Environmental Flows for the Huron River System

Zhenyue Duan, Chuck McDowell, Summer Roberts, Yu-Chen Wang, Xin Xu

A project submitted in partial fulfillment of the requirements
for the degree of Master of Science (Natural Resources and Environment)
at the University of Michigan
April 2014

Faculty Advisors: Dr. Allen Burton and Dr. Catherine Riseng

Acknowledgements

We thank our faculty advisors, Dr. Allen Burton and Dr. Catherine Riseng, for sharing their expert knowledge, thoughtful suggestions, and network of contacts as they helped to guide our exploration and analysis of this project.

We also acknowledge many other people who contributed their time, knowledge, resources, or data to the project. We thank Elizabeth Riggs and her colleagues from Huron River Watershed Council for providing directions and background information for this project. We thank Dr. Mike Wiley (SNRE), Dr. David Allan (SNRE), Dr. Jim Diana (SNRE), Dr. Drew Gronewold (NOAA), Timothy Hunter (NOAA), and Dr. Troy Zorn (MDNR) for sharing their resources and knowledge on fluvial systems, hydrology, and aquatic ecology. We thank Michael Saranen (Ford Lake Dam), Molly Robinson (City of Ann Arbor), David Kirkbach (Kent Lake Dam), Mike Brahm-Henkel (Kent Lake Dam), Rachol Cynthia (USGS), Thomas Weaver (USGS), and Stephanie Beeler (USGS) for providing data and information on dams and gauges on the Huron River.

We would also like to recognize the support received from the School of Natural Resources and Environment in conjunction with Rackham Graduate School, which helped to make this project possible.

Table of Contents

Abstract

This project aimed to provide the client, the Huron River Watershed Council (HRWC), with a framework for assessing flow alteration and its impact on the biological community of the Huron River. Within the watershed, analyses on annual, monthly, daily and sub-daily hydrological data, precipitation, land cover change, and fish and benthic invertebrate communities were conducted.

Most hydrologic parameters concerning flow volume demonstrated an upward or non-changing pattern for the most recent 100 years. The base flow gradually increased, while the reversal number gradually decreased, suggesting a more stable flow regime. In terms of daily and sub-daily flow regime, the largest flashiness was demonstrated by the gauge near Ann Arbor, which could be the result of dam regulation in the upstream region.

A strong correlation was found between precipitation and flow discharge. Both precipitation and flow discharge showed a similar increasing trend, while the runoff coefficient did not change significantly over time. This result implies that the increase in precipitation is a major driver of flow increase. With the current climate change trend, more water is expected in the river. Furthermore, increased impervious land in the watershed has resulted in more runoff from rainfall events and led to higher flashiness in the river. The corresponding increase of fine substrate and pollutants has also had a negative impact on stream habitats for benthic macroinvertebrates.

At sample sites along the river, fish preferences (e.g. water temperature, stream size, substrate type, etc.) defined two guilds: riverine and impoundment. In impoundment environments, a high percentage of the sample taxa were: game fish, tolerant species, substrate generalists, piscivores and had preferences for larger rivers and slow current velocity. Conversely, in riverine environments, a high percentage of the sample taxa were: darters, intolerant species, insectivores, and had preferences for rock or gravel substrate and wider range of current velocities.

Along the Huron River main stem, a habitat suitability model was used to predict expected fish communities at a given site and then compared to sampled fish communities. Fish communities around Ann Arbor and Ypsilanti were found to not be representative of model communities for the river type, temperature, and size. Present fish communities preferred a flow range with a significantly higher upper bound. An Adverse Resource Impact occurs in Ann Arbor at a low flow of around 45 cfs and in Ypsilanti at around 51 cfs. This serves as the critical low flow value for management purposes. Ann Arbor has the highest amount of historic ARI occurrences throughout the Huron River indicating that it is necessary to prioritize dam operations associated with this site.

