydrologic analysis for this study was not altered. Although temperature and precipitation have changed over time, the remaining statistics describing hydrologic conditions within the region, particularly peak streamflow, either appear stable or there is a lack of consensus on if they have changed.

## 4 Hydrologic Analysis

### 4.1 Basin Delineation

The HEC-RAS model created by SEH for their 2017 study includes three cross-sections for steady-state flow inputs, (Reference 6). To aid in updating the discharge estimates for these three locations, the HEC-RAS model was georeferenced using version 2.3 of Esri’s ArcGIS Pro software, (Reference 23), the Kinnickinnic Rivers centerline shapefile available through the USGS’s National Hydrography Dataset, (Reference 26), and the “World Imagery” basemap available in ArcGIS Pro. Once the steady-state flow input locations were determined, the following datasets and tools were used to determine the drainage areas and longest flow-paths for each of the three flow input locations, as well as the USGS gage on the Kinnickinnic River:

- The Kinnickinnic River watershed boundary, (Reference 11)
- The Kinnickinnic River’s HUC-12 subwatershed boundaries, available in the USGS’s National Watershed Boundary Dataset, (Reference 11)
- The “USA Topo Maps” basemap (available in ArcGIS Pro)
- The USGS’s 1 arc-second digital elevation model, (Reference 27), in conjunction with ArcGIS Pro’s Watershed Tool and Spatial Analyst+ Toolbox, (Reference 28)
- The Kinnickinnic River’s stream centerline, available in the USGS’s National Hydrography Dataset, (Reference 26)

Plate 1 is a map depicting the Kinnickinnic River, its watershed boundary, the three steady-state flow input locations, the location of the USGS gage on the Kinnickinnic River, the locations of Powell Falls and Junction Falls, and the outlines of the four watersheds determined through the process described in the previous paragraph. It should be noted that utilizing the USGS’s StreamStats tool for this process was attempted, (Reference 29), but the results did not agree well with known watershed information. For example, the USGS states that the Kinnickinnic River gage has a drainage area of 165 square miles, (Reference 5). However, the StreamStats tool determined a drainage area of 148 square miles, approximately a 10% difference. Table 4-1 shows the drainage areas and main channel slopes determined through ArcGIS Pro for the HEC-RAS model’s three flow input locations and the USGS gage on the Kinnickinnic River.

*Table 4-1. Watershed Characteristics Associated with the HEC-RAS Model’s Flow Input Locations and the USGS Gage on the Kinni*

Location	HEC-RAS Model Cross-Section	Drainage Area, A (square miles)	Main Channel Slope (feet/mile)
Upstream of State Route 35	RS-71222	102.9	7.020
Upstream Junction Falls Dam	RS-66059	112.8	6.898
Upstream of Powell Falls Dam	RS-53219	134.8	6.814
USGS Gage 05342000	N/A	162.5	9.896

## 4.2 Soil and Land Use Characteristics

Average saturated hydraulic conductivity ( $K_{sat}$ ) is often used as a proxy for how quickly precipitation can infiltrate the soil in a watershed. Soils with higher infiltration rates typically produce less direct runoff than soils with lower infiltration rates do.  $K_{sat}$  values were determined for each of the drainage areas, (defined in Section 4.1 of this report), using the Natural Resource Conservation Service’s (NRCS) Soil Survey Geographic Database (SSURGO), available through the U.S. Department of Agriculture’s (USDA) Web Soil Survey tool, (Reference 30). After importing shapefiles for each of the subbasins into the Web Soil Survey tool to define the “Area(s) of Interest”, the following parameters were chosen to extract  $K_{sat}$ :

- Aggregation Method = Weighted Average
- Tie Break Rule = Fastest
- Layer Option = Surface Layer

Once the Web Soil Survey tool is run it creates a report that defines every type of soil found within the defined “Area of Interest”, the number of acres defined as each soil type, and the  $K_{sat}$  values associated with each soil type. Using the generated reports, an area-weighted average  $K_{sat}$  value was determined for each subbasin.

Table 4-2. Area-Weighted Average Saturated Hydraulic Conductivity Values for Each Subbasin

Location	HEC-RAS Model Cross-Section	Average Saturated Hydraulic Conductivity, $K_{sat}$ (micrometers/second)
Upstream of State Route 35	RS-71222	15.06
Upstream Junction Falls Dam	RS-66059	14.87
Upstream of Powell Falls Dam	RS-53219	15.97
USGS Gage 05342000	N/A	16.34

It should be noted that attempts were made to utilize the USGS’s StreamStats tool in determining  $K_{sat}$  values for each subbasin, (Reference 29). However, the values it output were on magnitude of 113 micrometers per second, approximately 8 times the  $K_{sat}$  values estimated using the USDA’s Web Soil Survey tool, (Reference 30). Additionally, the values estimated using the Web Soil Survey tool correlate well to maps of  $K_{sat}$ , including Plate 2 and Figure 2-1, respectively, of the 2003 and 2017 versions of the USGS’s *Flood Frequency Characteristics of Wisconsin Streams* report, (References 10 and 31). After considering the other information on  $K_{sat}$  available for the watershed, the StreamStats tool was judged to be inaccurate for the Kinnickinnic River basin.

The percentage of a watershed that can be defined as “forest” was found to be an important parameter/predictor for estimating flood discharges in the region that the Kinnickinnic River

watershed is located in the USGS’s 2017 paper titled *Flood Frequency Characteristics of Wisconsin Streams*, (Reference 10). Land cover data for the entirety of the United States is available through the Multi-Resolution Land Characteristics Consortium’s (MRLC) National Land Cover Database (NLCD) up to 2016 (at the time of this study), (Reference 32). Areas defined as “forest” within the NLCD are classified as follows:

- **41, Deciduous Forest:** areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
- **42, Evergreen Forest:** areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
- **43, Mixed Forest:** areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.

To determine the percentage of each subbasin classified as forest, NLCD data was imported into ArcGIS Pro version 2.3. Areas classified as forest that fell within each subbasin were summed, and then divided by the total area of each subbasin. Table 4-3 displays the percentage of each subbasin determined to be forest through this process.

*Table 4-3. Percent Area of Each Subbasin that is Classified as Forest in the NLCD, (Reference 32)*

Location	HEC-RAS Model Cross-Section	Forest Land Use, F (%)
Upstream of State Route 35	RS-71222	12
Upstream Junction Falls Dam	RS-66059	12
Upstream of Powell Falls Dam	RS-53219	15
USGS Gage 05342000	N/A	17

It’s important to note, if this study is conducted again in the future, that as land is converted from fields or woodlands to roads and parking lots, it loses its ability to absorb rainfall. Urbanization increases the amount of impervious areas, causing runoff to be up to two to six times that of what would have occurred on natural terrain, (Reference 33). As the population of River Falls likely continues to grow, having more than doubled since 1970, it’s possible that an increase in impervious areas in the Kinnickinnic River basin will follow and contribute to increased runoff, (Reference 34).

### 4.3 USGS Regression Equations for Wisconsin

The USGS completed a study in 2017, (updated in 2020), relating watershed characteristics to flood frequency discharges for 360 gaged Wisconsin streams. A statistical analysis of these 360 gaged sites was used to develop regional regression equations that can be used for estimating flood discharges at ungaged sites for annual exceedance probabilities (AEP) ranging from the 50% AEP event to the 0.2% AEP event. AEP is defined as the chance that a certain streamflow condition will be met or exceeded in any year. For example, there may be a 1 in 100 chance (1% AEP) that a streamflow of 15,000 cubic feet per second (cfs, ft<sup>3</sup>/s) will occur during any year in a particular stream, (Reference 33). Data at these gaged locations was collected through water year 2010. Stations with a minimum of 10 years of record were used in the statistical regression analysis of rural streams, (Reference 10).

The 2017 USGS study separated stream gages in Wisconsin into eight areas of similar physiographic characteristics and developed a unique set of regression equations for each area. The Kinnickinnic River watershed falls within Area 5 in the analysis, which primarily encompasses the Driftless Area. Table 4-5 shows a summary of the basin characteristics used to define the regression equations for Area 5, along with the range of applicable values that can be used for other ungaged sites.

Regression equations relating basin characteristics to flood frequency were developed using multiple linear regression analysis. The principal method of regression analysis used to develop the 2017 regression equations was the generalized least squares (GLS) technique, (Reference 39). Significant regression characteristics included in the adopted equations are drainage area (A, square miles, mi<sup>2</sup>), saturated hydraulic conductivity ( $K_{sat}$ , micrometers per second,  $\mu\text{m/s}$ ), and forest cover (F, percent). A summary of the regression equations for the region encompassing the Kinnickinnic River watershed, (Area 5), is shown in Table 4-4.

The standard error of prediction of the 2017 regression equations for the 1% event varied between 56 percent and 70 percent for Wisconsin streams, (Reference 10). This standard error value is quite high and illustrates the large amount of uncertainty which arises from using regression equations to develop estimates for flood frequency analysis.

Regression equations are useful tools for estimating frequency curves at sites without observed data. However, this technique has limitations; the regression equations presented in this section of the report should only be applied to rural sites which are not affected by regulation from hydraulic structures. The regression characteristics are only valid within the area or region they were developed. Flood estimates can be made using basin characteristics outside the range of values shown in Table 4-5 from which the equations were derived, but it is not possible to estimate the error associated with those results using the methods presented in the regression study.

Table 4-4. 2017 USGS Regression Equations for the State of Wisconsin, Area 5, (Reference 10)

Best-fit equation						SEP, in percent
Area 5, 26 streamflow-gaging stations						
$Q_{50p}$	=	183	$A^{0.701}$	$K_{sat}^{-0.540}$	$F^{-0.422}$	47.5
$Q_{20p}$	=	521	$A^{0.707}$	$K_{sat}^{-0.701}$	$F^{-0.403}$	45.4
$Q_{10p}$	=	951	$A^{0.709}$	$K_{sat}^{-0.796}$	$F^{-0.383}$	45.1
$Q_{4p}$	=	1,870	$A^{0.709}$	$K_{sat}^{-0.906}$	$F^{-0.358}$	46.0
$Q_{2p}$	=	2,950	$A^{0.710}$	$K_{sat}^{-0.982}$	$F^{-0.340}$	47.7
$Q_{1p}$	=	4,530	$A^{0.709}$	$K_{sat}^{-1.05}$	$F^{-0.316}$	48.5
$Q_{0.5p}$	=	6,750	$A^{0.709}$	$K_{sat}^{-1.12}$	$F^{-0.302}$	50.1
$Q_{0.2p}$	=	11,100	$A^{0.708}$	$K_{sat}^{-1.21}$	$F^{-0.277}$	51.1

SEP, standard error of prediction;  $Q_{xp}$ , discharge for x-percent annual exceedance probability flood; A, drainage area, in square miles;  $K_{sat}$ , saturated hydraulic conductivity, in micrometers per second; F, land use classified as forest, (percent + 0.01)/100)

Table 4-5. The Typical Range of Basin Characteristics Used in Developing the 2017 USGS Regression Equations for the State of Wisconsin, Area 5, (Reference 10)

Basin characteristic	Minimum	Average	Maximum
Area 5, 26 streamflow-gaging stations			
Drainage area, mi <sup>2</sup>	0.27	264	2,082
Saturated hydraulic conductivity, $\mu\text{m/s}$	6.63	22.9	63.4
Land use, forest, percent	13.0	39.3	67.9

Table 4-6 summarizes the estimated discharges for the 50%, 10%, and 1% AEP events, determined using the 2017 USGS regression equations, and associated with the three HEC-RAS model steady-state flow input locations and the USGS gage on the Kinnickinnic River. It's interesting to note how the estimated discharge stays the same from cross-section RS-66059 downstream to RS-53219, and even drops slightly for the 1% AEP event. This is likely not reflective of reality, considering that the south branch of the Kinnickinnic River enters the main branch between these two cross-sections and consists of a primarily urban watershed. Cross-section RS-53219 also has a drainage area that's approximately 22 square miles larger than that of cross-section RS-66059's. This is an example of the significant uncertainty associated with the regression equations, and may also reflect the unique geomorphological environment that the Kinnickinnic River watershed is located in, described in Section 2.3. The results of the analysis

that utilized the USGS regression equations would likely not be suitable as direct inputs into the HEC-RAS model, but may help inform the expected magnitudes of discharges associated with the AEP floods of interest at these locations.

*Table 4-6. Discharge Estimates Associated with the 50%, 10%, and 1% AEP Events Determined Using the 2017 USGS Regression Equations for the State of Wisconsin, Area 5*

HEC-RAS Model Cross-Section/Location	50% AEP Discharge (cfs)	10% AEP Discharge (cfs)	1% AEP Discharge (cfs)
RS-71222	2,700	6,600	13,800
RS-66059	2,800	7,000	14,600
RS-53219	2,800	7,000	14,500
USGS Gage 05342000	3,000	7,500	15,600

#### 4.4 Drainage Area Transfer Method

General relations methodology (GRM), also known as the drainage area transfer method, can be applied to estimate flow at a location on a river by relating flow at a gaged location to the ratio of the drainage areas at both sites, raised to an exponent. The GRM is given by Equation 1 below.

*Equation 1. General Relations Method Equation, (Reference 35)*

$$\left(\frac{DA_1}{DA_2}\right)^n = \frac{Q_1}{Q_2}$$

Where: DA<sub>1</sub> = ungaged site

DA<sub>2</sub> = gaged site

Q<sub>1</sub> = flow at ungaged site for a given exceedance probability

Q<sub>2</sub> = flow at gaged site for the same exceedance probability

n = regional exponent

The drainage area transfer exponent, n, was determined from statistical regression analysis of 184 stream gages in the State of Wisconsin which had a minimum of 10 recorded annual peak flood events. The state of Wisconsin was divided into five areas based on similar physical basin characteristics to develop a transfer coefficient for each area. The Kinnickinnic River basin is in an area where the regional n value was determined to be 0.68, (Reference 35). This n value was used throughout the Bulletin 17C analysis, described in Section 4.5, to transfer frequency curves from one location in the watershed to another.

#### 4.5 Bulletin 17C Analysis for the USGS Gage on the Kinnickinnic River

Through a process called flood frequency analysis, statistical techniques can be used to estimate the probability that a given streamflow or rainfall event will occur. Methods for estimating annual exceedance probabilities are outlined in *Bulletin 17C* and are used to estimate discharge frequencies for the Kinnickinnic River in this analysis, (Reference 9).

The USGS gage on the Kinnickinnic River near River Falls, WI, (USGS gage 05342000), is located on the right bank of the Kinnickinnic River, approximately 325 feet upstream from County Trunk Highway F, 1.9 miles upstream from the river’s mouth, and 4.8 miles downstream from Powell Falls dam. The drainage area at the Kinnickinnic River gage is 162.5 square miles. The available systematic observed record, (also discussed in Section 2.5), at the gage extends from October 1916 to September 1921 and from July 2002 to present. At the time of this hydrologic analysis, the most recently published annual peak flow was the 2019 value, for a total of 23 systemic peak flow values, (not including 2020) (Reference 5).

In addition to the systematic records of annual peak flow, the discharge estimates for the floods of 1894, 1934, and 1965, (described in Section 2.5), are included as historical records, as well as the peak flow record for the 2020 event (that was only available as provisional data at the time of the writing of this report). The drainage area transfer method, (described in Section 4.4), was applied to estimate the discharges that would have occurred at the Kinnickinnic River gage during these floods had the gage been active during these events. As County Road MM (Powell Avenue) is located approximately 1 mile downstream from cross-section RS-66059 within the HEC-RAS model, (Reference 6), and approximately 1 mile upstream of the entrance of the south branch of the Kinnickinnic River, it’s assumed that the drainage area contributing to the historical floods is approximately the same as that for cross-section RS-66059.

*Table 4-7. Estimated Historical Flood Discharges at the USGS Gage on the Kinnickinnic River*

Location	Drainage Area (square miles)	1894 Flood Discharge (cfs)	1934 Flood Discharge (cfs)	1965 Flood Discharge (cfs)
RS-66059	112.8	8,900 - 9,900	8,600	7,200
USGS Gage 05342000	162.5	11,400 - 12,700	11,000	9,200

It should be noted that, due to the relatively short systematic record, a record extension was attempted for the USGS gage on the Kinnickinnic River using the methods described in Appendix 8 of *Bulletin 17C*, (Reference 9). In order to extend the record of a streamgage, another near-by streamgage in a hydrologically similar watershed must have an overlapping record of at least 10 years. Annual peak flows recorded at each gage during the same water year must also show a high degree of correlation with one-another. After fitting an exponential

trend line to the dataset plotted in log-log space, the correlation between peak annual flows at the two gages must have a correlation coefficient, R value, of at least 0.8.

After combing through dozens of nearby gages for unregulated streams in the surrounding area, only 13 had a long enough overlapping record with the Kinnickinnic gage that also had records predating its installation. Unfortunately, out of all of the streamgages for which this process was attempted, none showed a sufficient enough of a correlation in annual peak flows to the gage on the Kinni – this was even true for the USGS gage on the south branch of the Kinnickinnic River in River Falls (USGS gage 05341900), which showed the highest correlation. This is likely reflective of the unique geomorphological environment that the Kinnickinnic River finds itself in, described in Section 2.3. Additionally, as one of the primary flood mechanisms in the Kinnickinnic River is severe thunderstorms, it becomes increasingly unlikely that a separate storm of a similar severity would impact another watershed in the same water year as the storm frequency decreases.

