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St. Paul District

Appendix N: Hydrology Study and Report

CAP Section 205 Flood Risk Management Study

Arcadia, WI

Draft Feasibility Study Report with Integrated Environmental Assessment

CAP Section 205 Feasibility Study

Trempealeau River and Tributaries at Arcadia, WI

Hydrology Study and Report

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of Engineers ®

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1 Executive Summary

The City of Arcadia, WI requested federal assistance to evaluate the feasibility of constructing a flood risk reduction project. The feasibility study for the Trempealeau River at Arcadia, WI is being conducted as part of the United States Army Corps of Engineers (USACE) Continuing Authorities Program (CAP). The purpose of this hydrology study and report is to provide discharge frequency information needed to develop a flood risk reduction project for Arcadia, WI. The City of Arcadia and the USACE identified five critical points of interest near Arcadia to include in the analysis:

1. *Trempealeau River at Dodge, Wisconsin (gaged, USGS Gage ID 05379500)*
2. *Trempealeau River at Arcadia, Wisconsin (gaged, USGS Gage ID 05379400)*
3. *Trempealeau River above Turton Creek (ungaged)*
4. *Myers Valley Creek at Arcadia, Wisconsin (ungaged)*
5. *Turton Creek at Arcadia, Wisconsin (ungaged)*

Discharge frequency analysis is used to produce a reliable estimate of peak streamflow and is an essential element of water resources planning. Establishing discharge frequency relationships first involves determining a stationary, homogeneous period of record for each site of interest. Once a stationary record is determined, the annual peak flows at points of interest throughout the study area are selected for use in the discharge frequency analyses. Multiple small dams exist in the Trempealeau watershed; however, none of the dams has a significant impact on the flow regime within the watershed.

A qualitative climate change assessment is included to identify trends in observed hydro-climatological variables, detect nonstationarities in the flow record, and assess watershed vulnerability to projected climate change. The results of the climate assessment did not indicate any strong nonstationarities within the observed discharge record for the Trempealeau River at Dodge, WI. Consequently, the entire period of record available for all sites with observed, annual peak flow data is used in the analyses in this study. Based on the USACE Vulnerability Assessment Tool results, the Trempealeau River Watershed is not identified as vulnerable to the effects of climate change on flood risk management relative to the other 201 HUC04 watersheds in the continental United States.

Discharge frequency analysis methods outlined in "Bulletin 17C: Guidelines for Determining Flood Flow Frequency" are used to define frequency curves for the Trempealeau River at Dodge, WI and the Trempealeau River at Arcadia, WI. Computations are carried out using the Hydrologic Engineering Center's (HEC) Statistical Software Package (HEC-SSP version 2.1). The Maintenance of Variance Extension Type 3 (MOVE.3) technique is used to extend the period of record for the Trempealeau River at Arcadia using the nearby, downstream Dodge, WI USGS gage to estimate the frequency curve at Arcadia.

The frequency curve for the Trempealeau River above Turton Creek, upstream of Arcadia is computed by transferring the frequency curve developed for the Trempealeau River at Arcadia USGS gage using a drainage area based method. A frequency curve is developed for the French Creek near Ettrick, WI USGS gage using methods outlined in Bulletin 17C to aid in the estimation of frequency curves for Myers Valley Creek and Turton Creek. A drainage area transfer method is ued to estimate a frequency curve for Myers Valley Creek and Turton Creek using the frequency curve developed for the French Creek near Ettrick. Updated USGS regression equations were considered to estimate frequency curves for ungaged sites; however, a sensitivity analysis indicates that the regression equations likely underestimate flood risk in this region. Confidence limits for all ungaged frequency curves are derived using the Hydrologic Engineering Center Flood Damage Reduction Analysis (HEC-FDA version 1.4.1) program.

A coarse hydrologic model was used to estimate the volume of runoff from the 1% annual exceedance probability flood event hydrograph at Turton Creek. Because Turton Creek is ungaged, model parameters are derived by modeling the hydrologically similar, gaged French Creek watershed. This work was performed to carry out a screening level analysis of nonstructural flood risk reduction alternatives. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS version 4.2) software is used to estimate the shape of the 1% annual exceedance probability hydrograph for the Turton Creek watershed based on the 1% annual exceedance probability, 6 hour duration, rainfall event. It is assumed that the 1% storm event produces the 1% annual exceedance probability runoff hydrograph.

2 Purpose of Study

The scope of this feasibility study is to provide updated discharge frequency information for several stream sites near the city of Arcadia, WI to aid in the development of a flood risk reduction project. The city of Arcadia is vulnerable to flooding from three primary sources: (1) Trempealeau River, (2) Turton Creek, and (3) Myers Valley Creek. Analysis is carried out using the techniques outlined in *Engineering Manual (EM) 1110-2-1415: Hydrologic Frequency Analysis* and *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (References 6 and 29, respectively). At the request of the USACE St. Paul District hydraulics section, existing hydrologic models from previous analyses are updated and used to develop an estimate of the 1% annual exceedance probability (AEP) event hydrograph for Turton Creek at Arcadia. Detailed hydrologic modeling, reservoir modeling, and synthetic event analysis is beyond the scope of work for this feasibility level study.

3 Watershed Information

3.1 General Information

The Trempealeau River basin encompasses a 750 square mile drainage area located in west central Wisconsin between the cities of LaCrosse, WI and Eau Claire, WI (Reference 10). The mainstem of the Trempealeau River originates near Hixton, WI and flows in a westerly direction towards Independence, WI. After the river leaves Independence, it begins to flow in a southerly direction until it reaches its confluence with the Mississippi River at a point 716.2 river miles upstream of the confluence between the Mississippi and Ohio Rivers (Reference 10).

Flooding in the city of Arcadia, WI is caused by the mainstem of the Trempealeau River, as well as several local tributary streams. There are two creeks near the city of Arcadia which contribute to flooding. The first creek is called Turton Creek. Turton Creek encompasses a 23.6 square mile watershed which flows in a westerly direction toward Arcadia where it joins the Trempealeau River upstream of River Street West in Arcadia (Reference 22). The second creek is Myers Valley Creek. Myers Valley Creek begins southeast of Arcadia and flows in a northwesterly direction until it joins the Trempealeau River downstream of West Main Street in Arcadia, WI (Reference 22). Plate I shows the geographic layout of the streams near the city of Arcadia.

3.1.1 Vertical Datum Information

There are three common vertical datums used in the study area: Mean Sea Level (MSL) 1912 Adjustment, National Geodetic Vertical Datum of 1929 (NGVD 29), and the North American Vertical Datum of 1988 (NAVD 88). Differences between vertical datums vary widely depending on geographic location. It is necessary to select several benchmarks in an area of interest and compare the difference between the current datum and a desired datum to develop an appropriate conversion factor.

Common datum conversions for the study area are listed below. Equation 1 shows the conversion between NAVD 88 and NGVD 29 which was developed for this study. Equation 2 is an approximate conversion been NAVD 88 and MSL 1912 used by the United State Army Corps of Engineers (USACE) Saint Paul District Surveys section for survey work near Lock and Dam 5a in Winona, WI. Winona is located approximately 27 miles to the southwest of Arcadia, WI.

Equation 1 Conversion factor between NAVD 1988 vertical datum and NGVD 1929 vertical datum used for hydraulic analysis in this study

$$\text{NAVD 88 (ft)} = \text{NGVD 29 (ft)} - 0.06 \text{ (ft)}$$

Equation 2 Approximate conversion factor between MSL 1912 and NAVD 1988 used by USACE St. Paul District surveys section within the project vicinity

$$\text{NAVD 88 (ft)} = \text{MSL 1912 (ft)} - 0.427 \text{ (ft)}$$

3.2 Geomorphology

The Trempealeau River basin lies in the driftless area of the Western upland region of Wisconsin (Reference 10). Elevations in the basin vary from 1,360 feet MSL in the upper portions of the watershed to 650 feet MSL near the confluence of the Trempealeau River and Mississippi River. The upland portion of the basin is comprised of rugged ridges and round hills. Steep slopes in the watershed are covered by semi-impervious soils and allow for rapid runoff of rainfall and snowmelt (Reference 10). The valley was created by the meander of the Trempealeau River. Outcroppings along the sides of the valley are made of Cambrian sandstone which is underlain by easily erodible alluvial fill. Outwash sands and fluvial clays, silts, and sand fill the valleys of the Trempealeau River and its tributaries. Typical channel slopes in the watershed are approximately 3 to 4 feet per mile (Reference 10). Slopes in the upland areas are typically steeper and are approximately 5.8 feet per mile.

Main channel slopes within the tributary watersheds tend to be steep. The Turton Creek watershed and the Myers Valley Creek watershed have slopes of 23.6 feet per mile and 34.4 feet per mile, respectively (Reference 26). Areas with steep slopes in the watershed tend to have relatively impervious soils which allow for rapid runoff of surface water (Reference 22).

Although the Trempealeau River at Arcadia is substantially larger than either Turton Creek or Myers Valley Creek, significant flooding from these small creeks impacts the city of Arcadia. Small creeks in Midwestern watersheds tend to be “flashier” than large creeks and thus have a rapid runoff response to rainfall inputs. Flashiness refers to the frequency and rapidity of short term changes in streamflow during runoff events (Reference 1). A measure of the flashiness of a watershed is called its flashiness index or Richards-Baker (R-B) index (Reference 1). Higher R-B index numbers are indicative of a flashier streamflow response. Myers Valley Creek and Turton Creek are both ungaged watersheds; therefore, a quantitative flashiness index cannot be estimated for these watersheds.

Baker et al. (2004) studied flashiness of streams within a six state area including Wisconsin. The study found that as watershed drainage area decreases, the flashiness of the stream increases (Reference 1). Figure 1 shows the results of the Baker et al. (2004) study for a six state area encompassing Wisconsin (Reference 1).

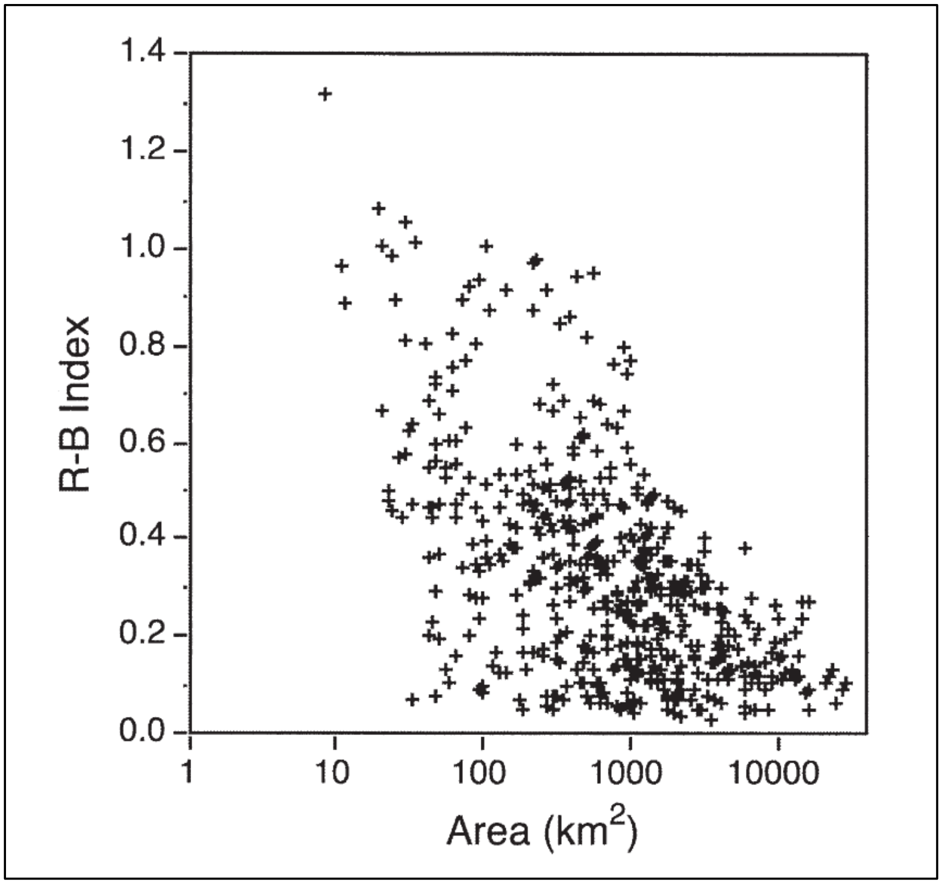


Figure 1 Flashiness index (R-B Index) for 6-state area including Wisconsin (Reference 1)

3.3 Climate

The climate of west central Wisconsin varies in temperature and includes ample rainfall and moderate snowfall. Average monthly temperatures in the region range from 16 degrees Fahrenheit in January to 73 degrees Fahrenheit in July. Annual precipitation is 31.5 inches and mean annual snowfall is 46 inches (Reference 22). Figure 2 below shows a climatograph with typical temperature and precipitation for Dodge, WI by month (Reference 47). The city of

Dodge, WI is located within the region of this study. The green bars in Figure 2 correspond to monthly, cumulative precipitation values. The red, black, and blue lines correspond to mean high, mean, and mean low temperatures, respectively. The climatograph in Figure 2 illustrates the variability of climate in Wisconsin throughout a typical year.

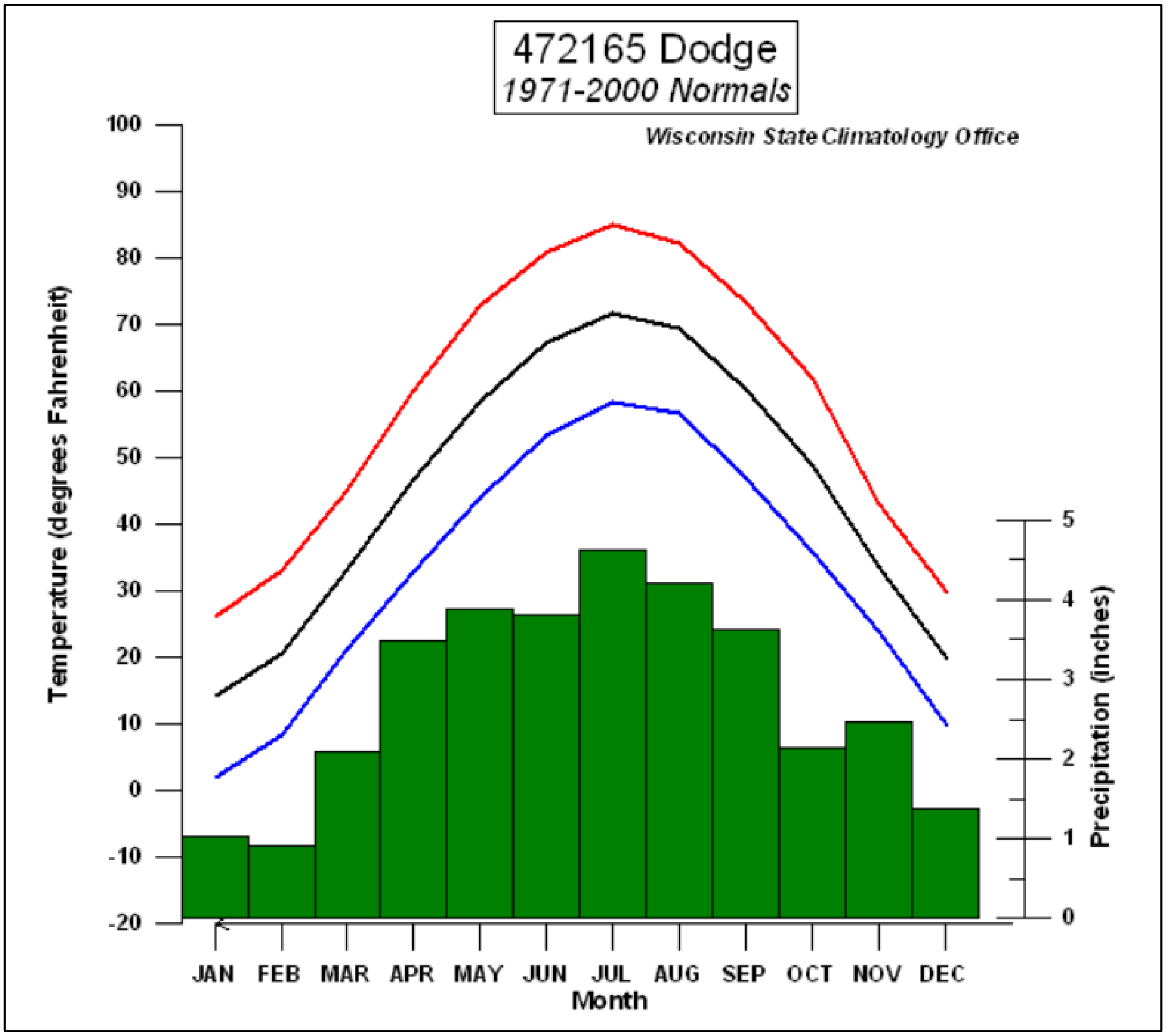


Figure 2 Climatograph of Wisconsin climate parameters (Red = avg. high, black = average, blue = avg. low, green = precipitation; Reference 47)

A cyclic analysis of mean daily flow data for the period of record 1914-1919 and 1934-2015 is included for the Trempealeau River at Dodge, WI USGS Gage (05379500) in Figure 3 below. The cyclic analysis function derives a set of cyclic statistics from a regular interval time series dataset. Daily data is apportioned into 365 bins, one for each day of the year and a statistical analysis is performed on all data which occurred on a particular date. For example, all mean daily flow data recorded on June 25th for the entire period of record would make up a single bin, and statistics are computed based on this resultant data set. The format of the resultant data set is a pseudo time series for an arbitrary water year which is used to represent the data.

Each pseudo time series represents a different statistical parameter. The cyclic analysis computes percentiles for the 5%, 10%, 25%, 50% (median value), 75%, 90%, and 95% percentiles. For example, the 50th percentile indicates that for a given day, half the flow values in the observed daily flow record recorded on that date are above the plotted line and half are below. Flows represented by the 95th percentile line indicate that 95% of flows recorded on that date are below the plotted value indicated by the line and 5% are above.

The cyclic analysis provides insight into the seasonal variation of flow magnitudes in the Trempealeau River Basin. The results of the cyclic analysis in Figure 3 show that most large scale flooding in the Trempealeau River watershed tends to occur during the March and April months. Flooding during the spring months tends to be much greater than flooding during other times of the year. The data in Figure 3 indicate that relatively large runoff events can occur during the summer and fall months, but most runoff events tend to be clustered in the early spring.

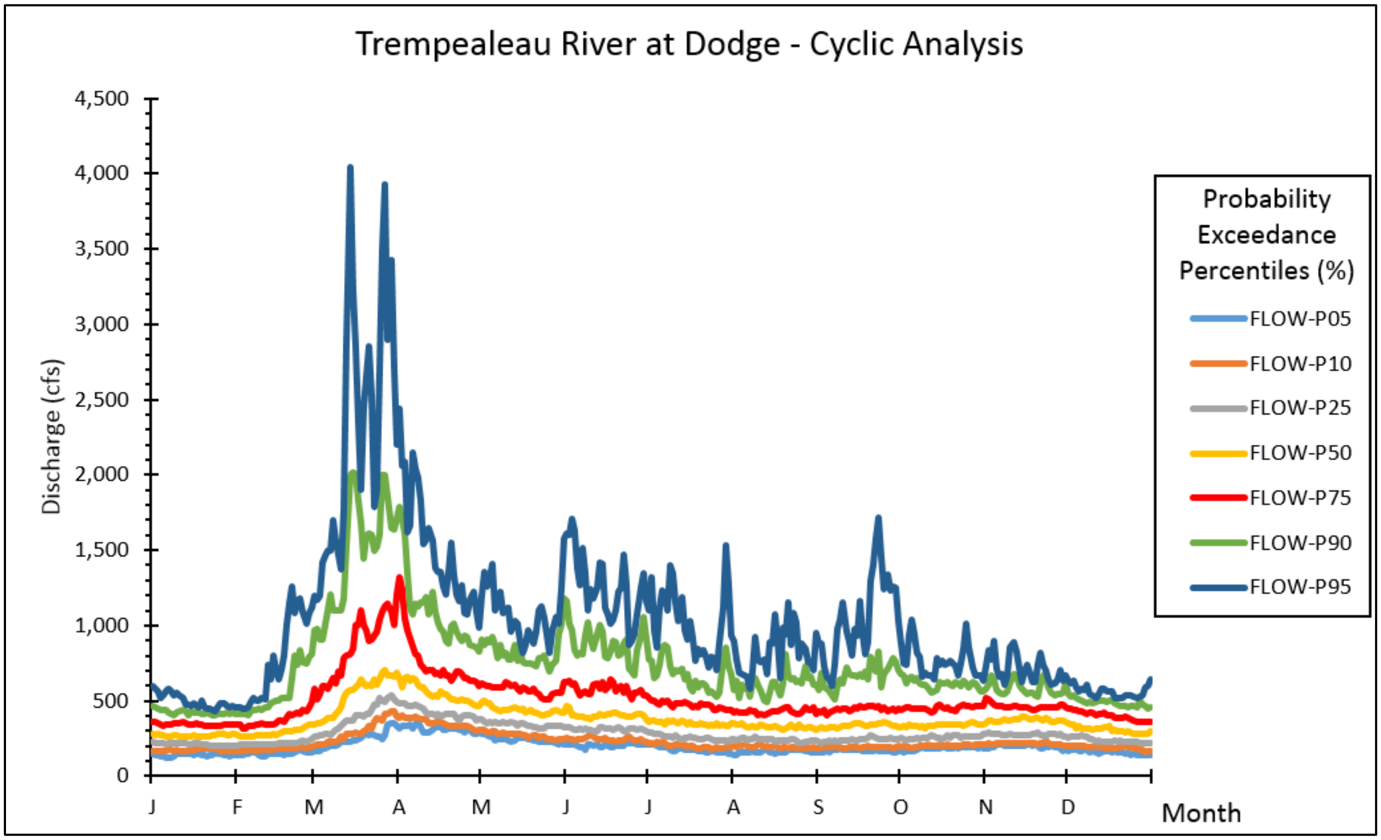


Figure 3 Trempealeau River at Dodge, WI Cyclical Analysis Results

3.3.1 Primary Causes of Flooding

Major floods in the Trempealeau River watershed have occurred during both the spring and summer months (Reference 10). This region typically experiences flooding during the early spring as the result of spring rains, snowmelt runoff, or a combination of rainfall and snowmelt. The small watersheds in this region tend to be quite responsive to local, intense rainfall events (Reference 22).

Floods in the region encompassing the Trempealeau River watershed tend to occur between the months of March and September, with the majority of floods occurring in March and April. Figure 4 below shows a histogram of the number of occurrences per month of the annual peak flood at the Trempealeau River at Dodge USGS gage (ID 05379500) for the 1914-1919 and 1935-2015 period of record (87 systematic events). As the histogram shows, annual peak floods primarily occur during the timeframe when temperatures are increasing and snowmelt is running off the watershed. A table of flood data represented by Figure 4 is included in Table 2 of Appendix C.

Section 6.1 provides qualitative descriptions of some of the largest floods in the region. The most severe floods tend to be the result of rainfall on snow during the spring snowmelt period. Severe flooding during the summer and fall months is often caused by an initial burst of rainfall, which saturates the soil, followed by an intense burst of rainfall which runs off the watershed and causes flooding. See Section 6.1 for more descriptions on large flood events which have occurred in the region which encompasses the Trempealeau River watershed.

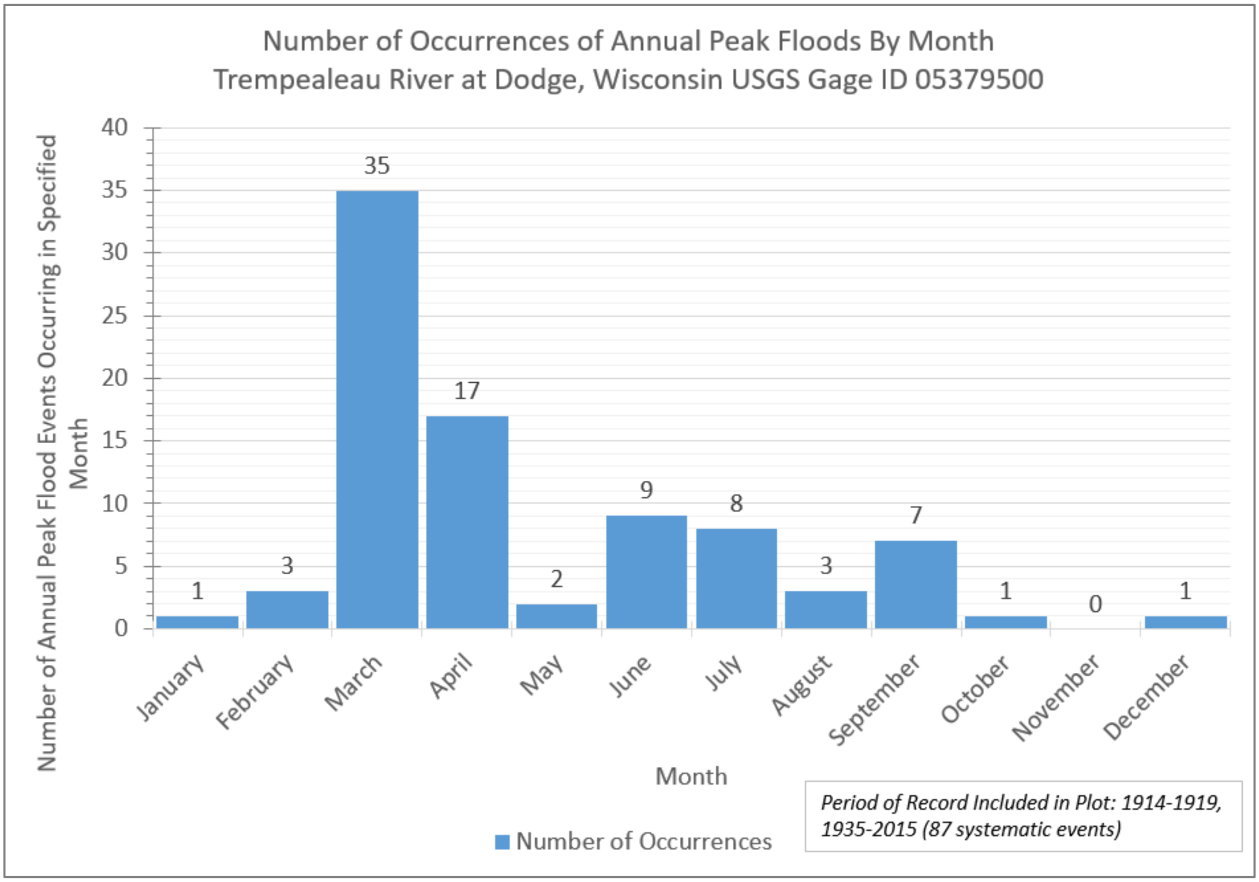


Figure 4 Relative number of occurrences of observed annual peak flow by month for the Trempealeau River at Dodge, WI USGS Gage

3.4 Land Cover and Use

The Trempealeau River basin contains rural and urban areas with rural areas comprising 90% of the watershed. Approximately 51% of land use in the Trempealeau River is devoted to agriculture, beginning in 1853 when the first farms were established (References 33 and 38). According to the *2011 National Land Cover Database,* the three primary land cover types in the watershed are pasture/hay, deciduous forest, and row crops. Primary crops in the watershed are alfalfa, hay, corn, and oats. Plate II illustrates all land cover types in the Trempealeau River Watershed and highlights the three common land cover types of (Reference 30). A notable change in agricultural practices occurred between the mid-1930s and the mid-1940s when agriculture practices switched from more intensive to less intensive land management. In general, less intensive land management promotes infiltration. For more information about land use see Section 3.3 of Appendix B.

4 Hydraulic Structures

Hydraulic structures like dams or reservoirs have to ability to impact the natural flow characteristics of streams and rivers. Large dams and reservoirs built for flood control typically have the most significant impact on streamflow. The *USACE National Inventory of Dams* (NID) database contains critical information about dams throughout the United States (Reference 36). All dams within the Trempealeau River watershed are summarized in Appendix A. None of the dams in the Trempealeau watershed are operated for flood control. Most of the dams are operated for recreation, water supply, or fire protection. None of the dams provide significant storage for flows and are thus are not anticipated to impact flows within the watershed. Consequently, it is assumed that peak streamflow data collected in the Trempealeau River watershed can be fit by the Log Pearson Type III statistical distribution suggested for analytical, flow-frequency analysis in Bulletin 17C.

5 Qualitative Climate Assessment

The potential for climate change to impact the hydrology of the Trempealeau River Basin is considered in accordance with USACE Engineering Construction Bulletin *(ECB) 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs and Projects* (Reference 9), as well as USACE Engineering Technical Letter *(ETL) 1110-2-3, Detection of Nonstationarities in Annual Maximum Discharges* (Reference 32). The guidance requires a literature review, an evaluation of the stationarity assumption, first order statistical analysis of both observed and projected streamflow data, and a relative assessment of the vulnerability of a given watershed to the impacts of climate change for select USACE business lines including flood risk management. Appendix B of this report provides a detailed qualitative analysis carried out to assess the impacts of climate change on the hydrology of the Trempealeau River Basin. The Trempealeau River at Dodge, WI USGS gage (05379500) is used to assess the effects of climate change on the hydrology of the Trempealeau River Basin.

5.1 Summary of Climate Assessment Findings

The Trempealeau River basin lies within the Upper Mississippi-Black-Root River (HUC 0704) watershed contained by the 2-digit Upper Mississippi River HUC 07 region. Based on a literature review, increases in temperature, precipitation, and streamflow are observed within the Upper Mississippi region (HUC 07). There is also consensus that the frequency of observed, extreme storm events has increased. Change in seasonality has also been noted in observed data. Spring warming is occurring earlier in the year and the length of the frost-free season has gradually increased.

A literature review of trends in projected climate meteorology and hydrology indicates that air temperatures are anticipated to increase within the study region. Precipitation and frequency of large storm events are projected to increase. Some portions of the region are predicted to experience increased drought as a result of increased temperature and evapotranspiration rates. The effect of climate change on projected, future hydrology is uncertain. Increases in precipitation indicate more streamflow could become an issue in the region, however, increases in temperature and evapotranspiration, changes in seasonality, and increases in soil moisture deficit may lessen the rainfall-runoff effect and could result in no change in the region's hydrology or even a decrease in streamflow.

Linear regression is used to assess if a statistically significant trend is present in the continuous, observed annual peak streamflow data for the Trempealeau River at Dodge, WI (USGS gage 05379500). Using the continuous period of record from 1935-2014, a statistically significant decreasing trend is detected within the observed, peak streamflow dataset. This decreasing trend is contradictory to the increasing trends in observed data identified at other sites in the region within the literature review. The stationarity of the flow record within the Trempealeau River Basin is assessed by applying a series of statistical tests to the observed annual peak flow record at Dodge, WI (1935-2014). No strong nonstationarities are identified in the observed annual instantaneous peak streamflow record at Dodge.

The USACE Climate Hydrology Assessment Tool (CHAT) is used to investigate potential future changes to annual maximum monthly flows within the Upper Mississippi-Black-Root River watershed region. Projected climate changed hydrology is generated using meteorological inputs derived based on various combinations of greenhouse gas (GHG) emission scenarios and Global Circulation Models (GCMs). The CHAT tool results indicate a statistically significant (p-value = 0.0367 < 0.05) increasing trend in the mean projected annual maximum monthly unregulated streamflow response for the Upper Mississippi-Black-Root River Basin computed from 2000-2099. The projected increase in annual maximum monthly flows is contradictory to the observed decreasing trend in annual peak streamflow observed at the Trempealeau River at Dodge, WI USGS gage, but is consistent with the trends identified based on the literature review. Contradictions in identified trends point to uncertainty in determining how the streamflow response will change as a result of climate change and other factors that may be impacting the hydrology of the study area.

The USACE Watershed Climate Vulnerability Assessment (VA) Tool facilitates a screening level, comparative assessment of the vulnerability of the Upper Mississippi-Black-Root River watershed (HUC04 0704) to the impacts of climate change relative to the other 201 HUC04 watersheds within the continental United States (CONUS) for the Flood Risk Reduction line. The default national standard settings (NSS) were used in the analysis.

The USACE Climate Vulnerability Assessment Tool makes an assessment for two 30-year epochs centered at 2050 and 2085 to evaluate future risk as a result of climate change. These two epochs are selected to be consistent with many other national and international analyses related to climate. The Vulnerability tool assesses climate change vulnerability for a given business line using climate changed hydrology based on a combination of projected climate outputs from the general circulation models (GCM) and representative concentration pathway

(RCPs) of greenhouse gas emissions resulting in 100 traces per HUC04 watershed per time period. 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.

Based on results of USACE vulnerability assessment tool, relative to other basins in the continental United States, the Upper Mississippi-Black-Root River Basin is not particularly vulnerable to impacts of climate change and variability for the Flood Risk Reduction business line. Note that while the Upper Mississippi-Black-Root River Basin is not particularly vulnerable to impacts from climate change relative to other watersheds, it may still be vulnerable in an absolute sense.

5.2 Climate Assessment Findings Summary

The results of the vulnerability assessment tool, along with the lack of consensus with regards to trends in streamflow peaks presented by both the literature review and the contradictory directionality of trends in streamflow magnitude, as well as the lack of strong nonstationarities in the peak flow record at Dodge suggest that the annual instantaneous peak streamflow records within the Trempealeau River Basin should be treated as being stationary for the current analysis. Based on this assessment, the recommendation is to treat the potential effects of climate change and long-term natural variability in climate as occurring within the uncertainty range calculated for the current hydrologic analysis.

Methods of translating long-term persistent natural climate trends and trends caused by anthropogenic climate change, as well as their associated uncertainty, into engineering-based analysis are not currently outlined in USACE guidance. Communities may wish to take on this responsibility locally based on the information provided in this assessment. It is recommended that the local community should seek opportunities to build resilience into all current and future Flood Risk Reduction projects and Water Management Plans to account for added uncertainty of climate change and other land use related impacts. It is recommended that the discharge frequency analysis of the Trempealeau River Watershed be regularly revisited to assess if the existing frequency analysis still provides an adequate characterization of flood risk. These steps are advisable for this watershed because some of the literature reviewed and the CHAT tool projected climate changed hydrology results do indicate a potential increase in flows in the future.

6 Analysis Period of Record

The criteria for application of probability theory to carry out discharge frequency analysis is that recorded stream events adopted for the analysis must be random, independent, stationary, and homogeneous. Discharge data selected for each site in this study is assumed to meet the criteria. In cases where peak flow data is available, the entire systematic period of record is adopted to perform the analysis. A summary of the period of record selected for each of the four points of interest within the Trempealeau watershed and a summary of the analysis method for each site is shown in Table 1.

An inventory of available annual instantaneous peak flow information is also conducted for watersheds near the Trempealeau River basin to assess the availability of regional information to augment flow frequency analysis at the four points of interest. The gage inventory includes small to medium sized watersheds in the region because the large watersheds included in this study appear to have adequate streamflow data. The streamflow gage summary for sites outside the Trempealeau River watershed is shown in Table 2 below.

The stream gages in Table 2 were selected as potential candidates to assist in defining a frequency curve for the ungaged watersheds of interest in this study and to define the 1% annual exceedance probability hydrograph for Turton Creek. To be considered for use in this analysis, the gages in Table 2 had to be continuous, active, unaffected by upstream regulation, include at least 30 systematic events, and be located in nearby hydrologically similar watersheds. Table 2 indicates whether or not the gages were included in this study.

Table 1 Critical study locations and available peak flow data in the Trempealeau Watershed

Site	State	USGS Gage ID	Drainage Area (mi^2)	Available Period of Record (Peak Data)	No. of Observed Systematic Events	Adopted Flow Frequency Analysis Methodology
Trempealeau River at Dodge	WI	05379500	643	1914-1919, 1935-Present	87	Analytical analysis, full period of record, historic record, Bulletin 17C methodology
Trempealeau River at Arcadia	WI	05379400	552	1961-1977, 2002-2004, 2014-Present	22	Analytical analysis, MOVE.3 record extension with Dodge USGS gage, Bulletin 17C methodology
Trempealeau River above Turton Creek	WI	Ungaged Watershed	528.4	Ungaged Watershed	Ungaged Watershed	Drainage Area transfer with Trempealeau River at Arcadia USGS gage, confidence limits computed with HEC-FDA
Myers Valley Creek at Arcadia	WI	Ungaged Watershed	6.4	Ungaged Watershed	Ungaged Watershed	Drainage area transfer with French Creek near Ettrick, WI USGS gage, confidence limits computed with HEC-FDA
Turton Creek at Arcadia	WI	Ungaged Watershed	23.6	Ungaged Watershed	Ungaged Watershed	Drainage Area transfer with the French Creek near Ettrick, WI USGS gage, confidence limits computed with HEC-FDA

Table 2 Gage Inventory of Nearby Streamflow Gages

Streamflow Gage Site Name	State	USGS Gage ID	Drainage Area (mi^2)	Start and End Year of Gage	Available Number of Systematic Events	Reason the Gage Was or Was Not Included in Analysis
Arkansaw Creek Tributary Near Arkansaw	WI	05370600	2.61	1959-1993	35	Not Included. Gage is discontinued and missed several large flood events in the region, drainage area is too small for consideration
Spring Creek Near Durand	WI	05370900	6.45	1962-Present	52	Not included. Discharge is affected by debris jams. Gage is listed as Inactive by USGS
Bruce Valley Creek Near Pleasantville	WI	05379288	10.1	1996-Present	17	Not included. Insufficient period of record, need at least 30 systematic events
Pine Creek At Taylor Road Near Taylor	WI	05379187	10.9	1996-Present	17	Not included. Insufficient period of record, need at least 30 systematic events
Eagle Creek Near Fountain City	WI	05378200	26.8	1961-1992	31	Not Included. Gage is discontinued and missed several large flood events in the region
Eagle Creek At Ct Highway G Near Fountain City	WI	05378185	14.3	1991-2007	16	Not included. Gage is discontinued. Insufficient period of record, need at least 30 systematic events
Glenn Creek Near Millston	WI	05381383	10.7	1996-Present	19	Not included. Insufficient period of record, need at least 30 systematic events
North Fork Whitewater River near Elba	MN	05376000	101	1940-1993	29	Not Included. Gage is discontinued and missed several large flood events in the region
South Fork Whitewater River near Altura	MN	05376500	76.8	1940-1986	48	Not Included. Gage is discontinued and missed several large flood events in the region
Rush Creek near Rushford	MN	05384500	132	1942-2014	73	Not Included. Drainage area is considerably greater than Turton Creek watershed
French Creek near Ettrick	WI	05382200	14.7	1960-1983, 1989-2004, 2006-2009, 2012-2013, 2015	47	Included to define the Turton Creek Frequency Curve and 1% AEP event hydrograph. The gage record is sufficiently long, the drainage area is similar to the Turton Creek drainage area, and French Creek is located next to the Turton Creek watershed
North Fork Bad Axe River near Genoa	WI	05387100	80.8	1959-Present	54	Included. Gage is continuous, active, and has enough systematic events for frequency analysis. Drainage area is large, but still reasonable
Crooked Creek near Boscobel	WI	05407200	12.9	1959-2002, 2017-Present	45	Not included. The gage did not record annual instantaneous peak flow data from 2003-2016 and was listed as inactive at the time of this study

6.1 Significant Floods

Information regarding significant, large scale flooding in the Trempealeau River watershed provides valuable perspective on flood mechanisms within the basin and allows large magnitude flood information from the systematic period of record to be put into a historic context. Rainfall runoff, snowmelt runoff, and a combination of rainfall and snowmelt runoff each have the potential to result in damaging floods. Severe floods are also the result of flash floods on small tributaries in the watershed which result from intense, locally concentrated rainfall events. The sections below provide descriptions of several large floods which occurred in the basin. Table 3 below summarizes the largest 10 observed, systematic flood events for the Trempealeau River at Dodge, WI USGS gage ranked in order of discharge.

Table 3 Top 10 Flood Events (sorted by discharge) for the Trempealeau River at Dodge, WI

Top 10 Flow Events - Trempealeau River at Dodge, WI USGS Gage ID 05379500			
Rank (Largest to Smallest)	**Date**	**Annual Peak Discharge (cfs)**	**Annual Peak Stage (feet)**
1	5-Apr-1956	17,400	10.35
2	8-Apr-1965	12,100	9.40
3	27-Mar-1961	11,100	9.20
4	18-Mar-1919	11,000	10.20
5	25-Aug-1975	10,600	11.36
6	5-Oct-1954	10,400	8.80
7	13-Mar-1985	9,310	11.18
8	26-Sep-2010	9,040	12.75
9	19-Sep-1992	8,230	11.44
10	17-Mar-1945	8,120	9.10

6.1.1 Flood Event of 1876

According to the *2000 WIGenWeb Project,* a significant flood event occurred on the Trempealeau River in 1876 (Reference 46). The flood of 1876 was driven by severe rainfall on frozen ground, causing a sudden runoff response. Quantitative information about the magnitude of the 1876 flood event is not available, but the *2000 WIGenWeb Project* indicates that many rivers and creeks in the watershed were flooded. Specific flooding is referenced in the Beaver Creek Valley near Galesville, WI and flooding at Independence, WI (Reference 46).

6.1.2 Flood Event of 1919

The spring thaw began in early March of 1919. By March 15, 1919 enough snow had melted to fill the Trempealeau River to bank full (Reference 11). Later that same day, rain fell for three hours onto frozen ground which prevented infiltration. The runoff caused the river to overflow its bank and flood several towns in the watershed. Lumber yards in Arcadia were swept clean by the flood waters and basements were filled with flood water. By early the next day on March 16th, the river had returned to its banks (Reference 11). By the time the initial flood waters receded into the river channel, additional water from Independence and Elk Creek Dams came down and once again flooded the city of Arcadia. Water on Main Street in Arcadia was several feet deep. High velocity flows undermined large pieces of sidewalk which were carried away by flood waters. A total of 15 roadway bridges in Trempealeau County were washed out during this flood event (Reference 11).

6.1.3 Flood Event of 1954

The October 1954 flood event resulted from a large rainfall event and saturated soil conditions from several previous rainfall events which prevented infiltration and promoted runoff. Approximately four inches of rain fell in less than one day on October 2, 1954 (Reference 11). The resulting flood caused substantial damages to the cities of Arcadia and Blair. The City of Independence was isolated due to destruction of numerous roadways and bridges used to access the city. The roadbeds of the Green Bay and Western Railroad companies were washed out at Blair and at several locations between Arcadia and Whitehall (Reference 11).

6.1.4 Flood Event of 1956

According to the *Summary of Floods in the United States During 1956,* the floods of April 2-6, 1956 resulted from melting of heavy snow which had fallen in March, warm temperatures, and rain during the early part of April (Reference 27). The precipitation was approximately 2.6 inches over 8 days, which is moderate, but the combination of precipitation, rapidly melting snow, and a high soil moisture content resulted in flooding for much of western Wisconsin (Reference 27). The peak flow of the 1956 event at the Trempealeau River at Dodge, WI was 58% greater than the previous maximum peak in 1919 and was the highest peak flood event since 1876 at Dodge, WI (Reference 27).

The greatest flood damage occurred in the Trempealeau Valley in the towns of Arcadia, Whitehall, and Blair (Reference 27). Dams at Blair and Whitehall were severely damaged (Reference 27). The 1956 event was the worst flood since 1919 in Arcadia (Reference 27). The *Summary of Floods in the United States During 1956* report does not indicate that the 1956 flood event was the largest observed at Arcadia, WI since 1876 (Reference 27). More than 20 blocks in the town of Arcadia were inundated with as much as 3.5 feet of water in low lying areas (Reference 27).

6.1.5 Flood Event of 1975

Drought conditions were pervasive throughout much of the summer of 1975. On August 22, 1975 approximately six inches of rain fell during a three hour period overnight. The rain continued until dawn in other regions of the watershed. The Green Bay and Western Railroad system and the county highway system experienced extensive damages due to washouts from flood waters. Roughly 75 percent of businesses in downtown Arcadia were flooded by 2.5 feet deep flood water. Multiple residences were evacuated in the city of Blair. At the time, the 1975 flood was the most damaging flood on record in the Trempealeau River basin (Reference 11).

6.1.6 Flood Event of 1992

The flood event of 1992 occurred as a result of a series of thunder storms across the watershed. Sudden, severe storms produced flash floods across the basin. In Mondovi, WI rainfall gages indicated that as much as 7.88 inches of rain fell during the event. The rainfall gage in LaFarge, WI captured 9.50 inches of rainfall over a five-day period from September 14-18, 1992 (Reference 3).

6.1.7 Flood Event of 2010

Heavy rains in the fall of 2010 led to flood conditions which caused the Governor of Wisconsin to declare a state of emergency for Trempealeau County. Approximately seven inches of rainfall were recorded in as little as 24 hours. Rising flood waters forced the evacuation of two-thirds of the 2,500 Arcadia residents. Most of the flooding occurred in downtown Arcadia. Storms and subsequent floods washed out roads, downed power lines, flooded basements, and caused damage to infrastructure in Trempealeau County. Initial flooding was the result of rising waters on the small creeks surrounding the City of Arcadia (Reference 31). Overtopping of Myers Valley Creek occurred along the bank upstream near the DSM Bridge and flooded the city, causing approximately $7,000,000 in property damage (Reference 5). A hydraulic model was used to estimate the magnitude of the peak flow by calibrating the model to high water marks. It was estimated that the 2010 flood event on Myers Valley Creek had an approximate magnitude of 850 cfs which includes weir discharge of 125 cfs down Washington Avenue (Reference 5).

7 Discharge Frequency Analysis Methods

The purpose of this study is to define discharge frequency values for streams and rivers which contribute to flooding in the City of Arcadia. Streams which affect Arcadia are the Trempealeau River, Turton Creek, and Myers Valley Creek. Within the Trempealeau River watershed, there is only one long term gage located along the Trempealeau River at Dodge, WI. A frequency curve was derived for the Dodge gage to extend the period of record of the short term Arcadia USGS gage. Methods used to extend the length of the Arcadia record are outlined below and a description of the analysis performed for each site is also described in the subsequent sections below.

7.1 Bulletin 17C Guidelines for Determining Flood Flow Frequency

In 2005, the Hydrologic Frequency Analysis Work Group (HFAWG), under the Subcommittee on Hydrology, began development on *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29). Bulletin 17C is a revision of *Bulletin 17B*: Guidelines for Determining Flood Flow Frequency (Reference 28). Bulletin 17B was published in 1982 and presents the previous standard of practice for performing analytical discharge frequency analysis. The final version of Bulletin 17C was published in March 2018. The HFAWG recommends using Bulletin 17C guidelines to estimate flood flow frequency curves. The latest version of the Hydrologic Engineering Center Statistical Software Package (HEC-SSP version 2.1, Reference 19) incorporates the methodology presented in Bulletin 17C. Bulletin 17C Guidelines improve on Bulletin 17B in the following ways:

(1) **Low Outlier Detection**: Bulletin 17C applies the Multiple Grubbs-Beck test versus the simple Grubbs-Beck test recommended by Bulletin 17B. The low outlier detection tests are used to identify influential low flood observations which unduly influence the characterization of the exceedance probability associated with large flow magnitudes. The Multiple Grubbs-Beck Test (MGBT) facilitates the identification of multiple low outliers including zero flow values.

(2) **Confidence Limits**: Large differences in confidence intervals may be observed between intervals computed with Bulletin 17B compared to intervals calculated with Bulletin 17C because the Bulletin 17B confidence intervals ignore uncertainty in estimating skew and has no provisions for recognizing the value of historical information. In Bulletin 17C the Expected Moments Algorithm (EMA) is applied to generate confidence limits and accounts for uncertainty in estimates of skew as well as historical flood information.

(3) **Expected Moments Algorithm (EMA)**: Instead of applying the method of moments procedure to estimate parameters of the sample to fit a Log Pearson Type III distribution to the observed data as suggested by Bulletin 17B, Bulletin 17C facilitates the use of the EMA. The EMA is a generalized method of moments procedure to estimate the Pearson Type III distribution parameters. The EMA provides a direct fit of the Pearson Type III distribution using the entire dataset, simultaneously employing regional skew information and a wide range of historical flood and threshold-exceedance information, while adjusting for any potentially influential low floods, missing values from an incomplete record, or zero flood years (Reference 29).

(4) **Record Extension**. To extend the period of record at a short-term gage using information from a nearby long-term gage, Bulletin 17C guidance recommends the Maintenance of Variance Extension Type 3 (MOVE.3) approach instead of relying on the two station comparison. The MOVE.3 approach is discussed in Section 7.3.

(5) **Plotting Positions**. Plotting positions are an empirical (non-parametric) method to judge the adequacy of the estimated flood frequency relationship for a particular set of data. In the previous Bulletin 17B guidelines, the adequacy of the Log Pearson Type III

distribution applied to a series of annual peak flood flows was assessed using Median plotting positions. Bulletin 17C guidelines utilize standard and non-standard flood data which are represented by perception thresholds and flow ranges; consequently, a multiple exceedance threshold plotting position formula is necessary to plot annual peak flood events. All flood events in the analytical frequency analysis cases are plotted with Hirsch-Stedinger plotting positions, except low outliers which are plotted using Median plotting positions.

7.1.1 Applicability of Bulletin 17C Guidelines

The guidelines in Bulletin 17C outline the process of defining flood potential at a specific location in terms of peak discharge and annual exceedance probability (AEP, %). The Bulletin 17C guidelines are applicable for defining the frequency of flood events rarer than and including the 10% AEP event (10-yr average return period). Flood AEPs ranging from 10% (10-yr return interval) to 0.2% (500-yr return interval) are estimated using annual peak discharge time series data and the methods described in Bulletin 17C in this study.

If frequency estimates are desired for events which occur more frequently than the 10% AEP event, it is recommended that a peaks over threshold analysis or partial duration series analysis using the generalized Pareto distribution (GPD) be performed to define that region of the frequency curve. A partial duration series analysis to define a broader range of the frequency curve was not included in the scope of work for this analysis and was not needed to define the flood frequency characteristics of the study site.

7.2 Perception Thresholds

The Expected Moments Algorithm (EMA) uses interval data rather than discrete data points in computations. This allows for the use of non-standard flood information such as historical flood data or paleoflood information to be incorporated into the analysis, especially if the exact magnitude of the historic or paleoflood event is not known. Each flow value used in the analysis is represented as a flow range interval, with both a high and low value.

The EMA approach requires that each year in the systematic record must be represented using perception thresholds and a flow range. Observed, systematic events are assumed to be known with a high degree of accuracy. Therefore, the perception thresholds for systematic events uses a low perception threshold equal to zero and a high perception threshold equal to infinity. A perception threshold which spans zero to infinity assumes that all discharges that occurred during periods when measurements were taken would have been recorded, regardless of magnitude. Applying a perception threshold in this manner implies that the low flow range value is equal to the high flow range value. Both the low and high flow interval values are equivalent to the observed event magnitude. This assumes that the gage measuring the data is accurate.

Flow intervals for years with missing information are estimated using an exceedance bound perception threshold. The exceedance perception threshold is defined with a lower limit equal to a reference, observed flow magnitude and an upper limit of infinity. The corresponding flow interval for years with missing information is simply the complement of the perception threshold range. Years for which discrete flow measurements are unavailable, but relative flow magnitudes can be defined as described above are referred to as censored data points within HEC-SSP (Reference 29). If available, historic flood information recorded outside of the systematic record is applied to define the lower limit of the exceedance perception threshold. By adopting historic flood information to define the lower limit, this implies that if a flood greater than the historic flood had occurred during the missing portion of the period of record, it would have been recorded. The discharge frequency analyses described in Sections 8.1-8.3 include information about how the perception thresholds for each individual analysis was selected and applied as a flow range.

In cases where the systematic streamflow record has gaps and where historic flood information is unavailable, the event of record (largest observed event) from within the systematic period of record is used to define the lower limit of the perception threshold for the missing flow years. Various resources including flows recorded at hydrologically similar locations, newspaper articles, USGS water supply papers and past studies are used to validate the assumption that the flow magnitudes associated with the missing data years would have been less than the largest event recorded. This methodology is consistent with the *Broken Record Example – Back Creek near Jones Springs, WV* contained in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29). This approach was also discussed with experts at the USACE Hydrologic Engineering Center (HEC). Experts at HEC indicated that using the event of record to define a perception threshold, in the absence of recorded data or historic information, is a conservative method of estimating the discharge frequency curve for sites with gaps in the systematic flow record.