1 Introduction

The Importance of Hydrologic Regime

The hydrologic regime of a river plays a crucial role to river ecology. The variation in the flow rate shapes the abiotic environment, which in turn, dictates the biotic elements of the ecosystem. Predation and competition are the predominant factors influencing biotic communities at small temporal and spatial scales; however, the impact of the hydrologic regime on the abiotic environment operates over millennia and significantly constrains the range of biotic interactions (Poff and Allan 1995, Lytle and Poff 2004, Biggs et al. 2005). Other numerous temporal scales can also be used to describe river flows: flood peaks, which operate on the order of minutes to hours; extreme low or high flow events, which can occur over a period or days; droughts, which can span months or years; to the decadal effect of climate change on precipitation and evapotranspiration within the watershed.

In addition, population size and species diversity is regulated by hydrologic disturbances, such as droughts or flood, which generally operate on a predictable spatial and temporal scale for a particular system (Lytle and Poff 2004). Organisms have evolved with, and consequently depend upon, the timing, frequency, and duration of flow events, such as flooding or low water, in their specific habitats to complete their life cycles (Poff et al. 1997). The natural flow pattern of water, sediments, and other organic materials maintain river ecosystem integrity by facilitating these life cycle events and modifying habitat (Richter et al. 2006).

Human activities often directly and indirectly affect stream flows. An example of an indirect affect is land use change within the watershed. As forest land is developed for urban and agricultural use, drainage patterns are altered, and the expansion of impervious cover in urban areas increases runoff into nearby water bodies (Bledsoe 2009). Flashy floods, which might scour bottom substrate, displace aquatic invertebrates, and wash away fish eggs and fry could result. Additionally, increases in runoff from cities or agriculture often increase the amount of pollutants or nutrients entering a system (Hay-Chmielewski et al. 1995).

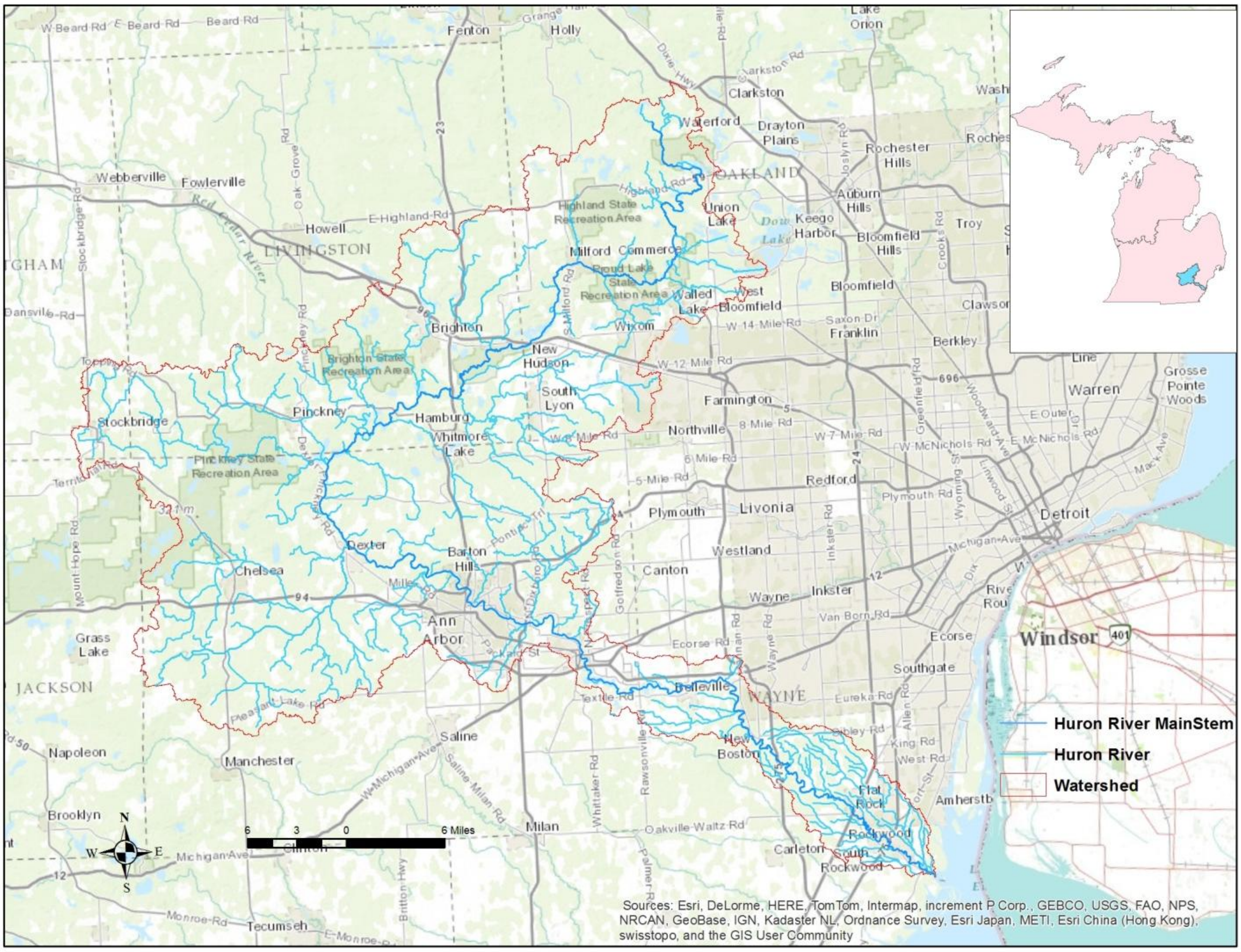
An example of a direct affect on flow regime is dams, which may be constructed for flood mitigation, hydropower, irrigation, municipal water needs, or recreation. Dams fragment nearly two-thirds of the largest rivers on Earth and, in the United States, less than 2% of rivers remain relatively undeveloped with an intact natural flow regime (Richter et al. 2006). The alteration of river flow, particularly in association with damming, has been acknowledged as a leading cause for global declines in freshwater diversity (Bunn and Arthington 2002, Richter et al. 2006). Hydrologic alteration in a highly regulated river can result in sediment accumulation, warmer surface waters and eventually hyper-eutrophication (Bunn and Arthington 2002).