*Table 4-8. Streamgages with a Sufficient Overlapping Systematic Record that were Examined for Use in a Record Extension*

USGS Gage	Correlation Coefficient (R Value) with USGS Gage 053242000, Kinnickinnic River near River Falls, WI
Kinnickinnic River Tributary at River Falls, WI, USGS Gage 05341900	0.73
Apple River near Somerset, WI, USGS Gage 05341500	0.01
Buffalo River near Mondovi, MN, USGS Gage 05371920	0.69
Cannon River at Welch, MN, USGS Gage 05355200	0.08
Hay River at Wheeler, WI, USGS Gage 05368000	0.64
Kettle River below Sandstone, MN, USGS Gage 05336700	0.34
Lightning Creek at Almena, WI, USGS Gage 05367700	0.00
Snake River near Pine City, MN, USGS Gage 05338500	0.37
Spring Creek near Durand, WI, USGS Gage 05370900	0.21
St. Croix River at St. Croix Falls, WI, USGS Gage 05340500	0.25
Straight River near Faribault, MN, USGS Gage 05353800	0.08
Vermillion River near Empire, MN, USGS Gage 05345000	0.21
Zumbro River at Zumbro Falls, MN, USGS Gage 05374000	0.09

To apply the *Bulletin 17C* methods for estimating a flow-frequency curve for the Kinnickinnic River gage, a Bulletin 17 analysis was conducted using version 2.2 of the Hydrologic Engineering Center – Statistical Software Package (HEC-SSP), (Reference 42). Low and high perception thresholds were set to values of 11,400 cfs and infinity, respectively, for the periods of 1854 to 1893, 1895 to 1916, and 1922 to 1933. The discharge of 11,400 cfs for these periods is equal to the lower discharge estimate for the 1894 flood. The Prairie Mill dam, the first dam on the Kinni constructed in 1854, was one of several dams that washed out during the 1894 event,

(Reference 21). Based on the historical record, it's assumed that any flood would have been recorded had it been equal to or greater in magnitude to the 1894 flood during these periods. Similarly, low and high perception thresholds were set to 11,000 cfs and infinity, respectively, for the period from 1935 to 1964 following the 1934 event, and to 9,200 and infinity, respectively, for the period from 1966 to 2001 following the 1965 event. Table 4-9 summarizes the perception thresholds used in the flood frequency analysis, as they appear in HEC-SSP.

Table 4-9. Perception Thresholds Used in the Flood Frequency Analysis

Perception Thresholds				
Start Year	End Year	Low Threshold	High Threshold	Comments
1854	2020	0.0	inf	Total Record
1854	1893	11400.0	inf	Historical Period
1895	1916	11400.0	inf	Historical Period
1922	1933	11400.0	inf	Discontinued Record
1935	1964	11000.0	inf	Historical Period
1966	2001	9200.0	inf	Historical Period

The Expected Moments Algorithm was used to estimate the statistical parameters and fit a Log Pearson Type III distribution to the available systematic streamflow data, as well as the discharge estimates gleaned from the historical record. Hirsh-Stedinger plotting positions were used to plot the observed events. A Median plotting position would have been used to plot low outliers, if any were detected. A weighted skew value was calculated, and adopted, using results from the 2017 USGS report on *Flood Frequency Characteristics of Wisconsin Streams*, (Reference 39). The weighted/adopted skew value of -0.159 was calculated by weighting the regional skew value of -0.23 with an MSE of 0.309, estimated in that report, and a calculated station skew of 0.018. Table 4-10 summarizes the flood frequency curve, and associated statistics, that was calculated through this process. Figure 4-1 shows the estimated flood frequency curve and the systematic and historical peak flow events included in the analysis.

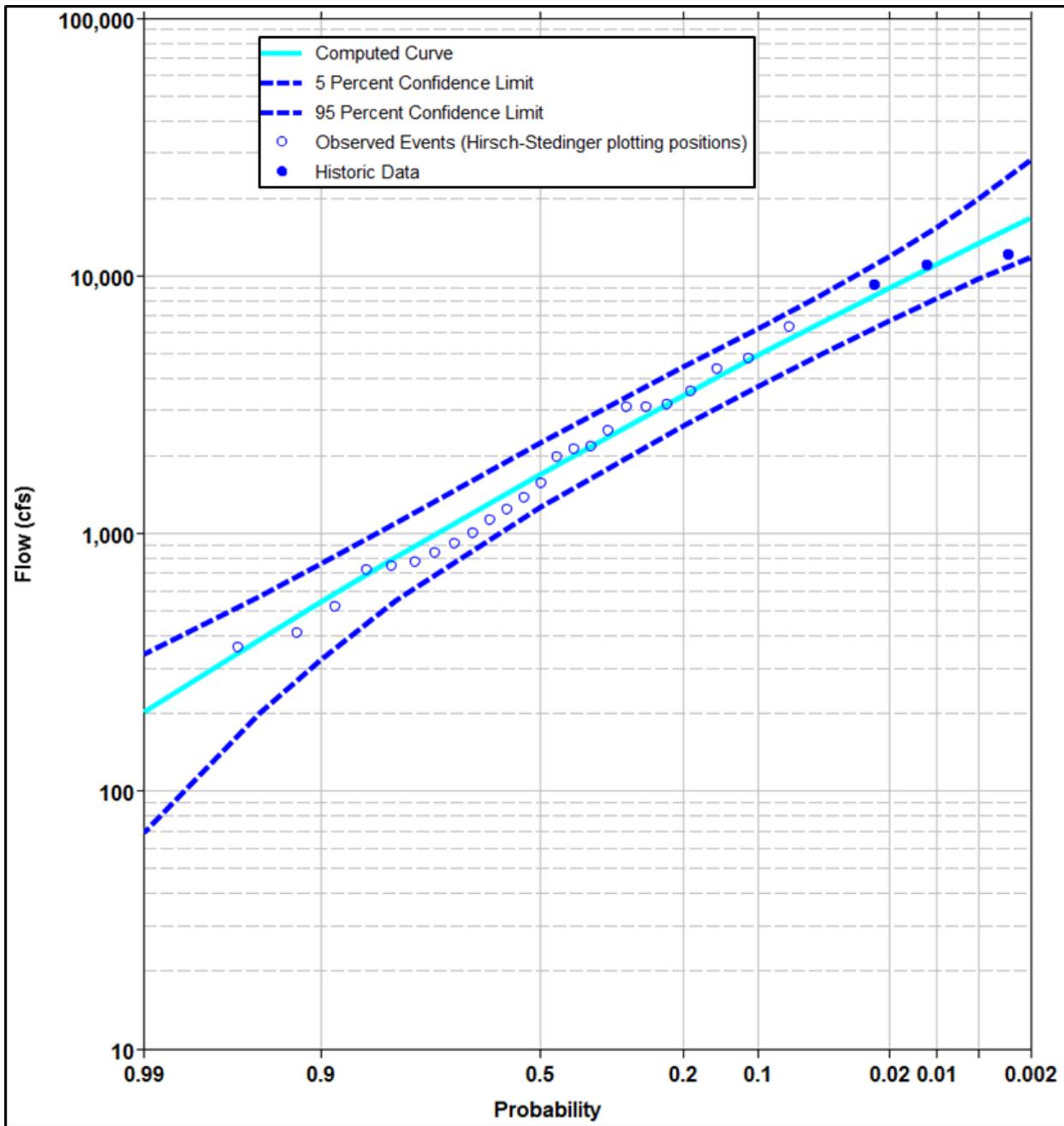


Figure 4-1. Flood Frequency Curve for the USGS Gage on the Kinnickinnic River (05342000), Calculated Using Bulletin 17C Methods

In practice, a minimum of 30 years of flood data is used for developing a flow-frequency curve. *Bulletin 17C* officially states that 10 years of information is the absolute minimum for frequency analysis and still may not produce an appropriate estimate of events like the 1% AEP event. Although the period of record for the Kinnickinnic River is less than 30 years, it should be considered appropriate for this analysis for a few reasons:

- The analysis includes three historical floods, one dating back to 1894, with knowledge of the river dating back to 1854, providing a historical context for flood magnitude estimations
- The 2020 event was relatively large, on the order of a 5% AEP event, and is included in the analysis
- 24 years of record is greater than the minimum recommended in *Bulletin 17C*

Table 4-10. Flood Frequency Curve for the USGS Gage on the Kinnickinnic River (05342000), Calculated Using Bulletin 17C Methods

Exceedance Probability	Peak Discharge Estimate (cfs)	90% Confidence Limits (cfs)	
		5%	95%
0.002 (0.2%)	16,690	28,060	11,740
0.005 (0.5%)	13,350	20,000	9,690
0.01 (1%)	11,070	15,390	8,170
0.02 (2%)	9,000	11,820	6,710
0.05 (5%)	6,550	8,320	4,950
0.1 (10%)	4,910	6,250	3,740
0.2 (20%)	3,440	4,450	2,620
0.5 (50%)	1,700	2,240	1,260
Statistics			
Mean	3.219	Systematic Record	24 Years
Standard Deviation	0.374	Historical Period	167 (1854-2020)
Station Skew	-0.061	Systematic Years in Record	1917-1921, 2002-2020
Regional Skew	-0.23	Missing Flows	140 Years
Regional Skew MSE	0.309	Low Outlier Test	Multiple Grubbs-Beck
Weighted Skew (Adopted)	-0.159	Number of Low Outliers	0

#### 4.6 Adopted Flow-Frequency Curve

Discharges for the three steady-state flow input locations were estimated using the flood frequency curve calculated for the Kinnickinnic River gage and the GRM methodology described in Section 4.4. Note that *Bulletin 17C* states that the results from a flood frequency analysis examining annual peak flows are most applicable to the upper end of the flood frequency curve, including and above the 10% AEP event, (Reference 9). The flow-frequency curves and

discharge estimates for the three steady-state flow input locations are compared against those generated for the Kinnickinnic River gage in Table 4-11 and Figure 4-2. The flow-frequency curves for the three flow input locations are also displayed in Figure 4-3 through Figure 4-5 and summarized in Table 4-12 through Table 4-14, along with their associated 90% confidence intervals.

The 90% confidence interval for the unaged frequency curves was estimated using the order statistics approach within HEC-SSP's General Frequency Analysis tool, (Reference 36). To compute the confidence limits, 12 years of record were used to define the equivalent record length required for the order statistics approach, along with the flow-frequency curves for each of the three steady-state flow input locations (summarized above). The value of 12 years was chosen in accordance with Engineering Manual (EM) 1110-2-1619, (Reference 37). According to EM 1110-2-1619, in the situation that a flow-frequency curve was estimated from an analytical distribution for a long-period gage in the same watershed, as is the case here, 50% to 90% of the systematic record length for that gage should be used. As the systematic record length of the USGS's gage on the Kinnickinnic River is 24 years, to be conservative, an equivalent record length equal to 50% of the length of the systematic record, 12 years, was chosen for this analysis.

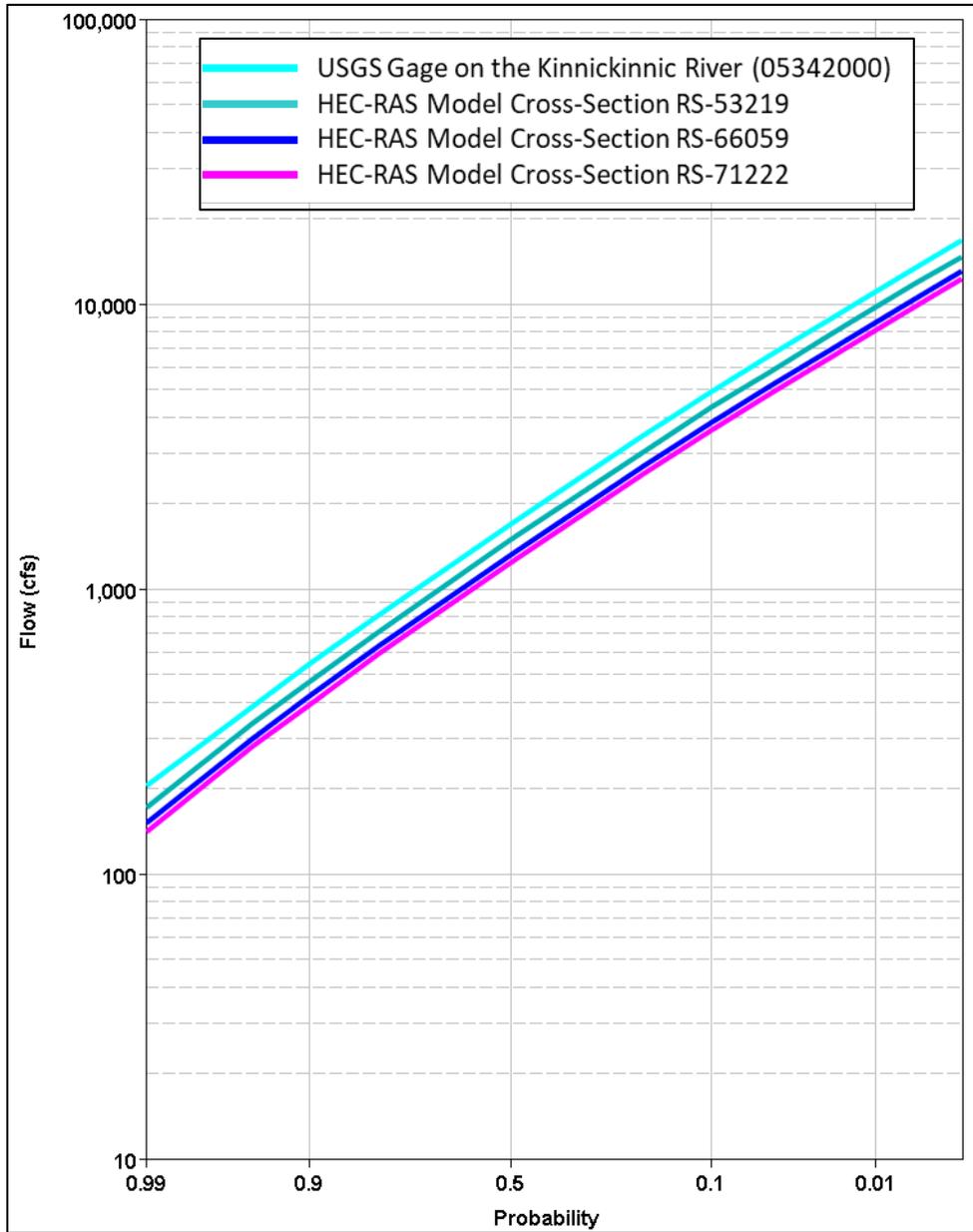


Figure 4-2. Graphical Comparison of Calculated Flow-Frequency Curves for Points of Interest to this Project

Table 4-11. Comparison of Discharge Estimates for the Points of Interest to this Project

Exceedance Probability	Discharge Estimates (cfs)			
	Cross-Section RS-71222	Cross-Section RS-66059	Cross-Section RS-53219	USGS Gage 05342000
0.002 (0.2%)	12,200	13,000	14,600	16,690
0.01 (1%)	8,110	8,630	9,740	11,070
0.02 (2%)	6,590	7,020	7,920	9,000
0.1 (10%)	3,590	3,830	4,320	4,910

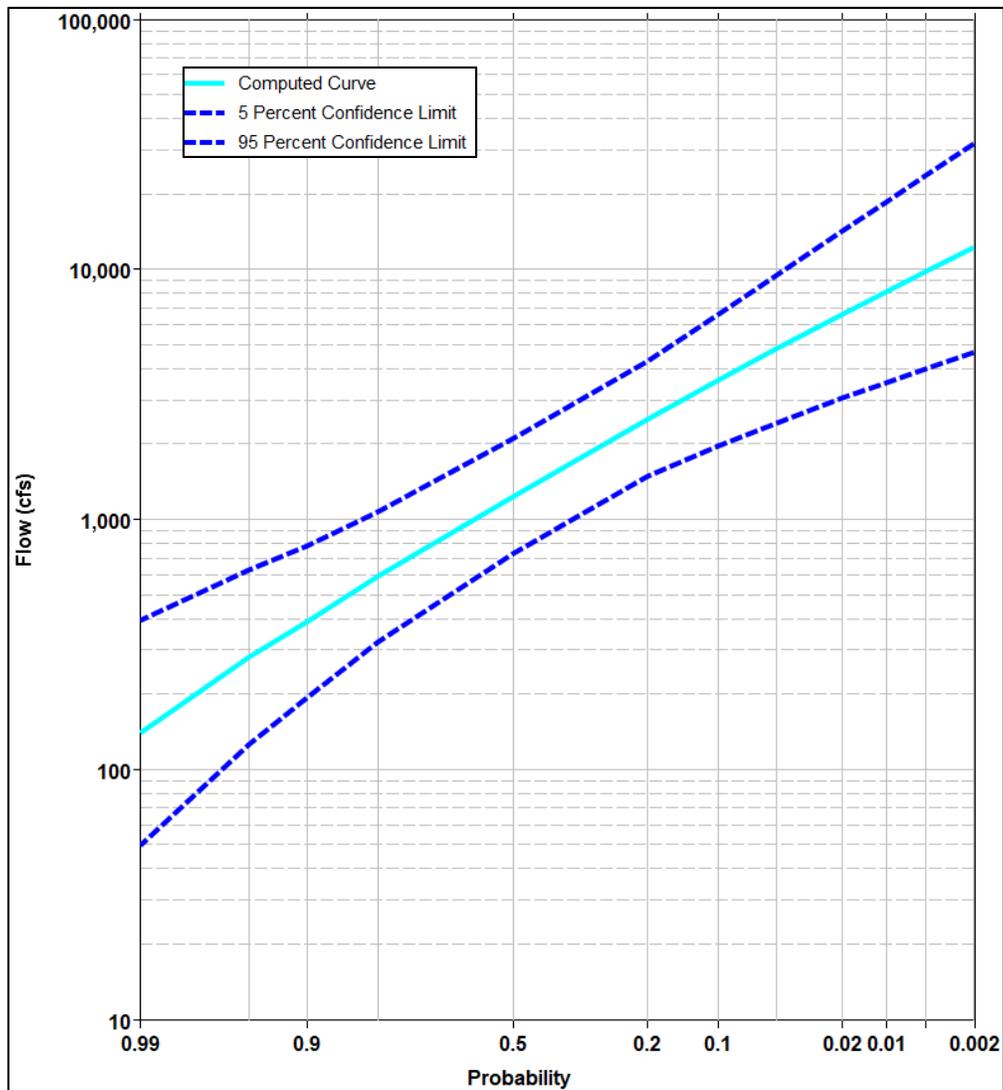


Figure 4-3. Flow-Frequency Curve Calculated for Cross-Section RS-71222

Table 4-12. Discharge Estimates for the HEC-RAS Model Steady-State Flow Input Location at Cross-Section RS-71222 (Upstream of State Route 35)