7.3 Record Extension Technique

At least one gage in the study area has a period of record which is short, discontinuous, and contains missing information. Observed, annual instantaneous peak flow records at nearby long term index stations are used to fill in and extend the peak discharge records observed at sites with partial or short term records. Initially, simple linear regression is used to identify correlation between observed annual instantaneous peak (AIP) flows at short term, partial stations and observed peaks at a long term, index stations. Bulletin 17C recommends that record augmentation be considered whenever the correlation coefficient, R, is greater than 0.80 (R^2 greater than 0.64) and the short record site is less than 20 years in length (Reference 29). Once an appropriate index (long-term) station is identified for each partially gaged location, the maintenance of variance extension type three (MOVE.3) method is used to estimate missing flows from the partial record station using information from the long-term, index station.

7.3.1 Maintenance of Variance Type 3 (MOVE.3)

The MOVE.3 technique is a statistical method for estimating missing flows from the record at a short term station by comparing the short term flow record to the long term flow record. The MOVE.3 technique produces a nearly unbiased estimate of mean and variance. MOVE.3 is primarily applied in support of water resources planning and management models, as well as for reservoir design and operation.

Equation 3 is the MOVE.3 regression relationship used to estimate missing flows at short record stations if there is a long term station nearby. The MOVE.3 technique is considered an appropriate technique for record extension if: (1) linear correlation exists between the concurrent record of the short term gage and the long term gage, (2) if the MOVE.3 modeled flows accurately predict observed flows at the short record station, and (3) if there is improvement to the mean and variance of the short record site, based on the longer period of record. Improvement of variance occurs when the variance of the combined record is less than the variance of the original, short record. Additional details about this technique can be found in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29) and a paper by Vogel and Stedinger (Reference 41).

Equation 3 MOVE.3 Analysis Equation

$$(\hat{y}_i) = a' + b(x_i - \bar{x}_2) \quad [LOG\ SCALE]$$

$(\hat{y}_i)$ = Estimated flow at the short record site
a’ = Intercept of regression line
b = Slope of regression line
x_i = Observed flow at long term site in year “i”
$\bar{x}_2$ = Mean of the long term station for the non-overlapping period

The Nash-Sutcliffe (NS) efficiency coefficient is used to assess how well the MOVE.3 results approximate flows at the short record site by comparing the MOVE.3 estimated flows to the observed, annual peak flow record. Nash-Sutcliffe coefficients can range between negative infinity and one. A NS coefficient of one indicates that the MOVE.3 modeled data exactly matches the observed data. A coefficient of zero indicates the mean of the observed flow record is a better predictor of discharge at the short term site than the MOVE.3 estimate. A NS efficiency index of 0.70 is selected as the index necessary to perform the record extension in this study. Equation 4 defines how the Nash-Sutcliffe efficiency index is computed.

Equation 4 Nash-Sutcliffe Efficiency Index

$$\mathbf{E = R_{NS}^2 = 1 - \frac{\sum_{t=1}^{T}(Qo^t - Qm^t)^2}{\sum_{t=1}^{T}(Qo^t - \overline{Qo})^2}}$$

$E = R_{NS}^2$ = Nash Sutcliffe model efficiency coefficient
Q_o^t = Observed discharge at time "t"
Q_m^t = Modeled discharge at time "t"
$\overline{Qo}$ = Mean of observed discharges

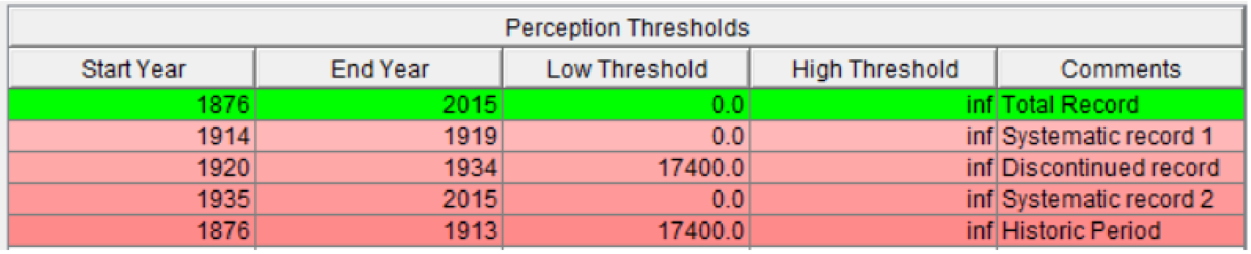
8 Discharge Frequency Analysis – Gaged Sites

8.1 Trempealeau River at Dodge, WI

The USGS gage for the Trempealeau River at Dodge, WI (USGS Gage ID 05379500) is located near the left bank of the Trempealeau River on the downstream side of the County Road P Bridge in Dodge, WI, approximately 9 miles upstream from the mouth of the river. The drainage area at the Dodge gage is 643 square miles. The available observed record at Dodge is December 1913 to September 1919 and April 1934 to present. At the time of this hydrologic analysis, the most recently published annual peak flow was the 2015 value. A total of 87 systematic peak flow values are published for this gage (Reference 25). Historic information is used to extend the period of record for the Trempealeau River at Dodge, WI analysis. According to the *1988 Flood Insurance Study Interim Hydrology Report: City of Arcadia, WI* and the USGS gage website for the Trempealeau River at Dodge, WI (USGS Gage ID 05379500), the April 1956 event at Dodge is the largest flood event since 1876 (References 10 and 25). Sections 6.1.1 and 6.1.4 have more information about the 1876 and 1956 flood events.

The flow frequency curve is calculated using the analytical methods described in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29). To apply the Bulletin 17C method a low perception threshold is set using the historic event information (1956 event: 17,400 cfs, largest since 1876) and a high perception threshold of infinity is used to fill the missing record from 1876-1913 and 1920-1934. The exact magnitude of the 1876 event is not known, therefore, the perception threshold of 17,400 cfs to infinity is also used to define the 1876 event information. This assumption indicates that if an event larger than the 1956 event had occurred during the missing period, it would have been noted. The perception thresholds used in the determination of the discharge frequency curve for the Trempealeau River at Dodge are listed in Table 4 below.

Table 4 Perception thresholds for the Trempealeau River at Dodge Discharge Frequency Analysis (thresholds in cfs)



Perception Thresholds				
Start Year	End Year	Low Threshold	High Threshold	Comments
1876	2015	0.0	inf	Total Record
1914	1919	0.0	inf	Systematic record 1
1920	1934	17400.0	inf	Discontinued record
1935	2015	0.0	inf	Systematic record 2
1876	1913	17400.0	inf	Historic Period

The Expected Moments Algorithm is used to estimate the statistical parameters and fit the Log Pearson Type III distribution to the available systematic streamflow data, as well as the information gleaned for the historic record. Hirsch-Stedinger plotting positions are used to plot observed events and Median plotting positions are used to plot low outliers. A weighted skew value is calculated using the results from the *1985 St. Paul District Skew* Study (Reference 21). The adopted skew value of -0.026 is computed by weighting the station skew of 0.086 with a regional skew of -0.200 and a regional skew mean square error (MSE) of 0.125 (Reference 21). Computation of the adopted flow-frequency curve and its 5% and 95% confidence limits are performed with the HEC-SSP version 2.1 computer program (Reference 19). A summary of the adopted frequency curve is shown in Table 5. Peak flows used in the analysis are located in Appendix C and the final discharge frequency curve is shown in Appendix D.

Table 5 Discharge frequency estimates for Trempealeau River at Dodge, WI (USGS Gage 05379500)

Annual Peak Discharge Frequency Analysis USGS Gage 05379500 Trempealeau River at Dodge, WI Methodology: Bulletin 17C/EMA - Log Pearson Type III Distribution			
Exceedance Probability (%)		**90% Confidence Limits (cfs)**	
	Peak Estimate (cfs)	**5%**	**95%**
0.2%	21,400	31,400	16,200
0.5%	17,800	24,500	14,000
1%	15,200	20,000	12,300
2%	12,800	16,200	10,700
5%	10,000	11,900	8,500
10%	7,900	9,200	6,900
	Statistics		
Mean	3.549	**Systematic Record**	87 Years
Standard Deviation	0.275	**Historic Period**	140 Years (1876-2015)
Station Skew	0.086	**Systematic Years in Record**	1914-1919, 1935-2015
Regional Skew	-0.200	**Missing Flows**	53 Years
Regional Skew MSE	0.125	**Low Outlier Test**	Multiple Grubbs-Beck
Weighted Skew (Adopted)	-0.026	**Number of Low Outliers**	0

8.2 Trempealeau River at Arcadia, WI

The USGS gage near the Trempealeau River at Arcadia, WI (USGS Gage ID 05379400) is located near the River Street (WI-95) Bridge in Arcadia, WI. The drainage area at the Arcadia site is 552 square miles. Gage records for the site are sporadic because the gage was commissioned and decommissioned numerous times throughout its service life. The observed period of record extends from July 1960 to September 1977, July 2001 to September 2004, and August 2013 to present. At the time this report was written, annual instantaneous peak flow information was available through water year 2015. A total of 22 observed systematic peak flow events are available for this site.

Annual instantaneous peak flow data from 1960 to 1967 is not presently published by the USGS for this site. Peak flow records for the 1960 to 1967 time period are available from the *1988 Flood Insurance Study Interim Hydrology Report: City of Arcadia, WI* report completed by the U.S. Army Corps of Engineers (Reference 10). These values are included in the period of record for the analysis and are listed in Table 1 of Appendix C.

The USGS published discharge for the 1975 event (one of the largest observed floods at Arcadia) is 15,900 cfs (References 10 and 24). This flow is published by the USGS as 15,900 cfs; however, issues with rating curve fluctuations indicate that the actual discharge is less than 15,900 cfs (Reference 20 and Appendix F). A copy of the memorandum for record discussing this event is included as Appendix F. An investigation by the Corps of Engineers St. Paul District and subsequent discussions with the Wisconsin Department of Natural Resources revealed that the sand bottom of the river at this location undergoes periodic scour and aggradation, which can cause the rating curve to fluctuate (References 10 and 20; Appendix F). Analysis by the USACE St. Paul District estimates that the flow associated with the 1975 peak flood is 12,000 cfs. This is the adopted value used for this study (Reference 10). Appendix F details the analysis which was performed to account for the rating curve fluctuations of the 1975 event; consequently, the 1975 event was not represented as a range in HEC-SSP version 2.1. Instead, the 1975 event was represented as a discrete value of 12,000 cfs (low flow range interval value is equal to the high flow range interval value which is equal to 12,000 cfs).

There is uncertainty in how fluctuations in rating curves at sites along the Trempealeau River will affect future flood stages as a result of periodic scour or aggradation of the sand bottom riverbed. A trend analysis was performed on stage and discharge data versus time for the Trempealeau River at Dodge, WI (USGS gage ID 05379500) to help understand how the rating curve variables have changed through time. The Arcadia USGS gage did not contain enough measurements to perform a reliable trend analysis. The stage data period of record at the Dodge USGS gage is 1914-1919, 1935-1958, and 1960-2015. The 1914-1919 period is omitted from the trend analysis to use the near continuous record 1935 to present. A statistically significant (p-value less than 0.05) increasing trend in stage was noted along with a statistically significant decreasing trend in streamflow over time. This divergent relationship indicates that peak stage has increased through time even as peak flow has decreased over time which suggests that aggradation could be occurring in the channel which would result in increased flood stages for smaller flood events in the future. Detailed sediment transport analysis is beyond the scope of this feasibility level study and a recommendation for future study is included in Section 14.

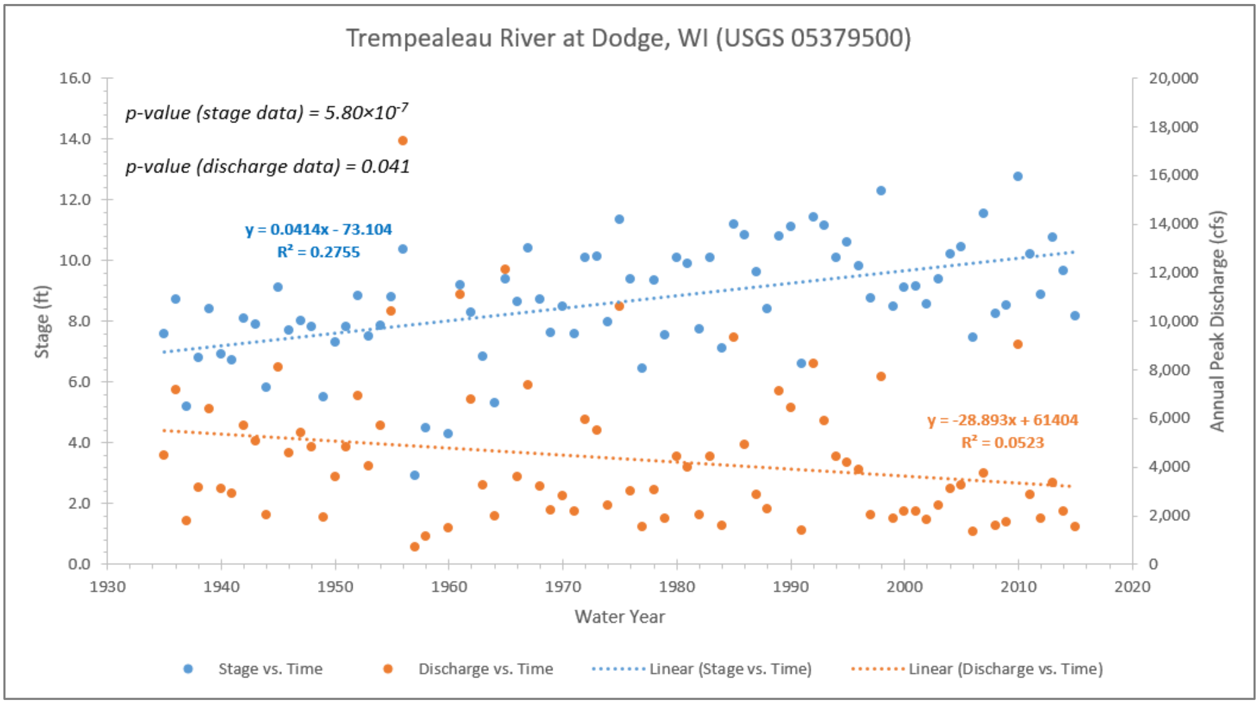


Figure 5 Trend analysis of stage and discharge vs. time for the Trempealeau River at Dodge, WI

The hydrology between the Arcadia and Dodge sites is complex, and at times flows at Dodge are less than flows at Arcadia even though the drainage area at Dodge is 91 square miles greater than the drainage area at Arcadia (Reference 10). The concurrent period of record between the Arcadia and Dodge USGS gages spans 22 years. For 12 of the 22 concurrent events, the observed annual peak flow at Dodge is less than the annual peak flow at Arcadia. Table 6 shows which years in the concurrent record have recorded peak flows at Dodge less than at Arcadia.

Table 6 Comparison of concurrent annual peak observed flow at the Arcadia and Dodge USGS gages

Number and Year		Comparison of Arcadia and Dodge Observed Flows			
No.	Water Year	(1) Arcadia AIP Observed Discharge (cfs)	(2) Dodge AIP Observed Discharge (cfs)	Dodge AIP Flow Minus Arcadia AIP Flow (cfs) (2) – (1) = Difference	Observed Flow Notes Arcadia Observed (1) vs. Dodge Observed Flow (2)
1	1961	7,840	11,100	3260	Dodge Peak > Arcadia Peak
2	1962	6,390	6,800	410	Dodge Peak > Arcadia Peak
3	1963	2,890	3,240	350	Dodge Peak > Arcadia Peak
4	1964	3,000	1,980	-1020	Dodge Peak < Arcadia Peak
5	1965	9,740	12,100	2360	Dodge Peak > Arcadia Peak
6	1966	3,200	3,600	400	Dodge Peak > Arcadia Peak
7	1967	8,340	7,350	-990	Dodge Peak < Arcadia Peak
8	1968	8,140	3,220	-4920	Dodge Peak < Arcadia Peak
9	1969	2,920	2,200	-720	Dodge Peak < Arcadia Peak
10	1970	3,290	2,830	-460	Dodge Peak < Arcadia Peak
11	1971	2,200	2,170	-30	Dodge Peak < Arcadia Peak
12	1972	4,510	5,950	1440	Dodge Peak > Arcadia Peak
13	1973	5,580	5,500	-80	Dodge Peak < Arcadia Peak
14	1974	3,520	2,430	-1090	Dodge Peak < Arcadia Peak
15	1975	12,000	10,600	-1400	Dodge Peak < Arcadia Peak
16	1976	5,310	3,030	-2280	Dodge Peak < Arcadia Peak
17	1977	1,250	1,520	270	Dodge Peak > Arcadia Peak
18	2002	1,810	1,830	20	Dodge Peak > Arcadia Peak
19	2003	1,500	2,420	920	Dodge Peak > Arcadia Peak
20	2004	3,080	3,130	50	Dodge Peak > Arcadia Peak
21	2014	2,610	2,180	-430	Dodge Peak < Arcadia Peak
22	2015	1,630	1,520	-110	Dodge Peak < Arcadia Peak

In general, peak flows due to rainfall events tend to result in flows which are greater at Arcadia than Dodge and peak flows due to snowmelt are greater at Dodge than Arcadia (Reference 10). This effect is potentially caused by large amount of valley storage between the two sites which attenuates the hydrograph as it travels downstream (Reference 10). The *1988 Flood Insurance Study Interim Hydrology Report: City of Arcadia, WI* hypothesized that during snowmelt events, runoff from snowmelt may add substantial volume to flows moving downstream and may also reduce available storage in the river between Arcadia and Dodge (Reference 10). Hydraulic evaluation of the natural storage downstream of Arcadia and upstream of Dodge would require unsteady hydraulic modeling which is beyond the scope of this feasibility analysis. See Section 14 for recommendations on how to study the storage characteristics between Arcadia and Dodge.

The historic period information discussed in Section 8.1 is not used to put the period of record at the Arcadia site into a historic context. The *1988 Flood Insurance Study Interim Hydrology Report: City of Arcadia, WI* report did not discuss or use the 1876 historic event information to derive the frequency curve at Arcadia (Reference 10). The USGS gage website for the Trempealeau River at Arcadia, WI (USGS Gage ID 05379400) does not indicate if the 1876 event is the largest event at Arcadia compared to any of the other observed events at Arcadia (Reference 24). The *Summary of Floods in the United States During 1956* report notes that the 1956 event at Arcadia is the largest since 1919; however, no observed peak flow information is available at Arcadia for either 1956 or 1919 (Reference 27). The *Summary of Floods in the United States During 1956* report also makes no mention of how either the 1919 flood event or 1956 flood event at Arcadia relate to the 1876 event (Reference 27).

The 22 concurrent observed peak flows from the Dodge record are compared to the peak flows in the Arcadia record. Bulletin 17C states that the MOVE.3 record extension technique may be appropriate when the cross-correlation computed form the MOVE.3 equations, R or ρ, is greater than 0.80 (R^2 or ρ^2 greater than 0.64). A correlation coefficient is computed from the regression analysis in Figure 6 as well as from the MOVE.3 equations. The cross-correlation computed from the MOVE.3 equations is the same as the correlation coefficient, R. In this case, ρ is equal to R at a value of 0.88. The high correlation coefficient indicates that the flows between the two sites are linearly correlated, and a record extension technique is recommended using these two gages.

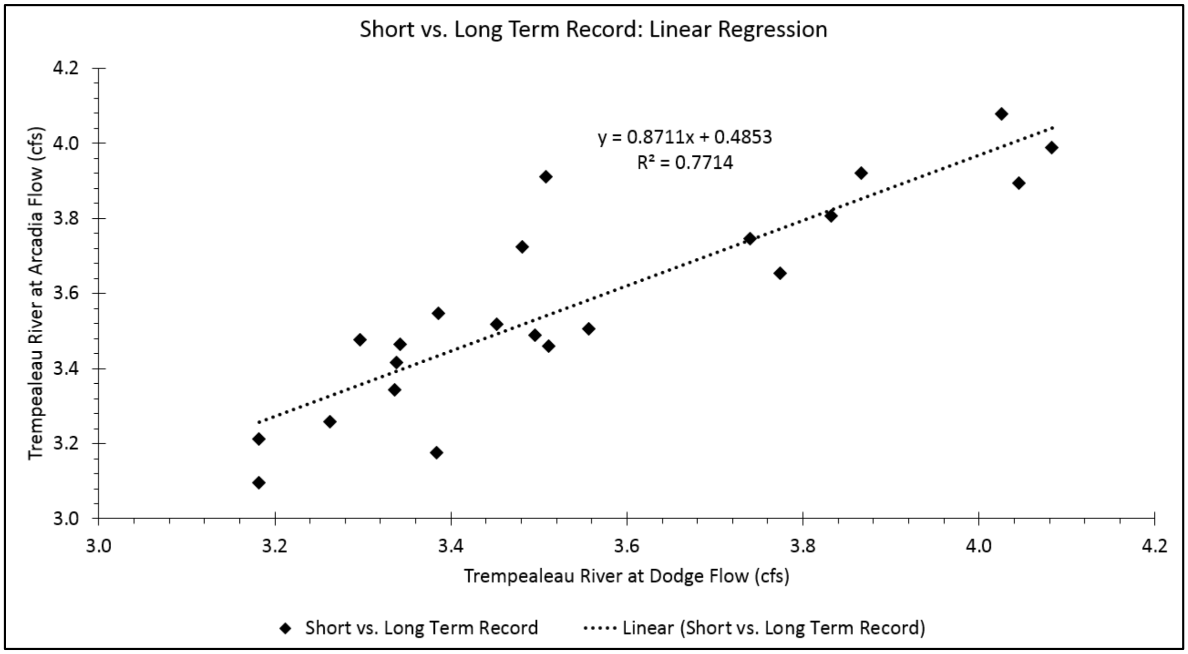


Figure 6 Linear regression between the short term (Arcadia) and long term (Dodge) gages

The MOVE.3 extension technique is used to extend the period of record at the Arcadia site even though flows at Dodge are not always greater than flows at Arcadia. Figure 7 shows the concurrent observed flows of the Dodge and Arcadia USGS gages along with the MOVE.3 estimated flow for Arcadia. Generally, the observed flood events between the two sites in the concurrent years is similar in magnitude. The MOVE.3 estimated flows for Arcadia are consistently greater than the observed flows at the Dodge USGS gage, which does not reflect the reality that sometimes flows are greater at Arcadia than at Dodge. This is likely because flow at Arcadia is often greater than flow at Dodge.

The adequacy of the MOVE.3 relationship is evaluated using the Nash-Sutcliffe method to assess how well the MOVE.3 estimated flows at Arcadia approximate the observed flows. The Nash-Sutcliffe coefficient for the extension is 0.69, which indicates that the MOVE.3 extension technique reasonably estimates the flows at Arcadia. A Nash-Sutcliffe coefficient of 0.69 is considered sufficiently close to the selected threshold of 0.70 (Section 7.3.1) for this feasibility study.

Bulletin 17C states that record extension is an appropriate technique when there is improvement to the mean and variance of the short record site (Arcadia). This occurs when the variance of the extended record is less than the variance of the original short record. The variance of the extended record at Arcadia is less than the variance of the original, short term record which suggests that the MOVE.3 record extension technique can be applied in this case and improves the dataset at Arcadia. Table 7 below summarizes the criteria used to determine the applicability of the MOVE.3 record extension technique in this case. Based on the information presented in Table 7, the application of the MOVE.3 record extension technique is appropriate between the Dodge, WI and Arcadia, WI USGS gage data.

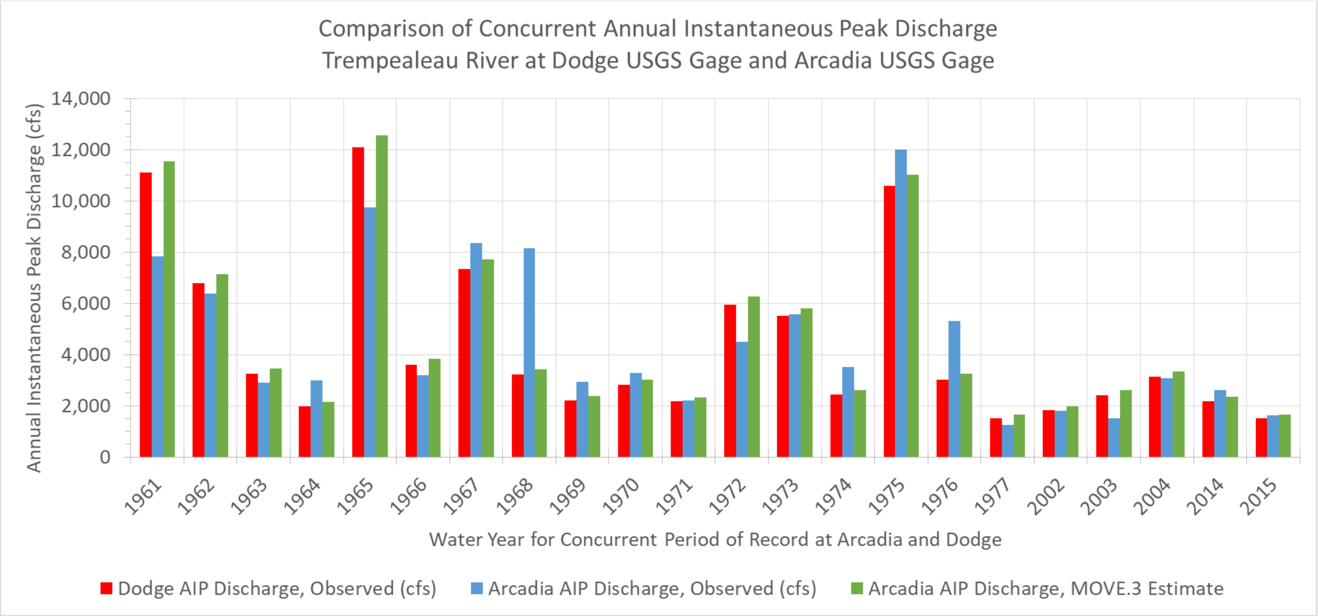


Figure 7 Comparison of concurrent observed annual peak flows at Dodge and Arcadia with MOVE.3 estimates of flows at Arcadia

Table 7 MOVE.3 extension usability criteria: Dodge & Arcadia

Parameter	Value
Correlation Coefficient, R^2	0.77
Nash-Sutcliffe Coefficient, R_{NS}^2	0.69
Variance of Short Record (from log of flow)	0.077
*Variance of Long Record (from log of flow)	0.074

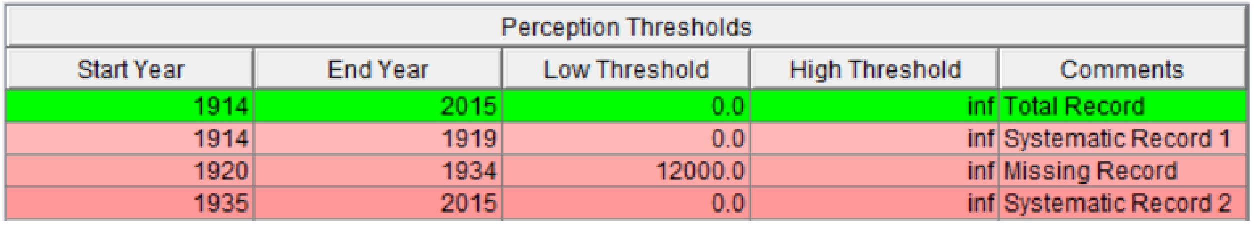
**Note that the variance of the extended record is less than the short, observed record*

Although the statistical criteria outlined above indicate that the MOVE.3 equations can be used to extend the period of record at the Arcadia gage based on information at the Dodge gage, half of the concurrent observed events at the two sites demonstrate a physical aberration which is impossible to replicate using the MOVE.3 equations. Additional study should be performed to develop a more appropriate relationship to capture what happens to discharge between Dodge and Arcadia. For this analysis, the MOVE.3 estimated flows at Arcadia are consistently higher than the observed flows at the Dodge USGS gage which is conservative from a flood risk management perspective. This knowledge, combined with the statistical tests discussed above support the use of the MOVE.3 equations to extend the period of record to develop a flood flow-frequency curve for the site. See Section 14 for recommendations of how to improve estimates of missing flow for the Trempealeau River at Arcadia which are presently outside the scope of work for this analysis.

8.2.1 Adopted Frequency Curve at Arcadia, WI

The flow frequency curve at Arcadia is determined by applying the analytical methods from Bulletin 17C (Reference 29). The Bulletin 17C Expected Moments Algorithm (EMA) requires the use of interval data, consequently, there cannot be missing data contained in the annual instantaneous peak flow record. A low perception threshold equal to the largest observed event (1975 event: 12,000 cfs) and a high perception threshold of infinity is used to represent the missing record from 1920-1934. The perception thresholds used in the analysis of the discharge frequency curve for the Trempealeau River at Dodge are listed in Table 8 below.

Table 8 Perception thresholds for the Trempealeau River at Arcadia Discharge Frequency Analysis (thresholds in cfs)



Perception Thresholds				
Start Year	End Year	Low Threshold	High Threshold	Comments
1914	2015	0.0	inf	Total Record
1914	1919	0.0	inf	Systematic Record 1
1920	1934	12000.0	inf	Missing Record
1935	2015	0.0	inf	Systematic Record 2

Hirsch-Stedinger plotting positions are used to plot observed events and Median plotting positions are used to plot low outliers. A weighted skew value is calculated using the results from the *1985 St. Paul District Skew* Study (Reference 21). The adopted skew value of -0.073 is computed by weighting the station skew of -0.007 with a regional skew of -0.200 and a regional skew MSE of 0.125 (Reference 21). Statistical computations are performed using the HEC-SSP computer program (Reference 19). A summary of the adopted frequency curve is shown in Table 9. Peak flows used in the analysis are located in Appendix C and the final discharge frequency curve plot is shown in Appendix D.

Table 9 Discharge frequency estimates for Trempealeau River at Arcadia, WI (USGS Gage 05379400)

Annual Peak Discharge Frequency Analysis			
USGS Gage 05379400 Trempealeau River at Arcadia, WI **Methodology: Bulletin 17C/EMA - Log Pearson Type III Distribution**			
Exceedance Probability (%)		**90% Confidence Limits (cfs)**	
	Peak Estimate (cfs)	**5%**	**95%**
0.2%	21,300	31,900	16,300
0.5%	17,900	25,100	14,200
1%	15,500	20,600	12,600
2%	13,200	16,800	11,000
5%	10,300	12,500	8,900
10%	8,300	9,700	7,300
Statistics			
Mean	3.575	**Systematic Record**	87 Years
Standard Deviation	0.270	**Historic Period**	Not Applicable
Station Skew	-0.007	**Systematic Years in Record**	1914-1919, 1935-2015
Regional Skew	-0.200	**Missing Record**	15 Years
Regional Skew MSE	0.125	**Low Outlier Test**	Multiple Grubbs-Beck
Weighted Skew (Adopted)	-0.073	**Number of Low Outliers**	0

8.3 French Creek near Ettrick, WI

The French Creek near Ettrick, WI USGS gage (05382200) is located west of the Village of Ettrick, WI on the right downstream pier of the County Trunk D Bridge, approximately 2.5 miles west from the junction with U.S. Highway 53 in Ettrick, WI (Reference 23). The drainage area of the French Creek near Ettrick, WI USGS gage (05382200) is 14.7 square miles (Reference 23). This site is included in the analysis to provide information needed to estimate discharge frequency curves at small, ungaged watersheds within the study area using a drainage area transfer method.

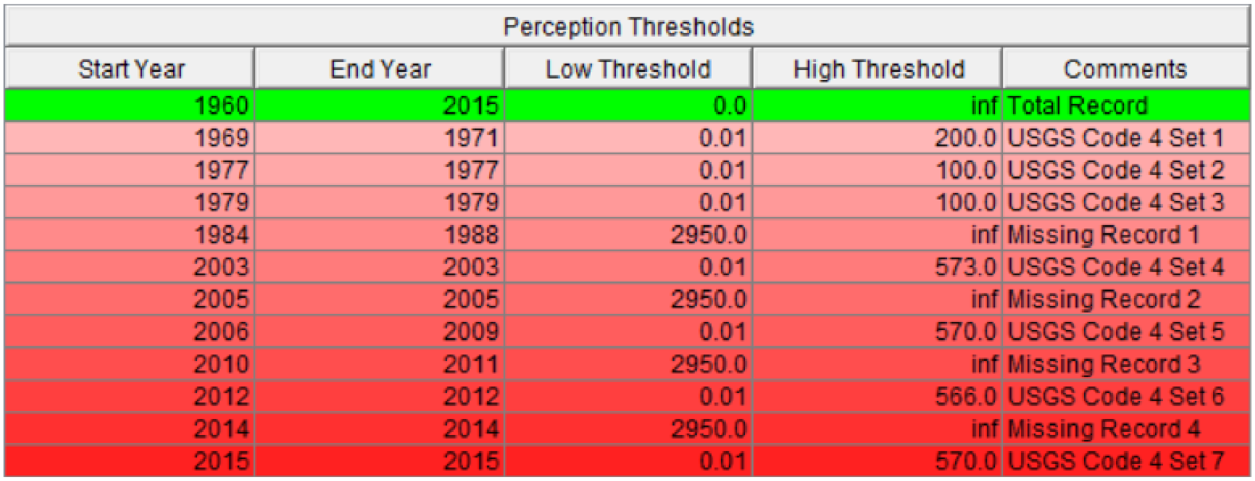
The published USGS annual instantaneous peak flow record available from the USGS website for the French Creek gage consists of 35 discontinuous systematic events spanning from 1960-1971, 1989-2004, 2006-2009, 2012-2013, and 2015 (Reference 23). An additional 12 systematic events are available in the *1988 City of Arcadia Flood Insurance Study Interim Hydrology Report* which are not listed on the USGS website (Reference 10). The additional 12 systematic events span 1972-1983 and are listed in Table 3 of Appendix C. The entire, combined systematic period of record is 47 systematic events from 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015.

Flow data for the French Creek near Ettrick, WI contains 12 peak flow events in the systematic record (47 years) which are below the minimum recordable elevation at the USGS gage. This data is referred to as “below gage base” data and is listed in Appendix C. Below gage base flows are indicated in the USGS flow record by a Peak Gage-Height Qualification Code of 4 and by a Peak Streamflow Qualification Code of 4. The USGS website for the French Creek near Ettrick, WI USGS gage provides a summary of these gage qualification codes with the observed annual peak flow record (Reference 23). The below gage base threshold is set based on the extents of the rating curve which is used to estimate a discharge from a measured stage. Any values which fall below the minimum recordable stage elevation are coded as below gage base flows.

Table 10 and Table 11 show the years in the systematic record which are listed with a USGS qualification code of 4 for being below the minimum recordable elevation. As Table 10 and Table 11 show, the minimum recordable flow value fluctuates in magnitude throughout the period of record. Some of these changes can likely be attributed to when the gage was decommissioned and re-commissioned. According to the USGS Wisconsin Water Science Center, a new rating curve was developed for this site in 1994 which is likely why the below gage base threshold for all discharges collected after 1994 is approximately 570 cfs (Reference 45). The USGS Wisconsin Water Science Center also indicated that the below gage base threshold may have changed as a result of bridge work on French Creek (Reference 45). The date of this bridge work was not specified (Reference 45).

In the past, below gage base data was treated as discrete data points during traditional Bulletin 17B frequency analysis. The new *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* allows below gage base data to be represented as a flow interval using perception thresholds and flow ranges to represent the uncertainty associated with a below gage base measurement (Reference 29). The below gage base data could range from 0 cfs to the minimum recordable discharge at the gage. The perception thresholds used in this analysis use the below gage base flow value indicated in Table 11 as a high threshold value. A value of 0.01 cfs is used as a low threshold for below gage base data because the analysis method applies logarithms to the flow values to generate the frequency curve and the logarithm of zero is undefined. The perception thresholds used in the determination of the discharge frequency curve for the Trempealeau River at Dodge are summarized in Table 10 below.

Table 10 Perception thresholds for the French Creek near Ettrick Discharge Frequency Analysis (thresholds in cfs)



Perception Thresholds				
Start Year	End Year	Low Threshold	High Threshold	Comments
1960	2015	0.0	inf	Total Record
1969	1971	0.01	200.0	USGS Code 4 Set 1
1977	1977	0.01	100.0	USGS Code 4 Set 2
1979	1979	0.01	100.0	USGS Code 4 Set 3
1984	1988	2950.0	inf	Missing Record 1
2003	2003	0.01	573.0	USGS Code 4 Set 4
2005	2005	2950.0	inf	Missing Record 2
2006	2009	0.01	570.0	USGS Code 4 Set 5
2010	2011	2950.0	inf	Missing Record 3
2012	2012	0.01	566.0	USGS Code 4 Set 6
2014	2014	2950.0	inf	Missing Record 4
2015	2015	0.01	570.0	USGS Code 4 Set 7

Table 11 French Creek near Ettrick, WI Perception Thresholds for Below Gage Base Flows

French Creek near Ettrick, WI USGS Gage 05382200 Perception Thresholds for Missing and Below Gage Base Flow				
Start Year	End Year	Low Threshold (cfs)	High Threshold (cfs)	Description
1969	1971	0.01	*200	Below Gage Base
1977	1977	0.01	*100	Below Gage Base
1979	1979	0.01	*100	Below Gage Base
1984	1988	2,950	Infinity	Missing Record
2003	2003	0.01	*573	Below Gage Base
2005	2005	2,950	Infinity	Missing Record
2006	2009	0.01	*570	Below Gage Base
2010	2011	2,950	Infinity	Missing Record
2012	2012	0.01	*566	Below Gage Base
2014	2014	2,950	Infinity	Missing Record
2015	2015	0.01	*570	Below Gage Base

**Below gage base high threshold selected based on values reported in observed peak flow record*

The discharge frequency curve is calculated using the analytical methods described in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29). The Expected Moments Algorithm is used to estimate the statistical parameters of the Log Pearson Type II distribution. The EMA method requires interval data for each year within the analysis period of record. The period of record used for the analysis spans 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015. The largest observed event (2001: 2,950 cfs) is used as the low threshold for periods of missing information. It is assumed that if a flood larger than the largest observed event had occurred during a period with unobserved record, it would have been recorded. The perception thresholds adopted to characterize missing data are displayed in Table 10 (above).

Hirsch-Stedinger plotting positions are used to plot observed events and Median plotting positions are used to plot low outliers. The adopted skew of -0.730 is the station skew. A regional skew value and a weighted skew value are considered for the analysis; however, the curves generated using the regional skew and weighted skew provided a poor fit of the frequency curve to the plotted data. The station skew provides the best fit of the frequency curve to the data. Statistical computations are performed with the HEC-SSP computer program version 2.1 (Reference 19). A summary of the adopted frequency curve is shown in Table 12. Peak flows used in the analysis are located in Appendix C and the final discharge frequency curve is shown in Appendix D.

Table 12 Discharge frequency estimates for French Creek near Ettrick, WI (USGS Gage 05382200)

Annual Peak Discharge Frequency Analysis			
USGS Gage 05382200 French Creek near Ettrick, WI **Methodology: Bulletin 17C/EMA - Log Pearson Type III Distribution**			
Exceedance Probability (%)		**90% Confidence Limits (cfs)**	
	Peak Estimate (cfs)	**5%**	**95%**
0.20%	5,100	12,600	2,200
0.50%	4,400	9,200	2,100
1%	3,800	7,100	2,100
2%	3,200	5,400	2,000
5%	2,500	3,600	1,700
10%	1,800	2,600	1,400
	Statistics		
Mean	2.650	**Systematic Record Including Below-Gage-Base Data**	47 Years (includes 12 Years of below-gage-base measurements)
Standard Deviation	0.523	**Historic Period**	Not Available
Station Skew (Adopted)	-0.730	**Systematic Years in Record Including Below-Gage-Base Data**	1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015
Regional Skew	Not Applicable	**Missing Record**	9 Years
Regional Skew MSE	Not Applicable	**Low Outlier Test**	Multiple Grubbs-Beck
Weighted Skew	Not Applicable	**Number of Low Outliers**	0

9 Discharge Frequency Analysis: Ungaged Methods

Discharge frequency information is required for ungaged sites near the city of Arcadia to provide information to aid in the design of a flood risk reduction project. The relatively small tributaries Turton Creek and Myers Valley Creek contribute to flooding within the City of Arcadia and are studied using approximate or ungaged methods. The Trempealeau River above the confluence with Turton Creek is included in the analysis to inform the development of a hydraulic model. Analytical flow frequency methods cannot be used to estimate the frequency statistics associated with flooding at these three sites because there is no observed data available. USGS regional regression equations for the state of Wisconsin and the general relations drainage area transfer method (GRM) are used to estimate frequency curves for the ungaged sites. A description of each method is included in the following sections.

9.1 USGS Regression Equations – 2003 Update

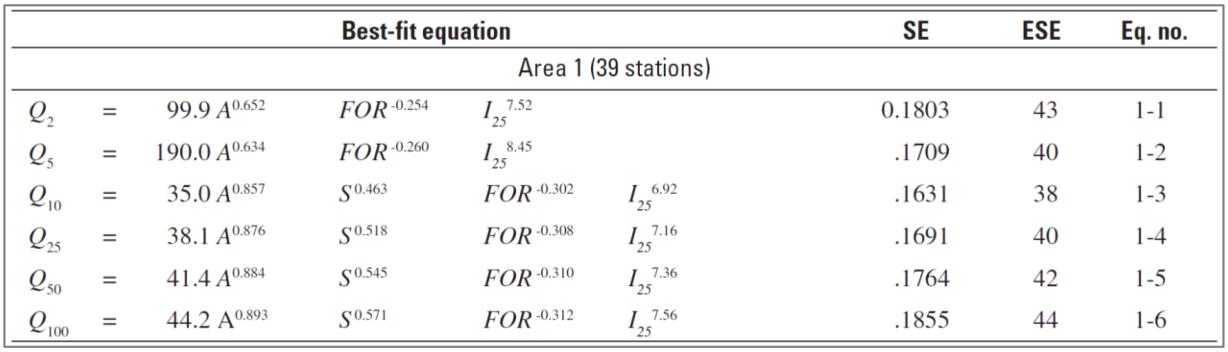
The USGS completed a study in 2003 relating watershed characteristics to flood frequency runoff for 312 gaged Wisconsin streams (Reference 42). A statistical analysis of gaged sites in Wisconsin was used to develop regional regression equations based on basin characteristics for annual exceedance probabilities ranging from the 50% exceedance probability (2-year average return interval) to the 1% exceedance probability (100-year average return interval) event. Data at gaged locations was collected through the water year 2000. Stations with at least 10 years of record were considered for the analysis of rural streams, and at least 28 years of flood peak data were used for most crest gage stations, such as the French Creek near Ettrick, WI USGS gage (Reference 42).

The 2003 USGS study separated stream gages in Wisconsin into five distinct areas, and developed a unique set of regression equations for each area. The Trempealeau River basin fell within Study Area 1 in the analysis. A summary of basin characteristics which are applicable to sites located in Region 1 of Wisconsin is shown in Table 14 below. Table 14 shows the basin characteristics used to define the regression equations for Region 1 along with the range of applicable values for each basin characteristic.

Regression equations relating basin characteristics to flood frequency were developed using multiple linear regression analysis. A combination of ordinary least squares (OLS) regression and generalized least squares (GLS) regression was used to define regression equations for each flood frequency area in Wisconsin (Reference 42). Significant regression characteristics included in the adopted equations are drainage area (A), main channel slope (S), storage (ST), rainfall intensity (I_{25}), and forest cover (FOR). The standard error of prediction of the regression equations for the 1% event varied between 22 percent and 44 percent (Reference 42). A standard error value between 22 percent and 44 percent is quite high, and illustrates the large amount of uncertainty which arises from using regression equations to develop estimates for flood frequency analysis.

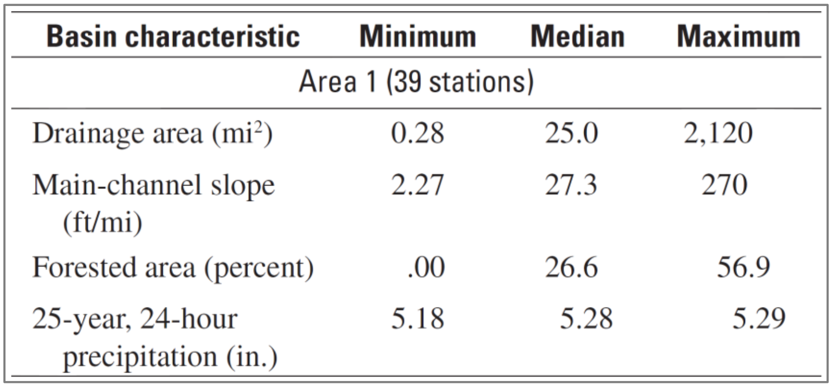
Estimates of basin characteristics are determined using the USGS "StreamStats" tool which computes basin characteristics for a particular point of interest (Reference 26). The tool provides a graphical user interface which allows the user to define a drainage area at any location. The resulting basin delineation is used in the National Streamflow Statistics (NSS) program to determine the required inputs to the USGS regression equations which define the discharge frequency results. A summary of the regression equations for the region encompassing the Trempealeau watershed (Area 1) is shown below in Table 13 (Reference 42).

Table 13 2003 USGS regression equations for the state of Wisconsin, Area 1 (Reference 42)



Best-fit equation	SE	ESE	Eq. no.
Area 1 (39 stations)			
$Q_2 = 99.9\,A^{0.652}\ FOR^{-0.254}\ I_{25}^{7.52}$	0.1803	43	1-1
$Q_5 = 190.0\,A^{0.634}\ FOR^{-0.260}\ I_{25}^{8.45}$	.1709	40	1-2
$Q_{10} = 35.0\,A^{0.857}\ S^{0.463}\ FOR^{-0.302}\ I_{25}^{6.92}$	.1631	38	1-3
$Q_{25} = 38.1\,A^{0.876}\ S^{0.518}\ FOR^{-0.308}\ I_{25}^{7.16}$	.1691	40	1-4
$Q_{50} = 41.4\,A^{0.884}\ S^{0.545}\ FOR^{-0.310}\ I_{25}^{7.36}$	.1764	42	1-5
$Q_{100} = 44.2\,A^{0.893}\ S^{0.571}\ FOR^{-0.312}\ I_{25}^{7.56}$	.1855	44	1-6

Table 14 2003 USGS regression equations typical range of basin characteristics for Wisconsin watersheds, Area 1 (Reference 42)



Basin characteristic	Minimum	Median	Maximum
Area 1 (39 stations)			
Drainage area (mi^2)	0.28	25.0	2,120
Main-channel slope (ft/mi)	2.27	27.3	270
Forested area (percent)	.00	26.6	56.9
25-year, 24-hour precipitation (in.)	5.18	5.28	5.29

9.2 USGS Regression Equations – 2017 Update

The USGS completed a study in 2017 relating watershed characteristics to flood frequency runoff for 360 gaged Wisconsin streams (Reference 43). A statistical analysis of gaged sites in Wisconsin was used to develop regional regression equations based on basin characteristics for annual exceedance probabilities ranging from the 50% exceedance probability (2-year average return interval) to the 0.2% exceedance probability (500-year average return interval) event. Data at gaged locations was collected through the water year 2010. Stations with a minimum of 10 years of record were used for the statistical regression analysis of rural streams (Reference 43).

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 Trempealeau River basin, Turton Creek watershed, and Myers Valley Creek watershed fell within Study Region 5 in the analysis. A summary of basin characteristics which are applicable to sites located in Region 5 of Wisconsin is shown in Table 16 below. Table 16 shows the basin characteristics used to define the regression equations for Region 5 along with the range of applicable values for each basin characteristic.

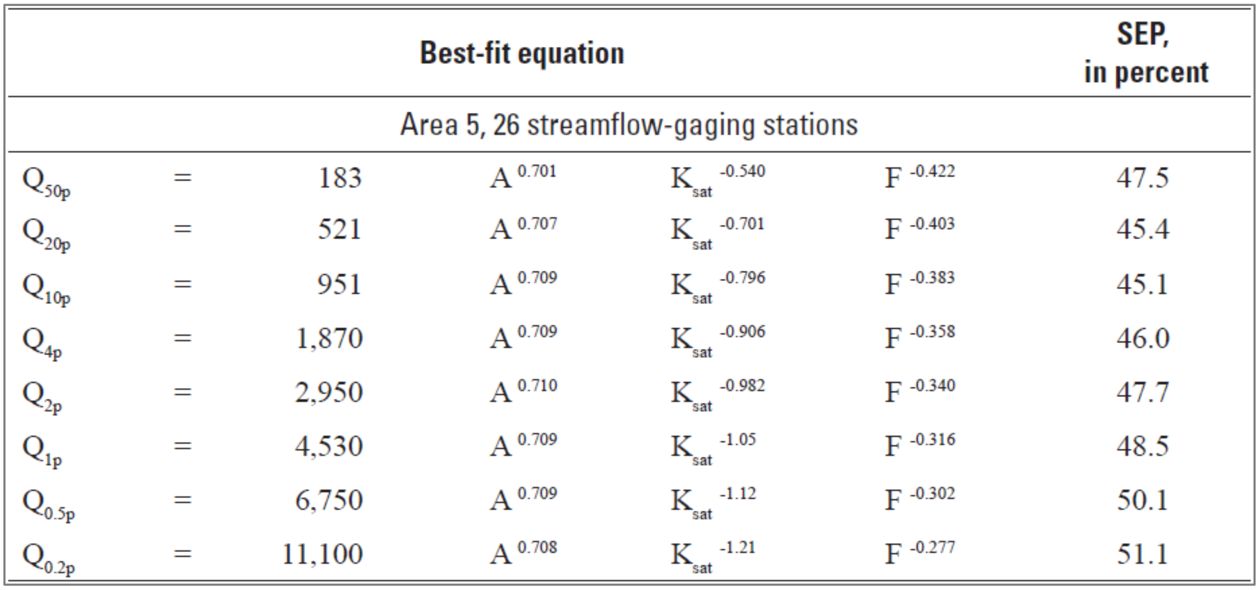
Regression equations relating basin characteristics to flood frequency were developed using multiple linear regression analysis. The principal method of regression analysis used to develop the 2017 regression equations was the generalized least squares (GLS) technique (Reference 43). Significant regression characteristics included in the adopted equations are drainage area (A, mi^2), saturated hydraulic conductivity (K_{sat}, inches per hour), and forest cover (F, percent).

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 43). A standard error value between 56 percent and 70 percent is quite high, and illustrates the large amount of uncertainty which arises from using regression equations to develop estimates for flood frequency analysis. The standard error associated with the 2017 regression equations (Reference 43) was higher than the standard error associated with the 2003 regression equations discussed in Section 9.1 (Reference 42). The *2017 Flood-Frequency Characteristics of Wisconsin Streams* authors hypothesized that the increase in the standard error of prediction is likely due to increased variability of the annual peak streamflow discharges, resulting in increased variability in the magnitude of flood peaks at higher frequencies (Reference 43).

Estimates of basin characteristics are determined using the USGS "StreamStats" tool which computes basin characteristics for a particular point of interest (Reference 26). The tool provides a graphical user interface which allows the user to define a drainage area at any location. The resulting basin delineation is used in the National Streamflow Statistics (NSS) program to determine the required inputs to the USGS regression equations which define the discharge frequency results. A summary of the regression equations for the region encompassing the Trempealeau watershed (Area 5) is shown below in Table 15 (Reference 43).

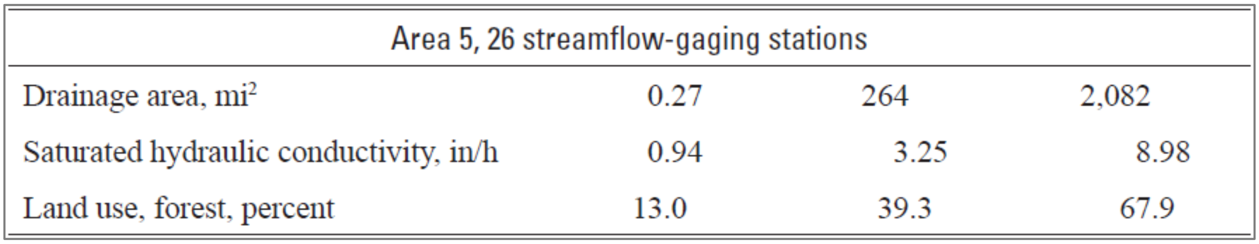
Regression equations are useful tools for estimating frequency curves at sites without observed data; however, this technique has limitations. The regression equations presented in this section of the report should only be applied to rural sites which are not affected by regulation from hydraulic structures. 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 16 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 15 2017 USGS regression equations for the state of Wisconsin, Area 5 (Reference 43)



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

Table 16 2017 USGS regression equations typical range of basin characteristics for Wisconsin watersheds, Area 5 (Reference 43)



Area 5, 26 streamflow-gaging stations			
Drainage area, mi^2	0.27	264	2,082
Saturated hydraulic conductivity, in/h	0.94	3.25	8.98
Land use, forest, percent	13.0	39.3	67.9

9.3 General Relations Method (Drainage Area Transfer)

General relations methodology (GRM), also known as a drainage area transfer, is applied to estimate the flow at an ungaged site by relating flow at a gaged site to the ratio of the drainage areas of the ungaged and gaged sites raised to an exponent. The GRM is given by Equation 5 below.