The Huron River Watershed

The Huron River watershed is approximately 900 square miles in size and flows through the southeast Michigan counties of Oakland, Ingham, Livingston, Washtenaw, Monroe, and Wayne. The Huron River system contains approximately 367 linear miles of streams and drains and the mainstream is roughly 125 miles long (MDNR 2002). The main stem originates from north central

Oakland County and meanders south into Lake Erie. Flow alteration due to indirect and direct affects, especially dams, has occurred over time as human demands on the system have increased. The extent of flow alteration and the feasibility of restoring it to a more natural flow regime depend on the particular characteristics of the system, as well as the historic and current conditions.

Figure 1.1 The Huron River watershed



Historical Conditions and Trends

Climate

The Huron River watershed has a humid, continental climate and is influenced by its proximity to the Great Lakes. The Great Lakes region is a mixing zone for tropical and polar air masses characterized by frequent and sometimes rapid weather changes (MDNR 2002). The city of Ann Arbor is located along the Huron River in the downstream portion of the watershed and has an annual average of 30.6 inches of rainfall and 37-38 inches of snowfall (MDNR 2002). Some studies have shown that the amount of precipitation in the Midwest has increased overall. In the Midwest and Great Lakes basins, some significant upward trends of local precipitation were identified (Kunkel et al. 1999). So far, total annual precipitation has increased in Ann Arbor and southeast Michigan, mostly due to increases in winter and fall totals (HRWC 2013b).

Land Use/ Land Cover

The Huron River watershed has undergone tremendous physical transition over its long history of human habitation. Historically, the land cover of the watershed was primarily deciduous forest intermixed with prairies, but has been converted to a landscape dominated by agriculture cover with urban areas interspersed (Albert et al. 1986). Future build out projections predict a continuing trend of land cover change from natural forest cover to agricultural and urban lands (Hay-Chmielewski et al. 1995). For example, the vast majority of suburban growth in the Detroit metropolitan area is expected to occur within the watershed (Hay-Chmielewski et al. 1995), potentially exacerbating current interactions between the urban land use and the physical, biological, and chemical makeup of the river system. Without the implementation of best management practices and low impact development, water resources will be further strained and degraded.

Dam construction and operation

Table 1.1 Dams on the main stem of Huron River. Year indicates the year of dam construction or the most recent reconstruction. Location shows the location of dams in terms of USGS flow gauges on the main stem.