Exceedance Probability	Peak Discharge Estimate (cfs)	90% Confidence Interval (cfs)	
		5%	95%
0.002 (0.2%)	12,200	31,900	4,660
0.005 (0.5%)	9,780	23,800	4,000
0.01 (1%)	8,110	18,600	3,520
0.02 (2%)	6,590	14,200	3,040
0.05 (5%)	4,800	9,480	2,420
0.1 (10%)	3,590	6,580	1,950
0.2 (20%)	2,520	4,280	1,480
0.5 (50%)	1,240	2,100	730

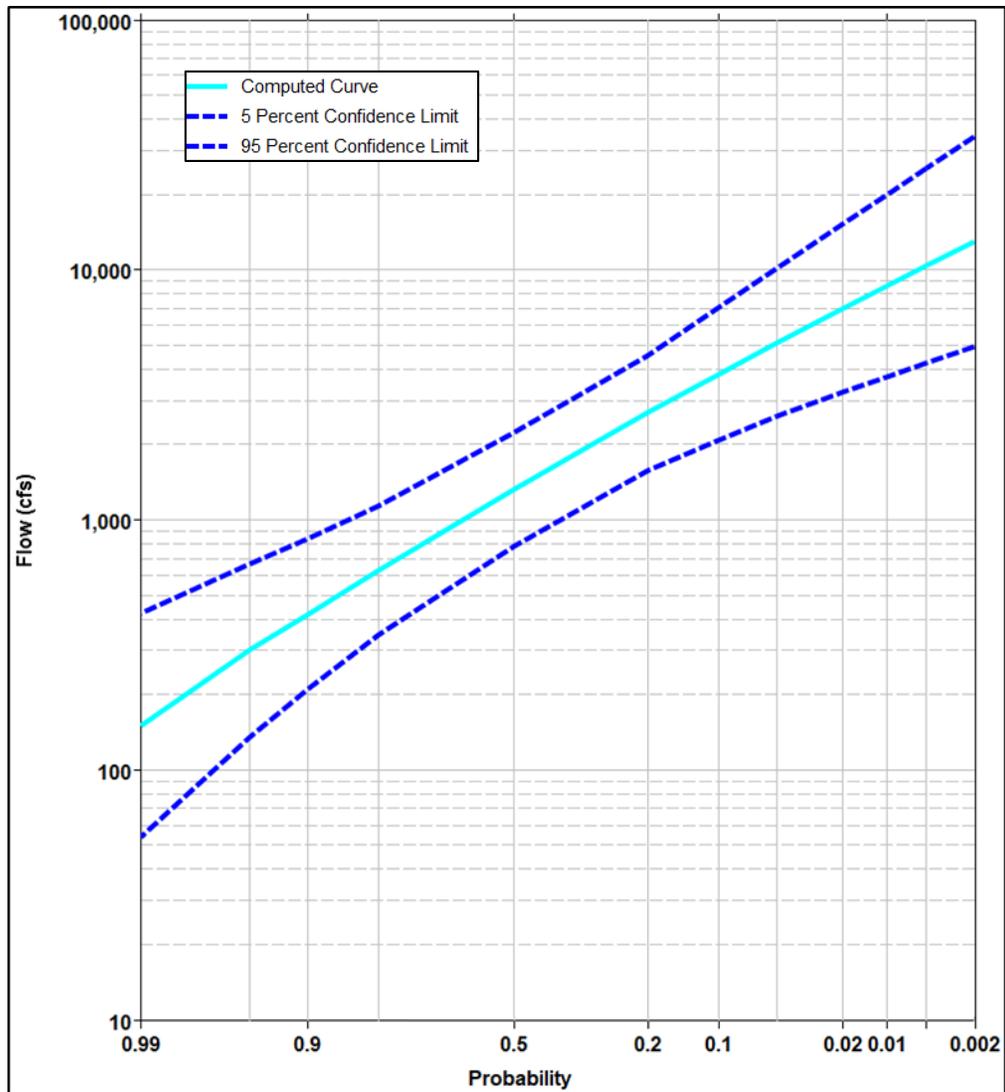


Figure 4-4. Flow-Frequency Curve Calculated for Cross-Section RS-66059

Table 4-13. Discharge Estimates for the HEC-RAS Model Steady-State Flow Input Location at Cross-Section RS-66059 (Upstream of Junction Falls)

Exceedance Probability	Peak Discharge Estimate (cfs)	90% Confidence Interval (cfs)	
		5%	95%
0.002 (0.2%)	13,000	34,100	4,950
0.005 (0.5%)	10,400	25,400	4,250
0.01 (1%)	8,630	19,800	3,740
0.02 (2%)	7,020	15,200	3,240
0.05 (5%)	5,110	10,100	2,580
0.1 (10%)	3,830	7,030	2,080
0.2 (20%)	2,680	4,550	1,570
0.5 (50%)	1,320	2,230	770

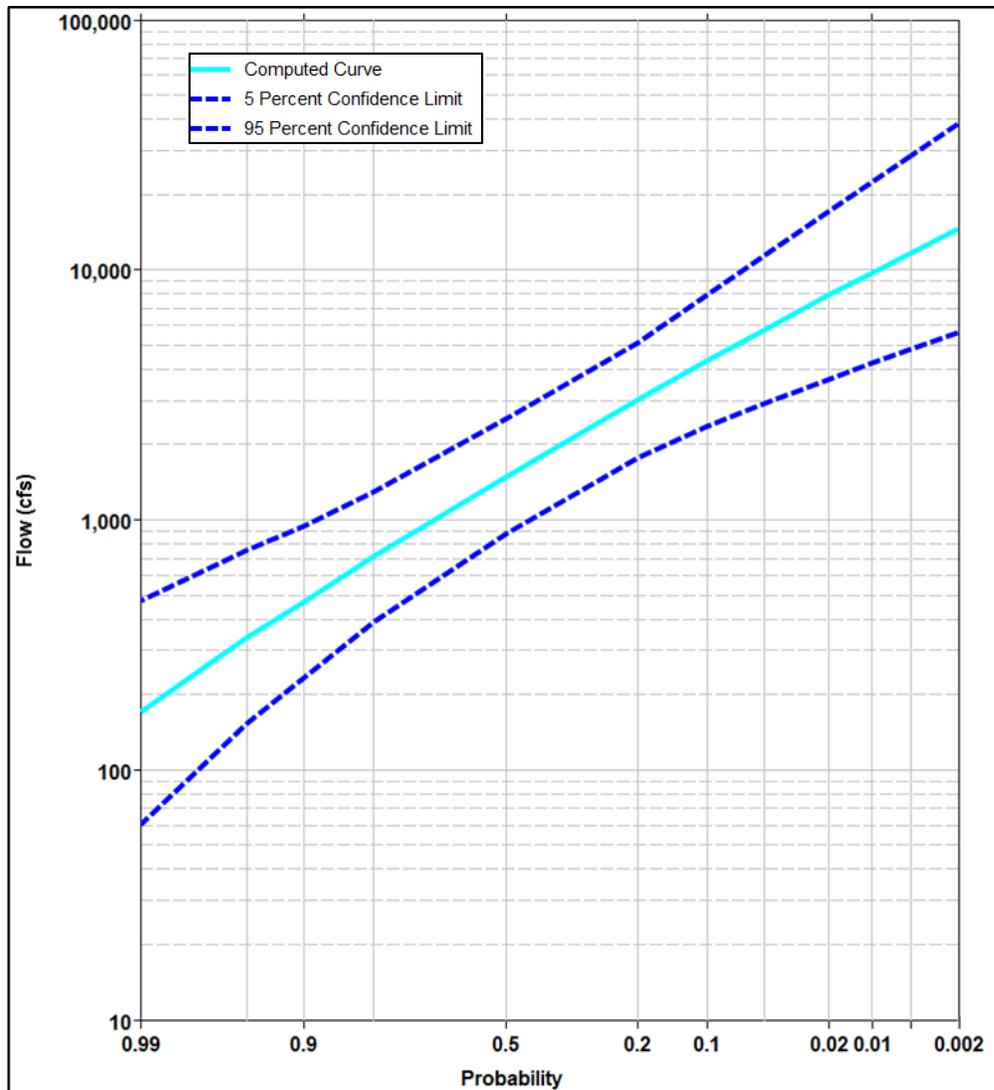


Figure 4-5. Flow-Frequency Curve Calculated for Cross-Section RS-53219

Table 4-14. Discharge Estimates for the HEC-RAS Model Steady-State Flow Input Location at Cross-Section RS-53219 (Upstream of Powell Falls)

Exceedance Probability	Peak Discharge Estimate (cfs)	90% Confidence Interval (cfs)	
		5%	95%
0.002 (0.2%)	14,600	38,200	5,570
0.005 (0.5%)	11,700	28,500	4,790
0.01 (1%)	9,740	22,400	4,220
0.02 (2%)	7,920	17,100	3,650
0.05 (5%)	5,760	11,380	2,910
0.1 (10%)	4,320	7,920	2,350
0.2 (20%)	3,020	5,130	1,770
0.5 (50%)	1,490	2,520	870

#### 4.7 Updated HEC-HMS Analysis

After an extensive search for the original HEC-HMS model, (that was used to calculate the flood discharges for the 2011 FIS), (Reference 39), including reaching out to FEMA, the Wisconsin Department of Natural Resources, and SEH, the study team has come to the conclusion that this model is either lost or no longer exists. According to unit hydrograph theory, (Reference 37), it may be possible to create updated discharge estimates for the three steady-state flow input locations in the HEC-RAS model using the discharge estimates available in the FIS report, (Reference 4), and updated precipitation values available in *Atlas 14*, (Reference 7). However, with the limited knowledge on loss rates that would be expected across the Kinnickinnic River's watershed during a large rainstorm event, and the consideration of past experience with hydrologic modeling that has shown loss rates are the most sensitive parameter in runoff modeling, it is impossible to conduct this analysis with a high degree of confidence. This may be a possibility in future studies though where a review of loss rates and, potentially, the creation of a new HEC-HMS are included in the scope of work and budget.

#### 4.8 Comparison to Past Hydrologic Studies

These discharge estimates compare reasonably well to those used as steady-state flow inputs in the HEC-RAS model created by SEH, (Reference 6), and in the 2011 FIS study, (Reference 4). Table 4-15 displays the discharges estimated in the 2011 FIS study. One notable difference between the two flow-frequency estimates is the greater increase in relative discharge between the RS-66059 and RS-53219 cross-sections in the FIS study discharges and the discharges displayed in Table 4-14 and Table 4-15. The south branch of the Kinnickinnic River enters the main branch of the Kinnickinnic between these two locations. One explanation for the higher discharge estimates included in the FIS study may be that this river is relatively more developed than the rest of the basin, meaning there is more impermeable land cover, and likely relatively greater runoff as a proportion of drainage area. This is difficult to discern without the hydrologic model used for the FIS study. Taking into consideration only the difference in drainage areas between the RS-66059 and RS-53219 watersheds of 17%, the discharges estimated in this study seem to align more with the discharges that may be expected. Thus, the updated discharges, calculated through the Bulletin 17C analysis conducted as part of this study, are adopted for use in the HEC-RAS model.

Table 4-16 compares the flow estimates for the location of cross-section RS-66059 from the 1976 hydrologic study, (Reference 21), the 2011 FIS study, and this study. It's notable how similar the discharge estimates are for this cross-section location in the 2011 FIS study and this study, especially considering the different methods used for estimating flood discharges in both studies. While this study estimated discharges using methods described in *Bulletin 17C*, (Reference 9), for estimating flood flow-frequency curves, the 2011 FIS study utilized a hydrologic (HEC-HMS) model. It is also notable that discharge estimates in the 1976 study for

this location differ from those made in this study and the 2011 FIS study by approximately 25% for the 10% and 0.2% AEP frequency events. All studies though have approximately the same discharge estimates at the 1% and 2% AEP events.

This differences in flow estimates between the studies may be indicative of greater variability in the magnitude of flood inducing events under current climatic conditions, (thunderstorms, for example), and hydrologic conditions that have remained relatively constant in time throughout the watershed, (land use, for example). More likely, this is model driven though, as both the 1976 and 2011 studies used the same precipitation inputs, and the 2011 study uses a more sophisticated hydrologic model. Moreover, the conclusion of the nonstationarity analysis of peak streamflow in the region, in particular, that the streamflow regime has remained stationary in time, provides evidence that this shift is likely not due to changing hydrologic conditions. (The nonstationarity analysis is summarized in Section 3.2 and described in detail in Appendix 1). It’s encouraging that this study found similar results to the 2011 study, especially considering different methods were used, and this provides greater confidence in the results of the *Bulletin 17C* analysis.

*Table 4-15. Discharge Estimates Included in the 2011 FIS Study, (Reference 4)*

Exceedance Probability (%)	Discharge at Cross-Section RS-71222 (Upstream of State Route 35) (cfs)	Discharge at Cross-Section RS-66059 (Upstream of Junction Falls) (cfs)	Discharge at Cross-Section RS-53219 (Upstream of Powell Falls) (cfs)
0.2	11,900	13,000	16,900
1	8,000	8,700	12,800
2	6,450	7,050	11,000
10	3,050	3,350	6,800

*Table 4-16. Comparison of Discharge Estimates for Cross-Section RS-66059 between the Various Studies Conducted on the Kinnickinnic River Watershed*

Exceedance Probability (%)	Discharge Estimates for Cross-Section RS-66059 (Upstream of Junction Falls) (cfs)		
	1976 Study (Reference 21)	2011 FIS Study (Reference 4)	This Study
0.2	9,900	13,000	13,000
1	8,600	8,700	8,630
2	7,200	7,050	7,020
10	4,200	3,350	3,830

## 5 Hydraulic Analysis

### 5.1 HEC-RAS Model Updates

As part of their 2017 *Kinni Corridor* study, SEH created an HEC-RAS model for use in modeling flood flows through the reach of the Kinnickinnic River that passes through River Falls, (Reference 6). The HEC-RAS model was adopted from the 2011 FIS, (Reference 4). SEH updated the model's terrain data and added stream cross-sections from downstream of Powell Falls dam to just upstream of Lake George. These updates were based on the sediment survey conducted by Inter-Fluve as part of their 2016 study, (Reference 8), LiDAR data, and as-built drawings of the dams, (Reference 6).

The HEC-RAS model updates based on sediment surveys were made to reflect the likely scenario that all of the sediment that has built up behind the dams since their construction would be removed through dredging and/or natural erosion, exposing the original channel bed, in the event both dams were removed. These bathymetric updates were made for both the "Proposed Conditions" geometry, representing the river channel as it would appear with both dams removed, and the "Existing Conditions" geometry, representing the channel as it exists now. It should be noted though that the bathymetry of the HEC-RAS model was only updated for cross-sections where the sediment survey was conducted, and the remainder of the channel's bathymetry is modeled as it was in the original FIS model. For additional information on the updates SEH made to the HEC-RAS model, please see their 2017 report, (Reference 6). The HEC-RAS model itself extends 3.9 river miles along the Kinnickinnic, from approximately 1 mile upstream of the Highway 35/65 bridge to just downstream of Powell Falls.

SEH assumed that both Junction Falls and Powell Falls dams would be removed when creating their model. Due to this, SEH's model includes one simulation with the Kinnickinnic's existing geometry, and one that shows both dams removed. However, the City of River Falls only plans to remove Powell Falls dam in the near future. As discussed in Section 1.4, Junction Falls dam was added back to the model geometry created under the assumption that both dams were removed. Additionally, cross-section RS-56095 through RS-53580, all immediately upstream of Junction Falls, were made consistent with the geometry of the existing conditions scenario, to reflect the sediment that has built up behind Junction Falls, which would remain in place with the dam. Figure 5-1 and Figure 5-2 show the parameters used for the "Inline Structure" added back into the HEC-RAS model to represent Junction Falls dam.