Equation 5 General relations method equation

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

Site 1 = Ungaged Site

Site 2 = Gaged Site

Q = flow at a given exceedance probability

DA = Drainage Area

The previous *1988 City of Arcadia Flood Insurance Study Interim Hydrology Report* states that an exponent 'n' value of 0.68 can be used in Equation 5 for the Trempealeau basin (Reference 10). A drainage area transfer exponent value of 0.68 is also supported in the *WI Department of Transportation Facilities Development Manual – Chapter 13: Drainage, Section 10: Hydrology* (Reference 44). The drainage area transfer exponent 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 (Reference 3). The state of Wisconsin was divided into five areas based on similar physical basin characteristics to develop a transfer coefficient for each area. The regional 'n' value of 0.68 is used to transfer frequency curves from a gaged watershed to an ungaged watershed in this study.

9.4 Selection of Appropriate Analysis Technique to Derive a Frequency Curve for an Ungaged Site

In this study, the derivation of a frequency curve for an ungaged site is limited to either the USGS regression equations (2003 version or 2017 version) or the general relations drainage area transfer method. Development of hydrologic models which can estimate a frequency curve from observed data and precipitation frequency rainfall or a more in-depth regional analysis is beyond the scope of work for this assessment. For sites which are similar in drainage area, the drainage area transfer method generally provides a reasonable estimate of flood risk. For sites which are not similar in drainage area or are hydrologically different from a gaged site, the regression equations can be used.

The USGS regression equations are developed using a large amount of data to approximate flood frequency information for streams without gage data. The Turton Creek watershed and the Myers Valley Creek watershed are two small watersheds which are candidates for using either the drainage area transfer method or the USGS regression equations to develop a frequency curve to estimate flood risk. A sensitivity analysis using the French Creek near Ettrick, WI USGS gage (ID 05382200) was performed to assess how the USGS regression equations approximate flood risk at a site with gage data. Section 8.3 provides information about the analytical flow frequency curve derived for the French Creek near Ettrick, WI (ID 05382200) using the methods outlined in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency*.

A frequency curve was derived for French Creek using an analytical technique, the 2003 USGS regression equations, and the 2017 USGS regression equations and the results are shown below in Table 17. Table 17 indicates that both the 2003 and 2017 regression equations substantially underestimate flood risk in this region when compared to methods which rely on observed, at site data. A plot of the data in Table 17 is also shown graphically in Appendix G. Based on this analysis, it is not recommended that the USGS regression equations be used as the design flood values for a Flood Risk Management project near Myers Valley Creek and Turton Creek.

Table 17 Comparison of frequency curves developed using regression equations to a frequency curve derived from observed data and analytical methods

Comparison of Frequency Curve Results: French Creek near Ettrick, WI (USGS Gage ID 05382200)			
Annual Exceedance Probability (%)	**Bulletin 17C Analysis Method Estimated Frequency Curve (Adopted)**	**2003 Regional Regression Equations Estimated Frequency Curve**	**2017 Regional Regression Equations Estimated Frequency Curve**
1	3,800	2,000	3,200
2	3,200	1,700	2,500
10	1,800	1,000	1,200

9.5 Confidence Limits of Ungaged Frequency Curves

Risk and uncertainty analysis is required to evaluate proposed USACE flood risk reduction projects. When peak flow data is available and fits a statistical distribution an analytical flow frequency curve and a confidence interval can be computed directly using the methods outlined in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29).

When observed flow data does not exist or flows are affected by upstream regulation, risk and uncertainty must still be accounted for. Risk and uncertainty for ungaged watersheds or sites affected by regulation is assessed using the methodologies outlined in *EM 1110-2-1619: Risk-Based Analysis for Flood Damage Reduction Studies* and *ETL 1110-2-537: Uncertainty Estimates for Nonanalytic Frequency Curves* (References 7 and 8, respectively).

The Hydrologic Engineering Center Flood Damage Reduction Analysis computer program (HEC-FDA version 1.4.1) is used to compute the confidence interval for the ungaged frequency curves estimated in this study. HEC-FDA version 1.4.1 has two options for computing confidence limits, an analytical option and a graphical option. The analytical option requires input of known Log Pearson Type III statistics derived from observed stream gages or modeling. The analytical option is not applicable to frequency curves developed without the use of a statistical distribution.

The graphical option can be used to compute the confidence interval if the ungaged curves do not fit a Log Pearson Type III distribution or if the Log Pearson Type III parameters cannot be computed from an observed data set. This option is preferred for curves based on ungaged analysis methods where observed data cannot be used to assess the adequacy of fit of the assumed distribution to the observed data. The graphical probability function is defined by ordered pairs of exceedance probability versus flow or stage and the uncertainty is calculated based on an assumed equivalent record length. For this Section 205 study, the graphical method of computing confidence limits is applied to estimate the confidence interval for frequency curves derived using ungaged analysis techniques.

Confidence intervals for frequency curves determined using observed data and the Log Pearson Type III procedure have confidence intervals computed using the methods defined in Bulletin 17C. The default confidence interval calculated using the Bulletin 17C guidelines is the 90% confidence interval. A 90% confidence interval indicates that there is a 90% probability that the true discharge associated with a specified exceedance probability event (e.g. 1% AEP event) is contained within the interval.

The order statistics method is used to calculate the confidence interval for ungaged sites in the basin (Reference 16). The order statistics method is based on both order statistics and the binomial distribution (Reference 16). Standard deviations computed from the order statistics method estimates are paired with the normal distribution to estimate the uncertainty around a graphical frequency curve (Reference 16). A normal (Gaussian) distribution has approximately 95% of its distribution within plus or minus two standard deviations from the mean (the frequency curve estimate in this case). The confidence limit expressed as the mean of the estimate minus two standard deviations indicates that there is approximately a 97.5% chance that the flow estimate is above the lower confidence limit. The confidence limit expressed as the mean of the estimate plus two standard deviations indicates that there is approximately a 2.5% chance that the flow estimate is above the upper confidence limit. There is no option within FDA to alter the upper and lower bounds of the confidence limits when the graphical analysis technique is specified. Consequently, the confidence interval used for curves computed with ungaged methods is the 95% confidence interval (plus or minus 2 standard deviations from the mean). A wider confidence interval is more conservative from a flood risk management perspective.

The order statistics approach requires an equivalent record length to estimate the confidence limits for the frequency curve. Equivalent record length guidelines used in this analysis are shown in Figure 8 from Table 4-5 of *ETL 1110-2-1619: Risk Based Analysis for Flood Damage Reduction Studies* (Reference 7). The selection of a longer equivalent record length results in a narrower confidence interval and less uncertainty compared to a shorter equivalent record length which results in a wider confidence interval and more uncertainty. The width of the confidence interval has implications for flood risk management and project economics. For flood risk management, the width of the confidence interval affects the assurance, performance, and risk of a flood protection project. For economics, the width of the confidence interval may impact the benefit-cost ratio and feasibility of the project. The confidence intervals included in this analysis are selected based on analysis of information available for each site. It is recommended that additional sensitivity testing be performed if levee performance and risk is a concern or if the feasibility of the overall project is heavily dependent on the confidence limits. Section 14 contains more information about this recommendation.

The equivalent period of record selected for each frequency analysis in this study is indicated below. Section 14 contains a recommendation for performing sensitivity testing using different equivalent periods of record to ensure the project has a feasible benefit-cost ratio. The computer program HEC-FDA version 1.4.1 is used to perform the order statistics calculations (Reference 16). The computation procedures are detailed in Appendix G of the *HEC-FDA, Flood Damage Reduction Analysis, Version 1.4.1* User's Manual (Reference 16).

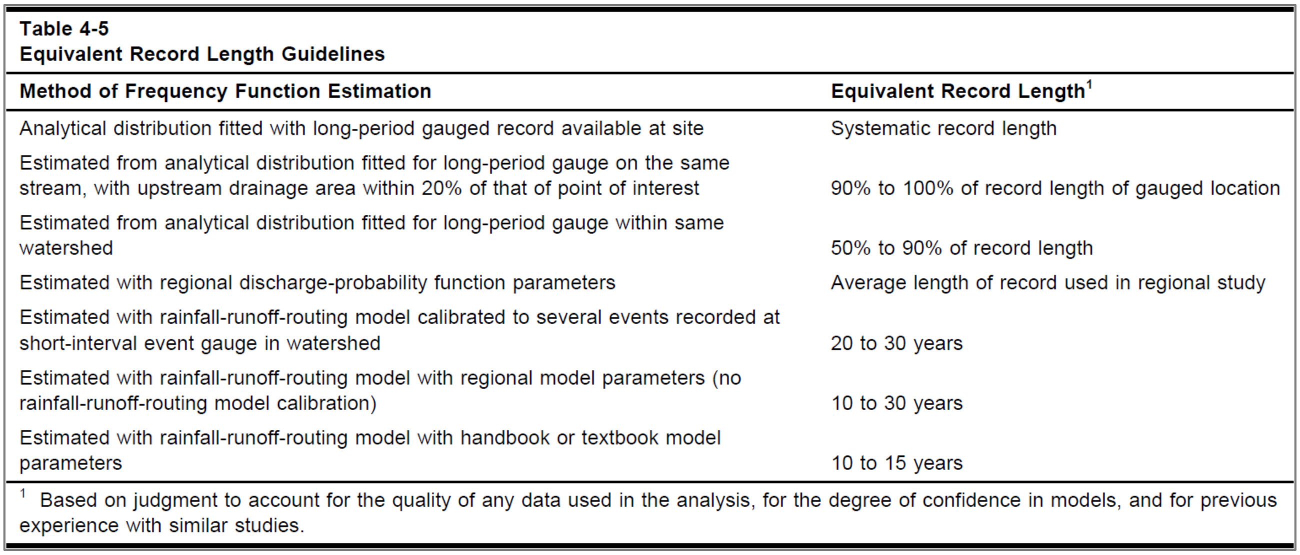


Table 4-5
Equivalent Record Length Guidelines

Method of Frequency Function Estimation	**Equivalent Record Length**[1]
Analytical distribution fitted with long-period gauged record available at site	Systematic record length
Estimated from analytical distribution fitted for long-period gauge on the same stream, with upstream drainage area within 20% of that of point of interest	90% to 100% of record length of gauged location
Estimated from analytical distribution fitted for long-period gauge within same watershed	50% to 90% of record length
Estimated with regional discharge-probability function parameters	Average length of record used in regional study
Estimated with rainfall-runoff-routing model calibrated to several events recorded at short-interval event gauge in watershed	20 to 30 years
Estimated with rainfall-runoff-routing model with regional model parameters (no rainfall-runoff-routing model calibration)	10 to 30 years
Estimated with rainfall-runoff-routing model with handbook or textbook model parameters	10 to 15 years

[1] Based on judgment to account for the quality of any data used in the analysis, for the degree of confidence in models, and for previous experience with similar studies.

Figure 8 EM 1110-2-1619 Equivalent Record Length Guidelines (Reference 7)

10 Discharge Frequency Analysis – Ungaged Sites

10.1 Trempealeau River above Turton Creek

A frequency curve is included for the Trempealeau River above the Turton Creek to support hydraulic modeling. The drainage area of the Trempealeau River above Turton Creek is approximately 528.4 square miles. This is 23.6 square miles less than the drainage area for the Trempealeau River at Arcadia. The general relations drainage area transfer method is used to transfer the frequency curve at the Arcadia USGS gage to the Trempealeau River above Turton Creek. The small difference in drainage area between the Arcadia USGS gage and the site above Turton Creek make the general relations method ideal for this type of analysis compared to the USGS regression equations.

The equivalent record length for this site is determined using guidelines in *EM 1110-2-1619 Risk Based Analysis for Flood Damage Reduction Studies* shown in Figure 8. *EM 1110-2-1619* recommends using an equivalent record length of 90% to 100% of the total record length if there is a long term gage on the stream and the drainage area difference between the two sites is less than 20%. The systematic period of record at the Arcadia USGS gage is extended using the downstream Dodge USGS gage. The adopted record length at the Arcadia gage is 87 years of record (1914-1919, 1935-2015). To account for the uncertainty involved in the record extension between the Arcadia and Dodge gaged sites and the drainage area transfer method used to define the frequency curve above Turton Creek, it is assumed that 90% of the systematic record length (78 years) at the Arcadia gage can be used to represent the equivalent record at the ungaged site above Turton Creek.

Using 90% of the record length instead of 100% of the record length is more conservative from a flood risk perspective because it results in a wider confidence interval. A regional exponent, 'n' value, of 0.68 in Equation 5 is used to transfer the flow-frequency curve at Arcadia upstream of Turton Creek using the general relations method. The confidence interval for the transferred curve is computed using the order statistic approach and 78 years of equivalent record in the HEC-FDA version 1.4.1 computer program (Reference 16). A summary of the adopted flow frequency curve along with the 95% confidence interval is shown in Table 18. A plot of the adopted frequency curve is located in Appendix E.

Table 18 Adopted discharge frequency estimates for Trempealeau River above Turton Creek

<table>
<tr><th colspan="4">Approximate Peak Discharge Frequency Analysis</th></tr>
<tr><th colspan="4">Trempealeau River above Turton Creek
Methodology: General Relations – Drainage Area Transfer – n value of 0.68</th></tr>
<tr><th>Exceedance Probability</th><th>Peak Estimate (cfs)</th><th>Upper (2.5%) Plus 2 Standard Deviation Confidence Limit (cfs)</th><th>Lower (97.5%) Minus 2 Standard Deviation Confidence Limit (cfs)</th></tr>
<tr><td>0.2%</td><td>20,700</td><td>31,900</td><td>13,400</td></tr>
<tr><td>1%</td><td>15,000</td><td>23,100</td><td>9,700</td></tr>
<tr><td>2%</td><td>12,800</td><td>18,900</td><td>8,800</td></tr>
<tr><td>10%</td><td>8,100</td><td>10,200</td><td>6,400</td></tr>
<tr><td>Mean</td><td>Not Available</td><td>Equivalent Record Length</td><td>78 Years</td></tr>
<tr><td>Standard Deviation</td><td>Not Available</td><td>Historic Period</td><td>Not Available</td></tr>
<tr><td>Adopted Skew</td><td>Not Available</td><td>Years in Record</td><td>Based on 1914-1919, 1935-2015 period of record at Arcadia</td></tr>
</table>

10.2 Turton Creek at Arcadia

The drainage area of Turton Creek at Arcadia is approximately 23.6 square miles (Reference 26). The USGS regression equations were not used to derive a frequency curve for the Turton

Creek watershed. Based on the information presented in Section 9.4 and Appendix G, the regression equations appear to underestimate flood risk in the study region.

The general relations method, or drainage area relations method, described in Section 9.3 is used to define the frequency curve for this location. A drainage area transfer using the nearby, hydrologically similar French Creek watershed is used to estimate a frequency curve for Turton Creek. It is assumed that the French Creek watershed and Turton Creek watershed are hydrologically similar because both the *2017 Flood-Frequency Characteristics of Wisconsin Streams* report and the *2003 Flood-Frequency Characteristics of Wisconsin Streams* report grouped these sites into the same hydrologic region. A hydrologic region outlined in the regression studies is a region encompasses sites with similar physiographic and climatic settings (Reference 43). The drainage areas of the two watersheds are similar, Turton Creek is 23.6 square miles and French Creek is 14.7 square miles. Additionally, the Turton Creek and French Creek watersheds border each other and are each part of the same larger scale watershed Upper Mississippi-Black-Root River basin. Plate I and Plate II attached to this report show the locations of the Turton Creek watershed and the French Creek watershed.

The discharge frequency curve shown in Section 8.3 for the French Creek near Ettrick, WI is used as the base, gaged annual instantaneous peak frequency curve in the drainage area transfer. The general relations drainage area transfer method exponent ‘n’ value of 0.68 listed in the 1997 *WI Department of Transportation Facilities Development Manual* is used to transfer the frequency curve from the French Creek near Ettrick, WI USGS site to Turton Creek above the Trempealeau River. For more information about the drainage area transfer method utilized in this analysis, view Section 9.3 and Reference 44.

The equivalent period of record is determined by applying the guidelines from *EM 1110-2-1619: Risk-Based Analysis for Flood Damage Reduction Studies* which are also shown in Figure 8 (Reference 7). According to *EM 1110-2*-1619, since the drainage area transfer is based upon an estimated frequency curve which applied an analytical distribution to a long period gage in the same watershed, an equivalent record length of between 50% and 90% of the long term gage length is recommended.

The systematic period of record of the French Creek near Ettrick Wisconsin is 47 years. It is assumed that since the watersheds border each other and are hydrologically similar, an equivalent record length of 80% of the systematic record of the French Creek near Ettrick, WI is a reasonable choice to use in this analysis. A selection of 80% of the record length of the French Creek near Ettrick, WI is justified over using the low end (50%) because the Turton Creek watershed borders the French Creek Watershed.

The selection of an equivalent record length has implications for the economic analysis. Generally, a shorter equivalent record results in more uncertainty and higher damages. Higher damages may have little impact on the benefit-cost ratio because an increase in damages due to changes in uncertainty would be evident in the without project and with project alternatives. If the benefit-cost ratio is close to the minimum value needed to ensure the project is feasible, it is recommended that sensitivity testing using different equivalent record lengths be performed to assess the effect different record lengths have on the feasibility of the project. If the benefit-cost ratio remains high, these sensitivity tests likely will not influence the feasibility of the project. See Section 14 for additional recommendations.

The equivalent record length of 38 years is used to represent the equivalent record length for confidence limits computed by the HEC-FDA version 1.4.1 computer program (Reference 16). A summary of the adopted flow frequency curve and the confidence interval (plus or minus two standard deviations, 95% confidence interval) is shown in Table 19. A plot of the adopted frequency curve is located in Appendix E.

Table 19 Adopted discharge frequency estimates for Turton Creek at Arcadia

Annual Peak Discharge Frequency Analysis			
Turton Creek above the Trempealeau River Methodology: General Relations – Drainage Area Transfer – n value of 0.68			
Exceedance Probability (%)		**HEC-FDA 95% Confidence Interval**	
	Peak Estimate (cfs)	**Upper (2.5%) Plus 2 Standard Deviation Confidence Limit (cfs)**	**Lower (97.5%) Minus 2 Standard Deviation Confidence Limit (cfs)**
0.2%	7,100	13,300	3,800
0.5%	6,100	11,400	3,200
1%	5,300	9,900	2,800
2%	4,500	8,300	2,500
5%	3,400	5,900	2,000
10%	2,500	4,100	1,600
Statistics			
Mean	Not Available	**Equivalent Record Length**	38 Years
Standard Deviation	Not Available	**Historic Period**	Not Available
Adopted Skew	Not Available	**Years in Record**	Based on 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015 period of record at French Creek near Ettrick

10.3 Myers Valley Creek at Arcadia

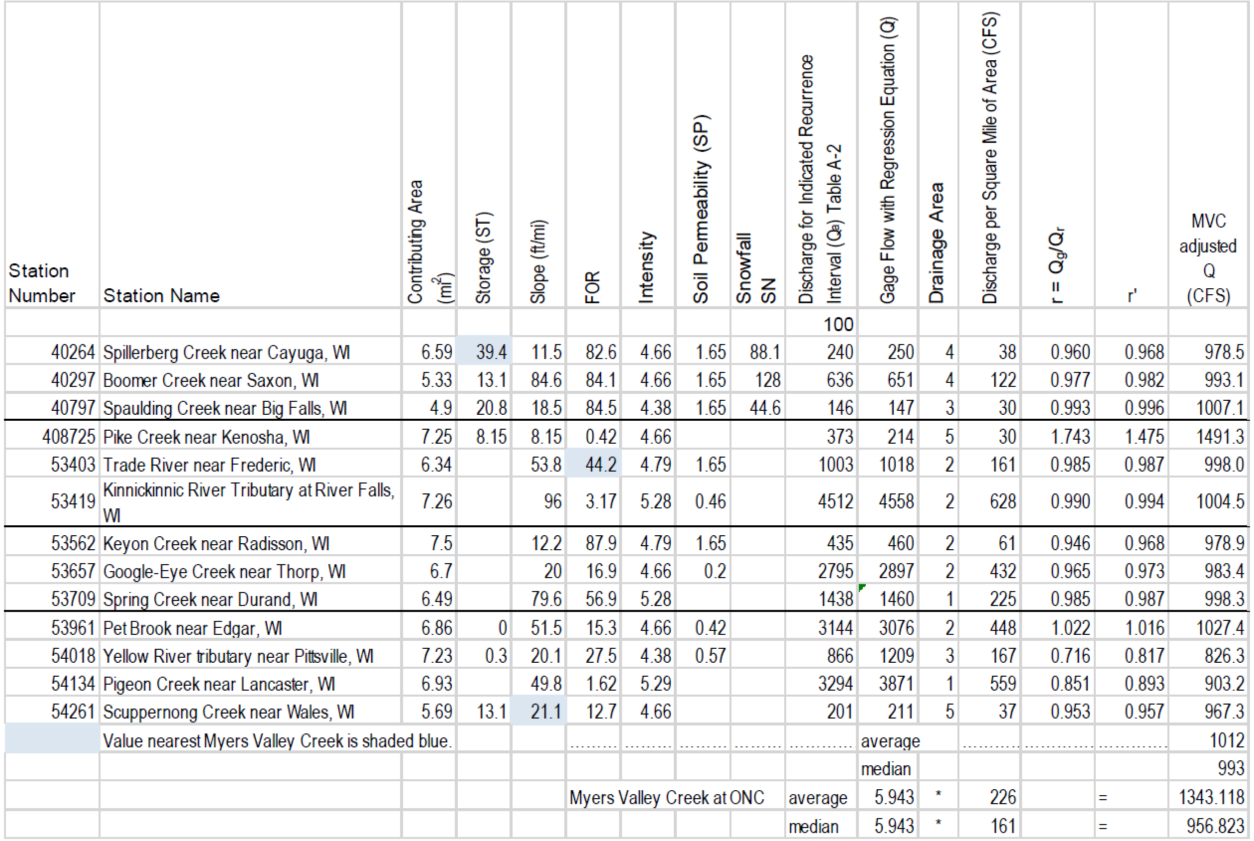
Myers Valley Creek is a small 6.4 square mile watershed located south of the City of Arcadia and flows into the Trempealeau River downstream of the Main Street Bridge in Arcadia. The only dam in the watershed is Schultz Dam located in the upstream portion of the watershed.

According to the *USACE National Inventory of Dams* in Appendix A, Schultz Dam is operated for fire protection and serves as a small fish stock pond and does not impact flood flows in the region since it is not operated for flood risk management (Reference 36).

10.3.1 Background: Previous Study

A discharge frequency estimate of the 1% AEP flood event for Myers Valley Creek was recently estimated by the *2014 Flood Study: Myers Valley Creek, Arcadia, Wisconsin* report by Davy Engineering. The purpose of this study was to relocate Myers Valley Creek to reduce the potential for flooding in the City of Arcadia, WI. The site of interest used in the *2014 Flood Study* was the DSM Bridge which is located upstream of where Myers Valley Creek joins the Trempealeau River. Myers Valley Creek has a drainage area of 5.94 square miles at the DSM Bridge and a drainage area of 6.4 square miles at its confluence with the Trempealeau River. The *2014 Flood Study* estimated the magnitude of the 1% AEP event using three different methods and gage information from the gages listed Table 20 below. The gages used in the *2014 Flood Study* are also shown in Plate III.

Table 20 USGS Streamgages used for the 2014 Flood Study to estimate flood frequency characteristics of Myers Valley Creek (Reference 5)



Station Number	Station Name	Contributing Area (mi^2)	Storage (ST)	Slope (ft/mi)	FOR	Intensity	Soil Permeability (SP)	Snowfall SN	Discharge for Indicated Recurrence Interval (Q_a) Table A-2	Gage Flow with Regression Equation (Q)	Drainage Area	Discharge per Square Mile of Area (CFS)	$r = Q_g/Q_r$	r'	MVC adjusted Q (CFS)
									100						
40264	Spillerberg Creek near Cayuga, WI	6.59	39.4	11.5	82.6	4.66	1.65	88.1	240	250	4	38	0.960	0.968	978.5
40297	Boomer Creek near Saxon, WI	5.33	13.1	84.6	84.1	4.66	1.65	128	636	651	4	122	0.977	0.982	993.1
40797	Spaulding Creek near Big Falls, WI	4.9	20.8	18.5	84.5	4.38	1.65	44.6	146	147	3	30	0.993	0.996	1007.1
408725	Pike Creek near Kenosha, WI	7.25	8.15	8.15	0.42	4.66			373	214	5	30	1.743	1.475	1491.3
53403	Trade River near Frederic, WI	6.34		53.8	44.2	4.79	1.65		1003	1018	2	161	0.985	0.987	998.0
53419	Kinnickinnic River Tributary at River Falls, WI	7.26		96	3.17	5.28	0.46		4512	4558	2	628	0.990	0.994	1004.5
53562	Keyon Creek near Radisson, WI	7.5		12.2	87.9	4.79	1.65		435	460	2	61	0.946	0.968	978.9
53657	Google-Eye Creek near Thorp, WI	6.7		20	16.9	4.66	0.2		2795	2897	2	432	0.965	0.973	983.4
53709	Spring Creek near Durand, WI	6.49		79.6	56.9	5.28			1438	1460	1	225	0.985	0.987	998.3
53961	Pet Brook near Edgar, WI	6.86	0	51.5	15.3	4.66	0.42		3144	3076	2	448	1.022	1.016	1027.4
54018	Yellow River tributary near Pittsville, WI	7.23	0.3	20.1	27.5	4.38	0.57		866	1209	3	167	0.716	0.817	826.3
54134	Pigeon Creek near Lancaster, WI	6.93		49.8	1.62	5.29			3294	3871	1	559	0.851	0.893	903.2
54261	Scuppernong Creek near Wales, WI	5.69	13.1	21.1	12.7	4.66			201	211	5	37	0.953	0.957	967.3
▨	Value nearest Myers Valley Creek is shaded blue.									average					1012
										median					993
					Myers Valley Creek at ONC				average	5.943	*	226		=	1343.118
									median	5.943	*	161		=	956.823

The first method used to estimate the 1% AEP flood event was the 2003 USGS regression equations for the state of Wisconsin (Reference 42). Using this method, the *2014 Flood Study* determined the 1% AEP event to be approximately 1,011 cfs.

The second method used to approximate the 1% AEP event for Myers Valley Creek used a combination of analytical curves estimated using data from streamgages in Table 20 and results from the 2003 USGS regression equations (Reference 42). Gages in Wisconsin between 5 and 7.5 square miles in drainage area were selected for the analysis. The 1% AEP event was estimated for each gage using the available data and analytical frequency curve methods. Next, an adjustment factor was developed by comparing the result from the regression analysis with the result from the analytical analysis. This adjustment factor was then modified using a ratio which accounted for the drainage area difference between the gaged site and the Myers Valley Creek watershed at the DSM Bridge. The final, adopted value was estimated by multiplying the modified adjustment factor by the flow estimated from the 2003 USGS regression equations to be 1,012 cfs.

The third method from the *2014 Flood Study* used to estimate the 1% AEP event at Myers Valley Creek was to estimate an average and median discharge of the 1% AEP event per square mile based on the results from the second estimation method. The *2014 Flood Study* determined an average discharge of 226 cfs/mi² and a median discharge of 161 cfs/mi². A summary of this computation and the final result is shown in Table 20 above. The point of interest for the *2014 Flood Study* was the DSM Bridge which has a drainage area of 5.94 square miles. The estimate of the 1% AEP event using this criteria resulted in 1,340 cfs from the average discharge per square mile and 960 cfs from the median discharge per square mile. The *2014 Flood Study* averaged these two values to determine a 1% AEP estimate of 1,150 cfs. Ultimately, the 2014 Flood Study averaged the results from the three methods and rounded to the nearest hundred to obtain an adopted 1% AEP discharge value of 1,100 cfs for Myers Valley Creek.

10.3.2 USACE Analysis

The two methods considered to estimate a frequency curve for this site were the USGS regression equations and a drainage area transfer with a nearby, hydrologically similar watershed. A sensitivity analysis discussed in Section 9.4 of this report and shown in Appendix G suggests that the USGS regression equations underestimate flood risk for small watersheds in the study area. Consequently, the regression equations are not used to develop flood frequency estimates for Myers Valley Creek.

Table 21 lists the gages that were used to estimate the 1% AEP event for Myers Valley Creek in the *2014 Flood Study* along with notes about each gage. The primary reason the methods used in the *2014 Flood* Study were not used in this analysis was because they relied heavily on the

USGS regional regression equations which appear to underestimate flood risk in this region. Many of the gages included in the original study are located in different physiographic regions than Myers Valley Creek, are inactive, or contain fewer data points than required to perform an analytical frequency analysis. Plate III shows the hydrologic regions with similar watershed characteristics and climate.

Table 21 Gages used in 2014 Flood Study

Gage ID	Site	POR Start Year	POR End Year	Annual Peak Events	DA (sq. mi.)	Notes
04026400	Spillberg Creek nr. Cyuga, WI	1958	1981	24	6.59	Not in same physiographic region, inactive gage with limited period of record, not enough systematic events to perform analytical frequency analysis
04029700	Boomer Creek nr. Saxon, WI	1958	1981	21	5.33	Not in same physiographic region, inactive gage with limited period of record, not enough systematic events to perform analytical frequency analysis
04079700	Spaulding Creek nr. Big Falls, WI	1959	2017	58	5.57	Not in same physiographic region
04087250	Pike Creek nr. Kenosha, WI	1960	2017	57	7.25	Not in same physiographic region
05340300	Trade River nr. Frederic, WI	1958	2016	59	6.34	Not in same physiographic region
05341900	Kinnickinnic River Tributary at River Falls, WI	1959	2017	57	7.26	Gage listed as inactive on USGS website, some peak discharges affected by ice jams and debris, some gage measurements affected by backwater
05356200	Keyon Creek nr. Radisson, WI	1960	1980	21	7.91	Not in same physiographic region, inactive gage with limited period of record, not enough systematic events to perform analytical frequency analysis
05365700	Google-Eye Creek nr. Thorp, WI	1958	1993	36	6.42	Inactive gage missing past 20 years of events
05370900	Spring Creek nr. Durand, WI	1962	2017	54	6.45	Discharge is affected by debris jams. Gage is listed as Inactive by USGS
05396100	Pet Brook nr. Edgar, WI	1962	1992	31	6.86	Not in same physiographic region
05401800	Yellow River tributary nr. Pittsville, WI	1959	2017	58	7.23	Not in same physiographic region
05413400	Pigeon Creek nr. Lancaster, WI	1960	2015	55	6.93	Not in same physiographic region
05426100	Scuppernong Creek nr. Wales, WI	1962	1980	19	8.39	Inactive gage, insufficient period of record

A drainage area transfer using the nearby, hydrologically similar French Creek watershed is used to estimate a frequency curve for Myers Valley Creek. It is assumed that the French Creek watershed and Myers Valley Creek watershed are hydrologically similar because both the *2017 Flood-Frequency Characteristics of Wisconsin Streams* report and the *2003 Flood-Frequency Characteristics of Wisconsin Streams* report grouped these sites into the same hydrologic analysis region. Hydrologic analysis regions are sites which have similar physiographic and climatic characteristics and the regions developed for the 2017 USGS regression equations are shownin Plate III (Reference 43). The drainage area of the French Creek watershed and Myers Valley Creek watershed is similar at 14.7 square miles and 6.4 square miles, respectively. The two watersheds are separated by less than 7 miles of distance and both are part of the larger Upper Mississippi-Black-Root River watershed.

The French Creek near Ettrick gage is the most appropriate site to use to estimate a frequency curve for Myers Valley Creek because it has similar physical characteristics as Myers Valley Creek and the two sites are close together. Flooding on the small study watersheds like Turton Creek and Myers Valley Creek is often caused by local, intense precipitation. Because French Creek and Myers Valley Creek are so close to each other and have similar physical characteristics, it is likely that flood events captured by the French Creek near Ettrick USGS gage provide the best insight into the flood frequency characteristics of the Myers Valley Creek watershed.

The discharge frequency curve shown in Section 8.3 for the French Creek near Ettrick, WI is used as the base, gaged annual instantaneous peak frequency curve in the drainage area transfer. The general relations drainage area transfer method exponent ‘n’ value of 0.68 listed in the 1997 *WI Department of Transportation Facilities Development Manual* is used to transfer the frequency curve from the French Creek near Ettrick, WI USGS site to Myers Valley Creek above the Trempealeau River. The drainage area transfer exponent is based on a statistical regression analysis of 184 Wisconsin stream gages which contained at least 10 annual peak flood events (Reference 3).

The equivalent period of record is determined by applying the guidelines from *EM 1110-2-1619: Risk-Based Analysis for Flood Damage Reduction Studies* which are also shown in Figure 8 (Reference 7). According to *EM 1110-2-*1619, since the drainage area transfer is based upon an estimated frequency curve which applied an analytical distribution to a long period gage in the same watershed, an equivalent record length of between 50% and 90% of the long term gage length is recommended.

The systematic period of record of the French Creek near Ettrick Wisconsin is 47 years. It is assumed that since the watersheds border each other and are hydrologically similar, an equivalent record length of 80% of the systematic record of the French Creek near Ettrick, WI is a reasonable choice to use in this analysis. The equivalent record length of 38 years is used to define the confidence limits computed by the HEC-FDA version 1.4.1 (Reference 16). A summary of the adopted flow frequency curve and the confidence interval (plus or minus two standard deviations, 95% confidence interval) is shown in Table 22. A plot of the adopted frequency curve is located in Appendix E. Section 13 discusses how the results in Table 22 compare to the results achieved from previous studies of this site.

Table 22 Discharge frequency estimates for Myers Valley Creek at Arcadia

Annual Peak Discharge Frequency Analysis Myers Valley Creek at Arcadia Methodology: General Relations – Drainage Area Transfer – n value of 0.68			
		HEC-FDA 95% Confidence Interval	
Exceedance Probability (%)	**Peak Estimate (cfs)**	**Upper (2.5%) Plus 2 Standard Deviation Confidence Limit (cfs)**	**Lower (97.5%) Minus 2 Standard Deviation Confidence Limit (cfs)**
0.2%	2,910	1,550	5,450
0.5%	2,500	1,330	4,690
1%	2,180	1,160	4,080
2%	1,840	1,020	3,410
5%	1,390	820	2,390
10%	1,050	660	1,670
Statistics			
Mean	Not Available	**Equivalent Record Length**	38 Years
Standard Deviation	Not Available	**Historic Period**	Not Available
Adopted Skew	Not Available	**Years in Record**	Based on 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015 period of record at French Creek near Ettrick

11 Coincident Flow Assessment

In hydrologic design, it is necessary to consider the probability of how flooding from a main stem river and a tributary river will influence the water surface profile for a potential flood risk reduction feature near the confluence of the two streams. This situation can be statistically assessed through a coincident frequency analysis. Coincident frequency is the probability of a given outcome resulting from each of several processes because they all influence a single variable of interest (e.g. stage near the confluence). Coincident flows are flows that either contribute to the annual instantaneous peak flow occurring at a downstream point of interest or are produced by an annual instantaneous peak flow occurring at an upstream point of interest.

Coincident frequency analysis verifies which flood scenarios result in the highest water surface elevations throughout the project using a probabilistic technique to quantify the likelihood of occurrence of a particular event. For example, Figure 9 shows a typical example of a problem requiring coincidental frequency analysis. The flow and stage of the main stem of the river and the flow and stage of the tributary each contribute to the stage at the confluence between the two waterways. If both streams are high at the same time, this would increase the design feature elevations of a levee or floodwall compared to the case when water is high on one stream, and low on the other.

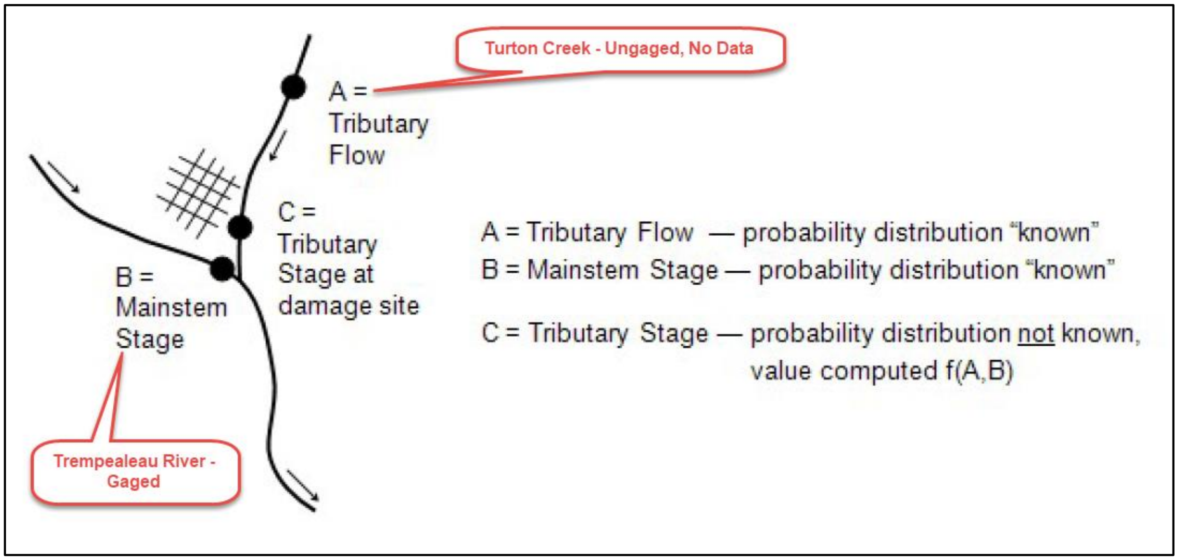


Figure 9 Typical situation which where coincident frequency analysis is required

Coincident frequency analysis depends on assumptions of coincidence, correlation, and dependence. Coincidence refers to whether or not events on stream A and stream B occur at the same time. Correlation is an indication of the relationship between the two variables (e.g. if they are high at the same time, low at the same time, etc.). Dependence refers to if the value of one variable is affected by the value of another. For independent events, the occurrence of one event does not rely on the occurrence of another event preceding it. Assumptions of coincidence, correlation, and dependence influence the probabilistic description of how simultaneous flooding from multiple sources affect a study site.

The scenario presented in Figure 9 describes the layout of the Trempealeau River and Turton Creek. Typically, the more influential variable, variable A (tributary flood peaks), and the less influential variable, variable B (daily and annual main stem stage) can be used to generate a frequency curve for the stage above the confluence, variable C. In this analysis, the Turton Creek watershed is ungaged and only a single high water mark exists which makes it impossible to establish correlation between the two watersheds. If adequate data is available for the main stem site and tributary site, frequency information from these two sites can be used with the law of total probability to generate a probability distribution for stage above the confluence of the two stream segments. Without adequate data for each variable, the law of total probability cannot be used to provide a probabilistic description about the characteristics of the stage at the confluence, unless assumptions are made about the tributary stream.

11.1 Adopted Coincident Flows

Due to the lack of flow data on Turton Creek, it is assumed that events are sometimes coincident (occur at the same time) but are not correlated (not high or low at the same time) and events on Turton Creek are not dependent on events which occur on the Trempealeau River. This assumption is typically used in situations where the main stem drainage area is much greater than the tributary drainage area (Reference 13). The drainage area of the Trempealeau River at Arcadia (550 mi²) is 23 times greater than the drainage area of Turton Creek (23.6 mi²), so this assumption is reasonable for this situation.

11.1.1 Peak Flow on Turton Creek and Coincidental Flow on Trempealeau River

In July 2017, a large storm event occurred over much of west central and south west Wisconsin which caused flooding on the Trempealeau River and Turton Creek. A survey by U.S. Army Corps of Engineers surveyors collected measurements of high water marks (HWMs) along Turton Creek. The HWM data was used in the calibrated HEC-RAS model developed for this study to estimate a discharge associated with the HWM data.

Based on analysis with the HEC-RAS model, the 2017 event produced a peak discharge of 6,300 cfs on Turton Creek which is approximately the 0.38% AEP (260-yr average return period) event. The peak discharge recorded by the Trempealeau River at Arcadia USGS gage (ID 05379400) was 9,260 cfs which is approximately equal to the 7% (14-yr average return period). This information was used as a basis to develop coincidental flows for Turton Creek and the Trempealeau River because it is the only quantitative information available about coincident flooding on these two sites. The assumptions used to develop the coincidental flow relationships for Turton Creek are listed in Table 23 below. The coincidental flows for the Trempealeau River when the peak flow is on Turton Creek is listed in Table 24 below.

Table 23 Coincident flow relationships: Which AEP event on Turton Creek corresponds to which AEP event on Trempealeau River

Trempealeau River at Arcadia		Turton Creek at Arcadia	
AEP (%)	Return Period (yr)	AEP (%)	Return Period (yr)
2	50	0.2	500
5	20	0.5	200
10	10	1	100
20	5	2	50
50	2	5	20

Table 24 Coincident flow frequency results: Peak flow on Turton Creek

Exceedance Frequency (%)	Recurrence Interval (yr)	Turton Creek Peak Flow (cfs)	Trempealeau River	
			Below Turton Peak Flow (cfs) *	Estimated Coincidental Flow (cfs)
0.2%	500	7,100	13,200	6,100
0.5%	200	6,100	10,300	4,200
1%	100	5,300	8,300	3,000
2%	50	4,500	6,400	1,900
5%	20	3,400	3,800	400

** Assuming Turton 0.2% AEP/Trempealeau 2% AEP, 0.5%/5%, 1%/10%, 2%/20%, 5%/50%*

11.1.2 Peak Flow on Trempealeau River

The coincidental discharge frequency curve for the Turton Creek at the mouth was determined by computing the difference in flows from the annual instantaneous peak flow frequency relationships developed for the Trempealeau River upstream and downstream of Turton Creek. This approach assumes that the peak on the Trempealeau River is independent of the Peak on Turton Creek and that events are sometimes coincident but not correlated. This assumption is often used when the difference in drainage areas between the two watersheds is large. The coincident frequency curve for Turton Creek coincident flows when the peak flow is on the Trempealeau River is listed below in Table 25.

Table 25 Turton Creek coincidental flows when the peak is on the Trempealeau River

Exceedance Frequency (%)	Recurrence Interval (yr)	Frequency Analysis		
		Trempealeau River Flows (cfs)		Turton Creek Coincidental Flow
		At Arcadia USGS Gage	Above Turton Creek	
0.2%	500	21,300	20,700	600
0.5%	200	17,900	17,400	500
1.0%	100	15,500	15,000	500
2.0%	50	13,200	12,800	400
5.0%	20	10,300	10,000	300
10.0%	10	8,300	8,100	200
20.0%	5	6,400	6,200	200
50.0%	2	3,800	3,700	100

11.1.3 Myers Valley Creek Coincident Flows

The Myers Valley Creek tributary joins the Trempealeau River in a similar manner as Turton Creek and is depicted in Figure 10 below. It is understood that the Trempealeau River controls flooding at the confluence between the two streams because its drainage area (550 mi²) is approximately 85 times larger than that of Myers Valley Creek. There is also a railroad bridge at the downstream end of Myers Valley Creek which is used as a boundary condition in the HEC-RAS model reflecting the water surface elevations from the Trempealeau River that back up to the railroad during floods. The railroad opening serves as a flow constriction. A coincident flow analysis was not performed at this site because the Trempealeau River controls at this location.

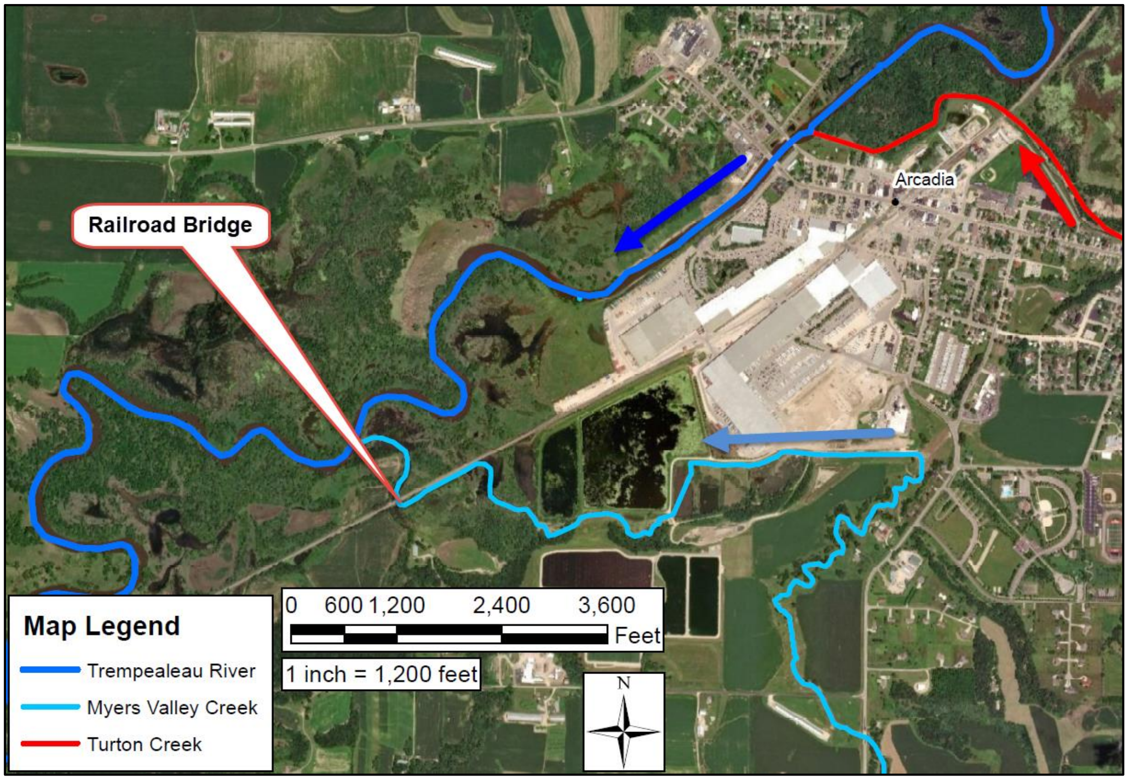


Figure 10 Myers Valley Creek near the Confluence with Trempealeau River

11.2 Coincident Flow Sensitivity Analysis

A limitation of the coincident frequency assessment in the preceding section is that it does not offer a statistical based description that can be used to describe the risk from coincident flooding to aid in the design of a flood risk management project. The coincident frequency analysis is limited because the tributary watersheds which affect the city of Arcadia, WI have never had a stream gage to collect data which is vital for performing coincident frequency analysis.

A sensitivity analysis using a potential worst-case scenario was performed to provide insight into how high the Trempealeau River and Turton Creek could get if simultaneous large scale flooding occurred on each stream. The largest flood estimated by the frequency curves in this report is the 0.2% AEP event. The worst-case scenario assumed that the 0.2% AEP (500-yr average return period) event occurred at the same time on both streams. As noted in the previous section, Myers Valley Creek coincidental flows were not considered in this analysis because the Trempealeau River appears to control water surface elevations at the confluence of the Trempealeau River and Myers Valley Creek.

The sensitivity test for the Trempealeau River compares the water surface profile resulting from the adopted coincident flows in Table 25 (peak on the Trempealeau River, adopted coincidental flows on Turton Creek) to the water surface profile resulting from the worst-case scenario to determine the potential increase in WSE for this unlikely event. Figure 11 below shows that the WSE from the worst-case scenario is greater than the WSE from the adopted coincidental flows. The increase in WSE computed by the HEC-RAS model is 0.62 feet at HEC-RAS Trempealeau River station 17927.13 feet, which is the confluence between the Trempealeau River and Turton Creek.

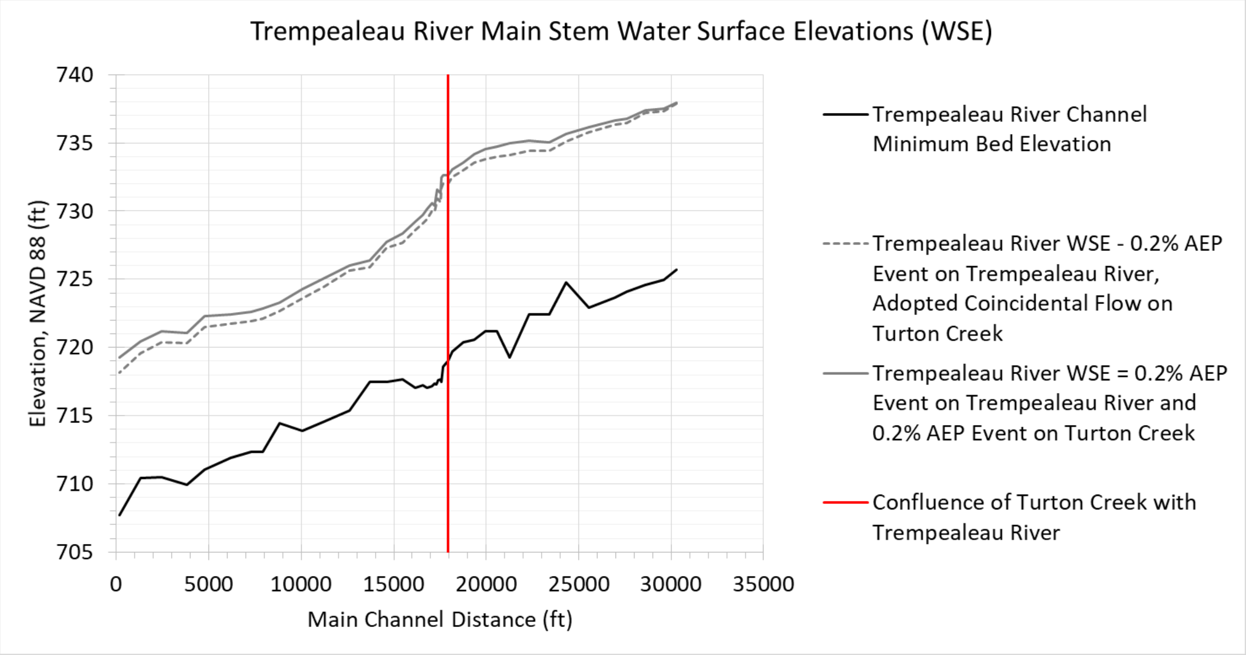


Figure 11 Coincident flow sensitivity analysis: Trempealeau River

The sensitivity test for Turton Creek compares the water surface profile resulting from the adopted coincident flows in Table 24 (peak flow on Turton Creek, adopted coincident flow on the Trempealeau River) to the water surface profile resulting from the worst-case scenario to determine the potential increase in WSE for this unlikely event. Figure 12 below shows that the WSE from the worst-case scenario is greater than the WSE from the adopted coincidental flows. The increase in WSE computed by the HEC-RAS model is 2.17 feet at HEC-RAS Turton Creek station 196.464 feet which is near the confluence of Turton Creek and the Trempealeau River.