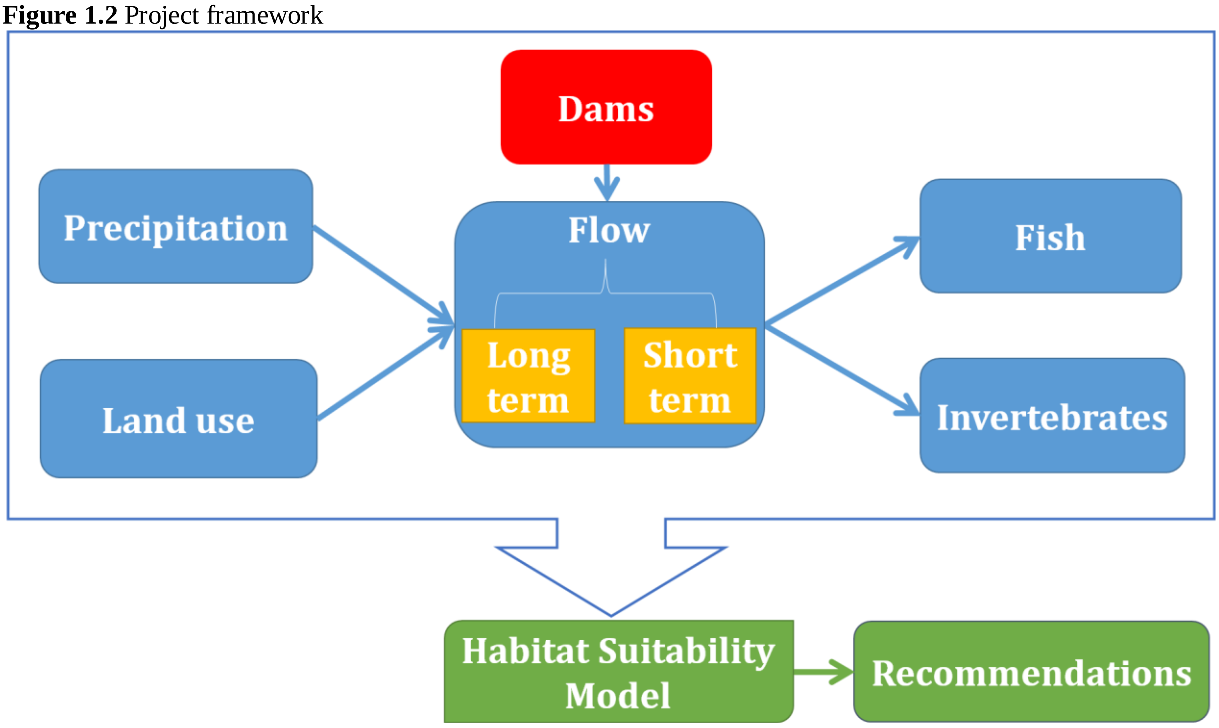
Dam	Year	Location
Peninsular Paper Dam	1914	Between "Ann Arbor" and "Ypsilanti"
Barton Dam	1915	Between "Dexter" and "Ann Arbor"
Commerce Dam	1915	Between "Commerce" and "Milford"
Pontiac Lake Dam	1920	Upstream of "Commerce"
Superior Dam	1920	Between "Ann Arbor" and "Ypsilanti"
Flat Rock Dam	1924	Downstream of "Ypsilanti"
French Landing Dam	1925	Downstream of "Ypsilanti"
Rawsonville Dam	1932	Downstream of "Ypsilanti"
Hubble Pond	1939	Between "Commerce" and "Milford"
Kent Lake Dam	1946	Between "Milford" and "New Hudson"
Proud Lake Dam	1962	Between "Commerce" and "Milford"
Oxbow Dam	1964	Upstream of "Commerce"
Cedar Island Lake Dam	1965	Upstream of "Commerce"
Flook Dam	1965	Between "Hamburg" and "Dexter"
Fox Lake Dam	1965	Upstream of "Commerce"
Big Lake Dam	1969	Upstream of "Commerce"
Argo Dam	1972	Between "Dexter" and "Ann Arbor"
Geddes Dam	1972	Between "Ann Arbor" and "Ypsilanti"

There are about 100 dams in the Huron River Watershed. Among them 18 dams are on the main stem of the Huron River (Table 1.1; modified from HRWC 2013a). Many of the dams in the Huron River Watershed are a few feet high, serving the purpose to slightly control the water level. However, some dams with larger size, most of which located on the main stem of Huron River, were built for mill or hydropower, creating large impoundment located on the upstream. Currently the main function of dams on the main stem of Huron River includes recreation, hydropower, and impoundment level controls (HRWC 2013a).