Junction Falls dam acts as a run-of-river dam, in that it does not regulate flows in excess of the powerhouse capacity at the dam site. Because of this, the dam is modeled as a weir. As the maximum controlled flow capacity of the facility is 960 cfs when the water level is at the dam's crest, (Reference 39), this is considered reasonable for modeling flood flows. Flows at the 10% AEP event magnitude are over 4 times this flow rate, and it's expected that flood flows would

quickly eliminate any storage capacity in the lake upstream of Junction Falls, as the maximum available storage of the lake is 39 acre-ft under current conditions, (Reference 39). A flood scenario would cause uncontrolled flows to spill over the dam's crest; this, in conjunction with the maximum flow capacity going through the controlled outlets would mimic unregulated conditions upstream and downstream from the dam. As the controlled outlet is not included in the HEC-RAS model, flows over the Junction Falls crest are overestimated. However, as flows over the dam would also likely enter a supercritical flow state, and the model is not configured to calculate this condition, flows at the dam should not be considered fully representative of real conditions. Updating the HEC-RAS model to include the controlled outlet and to be able to calculate supercritical flow conditions was outside the scope of this study. Updating both in future studies would lead to model improvements. The controlled outlet becomes more influential the more common an event is, (the higher its frequency), as its discharge decreases.

Discharge estimates summarized in Table 4-12 were used as flow inputs for the three steady-state flow change locations included in the HEC-RAS model. Five scenarios were modeled, including the 0.2%, 1%, 2%, 10%, 50% AEP floods, as well as a summer low-flow/baseflow condition. A baseflow discharge value of 100 cfs was chosen for the model, as SEH did in their 2017 study, (Reference 6).

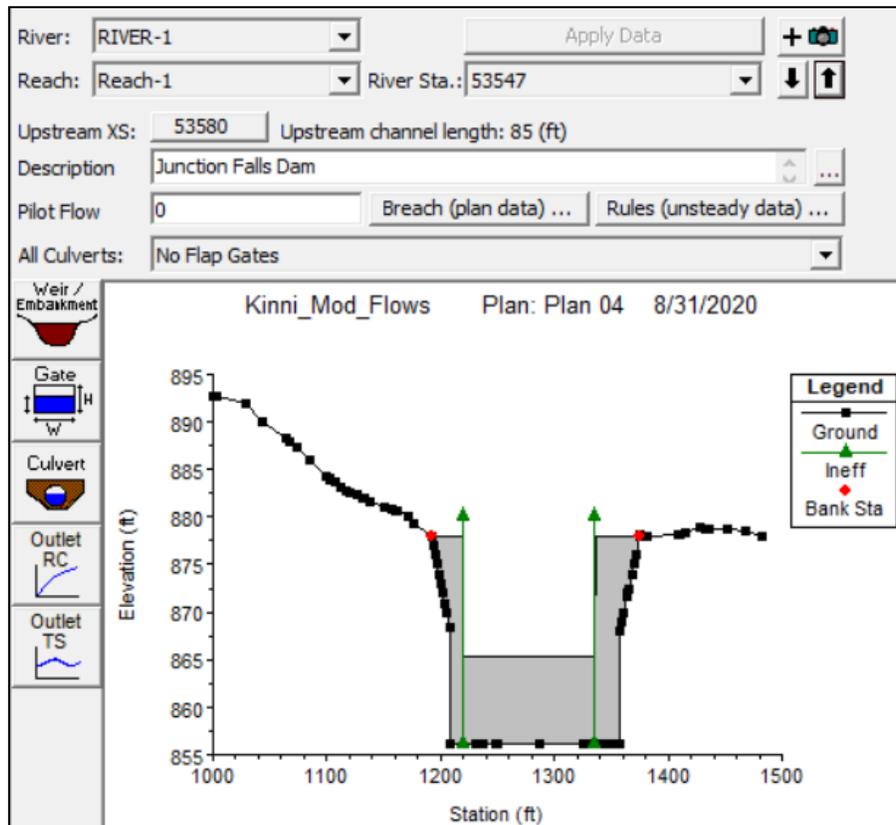


Figure 5-1. Inline Structure Parameters Used to Represent Junction Falls, as it Appears in the HEC-RAS Model

Distance	Width	Weir Coef
33.	21.	4.1

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Edit Station and Elevation coordinates

	Station	Elevation
1	1100	877.95
2	1219	877.95
3	1220	865.3
4	1335	865.3
5	1336	877.95
6	1400	877.95
7		
8		

U.S Embankment SS  D.S Embankment SS

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Spillway Approach Height:

Design Energy Head:

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Figure 5-2. Weir Parameters Used to Model Flow Over Junction Falls Dam

## 5.2 Results of the HEC-RAS Simulations

Results from the HEC-RAS simulations are summarized below. Table 5-1 and Table 5-2 display the average cross-sectional flow velocities modeled for multiple scenarios for the channel geometries with and without Powell Falls dam, respectively, for several cross-sections. These cross-sections correspond to those in the cross-sectional velocities table included in SEH’s 2017 report, (Reference 6). Of note, the cross-sections upstream of Junction Falls dam, (located at cross-section 53547), are the same for both geometries, which would be expected. In general, channel velocities increase as the flowrate increases, which would also be expected in a well-defined channel like the Kinnickinnic River.

Figure 5-3 and Figure 5-4 are inundation maps of the area surrounding Lake George and Lake Louise, (the impoundments formed by Junction Falls dam and Powell Falls dam). The map compares modeled flood conditions for the 1% AEP event under the scenarios with and without Powell Falls dam. The map in Figure 5-4 also shows the area that is included in FEMA’s National Flood Hazard Layer, (Reference 40); this area corresponds to the inundated area along the Kinnickinnic River in FEMA’s 2011 FIS, (Reference 4). Note that information on the channel geometry for the South Branch of the Kinnickinnic River, (the stream that enters the Kinni from the southeast, below Junction Falls dam), was not available for this analysis. Because of this, the inundated area along the South Branch of the Kinnickinnic River is drawn as it is in FEMA’s National Flood Hazard Layer. As the inundated area above Lake Louise does not differ significantly between the scenarios with and without Powell Falls dam, and the discharge

estimates in this study are similar to those in FEMA’s FIS, this is likely a reasonable assumption. However, updated modeling of this reach in future flood studies would be recommended.

Figure 5-5 and Figure 5-6 show the flow profiles of the 1% AEP event and baseflow conditions modeled in both scenarios, (with and without Powell Falls dam). Of note, the Main Street bridge appears to be overtopped and pressure flow conditions occur under the Highway 35/65 bridge during the 1% AEP event and less frequent floods. Additionally, both flood profiles are exactly the same above Junction Falls dam, which would be expected.

When examining the HEC-RAS results for this study, it is important to note that a few reaches would likely enter a supercritical flow regime, particularly at locations downstream of Lake George and below a few of the bridges. This can be seen when examining individual flow profiles where the critical depth is equal to the water surface elevation. The model is only configured to calculate water surface profiles under a subcritical flow regime. In this scenario, when the model is attempting to calculate a subcritical flow profile that is truly supercritical, the program will default to the critical depth, (Reference 41). This means that the elevations of the water surface profiles are overestimated for these cross-sections, and that the flow velocities are underestimated. Using an unsteady flow input for this model would remedy this and would be more appropriate than the current steady-state model. Unfortunately, reconfiguring the model in this way was outside the scope of this project, but would offer a significant opportunity for improvement.

*Table 5-1. Average Cross-Sectional Velocity, (feet per second), Corresponding to Flood Events with Both Dams in Place*

Exceedance Probability (%)	HEC-RAS Model Cross-Section/River Station								
	51060	52038	53219	53389	53495	53978	54260	54912	55167
0.2	7.10	4.33	7.82	25.21	23.26	7.54	6.07	5.64	6.38
1	5.38	3.67	6.26	21.89	20.00	5.81	5.03	4.94	5.29
2	4.71	3.43	5.62	20.48	18.61	5.10	4.57	4.63	4.75
10	3.14	2.82	4.04	16.53	14.84	3.42	3.39	3.86	3.40
Base Flow	0.13	0.32	0.37	8.65	7.03	0.16	0.27	0.48	0.25

*Table 5-2. Average Cross-Sectional Velocity, (feet per second), Corresponding to Flood Events with Powell Falls Dam Removed*

Exceedance Probability (%)	HEC-RAS Model Cross-Section/River Station								
	51060	52038	53219	53389	53495	53978	54260	54912	55167
0.2	12.93	11.89	14.31	26.33	23.63	7.54	6.07	5.64	6.38
1	13.30	11.99	12.46	23.10	20.37	5.81	5.03	4.94	5.29
2	13.48	11.27	11.69	21.59	18.85	5.10	4.57	4.63	4.75
10	11.27	9.41	9.73	17.51	15.07	3.42	3.39	3.86	3.40
Base Flow	3.34	3.21	3.80	7.42	7.09	0.16	0.27	0.48	0.25

Figure 5-3. Flood Inundation Map for the 1% AEP Event



Figure 5-4. Flood Inundation Map for the 1% AEP Event with Superimposed FEMA Layers

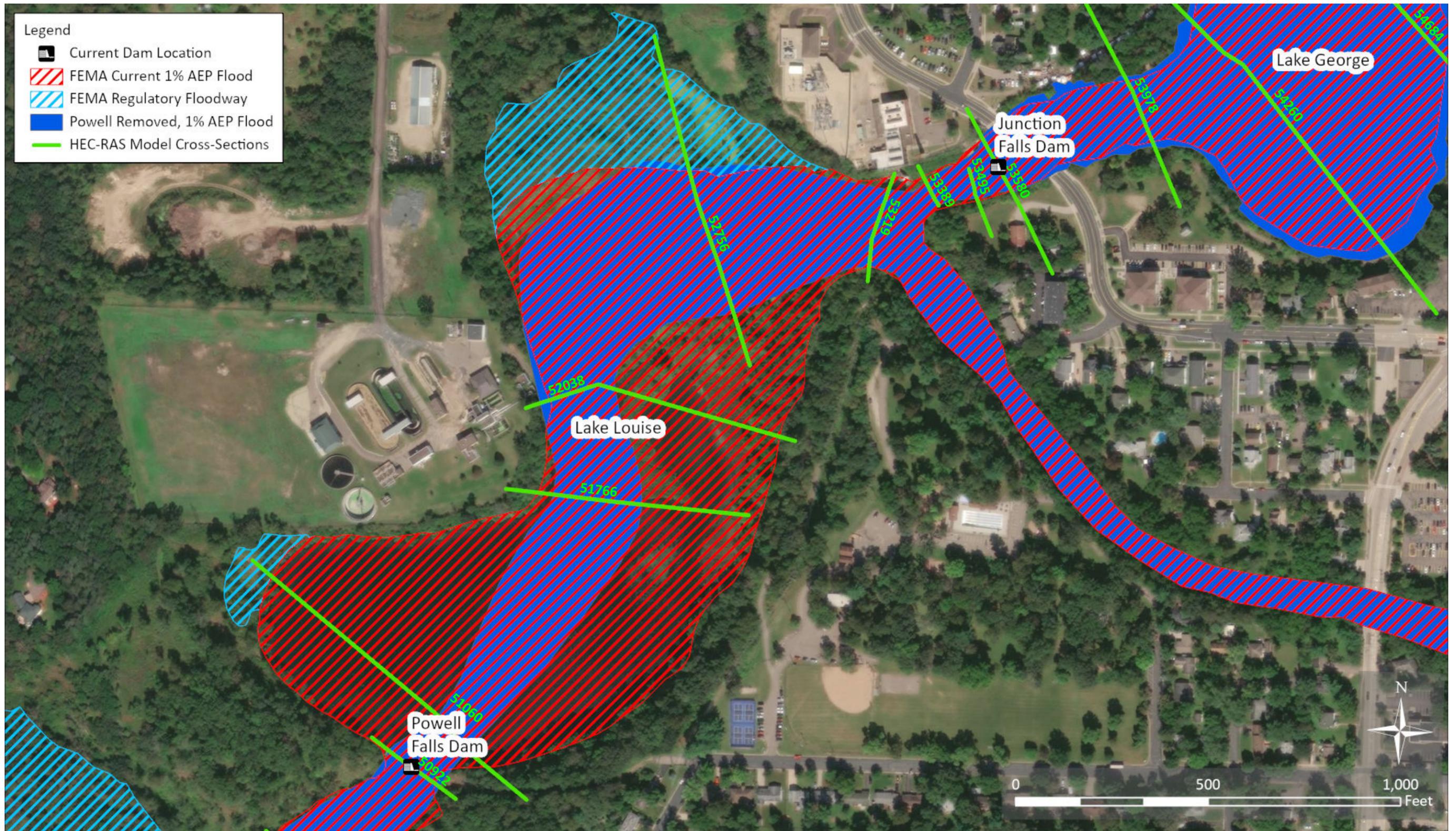


Figure 5-5. 1% AEP Event and Baseflow Profiles under Current Channel Conditions with Both Dams in Place

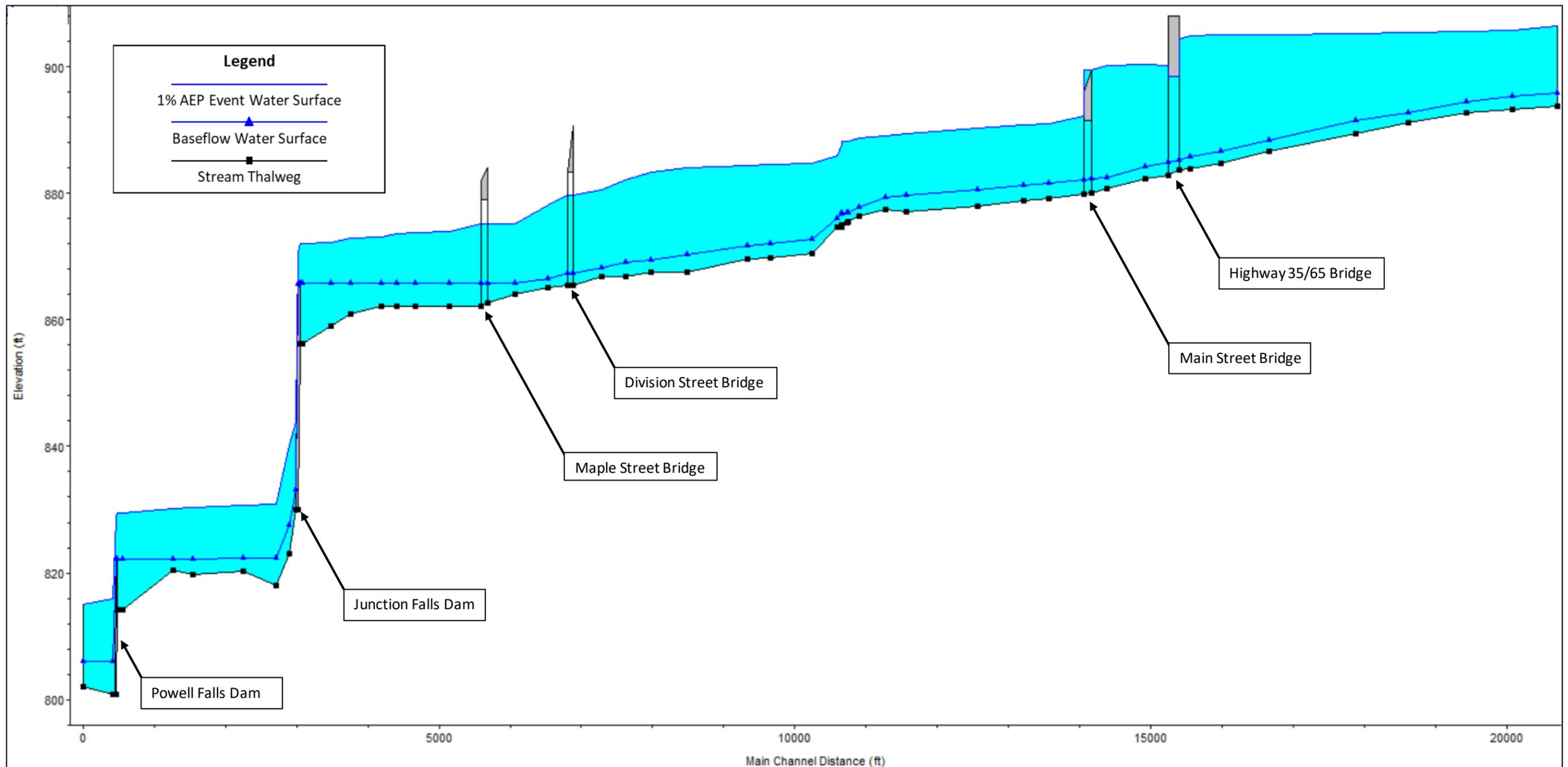
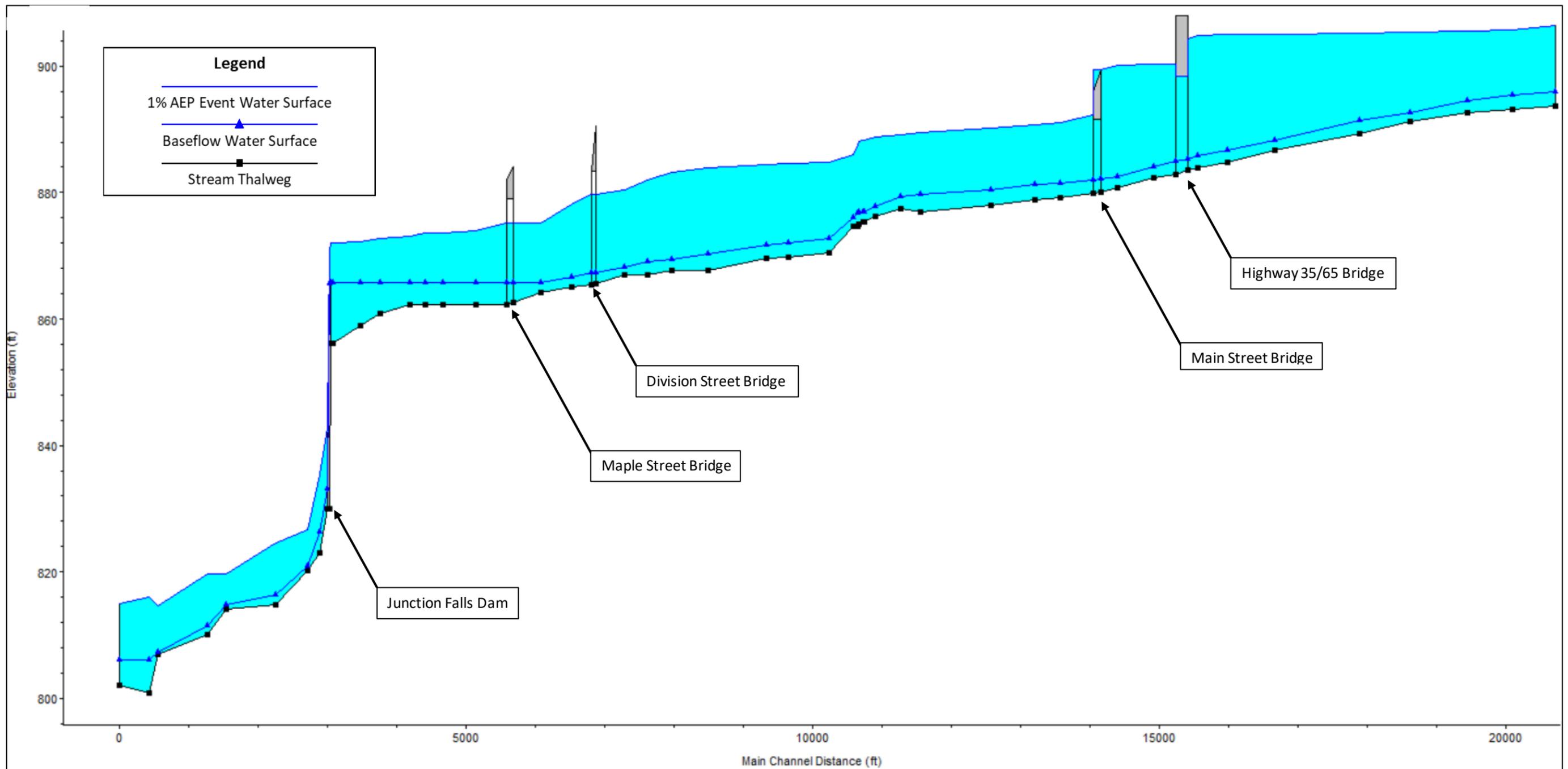