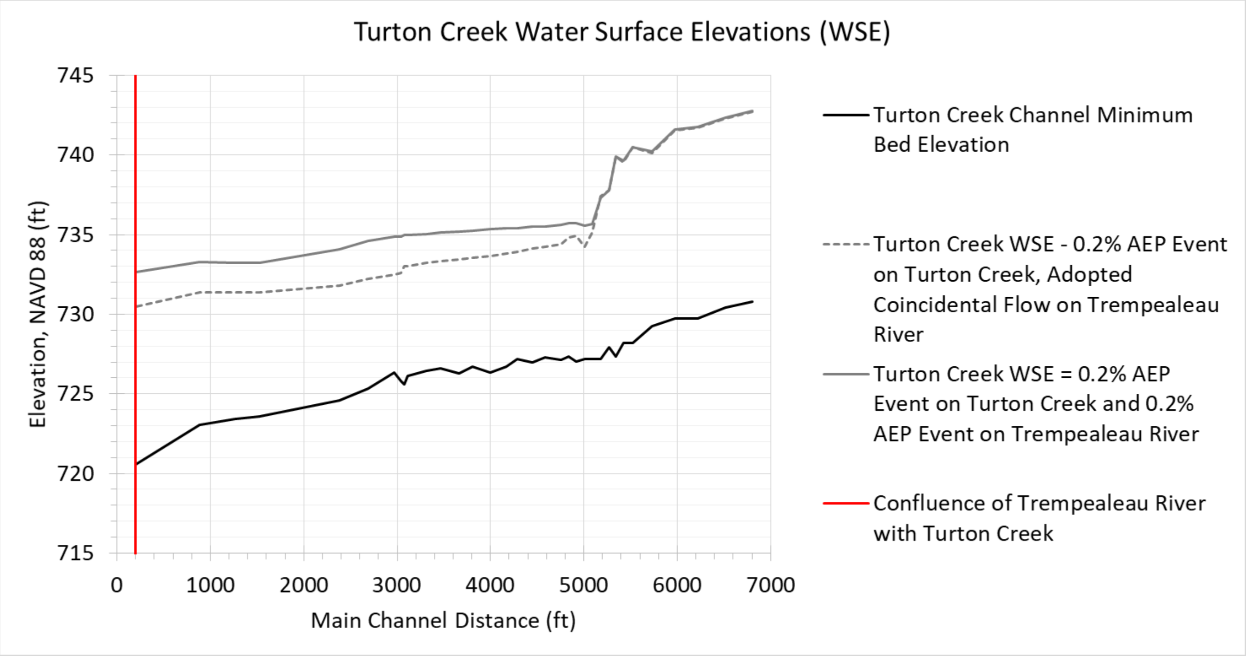


Figure 12 Coincident flow sensitivity analysis: Turton Creek

11.2.1 Coincident Flow Sensitivity Discussion

The worst-case scenario of simulating the 0.2% AEP event on both the Trempealeau River and Turton Creek resulted in considerable increases in the WSE of both streams when compared to the adopted coincidental flows. The available information from the 2017 flood event suggests that the worst-case scenario sensitivity test represents an extreme, improbable event which may be overly conservative for this watershed. Since the probability that the 0.2% AEP event will occur simultaneously on Turton Creek and the Trempealeau River is low, the sensitivity test represents a potential upper limit for the simulated WSEs at these sites, absent the occurrence of a probable maximum precipitation (PMP) event which would result in a probable maximum flood (PMF).

Flood risk reduction features like levees and flood walls typically incorporate additional height beyond the design WSE to account for risk and uncertainty associated with the hydrologic analysis. The additional feature height to account for risk and uncertainty is typically 3 feet, but varies depending on the analysis and design considered. Based on this assessment, a typical risk and uncertainty height of 3 feet would contain the worst-case scenario event on Turton Creek and the Trempealeau River. The worst-case scenario is believed to be conservative for this watershed, and the adopted coincidental flow analysis provides a reasonable estimate of the coincidental flow frequency curves based on the limited information at the study site. See Section 14 for recommendations of how to improve this analysis.

12 Turton Creek 1% AEP Hydrograph Estimate

12.1 Purpose of this Hydrologic Modeling Effort

An estimate of the 1% annual exceedance probability (AEP) event (100-year return period) hydrograph volume and shape for the Turton Creek watershed at Arcadia is included to assess nonstructural storage alternatives in upstream portions of the Turton Creek basin. The 1% AEP runoff event hydrograph is developed to provide a screening tool to determine if nonstructural storage is a feasible alternative. Detailed hydrologic modeling is beyond the scope of this feasibility level analysis. Previously developed HEC-1 models from the *1988 Flood Insurance Study for the City of Arcadia* report for the 1% exceedance probability event were readily available and were used to provide an estimate of the 1% AEP event hydrograph at Turton Creek. Guidelines used to approximate the runoff hydrograph are outlined in the *Hydrologic Analysis of Ungaged Watersheds using HEC-1* document (Reference 12). The models included in this effort were not used to determine the frequency curve for French Creek or Turton Creek nor to provide design level information. Please see Section 14 for a recommendation of how to proceed if nonstructural storage is deemed feasible as a result of this effort and design hydrographs are required.

12.2 Methodology

The *1988 FIS* uses the methodology specified in the *1982 Training Document No. 15: Hydrologic Analysis of Ungaged Watersheds* to generate an approximation of the 1% AEP event hydrograph for Turton Creek (References 10 and 12, respectively). The guidance outlined in *Training Document No. 15* is also applied for this study. The basic process for tying a hydrologic model to a frequency curve at an ungaged location involves the following steps:

A. Develop a hydrologic model for a nearby gaged watershed by assembling regional watershed parameters.
B. Develop a synthetic storm tied the recurrence interval of interest (1% AEP event) and modify loss parameters within the HEC-HMS model for the gaged watershed until the streamflow response corresponding to that storm matches the data based 1% peak flow from the frequency curve at the streamflow gage location.
C. Develop a hydrologic model for the ungaged watershed by using the regional watershed parameters developed for the gaged watershed.
D. Use the same HEC-HMS model loss parameters and meteorological inputs used to generate the 1% AEP in the gaged model for the ungaged model to generate the 1% event hydrograph at the ungaged location of interest.

Turton Creek is an ungaged basin, so synthetic methods of analysis were used to develop an estimate of the hydrograph shape for the 1% AEP runoff event defined by the frequency curve in Section 10.2. The adopted method is dependent on generating an HEC-HMS model of the

Turton Creek watershed and the French Creek watershed. The HEC-HMS models used to model Turton Creek and French Creek use the same modeling technique and parameters that were used within the HEC-1 models produced for the *1988 Flood Insurance Study Interim Hydrology Report, City of Arcadia, WI*.

12.3 Background information on HEC-1 Models from 1988 FIS Report

The Turton Creek HEC-1 model was divided into three subbasins for the *1988 Flood Insurance Study Interim Hydrology Report, City of Arcadia, WI*: Newcomb Valley subbasin, American Valley subbasin, and Thompson Valley subbasin (see Figure 13). The French Creek watershed was defined by a single subbasin because there was only one distinct valley draining to the French Creek at Ettrick, WI USGS gage (see Figure 14).

The *1988 FIS* HEC-1 models used the Snyder transform method to define the unit hydrograph. Snyder's parameters were adopted from a model generated for a nearby, hydrologically similar Crooked Creek watershed. The Crooked Creek gage is located at Boscobel, WI (USGS gage 05407200, drainage area: 12.9 square miles). Crooked Creek is also located in southeast Wisconsin approximately 85 miles from the Turton Creek watershed. The Snyder's parameters are a storage coefficient, peaking coefficient, and a time to peak. The Snyder's parameters for the Crooked Creek used a storage coefficient (C_p) of 0.20 and peaking coefficient (C_t) of 0.39 (Reference 10). These Snyder's parameters were adopted for all the subbasins in the Turton Creek and French Creek hydrologic models.

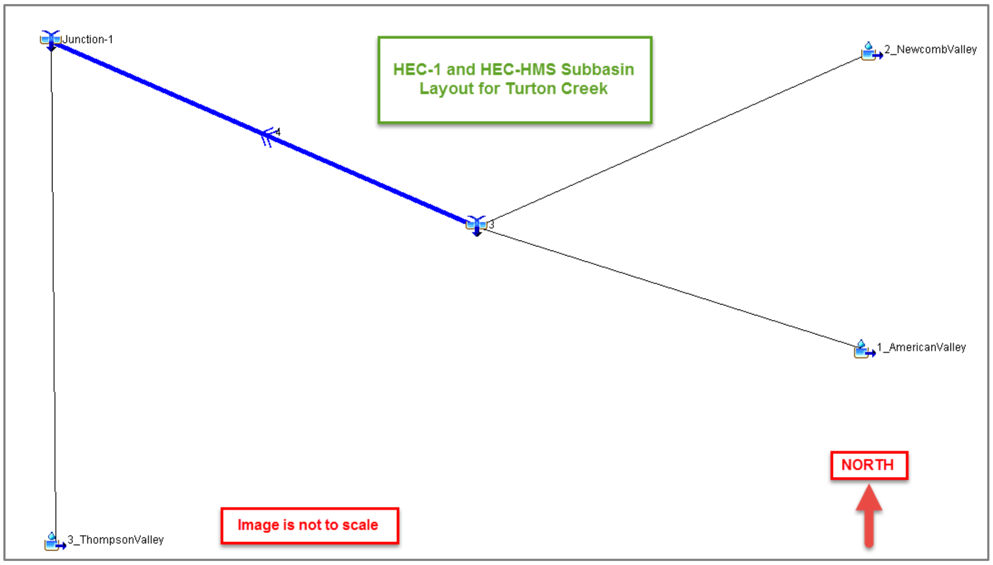


Figure 13 HEC-1 and HEC-HMS model layout for Turton Creek Model

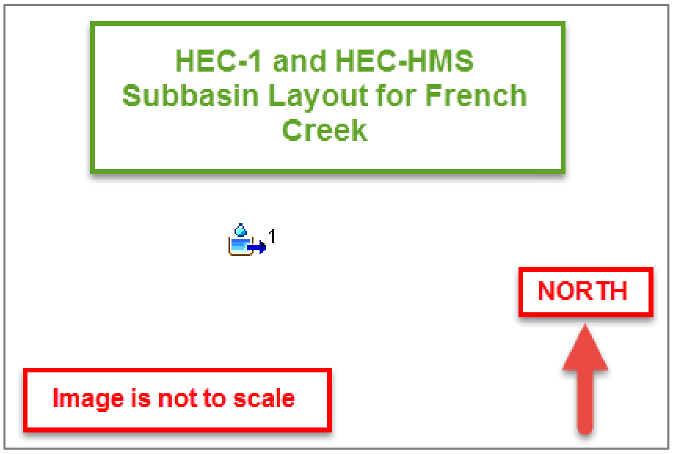


Figure 14 HEC-1 and HEC-HMS model layout for French Creek Model (modeled as single subbasin)

Snyder's standard lag (t_p) was calculated for each subbasin in the Turton Creek model and French Creek model using the Snyder's Standard Lag Equation (Equation 6). In Equation 6, the length of the longest watercourse from the outlet to the drainage divide (L) and the length of the longest watercourse from the outlet to the point opposite the centroid of the drainage area (L_{CA}) were estimated from measurements of 7.5 minute USGS topographic maps. The storage coefficient and peaking coefficient is the same for all subbasins in both the French Creek and Turton Creek models; however, the time to peak varies and depends on the physical features of the watershed. Therefore, each subbasin has a unique set of transform parameters to define the unit hydrograph of that particular subbasin.

Equation 6 Snyder's standard lag equation (Reference 10)

$$t_P = C_t(LL_{CA})^{0.3}$$

t_P = Snyder's time to peak (hours)
L = Length of the longest watercourse from outlet to drainage divide (miles)
L_{CA} = Length of longest watercourse from outlet to point opposite the centroid of the drainage area

No routing reaches were included in the French Creek HEC-1 model because it was represented as a single subbasin. A single routing reach was included in the Turton Creek HEC-1 model and is shown in the model schematic in Figure 13. Basin routing reach lengths and channel slopes were measured from 7.5 minute USGS topographic maps. Channel velocities (v) were estimated using the measured slope of the watershed and Figures 4.1-4.4 from the *SCS Hydrology Guide for Minnesota* (included in Reference 10).

The Muskingum routing method was applied to translate the flood hydrograph through the routing reach included in the Turton Creek HEC-1 model. Inputs for the Muskingum routing method are the Muskingum K (hr), the Muskingum X, and the number of subreaches. The

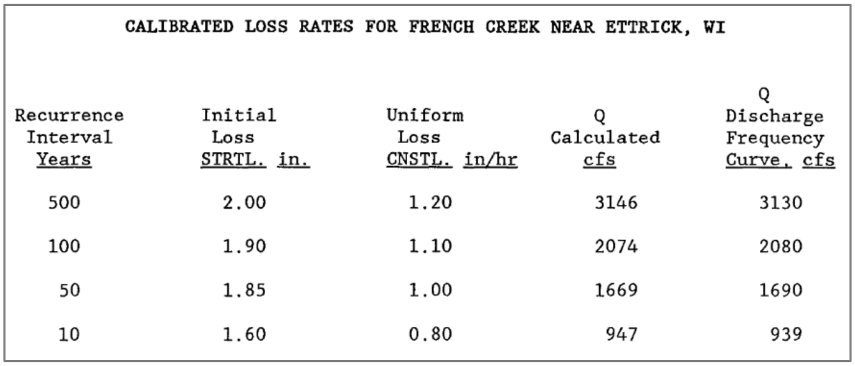
Muskingum K estimates the travel time through a particular reach. Muskingum X represents a weighting between inflow and outflow, and ranges from 0 to 0.5, where 0 represents maximum attenuation and 0.5 represents no attenuation. Since the channel valleys in both the Turton Creek watershed and French Creek watershed provide some storage, a Muskingum X coefficient of 0.30 was selected and used in the model (Reference 10). The Muskingum K value was estimated from the reach length, L, divided by the estimated channel velocity, v (K = L/v).

Baseflow was not included in the *1988 FIS* HEC-1 model of French Creek. The 1988 FIS HEC-1 model of Turton Creek does include a baseflow component. To make the French Creek and Turton Creek models consistent for this modeling effort, baseflow was removed from the Turton Creek model. The Turton Creek watershed and the French Creek watershed both have small drainage areas and exhibit a rapid response to high intensity, local rainfall. Since this model is attempting to estimate the 1% AEP hydrograph, typical baseflow is negligible compared to the flows produced by the 1% rainfall runoff event.

The loss method in the model was specified as the initial and constant loss rate method. This method utilizes an initial loss, a constant loss rate, and a percent impervious area to perform loss calculations. The percent impervious area was assumed to be zero for both watersheds since the Turton Creek and French Creek watersheds are largely undeveloped.

The initial loss represents the initial abstractions due to pore space in the soil column and varies considerably from event to event depending on antecedent basin conditions. The constant loss rate is the saturated hydraulic conductivity of the soil column after the pore spaces are filled with water.

According to the *1988 FIS* document, initial and constant loss rate parameter estimates were adopted from the *SCS Soil Survey for Trempealeau County, WI* (see Reference 10). The soils in the area are noted as being primarily loam and silty loam with sandy river valley bottoms. The values for the adopted loss rates summarized in Figure 15 are consistent with saturated hydraulic conductivity values presented in Rawls et al. (1982) which were developed from permeability studies of difference soil types (Reference 37). The adopted loss rates for the 1% AEP simulation using HEC-1 models is summarized in Figure 15 below. The adopted loss rates for the 1% AEP event in the French Creek HEC-1 model and the Turton Creek HEC-1 model are an initial loss of 1.90 inches and a constant loss rate of 1.10 inches/hour.



CALIBRATED LOSS RATES FOR FRENCH CREEK NEAR ETTRICK, WI

Recurrence Interval Years	Initial Loss STRTL. in.	Uniform Loss CNSTL. in/hr	Q Calculated cfs	Q Discharge Frequency Curve, cfs
500	2.00	1.20	3146	3130
100	1.90	1.10	2074	2080
50	1.85	1.00	1669	1690
10	1.60	0.80	947	939

Figure 15 Adopted Loss Rates for French Creek near Ettrick from 1988 Flood Insurance Study which were used as inputs into the Turton Creek 1988 HEC-1 model for the recurrence interval specified (Reference 10)

Table 26 Saturated Hydraulic Conductivity from Rawls et al. 1982 (Reference 37)

Texture Class	Saturated Hydraulic Conductivity (cm/hr)	Saturated Hydraulic Conductivity (in/hr)
Loamy Sand	6.11	2.41
Sandy loam	2.59	1.02
Loam	1.32	0.52
Silt loam	0.68	0.27

Hypothetical rainfall events were used to tie the HEC-1 model results to the established frequency curve for the French Creek near Ettrick, WI. Hypothetical rainfall values for events ranging from the 0.2% AEP storm to the 10% AEP storm were obtained from HYDRO-35 and TP 40. The TP-40 and HYDRO-35 documents define rainfall intensity-duration-frequency curves from the National Weather Service (formerly the Weather Bureau) recording stations to develop isopluvial maps for different exceedance probability rainfall events and different durations. The isopluvial maps from HYDRO-35 and TP-40 were used to estimate rainfall frequency information for the Arcadia, WI *1988 FIS* study area (see Table 35 for the values used in the original *1988 FIS* HEC-1 models).

For the *1988 FIS* it was assumed that a storm event with a defined exceedance probability value would produce a peak discharge with the same probability of exceedance. It was assumed that the 1% AEP rainfall from HYDRO-35 and TP 40 that produced the 1% AEP runoff event on French Creek would also produce the 1% AEP discharge for Turton Creek. The same assumptions were adopted as part of this analysis. Storm events of different exceedance probabilities were simulated in the French Creek HEC-1 model and loss rates were adjusted to tie the French Creek model to the 1% AEP peak discharge from the French Creek frequency curve.

The French Creek HEC-1 model was not calibrated to observed data. The only data collected at the French Creek near Ettrick, WI USGS gage site is peak stage data which is then converted to a discharge using a USGS rating curve. Since only the peak discharge is available, it is not possible to calibrate the model to the full streamflow response. Consequently, rather than attempting to calibrate the model to inadequate flow data it was tied to the frequency curve by applying the hypothetical storm events described in the previous paragraphs.

The French Creek HEC-1 model, and the subsequently developed HEC-HMS model used for this study were run with a 10 minute computation interval over a 9 hour and 10 minute simulation period. A computation interval of 10 minutes was selected because it was sufficiently small enough to provide definition of the outflow hydrograph to determine the peak event. The simulation time period was selected to allow 3-5 points to define both the rising and falling limb of the hydrograph. A summary of how the computation interval was computed is given in Table 27.

The Turton Creek HEC-1 model, and the subsequently developed HEC-HMS model used for this study, was run with a 5 minute computation interval over a 22 hour and 15 minute simulation period. A computation interval of 5 minutes was selected because it was sufficiently small enough to provide definition of the runoff hydrograph to determine the peak event. The simulation time period is selected to allow the simulation sufficient time to define the peak outflow from the Turton Creek watershed. A summary of how the computation interval was computed is given in Table 27.

Table 27 Computation Interval Summary

Computation Step Interval Information		
	Watershed Model	
Subbasin Information	**French Creek Model**	**Turton Creek Model**
Subbasin With Shortest Tc	1 (Only 1 Subbasin)	3 Thompson Valley
Time of Concentration, Tc (hr)	0.8658	0.5670
Time of Concentration, Tc (min)	51.9	34.0
Tc/3 (min)	17.3	11.3
Tc/5 (min)	10.4	6.8
Adopted Computation Interval	10 Minutes	5 Minutes

A summary of the methods used to model the French Creek and Turton Creek watersheds is included in Table 28 below.

A HEC-1 model of Turton Creek using the unit hydrograph parameters described previously, rainfall values from HYDRO-35 and TP 40, and the loss rates obtained for each event from the French Creek HEC-1 model was used to estimate the frequency curve for Turton Creek. The layout of the Turton Creek HEC-1 model and a summary of the hydrologic methods used for the model is shown in Figure 13 and Table 28, respectively. The adopted loss Rates for the French Creek model are shown in Figure 15. The final, recommended parameters for the Turton Creek HMS model are shown in Table 29.

Table 28 Summary of HEC-1 Model Methods for French Creek and Turton Creek as part of the 1988 FIS Study Effort

Method	1988 FIS Study HEC-1 Model Summary	
	French Creek HEC-1 Model	**Turton Creek HEC-1 Model**
Number of Subbasins	1	3
Number of Routing Reaches	0	1
Channel Routing Method	Not Applicable	Muskingum
Baseflow Method	None	None
Loss Method	Initial and Constant	Initial and Constant
Percent Impervious (%)	0%	0%
Transform Method	Snyder Unit Hydrograph	Snyder Unit Hydrograph

Table 29 Drainage Basin Characteristics for Turton Creek Subbasins from 1988 FIS study, determined from regional relationships, USGS quad maps, and previous studies (Reference 10)

Watershed	Subbasin	Drainage Area (mi²)	Length of Longest Watercourse, L (mi)	Length to Centroid, L_{CA} (mi)	Storage (Peaking) Coefficient, C_p	Standard Lag, t_p (hr)	Time of Conc., T_c (hr)
Turton Creek	1 - American Valley	7.47	6.15	3.13	0.20	0.95	2.09
	2 - Newcomb Valley	8.41	5.78	3.03	0.20	0.92	3.26
	3 - Thompson Valley	6.22	2.59	1.52	0.20	0.59	0.98
French Creek	French Creek	14.3	6.06	3.21	0.20	0.95	2.00

The HEC-1 model parameters estimated in the *1988 FIS* report appear to be reasonable when compared to regional information. All parameters were either estimated from other hydrologic modeling studies in the region or were estimated based on the physical features of the watershed. Additionally, the adopted discharge results achieved in the *1988 FIS* document were compared to discharges from Flood Insurance Studies performed for other hydrologically similar streams in Wisconsin to ensure the results achieved were reasonable. The peak discharge computed for each of these streams for the 10% AEP, 2% AEP, and 1% AEP events was plotted against drainage area size and the relative magnitude of peak flows. The adopted discharges for Turton Creek were then graphically compared to the peak flows for these other streams to ensure the model produced reasonable results. The HEC-1 models developed for the *1988 Flood Insurance Study Interim Hydrology Report, City of Arcadia, WI* are suitable to develop a screening level assessment of whether or not the Turton Creek watershed is capable of providing storage to reduce flood risk downstream near the City of Arcadia. Please see the recommendations in Section 14 for a description of what changes would need to be made to the model in order to use the model for design.

12.4 Application of 1988 FIS HEC-1 models to Current Assessment

The HEC-1 models developed as part of the *1988 FIS* report for the gaged French Creek Watershed and ungaged Turton Creek Watershed discussed in the previous section are updated to estimate a hydrograph with the 1% AEP event discharge at Turton Creek defined by the frequency curve in Section 10.2 (Reference 10). The updated models are used to facilitate a screening level analysis to determine the feasibility of nonstructural storage alternative on Turton Creek and these models should not be used for design.

12.4.1 HEC-1 to HEC-HMS Conversion

For this analysis, hydrologic modeling is carried out by converting the original HEC-1 models to HEC Hydrologic Modeling System (HEC-HMS) models version 4.2 (Reference 15). The original HEC-1 model from the *1988 FIS* report is referred to as the “original” model and the HEC-HMS model updated for this study is referred to as the “updated” or “upgraded” model throughout this report.

Initially, The HEC-HMS models of Turton Creek and French Creek were analyzed to verify that the models provide consistent results compared to what is observed in the *1988 FIS* report (Reference 10). The precipitation values and HEC-1 model parameters listed in the *1988 FIS* report match the values in the upgraded HEC-HMS models for French Creek and Turton Creek (Reference 10).

After converting the models from HEC-1 to HEC-HMS, a consistency check of the 1% AEP event simulation is performed using the HEC-HMS models to ensure they produce the same peak discharges that the original HEC-1 models produced (Reference 10). The 1% AEP event consistency check results are located in Table 30. As the table shows, the HEC-HMS models produced nearly the same results as the original HEC-1 models.

Table 30 Consistency check of hydrologic model upgraded from HEC-1 to HEC-HMS version 4.2 (no changes to model parameters or meteorological inputs)

Category	French Creek 1% AEP Model Event Discharge (cfs)	Turton Creek 1% AEP Model Event Discharge (cfs)
1988 Original HEC-1 Model	2,074	2,770
Updated HEC-HMS Model	2,068	2,754
Percent Difference Between Discharges (%)	-0.3%	-0.6%

12.4.2 Model Input Parameter Updates (Drainage Area, Transform, Losses)

Updates are made to the HEC-HMS hydrologic models of French Creek and Turton Creek to reflect information that has been collected since the *1988 FIS* analysis was completed. Updates include applying the Clark transform method instead of the Snyder method, modifying the subbasin areas, updating the TP-40/HYDRO-35 precipitation frequency values with values from National Oceanic and Atmospheric Administration (NOAA) Atlas 14, and tying the updated French Creek and Turton Creek models to their respective frequency curves estimated as part of this this study effort.

The rainfall-runoff transform used in the HEC-1 models was the Snyder method. The original transform parameters were converted from the Snyder's method to the Clark's method to be consistent with current USACE St. Paul District modeling guidelines. Collectively, Snyder's parameters are similar to the Clark's time of concentration (Tc) and watershed storage coefficient (R). The time of concentration is the time required for a wave of water to propagate from the most distant point in the watershed to the outlet of the watershed. The Clark's storage coefficient is a unit hydrograph parameter which represents natural watershed storage in the basin.

The Snyder equations estimate the peak flow as the result of a unit of precipitation and do not define the shape of the hydrograph. Equations were developed to estimate the time base of the hydrograph and the width at 50% of the peak flow using the Snyder method. Since the Snyder method does not compute all ordinates of the hydrograph, HEC-HMS computes equivalent Clark transform parameters to define the shape of the hydrograph. A Clark hydrograph is created in such a way that the Snyder properties are maintained during the computations (Reference 16). Table 31 shows the equivalent Clark's parameters for the given Snyder's parameters used in this modeling effort.

Table 31 Original Snyder's Transform Parameters and Equivalent Clark's Parameters

Original Snyder's Transform Parameters and Equivalent Clark's Parameters						
		Snyder's Parameters			Equivalent Clark's Parameters	
Model	**Subbasin**	**Storage Coefficient, Cp**	**Regional Watershed Coefficient, Ct**	**Standard Lag Time (hr)**	**Time of Concentration, Tc (hr)**	**Storage Coefficient, R (hr)**
French Creek	French Creek	0.20	0.39	0.95	0.8658	4.4194
Turton Creek	American Valley	0.20	0.39	0.95	0.9204	4.3331
Turton Creek	Newcomb Valley	0.20	0.39	0.92	0.8832	4.2096
Turton Creek	Thompson Valley	0.20	0.39	0.59	0.5670	2.5781

The drainage area of the French Creek subbasin in the original HEC-1 model was 14.3 square miles. This differed from the current, USGS published drainage area for the French Creek near Ettrick, WI USGS gage of 14.7 square miles (Reference 23). The drainage area in the updated model was revised to match what is currently published by the USGS. Inputting the updated drainage area caused minor differences in the simulated 1% AEP event peak (1988 value) at French Creek. The computed peak of the 1% AEP runoff event in the HEC-HMS model was 2,046 cfs which is similar to the value in the *1988 FIS* report of 2,074 cfs. The difference is less than 2%.

The original Turton Creek model specified a total drainage area of 22.1 square miles. A review of the watershed delineation from the *1988 FIS* report indicates that the original drainage area delineation terminated upstream of the city of Arcadia (see Figure 16). The drainage area of the Turton Creek near Arcadia upstream of the mouth of the Trempealeau River is 23.6 square miles according to USGS StreamStats tool (Reference 26). In HEC-HMS, the Thompson Valley subbasin area (downstream most subbasin #3, see Figure 16) is increased by 1.5 square miles so that the drainage area of the HEC-HMS model matched what was determined using the USGS StreamStats tool. The updated model now extends from the headwaters of Turton Creek to immediately upstream of the mouth of the Trempealeau River. A table of original and updated drainage areas is shown below in Table 32. The computed peak of the 1% AEP runoff event in the HEC-HMS model was 2,836 cfs which is similar to the value in the *1988 FIS* report of 2,770 cfs. The difference is less than 3%.

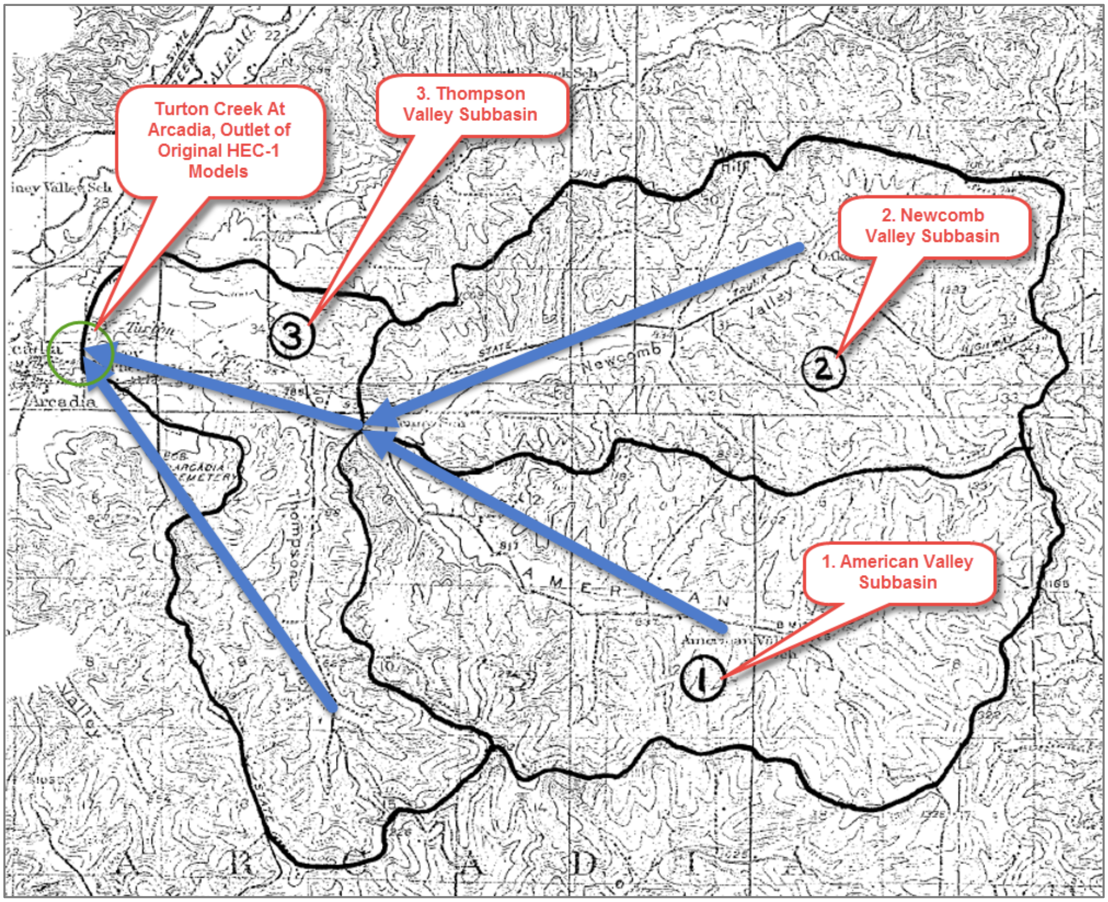


Figure 16 Turton Creek subbasin area delineations in original HEC-1 model (1 = American Valley, 2 = Newcomb Valley, 3 = Thomson Valley, Reference 10)

Table 32 Turton Creek hydrologic model subbasin areas (original and modified)

Turton Creek Subbasin	Original Model Drainage Area (sq. mi.)	Revised Model Drainage Area (sq. mi.)
American Valley	7.47	7.47
Newcomb Valley	8.41	8.41
Thompson Valley	6.22	7.72
TOTAL	22.1	23.6

To assess how results produced using HEC-HMS compare to results produced using the original HEC-1 model, the loss rates for the French Creek HEC-HMS watershed model are adjusted to tie the model results to the flow frequency curve for French Creek determined from the *1988 FIS* report. To generate the 1% annual instantaneous peak listed in the 1988 FIS in HEC-HMS, the constant loss rate did not have to be modified from what was used in HEC-1, but initial losses were decreased slightly to increase the peak runoff from 2,046 cfs to match the 1% annual exceedance probability *1988* FIS discharge of 2,074 cfs. The adjusted initial and constant losses adopted to match the *1988 FIS* 1% AEP peak discharge for the French Creek watershed are shown in Table 33 below. After adjusting the loss parameters, the French Creek model achieved a peak flow of 2,078 cfs which nearly matches the 2,074 cfs produced by the original, 1988 HEC-1 *FIS Study* model. This indicates that the updated model is able to reasonably reproduce the discharge results obtained in the *1988 FIS Study*.

Table 33 Interim Loss Rate parameters for consistency of hydrologic model after updating in HEC-HMS

Interim Loss Rate Parameters Tying the updated HMS model to the 1988 FIS 1% Annual Exceedance Probability Event				
Model	**Initial Loss Rates (1988 HEC-1 Model)**		**Adjusted Loss Rates (Upgraded HEC-HMS model)**	
	Initial Loss (in)	**Constant Rate (in/hr)**	**Initial Loss (in)**	**Constant Rate (in/hr)**
French Creek	1.90	1.10	1.88	1.10

A similar process was undertaken for the Turton HEC-HMS watershed model to ensure it produced results consistent with the *1988 FIS* report. After updating the Turton Creek model, the model estimated a peak runoff from the watershed of 2,836 cfs. Loss rates for the model were adjusted slightly to ensure that the updated HEC-HMS model is able to replicate the original 1988 discharge frequency value for the 1% AEP event at the outlet of Turton Creek.

The value of the 1% AEP discharge defined by the *1988 FIS Study* was 2,770 cfs. The initial and constant loss rates in the Turton Creek model were uniformly increased to produce a peak discharge of 2,771 cfs, which nearly matches the value obtained from the *1988 FIS Study*. The adopted loss parameters are listed in Table 34, below. The results indicate that the model reasonably reproduces the results from the *1988 FIS* report even after updating the model drainage areas and transform.

Table 34 Turton Creek Interim loss rate parameters used to tie the model to the frequency curve via Clark Transform model to 1988 discharge frequency results

Interim Loss Rate Parameters Tying the updated HMS model to the 1988 FIS frequency curve				
Model/Subbasin	**Initial Loss Rates (1988 Model)**		**Adjusted Loss Rates (Upgraded HEC-HMS model)**	
	Initial Loss (in)	**Constant Rate (in/hr)**	**Initial Loss (in)**	**Constant Rate (in/hr)**
Turton Creek/All Subbasins	1.90	1.10	1.92	1.11

12.5 Updated Hypothetical Storm Event

The next step in the process is to tie the updated French Creek HEC-HMS model to the updated discharge frequency information for the French Creek near Ettrick, WI listed in Section 8.3 using current NOAA Atlas 14 precipitation frequency data instead of the precipitation frequency data used for the *1988 FIS* study generated using TP-40/HYDRO-35.

Atlas 14/HYDRO-35/TP-40 precipitation frequency values are derived from statistical analysis of hundreds of gage stations nationwide. Frequency analysis of rain gages is compiled and statistically analyzed to produce isopluvial lines for select exceedance frequencies and storm durations. The new Atlas 14 methodology allows the user to select any geographic location in the United States and the Atlas 14 precipitation frequency data is interpolated for the selected location. The location used to define the Atlas 14 precipitation frequency estimates in this model is shown in Figure 17 and is located at the city of Arcadia, WI.

The NOAA Atlas 14 precipitation frequency values for the region encompassing Turton Creek and French Creek are listed in Table 35 below along with the previous modeling values from the TP-40/HYDRO-35 documents. Note that the Atlas 14 partial precipitation duration depth values are substantially greater than the TP-40/HYDRO-35 values for each partial duration considered in the analysis. This result is consistent with the observed increases in precipitation in the region noted in the Climate Assessment summarized in Section 5 and Appendix B.

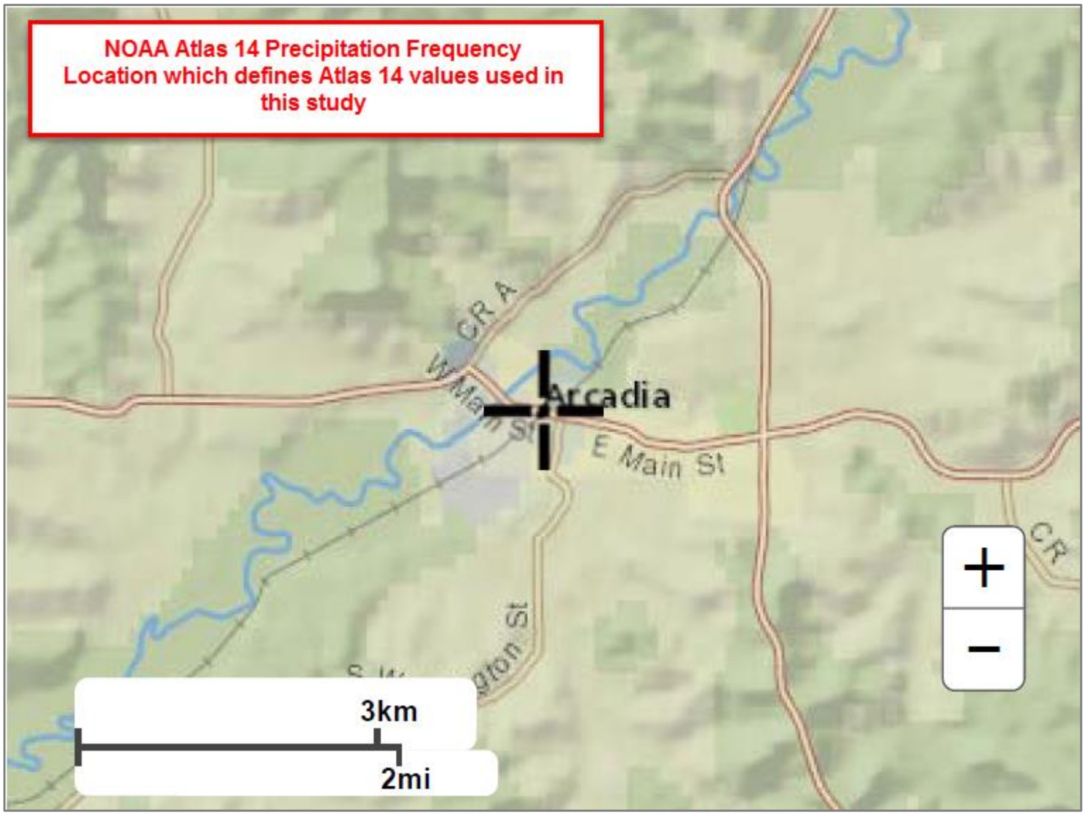


Figure 17 Location used to generate NOAA Atlas 14 precipitation frequency values for this study

Table 35 NOAA Atlas 14 Precipitation Frequency Values and Original Values

Duration	Updated Analysis NOAA Atlas 14 1% Annual Exceedance Probability Storm Event Partial Duration Rainfall Depth (in)	1988 Study TP-40/HYDRO-35 Precipitation Frequency Values Partial Duration Rainfall Depth (in)
5-min	1.02	0.81
15-min	1.82	1.70
60-min	3.38	3.00
2-hr	4.22	3.45
3-hr	4.80	3.70
6-hr	5.73	4.40

Within HEC-HMS version 4.2, the precipitation frequency data from Table 35 is entered using the Frequency Storm method. The frequency storm method is designed to produce a synthetic storm from statistical precipitation data (Reference 16). Each storm has a single exceedance probability which must be selected from the available list of choices. In this case, the 1% exceedance probability storm was selected. Atlas 14 precipitation frequency estimates are generated from partial duration series analysis since multiple, small magnitude storm events can occur in the same year. For this reason, the partial duration storm type is selected in HEC-

HMS. The difference between partial and annual duration output is extremely small for exceedance probabilities of 4% and smaller, therefore, the input data should be the same for the 1% AEP storm event regardless of whether the annual duration series or partial duration series is selected (Reference 16).

A 6-hour storm duration was selected because the minimum storm duration must be greater than the longest time of concentration in the watershed to ensure that all parts of the watershed are contributing to runoff. Generally, the storm duration should be at least two times greater than the longest time of concentration. Based on the layout of the Turton Creek and French Creek models and the time of concentration values listed in Table 31, the longest time of concentration was approximately 2 hours. The longest time of concentration was estimated from the American Valley subbasin within the Turton Creek model plus the travel time in the routing reach of the Turton Creek model to the outlet. A storm duration of 6 hours ensures that all portions of the watershed contribute to the peak flow at the outlet of the watershed.

The intensity duration selected in HEC-HMS specifies the shortest time period of the storm and is typically equal to the time step of the simulation and must be less than the total storm duration. In this analysis, since the shortest computation interval was 5 minutes, an intensity duration of 5 minutes was selected (Reference 16). The storm intensity position in HEC-HMS defines where in the storm the period of peak intensity will occur. Changing the position does not change the total depth of the storm, but does change the temporal distribution of the storm. The original *1988 FIS* model used a default 50% intensity position. This storm position was also adopted for this modeling effort.

Atlas 14 precipitation frequency information is representative of point rainfall data. A depth-area reduction factor must be applied to the Atlas 14 data so that it is representative of a larger storm area. In most cases, the specified storm area should be equal to the watershed drainage area at the point of evaluation (the outlet) to produce the maximum amount of runoff. A storm area equal to the area of each watershed model is applied in HEC-HMS. Depth-area reduction factors are automatically included in HEC-HMS to reduce the point Atlas 14 rainfall values so that they are representative of falling over a larger watershed area.

12.6 Tying the HEC-HMS French Creek Model to the Updated Discharge Frequency Curve

The initial simulation run of the French Creek watershed using the NOAA Atlas 14 precipitation frequency values and the updated model parameters resulted in a peak discharge of 3,303 cfs, which is 13% less than the 1% AEP event discharge of 3,800 cfs defined in this study. The actual value of the 1% AEP event was computed as 3,832 cfs using a drainage area transfer, but this value was rounded to the nearest 100 cfs to be consistent with other curves defined in this study. The 1% AEP event initial and constant loss rates based on the results of the French Creek model are adjusted (decreased) to tie the model to the adopted 1% AEP discharge frequency value. Loss rates were adjusted by multiplying the interim adjusted loss rates in Table 33 by a factor of 0.85. An initial loss value of 1.59 inches and a constant rate of 0.93 inches/hour achieved a simulated peak of 3,841 cfs which reasonably matches the 3,800 cfs value defined for the 1% AEP event at French Creek.

12.7 HEC-HMS Based Estimate of the 1% AEP Event Hydrograph for Turton Creek

The purpose of this modeling effort is to estimate the shape and volume of runoff from the Turton Creek watershed for the 1% AEP runoff event. To estimate the volume and shape of the 1% AEP event hydrograph for Turton Creek, it is necessary for the HEC-HMS model to produce the adopted 1% AEP event peak flow magnitude specified in Section 10.2 (5,300 cfs). This value was generated using drainage area transfer (general relations). Note that the drainage area transfer method resulted in an estimated 1% AEP discharge of 5,288 cfs and that this value was rounded to the nearest 100 cfs to be consistent with the rest of the curves presented in this report.

12.7.1 Verification of the Adopted 1% AEP Peak Magnitude

Initially, the TP-40 and HYDRO-35 precipitation frequency rainfall values in HEC-HMS are updated to the NOAA Atlas 14 precipitation frequency values listed in Table 35. The primary assumption followed in this modeling approach is the same 1% AEP storm event and loss rates will produce the 1% AEP runoff event on the French Creek and Turton Creek watersheds. The loss parameters from the updated French Creek HEC-HMS model, discussed in the previous section are input into the updated Turton Creek model (initial loss of 1.59 inches, constant rate of 0.93 inches/hour for all subbasins).

The model is run using the French Creek loss parameters and the precipitation frequency values in Atlas 14. This results in a modeled peak discharge of 5,637 cfs. Generating the 1% AEP using the HEC-HMS model populated with parameters used to generate the 1% AEP peak in a hydrologically similar watershed is an alternate way of approximating the flow-frequency relationship. The magnitude of the 1% AEP peak discharge approximated using the model is similar to the estimated magnitude of the 1% AEP event specified in Section 10.2 (5,300 cfs) using the drainage area transfer method. There is less than a 7% difference between the model results generated using the hydrologic modeling approach versus the results achieved using the general relations method. This serves to verify the adopted flow-frequency analysis presented in Section 10.2.

12.7.2 Generation of Adopted 1% AEP Hydrograph

In order to exactly match the 1% AEP peak magnitude defined by the adopted Turton Creek flow-frequency curve, the loss rate parameters identified in the previous section (initial loss = 1.59 inches, constant rate = 0.93 inches/hour) are further adjusted.

Loss parameters are increased by a factor of 1.07 (7% increase, Initial Loss = 1.70 inches, Constant Rate = 1.00 inches per hour) to get the peak flow of the HEC-HMS model to match the adopted discharge frequency value of 5,288 cfs for the 1% AEP event. The HEC-HMS model produced a peak discharge estimate of 5,286 cfs which closely matches the adopted frequency curve value of 5,288 cfs. The adopted loss rate values are reasonable when compared to the typical hydraulic conductivity values displayed in Table 26. A graphical depiction of the 1% AEP event hydrograph is shown below in Figure 18. The hydrograph in Figure 18 represents a screening level estimate of the shape and volume of the 1% AEP discharge event hydrograph for Turton Creek.

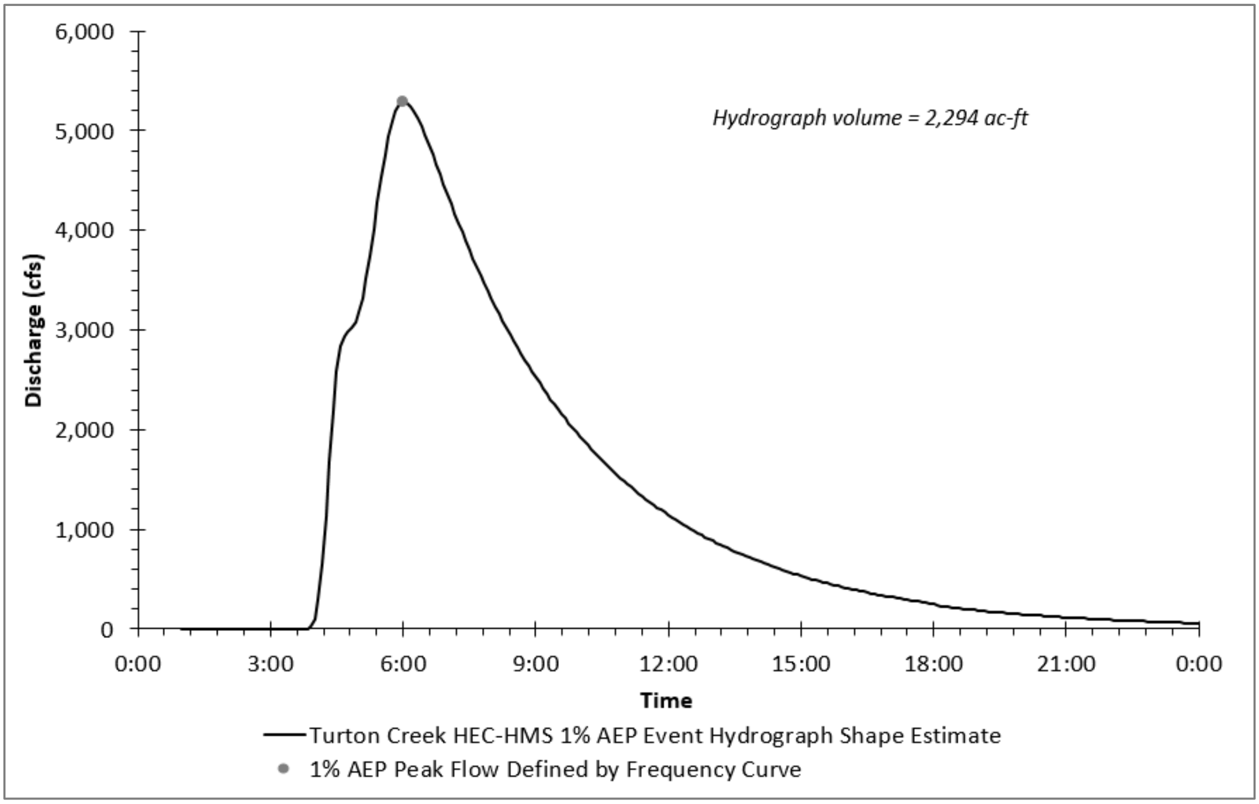


Figure 18 Turton Creek 1% AEP Event Hydrograph Estimate (1% AEP storm, 6-hour duration)

The hydrograph in Figure 18 was used in a hydraulic assessment (see the Hydraulics Appendix of the Arcadia Feasibility Study Report) to determine if nonstructural storage was feasible on Turton Creek. Ultimately, nonstructural storage was deemed infeasible because it only provided a small decrease in the 1% AEP discharge. It is important to recognize the limitations of the models developed as part of this study. Please see Section 14 for recommendations to refine this modeling effort if in the future the models are to be adopted to carry out analysis in support of design or for floodplain management purposes. The results from this HEC-HMS modeling effort should be used for screening only, and should not be used for design.

13 Comparison of Results

Flood frequency analysis estimates play a critical role in the design of flood risk management projects. It is important to compare past results to the results generated in this study to evaluate how flood risk has changed over time and to determine if the results are consistent with previous analyses.

The Trempealeau River at Dodge, WI. The most recent flow frequency curve for Dodge is published in the 2003 *Water-Resources Investigations Report 03-4250: Flood-Frequency Characteristics of Wisconsin Streams* report (Reference 42). The percent difference between the USGS curve and the USACE curve is computed for select exceedance probabilities and is shown in Table 36. The USACE curve is slightly less than the USGS curve for all annual exceedance probabilities compared. The frequency curves are within 10% of each other for critical discharge frequency magnitudes.

A primary source of this difference is that the discharge frequency curve published in the *Water-Resources Investigations Report* did not include the historic event information from 1876 in the analysis (Reference 42). The analysis presented in this study incorporates the 1876 historic event information. Additionally, this study used the methods outlined in *Bulletin 17C* whereas the previous study used methods outlined in *Bulletin 17B*. The period of record used in this study also is longer than the period of record used in the previous study. The *Water-Resources Investigations Report* used regional skew values defined from a skew map in *Bulletin 17B* which is no longer recommended as a source for skew information. This study uses a regional skew values from the *St. Paul District* skew study which utilized regional information to define a recommended regional skew value and is more appropriate for this analysis.

Table 37 shows a comparison between the frequency curves generated for the 2003 *Water-Resources Investigations Report* and the curve generated for this analysis, produced without using 1876 historic event information. The results in Table 37 show that when the historic event information is omitted, the critical, 1% annual exceedance probability flows are equivalent for both analyses.

It is recommended that the discharge frequency curve from Section 8.1 of this feasibility study be adopted because it utilizes historic event information, has a longer period of record, and utilizes the discharge frequency methods outlined in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency*. Guidance in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* indicate that it is best practice to extend the period of record using historic information if historic information is available (Reference 29).

Table 36 Comparison of Results, Trempealeau River at Dodge, WI (Adopted)

Comparison of Results: Trempealeau River at Dodge, WI				
Return Period (yr)	Annual Exceedance Probability (%)	USGS Flood-Frequency Characteristics of Wisconsin Streams Report Published Flow (cfs) 1914-1919, 1935-2000	USACE Feasibility Study - With 1876 Historic Event Information Flow (cfs) 1914-1919, 1935-2015	Percent Difference (%)
100	1	15,700	15,200	-3.2%
50	2	13,500	12,800	-5.2%
10	10	8,610	7,900	-8.2%

Table 37 Comparison of Results, Trempealeau River at Dodge, WI (Sensitivity without historic information)

Comparison of Results: Trempealeau River at Dodge, WI - Sensitivity Analysis - Without 1876 Event				
Return Period (yr)	Annual Exceedance Probability (%)	USGS Flood-Frequency Characteristics of Wisconsin Streams Report Published Flow (cfs) 1914-1919, 1935-2000	USACE Feasibility Study - Without 1876 Historic Event Information Flow (cfs) 1914-1919, 1935-2015	Percent Difference (%)
100	1	15,700	15,700	0.0%
50	2	13,500	13,200	-2.2%
10	10	8,610	8,000	-7.1%

Trempealeau River at Arcadia, WI. A recently published frequency curve for the Trempealeau River at Arcadia is available from the *2011 Flood Insurance Study (FIS): Trempealeau County, Wisconsin* (Reference 22). The *2011 FIS* adopted the results of the *1988 FIS* report. The percent differences between the FIS frequency curve and the USACE frequency curve are computed for select exceedance probabilities and are shown in Table 38 below.

As Table 38 shows, the USACE curve is greater than the curve presented in the *2011 Flood Insurance Study: Trempealeau County, Wisconsin*. It is recommended that the curve developed as part of this study be adopted because it is more conservative from a flood risk management perspective, it uses current frequency analysis guidance, and it incorporates more observed data.

The *2011 FIS* utilized *Bulletin 17B* methods to develop the frequency curve and the two station comparison method to adjust the frequency curve at Arcadia, WI based on the data present at the Trempealeau River at Dodge, WI. The two station comparison method is no longer recommended as the default record extension technique. The MOVE.3 approach is now recommended by *Bulletin 17C*. This study applies a MOVE.3 record extension technique instead of a two-station comparison and uses the guidelines presented in *Bulletin 17C*. The *2011 FIS* and the *1988 FIS* only used a period of record from 1961-1977. This study incorporated all available information through water year 2015. The expanded period of record contributes to the difference between the two frequency curves.