Dams alter the natural flow regime of the river, resulting in changes to the river ecosystem, and often impacting habitat for fish and invertebrates. However, it is possible that through collaboration and research, humans can implement ecologically based dam operation plans (Postel et al. 2003). In addition, for future dam management, it is also important to cope with the possible climate change scenarios. In the past, the dam operators on the main stem of Huron River usually worked independently, but this did not consider the fact that there is a network of dams on the main stem of Huron River. To facilitate the access of data and communication between dam operators in order to improve the efficacy of flow management and prepare for extreme events and droughts, the Instream Flows Workgroup was established in 2012 with the collaboration between the Huron River Watershed Council, Ypsilanti Charter Township, City of Ann Arbor, and operators of dams on the main stem. The Instream Flows Workgroup meets regularly, working to share data and information with the group members in order to improve the communication between dam operators (HRWC 2013a).

Project Framework

Figure 1.2 Project framework



A number of key research questions were considered in the formulation and the completion of this environmental flows assessment. These questions provided the framework and workflow for the various analyses which contributed to the finalization of the report. The three primary research questions were:

1) What are the historical drivers of flow alteration within the Huron River?

2) What are the ecological implications of flow alteration within the Huron River?

3) What are potential options for addressing the altered flow regime of the Huron River?

In answering these research questions, a number of analyses were completed looking at the historic and current conditions of the hydrology and biology of the Huron River. Figure 1.2 summaries the analyses and process of the study. Both long term and short term flow patterns were studied to determine both the historic and current flow regime for the Huron River. Biological patterns were also taken into consideration with detailed analysis of invertebrate and fish communities of the Huron River. To better inform the hydrological and biological studies, changing precipitation patterns as well as change in land cover was analyzed to determine the influence on the environmental flows of the river. To connect the observed hydrological and biological patterns of the Huron River, a habitat suitability model for the fish community was used to help inform a number of management recommendations and conclusions for flow management of the river.

Environmental flow recommendations and conclusions proposed through this study are focused on the Huron River main stem for the segment near Dexter, Ann Arbor and Ypsilanti, between Hudson Mills Metropark and Belleville Lake. Final recommendations apply to the site scale for this general reach.

Although the study primarily focused on the site and reach scale, it was necessary to conduct analyses at four scales in order to gain meaningful insight into the hydrological and biological process of the Huron River. The scales for which analysis was completed are: watershed, Huron River main stem, reach, and site. The background analyses of land cover and precipitation were conducted at the watershed scale. The long and short term flow analysis were completed at the main stem and reach scales. The biological analyses including the studies of invertebrate and fish communities were conducted at the site scale. Finally the habitat suitability model was applied to the reach and site scales. The USGS stream gages, invertebrate and fish sample sites, and dam locations used for these analyses are found throughout the Huron River main stem (Figure 1.3). The combination of these studies at various scales has provided a methodology that can be replicated to produce recommendations for locations throughout the Huron River main stem.

REFERENCES

Albert, D. A., S. R. Denton, and B. V. Barnes. 1986. Regional landscape ecosystems of Michigan. School of Natural Resources, University of Michigan. Ann Arbor 32.

Biggs, B. J. F., V. I. Nikora, and T. H. Snelder. 2005. Linking scales of flow variability to lotic ecosystem structure and function. River Research and Applications 21:283.

Bledsoe, B. P. 2009. Streams and Urbanization. Page 93. Springer US, Boston, MA.

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492-507.

Hay-Chmielewski, E. M., P. W. Seelbach, G. E. Whelan, and D. B. Jester Jr. 1995. Huron River Assessment.in F. D. Michigan DNR, editor.

HRWC. 2013a. Improving information access and communication among dam operations of the Huron River main stem. Huron River Watershed Council.