Figure 5-6. 1% AEP Event and Baseflow Profiles under Proposed Channel Conditions with Powell Falls Dam Removed



### 5.3 Opportunities for HEC-RAS Model Improvements

Updating the HEC-RAS model's terrain/geometry data was outside the scope of work for this study. However, there are several improvements that would be worthwhile for future studies to consider undertaking, as they offer the opportunity to improve the model's accuracy.

A few of the cross-sections upstream of the dams should be replaced, or expanded, so that they capture the full extent of flood inundation. Figure 5-7 below, for example, shows a cross-section where the water surface profile of the 1% AEP flood is higher than the elevation of the outermost station. This eliminates possible area within the stream cross-section for water to be conveyed, likely increasing the water surface elevation at these locations, as well as cross-sections upstream from them. In addition to raising the water surface profile, the full horizontal extent of flooding is not fully represented at these locations. This is a greater issue for modeling the 0.2% AEP flood, as this occurs at even more cross-sections.

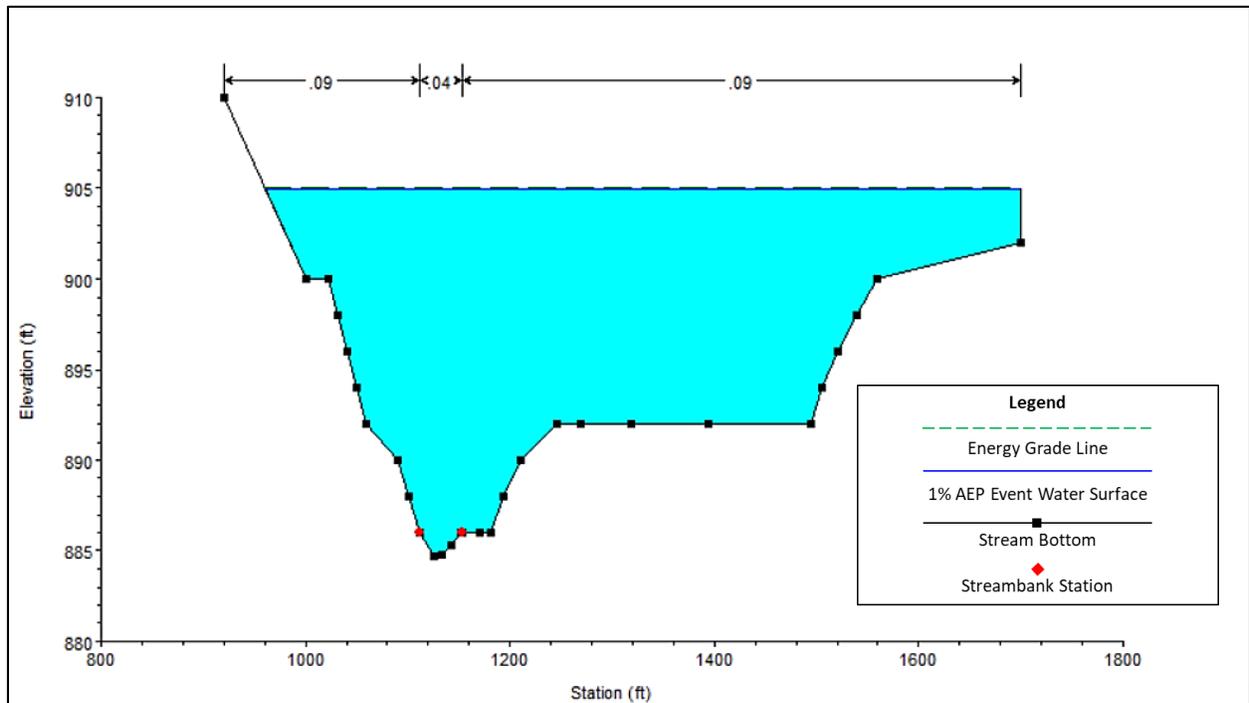


Figure 5-7. Example of a Cross-Section where the Water Surface Elevation is above the Elevation of the Outer Most Station

It would be worthwhile to resample the Kinnickinnic River's bathymetry beyond the locations examined by Inter-Fluve in their 2016 analysis to cover the full extent of the river included in the model. Much of the bathymetric data presumably dates back to at least 1995, when the hydraulic model for the current FIS was developed, (Reference 3). Since then, the river has experienced numerous significant flood events, including four that were considered major flood stage. Floods are a significant geomorphological force that can reshape all rivers over time.

Additionally, there is still considerable uncertainty in what the channel immediately upstream of Powell Falls dam will look like following the dam's removal. This uncertainty was highlighted

during an October 2020 drawdown of Lake Louise; during this drawdown, the channel that formed in the sediment did not align well with what was estimated by Inter-Fluve following their sediment survey and analysis. This suggests that the refusal surface identified by Inter-Fluve may not be the ultimate, post-removal channel. However, it is possible that significantly more sediment would have needed to have eroded for the original, pre-dam channel to be revealed. This aspect is highlighted by the waterfall, (Powell Falls), not being visible during the drawdown. As the USACE was not present for the drawdown, and no formal documentation on these observations was available at the time of the writing of this report, it is impossible to comment on the accuracy of Inter-Fluve's estimated channel. Through conversation with engineers who are familiar with the project though, there is consensus that a more thorough sediment survey and fluvial geomorphological analysis of this river reach would be necessary prior to submitting a formal floodplain to FEMA, if one was desired prior to dam removal. However, as the removal of Powell Falls dam does not require a determination of the expected stream profile, beyond the generalized one through Lake Louise that this analysis utilized, such an investigation would be premature. The most accurate hydraulic analysis would occur either in conjunction with or after the final stream restoration design is determined.

Beyond updating the channel's bathymetry, updating the overbank data using LiDAR data would provide significant model improvements. The cross-section shown in Figure 5-7, for example, suggests that the overbank area is completely flat for over 2,000 feet; this level of detail is typical of FEMA FIS models of the era when this one was developed. Updating the overbank data using higher resolution data available now would better capture secondary channels, embankments, etc., and would produce a more accurate model. SEH updated this overbank data to a limited extent as part of their 2017 Kinni Corridor study, (Reference 6). It is recommended that the model be updated in this way over its full extent.

An additional recommendation would be to georeference the hydraulic model, or, rather, put it in the context of its geographical location. The current HEC-RAS model depicts the river as a straight channel, not capturing its many bends and meanders throughout this reach. The current model will likely produce a reasonable water surface profile, but it is more difficult to place accurate banks and ineffective flow areas. Georeferencing the model would also allow for the easier implementation of all the other geometry upgrades discussed previously.

Finally, as discussed in Section 5.2, the model should be updated to run as an unsteady flow model. Reconfiguring the model in this way would allow for a more accurate calculation of water surface profiles and flow velocities in reaches where flows enter a supercritical flow regime. This would reduce the current limitations of the model and the applicability of its results. Additional cross-sections in reaches that transition from subcritical to supercritical flow regimes and vice versa, particularly downstream of Junction Falls, would also improve the model's accuracy and resolution.

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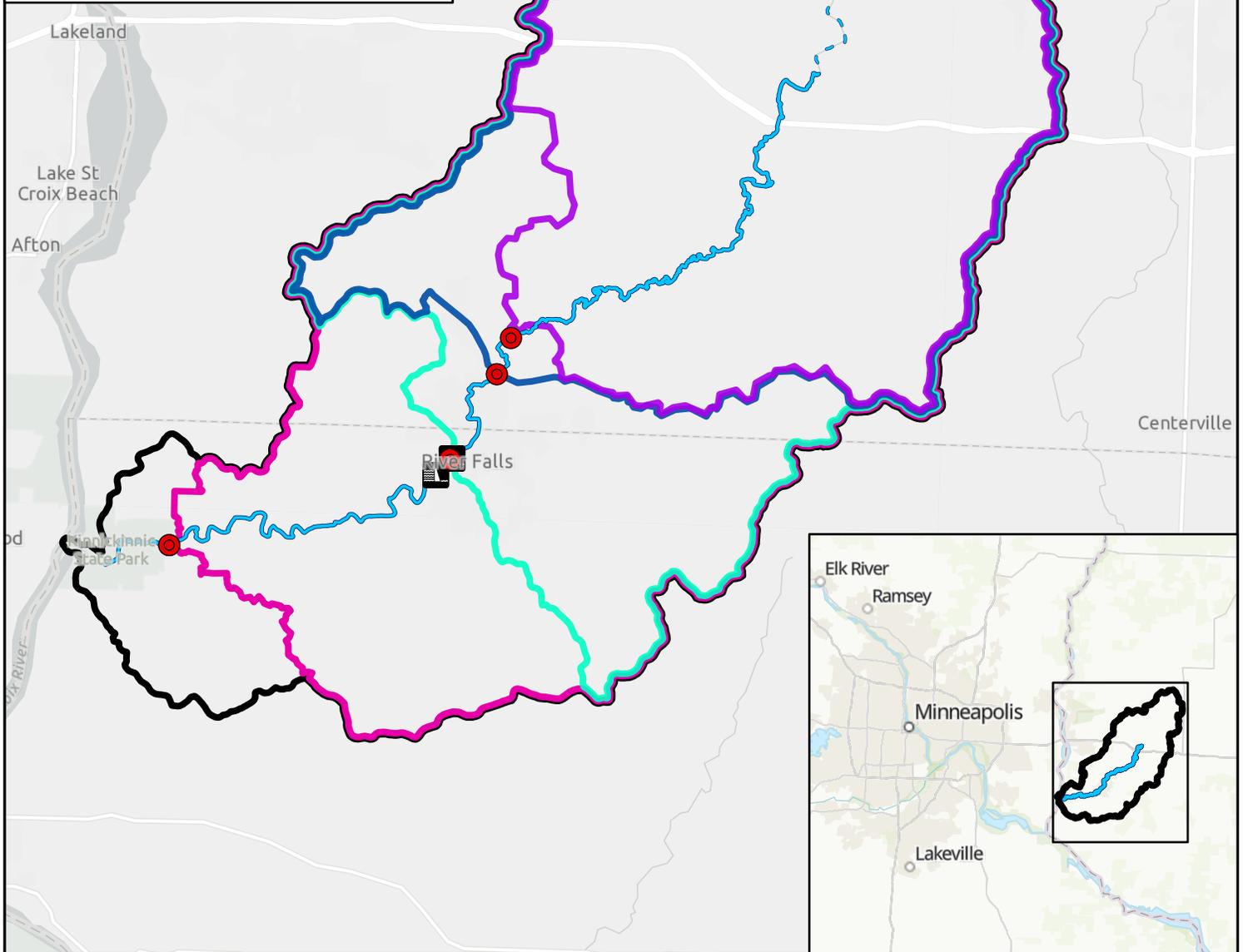
# Legend

## River Features

-  Junction Falls & Powell Falls dam
-  Flow Input Location
-  USGS Gage 05342000
-  Kinnickinnic River Centerline
-  Kinnickinnic River Intermittent Centerline

## Subwatersheds

-  RS 71222 watershed
-  RS 66059 watershed
-  RS 53219 watershed
-  Gage watershed
-  Kinnickinnic Watershed (HUC-10)



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## Kinnickinnic River Watershed Overview



# **Appendix 1: Climate Change Analysis**

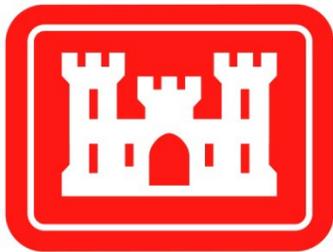
**Kinnickinnic River, Wisconsin**

**Hydraulic and Hydrologic Analysis**

**River Falls Hydroelectric Project**

**Planning Assistance to States (PAS)**

January 2021



**US Army Corps  
of Engineers** ®

Prepared by:

U.S. Army Corps of Engineers

St. Paul District

180 Fifth Street East, Suite 700

St. Paul, Minnesota 55101-1678

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ATR – Agency Technical Review

DQC – District Quality Control (U.S. Army Corps of Engineers)

EIT – Engineer In Training

MVP – St. Paul District (U.S. Army Corps of Engineers)

NWS – Seattle District (U.S. Army Corps of Engineers)

PE – (Registered) Professional Engineer

PhD – Doctor of Philosophy

USACE – U.S. Army Corps of Engineers

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## 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. Current USACE 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. Qualitative analyses required include consideration of both past (observed) changes, as well as potential future (projected) changes to relevant hydrologic inputs. Climate change impacts on the hydrology of the Kinnickinnic River around River Falls, WI are evaluated in accordance with USACE Engineering and Construction Bulletin (ECB) 2018-14, (Reference 1), *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs and Projects*, and USACE Engineering Technical Letter (ETL) 1100-2-3 *Guidance for Detection of Nonstationarities in Annual Maximum Discharges*, (Reference 2).

The Kinnickinnic River is a tributary to the St. Croix River (HUC0703) in western Wisconsin (see Figure 1-1). According to the Wisconsin DNR, the Kinnickinnic River originates from a series of springs in central St. Croix County and flows through the City of River Falls into Pierce County and eventually enters the St. Croix River south of the City of Hudson in Kinnickinnic State Park. The Kinnickinnic River reaches its confluence with the St. Croix just upstream of where the St. Croix combines with the Mississippi River, between St. Paul, MN and Red Wing, MN. The Kinnickinnic River is 22 miles long and captures 174 square miles of drainage area. The proposed project consists of removing Powell Dam. Powell Dam is a hydropower dam on the Kinnickinnic River and it currently impounds Lake Louise. Removal of the hydropower dam is not anticipated to have a detrimental hydrologic impact on the study area in any way. Removing the structure will return the river to a more natural state and will result in a reduction in localized flood risk.