Table 38 Comparison of Results, Trempealeau River at Arcadia, WI

Comparison of Results: Trempealeau River at Arcadia, WI				
Return Period (yr)	Annual Exceedance Probability (%)	2011 Trempealeau County FIS Flow (cfs) 1961-1977	USACE Feasibility Study Flow (cfs) 1914-1919, 1935-2015	Percent Difference (%)
500	0.2	18,980	21,300	12.2%
100	1	14,430	15,500	7.4%
50	2	12,600	13,200	4.8%
10	10	8,350	8,300	-0.6%

Trempealeau River above Turton Creek. The Trempealeau River above Turton Creek is an ungaged location. As part of this study, the frequency curve above Turton Creek is derived using a drainage area transfer method similar to the method used in the *2011 Flood Insurance Study (FIS): Trempealeau County, Wisconsin* (Reference 22). This is why the percent differences between the 2011 FIS frequency curve and the curve generated as part of this study are nearly identical to the percent differences for the Trempealeau River at Arcadia shown in Table 38. It is recommended that the frequency curve for the Trempealeau River above Turton Creek developed for this USACE study be adopted because it utilizes the latest guidance for developing frequency curves and it is more conservative from a flood risk management perspective. The frequency curve for this analysis also incorporates all data available at the time of this study. The comparison of the 2011 FIS frequency curve and the curve generated for this study is shown in Table 39.

Table 39 Comparison of Results, Trempealeau River above Turton Creek, WI

Comparison of Results: Trempealeau River above Turton Creek				
Return Period (yr)	Annual Exceedance Probability (%)	2011 Trempealeau County FIS Flow (cfs)	USACE Feasibility Study Flow (cfs)	Percent Difference (%)
500	0.2	18,430	20,700	12.3%
100	1	14,010	15,000	7.1%
50	2	12,190	12,800	5.0%
10	10	8,110	8,100	-0.1%

French Creek near Ettrick, WI. The French Creek near Ettrick, WI flow-frequency curve was last updated as part of the *1988 Flood Insurance Study (FIS) Interim Hydrology Report: City of Arcadia, WI* study. A comparison plot in Appendix G shows the differences between the discharge frequency curves developed for the French Creek near Ettrick, WI as part of the *1988 FIS* and this analysis. A comparison of the 1988 frequency curve and the updated USACE frequency curve for the French Creek near Ettrick, WI is also shown in Table 40.

The French Creek near Ettrick updated USACE curve is significantly greater than the 1988 curve. This is likely because the period of record used to generate the frequency curve for this study is longer than it was for the curve generated in 1988. The period of record used in the *1988 FIS* study is 1960-1983 and the period of record used in this analysis is 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015. Additionally, the plot in Figure 19 shows that many of the large magnitude floods in the French Creek watershed occurred in the latter portion of the period of record, after the *1988 FIS* study was completed. This likely explains why the frequency curve increased so much relative to the previously adopted curve.

Table 40 Comparison of Flow-Frequency Curve Results, French Creek near Ettrick, WI – Adopted vs. 1988 FIS Study Values

Comparison of Results: French Creek near Ettrick, WI - Adopted vs. 1988 FIS Results				
Return Period (yr)	**Annual Exceedance Probability (%)**	**1988 FIS City of Arcadia, WI Flow (cfs) 1960-1983**	**USACE Feasibility Study Flow (cfs) 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015**	**Percent Difference (%)**
500	0.2	3,130	5,100	62.9%
100	1	2,080	3,800	82.7%
50	2	1,690	3,200	89.3%
10	10	939	1,800	91.7%

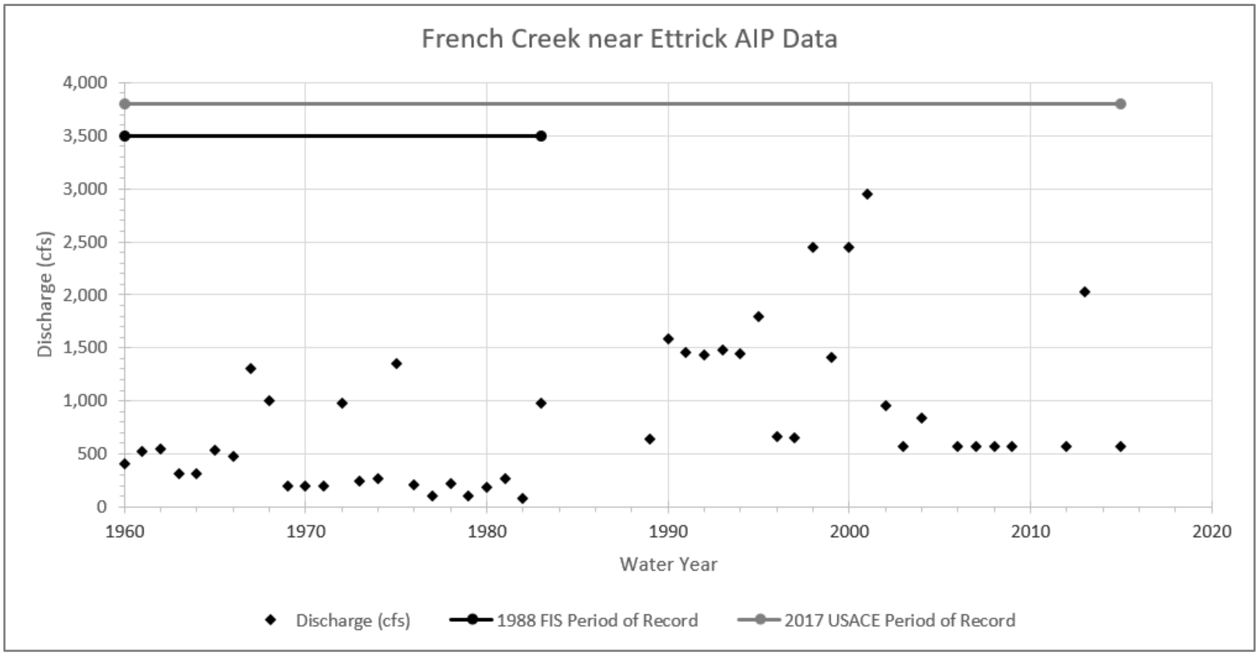


Figure 19 French Creek near Ettrick, WI Observed Annual Peak Flow Data

The benefit of analyzing the French Creek watershed is that it allowed for the characterization of flood risk on Turton Creek and Myers Valley Creek using a drainage area transfer. Another method for determining the frequency curve for small, rural, ungaged watersheds is to use USGS regression equations. The regression equations discussed in Sections 9.1 and 9.2 were used to estimate the frequency curve for French Creek near Ettrick, WI. The results of the regression analysis are compared to the adopted frequency curve generated using observed data and the guidelines specified in *Bulletin 17C* are shown in Table 41 below. The regression equations appear to substantially underestimate flood risk when compared to the adopted curve which is developed from observed data. A plot of the Adopted French Creek near Ettrick, WI frequency curve compared to the 2003 USGS regression equations and 2017 regression equations curves is shown in Appendix G and illustrates the information presented in Table 41 and Table 42 below.

Table 41 and Table 42 show that the 2017 regression frequency curve is greater than the 2003 regression equation frequency curve, which supports the fact that the French Creek discharge frequency curve, the Turton Creek discharge frequency curve and they Myers Creek frequency curve should be increased, from what was originally generated in support of the 1988 FIS. The significant differences between the regression equations based curves at French Creek and the curve generated using observed data undermines the validity of results generated using regression equations and supports using a general relations based method instead.

Table 41 Comparison of Flow-Frequency Curve Results, French Creek near Ettrick, WI - Adopted vs. 2003 USGS Regression Values

Comparison of Results: French Creek near Ettrick, WI - Adopted vs. USGS Regression Results				
Return Period (yr)	Annual Exceedance Probability (%)	2003 USGS Regression Equations Flow (cfs)	USACE Feasibility Study Flow (cfs) 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015	Percent Difference (%)
100	1	2,000	3,800	90.0%
50	2	1,700	3,200	88.2%
10	10	1,000	1,800	80.0%

Table 42 Comparison of Flow-Frequency Curve Results, French Creek near Ettrick, WI - Adopted vs. 2017 USGS Regression Values

Comparison of Results: French Creek near Ettrick, WI - Adopted vs. USGS Regression Results				
Return Period (yr)	Annual Exceedance Probability (%)	2017 USGS Regression Equations Flow (cfs)	USACE Feasibility Study Flow (cfs) 1960-1983, 1989-2004, 2006-2009, 2012-2013, and 2015	Percent Difference (%)
100	1	3,200	3,800	18.8%
50	2	2,500	3,200	28.0%
10	10	1,200	1,800	50.0%

Turton Creek at Arcadia, WI. Turton Creek is an ungaged subbasin within the Trempealeau River Watershed. The most recent published frequency curve for the Turton Creek at Arcadia is listed in the *2011 Flood Insurance Study (FIS): Trempealeau County, Wisconsin* (Reference 22) and was directly adopted from the *1988 Flood Insurance Study Interim Hydrology Report: City of Arcadia, WI* (Reference 10). The published FIS curve is compared to the curve developed for this study. The percent difference for select exceedance probabilities is shown in Table 43 below. The frequency curve developed as part of this study for Turton Creek at Arcadia is significantly greater than the curve generated as part of the *1988 FIS* and carried forward within the *2011 FIS*. The Turton Creek curve is based on a drainage area transfer with the nearby French Creek watershed, therefore, the increases in this frequency curve are likely due to the same factors that increased the French Creek near Ettrick frequency curve such as a longer period of record and the fact that multiple, large magnitude flood events occurred in the later portion of the period of record.

Table 43 Comparison of Results, Turton Creek at Arcadia, WI – FIS Flows vs. Current USACE Flows

Comparison of Results: Turton Creek at Arcadia, WI – Adopted vs. FIS Flows				
Return Period (yr)	**Annual Exceedance Probability (%)**	**2011 Trempealeau County FIS Flow (cfs)**	**USACE Feasibility Study Flow (cfs)**	**Percent Difference (%)**
100	1	2,770	5,300	91.3%
50	2	2,200	4,500	104.5%
10	10	1,190	2,500	110.1%

The adopted curve recommended by this study is also compared to a frequency curve estimated from the USGS regression equations discussed in Sections 9.1 and 9.2. The adopted curve is significantly greater than the curve estimated from the regression equations. Table 44 and Table 45 show the adopted USACE frequency curve for Turton Creek compared to the 2003 and 2017 regression equation curves, respectively. To explain this large increase in the frequency curve at Turton Creek, additional comparison plots are included in Appendix G. The plot in Appendix G, page G-1 shows the adopted curves for Turton Creek at Arcadia, WI and the French Creek near Ettrick, WI.

Table 44 Comparison of Results, Turton Creek at Arcadia, WI – 2003 Regression Flows vs. Current USACE Flows

Comparison of Results: Turton Creek at Arcadia, WI – Adopted vs USGS Regression Flows				
Return Period (yr)	**Annual Exceedance Probability (%)**	**2003 USGS Regression Equations Flow (cfs)**	**USACE Feasibility Study Flow (cfs)**	**Percent Difference (%)**
100	1	2,800	5,300	89.3%
50	2	2,300	4,500	95.7%
10	10	1,400	2,500	78.6%

Table 45 Comparison of Results, Turton Creek at Arcadia, WI – 2017 Regression Flows vs. Current USACE Flows

Comparison of Results: Turton Creek at Arcadia, WI – Adopted vs USGS Regression Flows				
Return Period (yr)	**Annual Exceedance Probability (%)**	**2017 USGS Regression Equations Flow (cfs)**	**USACE Feasibility Study Flow (cfs)**	**Percent Difference (%)**
100	1	3,640	5,300	45.6%
50	2	2,910	4,500	54.6%
10	10	1,590	2,500	57.2%

The updated, adopted frequency curve for Turton Creek also agrees with results generated for the 1% AEP event using the HEC-HMS model. When model parameters used to generate the gage based 1% event in neighboring, French Creek are applied to model the 1% event for Turton Creek the resulting magnitude is 5,637 cfs. This value is much closer to the 1% event magnitude adopted as part of this study (5,300 cfs) than the 1% event magnitudes defined by the 2003 and 2017 USGS regression equations (2,800 cfs or 3,600 cfs, respectively) or the 1988 analysis adopted for the 2011 FIS (2,800 cfs). Additionally, a large rainfall driven summer flood event occurred on Turton Creek in July 2017. Turton Creek is ungaged, but high water marks were surveyed for the July 2017 event to aid in developing an estimate of how large the event was. A discharge associated with the July 2017 event was estimated by using the calibrated Hydrologic Engineering Center River Analysis System (HEC-RAS) model developed for this study and the surveyed high water mark information upstream of the Oak Street and Railroad Bridges. Based on this estimate, it was determined that the discharge was approximately equal to 6,300 cfs which is approximately 0.5% AEP flood event defined in Table 19. This is further evidence to support the idea that flood risk has increased on Turton Creek since the last frequency analysis was completed.

Myers Valley Creek at Arcadia, WI. There is limited information available for Myers Valley Creek at Arcadia. The *2014 Flood Study* performed an analysis to define the 1% exceedance (Reference 5, Section 10.3.1). The 1% AEP flow value from the USACE study is compared to the value from the *2014 Flood Study* and the percent different between these two values is shown in Table 46 below. Table 46 illustrates that the 1% annual exceedance probability discharge increased 98% relative to the previously adopted discharge. This increase in similar in magnitude to the 82% increase observed at the French Creek near Ettrick frequency curve shown in Table 40.

Table 46 Comparison of Results, Myers Valley Creek at Arcadia

Comparison of Results: Myers Valley Creek				
Return Period (yr)	Annual Exceedance Probability (%)	**2014 Flood Study* Hydrologic Analysis Flow (cfs)	USACE Feasibility Study Flow General Relations Based Analysis Flow (cfs)	Percent Difference (%)
100	1	1,100	2,180	98.2%

**The 2014 Flood Study: Myers Valley Creek, Arcadia, Wisconsin only estimated the 100-yr event (Reference 4)*

A USGS regression study published in 2017 (Reference 43) provides more insight into how flood risk has changed in the study area based on regional information. Frequency curves derived using the 2017 regression equations were generally higher than frequency curves derived using the 2003 regression equations for the sites considered in this analysis. An example of this is shown in Appendix G, page G-2 for the French Creek near Ettrick USGS gage.

14 Recommendations

The hydrologic analysis performed in this study to define the discharge frequency relationships for rivers and tributaries near the city of Arcadia follows all applicable Corps of Engineers guidance as well as the latest techniques for discharge frequency analysis outlined in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29). During the course of this study, recommendations were developed which could provide additional information to aid in the assessment of peak streamflow frequency in the Trempealeau River Basin.

Recommendations for future study are described below:

A. **Complete a Regional Skew Study**. The regional skew information used in this report comes from the *1985 St. Paul District Skew Study* (Reference 21). In the time since the District Skew Study was completed, more than 30 years of additional flow data has become available. It is recommended that a regional skew study be conducted using the Bayesian Weighted Least Squares (B-WLS) or Bayesian Generalized Least Squares (B-GLS) methods. The results from the regional skew study should be used to update the flow frequency curves estimated in this report.

B. **Unsteady HEC-RAS Modeling.** It is recommended that an Unsteady Hydraulic Model be developed to better understand Natural Floodplain Storage in the Basin. There appears to be significant floodplain storage between the Trempealeau River at Arcadia, WI (upstream) and the Trempealeau River at Dodge, WI (downstream). Under certain circumstances, the peak flows at the upstream gage (Arcadia) can be greater than the peak flows at the downstream gage (Dodge). It is recommended that an unsteady hydraulic model be developed to study how flows are stored and attenuated as they travel downstream. Results from this type of analysis could be used in conjunction with the MOVE.3 estimated flows for the Arcadia USGS gage to improve the estimated flow values at Arcadia for years with missing information.

C. **Detailed Hydrologic Modeling.** The results presented in this study are targeted at supporting a feasibility level design and are consistent with the analysis approach completed for previous hydrologic studies of the area. Development of detailed hydrologic models is beyond the scope of work for this feasibility level analysis. It is recommended that prior to design and prior to any updates to floodplain mapping, a detailed hydrologic model be developed for Turton Creek, Myers Valley Creek, and the mainstem of the Trempealeau River and as well as for other nearby gaged watersheds.

   Developing these models will better inform the frequency curve at ungaged locations of interest for events less frequent than the 10% AEP event. It is especially important to develop hydrologic models for the Turton Creek and Myers Valley Creek watersheds because evidence indicates that the regression equations underestimate flood risk in this region. Consequently, a drainage area transfer method was used to estimate flood frequency curves for ungaged sites included in this analysis to provide a conservative estimate of flood risk. A detailed hydrologic model could help explain and resolve differences between the USGS regression equation approach and the drainage area transfer approach.

USACE currently has research and development efforts to improve snowmelt modeling and rain on snow modeling using hydrologic models. If this recommendation is pursued, the local sponsor and design team could consider using this basin as a pilot study for snowmelt modeling.

D. **Detailed Assessment of Nonstructural Storage Alternatives.** As noted in Section 11, previously adopted FIS models of French Creek and Turton Creek were used to estimate a 1% AEP event runoff hydrograph for Turton Creek to assess nonstructural storage alternatives in the watershed. The estimate of the 1% AEP hydrograph from Turton Creek presented in this analysis is reasonable and uses the best available regional information; however, if nonstructural storage alternatives on Turton Creek are preferable and real estate is obtainable it is recommended that detailed hydrologic modeling be performed. The modeling in this analysis for nonstructural storage is limited and should only be used as a tool to determine if nonstructural storage is a feasible alternative.

E. **Streamflow Gage Installation**. Due to the important role that many of the tributaries to the Trempealeau have during basin wide flood events, it would be advisable to install stream gages on ungaged creeks near Arcadia, WI. The frequency curves developed for both Turton Creek and Myers Valley Creek rely upon the drainage area transfer method and the USGS regression equations, respectively. These are both approximate methods for developing discharge frequency curves. The best approach for developing frequency curves is to statistically analyze the annual instantaneous flood peaks in accordance with the methods presented in *Bulletin 17C: Guidelines for Determining Flood Flow Frequency* (Reference 29). Statistical analysis allows for an accurate characterization of flood risk and a more reliable way to estimate uncertainty in the frequency curve.

The best option would be to install continuous recording gages which have the ability to capture flood event hydrographs. In the absence of continuous recording gages, a stage recording gage on both Myers Valley Creek and Turton Creek would still provide valuable annual peak flood information over time. Installing gage sites would allow a more accurate assessment of flood risk to be conducted at these sites.

F. **Update Discharge Frequency Curves**. Hydrology changes with respect to time. It is recommended the frequency curves presented in this study be updated during the design phase to incorporate additional annual peak flood data that was not available at the time this analysis was performed to provide the best estimate of flood risk possible.

G. **Sensitivity Testing With Different Equivalent Record Lengths**: Confidence limits and uncertainty for frequency curves of ungaged watersheds studied in this effort were estimated using the guidelines found in EM 1110-2-1619 (Reference 7). The equivalent record length estimated for ungaged frequency curves effects the confidence limits of the frequency curve. Using a longer equivalent period of record results in a narrower confidence interval (less uncertainty) and using a shorter period of record results in a larger confidence interval (more uncertainty). It is recommended that sensitivity analysis be performed if the benefit-cost ratio is close to the minimum value needed to justify the project to ensure the project is warranted. For sufficiently high benefit-cost ratios, the equivalent record length has less weight on the overall decisions to design and construct a project because damages would be increased for both the with project and without project alternatives, which would have little influence on the overall benefit-cost ratio.

H. **Hydrologic Modeling to Improve Coincident Frequency Analysis**: A detailed coincidental frequency analysis which uses the law of total probability to estimate coincident flow frequency curves cannot be performed for this study because no time series data for flow or stage exists for the Turton Creek watershed. Additional study to further investigate coincidental flows is beyond the scope and budget allotted for this feasibility level analysis. It is recommended that detailed hydrologic models be developed to perform analysis that can better inform the coincidental frequency analysis if the project proceeds to the design phase.

The hydrologic models used in this study (described in Section 12) are coarse models which cannot provide the level of detail needed to bolster the coincident frequency analysis. A detailed hydrologic model using the HEC-HMS software should be developed and calibrated to available gage data in the watershed using 2-3 calibration events and 1-2 verification events, as well as a continuous simulation period. The calibrated model could provide estimates of the peak discharge and hydrograph for ungaged watersheds like Turton Creek.

The model could be used to perform event based simulations or continuous simulations which would allow a statistical distribution for Turton Creek to be estimated from the simulated results provided by the model. The results from the simulation could be used to establish correlation between simulated peak flows on Turton Creek and the main stem of the Trempealeau River. If correlation is established, correlated random sampling should be performed in a Monte Carlo simulation. The results from the Monte Carlo simulation can then be used to improve the coincident frequency analyses presented in this report.

I. **Study sediment transport, scour, and aggradation along the Trempealeau River**: Section 8.2 found that peak streamflow for the Trempealeau River at Dodge, WI showed a statistically significant decrease over time and the peak stage had a statistically significant increase. This suggests that for smaller flood flows, higher stages are present along the Trempealeau River. Section 8.2 also noted that there are issues with periodic scour and aggradation for the Trempealeau River at Arcadia, WI. This results in uncertainty in the rating curve and suggests that the rating curve has changed over time. It is recommended that a sediment transport analysis be performed to better understand how sediment transport will affect the flood stage in the future. It is also recommended that the local sponsor monitor the river bed depth along the project area to understand how increases in river bed elevation could impact their level of protection from flood events.

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CAP Section 205 Trempealeau River Flood Risk Reduction Study

Arcadia, WI

Qualitative Assessment of Climate Change

June 2020

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Attachments

Plate B-1: Trempealeau River Watershed Climate Assessment Reference Map

1 Purpose

United States Army Corps of Engineers (USACE) projects, programs, missions, and operations have generally proven to be robust enough to accommodate the range of natural climate variability over their operating life spans. Recent scientific evidence shows that in some places and for some impacts relevant to USACE operations, climate change has shifted 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 a fixed range of natural variability, as captured in the historic hydrologic record, may no longer be appropriate for long-term projections of risk to select USACE business lines such as Flood Risk Reduction.

Long-term, natural fluctuations in climate or anthropogenic driven climate change have the ability to alter regional precipitation, temperature, hydrology patterns, and ecosystem functions. The purpose of this analysis is to provide a qualitative assessment to determine if climate change is relevant to Flood Risk Reduction projects in the Trempealeau River Watershed. This study also seeks to provide qualitative information which can be used to determine how hydrologic variables have responded to climate change in the past and may respond to climate change in the future. The results of this qualitative assessment can be used to increase the resilience of existing and proposed USACE projects in the watershed.

2 Background

Climate change impacts on the hydrology of the Trempealeau River Basin are considered in accordance with the USACE Engineering Construction Bulletin (ECB) 2018-14, *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects* (USACE, 2018), as well as USACE Engineering Technical Letter (ETL) 1100-2-3, *Guidance for Detection of Nonstationarities in Annual Maximum Discharges* (Friedman et al., 2016). 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 particular USACE hydrologic analysis being performed. As indicated in Figure 1, qualitative analysis includes consideration of both past (observed) changes, as well as potential, future (projected) changes to applicable hydrologic inputs. This analysis uses a weight of evidence based approach to make a qualitative assessment of climate change impacts to Flood Risk Reduction projects in the Trempealeau River Basin.

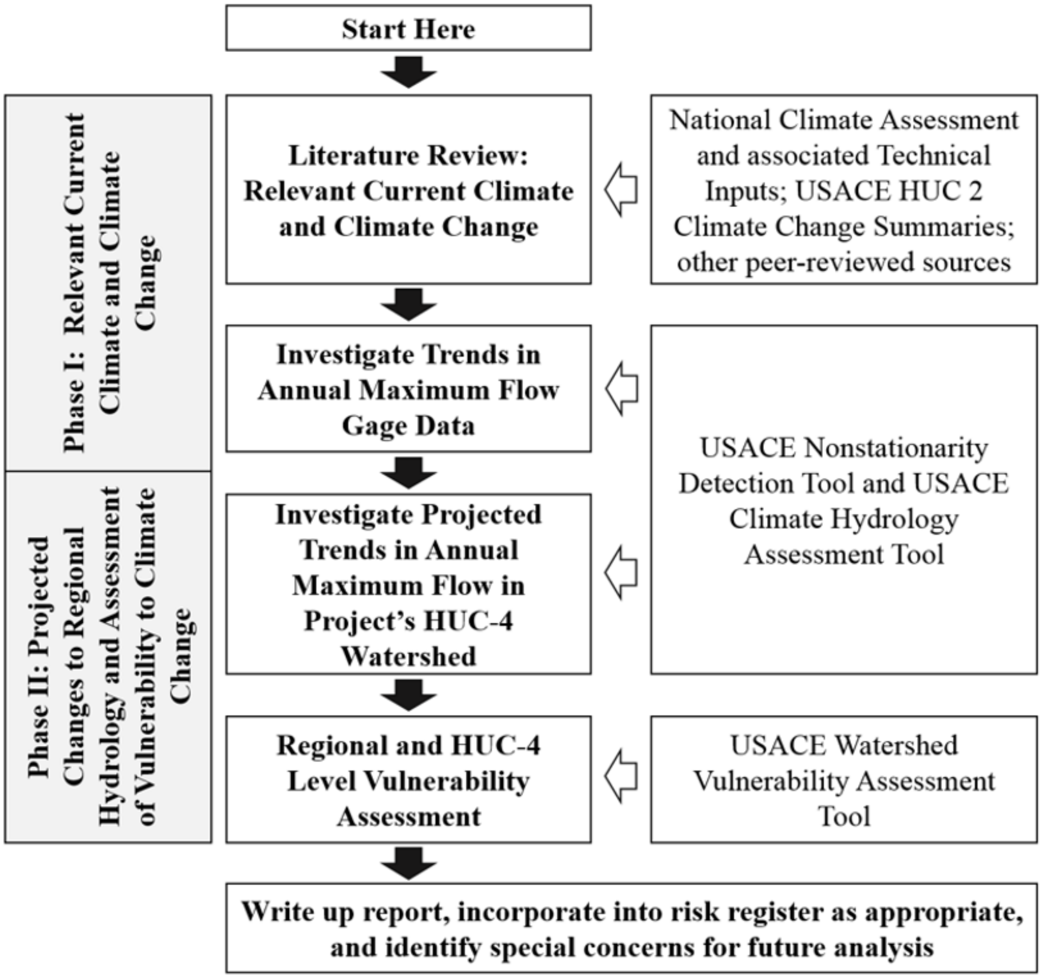


Figure 1 Flow chart for performing change point assessment (USACE, 2016)

3 Literature Review

A literature review is included to summarize peer reviewed science regarding both natural and human driven climate trends in the region which encompasses the Trempealeau River. A meta-study of regional, peer reviewed climate literature was compiled by the Corps of Engineers for the Upper Mississippi River Region-Hydrologic Unit Code, HUC07, and is referenced as the primary source of information in this review (USACE, 2015). The Trempealeau River watershed falls within the Water Resources Region 07 (HUC07) shown in Figure 2. Collectively, the meta-study identifies observed changes in hydro-climatic variables and assesses projected future changes in hydro-climatic variables. The literature review focuses on identifying trends in observed data and projections and does not attempt to identify the causes of climate change (e.g. natural or anthropogenic sources). Additional resources include the Third National Climate Assessment (Melillo et al. 2014). Where available, local scale climate information not included in the USACE literature synthesis is also included in this literature review.

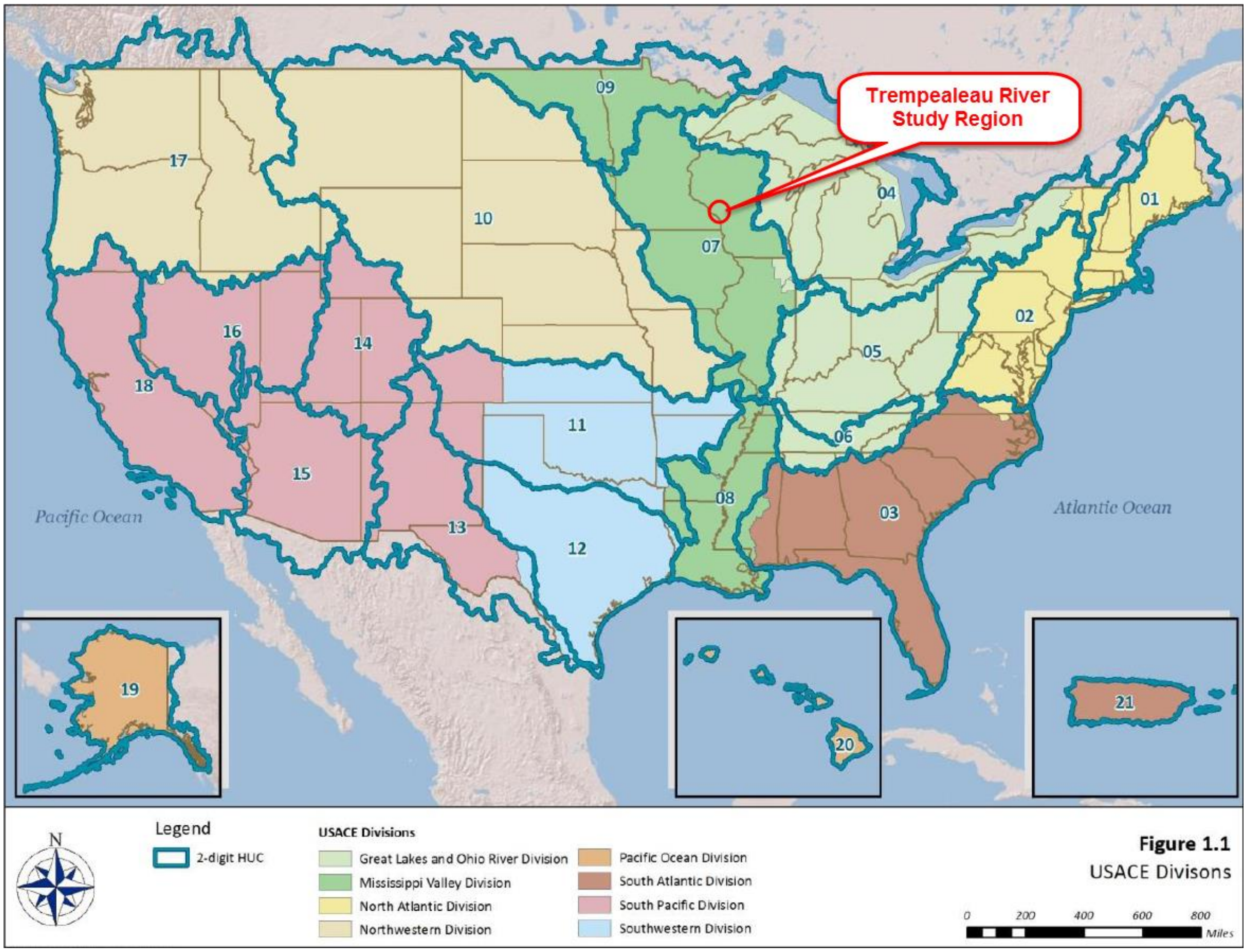


Figure 2 2-digit Water Resources Regional Boundaries (HUC02 watersheds) for the Continental United States, Alaska, Hawaii, and Puerto Rico (USACE, 2015)

3.1 Precipitation

3.1.1 Observed Precipitation

3.1.1.1 Third National Climate Assessment (Melillo et al., 2014)

The third National Climate Assessment (3rd NCA) considers the science of climate change and impacts of climate change within the Continental United States (CONUS) and at a regional scale (Melillo et al., 2014). On a national scale, the 3rd NCA concluded that average annual precipitation in the United States increased by approximately 5% since 1900. Average annual precipitation in the Midwest region (the region encompassing the Trempealeau River basin) increased by 9% since 1991 (Melillo et al., 2014). Significant trends in precipitation are detected, but the fraction of these trends that are attributed to climate change is difficult to quantify due to the large, natural variability of storm events in the region (Melillo et al., 2014).

According to the 3rd NCA, increases in the amount of precipitation are primarily driven by intensification of the heaviest rainfall events (Melillo et al., 2014). Heavy, extreme rainfall events are more frequent now than in the past, particularly in the Midwest and Northeast United States during summer and fall months (Melillo et al., 2014). The amount of rain falling in heavy precipitation events in the Midwest is 30% greater for the most recent period between 1961 and 2012, than it was relative to a 1901 to 1960 average. Frequency of heavy precipitation events in the Midwest has increased nearly 37% between 1958 and 2012 (Melillo et al., 2014).

3.1.1.2 USACE Literature Synthesis (USACE, 2015)

Numerous studies identify increasing trends in the total amount of annual precipitation for the region encompassing the Trempealeau River Watershed (USACE, 2015). Palecki et al. (2005) studied historic precipitation data from across the continental United States from 1972-2002 using National Climatic Data Center (NCDC) 15-minute rainfall data, and found statistically significant increases in winter storm total precipitation. This finding is supported by a similar study completed by Grundstein (2009) which indicates that there is a statistically significant, positive linear trend for annual precipitation and soil moisture index for multiple sites within the Upper Mississippi River region (HUC07) using data from 1895-2006. Grundstein (2009) examined the effect of observed long-term temperature and precipitation trends on soil moisture using a moisture index which is a function of precipitation supply and evapotranspiration (ET) demand. Grundstein (2009) noted that the observed trends in the moisture index are primarily related to variability in precipitation but approximately 20% of the variation is due to changes in climatic demand such as potential evapotranspiration. The positive trends in potential evapotranspiration (reflecting higher average air temperatures) do not lead to a drier climate because the positive precipitation trend dominates the overall moisture index.

Another study by Wang et al. (2009) examines climate trends across the continental United States using gridded, mean monthly climate data for 1950-2000. This study identifies positive trends in annual precipitation for the Upper Mississippi River region (HUC07), primarily in the summer and fall seasons, but notes decreasing trends during winter and spring months. A finding of decreasing precipitation during the winter month contradicts the Palecki et al. (2005) study. The Palecki et al. (2005) study and the Wang et al. (2009) studies both used observed precipitation; however, the types of data and period of record was different for each study.

A study by McRoberts and Nielsen-Gammon (2011) performed trend analysis of homogeneous precipitation datasets from 1895-2009 across the United States for multiple sub-basins and found positive, linear trends in annual cumulative precipitation for the Upper Mississippi River region (HUC07; illustrated in Figure 3).

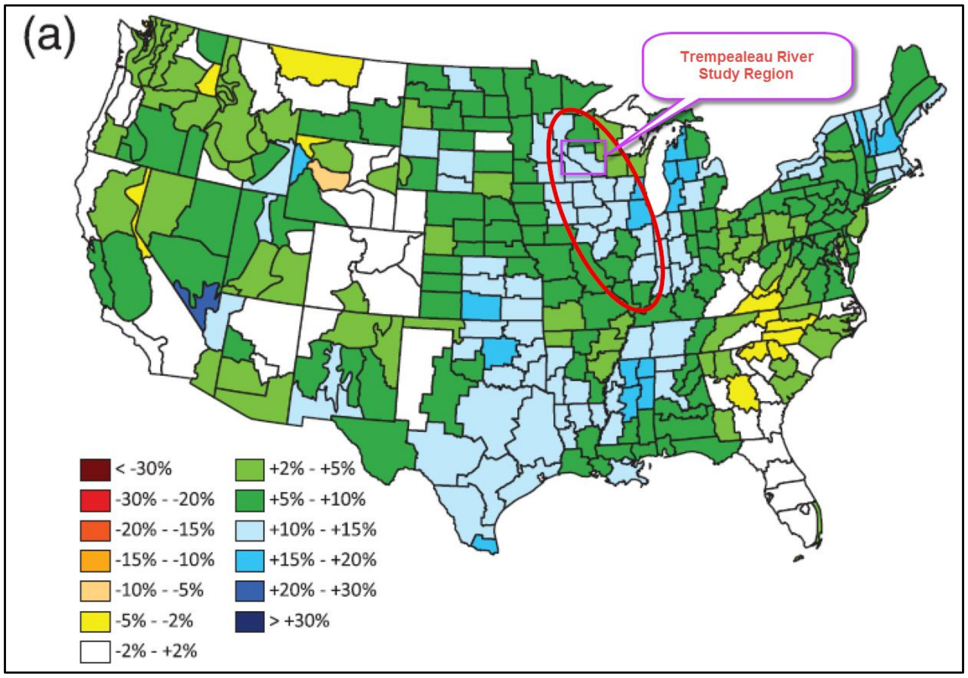


Figure 3 Linear trends in annual precipitation 1895-2009, percent change per century (McRoberts and Nielsen-Gammon, 2011)

McRoberts and Nielsen-Gammon (2011) estimate a 10% to 15% increase in annual cumulative precipitation occurred per century for the Upper Mississippi River region (HUC07). A statistical analysis of 20th century annual cumulative precipitation and the number of precipitation days per year scattered across 643 stations in the continental United States by Pryor et al. (2009) shows a statistically significant, positive trend in both variables (Pryor et al., 2009).

3.1.1.3 Additional Climate Information

The Wisconsin Initiative on Climate Change Impacts (WICCI, 2017) applied a statistical analysis of precipitation data for sites across Wisconsin to estimate changes in precipitation using data collected from 1950-2006. Increases in precipitation are noted throughout the state, particularly in the west-central region encompassing the Trempealeau Watershed. The statewide increase in average annual precipitation is 3.1 inches. This increase primarily occurred in southern and western Wisconsin. Figure 4 shows how annual average precipitation has changed (in inches) throughout the state of Wisconsin for the time period 1950-2006.

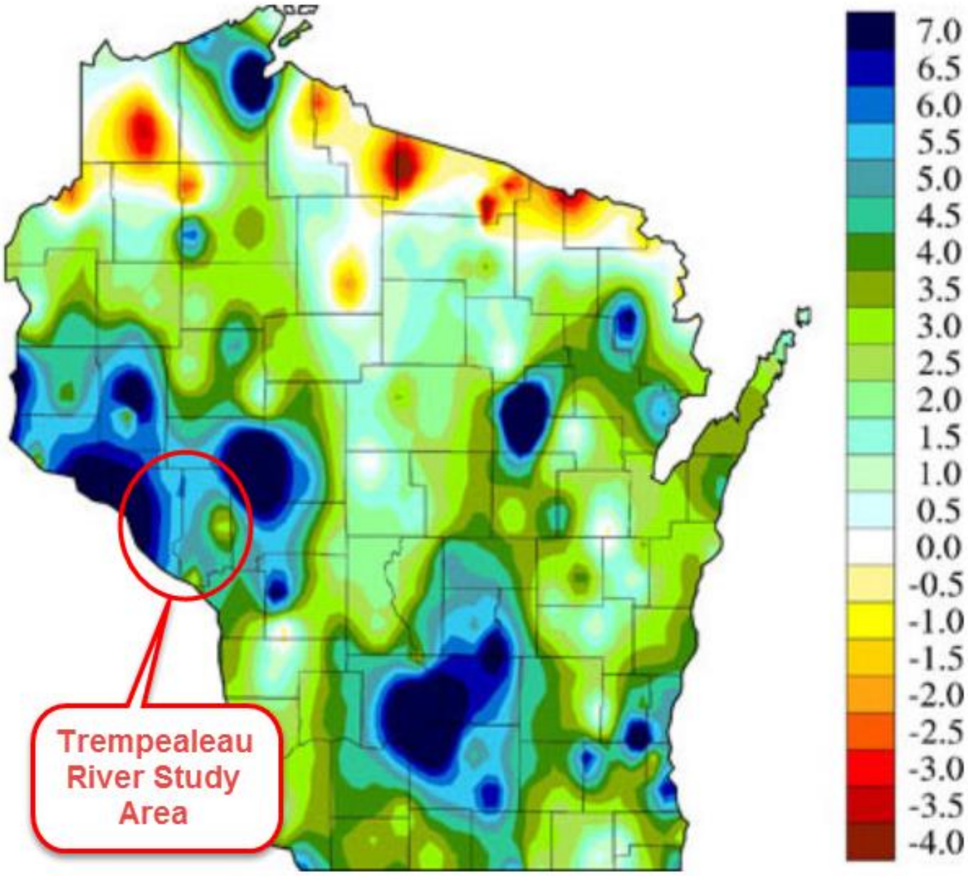


Figure 4 WICCI Changes in Wisconsin Annual Average Precipitation (in inches), 1950-2006 (WICCI, 2017)

3.1.1.4 Observed Precipitation Summary

Based on observed precipitation data, multiple authors identified an upward trend in precipitation within the study region. The literature synthesis also indicates that based on historic data, the frequency and intensity of extreme precipitation events is likely to increase (USACE, 2015).

3.1.2 Projected Precipitation

3.1.2.1 Third National Climate Assessment (Melillo et al., 2014)

The Third National Climate Assessment (NCA) provides information regarding projected, future precipitation at global, national, and regional scales (Melillo et al., 2014). On a global scale, climate models show consistent projections of future increases in precipitation for northern climates under a range of greenhouse gas (GHG) emissions scenarios (Melillo et al., 2014). In addition to increases in annual precipitation, the frequency of heavy storm events is expected to increase relative to current conditions (Melillo et al., 2014).

According to the 3rd NCA, under a high greenhouse gas emissions scenario (A2 scenario), Global Circulation Models (GCMs) used to model future climate predict that average winter and spring precipitation in 2071-2099 will increase between 10% and 20% for the Midwestern United States relative to a 1971-2000 baseline condition (Melillo et al., 2014). Increases in summer and fall precipitation are not expected to be greater than the natural, observed variation in rainfall quantities

(Melillo et al., 2014). Regional climate models (RCMs) for the Midwest using the same high emissions scenarios as the previously mentioned study project an increase in spring precipitation of 9% for the 2041-2062 timeframe relative to the 1979-2000 time period (Melillo et al., 2014). Projected changes in precipitation in the northern United States are a consequence of a warmer atmosphere (temperatures, see Section 3.2.2) which can hold more moisture and changes in large scale weather patterns (Melillo et al., 2014). Climate model projections for the midwestern region of the United States indicate a significant increase in annual precipitation (2.4 inches to 4.0 inches) by the middle of the 21st century (Melillo et al., 2014).

3.1.2.2 USACE Literature Synthesis (USACE, 2015)

A study by Johnson et al. (2012) applied GCM projections using hydroclimatic variables and streamflow to create predictive scenarios for water quality for 20 large HUC08 watersheds across the United States, including the Upper Mississippi River watershed (HUC07). GCM based projections of average annual precipitation for the 2055 planning horizon in the Upper Mississippi River Basin (HUC07) estimate a 5% to 15% increase in average annual precipitation when compared to the historical baseline (Johnson et al., 2016).

Notaro et al. (2011) applied a total of 15 different GCMs using three different greenhouse gas (GHG) emissions scenarios (B1, A1B, and A2) to assess the impact of climate change on snow pack in Wisconsin. The results indicate that warmer and wetter winters are anticipated in the future. Snow pack is anticipated to be reduced and earlier snowmelt is expected, resulting in a shortened snow season. Notaro et al. (2011) predicts that precipitation in the form or rain may increase nearly 1 cm to 3 cm in the winter and spring months and decrease by 1 cm in the summer months by the end of the 21st century.

A study by Vavrus and Behnke (2013) of climate change in Wisconsin agrees with the results produced by Notaro et al., (2011). Vavrus and Behnke (2013) studied precipitation only and used 11 different GCMs with two different downscaling techniques and a single greenhouse gas emissions scenario (A2). The results of the Vavrus and Behnke (2013) study indicate a wetter future climate compared to the recent past with average projected annual precipitation increases of 4% to 15% across the state of Wisconsin. The largest seasonal increases are anticipated during the winter months (Vavrus and Behnke 2013). The authors also quantified the changes in 24-hour extreme storm events and note that both the 2% and 1% annual chance exceedance precipitation events are projected to increase by approximately 5% to 15% across the state of Wisconsin (Vavrus and Behnke 2013). There is a high degree of uncertainty associated with projected precipitation estimates due to the use of GCMs, the natural variability of precipitation, and assumed greenhouse gas emissions scenarios.

3.1.2.3 Additional Climate Information

The Wisconsin Initiative on Climate Change Impacts (WICCI, 2017) applied downscaled GCM model results to project how Wisconsin's climate may change in the future. Climate output was produced by fourteen global circulation models (GCMs) from the Coupled Model Inter-comparison Project Phase 3 (CMIP3) based on the A1B emissions scenario. Climate projections were downscaled to 0.1 degree by 0.1 degree grids over Wisconsin and were de-biased against observed temperature and precipitation from the National Weather Service (NWS) observation stations (WICCI, 2017). The models analyzed the difference in mean December-February precipitation between 2046-2065 and 1961-2000 (WICCI, 2017).

In general, winter precipitation is projected to increase by 0.1 to 1.2 inches by the mid-21st century. The average projected increase in winter precipitation for the state of Wisconsin is 20% (WICCI, 2017).

The WICCI (2017) study also assessed projected changes in the frequency of precipitation events from 1980-2055. The same modeling method described in the previous paragraph was used to assess the projected frequency of large precipitation events (WICCI, 2017). The projected change in frequency of 2-inches (or greater) precipitation days is computed as the difference in the number of such wet days during 2046-2065 and 1961-2000 (WICCI, 2017). Presently, heavy precipitation events of two inches or greater occur 12 times per decade in southern Wisconsin and 7 times per decade in northern Wisconsin (WICCI, 2017). The WICCI (2017) study results indicate that the state of Wisconsin may receive 2-3 more extreme precipitation events per decade which represents a 25% increase in frequency.

3.1.2.4 Projected Precipitation Summary

Collectively, the studies summarized in the USACE literature synthesis indicate that annual, projected future precipitation and extreme precipitation totals and frequency will likely increase within the Mississippi River region (HUC07; USACE, 2015).

3.2 Temperature

3.2.1 Observed Temperature

3.2.1.1 Third National Climate Assessment (Melillo et al., 2014)

According to the Third National Climate Assessment (NCA), observed average temperature in the United States increased 1.3-1.9 degrees Fahrenheit since 1895, and the largest proportion of this increase occurred after 1970 (Melillo et al., 2014). Much of the warming occurred in recent decades. Since 1991, average temperature rose 1-1.5 degrees Fahrenheit over most of the United States relative to a 1901-1960 time period. Recent work by Pryor et al. (2014) for the Upper Mississippi River region estimates that from 1895-2012, temperatures in the region increased by an average of 1.5 degrees Fahrenheit.

According to the 3rd NCA the largest increases by season occurred during the winter and spring months (Melillo et al., 2014). The length of the frost-free season has gradually increased since the 1980s. The last occurrence of freezing temperatures presently occurs earlier in the spring and later in the fall than it has in the past, which suggests a change in seasonality (Melillo et al., 2014). Nationally, the average frost-free season from 1991-2011 is ten days longer relative the 1901-1960 timeframe. The frost-free season length increased by 9 days in the Midwestern United States when compared to the typical season length (Melillo et al., 2014).

3.2.1.2 USACE Literature Synthesis (USACE, 2015)

Trends in observed temperature are available from national and regional scale studies (USACE, 2015). A study of mean monthly climate data and temperature across the United States by Wang et al. (2009) using data from 1950-2000 notes a statistically significant positive trend in observed mean seasonal air temperature. For the upper Mississippi River region (HUC07), a similar positive trend in mean air temperatures is observed for the winter, spring, and summer months, but a slight decreasing trend is observed for fall months (Wang et al., 2009).

A study of trends in extreme maximum and minimum one day temperatures across the continental United States is compiled by the National Climatic Data Center (NCDC) for 187 stations from 1949-2010 (Grundstein and Dowd, 2011). Grundstein and Dowd (2011) showed a statistically significant increasing trend in the number of one day minimum temperatures, but no trend for the number of one day extreme, maximum temperatures. The studies note that daily mean and minimum temperatures increased within the study region during the observed period of record.

Shifts in seasonality as a result of temperature changes are occurring within this HUC02 watershed (USACE, 2015). A study by Schwartz et al. (2013) investigated changes in spring onset for the United States by focusing on changes in seasonality of plant growth due to changes in temperature. Data from 22,000 NCDC stations with periods of record through 2010 were used in the study and the findings indicate spring onset is occurring at least several days earlier for the current period of 2001-2010 compared to the baseline period of 1951-1960. In the Upper Mississippi River Region (HUC07), spring warming is occurring earlier than in the past which suggests a change in seasonality (Schwartz et al., 2013).

3.2.1.3 Additional Climate Information

The Wisconsin Initiative on Climate Change Impacts (WICCI, 2017) used observed daily maximum and minimum temperature data from 176 different weather stations in and around Wisconsin to quantify observed changes in temperature. Data collected and used for the analysis was interpolated to an 8-kilometer grid. Daily average temperature was estimated by averaging the daily maximum and minimum temperatures. Trends in annual and seasonal temperature were estimated using the slopes of linear regression fits for the entire 1950-2006 time series (WICCI, 2017). The average annual temperature increase across the state of Wisconsin for the 1950-2006 timeframe is 1.1 degrees Fahrenheit (WICCI, 2017). The greatest increase occurred during the winter and spring months and night time temperatures experienced a greater increase than day time temperatures. When analyzed seasonally, average springtime temperatures increased across Wisconsin by 1.7 degrees Fahrenheit, average summer temperatures increased by 0.5 degrees Fahrenheit, average fall temperatures cooled 0.6 degrees Fahrenheit, and winter temperatures increased 2.5 degrees Fahrenheit.

3.2.1.4 Observed Temperature Summary

Based in the results from this assessment, observed temperature in the study region has increased. Increases in daily minimum and daily mean temperatures were especially notable.

3.2.2 Projected Temperature

3.2.2.1 Third National Climate Assessment (Melillo et al., 2014)

According to the Third National Climate Assessment (NCA), warming is projected for all parts of the United States during the next century (Melillo et al., 2014). Future temperature projections are estimated using Global Circulation Models (GCMs) run using various greenhouse gas emissions scenarios. Estimates indicate that the magnitude of warming will be 2-4 degrees Fahrenheit over the coming decades (Melillo et al., 2014). By the end of the century it is estimated that temperatures will be roughly 3-5 degrees Fahrenheit greater, even under a lower greenhouse gas (GHG) emissions scenario which incorporates assumed reductions in GHG emissions. For higher GHG emissions scenarios, warming is anticipated to increase by 5-10 degrees Fahrenheit by the end of the 21st century. The largest temperature increases are expected in the upper Midwestern United States and Alaska (Melillo et al., 2014).

The 3rd NCA for the midwestern region of the United States indicates a significant increase in both annual average temperature and the number of extreme heat days over the next century (Pryor et al., 2014). Uncertainty in these estimates is high and depends largely on greenhouse gas emission levels in the future. Moderate increases in extreme heat days has the potential to increase the duration of droughts in the Midwest in the future (Pryor et al., 2014).

The length of the frost-free season increases under higher greenhouse gas emissions scenarios. The frost-free growing season is anticipated to increase by one month for most of the United States by the end of the 21st century (Melillo et al., 2014).

3.2.2.2 USACE Literature Synthesis (USACE, 2015)

The thermodynamic systems which make up the earth's climate are complex. Consequently, different greenhouse gas emissions scenarios are used to estimate projected trends in climate variables like temperature. A study by Liu et al. (2013) investigated maximum air temperatures using a single GCM which assumed an A2 (high) greenhouse gas emissions scenario. The spatial scale of the study is the Upper Mississippi River region (HUC07) and the study forecasts that periods of droughts in the region will become more severe in the future because the effects of projected temperature and evapotranspiration increases are expected to outweigh increases in precipitation. The work of Liu et al. (2013) applied a worst case greenhouse emission scenario for the 2055 planning horizon and showed that temperatures could be expected to rise by 2.7 to 8.1 degrees Fahrenheit compared to a baseline period from 1971-2000 (Liu et al., 2013). Climate model projections for the Midwest region of the United States show a statistically significant increase in both annual average temperature and the number of extreme heat days over the next century (Vavrus and Behnke, 2013). There is a high degree of uncertainty associated with temperature estimates due to the use of GCMs, the natural variability of temperature, and assumed greenhouse gas emissions scenarios.