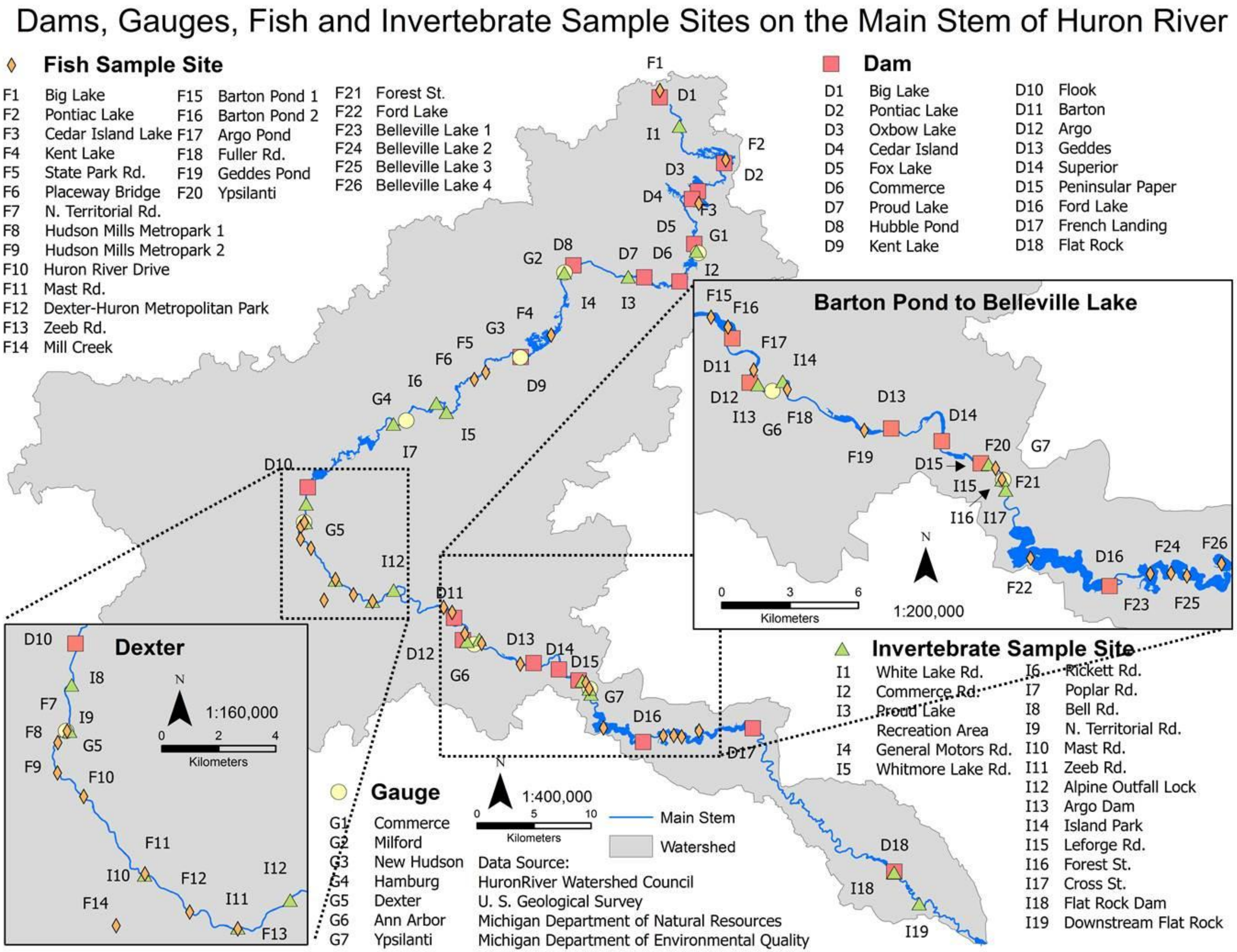
HRWC. 2013b. Review of climate impacts to tree species of the Huron River watershed. Huron River Watershed Council, Ann Arbor.

Kunkel, K. E., K. Andsager, and D. R. Easterling. 1999. Long-term trends in extreme precipitation events over the conterminous United States and Canada. Journal of Climate 12.

Lytle, D. A., and N. L. Poff. 2004. Adaptation to natural flow regimes. Trends in ecology & evolution 19:94.