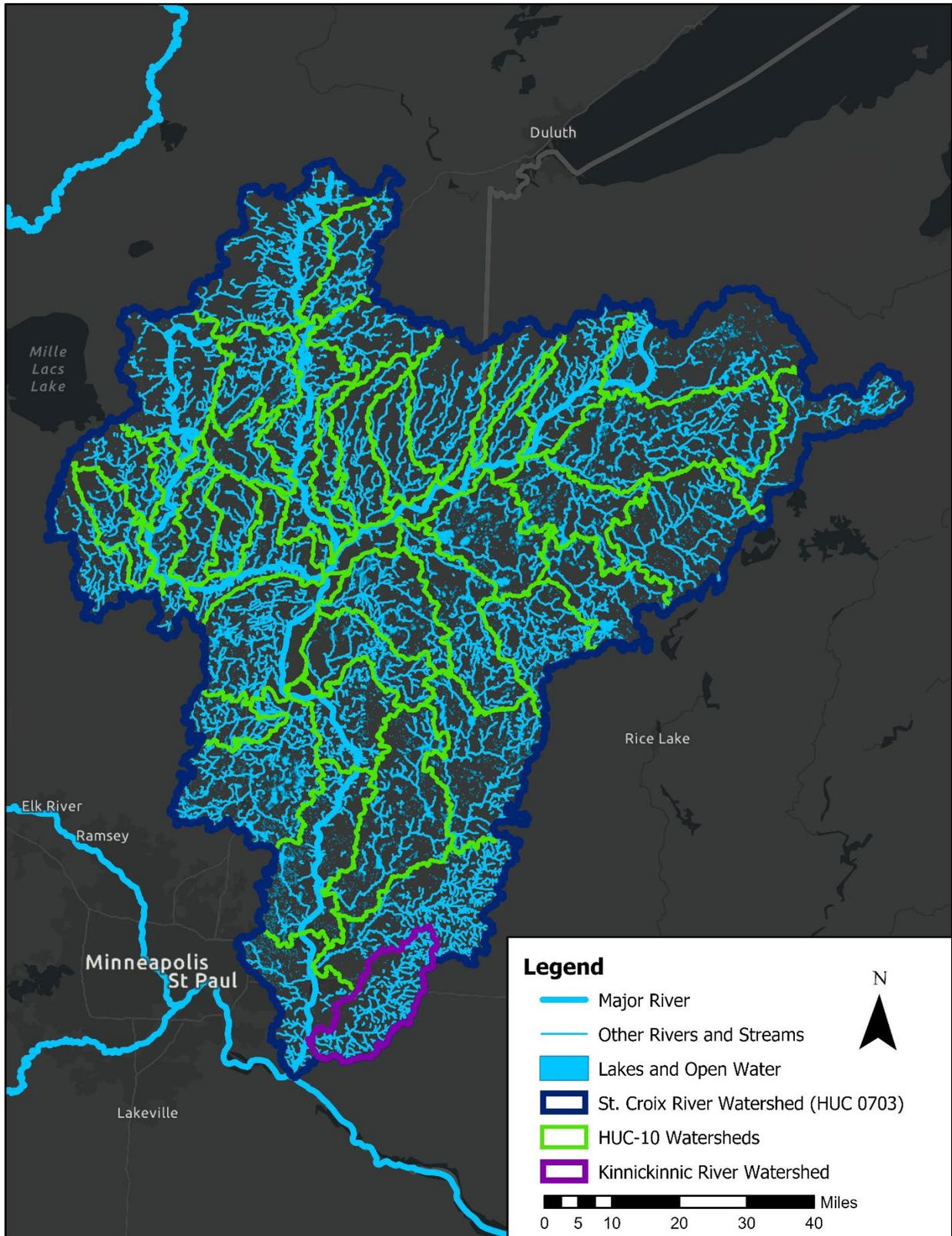


Figure 1-1. Map of the St. Croix River Watershed (HUC 0703) with the Kinnickinnic River Highlighted

## 2 Literature Review

The literature review summarizes peer reviewed science regarding both natural and human driven climate trends in the region which encompasses the Kinnickinnic River. The Kinnickinnic River watershed falls within the Water Resources Region 07 (HUC 07): Upper Mississippi River. The Upper Mississippi River HUC 07 encompasses the drainage of the Mississippi River basin above the confluence with the Ohio River, excluding the Missouri River Basin. The Upper Mississippi River basin includes parts of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, South Dakota, and Wisconsin. The reviewed sources identify observed changes and assess projected future changes in hydro-climatic variables. The literature review does not attempt to identify the causes of climate change, (e.g. natural or anthropogenic sources).

### 2.1 Temperature

According to the 4<sup>th</sup> National Climate Assessment, (Reference 3), temperatures have been rising in the Midwest over the last century and projections show the average temperature throughout the region increasing between 5.6°F and 9.5°F by 2100.

#### 2.1.1 Observed Temperature Trends

**Regional Observed Temperature Trends** – A literature synthesis carried out by USACE in 2015, (Reference 5), reported statistically significant warming in the Upper Mississippi Region’s observed seasonal temperatures for winter, spring, and summer. The fall season saw a slight decrease in temperature over several studies, but this change was not statistically significant.

**Local Observed Temperature Trends** – The U.S National Oceanographic and Atmospheric Administration (NOAA) State Climate Summary for Wisconsin, (Reference 4), has observed a temperature increase of about 2 degrees Fahrenheit for the state since 1900. According to Wisconsin Initiative on Climate Change Impacts, (Reference 6), all nine subregions in Wisconsin saw statistically significant increases in daily average temperature for each season. This increase was the most prominent in the winter season and largely reflects an increase in the daily minimum temperatures. Daily maximum temperatures have experienced statistically significant increases as well, but to a lesser degree than the daily minimum temperatures, (Reference 6).

#### 2.1.2 Projected Temperature Trends

**Regional Projected Temperature Trends** – According to the 2015 USACE literature synthesis, there is consensus amongst temperature projections in the Upper Mississippi Region that significant warming will occur, (Reference 5). The 4<sup>th</sup> National Climate Assessment considers the Midwest to be particularly susceptible to warming due to its relatively high latitude and lack of nearby oceans. The high emission scenario (RCP 8.5) projects temperatures in the Midwest to increase roughly 9 degrees Fahrenheit by late-century, (Reference 3).

**Local Projected Temperature Trends** – Relative to the period 1981-2010, Wisconsin’s temperatures around 2050 are projected to increase by about 5 degrees Fahrenheit, (Reference 6). This warming is expected to affect all seasons to a similar extent (within several degrees) for both the average daily minimum and daily maximum temperatures. This rise in temperature is expected to deplete soil moisture and cause an earlier snowmelt, (Reference 4).

## 2.2 Precipitation

Within the Upper Mississippi Region, there is evidence that climate change is impacting precipitation. Throughout the United States, trends in precipitation vary by region, but observations and projections in the Midwest show a notable increase, (Reference 5).

### 2.2.1 Observed Precipitation Trends

**Regional Observed Precipitation Trends** – The USACE Literature Synthesis, (Reference 5), reported that statistically significant precipitation increases have been observed in the Upper Mississippi Region. This increase is evident for both total annual precipitation and for the frequency and magnitude of precipitation events. The 4<sup>th</sup> National Climate Assessment, (Reference 3), agrees with both trends for the Midwest.

**Local Observed Precipitation Trends** – Wisconsin Climate Trends and Projects, (Reference 6), offers an assessment of historic trends in climate for nine regions within the state of Wisconsin. From 1950 to 2018, a statistically significant increase of about 20% has been observed in the annual precipitation in the region which contains the Kinnickinnic River watershed. A similar increase has been observed on a seasonal basis, (fall, winter, spring, and summer), but is only statistically significant for the winter. NOAA, (Reference 4), has found similar trends in precipitation, noting an influx of unusually wet years in recent history as well as an increase in annual snowfall totals. Additionally, the occurrence of extreme rain events has been increasing in frequency since 1990.

### 2.2.2 Projected Precipitation Trends

**Regional Projected Precipitation Trends** – For the Upper Mississippi Region, a reasonable consensus supports a projected increase in annual precipitation totals and extreme precipitation intensity and frequency, (Reference 5). The 4<sup>th</sup> National Climate Assessment, (Reference 3), supports this finding, citing a projected increase in springtime precipitation by 20 to 40%. The intensity and frequency of extreme precipitation events are projected to continue to increase with temperature as well.

**Local Projected Precipitation Trends** – NOAA, (Reference 4), projects an increase in annual precipitation throughout all of Wisconsin of at least 15% by the middle of the 21<sup>st</sup> century, relative to the late 20<sup>th</sup> century averages. The most likely increases will occur in the winter and spring. Despite the increase in winter precipitation and the observed increases in annual snowfall totals, Wisconsin’s average annual snowfall is projected to decline due to warmer

temperatures. Extreme precipitation is projected to continue to increase in the state. Over a similar period, Wisconsin Climate Trends and Projects, (Reference 6), suggests a more conservative annual precipitation increase that is closer to 5%, based on a moderate assumption of greenhouse gas emissions (the RCP 4.5 scenario). The projections also show a large increase in the frequency of extreme precipitation events by as much as two times.

## 2.3 Hydrology & Streamflow

### 2.3.1 Observed Hydrologic Trends

The 4<sup>th</sup> National Climate Assessment reports that a statistically significant increase in annual maximum streamflow has been observed in the Upper Mississippi River valley, (Reference 3). According to the 2015 USACE Literature Synthesis, the Upper Mississippi Region, HUC02 watershed has observed a general increase in river flow, as well, (Reference 5). Increases in annual peak flows have resulted in increases in the risk and severity of floods. What is driving this increase in streamflow peaks has been assessed throughout the region. Although it has been found that changes in land use and agricultural practices may have some influence on streamflow trends, this trend has been attributed mostly to the increase in observed precipitation throughout the Midwest, (Reference 3).

### 2.3.2 Projected Hydrologic Trends

Generally, projected increases in extreme precipitation are expected to result in an increase in the frequency and intensity of floods, (Reference 4). Increases in temperature may offset future flood magnitudes as a result of increased evapotranspiration and changes in snowmelt timing and volume. This contributes to the high degree of uncertainty in projecting future hydrologic trends, as noted by the USACE Literature Synthesis, (Reference 5). Not only do the reports cited by the 2015 USACE Synthesis lack consensus, but the different models within the same reports sometimes showed opposite results. Although lacking a strong consensus, studies generally supported the idea of regional flows increasing in the winter and spring and decreasing in the summer, (Reference 5).

## 2.4 Literature Review Summary

The consensus from the literature review indicates that increases in temperature, precipitation, and streamflow have been observed within the Upper Mississippi River Region. Some consensus shows that extreme storms have increased in frequency in the region. Projections have a strong consensus that air temperature will increase significantly over the next century. Both precipitation and the frequency of large storms are projected to increase; however, some portions of the region will experience decreases in precipitation. There is little consensus on projected streamflow amounts, as increases in precipitation could be offset by increased evapotranspiration rates and changes in snowmelt timing. These observed and projected trends

are summarized in Figure 2-1, which includes an indication of the level of consensus within the 2015 USACE synthesis peer reviewed literature, (Reference 5).

PRIMARY VARIABLE	OBSERVED		PROJECTED	
	Trend	Literature Consensus (n)	Trend	Literature Consensus (n)
 Temperature	↑	 (7)	↑↑	 (14)
 Temperature MINIMUMS	↑	 (3)	↑↑	 (4)
 Temperature MAXIMUMS	↓	 (3)	↑↑	 (6)
 Precipitation	↑↑	 (12)	↑	 (15)
 Precipitation EXTREMES	↑	 (2)	↑	 (10)
 Hydrology/ Streamflow	↑	 (10)	↕	 (15)

**TREND SCALE**

 = Large Increase   
  = Small Increase   
  = No Change   
  = Variable  
 = Large Decrease   
  = Small Decrease   
  = No Literature

---

**LITERATURE CONSENSUS SCALE**

 = All literature report similar trend   
  = Low consensus  
 = Majority report similar trends   
  = No peer-reviewed literature available for review  
**(n)** = number of relevant literature studies reviewed

Figure 2-1. Summary Matrix of Observed and Projected Climate Trends and Literature Consensus for the Upper Mississippi Region 07, (Reference 5)

### 3 First Order Statistical Analysis

ECB 2018-14, (Reference 1), requires a first order statistical analysis of hydrometeorological variables relevant to the study objective. For this assessment peak streamflow will be analyzed. The removal of the River Falls Hydropower structure will result in a reach of river that is no longer inundated due to the upstream impacts of the dam, reducing flood risk within this reach of the river. (See Section 5 of the Main Report for details). Because this dam is operated as run-of-the-river and does not impact peak flows, its removal will not increase the flood risk

downstream. Removing the hydropower dam is not expected to negatively impact the hydrology of the study area in an operationally significant way. Thus, the potential negative effects of climate change on the study area in terms of the USACE Flood Risk Reduction business line are not anticipated to be compounded by the proposed hydropower dam removal. To provide for a study area specific assessment of how climate change is impacting streamflow in the study area, annual peak flows are analyzed.

### 3.1 Streamflow Gage Sites – Background Information

There are two dams on the Kinnickinnic River that support hydropower operation: Junction Falls dam/Lake George and the dam being assessed as part of this study: Powell Falls dam/Lake Louise. Neither dam is thought to impact high flows. The Powell Falls dam is scheduled for removal in 2026, part of a FERC relicensing and decommissioning plan for the City's hydroelectric operations. The second dam, Junction Falls, is scheduled for removal between 2035 and 2040. Neither dam impacts peak streamflows.

The historic annual peak streamflows on the Kinnickinnic River, as recorded by USGS gage 05324200, were considered for this assessment. However, USGS gage 05324200 has less than 30 years of continuous data. A minimum of 30 years of record is required for first order statistical analysis, (including trend analysis and nonstationarity detection). As further described in Section 4.5 of the Main Report, nearby gages were analyzed to evaluate hydrologic similarity to the drainage area captured by USGS gage 05324200. The three gages with the best correlation to USGS gage 05324200 were chosen for analysis: Kinnickinnic River Tributary at River Falls, WI (USGS gage 05341900); the Buffalo River near Mondovi, WI (USGS gage 05371920); and the Hay River at Wheeler, WI (USGS gage 05368000).

The gaged Kinnickinnic River Tributary is upstream of USGS gage 05324200. The USGS does not flag the annual instantaneous peak streamflow record collected at USGS gage 05324200 as being significantly impacted by regulation. Consequently, it can be assumed that peak flows measured along the Kinnickinnic River Tributary are not impacted by regulation. Despite there being several small, earthen structures located throughout the Hay River and Buffalo River watersheds, there are no significant sources of regulation on these two rivers that would impact the high flow regimes. The location of these gages, relative to the Kinnickinnic Watershed and USGS gage 05324200 are illustrated in Figure 3-1 and analyzed in Section 3.2. The period of record associated with each gage, drainage area captured by each gage site and pertinent information from the USGS related to regulation, data quality etc. is included in Table 3-1.

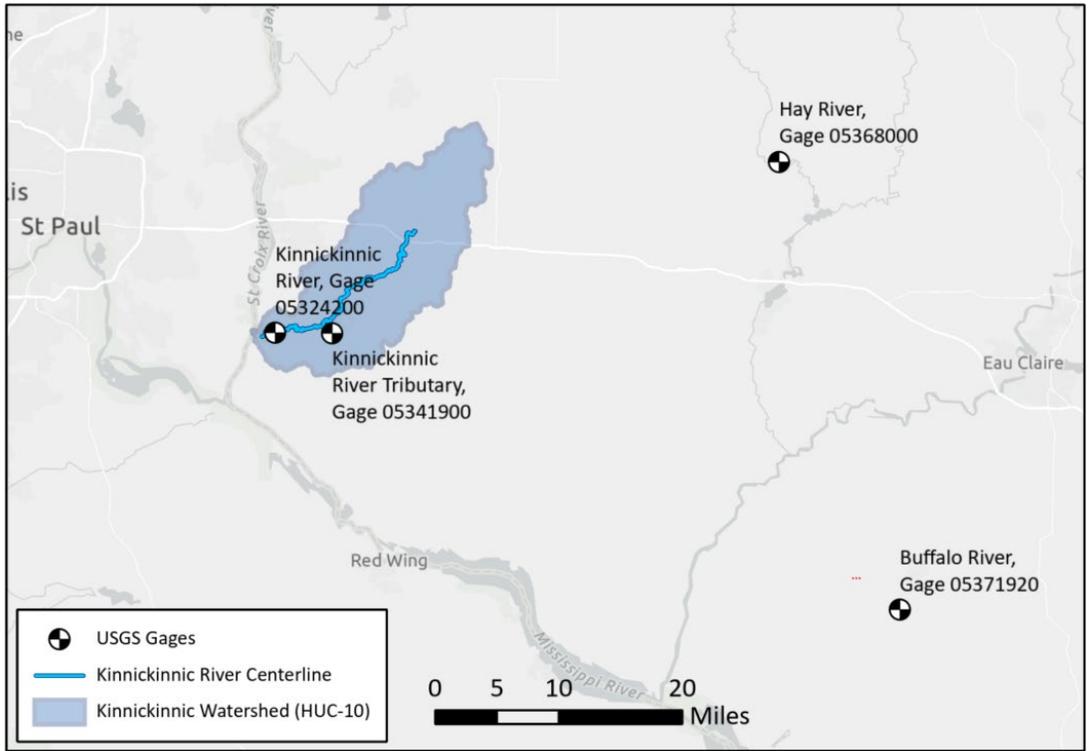


Figure 3-1. Locations of USGS Gages Considered in the Climate Assessment

Table 3-1. Information about USGS Gages Considered in the Climate Assessment

USGS Gage ID	Location	Period of Record	Drainage Area (sq. mi.)	Pertinent Information
05342000	Kinnickinnic River near River Falls, WI	1917 - 1921, 2002 - Present	165	Gage moved 325 feet upstream in 2012; 4.8 mi Downstream of Lake Louise Dam, Peak flows unimpacted by Regulation
05341920	Kinnickinnic River Tributary (Rocky Branch) at River Falls, WI	1959 - Present	10.4	Peak flows unimpacted by Regulation, Gage replaced in 1999
05371920	Buffalo River near Mondovi, WI	1974 - Present	279	On Hwy 88 bridge, 4.0 mi south of Mondovi, no regulation known to significantly impact peak flows
05368000	Hay River at Wheeler, WI	1950 - Present	418	2.4 mi Downstream of South Fork Hay River, no regulation known to significantly impact peak flows

### 3.2 Assessment of Trends & Nonstationarities in Observed Data

The USACE Nonstationarity Detection (NSD) Tool, (Reference 8), was applied to the full period of record to determine whether annual instantaneous peak flows recorded by the three analyzed gages are representative of stationary hydroclimatic conditions. The stationarity of the flow record at the gages was assessed by applying twelve statistical tests to the observed, annual maximum instantaneous peak flow record. These tests identify changes in the statistical properties of the dataset, including the mean, standard deviation, and overall distribution. The data was also evaluated for monotonic trends using the Mann-Kendall Test and the Spearman Rank Order Test. For gages not included within the NSD Tool, the USACE Time Series Toolbox was used to apply the same statistical tests.