3.2.2.3 Additional Climate Information

The Wisconsin Initiative on Climate Change Impacts (WICCI, 2017) study described in Section 3.1.2 estimated projected changes in annual average temperature for the State of Wisconsin. Differences in temperature are computed based on the time periods 2046-2065 and 1961-2000. To define the seasons, March to May was used for spring, June to August was used for summer, September to November was used for autumn, and December to February was used for winter (WICCI, 2017). Average annual temperature in Wisconsin is projected to warm by 4-9 degrees Fahrenheit by the middle of the 21st century. Mean spring temperatures are anticipated to increase by 3-9 degrees Fahrenheit by the middle of the 21st century. Mean summer temperatures are anticipated to increase by 3-8 degrees Fahrenheit by the middle of the 21st century. Mean autumn temperatures are anticipated to increase by 4-10 degrees Fahrenheit by the middle of the 21st century. Mean winter temperatures are anticipated to increase by 5-11 degrees Fahrenheit by the middle of the 21st century (WICCI, 2017).

The WICCI 2017 study also projected the change in the frequency of 90 degree Fahrenheit days per year. The assessment states that typical daily high temperatures which exceed 90 degrees Fahrenheit occur 12 times per year in southern Wisconsin and 5 times per year in northern Wisconsin. It is projected that by the middle of the 21st century, the frequency of hot days may triple (WICCI, 2017). The increase indicates 2-5 more weeks each year with daily high temperatures in excess of 90 degrees Fahrenheit (WICCI, 2017). In general, consensus among the studies indicates that projected temperatures in Wisconsin will rise over the next century and drought conditions are likely to become more prevalent (USACE, 2015).

3.2.2.4 Projected Temperature Summary

In general, the studies summarized in the USACE literature synthesis and other sources indicate that projected air temperature is anticipated to increase in the future.

3.3 Hydrology

3.3.1 Observed Streamflow Trends

3.3.1.1 Third National Climate Assessment (Melillo et al., 2014)

The Third National Climate Assessment (NCA) indicates that the magnitude of floods has changed in many parts of the United States (Melillo et al., 2014). Due to variations in climate across the country, there is no national trend in flood magnitude. In general, flood magnitudes observed in the midwest have been increasing (Melillo et al., 2014). The regional increasing trends in observed flooding are consistent trends in precipitation. As precipitation and the frequency of extreme precipitation has increased in the Midwest, so have the number of flood events. Extreme precipitation events now occur more frequently during the summer and fall months. Although the frequency of summer and fall floods has increased, these events are less likely to produce floods as large as spring, snowmelt driven events. This is in part because of the soil water storage capacity of the soil is typically larger during the summer and fall months (Melillo et al., 2014). According to the 3rd NCA, drought duration in the Midwest has not changed substantially over the past century (Melillo et al., 2014).

3.3.1.2 USACE Literature Synthesis (USACE, 2015)

Xu et al. (2013) studied trends in streamflow for multiple gages in the Upper Mississippi River region (HUC07) using Model Parameter Estimation Experiment (MOPEX) data for 1950-2000. The study found that of 302 watershed gages across the United States, 20%-30% of sites used in the study showed significant increases in annual streamflow and baseflow and 65% of sites showed non-significant trends. Most of the sites which showed significant increases in annual streamflow and baseflow are located in the Midwestern United States (Xu et al., 2013). This finding is consistent with what is presented in the 3rd NCA: northern climates have shown increases in streamflow over the observed period of record (Melillo et al., 2014).

A statistical assessment of daily streamflow data (1939-1998) from 42 daily gages across the United States shows an increase in river flow and the number of surplus flow days, as well as a decrease in drought incidence for the latter part of the record compared to earlier years (Vavrus and Behnke, 2013). Villarini et al. (2013) studied trends in the frequency of occurrence of heavy rainfall in the Upper Mississippi River region (HUC07) for multiple climate stations with at least 50 years of historic data. The majority of climate stations in this region exhibited statistically significant increasing trends. Based on this assessment it was found that total flow and seasonal flow for the period of record 1951-2002 show an increasing trend in streamflow within the Upper Mississippi River region (Villarini et al., 2013). A review of streamflow data for 36 gages across Minnesota (Figure 5) by Novotny and Stefan (2007) indicates that streamflow in the region exhibits statistically significant increasing trends in mean annual flow, 7-day low flow, and annual peak flow (spring and summer) for the period of record 1913 to 2002 (Novotny and Stefan, 2007).

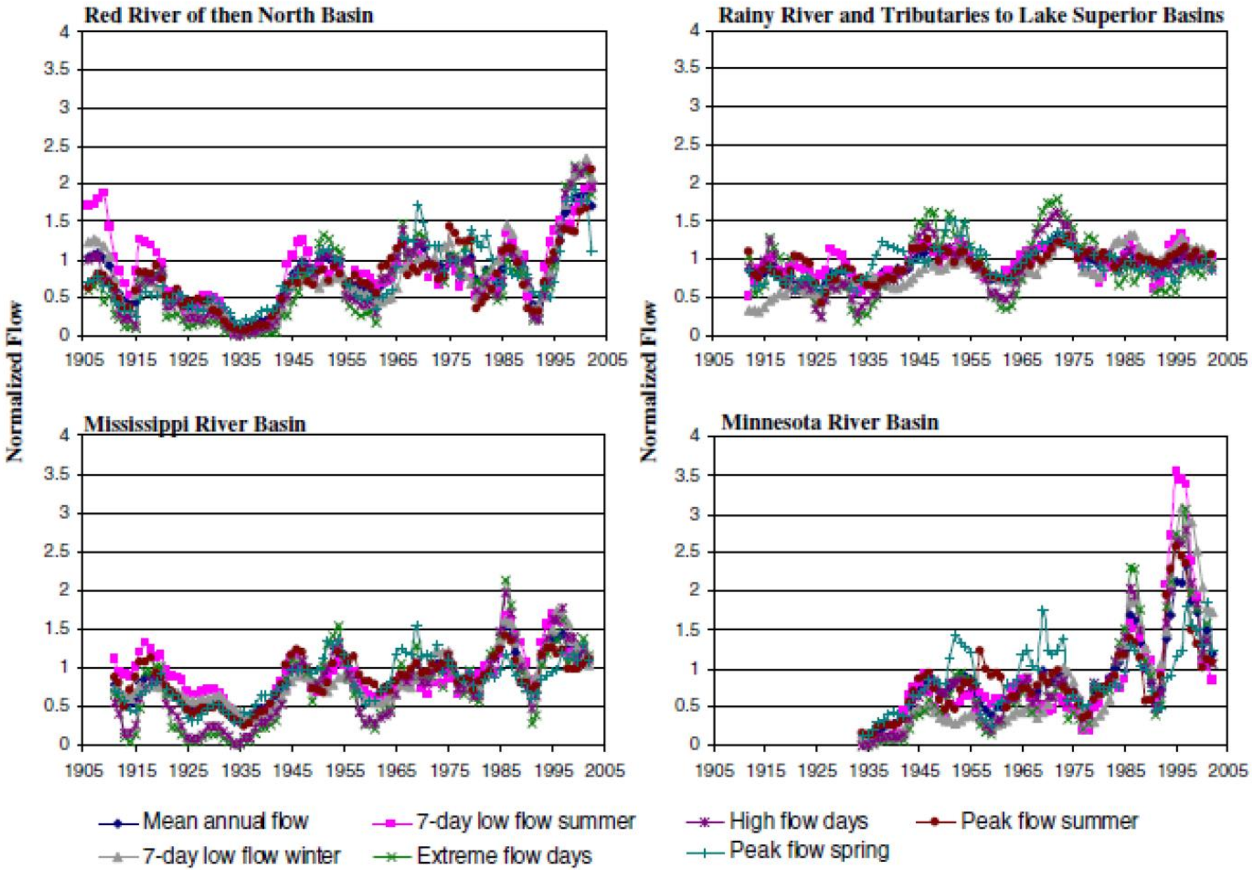


Figure 5 Five year running averages of multiple streamflow statistics averaged for major river basins of Minnesota (Novotny and Stefan, 2007)

3.3.1.3 Additional Climate Information

A study by Juckem et al. (2008) assessed the relationship that precipitation and land management practices had on baseflow and storm flow for a single watershed in the driftless region of southwestern Wisconsin. The driftless region encompasses the Trempealeau River watershed. Land management practices for the driftless region changed in the mid-1930s from more intensive agriculture practices to less intensive practices. The results of the Juckem et al. (2008) study indicated a step-wise increase in both precipitation and stream baseflow in approximately 1970. Juckem et al. (2008) applied simple hydrologic models and demonstrated that only a portion of the hydrologic changes could be attributed to the increase in precipitation. The rest of the changes were attributed to changes in land management practices (Juckem, 2008).

Land management practices influence how precipitation is partitioned into runoff or groundwater recharge and baseflow. The Juckem et al. (2008) study noted that site-scale infiltration rates of watersheds with less intensive agriculture had higher infiltration rates (Juckem et al., 2008). The higher infiltration rates and subsequent groundwater recharge may potentially offset increases in precipitation that would have resulted in higher runoff during flood events under more intensive agricultural conditions (Juckem et al., 2008).

Gebert et al. (2016) studied trends in streamflow characteristics and precipitation for 15 watersheds in Wisconsin for several time periods. The streamflow characteristics studied included 7-day annual average low flow, annual average flow, and annual peak flow (Gebert et al., 2016). Streamflow characteristics were determined for 10 watersheds which were predominantly used for agriculture (including the Trempealeau River basin, 51% agriculture) and 5 watersheds which were predominantly covered by forest. All watersheds were either unregulated or had negligible impacts from regulation. Of the 15 stations included in the study, 5 were included in the USGS Hydro-Climatic Data Network (HCDN) established in 2011.

The time periods used for comparison were 1915-1968 and 1969-2008. More trends in streamflow were observed in agricultural basins compared to forested basins. Between 1915-1968 and 1969-2008, the average 7-day, 10% exceedance probability low flow increased an average of 91% for 9 of the 10 agricultural watersheds and increased an average of 18% in the forested watersheds. The Trempealeau River watershed experienced a 76% increase in the 7-day, 10% exceedance probability flow the 1969-2008 period relative to the 1915-1968 period (Gebert et al., 2016).

Average annual flow increased an average of 23% for agricultural watersheds and 0.6% for forested watersheds for the 1969-2008 time period relative to the 1915-1968 period. The Trempealeau River watershed experienced a 35% increase in annual average discharge for the 1969-2008 period relative to the 1915-1968 period.

The 1% annual exceedance probability discharge decreased by an average of 15 percent for streams in agricultural areas and decreased an average of 27% for streams in forested areas (Gebert et al., 2016). The Trempealeau River had a 31% decrease in the 1% AEP discharge for the 1969-2008 period relative to the 1915-1968 period (Gebert et al., 2016).

Gebert et al. (2016) postulated that increased precipitation and changes in precipitation seasonality indicate that climatic change is contributing to changes in streamflow. The authors stated that changes in agricultural practices and land use had a dominant effect for increased low flow and average annual flow. This finding is important because Section 3.1.1 noted that increases in precipitation have been observed throughout the region yet peak streamflow has decreased in the driftless region of Wisconsin. This suggests that the change in land use practices has a significant effect on annual peak streamflow (Gebert et al., 2016).

3.2.2.4 Observed Streamflow Summary

The consensus amongst the literature reviewed indicates a general increase in river flow throughout the study region and an upward trend in mean, low, and peak streamflow (USACE, 2015). Studies of watersheds in the driftless region of Wisconsin agree with other regional studies; however, the watersheds in the driftless region experienced a decrease in peak annual streamflow. This watershed specific decrease in peak flows may be driven by agricultural drainage practices.

3.3.2 Projected

3.3.2.1 Third National Climate Assessment (Melillo et al., 2014)

The Third National Climate Assessment (3rd NCA) states that extreme rainfall events have increased throughout the United States during the last century (see Sections 3.1.1 and 3.3.1) and that these trends are expected to continue in the future (Melillo et al., 2014). The number of non-snowmelt driven flood events in the Midwest region is projected to increase due to an increase in the magnitude and frequency of large precipitation events during summer and fall months (Melillo et al., 2014).

3.3.2.2 USACE Literature Synthesis (USACE, 2015)

The number of days without precipitation has increased in the Upper Mississippi Watershed (HUC07) and is projected to increase in the future which may contribute to additional periods of drought (Pryor et al., 2014). The increase in drought in the Midwest is expected to be the most severe in Missouri and Southern Illinois and less severe in the northern states. The increase in consecutive dry days will likely result in agricultural drought and reduced crop yields (Pryor et al., 2014).

Global and national scale studies attempt to predict future changes in hydrology through a combination of Global Circulation Models (GCMs), future precipitation, temperature projections, and macro-scale hydrologic models. Uncertainty is inherent with climate modeling due to the large scale of the models and the many variables needed to create projections. Many variables contribute to the uncertainty of the GCMs and macro-scale hydrology models including error in temporal downscaling, error in spatial downscaling, errors in the hydrologic models, errors associated with emissions scenarios, and errors associated with GCMs themselves (USACE, 2015). Although there is much uncertainty associated with climate modeling, these models represent the best available science to make predictions of climate and are successful at estimating trends in hydroclimatic variables.

A study by Hagemann et al. (2013) applied three separate GCMs to two different emissions scenarios to supply data to eight hydrologic models to project future precipitation, evapotranspiration, and runoff at the global scale. The findings indicate uncertainty associated with this type of modeling is high; however, the study indicates that within the Upper Mississippi River Region (HUC07) it is likely that an overall increase in runoff (100 mm per year) will occur for the 2071-2100 planning horizon relative to historic conditions (Hagemann et al., 2013).

A study of the Upper Minnesota River basin (HUC07) using GCM predictions and mechanistic hydrologic models to develop and translate projected changes in meteorology into changes in river summer low flow (7-day low flow) achieved mixed results (Johnson et al., 2016). Some scenarios predict decreases in flow and others predict increases in flows (Johnson et al., 2016).

3.2.2.4 Projected Streamflow Summary

There is little to no consensus in the literature regarding changes in projected, future streamflows. There could be an increase in streamflow due to projected increases in precipitation, but there could also be a decrease in streamflow due to increases in temperature which drive increases in evapotranspiration rates and changes in seasonality and snow cover.

3.4 Overall Summary

3.4.1 Observed

The general consensus from the literature review indicates that increases in temperature, precipitation, and streamflow have occurred within the Upper Mississippi River Region during the observed period of record. Some consensus shows that the frequency of extreme storm events has also increased. Multiple authors identify a transition point in the climate data records near the year 1970 (USACE, 2015). Figure 6 below shows a summary of the trends in observed climate and streamflow, as well as an indication of the level of consensus within the peer reviewed literature considered for each variable.

3.4.2 Projected

There is strong consensus that air temperatures will increase within the study region over the next century. Precipitation is projected to increase and the frequency of large storm events is also expected to increase; however, some portions of the region will experience decreases in precipitation. Droughts are expected to increase as a result of increased temperatures and evapotranspiration rates. There is little to no consensus amongst projections of future streamflow (USACE, 2015). Figure 6 below shows a summary of trends in projected climate and streamflow, as well as an indication of the level of consensus within the peer reviewed literature considered for each variable.

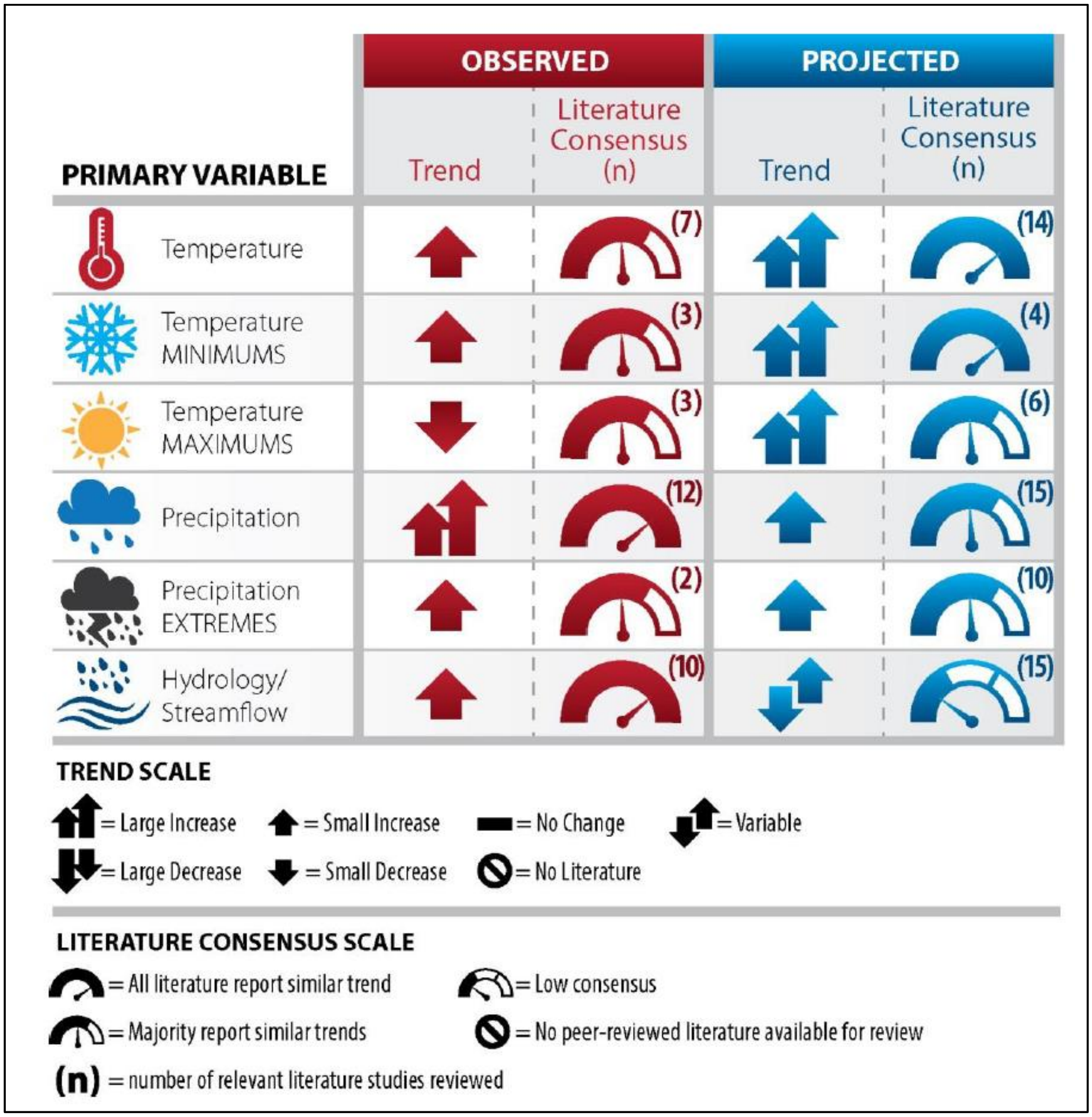


Figure 6 Summary matrix of observed and projected climate trends and literary consensus for the Upper Mississippi River Region 07 (USACE, 2015)

4 Phase I Assessment: Trends in Observed Streamflow Record

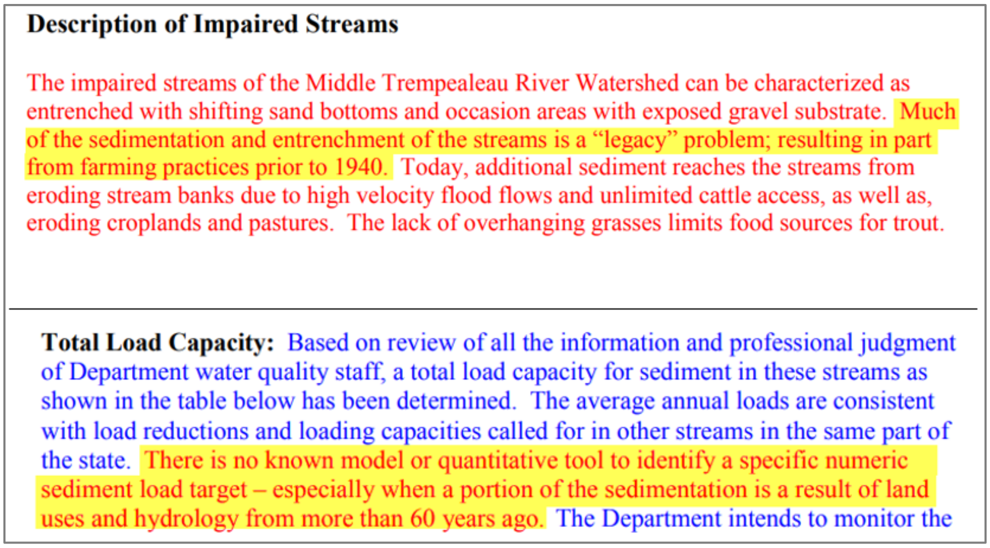
This portion of the climate change assessment focuses on carrying out first order statistical analysis using observed annual peak streamflow data observed at the Trempealeau River at Dodge, WI USGS gage (05379500). Annual peak streamflow is the variable of interest for this assessment because the purpose of the Arcadia feasibility study is to develop a flood risk management strategy to reduce damage to the city during high water events.

4.1 Data Preparation and Exploratory Analysis

The Trempealeau River at Dodge, WI USGS gage (ID 05379500) is the only continuous, long-term streamflow gage in the basin; therefore, it is used for this climate assessment. The period of record at the site is not continuous. The two segments of the systematic period of record are 1914-1919 and 1935-2015.

Background information about the Trempealeau River watershed is assessed to determine if “a priori” knowledge of a nonstationarity in the streamflow record exists. Examples of “a priori” knowledge that could cause a nonstationarity are land use changes such as urbanization or an increase in area devoted to agriculture. Other examples of a nonstationarity include construction of a hydraulic structure, like a Dam. A nonstationarity can also be the result of a change in climate conditions.

Approximately 51% of land use in the Trempealeau River is devoted to agriculture, beginning in 1853 when the first farms were established (Gebert et al., 2016 and Trempealeau County Historical Society 2018). It is unknown how quickly the landscape was developed for agricultural purposes. The *Sediment Total Maximum Daily Load (TMDL) for Impaired Streams in the Middle Trempealeau River Watershed* report indicates a potential change in agricultural practices may have occurred in approximately 1940 (Wisconsin Department of Natural Resources, 2002). Figure 7 below shows two excerpts from the TMDL analysis of the Middle Trempealeau River watershed which imply that agriculture practices may have changed around 1940 (Wisconsin Department of Natural Resources, 2002). This timeline also matches information from Juckem et al. (2008) which noted that concerted efforts since the mid-1930s to switch from intensive to less intensive agricultural practices impacted streamflow trends.



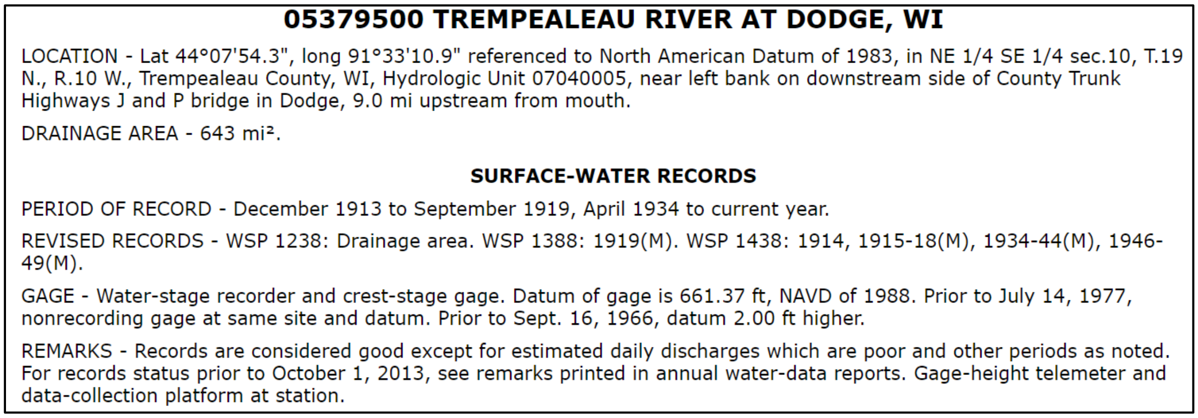
Description of Impaired Streams

The impaired streams of the Middle Trempealeau River Watershed can be characterized as entrenched with shifting sand bottoms and occasion areas with exposed gravel substrate. Much of the sedimentation and entrenchment of the streams is a “legacy” problem; resulting in part from farming practices prior to 1940. Today, additional sediment reaches the streams from eroding stream banks due to high velocity flood flows and unlimited cattle access, as well as, eroding croplands and pastures. The lack of overhanging grasses limits food sources for trout.

Total Load Capacity: Based on review of all the information and professional judgment of Department water quality staff, a total load capacity for sediment in these streams as shown in the table below has been determined. The average annual loads are consistent with load reductions and loading capacities called for in other streams in the same part of the state. There is no known model or quantitative tool to identify a specific numeric sediment load target – especially when a portion of the sedimentation is a result of land uses and hydrology from more than 60 years ago. The Department intends to monitor the

Figure 7 Excerpts from Sediment TMDL Impaired Streams report (Wisconsin Department of Natural Resources, 2002)

The USGS water year summary for the Trempealeau River at Dodge, WI USGS gage (ID 05379500) states there is no evidence that flows at Dodge are affected by regulation from upstream dams. None of the peak flows listed for the USGS gage indicate any impacts from regulation (Department of the Interior, 2016). A summary of dams in the Trempealeau River watershed is included in Appendix A of the overall Hydrology Study Report for the 2018 CAP 205 Feasibility Study at Arcadia, WI. There are several large dams in the watershed, but none are operated for flood control and most of the dams have relatively small, upstream contributing drainage areas. It is not anticipated that these dams have any effect on peak discharges in the basin.



05379500 TREMPEALEAU RIVER AT DODGE, WI

LOCATION - Lat 44°07'54.3", long 91°33'10.9" referenced to North American Datum of 1983, in NE 1/4 SE 1/4 sec.10, T.19 N., R.10 W., Trempealeau County, WI, Hydrologic Unit 07040005, near left bank on downstream side of County Trunk Highways J and P bridge in Dodge, 9.0 mi upstream from mouth.

DRAINAGE AREA - 643 mi^2.

SURFACE-WATER RECORDS

PERIOD OF RECORD - December 1913 to September 1919, April 1934 to current year.

REVISED RECORDS - WSP 1238: Drainage area. WSP 1388: 1919(M). WSP 1438: 1914, 1915-18(M), 1934-44(M), 1946-49(M).

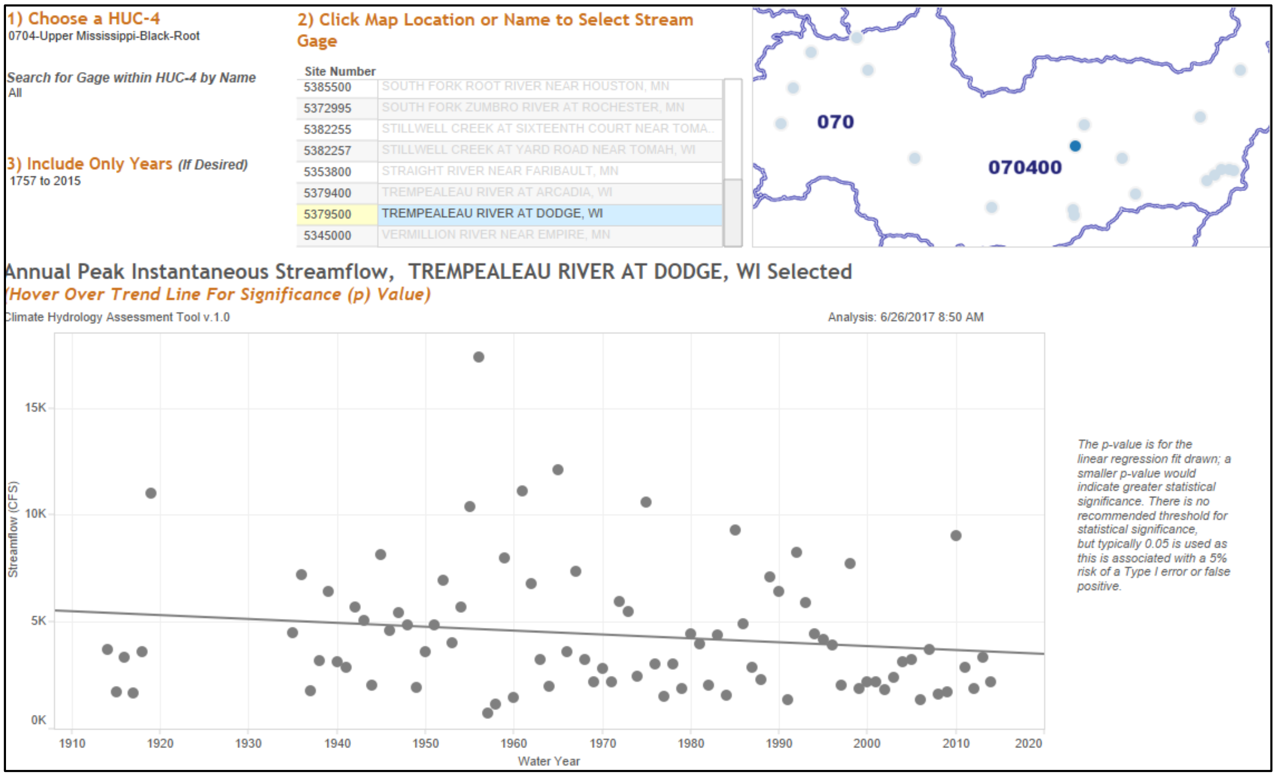
GAGE - Water-stage recorder and crest-stage gage. Datum of gage is 661.37 ft, NAVD of 1988. Prior to July 14, 1977, nonrecording gage at same site and datum. Prior to Sept. 16, 1966, datum 2.00 ft higher.

REMARKS - Records are considered good except for estimated daily discharges which are poor and other periods as noted. For records status prior to October 1, 2013, see remarks printed in annual water-data reports. Gage-height telemeter and data-collection platform at station.

Figure 8 USGS Gage Summary for the Trempealeau River at Dodge USGS Gage 05379500 (Department of the Interior, 2016)

4.2 Climate Hydrology Assessment of Observed Data

The Climate Hydrology Assessment Tool (CHAT) applies a linear regression to the observed annual instantaneous peak flow for the Trempealeau River at Dodge. Peak streamflow data is shown in Figure 9, as well as the fitted trend line using the entire systematic period of record from 1914-1919 and 1935-2014. The p-value associated with the trend line is 0.136 which is greater than the generally accepted threshold for statistical significance of 0.05. This indicates that the trend line does not have a statistically significant slope at the 95% level of confidence. This implies that there is no significant trend in the data when the entire period of record is considered.



1) Choose a HUC-4
0704-Upper Mississippi-Black-Root

Search for Gage within HUC-4 by Name
All

3) Include Only Years (If Desired)
1757 to 2015

2) Click Map Location or Name to Select Stream Gage

Site Number	
5385500	SOUTH FORK ROOT RIVER NEAR HOUSTON, MN
5372995	SOUTH FORK ZUMBRO RIVER AT ROCHESTER, MN
5382255	STILLWELL CREEK AT SIXTEENTH COURT NEAR TOMA..
5382257	STILLWELL CREEK AT YARD ROAD NEAR TOMAH, WI
5353800	STRAIGHT RIVER NEAR FARIBAULT, MN
5379400	TREMPEALEAU RIVER AT ARCADIA, WI
5379500	TREMPEALEAU RIVER AT DODGE, WI
5345000	VERMILLION RIVER NEAR EMPIRE, MN

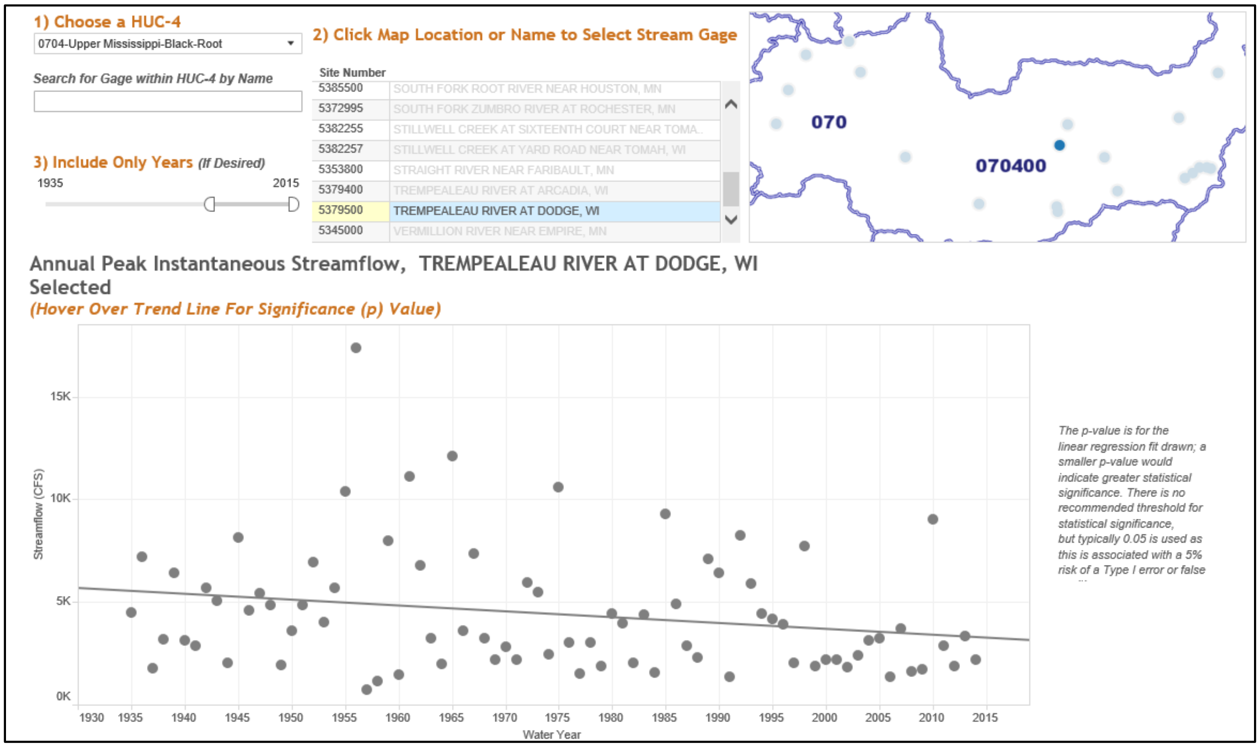
Annual Peak Instantaneous Streamflow, TREMPEALEAU RIVER AT DODGE, WI Selected
(Hover Over Trend Line For Significance (p) Value)
Climate Hydrology Assessment Tool v.1.0
Analysis: 6/26/2017 8:50 AM

The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive.

*Figure 9 Climate Hydrology Assessment using observed data for whole POR; Discharge = -18.1413*Water Year + 40144, R-Squared = 0.0263319, P-Value = 0.135507*

A separate analysis of the Trempealeau River at Dodge USGS gage using the Climate Hydrology Assessment Tool (CHAT) is performed using the continuous period of record from 1935-2014. The continuous period of record is used in the CHAT tool because the statistical methods in the Nonstationarity Detection Tool (NSD) requires a continuous record. To compare the results for the same time period, it is necessary to perform a separate analysis using the 1935-2014 period of record.

Peak streamflow data is shown in Figure 10, as well as the fitted trend line using the continuous period of record from 1935-2014. The p-value associated with the trend line is 0.048 which is less than the generally accepted threshold for statistical significance of 0.05. This indicates that the trend line does have a statistically significant slope at the 95% level of confidence. This implies that there is evidence of a decreasing trend in the data. This result is consistent with the Gebert et al. (2016) study discussed in the Literature Review of this report. In general, streams in agricultural watersheds in the driftless region of Wisconsin have shown a decrease in the average annual flood peak discharge.



Site Number	
5385500	SOUTH FORK ROOT RIVER NEAR HOUSTON, MN
5372995	SOUTH FORK ZUMBRO RIVER AT ROCHESTER, MN
5382255	STILLWELL CREEK AT SIXTEENTH COURT NEAR TOMA..
5382257	STILLWELL CREEK AT YARD ROAD NEAR TOMAH, WI
5353800	STRAIGHT RIVER NEAR FARIBAULT, MN
5379400	TREMPEALEAU RIVER AT ARCADIA, WI
5379500	TREMPEALEAU RIVER AT DODGE, WI
5345000	VERMILLION RIVER NEAR EMPIRE, MN

Annual Peak Instantaneous Streamflow, TREMPEALEAU RIVER AT DODGE, WI Selected

(Hover Over Trend Line For Significance (p) Value)

The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false ...

*Figure 10 Climate Hydrology Assessment using observed data for continuous POR; Discharge = -28.4761*Water Year + 60640.7, R-Squared = 0.0488989, P-Value = 0.0487006*

4.3 Detection of Nonstationarities in Observed Streamflow Record

A data series is considered stationary if the statistical properties of the sample are constant with respect to time. If the statistical properties of a sample of time series data changes or varies with respect to time, the time series is considered nonstationary. The USACE Engineering Technical Letter *ETL 1100-2-3 Guidance for Detection of Nonstationarities in Annual Maximum Discharges* specifies how to identify nonstationarities in an annual peak discharge record (USACE, 2018).

The USACE Nonstationarity Detection (NSD) tool is used to determine if the flow recorded in the Trempealeau River Basin between 1935 and 2014 is representative of homogenous (stationary) hydroclimatic conditions. Application of the statistical tests included in the USACE NSD tool require that the record analyzed be continuous. Consequently, the period of record from 1935-2014 is evaluated and the data from 1914-1919 is omitted. The stationarity of the flow record within the Trempealeau River Basin is assessed by applying a series of eleven nonparametric statistical tests and one Bayesian parametric statistical test to the observed peak flow record at one, long-term gage site. Note that the single parametric statistical test is not applied to time series data sets which do not reasonably fit a normal distribution.

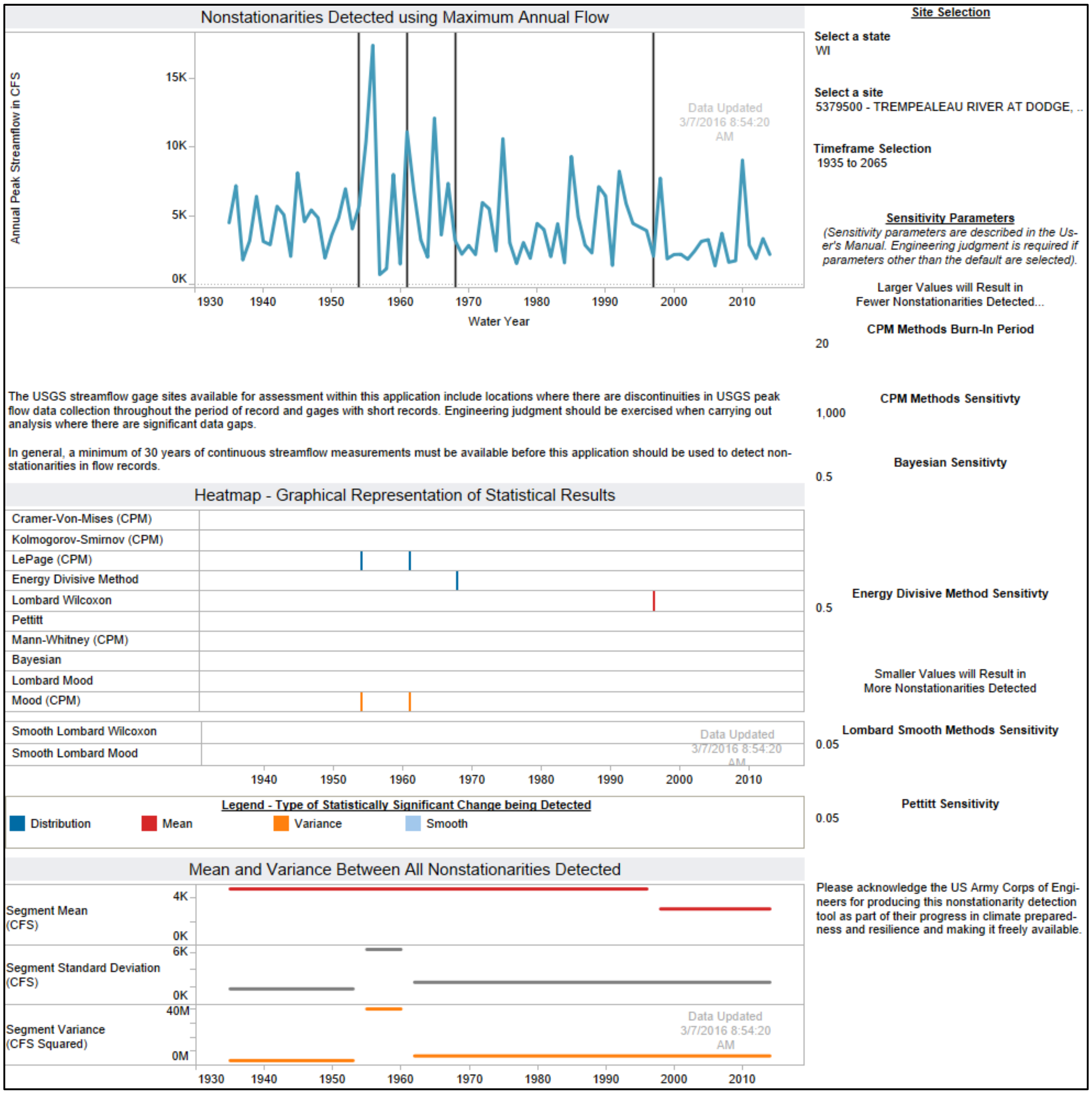
All change points detected by the tool are considered statistically significant. The relative strength of a statistically significant nonstationarity is evaluated using criteria of consensus, robustness, and magnitude. The NSD tool does not facilitate the attribution of change points to a specific driver like land use changes, changes in geomorphology, land cover changes, natural climate variability, and anthropogenic climate change.

The 12 statistical tests collectively identified nonstationarities in four different years (1954, 1961, 1968, and 1997). The relative strength of each nonstationarity is determined by considering the level of consensus between different statistical method tests targeted at detecting the same type of nonstationarity (e.g. variance/standard deviation, mean, distribution) in the flow data series. None of the nonstationarities illustrate consensus. Without consensus, it is reasonable to discount the nonstationarities being detected as being captured within the generally accepted level of uncertainty associated with flow frequency analysis (USACE. 2016b).

Two additional criteria for assessing the strength of a nonstationarity are robustness and magnitude. Robustness is achieved when tests targeting changes in two or more different statistical properties indicate a statistically significant nonstationarity in the same year. Robust criteria is met in 1954 and 1961. Magnitude refers to a change in the mean or standard deviation/variance in the peak streamflow dataset. Magnitude changes in the mean were noted in 1997 and changes to the standard deviation/variance were noted in 1954 and 1961.

Because the standard deviation/variance for the record prior to the 1956 event and after the 1956 event are approximately the same, this suggests that the magnitude change was not significant, but rather the 1956 event was so large it indicated a magnitude change when there was none.

Because the nonstationarities lack consensus and the magnitude changes detected in the standard deviation/variance occurred near the event of record, the results of this assessment do not singularly, provide enough evidence to warrant rendering the flow record recorded at Dodge nonstationary. The results of the nonstationarity assessment indicate that no strong nonstationarities exist within the observed, annual instantaneous peak flow record for the Trempealeau River at Dodge, WI USGS gage (05379500).



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

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

Site Selection

Select a state
WI

Select a site
5379500 - TREMPEALEAU RIVER AT DODGE, ..

Timeframe Selection
1935 to 2065

Sensitivity Parameters

(Sensitivity parameters are described in the Us-er's Manual. Engineering judgment is required if parameters other than the default are selected).

Larger Values will Result in Fewer Nonstationarities Detected...

CPM Methods Burn-In Period
20

CPM Methods Sensitivty
1,000

Bayesian Sensitivty
0.5

Energy Divisive Method Sensitivty
0.5

Smaller Values will Result in More Nonstationarities Detected

Lombard Smooth Methods Sensitivity
0.05

Pettitt Sensitivity
0.05

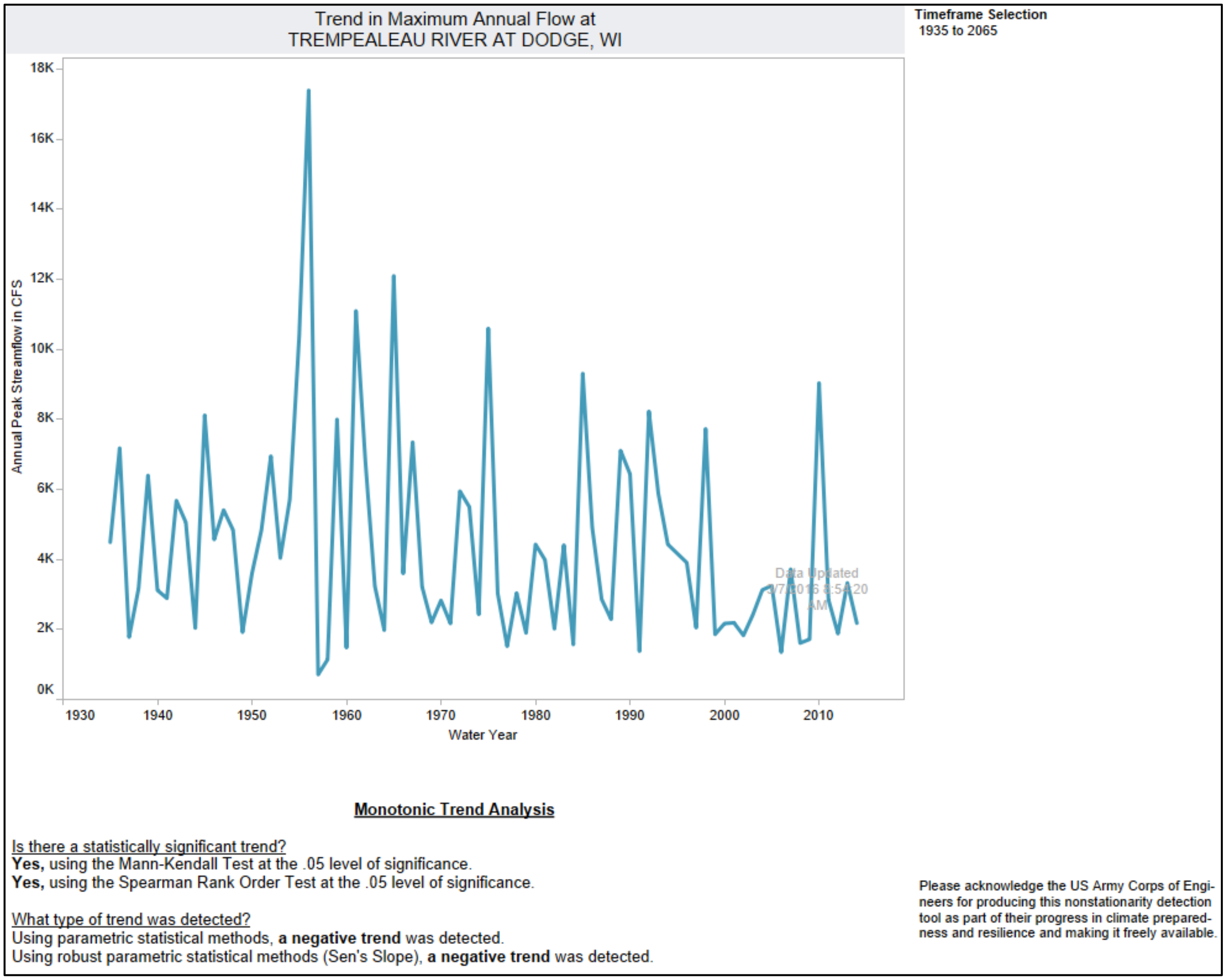
Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 11 Nonstationarity detection tool results – Trempealeau River at Dodge, WI (POR 1935-2015)

4.4 Monotonic Trend Analysis

A statistical trend in a set of time series data is defined as a gradual and continuous change in the mean of the variable of interest. Trends in hydrologic time series data are often the result of gradual changes in hydroclimatic variables or can result from anthropogenic changes to the watershed. Trends can also be a combination of natural changes in hydroclimatic variables and anthropogenic impacts. The USACE Engineering Technical Letter *ETL 1100-2-3 Guidance for Detection of Nonstationarities in Annual Maximum Discharges* specifies how to identify monotonic trends in an annual peak discharge record (USACE, 2018).

A monotonic trend analysis using the Mann-Kendall Test and the Spearman Rank Order Test (α =.05 level of significance) is shown in Figure 12. A statistically significant negative trend in annual peak streamflow is present in the period 1935 to 2014. The result of the Mann-Kendall and Spearman Rank Order tests is consistent with the trend noted in the Climate Hydrology Assessment Tool results in Section 4.2. The result of the trend analysis indicates that peak annual flows are decreasing between 1935 and 2014. This decreasing trend implies that although the nonstationarity detection tests are not flagging a particular point in time where the overall mean of annual streamflow peaks is decreasing, there may be some evidence that the record is not representative of truly homogenous conditions due to an overall, statistically significant decreasing trend in the dataset.



Monotonic Trend Analysis

Is there a statistically significant trend?
Yes, using the Mann-Kendall Test at the .05 level of significance.
Yes, using the Spearman Rank Order Test at the .05 level of significance.

What type of trend was detected?
Using parametric statistical methods, **a negative trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **a negative trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 12 Trempealeau River at Dodge, WI:1935-2015

4.5 Summary of Trends and Nonstationarities in Observed Streamflow

The results from the CHAT tool and the monotonic trend analysis indicate a decreasing trend in annual peak streamflow in the Trempealeau River watershed. This result is consistent with studies cited in the literature review which note flood peaks throughout the driftless area of Wisconsin have decreased over time. Multiple nonstationarities were detected between 1954 and 1968. Although these nonstationarities are not considered strong, they are statistically significant. The timing of the detected nonstationarities coincides with a period after the Trempealeau River basin switched from more intensive to less intensive agricultural practices which promoted infiltration of precipitation. This suggests that decreasing trend in annual peak streamflow within the Trempealeau River watershed could be driven by land use changes rather than changes in climate. This result is qualitative only. Additional analysis beyond the scope of this qualitative assessment is needed to accurately attribute changes in the basin to one or more factors.

5 Phase II Assessment: Projected Changes to Watershed Hydrology and Assessment of Vulnerability to Climate Change

5.1 USACE Climate Hydrology Assessment for Projected Data

The USACE Climate Hydrology Assessment Tool (CHAT) is used to investigate potential future changes to annual maximum monthly flows for the Trempealeau River Watershed. The HUC04 watershed used in the Climate Hydrology Assessment analysis is the Upper Mississippi-Black-Root River Watershed (HUC 0704). The Upper Mississippi-Black-Root River Watershed encompasses the Trempealeau River Watershed (see Figure 13). Figure 14 displays the range of forecasted annual maximum unregulated monthly streamflows computed from 93 different hydrologic model runs for the period from 2000-2099. Hydrologic model output is generated using meteorological inputs derived based on various combinations of representative concentration pathways (RCPs) of greenhouse gas emission scenarios and Global Circulation Models (GCMs). Couplings of RCPs and GCMs are used to project precipitation and temperature data into the future. These meteorological outputs are spatially downscaled using the bias corrected spatially downscaled (BCSD) statistical method and then inputted in the U.S. Bureau of Reclamation's 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 (Figure 14). This spread is indicative of the uncertainty associated with climate changed hydrology.