The criteria of consensus, robustness, and magnitude were used to assess the relative strength of a nonstationarity. The level of consensus refers to different statistical tests targeted at detecting the same type of nonstationarity (mean, variance/standard deviation, distribution), in the flow data series, indicating a changepoint. A second criterion for adopting nonstationarities is robustness. Robustness is achieved when tests targeting changes in two or more different statistical properties, (mean, variance/standard deviation, and overall distribution), indicate a statistically significant nonstationarity. Another criterion for detection of nonstationarities is change in magnitude. To be considered strong a nonstationarity, there must be a significant change in the magnitude of the mean or standard deviation/variance.

Neither the Hay River nor Buffalo River gages showed any strong nonstationarities in the observed time series data. The Nonstationarity Detection Tool was used to analyze the annual instantaneous peak streamflow record collected by the Hay River gage at Wheeler, WI for the period or record of 1950-2019. On the Hay River, three nonstationarities were detected in the record in 1985, 1990, and 2007 by a single test each. Because there is no consensus between results, the evidence of nonstationarity is not considered strong enough to warrant further consideration. As can be seen from Figure 3-2, simple linear regression analysis applied within Microsoft Excel indicates that there is evidence of a decreasing trend ( $p\text{-value} = 0.03 < 0.05$ ). Additionally, the more robust Mann-Kendall and Spearman Rank Order monotonic trend analysis tests applied within the Nonstationarity Detection tool indicate no statistically significant trends at a 0.05 significance level ( $p\text{-values}$  of 0.14 for both) within the annual peak streamflow record for the Hay River.

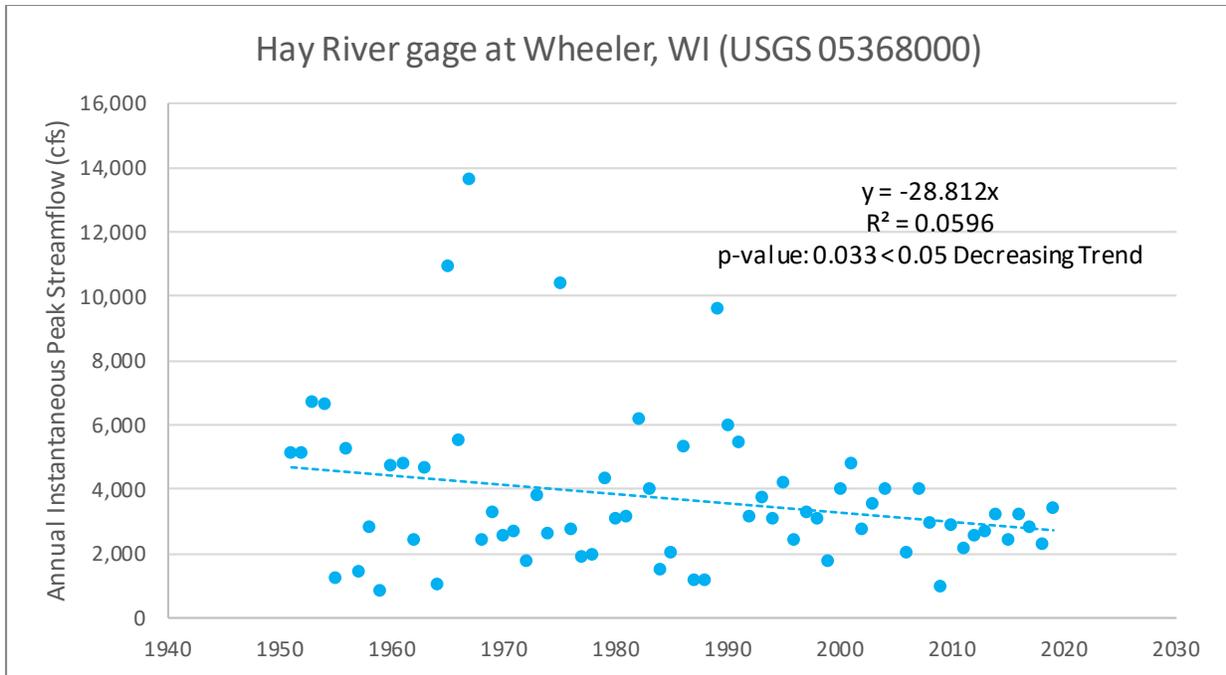


Figure 3-2. Observed Peaks & Linear Regression Analysis Hay River (1950-2019)

The Time Series Toolbox (TST) was used to analyze the annual instantaneous peak streamflow record collected between 1974 and 2017, (42 years), by the Buffalo River gage near Mondovi, MN. Data is missing in 1981, 1988 and 2014. The TST and the NSD tool are configured to analyze continuous datasets. When datasets are missing data, it has the potential to undermine results. However, one to three years of missing data is not likely to produce misleading output, particularly when they aren't consecutive years. On the Buffalo River, no nonstationarities were detected in the record. Additionally, TST output identified no statistically significant monotonic trends, (t-test, Mann-Kendall, Spearman Rank-Order at a 0.05 significance level), in the annual peak streamflow record for the Buffalo River. Annual peak flow data plotted in Microsoft Excel is displayed in Figure 3-3.

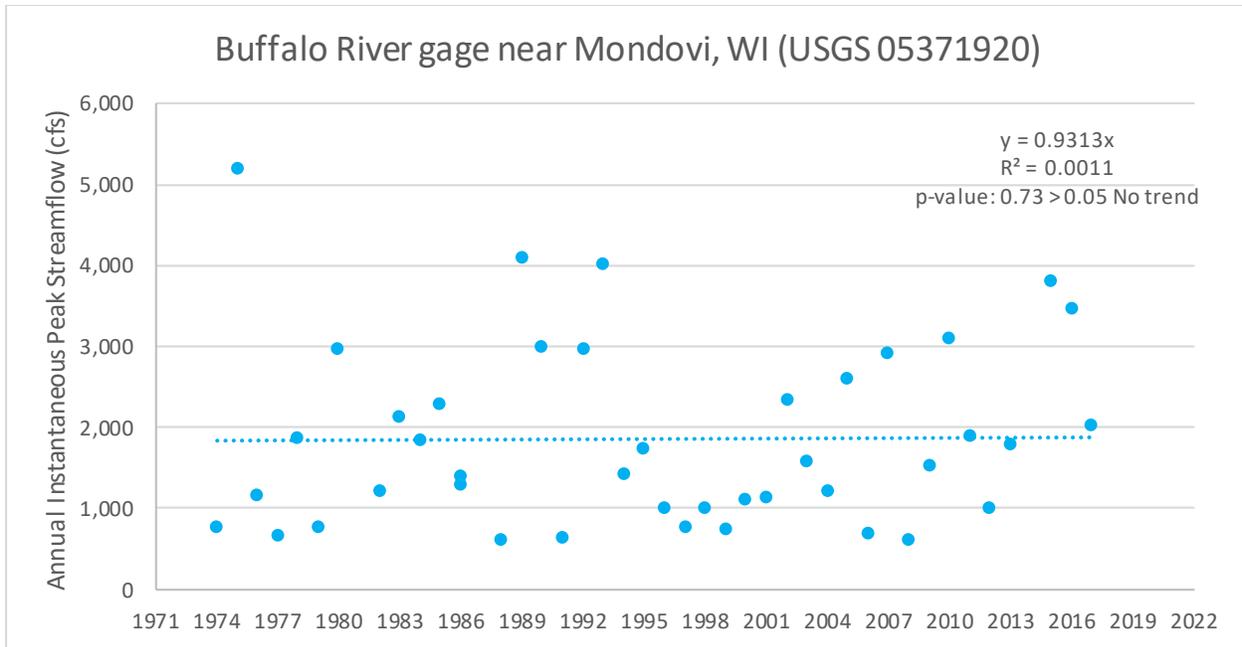
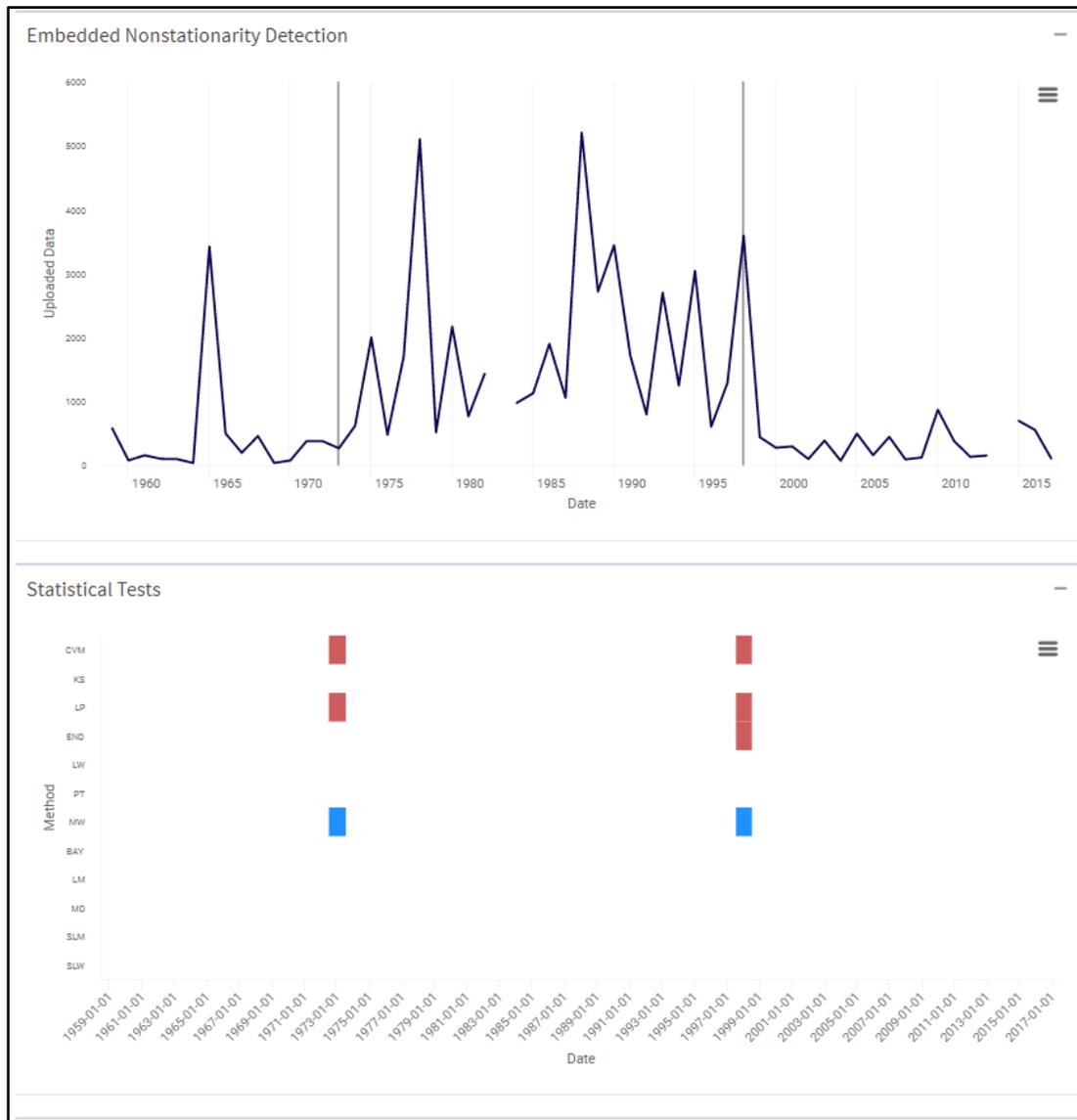


Figure 3-3. Observed Peaks & Linear Regression Analysis Buffalo River (1974-2017)

The Time Series Toolbox was used to analyze peak streamflows on the Kinnickinnic River Tributary between 1959 and 2019. The nonstationarity detection results for Kinnickinnic River Tributary gage, (USGS gage 05341900), showed two, strong nonstationarities, which are shown in Figure 3-4. A strong, nonstationarity was identified circa water year 1973 and 1998. The Cramer-Von-Mises (CVM) test, LePage test (LP), and Mann Whitney (MW) test all detect abrupt nonstationarities within a five-year span that encompasses 1973 and 1998. The 1973 and 1998 nonstationarities are considered strong because they demonstrate a degree of consensus, robustness, and a significant shift in the magnitude of the dataset’s statistical properties. The criteria of consensus are fulfilled because multiple tests targeted at detecting shifts in the distribution of the dataset, (i.e. CVM and LP), indicate nonstationarities. The detected nonstationarities are considered robust because tests targeted at detecting abrupt shifts in multiple statistical properties, overall distribution and mean, indicate that 1973 and 1998 are nonstationarities. Additionally, the results presented by the Time Series Toolbox indicate a significant shift in both the magnitude of the mean and standard deviation. The standard deviation was assessed through the Coefficient of Variance (CoV). The Time Series Toolbox found the following results for each of the individually assessed data subsets: 1959-1973 (mean = 453 cfs; CoV = 0.67); 1974-1998 (mean = 1926 cfs; CoV = 0.38); and 1999-2017 (mean = 324 cfs; CoV = 0.4). Within the period of record analyzed (1959-2019) and the subsets of data prior to and after the detected, strong nonstationarities, no statistically significant trends were detected, (t-test, Mann-Kendall, Spearman Rank-Order at a 0.05 significance level). A simple linear regression analysis carried out in Microsoft Excel also did not find a significant trend at a 0.05 significance level, see Figure 3-5.



Type: ■ Mean ■ Distribution ■ Variance ■ Smooth

Figure 3-4. Time Series Plot (y-axis is annual peak flow, in cfs) and Nonstationarity Detection Results, (see Table 3-2), of the Annual Peak Streamflow for the Kinnickinnic River Tributary (USGS Gage 05341900)

Table 3-2. Abbreviations of Statistical Test Methods.

Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	BAY	Bayesian
KS	Kolmogorov-Smirnov	LM	Lombard Mood
LP	LePage	MD	Mood
END	Energy Divisive	SLM	Smooth Lombard Mood
LW	Lombard Wilcoxon	SLW	Smooth Lombard Wilcoxon
PT	Pettitt	MW	Mann-Whitney

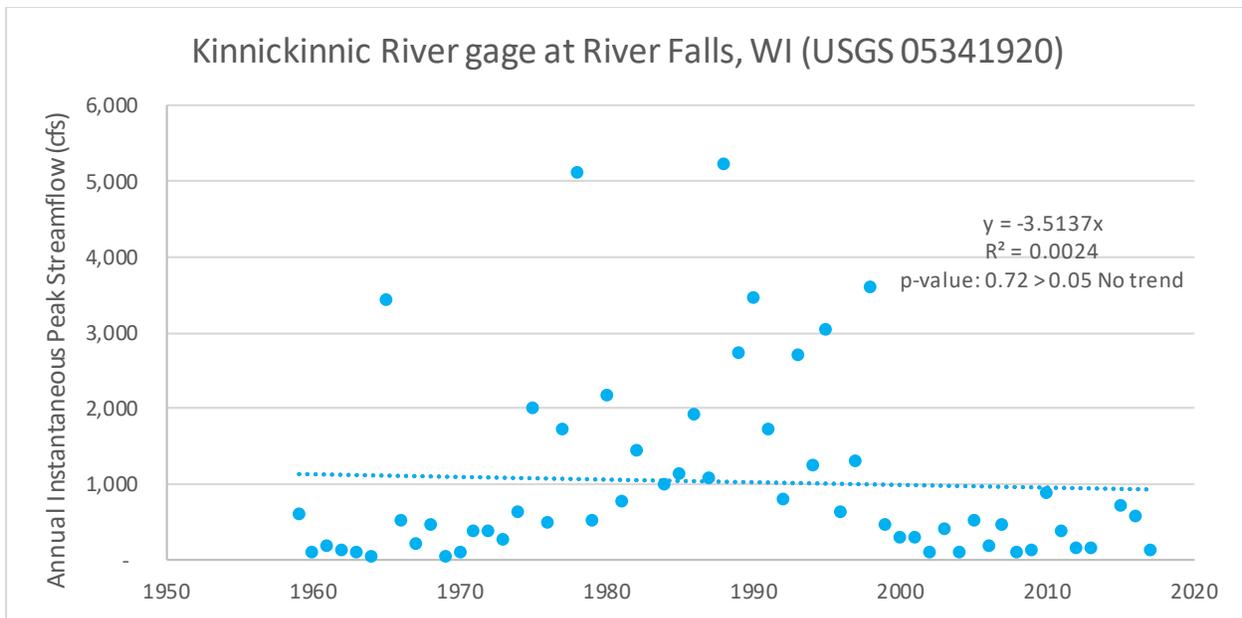


Figure 3-5. Linear Trend Analysis Annual Peak Streamflow for USGS Gage 05341900

It was discovered that the heavy rains in 1998 washed away the staff gage on the Kinnickinnic River. This coincides with the second nonstationarity. A new crest gage was installed the following year. It is unclear what is driving the nonstationarity detected in 1973 and whether nonstationarity detected in 1998 is caused by the change in monitoring equipment. Generally, the installation of a new gage should not result in such an abrupt shift in the range of streamflow peaks observed. Further investigation would be required to definitively attribute the detected nonstationarities to a specific driver.