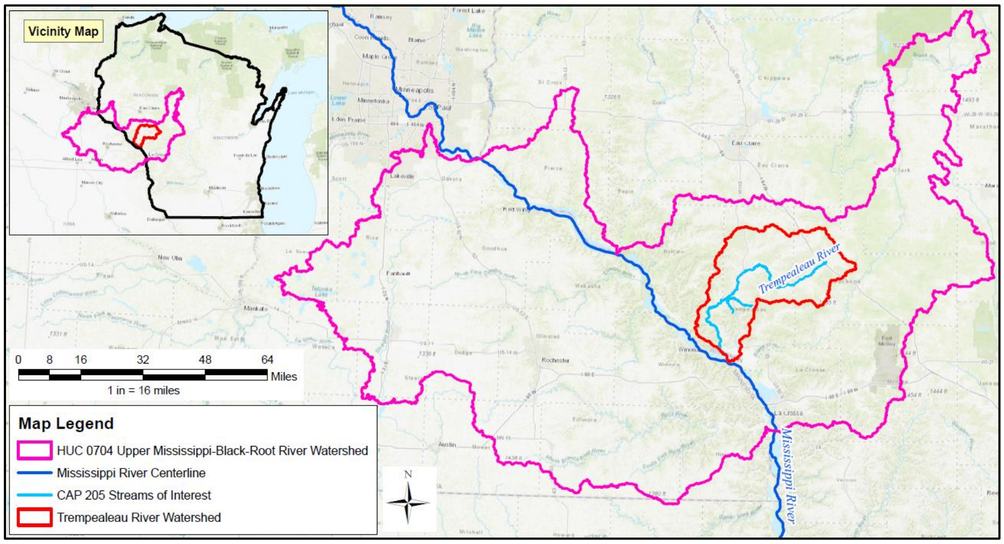


Figure 13 Upper Mississippi-Black-Root River watershed vicinity map

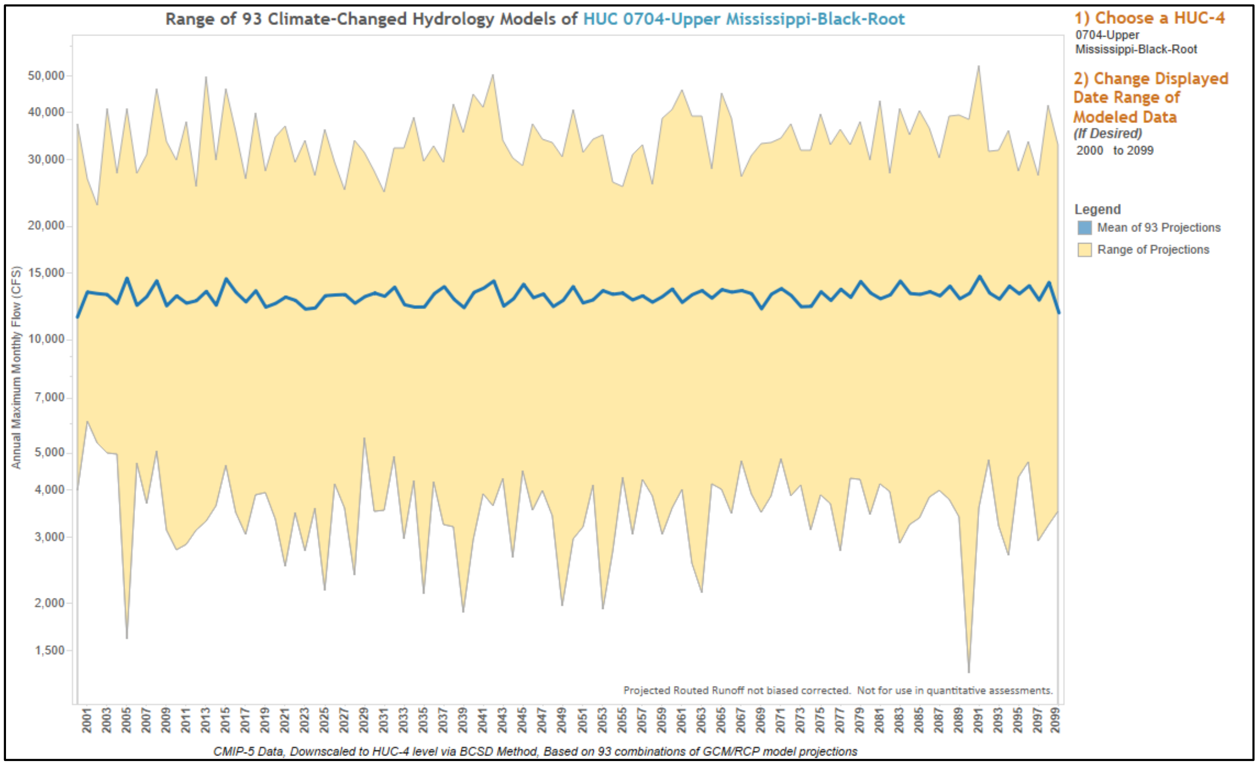
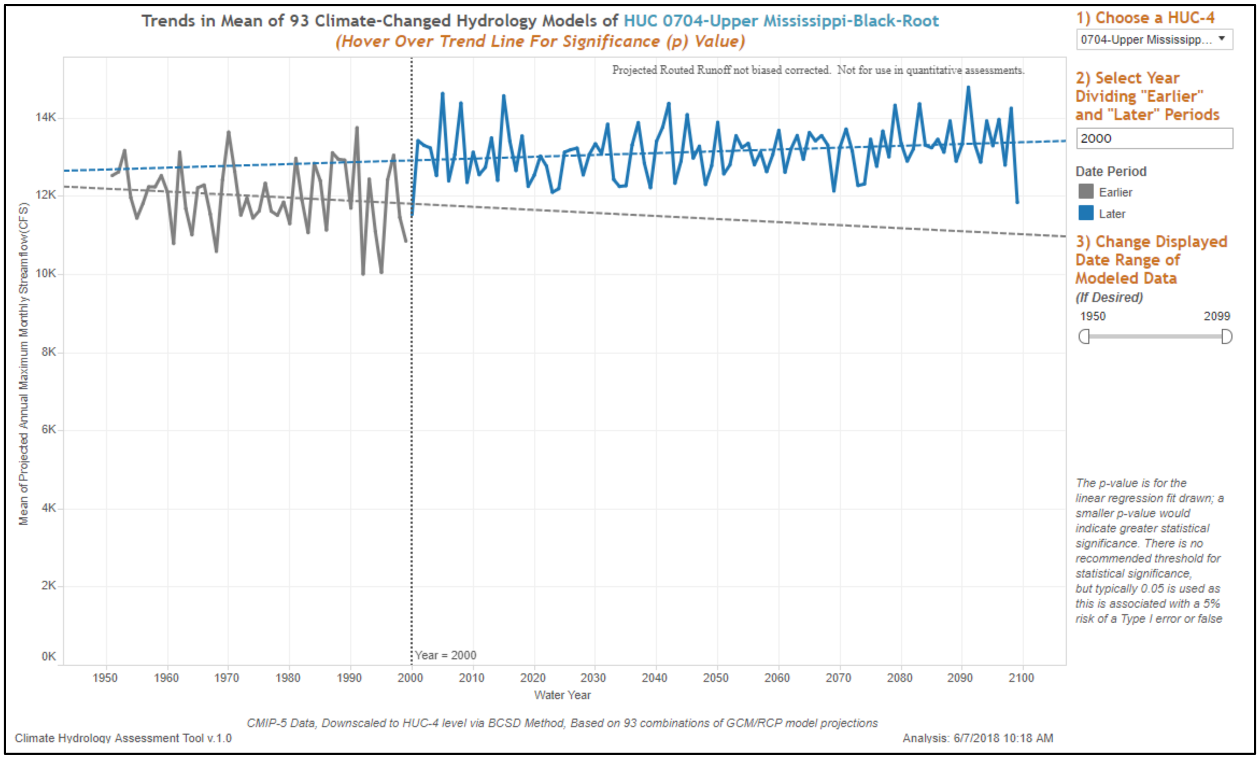


Figure 14 Upper Mississippi-Black-Root River HUC-04 0704 Range of 93 Climate-Changed Hydrology Models; CMIP-5 Data, Downscaled to HUC-4 level via BCSD Method, Based on 93 combinations of GCM/RCP model projections

In addition to providing a visualization of projected climate changed streamflow data for the Upper Mississippi-Black-Root River Watershed (HUC04 0704), the CHAT tool also fits a linear trend line to the mean projected annual maximum monthly streamflow data for the period from 2000-2099 computed for the HUC 0704 watershed. The trend in the mean projected annual maximum monthly streamflow increases over time (Figure 15). This increase is statistically-significant (p-value 0.0367 < 0.05) and suggests the potential for flood risk to increase in the future relative to the current time. This result is qualitative only.

The Climate Hydrology Assessment Tool projections in Figure 15 indicate that a statistically significant increase in annual maximum monthly streamflows is anticipated in the future between 2000 and 2099. The directionality of this trend is inconsistent with the directionality of the trend determined using observed annual instantaneous peak flow data. The analysis of annual peak streamflow data (1935-2014) in Figure 10 indicates a statistically significant decrease was observed in annual peak streamflow. The monotonic trend analysis results in Figure 12 also indicates that there is a statistically significant decreasing trend in annual peak streamflow data.

The difference in the direction of the trend is possibly due to the different spatial and temporal scale of the data. For example, the decreasing trend in annual peak streamflow uses at-site annual peak streamflow data for the Trempealeau River at Dodge, WI. The CHAT projections of annual maximum monthly streamflow uses climate models and greenhouse gas emission scenarios to project precipitation and temperature into the future and then downscales the outputs for analysis for input into precipitation-runoff models. The different spatiotemporal scales used in the analysis of observed data versus project data could result in the discrepancy between the directions of the trend in streamflow.



The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false

*Figure 15 Trends in Mean of 93 Climate-Changed Hydrology Models of HUC 0704 Upper Mississippi-Black-Root River Basin; Annual Max Monthly Flow = 4.65976*Year of Water Year + 3586.52; P-Value = 0.0367148*

5.2 USACE Watershed Climate Vulnerability Assessment Tool

The USACE Watershed Climate Vulnerability Assessment (VA) Tool facilitates a screening level, comparative assessment of the vulnerability of a given HUC04 watershed to the impacts of climate change relative to a maximum of 201 (depending on which business line is specified) HUC04 watersheds within the continental United States (CONUS). The HUC04 watershed used in the Vulnerability Assessment analysis is the HUC 0704 Upper Mississippi-Black-Root River Watershed. The HUC 0704 watershed contains the Trempealeau River Basin. The tool can be 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 (vulnerability score or WOWA score) of how vulnerable a given HUC04 watershed is to climate change specific to a given business line by using a set of specific indicator variables which relate to a particular business line. The HUC04 watersheds with the top 20% of WOWA scores are flagged as vulnerable. The vulnerability assessment analysis for this study is performed using the National Standard Settings (USACE, 2016c).

Indicators considered within the WOWA score for Flood Risk Reduction include: the acres of urban area within the 0.2% annual exceedance probability event floodplain, the coefficient of variation in cumulative annual flow, runoff elasticity (ratio of streamflow runoff to precipitation), and two indicators of flood magnification (how flood flow is projected to change in the future). The first flood magnification factor is a local factor which only considers the HUC04 watershed being studied. The second is the cumulative factor which also considers any watersheds upstream of the watershed being studied. Additional information about each of these indicator variables and how they are used to determine a WOWA score (vulnerability score) is described in the Vulnerability Assessment User Manual (USACE, 2016c).

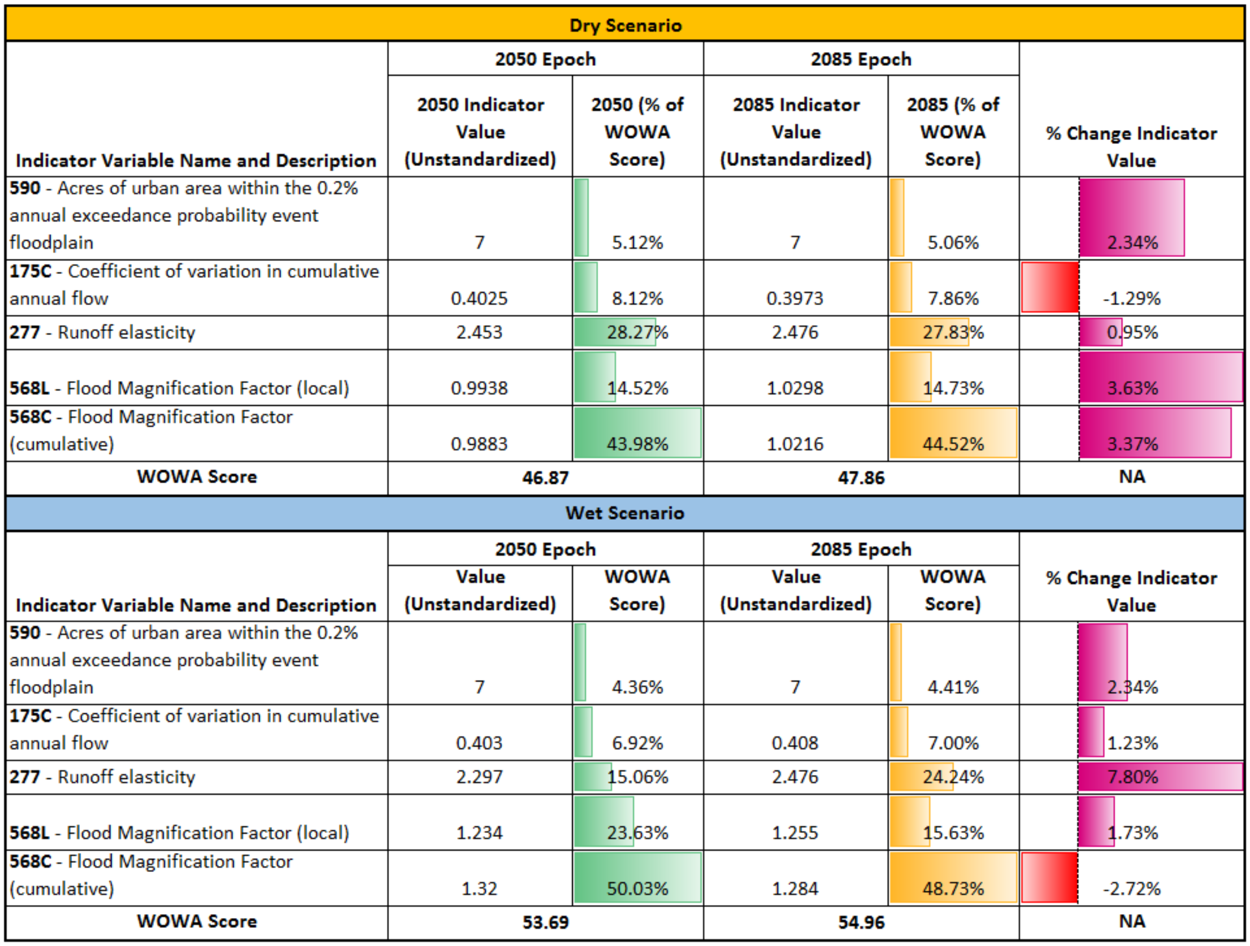
The USACE Climate Vulnerability Assessment Tool makes an assessment for two 30-year epochs centered at 2050 and 2085 to evaluate future risk due to climate change. These two epochs are selected to be consistent with many other national and international analyses related to climate. The Vulnerability tool assesses climate change vulnerability for a given business line using climate changed hydrology based on a combination of projected climate outputs from the general circulation models (GCM) and representative concentration pathway (RCPs) of greenhouse gas emissions resulting in 100 traces per HUC04 watershed per time period. 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 U.S Bureau of Reclamation's Variable Infiltration Capacity (VIC) macroscale hydrologic model. There is a great deal of uncertainty with the climate changed hydrology given by the VA tool. The user should always note that the uncertainty with climate changed hydrology projects is high and not always quantifiable.

Table 1 below summarizes the indicator variables which contribute to the vulnerability score for the Flood Risk Management business line with respect to the HUC 0704 watershed. The color ramps in Table 1 help illustrate the relative contributions of each indicator variable to the overall vulnerability score. The dominant indicator variable in determining the vulnerability score (WOWA score) for each scenario (Wet vs. Dry) and each epoch (2050 vs. 2085) is the 568C Cumulative Flood Magnification Factor which represents how flood flow is predicted to change in the future. The Cumulative Flood Magnification Factor reflects all flow generated within a HUC 04 watershed and any upstream watersheds. In watersheds with indicator values greater than 1, flood flow is predicted to increase. In watersheds with indicator values less than 1, flood flow is predicted to decrease.

Under the dry scenario, the percent each indicator variable contributes to the vulnerability score does not change significantly between the 2050 epoch to the 2085 epoch. For the wet scenario, the Runoff Elasticity (277) and Local Flood Magnification Factor (568L) are the only two indicator variables whose percent contribution to the vulnerability score changes significantly.

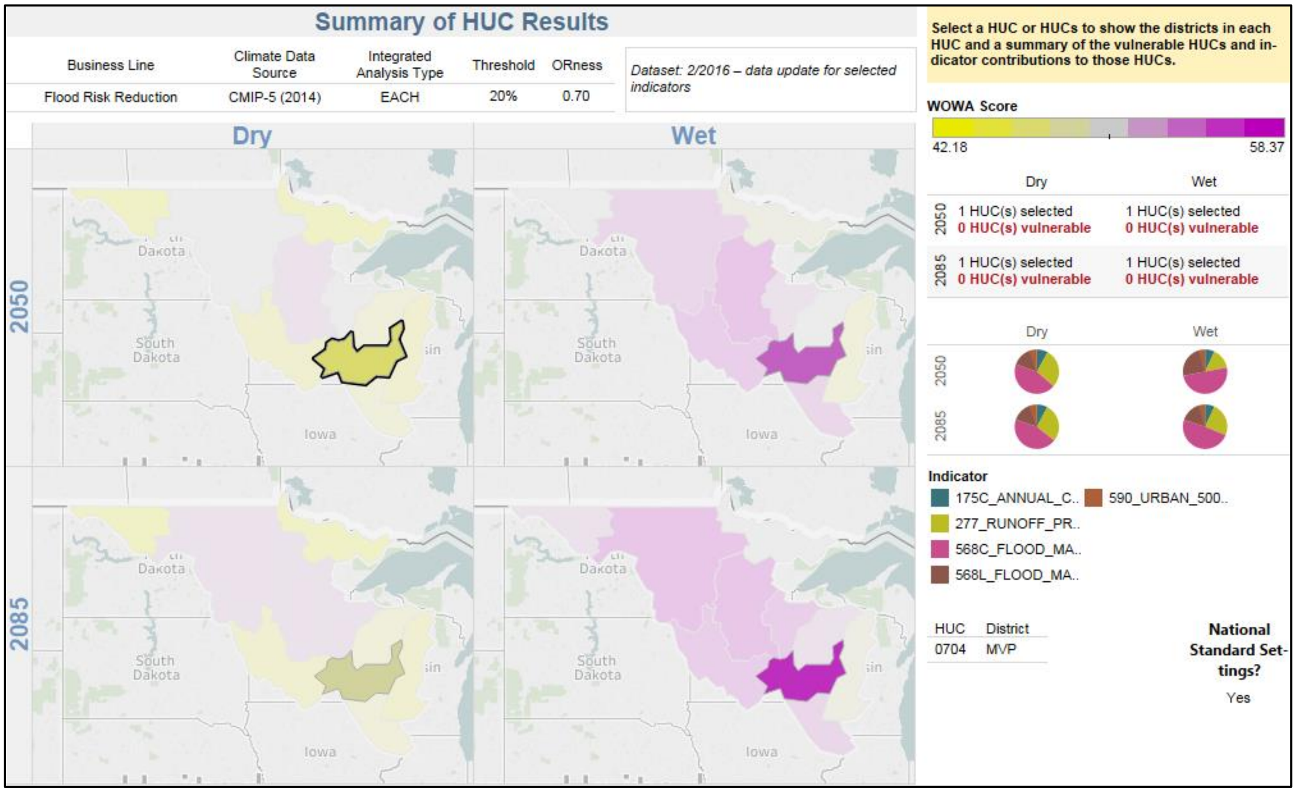
Under the wet scenario the 2085 epoch shows a larger proportion of vulnerability coming from runoff elasticity compared to the 2050 epoch. The 2085 epoch also indicates that a smaller portion of the vulnerability score comes from the local Flood Magnification factor compared to the 2050 epoch. This indicates that a larger share of the vulnerability in the 2085 epoch will be a result of runoff elasticity. Therefore, increases in precipitation will drive more of the overall vulnerability in the future.

Table 1 Comparison of indicator variables, percent of WOWA (vulnerability) score, and percent change in indicator variable



Dry Scenario					
	2050 Epoch		**2085 Epoch**		
Indicator Variable Name and Description	**2050 Indicator Value (Unstandardized)**	**2050 (% of WOWA Score)**	**2085 Indicator Value (Unstandardized)**	**2085 (% of WOWA Score)**	**% Change Indicator Value**
590 - Acres of urban area within the 0.2% annual exceedance probability event floodplain	7	5.12%	7	5.06%	2.34%
175C - Coefficient of variation in cumulative annual flow	0.4025	8.12%	0.3973	7.86%	-1.29%
277 - Runoff elasticity	2.453	28.27%	2.476	27.83%	0.95%
568L - Flood Magnification Factor (local)	0.9938	14.52%	1.0298	14.73%	3.63%
568C - Flood Magnification Factor (cumulative)	0.9883	43.98%	1.0216	44.52%	3.37%
WOWA Score	**46.87**		**47.86**		**NA**
Wet Scenario					
	2050 Epoch		**2085 Epoch**		
Indicator Variable Name and Description	**Value (Unstandardized)**	**WOWA Score)**	**Value (Unstandardized)**	**WOWA Score)**	**% Change Indicator Value**
590 - Acres of urban area within the 0.2% annual exceedance probability event floodplain	7	4.36%	7	4.41%	2.34%
175C - Coefficient of variation in cumulative annual flow	0.403	6.92%	0.408	7.00%	1.23%
277 - Runoff elasticity	2.297	15.06%	2.476	24.24%	7.80%
568L - Flood Magnification Factor (local)	1.234	23.63%	1.255	15.63%	1.73%
568C - Flood Magnification Factor (cumulative)	1.32	50.03%	1.284	48.73%	-2.72%
WOWA Score	**53.69**		**54.96**		**NA**

Based on results of USACE vulnerability assessment tool, relative to the other basins in the United States, the Trempealeau River Basin (Upper Mississippi-Black-Root River Watershed) is not particularly vulnerable to impacts of climate change to flood risk for either the wet or dry periods considered in 2050 and 2085 (Figure 16). Note that this result is qualitative only and does not imply that the watershed will not be impacted by future changes in flood risk driven by climate change, rather, the results simply imply that this watershed is not among the top 20% of HUC04 watersheds indicated as being vulnerable to future flood risk in the continental United States.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Flood Risk Reduction	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

42.18 58.37

	Dry	Wet
2050	1 HUC(s) selected **0 HUC(s) vulnerable**	1 HUC(s) selected **0 HUC(s) vulnerable**
2085	1 HUC(s) selected **0 HUC(s) vulnerable**	1 HUC(s) selected **0 HUC(s) vulnerable**

Indicator

- 175C_ANNUAL_C..
- 277_RUNOFF_PR..
- 568C_FLOOD_MA..
- 568L_FLOOD_MA..
- 590_URBAN_500..

HUC	District
0704	MVP

National Standard Settings?

Yes

Figure 16 Projected Relative Vulnerability for the Upper Mississippi-Black-Root River Watershed (HUC 0704) with Respect to Flood Risk

6 Description of Proposed Project Features

At the time this climate assessment document was written, options for the recommended plan were presented but a formal selection had not occurred. A set of flood risk reduction features has been proposed and analysis is ongoing to determine if these features can collectively meet the recommended plan criteria. The proposed flood risk reduction project is divided into four separate reaches (Reach 1, 2, 3, and 4) which involve stream relocation, levee construction, floodwall construction, construction of engineered high ground, a railroad raise, and new interior drainage facilities. Figure 17 shows a layout of the proposed flood risk reduction features and identifies where the levee, floodwall, engineered high ground, and railroad lines will be located within the project area.

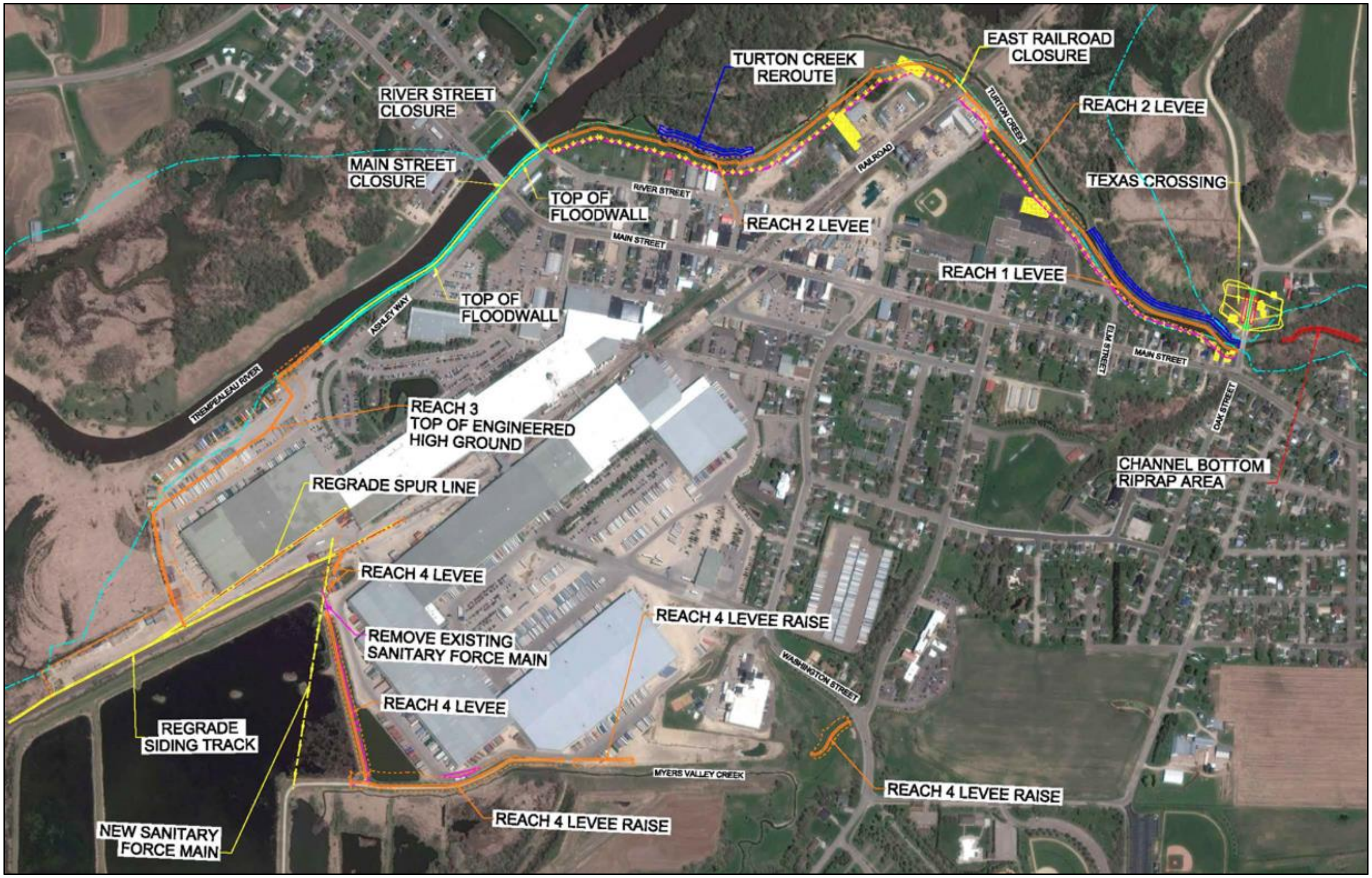


Figure 17 Layout of proposed flood risk reduction features

All levee and floodwall features in Reaches 1, 2, and 4 will be constructed to the 1% AEP (100-yr) flood elevation plus an additional 3 feet for risk and uncertainty. The intermodal area and railroad spur lines in Reach 3 will be built to an elevation of the 1% AEP (100-yr) flood elevation plus an additional 3.5 feet. The additional 0.5 foot of project elevation is included to make the project more resilient to future changes in basin hydraulics and hydrology. Based on this assessment a potential driver of future change in hydrology is climate change. This climate assessment noted a decreasing trend in observed peak streamflow through time. This project is designed to reduce flood risk based on current hydrologic conditions and current USACE policy, even if decreases in flood magnitude have decreased through time.

7 Conclusion

The primary objective of the USACE CAP Section 205 Feasibility Study for the Trempealeau River is to reduce flood risk. Based on the information presented in the literature review, regression analysis, climate hydrology assessment, and vulnerability assessment it is not clear how climate change will impact flood risk in the basin. The increase in observed temperature is the strongest evidence that climate change effects hydroclimatic conditions in the region. The literature review indicates that precipitation in the Midwestern United States has increased over the observed period of record and is projected to increase in the future as a result of climate change. The complex interrelationships between streamflow, precipitation, and temperature make it difficult to predict future flood flows. While precipitation increased during the observed record and may continue to increase in the future, increases in temperature and evapotranspiration, as well as changes in seasonality and snowmelt timing/volume may offset increasing precipitation trends making the effects on future flood flows difficult to predict.

The first order statistical analysis carried out as part of this assessment indicates a statistically significant decreasing trend in observed, annual peak flows between1935-2014. This trend is apparent in the results produced by both the CHAT linear trend analysis tool and the NSD Tool monotonic trend analysis. The CHAT tool indicates an increasing trend in modeled mean annual maximum monthly flows generated at a HUC04 watershed scale based on projections of future climate changed hydrology. These contradictory trends point to uncertainty in determining how the streamflow response will change as a result of climate change.

The NSD tool detected several statistically significant nonstationarities during the continuous 1935-2014 period of record. However, none of the detected nonstationarities are considered strong, as defined by consensus and robustness of test results and a significant change in the magnitude of the statistical properties of the dataset over time. Based on the USACE vulnerability tool results, when compared to other HUC04 watersheds in the continental United States, the Trempealeau River basin is not particularly vulnerable to flooding as a result of climate change. Although the Trempealeau River basin is not vulnerable to flooding in a relative sense, it is still potentially vulnerable to flooding in an absolute sense.

The results of the vulnerability tool, along with the lack of consensus with regards to trends in streamflow peaks presented by both the literature review and the contradictory directionality of trends in streamflow magnitude, as well as the lack of strong nonstationarities in the peak flow record at Dodge suggest that the annual instantaneous peak streamflow records within the Trempealeau River Basin should be treated as being stationary for the current analysis. Based on this assessment, the recommendation is to treat the potential effects of climate change and long-term natural variability in climate as occurring within the uncertainty range calculated for the current hydrologic analysis.

The risks posed by climate change are anticipated to be accounted for by the standard design practices used to design and construct Federal flood risk reduction projects. Residual risks, or risks to the project which are not explicitly accounted for in standard design techniques, should be low for this study. Table 2 below indicates potential residual risks for this project along with a qualitative rating of how likely those residual risk are to occur.

Table 2 Potential residual risks

Phase III Residual Risks					
Project Feature	**Trigger**	**Hazard**	**Harm**	**Qualitative Likelihood (Low, Moderate, High)**	**Qualitative Justification for Likelihood Rating**
Levee/Floodwall	Increased precipitation from more intense, frequent storm events and increases in winter and spring precipitation	Future flood volumes and peak discharges may be larger than in the past Higher flood stages resulting from larger amounts of runoff	Floods occurring more frequently will remain on the levee/floodwall longer, potentially damaging the project feature Floods may reach higher elevations than what was experienced in the past	Low	Increases in temperature are also expected which could potentially increase evapotranspiration and offset increases in flood flow. The evidence presented in the climate assessment indicates that annual peak flood flows have decreased over the observed period of record for this part of Wisconsin; however, climate model projections indicate that projected mean annual maximum monthly flows will increase so future risk could be higher relative to the current risk.
Engineered High Ground/Railroad Raise	Increased precipitation from more intense, frequent storm events and increases in winter and spring precipitation	Future flood volumes and peak discharges may be larger than in the past Higher flood stages resulting from larger amounts of runoff	Floods may reach higher elevations than what was experienced in the past	Low	The engineered high ground and railroads on Reach 3 will be constructed to the 1% AEP flood elevation, plus 3 feet of elevation for risk and uncertainty, plus an additional 0.5 feet for potential changes in hydrology, which is an added resilience measure to address potential changes to study area hydrology like climate change.
Interior Drainage Facilities	Increased precipitation from more intense, frequent storm events and increases in winter and spring precipitation	Future flood volumes from intense, frequency storms will be greater than in the past	The interior area may need to handle larger volumes of water than it was design for	Low to Moderate	Magnitude and frequency of large storm events is anticipated to increase in the future, which could stress the interior drainage facilities. Intense, localized precipitation is more common than in the past. Increases in future temperature and evapotranspiration have the potential to offset increased in runoff.

It is recommended that the local community seek opportunities to build resiliency into all current and future Flood Risk Reduction projects and Water Management Plans to account for added uncertainty of climate change and other land use related impacts. It is recommended that the discharge frequency analysis of the Trempealeau River Watershed be regularly revisited to assess if the existing frequency analysis still provides an adequate characterization of flood risk. These steps are advisable for this watershed because some of the literature reviewed and the CHAT tool projected climate changed hydrology results do indicate a potential increase in flood flows in the future.

8 Works Cited

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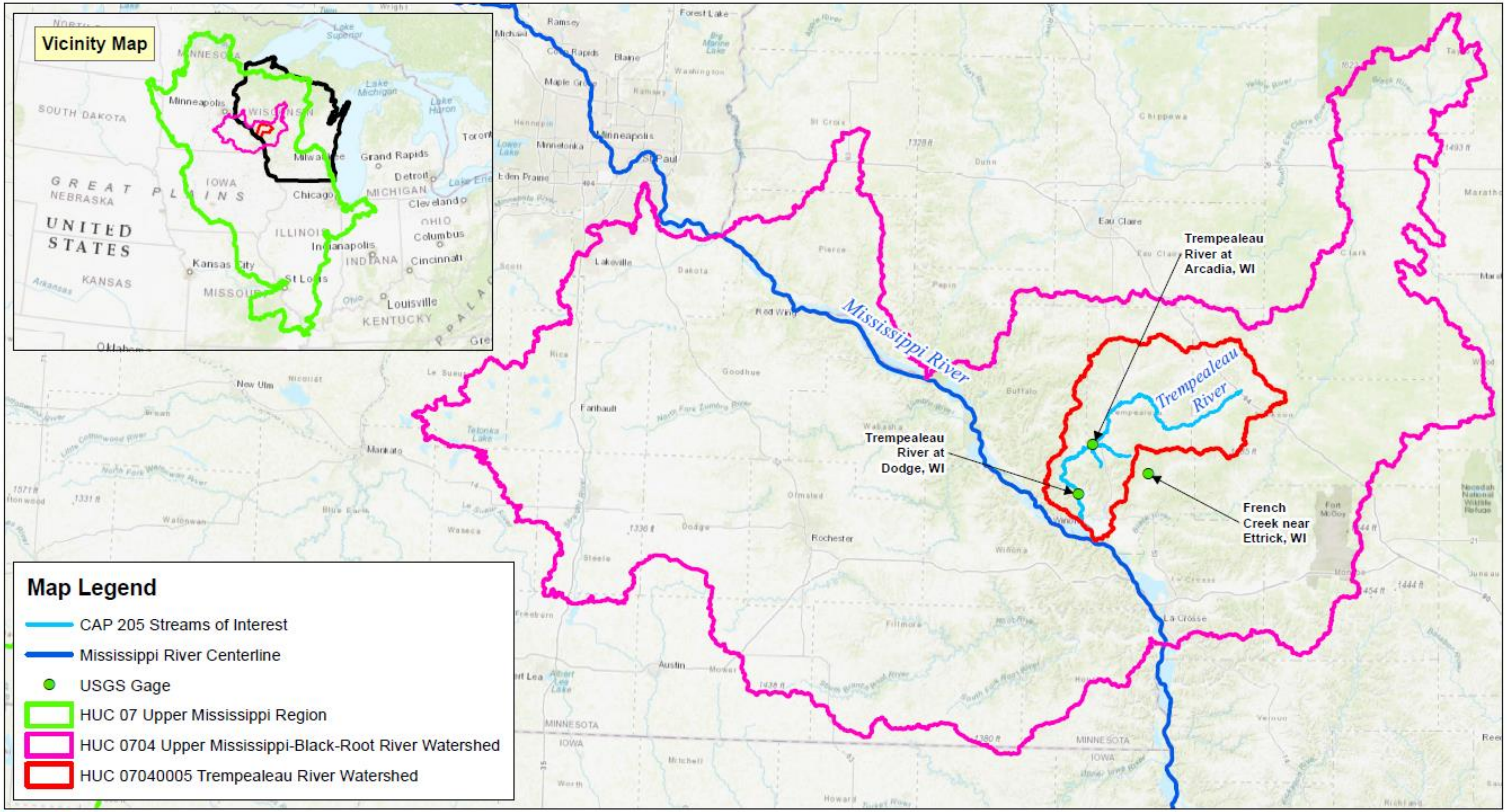
Trempealeau River Watershed



St. Paul District
HYDRAULICS
HYDROLOGY
US Army Corps of Engineers®

Trempealeau River Watershed
Climate Assessment Reference Map

0 8 16 32 48 64 Miles
1 in = 16 miles

N

Plate B-1

APPENDIX C: Peak Flow Data Tables for Gaged Sites

Normal Text = Observed Event
Italic Text = Estimated Event (MOVE.3 estimate)
Underlined Text = Below-gage-base discharge

Table 1 Peak Flow Data – Trempealeau River at Arcadia, WI USGS Gage ID 05379400

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
9-Jun-1914	*3,937*	*28-Feb-1958*	*1,244*	*29-Jul-1987*	*3,060*
26-Mar-1915	*1,839*	*27-Mar-1959*	*8,372*	*9-Mar-1988*	*2,462*
26-Mar-1916	*3,582*	*30-Dec-1959*	*1,606*	*28-Mar-1989*	*7,460*
3-Apr-1917	*1,786*	26-Mar-1961	7,840	*15-Mar-1990*	*6,771*
20-Mar-1918	*3,832*	29-Mar-1962	6,390	*30-May-1991*	*1,500*
17-Mar-1919	*11,433*	26-Mar-1963	2,890	*18-Sep-1992*	*8,608*
29-Jul-1935	*4,757*	9-Sep-1964	3,000	*22-Jun-1993*	*6,194*
22-Mar-1936	*7,531*	6-Apr-1965	9,740	*16-Sep-1994*	*4,695*
3-Apr-1937	*1,924*	10-Feb-1966	3,200	*16-Aug-1995*	*4,425*
10-Sep-1938	*3,384*	27-Mar-1967	8,340	*27-Mar-1996*	*4,155*
24-Mar-1939	*6,730*	27-Jul-1968	8,140	*31-Mar-1997*	*2,209*
1-Apr-1940	*3,332*	6-Apr-1969	2,920	*29-Jun-1998*	*8,095*
2-Apr-1941	*3,091*	28-May-1970	3,290	*23-Jul-1999*	*2,008*
3-Jun-1942	*5,988*	1-Apr-1971	2,200	*26-Feb-2000*	*2,335*
27-Mar-1943	*5,348*	27-Sep-1972	4,510	*14-Apr-2001*	*2,356*
29-Feb-1944	*2,198*	11-Mar-1973	5,580	4-Jun-2002	1,810
16-Mar-1945	*8,495*	4-Apr-1974	3,520	17-Mar-2003	1,500
14-Mar-1946	*4,840*	23-Aug-1975	12,000	1-Jun-2004	3,080
7-Apr-1947	*5,709*	12-Mar-1976	5,310	*1-Apr-2005*	*3,467*
21-Mar-1948	*5,120*	11-Mar-1977	1,250	*1-Apr-2006*	*1,468*
29-Jul-1949	*2,072*	*6-Jul-1978*	*3,248*	*15-Mar-2007*	*3,957*
29-Mar-1950	*3,832*	*20-Mar-1979*	*2,051*	*20-Apr-2008*	*1,744*
10-Jul-1951	*5,120*	*20-Mar-1980*	*4,695*	*11-Aug-2009*	*1,860*
2-Apr-1952	*7,295*	*24-Feb-1981*	*4,238*	*25-Sep-2010*	*9,436*
19-Mar-1953	*4,290*	*17-Mar-1982*	*2,177*	*24-Mar-2011*	*3,049*
21-Jun-1954	*6,019*	*31-Dec-1982*	*4,674*	*2-Mar-2012*	*2,029*
4-Oct-1954	*10,823*	*13-Jul-1984*	*1,701*	*11-Apr-2013*	*3,551*
4-Apr-1956	*17,908*	*12-Mar-1985*	*9,711*	19-Jun-2014	2,610
23-Jun-1957	*786*	*24-Sep-1986*	*5,203*	8-Jun-2015	1,630

Table 2 Peak Flow Data – Trempealeau River at Dodge, WI USGS Gage ID 05379500

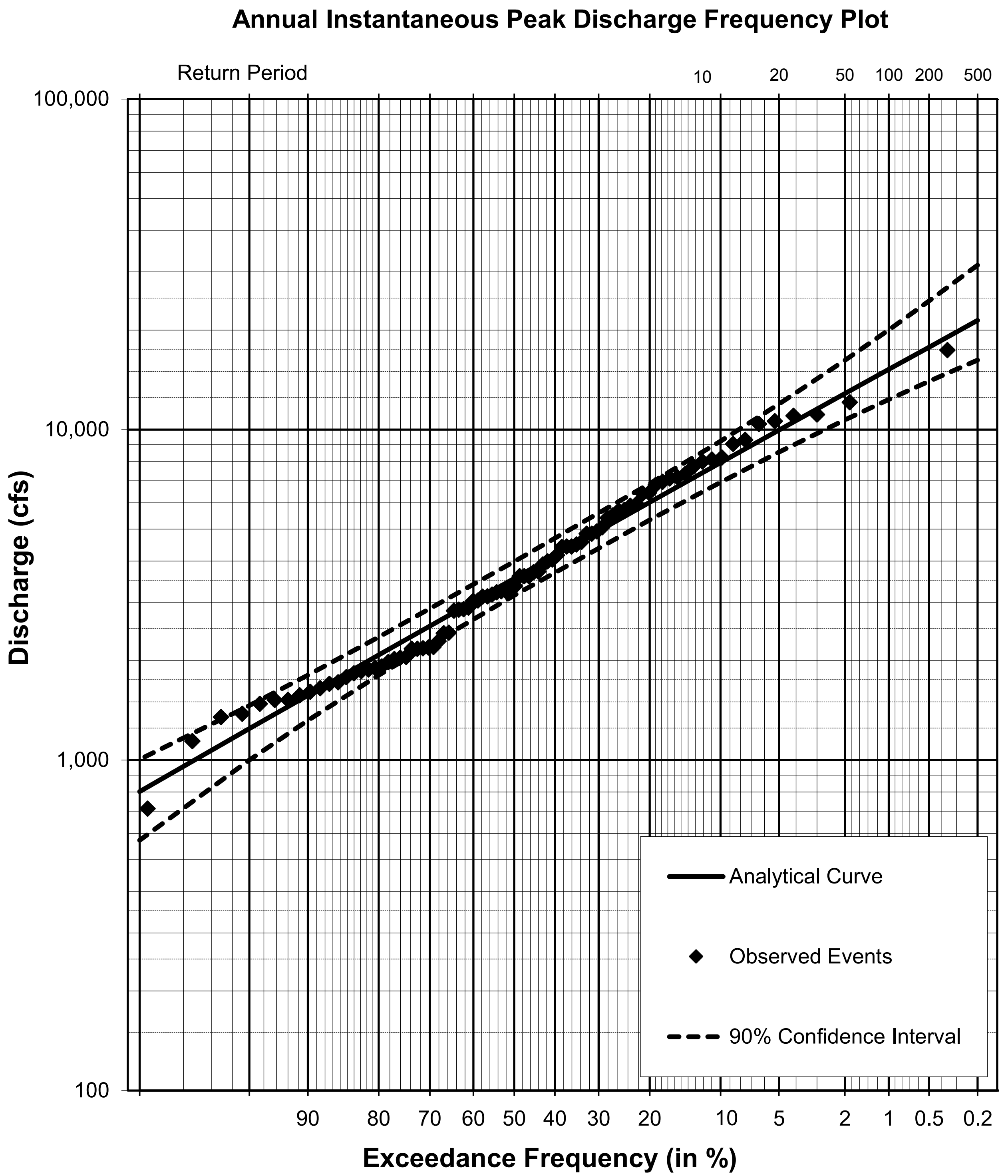
Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
9-Jun-1914	3,700	28-Feb-1958	1,140	29-Jul-1987	2,860
26-Mar-1915	1,700	27-Mar-1959	8,000	9-Mar-1988	2,290
26-Mar-1916	3,360	30-Dec-1959	1,480	28-Mar-1989	7,110
3-Apr-1917	1,650	26-Mar-1961	11,100	15-Mar-1990	6,440
20-Mar-1918	3,600	29-Mar-1962	6,800	30-May-1991	1,380
17-Mar-1919	11,000	26-Mar-1963	3,240	18-Sep-1992	8,230
29-Jul-1935	4,490	11-Sep-1964	1,980	22-Jun-1993	5,880
22-Mar-1936	7,180	7-Apr-1965	12,100	16-Sep-1994	4,430
3-Apr-1937	1,780	10-Feb-1966	3,600	16-Aug-1995	4,170
10-Sep-1938	3,170	28-Mar-1967	7,350	27-Mar-1996	3,910
24-Mar-1939	6,400	28-Jul-1968	3,220	31-Mar-1997	2,050
1-Apr-1940	3,120	7-Apr-1969	2,200	29-Jun-1998	7,730
2-Apr-1941	2,890	30-May-1970	2,830	23-Jul-1999	1,860
3-Jun-1942	5,680	4-Apr-1971	2,170	26-Feb-2000	2,170
27-Mar-1943	5,060	29-Sep-1972	5,950	14-Apr-2001	2,190
29-Feb-1944	2,040	13-Mar-1973	5,500	6-Jun-2002	1,830
16-Mar-1945	8,120	6-Apr-1974	2,430	18-Mar-2003	2,420
14-Mar-1946	4,570	24-Aug-1975	10,600	4-Mar-2004	3,130
7-Apr-1947	5,410	14-Mar-1976	3,030	1-Apr-2005	3,250
21-Mar-1948	4,840	13-Mar-1977	1,520	1-Apr-2006	1,350
29-Jul-1949	1,920	6-Jul-1978	3,040	15-Mar-2007	3,720
29-Mar-1950	3,600	20-Mar-1979	1,900	20-Apr-2008	1,610
10-Jul-1951	4,840	20-Mar-1980	4,430	11-Aug-2009	1,720
2-Apr-1952	6,950	24-Feb-1981	3,990	25-Sep-2010	9,040
19-Mar-1953	4,040	17-Mar-1982	2,020	24-Mar-2011	2,850
21-Jun-1954	5,710	31-Dec-1982	4,410	2-Mar-2012	1,880
4-Oct-1954	10,400	13-Jul-1984	1,570	11-Apr-2013	3,330
4-Apr-1956	17,400	12-Mar-1985	9,310	22-Jun-2014	2,180
23-Jun-1957	713	24-Sep-1986	4,920	13-Jun-2015	1,520

Table 3 Peak Flow Data – French Creek near Ettrick, WI USGS Gage ID 05382200

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
28-Aug-1960	410	11-Mar-1976	205	24-Mar-1997	650
26-Mar-1961	520	1977	100	26-Jun-1998	2,450
30-Aug-1962	550	6-Jul-1978	215	17-Jul-1999	1,410
22-Mar-1963	315	1979	100	31-May-2000	2,450
7-Sep-1964	310	20-Sep-1980	184	11-Jun-2001	2,950
5-Apr-1965	530	3-Apr-1981	270	9-Oct-2001	957
7-Feb-1966	480	29-Mar-1982	75	2003	573
26-Mar-1967	1,300	27-Dec-1982	980	8-Jun-2004	834
19-Aug-1968	1,000	26-Mar-1989	643	2006	570
1969	200	11-Mar-1990	1,590	2007	573
1970	200	16-May-1991	1,460	2008	573
1971	200	15-Apr-1992	1,430	2009	573
25-Sep-1972	980	19-Jun-1993	1,480	2012	566
31-Mar-1973	240	13-Sep-1994	1,440	29-Mar-2013	2,030
21-Aug-1974	270	13-Aug-1995	1,790	2015	570
27-Apr-1975	1,350	18-Mar-1996	658	--	--

Note: The exact date of the “below-gage-base” flow is not known in many instances; consequently, the discharge may be less than the indicated value which is listed as the minimum recordable discharge at the site, at the time it was recorded

Appendix D: Flow Frequency Curves Gaged Sites



Summary Statistics
Solution: Analytical-Bulletin 17C/EMA
Distribution: Log Pearson Type 3
Plotting Positions: Hirsch-Stedinger (observed), Median (low outliers)

Mean: 3.549
Standard Deviation: 0.275
Station Skew: 0.086
Regional Skew: -0.200
Regional Skew MSE: 0.125
Adopted Skew: -0.026

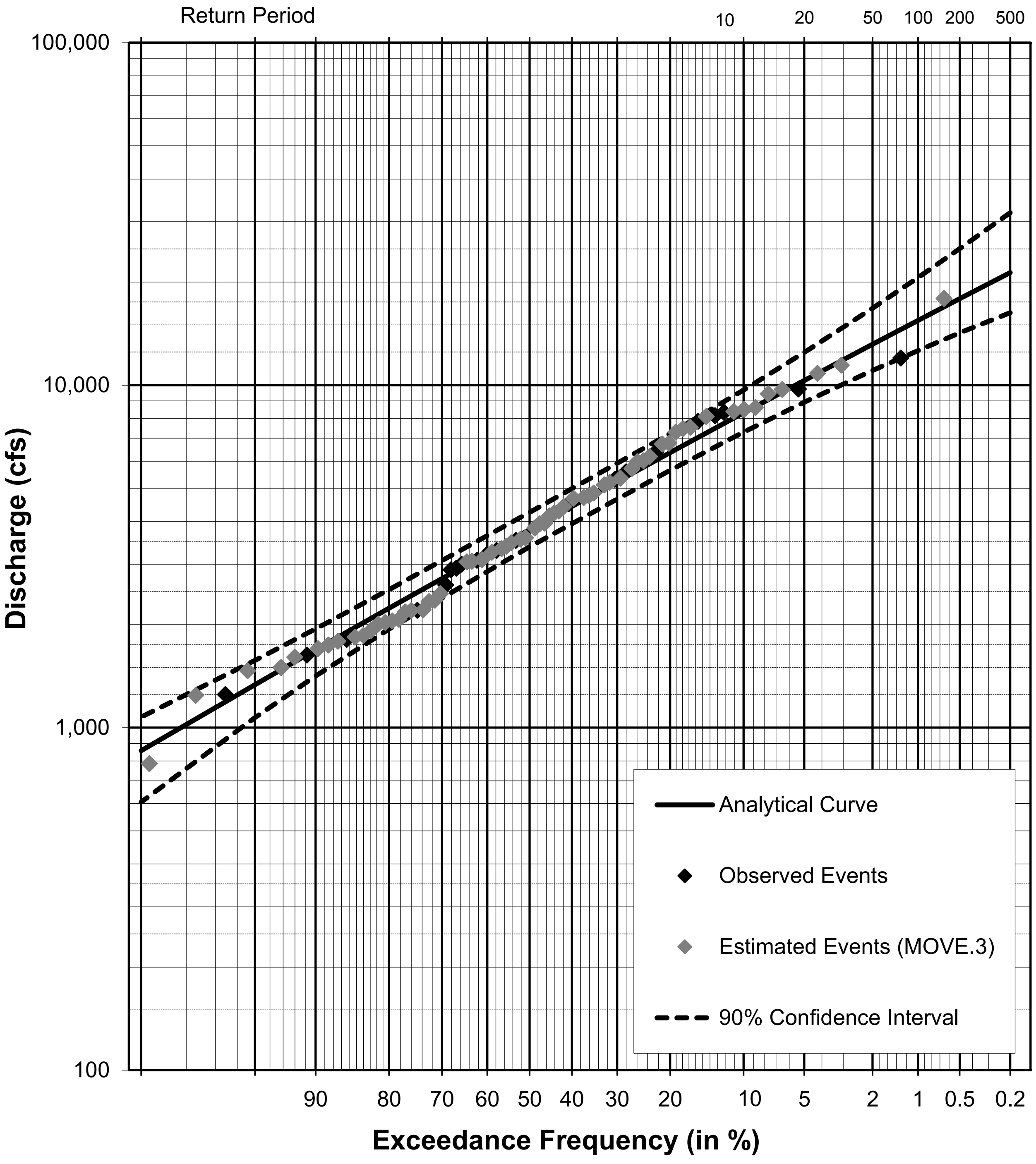
Number of Events
Historic Events: 0
High Outliers: 0
Low Outliers: 0

Years
Systematic Record: 87 Years
Historic Period: 140 Years

Notes
The magnitude of the 1876 event is unknown, but historic records indicate that the 1956 event of record was the largest event since 1876

Trempealeau River at Dodge, WI
USGS Gage ID 05379500
Flow-Frequency Analysis
Annual Instantaneous Peak Flows
Water Years in Record: 1914-1919, 1935-2015
Historic Period: 1876-2015
Drainage Area: 643 sq. mi

Annual Instantaneous Peak Discharge Frequency Plot



Summary Statistics
Solution: Analytical-Bulletin 17C/EMA
Distribution: Log Pearson Type 3
Plotting Positions: Hirsch-Stedinger (observed), Median (low outliers)

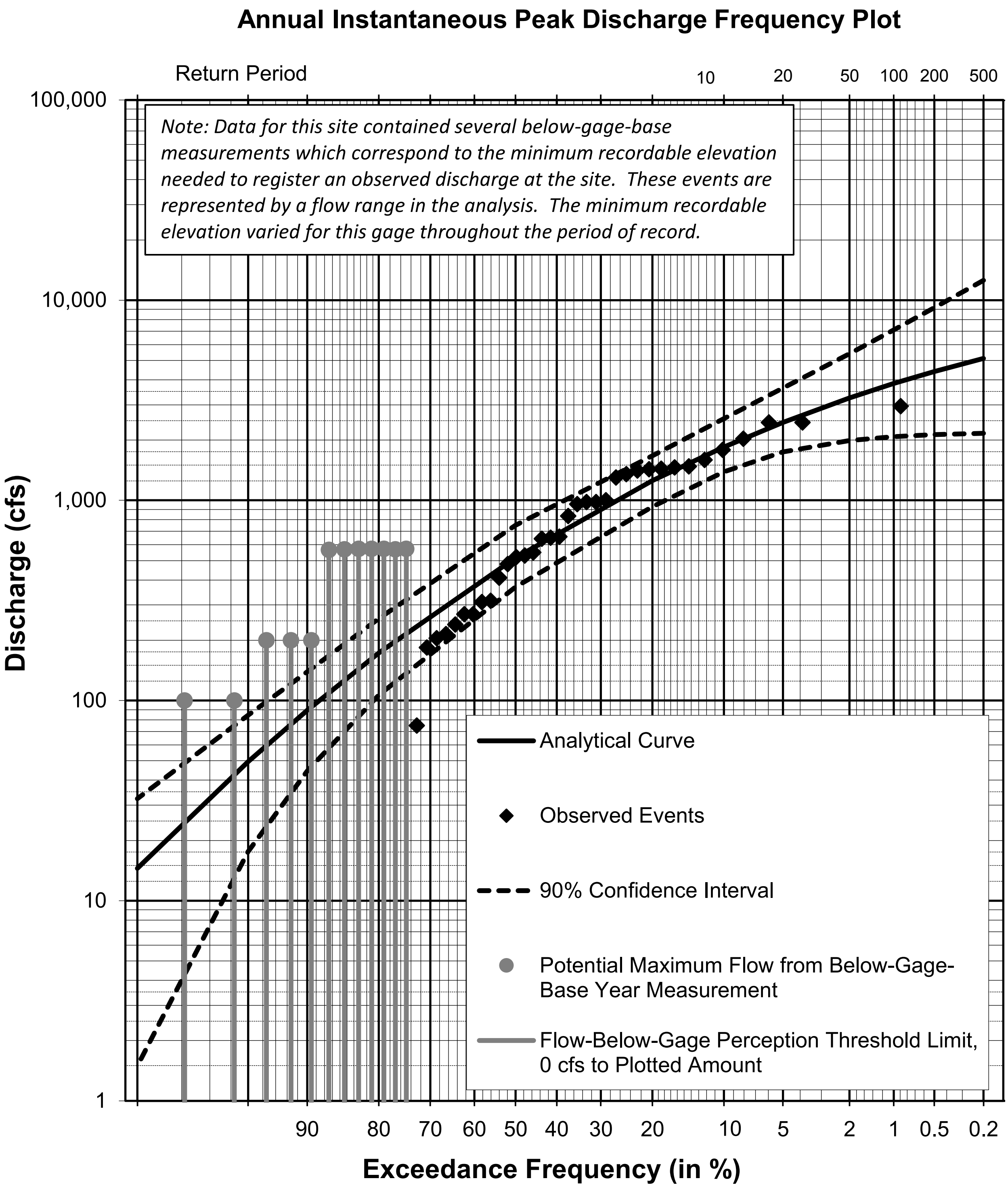
Mean: 3.575
Standard Deviation: 0.270
Station Skew: -0.007
Regional Skew: -0.200
Regional Skew MSE: 0.125
Adopted Skew: -0.073

Number of Events
Historic Events: 0
High Outliers: 0
Low Outliers: 0

Years
Systematic Record: 87 Years
Historic Period: NA

Notes
Record extension performed using MOVE.3 technique with USGS Gage 05379500 Trempealeau River at Dodge, WI

Trempealeau River at Arcadia, WI
USGS Gage ID 05379400
Flow-Frequency Analysis
Annual Instantaneous Peak Flows
Water Years in Record: 1914-1919, 1935-2015
Record Extension Using MOVE.3 Technique
Drainage Area: 553 sq. mi



Note: Data for this site contained several below-gage-base measurements which correspond to the minimum recordable elevation needed to register an observed discharge at the site. These events are represented by a flow range in the analysis. The minimum recordable elevation varied for this gage throughout the period of record.