### 3.3 Projected Hydrologic Trends

The USACE Climate Hydrology Assessment Tool, (CHAT; Reference 9), was used to investigate potential future changes to annual maximum monthly flows. CHAT works by combining the results of 93 different unregulated hydrologic model simulations for the St. Croix HUC-04 (HUC 0703) between 2000 and 2099. The hydrologic model simulations are forced with meteorological data derived from General Circulation Model (GCM) simulations that represent multiple future emissions scenarios, referred to as Representative Concentration Pathways (RCPs). The meteorological projections (temperature and precipitation) from the GCMs are spatially downscaled using the bias corrected spatially downscaled (BCSD) statistical method and then inputted in the Variable Infiltration Capacity (VIC) precipitation-runoff model. The VIC model is a macro-scale model representative of unregulated basin conditions and is used to generate a streamflow response.

As expected for this type of qualitative analysis, there is a considerable, but consistent spread in the projected annual maximum monthly flows, as shown in Figure 3-6. This spread is indicative

of the uncertainty associated with climate changed hydrology and range in natural variability. Uncertainty in projected, climate changed hydrology is generated as a result of each component of the modeling chain. For instance, assumptions related to selected RCPs, downscaling techniques, and hydrologic modeling each insert their associated uncertainties into the projected, climate changed hydrology. The CHAT tool fits a linear trend line to the mean projected annual maximum monthly streamflow data for the period from 2000-2099 computed for the HUC 0703 watershed, as shown in Figure 3-7. The mean projected annual maximum monthly streamflow increases slightly over time, but this increase is not statistically significant, ( $p\text{-value } 0.585 < 0.05$ ).

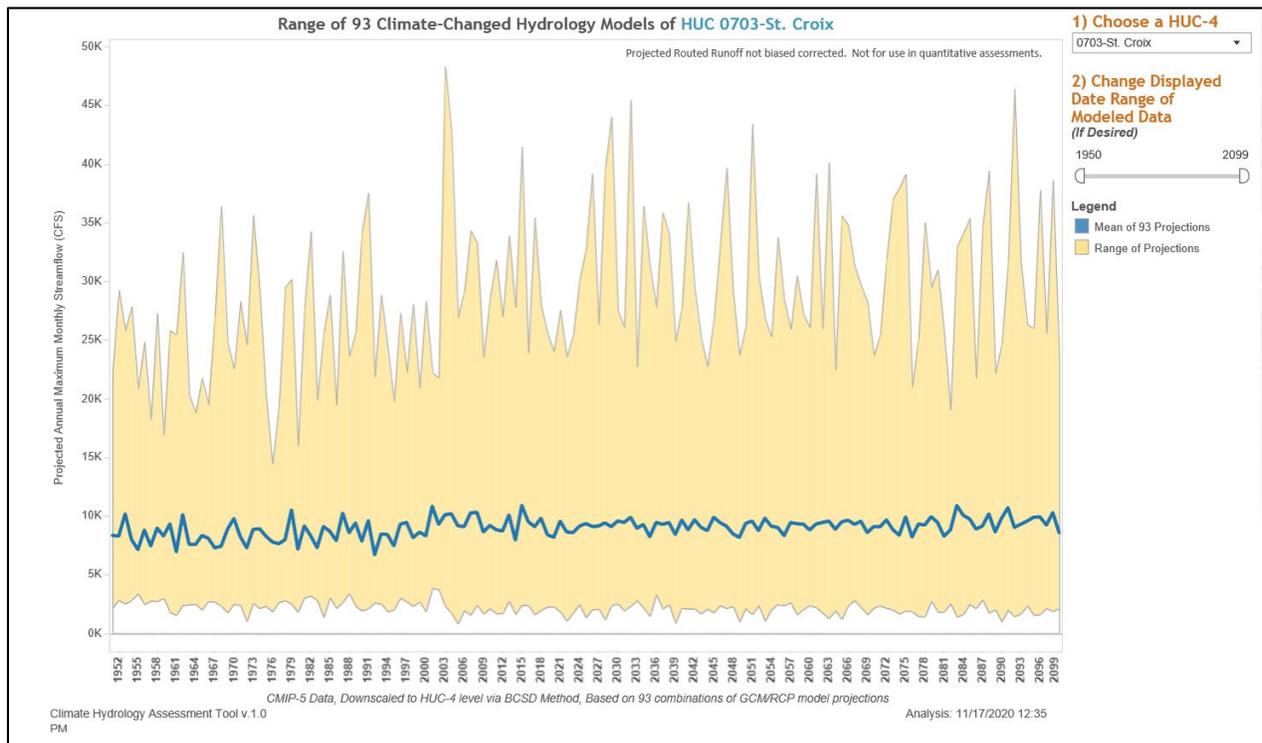


Figure 3-6. Range of 93 Climate-Changed Hydrology Model Runs for HUC 0703.

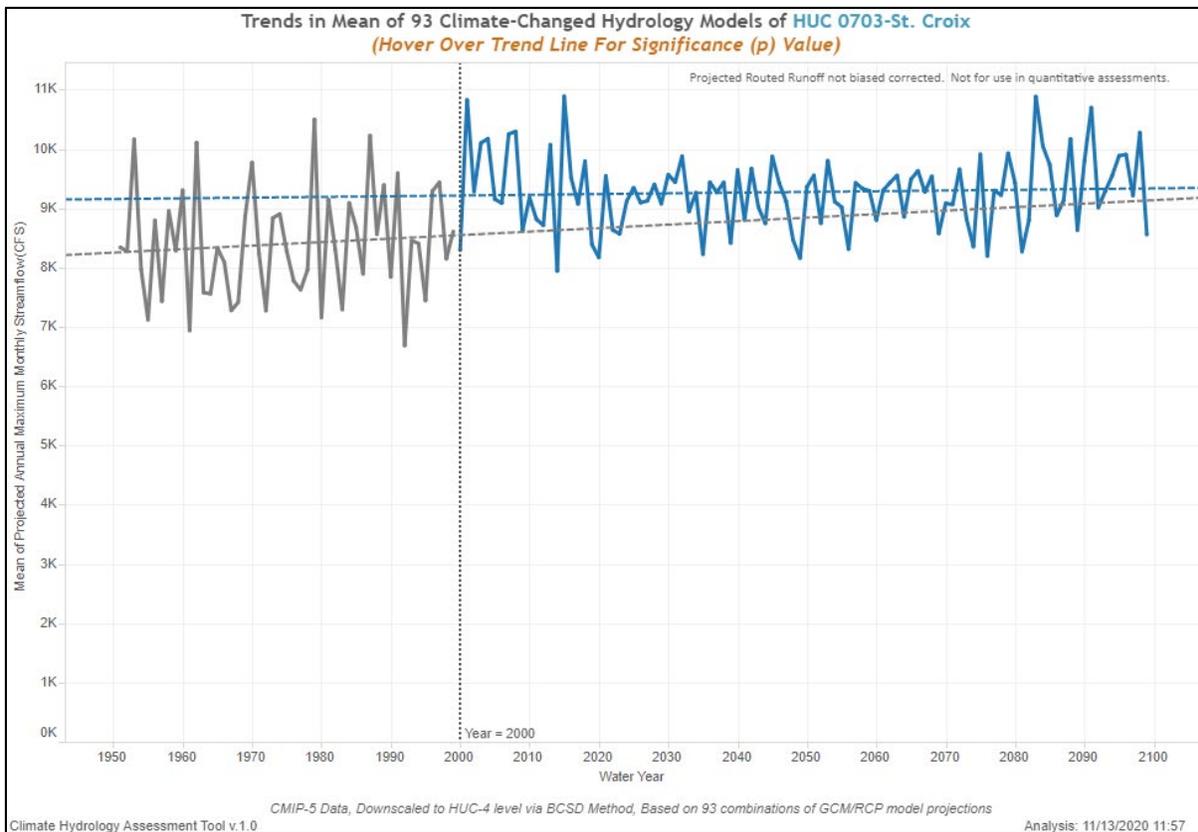


Figure 3-7. Trends in Means of 93 Climate-Changed Hydrology Model Runs for HUC 0703

## 4 Vulnerability Assessment

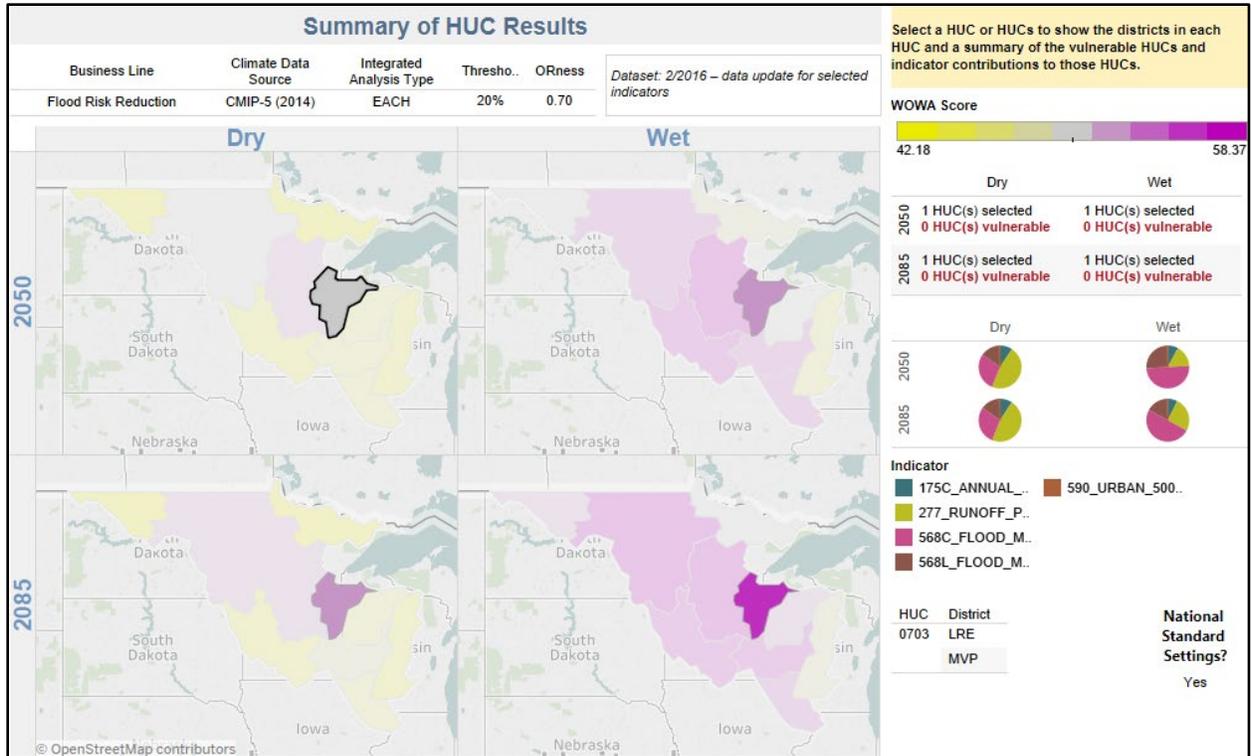
The USACE Watershed Climate Vulnerability Assessment (VA) Tool, (Reference 10), facilitates a screening level, comparative assessment of the vulnerability of a given HUC-04 watershed to the impacts of climate change relative to all other HUC-04 watersheds within the continental United States (CONUS). The HUC-04 watershed used in the Vulnerability Assessment analysis is the HUC 0703 St. Croix subbasin, which contains the Kinnickinnic River watershed. The tool is used to assess the relative vulnerability of a specific USACE business line, such as Flood Risk Reduction, to projected climate change impacts. 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.

The Watershed Vulnerability tool uses the Weighted Order Weighted Average (WOWA) method to compute a composite index, (i.e. vulnerability score or WOWA score), of how vulnerable a given HUC-04 watershed is to climate change specific to a given business line. The HUC-04 watersheds with the top 20% of WOWA scores across CONUS are flagged as vulnerable. The vulnerability assessment analysis for this study was 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 evaluate 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 GCMs and RCPs of greenhouse gas emissions resulting in 93 traces per HUC-04 watershed per epoch. The top 50% of the traces by flow magnitude is called the “wet” subset of traces and the bottom 50% of traces is called the “dry” subset of traces. Meteorological data projected by the GCMs is translated into runoff using the Variable Infiltration Capacity (VIC) macro-scale hydrologic model. This model represents unregulated basin conditions. Presenting results based on two epochs and two subsets of GCM model outputs reveals some of the uncertainty of potential future conditions.

The Flood Risk Reduction business line is used to carry out the vulnerability assessment. Removing the structure will result in a reduction in flood risk. The primary purpose of this hydrologic and hydraulic study is to generate information which will be utilized in a submittal related to floodplain zoning; therefore, the USACE flood risk reduction business line is the most appropriate to evaluate vulnerability of this watershed to climate change. While recreation opportunities and ecosystem habitats are expected to increase as a result of the dam removal (Reference 7), their business lines were not analyzed, as the vulnerability of these parameters is less relevant to the primary purpose of the submittal. Indicators considered within the WOWA score for Flood Risk Reduction representing changes to the flow characteristics of the river include: the coefficient of variation in cumulative annual flow; runoff elasticity, (i.e. the ratio of streamflow runoff to precipitation); and flood magnification, (i.e. how flood flow is projected to change in the future).

Based on results of USACE vulnerability assessment tool, relative to the other basins in the United States, the Kinnickinnic River Basin is not particularly vulnerable to impacts of climate change to flood risk for either the wet or dry subsets of traces representing the 2050 and 2085 epochs, as shown in Figure 4-1. Note that this result is qualitative only and does not imply that the watershed will not be affected by future changes in flood risk driven by climate change. The results simply imply that this watershed is not among the top 20% of HUC-04 watersheds indicated as being vulnerable to future flood risk in the continental United States. The WOWA score for The St. Croix River watershed, (HUC 0703), was lower for the dry subsets of traces, at 50.71, compared to the wet subset, at 52.46, in the year 2050. Scores for both subsets increased for the 2085 projection, by 2.13% and 7.08%, respectively. The primary driver of the vulnerability score for the dry subset of traces is runoff elasticity. The primary driver of the vulnerability score for the wet subset of traces is flood magnification.



*Figure 4-1. Projected Relative Vulnerability for the St. Croix Watershed (HUC 0703) with Respect to Flood Risk*

## 5 Summary & Residual Risk

The consensus from the literature review is that temperature and precipitation is increasing within the region. The frequency and the intensity of extreme storms is increasing as well. Projections of future climate show a continued increase in temperature, precipitation, and the frequency of large storms. There is considerable variability and uncertainty associated with trends in observed and projected streamflow. A first order statistical analysis of observed and projected streamflow for the study area and a screening level vulnerability assessment of flood risk does not provide strong evidence that the hydrology in the basin is changing.

The risk that climate change could pose to the study area in terms of flood risk is described in Table 5-1. The proposed project will not impact flood risk in a detrimental way. The proposal to remove the hydropower structure and allow the river to return to a more natural state will serve to offset any potential negative impacts that climate change could induce in the study area in the future. For example, as described in Table 5-1, there is a low, qualitative likelihood that climate change might increase the risk of floods due to an increased frequency of extreme precipitation events. Removing the hydropower structure will result in a drop in water level in the study area. Thus, the dam removal will effectively reduce flood risk and offset any potential future increases in flood risk that might occur due to climate change.

*Table 5-1. Potential Residual Risks*

Project Feature	Trigger	Hazard	Harm	Qualitative Likelihood	Qualitative Justification for Likelihood Rating
Return to run-of-the-river conditions downstream of Junction Falls Dam	Increased precipitation year-round, increased frequency and intensity of extreme storms	Future flood volumes and peak discharges may increase relative to present day run-of-the-river conditions	Floods may reach higher elevations than what was experienced in the past	Low	Increases in temperature could potentially increase evapotranspiration and offset increases in flood flow. First order statistical analysis of streamflows in the basin do not provide strong evidence that basin hydrology is changing.

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