Summary Statistics
Solution: Analytical-Bulletin 17C/EMA
Distribution: Log Pearson Type 3
Plotting Positions: Hirsch-Stedinger (observed), Median (low outlier)

Mean: 2.650
Standard Deviation: 0.523
Station Skew: -0.730
Adopted Skew: -0.730

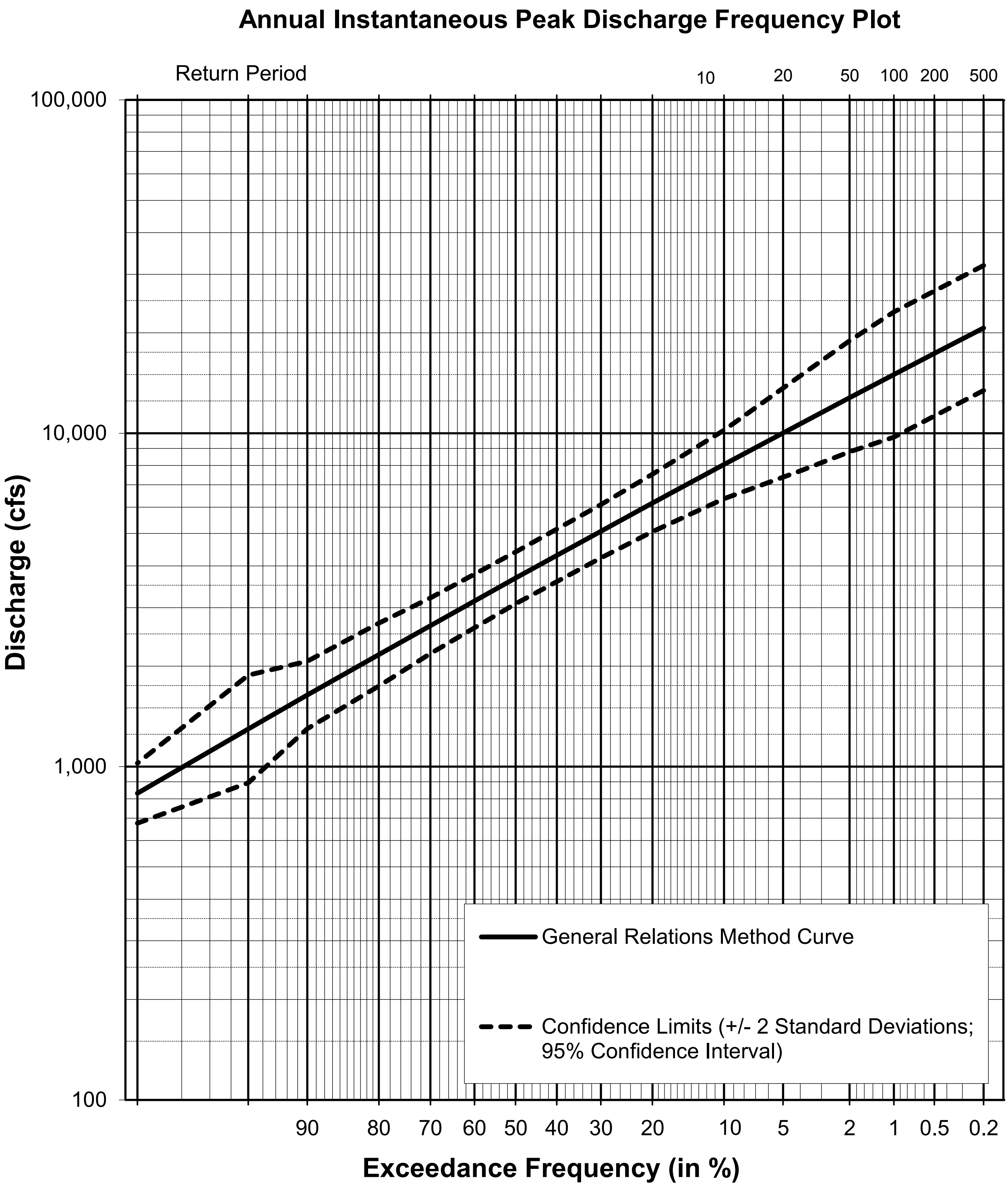
Number of Events
Historic Events: 0
Low Outliers: 0

Years
Systematic Events: 47 Years
Historic Period:

Notes
Perception thresholds used to define low flow at or below a specified discharge value

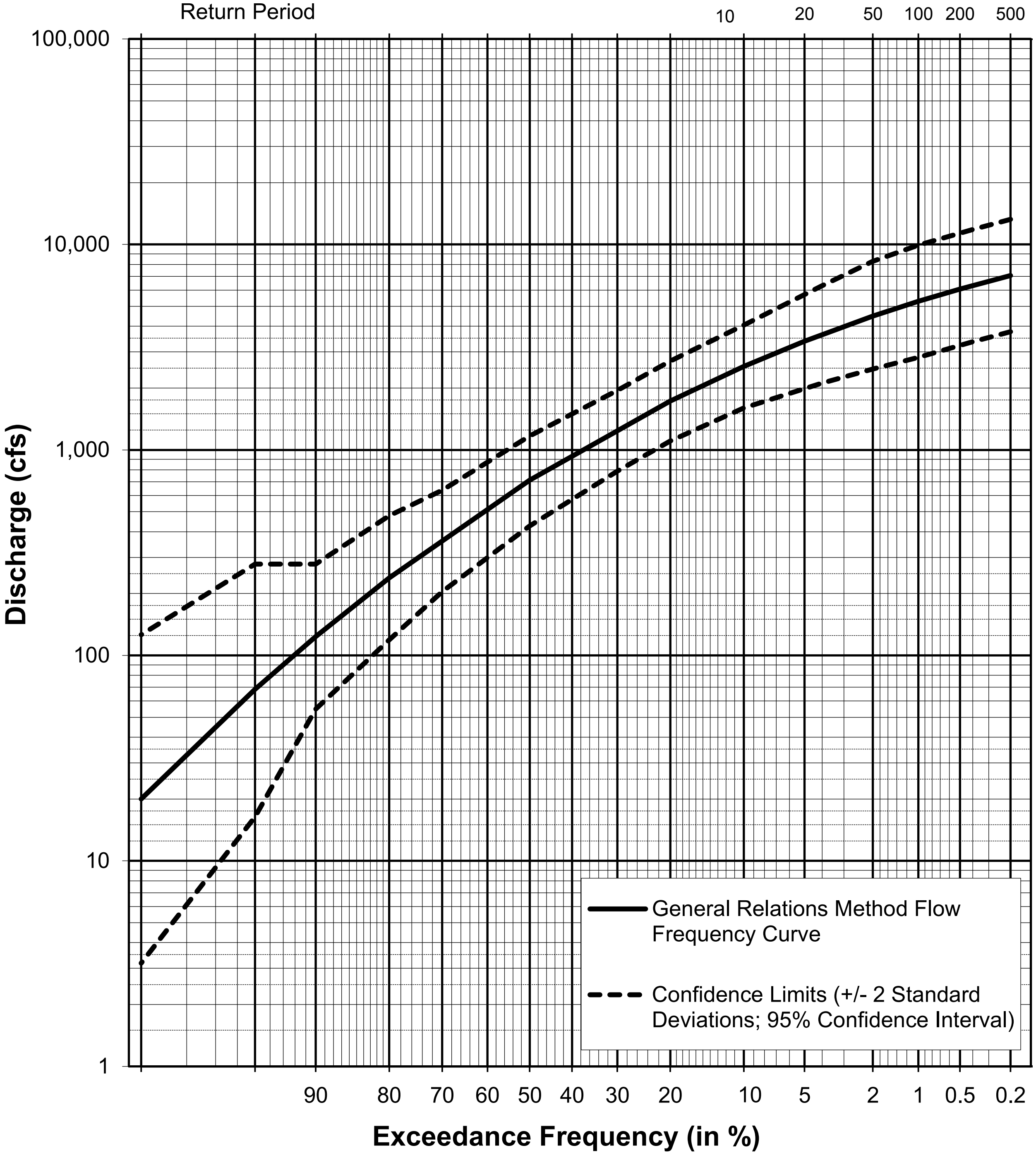
French Creek near Ettrick, WI
USGS Gage ID 05382200
Flow-Frequency Analysis
Annual Instantaneous Peak Flows
Water Years in Record: 1960-1983, 1989-2004, 2006-2009, 2012-2013, 2015
Drainage Area: 14.7 sq. mi

Appendix E: Flow Frequency Curves Ungaged Sites



Trempealeau River above Turton Creek, WI
Ungaged Watershed
Flow-Frequency Analysis
General Relations Method - Drainage Area Transfer
Equivalent Period of Record: 78 years
Drainage Area: 528.4 sq. mi

Annual Instantaneous Peak Discharge Frequency Plot



Summary Statistics

Solution: Analytical-Bulletin 17C/EMA
Distribution: Log Pearson Type 3
Plotting Positions: H-S (observed), Median (low outliers)

Mean:
Standard Deviation:
Station Skew:
Regional Skew:
Regional Skew MSE:
Adopted Skew:

Number of Events

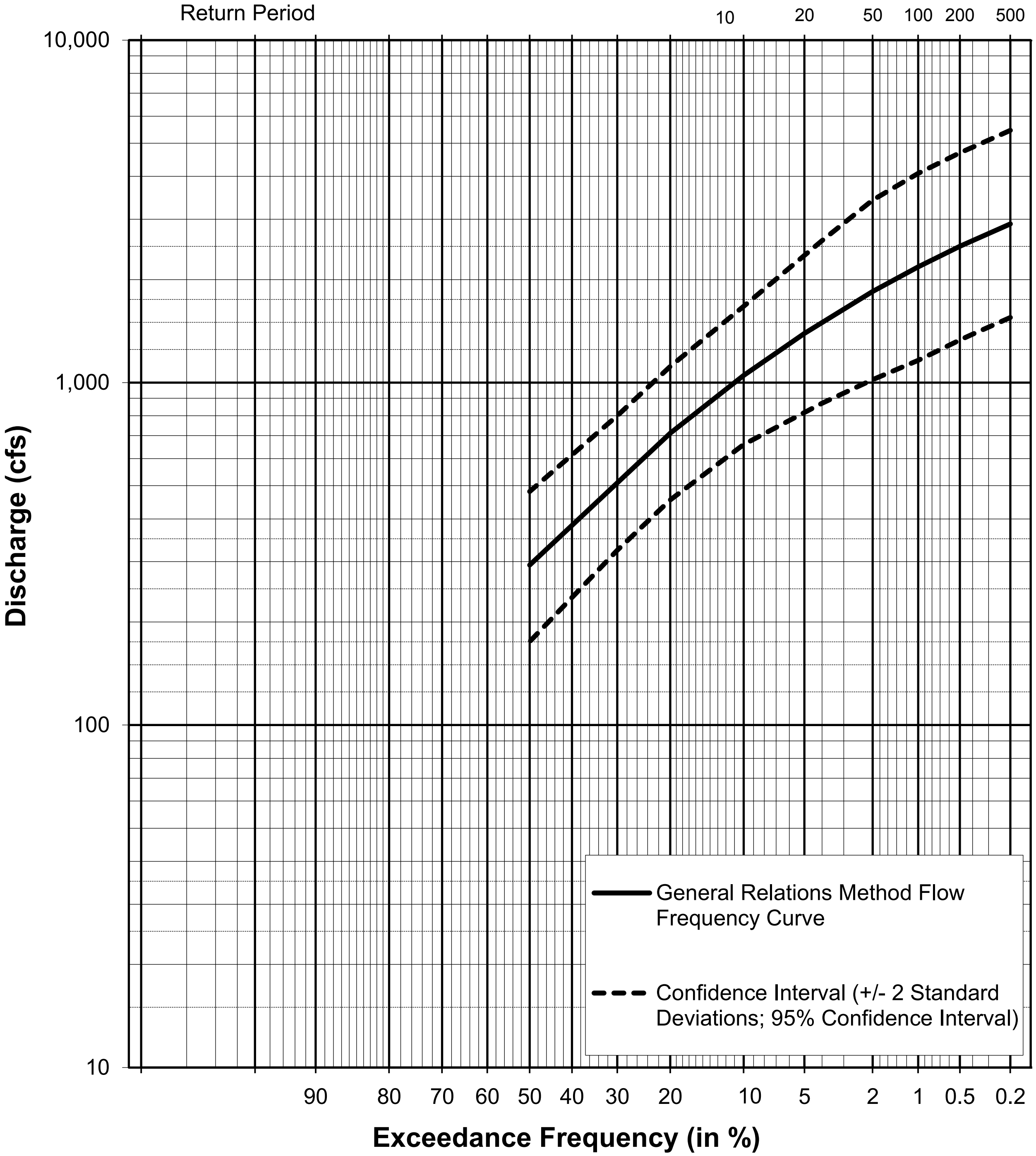
Historic Events: 0
High Outliers: 0
Low Outliers: 0

Years

Systematic Record: Years
Historic Period: NA

Turton Creek at Arcadia, WI
Ungaged Watershed
Flow-Frequency Analysis
General Relations Method - Drainage Area Transfer
Equivalent Period of Record: 38 years
Drainage Area: 23.6 sq. mi

Annual Instantaneous Peak Discharge Frequency Plot



Myers Valley Creek at Arcadia, WI
Ungaged Watershed
Flow-Frequency Analysis
General Relations Method - Drainage Area Transfer
Equivalent Period of Record: 38 years
Drainage Area: 6.4 sq. mi.

Appendix F: Memorandum for Record

SPADING

FYI

Dave

CENCS-ED-GH (1110-2-1403) September 24, 1992

MEMORANDUM FOR RECORD

SUBJECT: Arcadia, Wis, Sept 1992 Flood

1. The largest flood stage in over 30 years was reached on 17 Sept 1992 on the Trempealeau River at Arcadia, Wis. The flood was caused by a heavy rain the evening of 15 Sept and morning of 16 Sept 92. The Flood Forecast Center of the NWS made a flood prediction at about 8 pm on 16 Sept that was within 0.2 feet of the actual peak. Previous work by the Corps on Arcadia had found significant fluctuations in the rating curve. On 21 Sept 92 I called John Seeman of the FFC and asked him how he could be so accurate. The result of that conversation and ones with Barry Holmstrum of the USGS convinced me that it would be worthwhile having the USGS make periodic discharge measurements to better define the discharge-stage rating curve for Arcadia. I propose adding this work to our data collection contract with the USGS through water control. I feel 4 measurements a year during during high flows would be adequate.

2. John Seeman said the FFC has very limited knowledge of Arcadia, it is not one of their forecast points. He said he expects it to become one. He based his forecast on USGS published records for the 1975 flood. The published values are:

1975 FLOOD

Arcadia Peak Stage = 8.64 Peak Discharge = 15,900 cfs
Dodge Peak Stage = 11.36 Peak Discharge = 10,600 cfs.

The 1992 peaks were:

Arcadia Peak Stage = 8.7
Dodge Peak Stage = 11.44.

The USGS measured a discharge of 7650 cfs at Dodge at a stage of 11.35. I estimate the peak discharge was about 8000 cfs at Dodge. During the FIS study of Arcadia the WDNR and the Corps became suspect of the published 1975 peak at Arcadia. The USGS peak was based on an indirect measurement. Examining the data from the USGS and the Corps HEC-2 model, we felt the 1975 peak was probably about 12,000 cfs at Arcadia. We informed the USGS of our opinion and used the lower value for the FIS study.

3. When I talked to John Seeman he felt the 1992 discharges at Arcadia and Dodge were probably about the same as the published 1975 values of 15,900 and 10,600 cfs since the stages were so similar. However, the actual peak at Dodge was only about 75% (8000 vs 10,600) of the 1975 peak. Assuming the Arcadia peak was also about 75% of the 1975 peak, and that the actual 1975 peak was 12,000 cfs, I estimate a 1992 peak of about 9000 cfs at Arcadia. This is only about 57% of the USGS published value for 1975.

4. When I told John Seeman about the uncertainty in the Arcadia rating curve he said that additional measurements by the USGS would be of great value to him for future flood predictions.

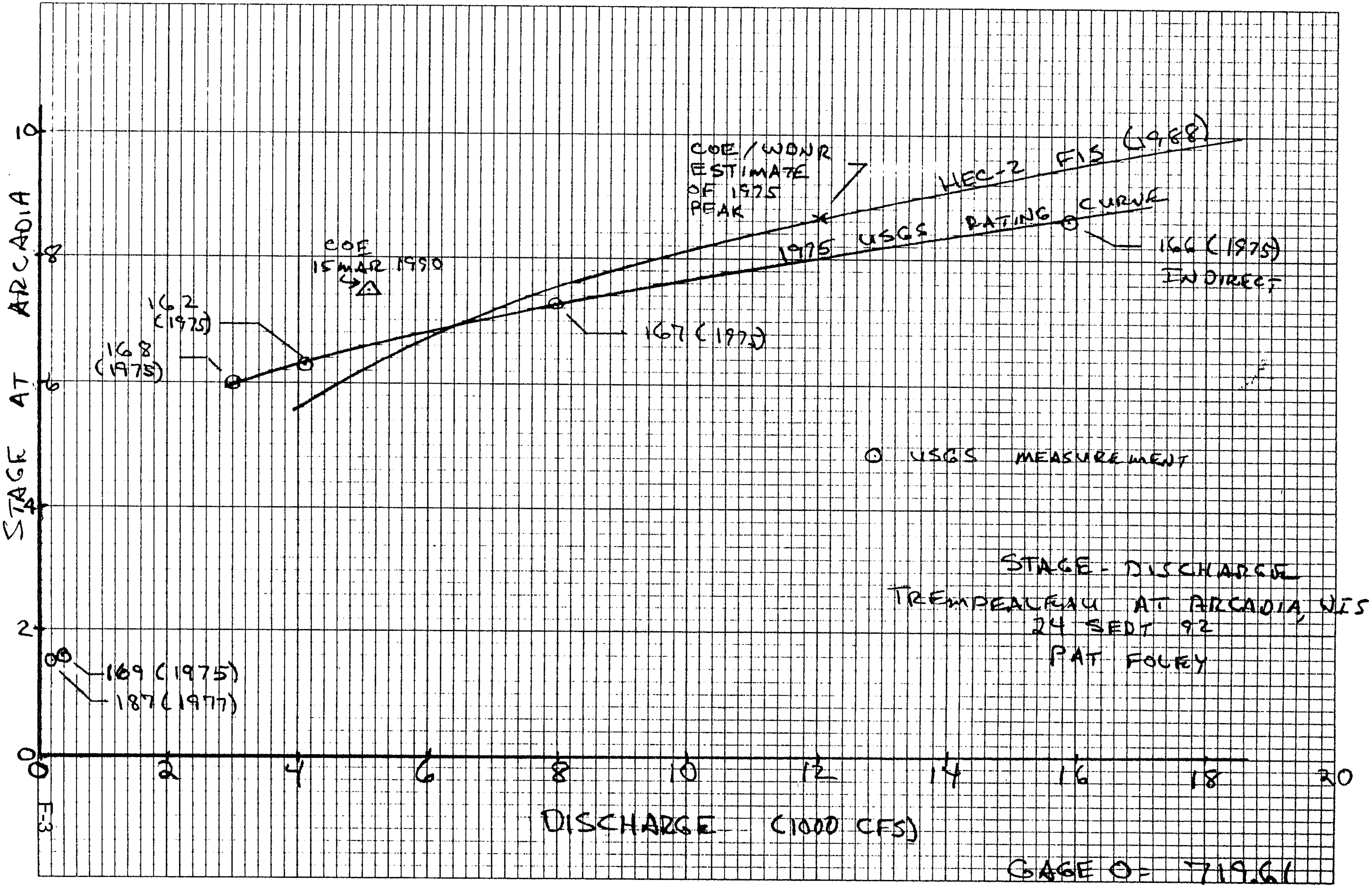
5. On 21 Sept 92 I called Barry Holmstrum of the USGS and discussed the variations in the rating curve. He said both Arcadia and Dodge are sand channel rivers with lots of movement of the rating curve. He said the discharge measurement at Dodge (7650 cfs at 11.35) was a shift of 0.44 feet from the rating curve. He said the rating curve gives a discharge of 10,800 cfs at a stage of 11.4. The 1992 actual discharge at this stage was about 8,000 cfs. Barry said this amount of shift is large but not that unusual.

6. If the rating curve at Arcadia was just fluctuating up and down it would not be as important to get new measurements. However, our FIS study indicated the channel bottom was aggrading with time. The attached graph shows the last USGS rating curve; the one we developed for the flood insurance study; and a discharge measurement made by the Corps in 1990. The proposed USGS measurements would be used to determine if there is a general trend towards a higher rating curve or if the variation is just the normal shifts seen in sand bed channels.

Encl:
1. As stated
2. MFR on 1990
   Discharge Measurement

PATRICK M. FOLEY, P.E
Supervisory Hydraulic Engineer
Hydraulics Section
Geotechnical, Hydraulics
 and Hydrologic Engineering Branch

cf: John Seeman, FFC


COE/WDNR ESTIMATE OF 1975 PEAK
HEC-2 FIS (9.88)
1975 USGS RATING CURVE
COE 15 MAR 1990
162 (1975)
168 (1975)
167 (1975)
166 (1975) INDIRECT
169 (1975)
187 (1977)
⊙ USGS MEASUREMENT
STAGE-DISCHARGE
TREMPEALEAU AT ARCADIA, WIS
24 SEPT 92
PAT FOLEY
STAGE AT ARCADIA
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
DISCHARGE (1000 CFS)
GAGE 0 = 719.61

CENCS-ED-GH (1110-2-1403)

12 April 1990
Foley/jl/610

MEMORANDUM FOR RECORD

SUBJECT: Impact of March 1990 Arcadia Discharge Measurement on Past Hydraulic Studies

1. Summary:

The March 1990 discharge measurement on the Trempealeau River at Arcadia, Wisconsin, tends to confirm that flood stages for a given discharge are increasing at Arcadia. The measurement indicates the existing conditions water surface profiles used in the flood control project study for the more frequent floods are probably low and benefits understated. Because this was only one measurement at a discharge far below the 100-year (5060 cfs vs 14400 cfs), I do not feel a reanalysis of the FIS hydraulics is warranted.

2. Data:

The attached Memorandum for Record by Kent Spading, enclosure 1, describes the discharge measurement made on 14-15 March 1990 at Arcadia. They measured a discharge of 5060 cfs at an average stage of 7.46 which equals elevation 727.07. From their measurements, the width was 157.5 feet and the flow area 1262.7 square feet. From this the average bottom elevation was stage -0.5 or elevation 719.1. The peak stage occurred on 14 March and was 7.96 or elevation 727.57. At the time of the peak stage, the left bank levee downstream of the bridges (furniture factory side of the river) had to be raised to provide protection.

3. Discussion:

a. The data collected in 1990 was compared to the FIS hydraulic study results. The FIS results were used for existing conditions for the flood control study. One of the conclusions of the FIS was that the channel bottom has been aggrading and flood stages for a given discharge have been increasing and would likely continue to increase in the future. The 1990 discharge measurement tends to confirm this. The measured point is shown on enclosure 2, as are the rating curves developed from the HEC-2 FIS model and from the last USGS discharge measurements. The USGS last measurement was in 1977. The 1990 point is about 1 foot above both rating curves. For an elevation of 727.1 the HEC-2 rating curve gives 7900 cfs and the USGS curve gives 9100 cfs, as compared to the 1990 flow of 5060 cfs. The last high measurement the USGS made was 7920 cfs at elevation 726.87 (stage 7.26) in 1975. Note that this is over 50% more flow than the 1990 measurement at a slightly lower stage. The 1990 measurement tends to confirm the prediction of increasing stages for given flood discharges. However, it is important to note that this was just one measurement at a fairly low flood flow and it can only be said that it tends to confirm the trend not that it definitely confirms the trend. On enclosure 2 the average bottom elevation from 1990 is compared to previous measured bottom elevations. This plot does **NOT** tend to confirm the trend of rising bottom elevations. The 1990 bottom elevation is not above the 1970-77 curve, which is what would be expected if the assumption of continuing aggradation of the bottom were correct. The reason the stage would increase if the bottom has not raised is not readily apparent to me. However, since this is only one measurement and because scour at bridges can be erratic, it is probably not worth spending time analyzing this apparent inconsistency.

b. The 1990 flood required raising the local levees. The river peaked 0.5 foot above the stage at the time of the measurement. With only one measurement it is not possible to develop a rating curve to accurately define the peak discharge. However, assuming the rating curve parallels the past USGS curve, I get a peak discharge of about 7600 cfs. This is less than a 10-year flood. This points out the low protection afforded by these levees.

3 Encls
1. MFR-Spading
2. Elevation Discharge Curve
3. Avg. Bottom Elevation Discharge Curve

PATRICK M. FOLEY
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Copy furnished w/Encls:
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extra

CENCS-ED-GH (1110-2-1403) March 23, 1990

MEMORANDUM FOR RECORD

SUBJECT: Summary of a flood reconnaissance trip to Arcadia, Wisconsin following a rain storm the week of 11 March 1990.

1. On 14 March 1990, Kenton Spading and Marvin Hrdlicka departed for Arcadia, Wisconsin to investigate a storm that passed through the area on 13 March 1990. Arcadia received 0.75 inches of rain on 11-12 March. One to two inches of rain were reported in the area on 13 March. An additional inch of rain fell on 14 March. A local meteorologist (Jim Skroch) reported that the resulting runoff was increased by the existence of frost and up to two feet of snow on the north side of hills in the valleys tributary to the Trempealeau River.

2. On the morning of 14 March the City reported that the river had risen to the top of the levees in town. A report was also received from Independence, Wisconsin saying that ice had torn the stop logs out of the dam on Bugle Lake at 0300 on 14 March resulting in a loss of the pool.

3. After arriving in Arcadia, we meet with Mr. David Krett (water superintendant), Mr. David Kokott (street superintendant), the Chief of Police, and some county officials. The City started raising the levees along the Trempealeau River with sandbags at 0400 on 14 March 1990 due to the threat of rising water. The river peaked at 1340 on 14 March 1990 near the top of the levee at a stage of 7.96 feet. (gage zero = 719.61 feet (1929 NGVD)) The City had no significant flood damage to report. Some street intersections were flooded and a few houses near the mouth of Turton Creek were damaged due to storm sewer backup. The County had to close a number of roads due to high water.

4. Our mission involved coordinating with local officials, measuring the discharge in the river, and setting high water marks.

a. The discharge on the Trempealeau was measured from the Highway 93/95 bridge in Arcadia starting at 2216 on 14 March at a stage of 7.60 feet. The stream gaging operation was concluded at 0310 on 15 March at a stage of 7.32 feet. The resulting discharge was 5060 cfs.

b. Water surface elevations were recorded both upstream and downstream during the stream gaging operation. In addition, high water marks were recorded both upstream and downstream.

5. The bed of the Trempealeau at Arcadia erodes significantly during periods of high flow. During periods of normal flow the deposition of sediment raises the elevation of the bed. As a result, the elevation-discharge curve at Arcadia is not constant. The attached cross section plot compares various measured and assumed cross sections.

6. If you have questions, please feel free to call myself (220-0611) or Marv Hrdlicka (220-0628).

Kenton Spading

KENTON E. SPADING
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Hydrology Section
Geotechnical, Hydraulic
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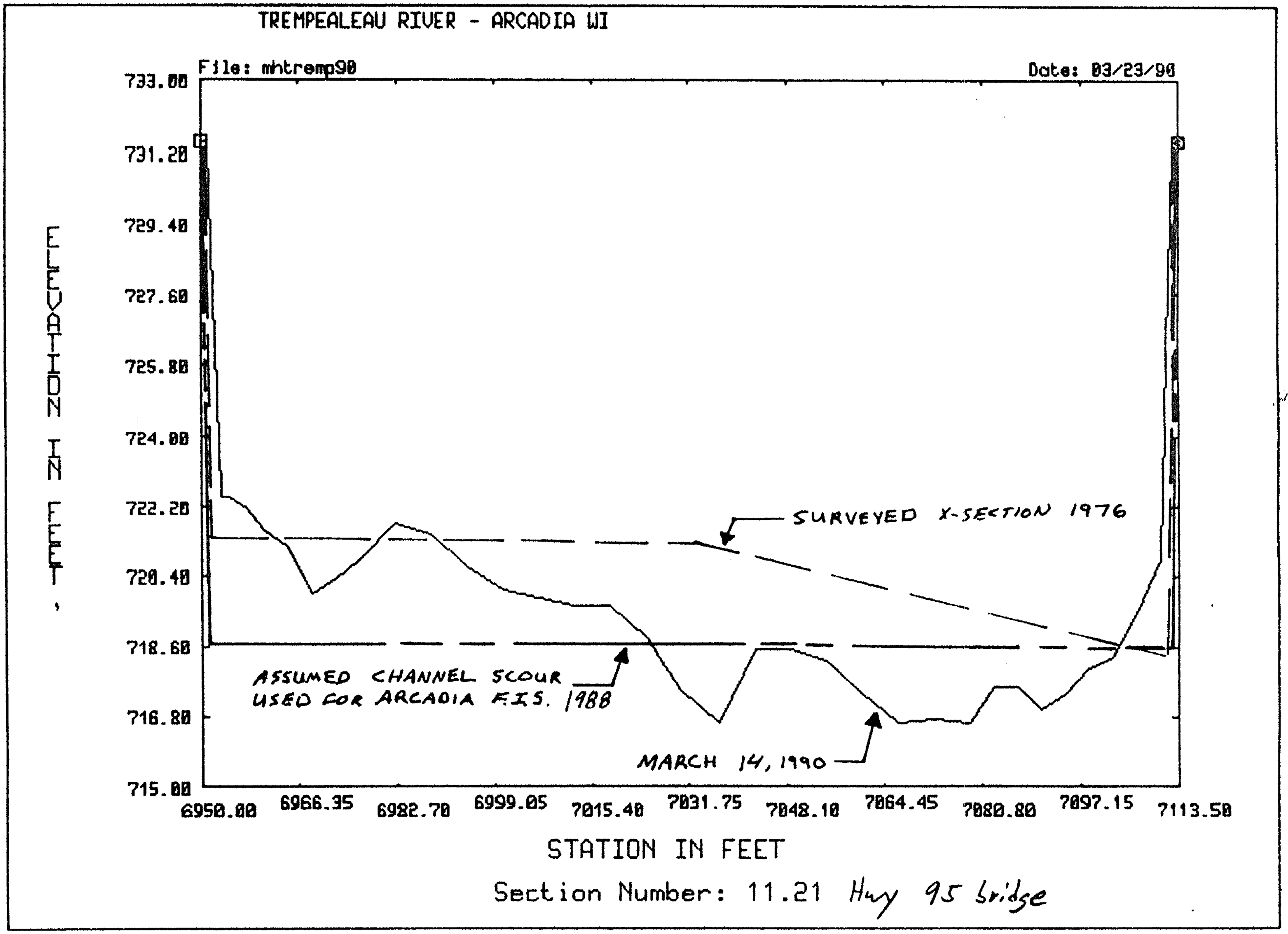
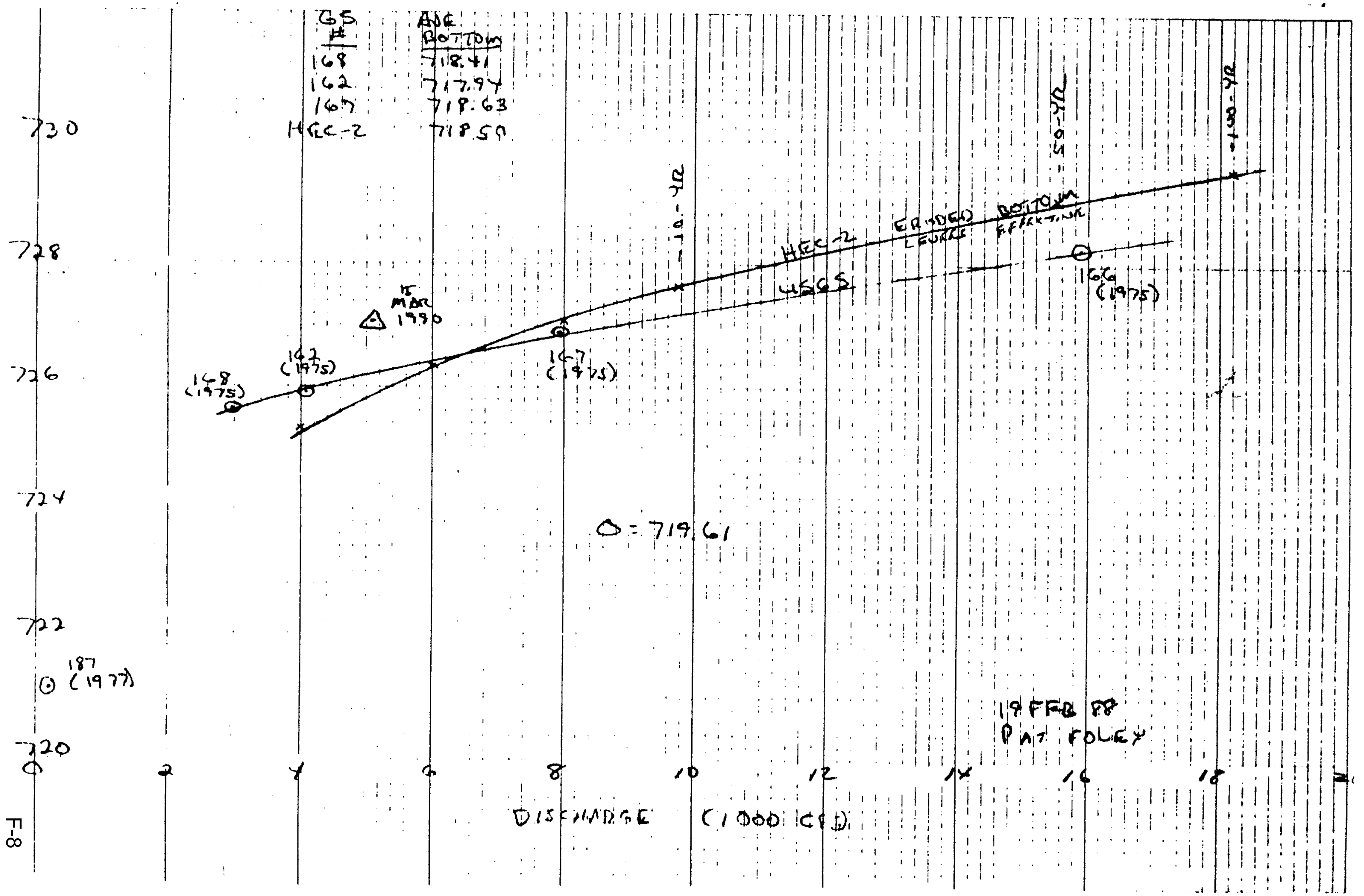
Encl 1

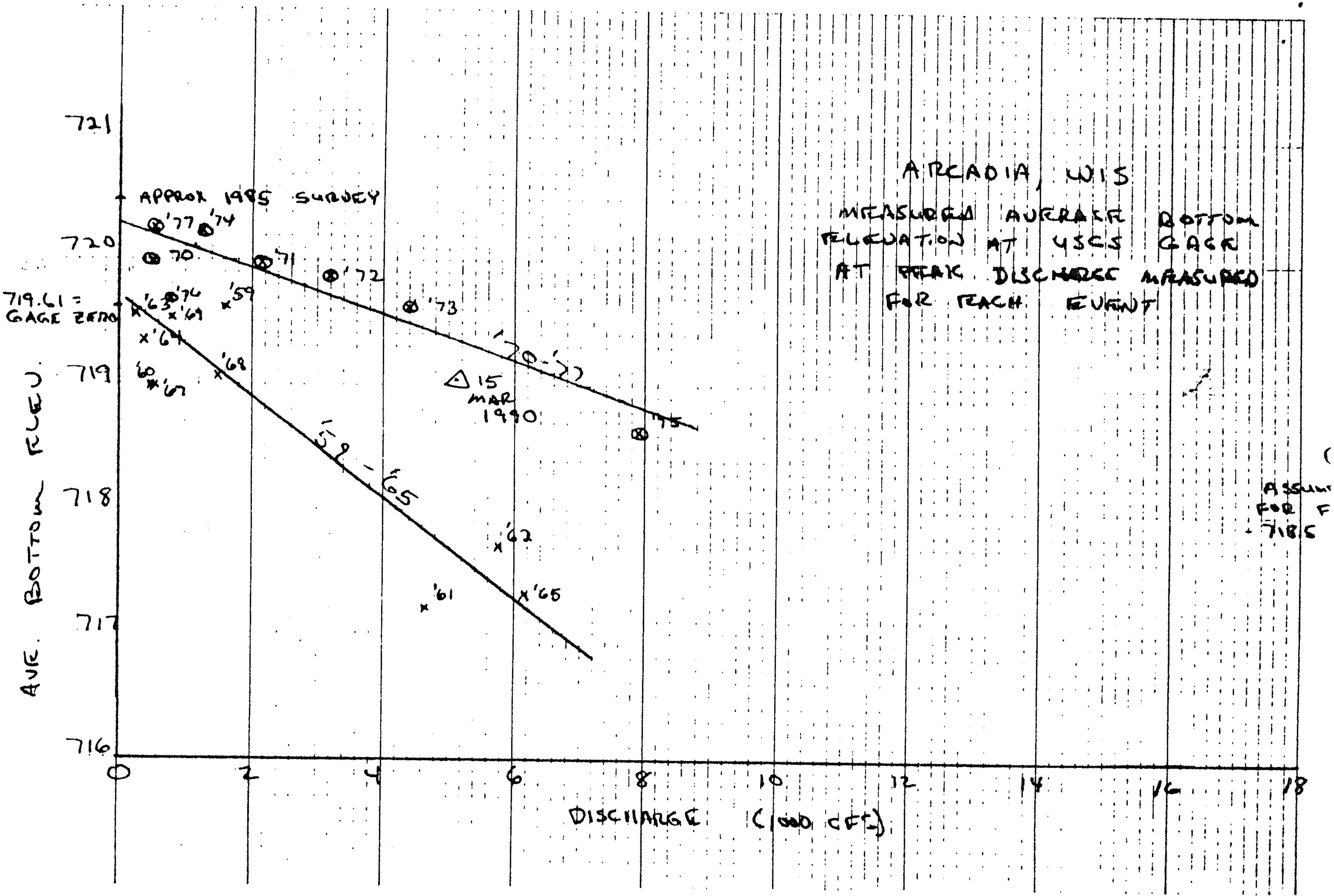

TREMPEALEAU RIVER - ARCADIA WI
File: mhtremp90
Date: 03/23/90
ELEVATION IN FEET
733.00
731.20
729.40
727.60
725.80
724.00
722.20
720.40
718.60
716.80
715.00
6950.00
6966.35
6982.70
6999.05
7015.40
7031.75
7048.10
7064.45
7080.80
7097.15
7113.50
STATION IN FEET
SURVEYED X-SECTION 1976
ASSUMED CHANNEL SCOUR
USED FOR ARCADIA F.I.S. 1988
MARCH 14, 1990
Section Number: 11.21 Hwy 95 bridge



GS #	AVE BOTTOM
168	718.41
162	717.94
167	718.63
HEC-2	718.50

19 FEB 88
PAT FOLEY

ENCL ~~6~~ 2

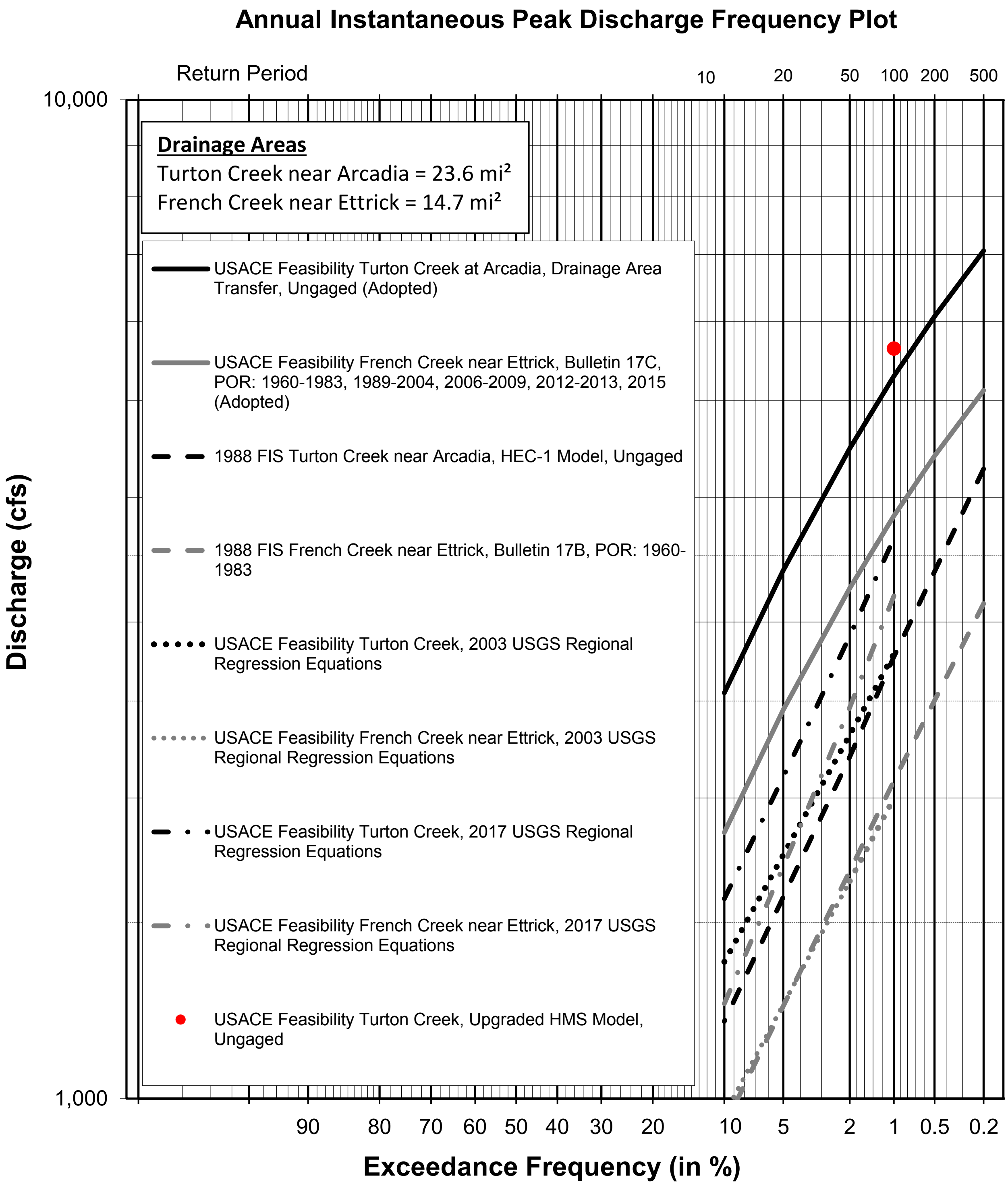


ARCADIA, WIS

MEASURED AVERAGE BOTTOM ELEVATION AT USGS GAGE AT PEAK DISCHARGE MEASURED FOR EACH EVENT

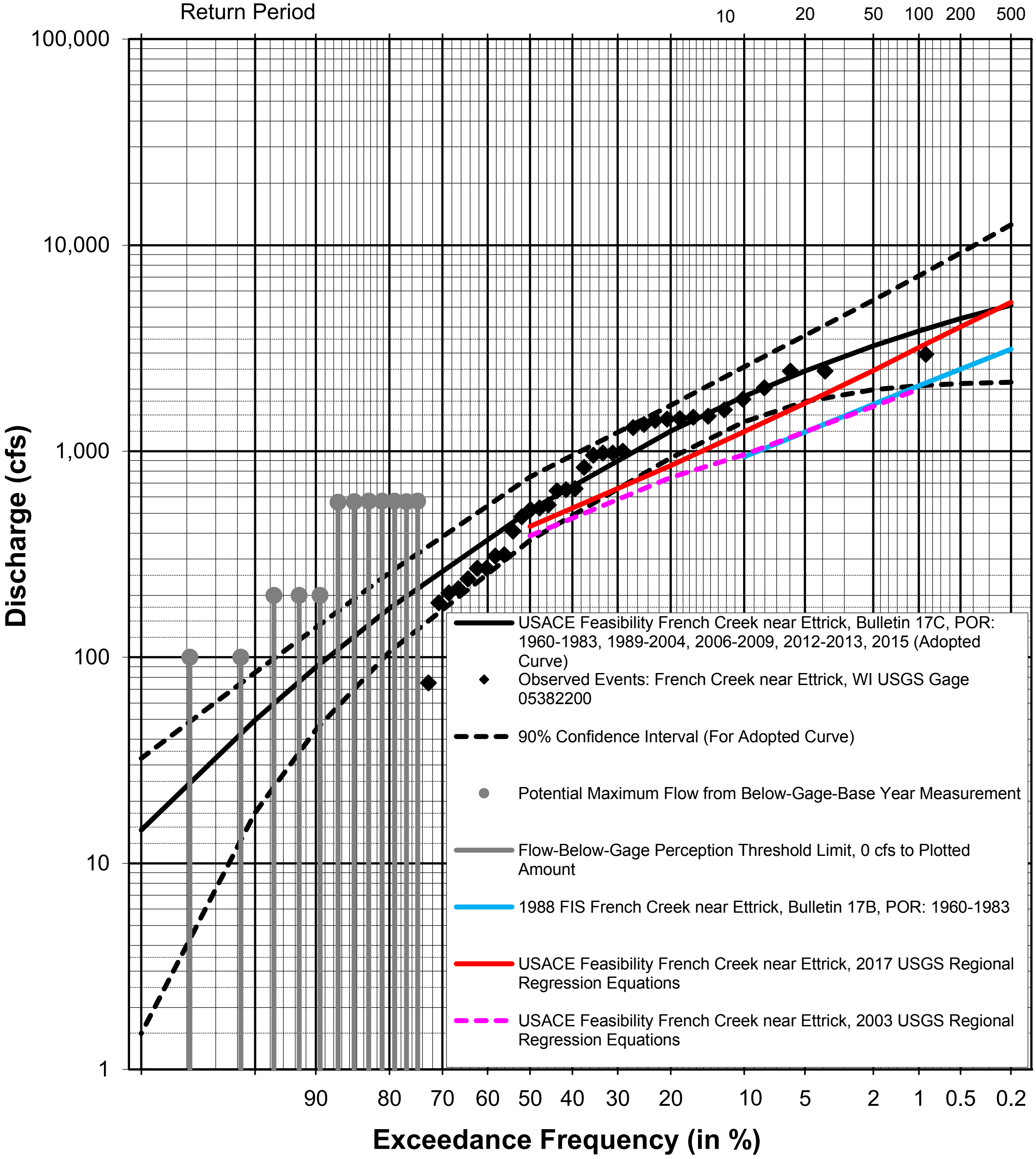
ENCL ~~8~~ 3

Appendix G: Select Frequency Curve Comparison



Turton Creek at Arcadia, WI (Ungaged)
French Creek near Ettrick, WI (USGS Gage 05382200)
Flow-Frequency Analysis
Comparison of Results

Annual Instantaneous Peak Discharge Frequency Plot



French Creek near Ettrick, WI
USGS Gage ID 05382200
Flow-Frequency Analysis
Comparison of Analytical Methods to USGS Regression
Equations for a Site with Observed Data
Annual Instantaneous Peak Flows
Drainage Area: 14.7 sq. mi

Appendix H: USACE St. Paul District 1985 Regional Skew Map

GENERALIZED SKEW COEFFICIENTS
OF
ANNUAL MAXIMUM STREAMFLOW
ST. PAUL DISTRICT BOUNDARIES

MSE = 0.125

Z10-1-5