MDNR. 2002. Huron River Plan.in M. D. o. N. Resources, editor.
Poff, N. L., and J. D. Allan. 1995. Functional Organization of Stream Fish Assemblages in Relation to Hydrological Variability. Ecology 76:606.
Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. Bioscience 47:769-784.
Postel, S., B. Richter, and T. N. Conservancy. 2003. Rivers for Life: Managing Water For People And Nature. Island Press.
Richter, B. D., A. T. Warner, J. L. Meyer, and K. Lutz. 2006. A collaborative and adaptive process for developing environmental flow recommendations. River Research and Applications 22:297-318.

Figure 1.3 Dams, gauges, fish and invertebrate sample sites on the main stem of the Huron River



2 Long Term Flow Analysis

There are two purposes for the long term flow analysis, to determine whether there is an upward or downward trend in flow rate and to identify whether an upward or downward trend exists in a gradual or abrupt change. Indicator of Hydrologic Alteration (IHA) software was applied to calculate the IHA flow parameters. Mann-Kendall Trend Analysis, Sen's slope Estimator, and Repeated Mann-Kendall Trend Analysis were then conducted to analyze each IHA flow parameters.

Methods

Gauge stations

There are seven U.S. Geological Survey (USGS) gauges on the main stem of the Huron River (Table 2.1). Flow rate (discharge) data, in cubic feet per second (cfs), from these seven gauge stations were downloaded from the USGS website (http://waterdata.usgs.gov/mi/nwis/rt). Annual and monthly flow data from all seven gauge stations were used for exploratory data analysis, while daily flow data from the gauge station "Ann Arbor" (USGS Site No. 04174500) were used for long term flow analysis because this gauge has data for the longest period of record (1914 to present) among all these gauges.

Table 2.1 Gauge stations on the main stem of the Huron River. Begin date and end date show the time span of flow data used in this section. Asterisk indicates the gauge is still functioning. Note that only the daily flow data from the Ann Arbor gauge were used for long term flow analysis.

USGS Site No.	Site Name (in this report)	Begin Date	End Date
04169500	Commerce	3/1/1946	9/30/1975
04170000	Milford	9/23/1948	9/30/2011
04170500	New Hudson*	8/20/1948	12/11/2013
04172000	Hamburg*	10/1/1951	12/11/2013
04173000	Dexter	3/1/1946	10/31/1977
04174500	Ann Arbor*	1/1/1914	12/11/2013
04174800	Ypsilanti	6/1/1974	9/30/1994

Exploratory Data Analysis

There are 18 dams on the main stem of the Huron River (Table 1.1). If the construction or management practices of a particular dam cause changes in discharge, the changes are revealed in flow time-series data from one or multiple downstream gauges. To detect potential impacts of the construction and management of dams on the Huron River, annual and monthly discharge data (1914 to 2012) from all gauge stations were plotted against years using the statistical software R (http://www.r-project.org/) and R package "ggplot2" (version 0.9.3.1). The year of dam construction or the most recent reconstruction for each dam was marked on the time-series plots using colored lines (Figure 2.1, Appendix 2). Red lines indicate dams located upstream of the gauge station, while purple lines indicate dams located downstream of the gauge stations (Table 1.1).

Table 2.2 IHA Parameters. Table adopted from User's Manual of Indicator of Hydrologic Alteration (The Nature Conservancy, 2009)

IHA Parameter Groups	Hydrologic Parameters	Notes
1. Magnitude of monthly water conditions	Mean or median value for each calendar month	Annual mean flow rate, which is not an IHA parameter, was also included in this analysis.
2. Magnitude and duration of annual extreme water conditions	1-day, 3-day, 7-day, 30-day, and 90-day max mean value	
	1-day, 3-day, 7-day, 30-day, and 90-day min mean value	
	Number of zero-flow days	
	Base flow index	Base flow index is defined as 7-day min mean flow divided by the annual mean flow
3. Timing of annual extreme water conditions	Julian date of each annual 1-day maximum	Group 3 IHA parameters were not applied in this report.
	Julian date of each annual 1-day minimum	
4. Frequency and duration of high and low pulses	Number of low pulses within each water year	Two ways to define a low pulse in this report. Q75 low pulse means a flow rate that is below the 75% percentile. One-SD low pulse means a flow rate that is below one standard deviation of the mean.
	Mean or median duration of low pulses (days)	
	Number of high pulses within each water year	Two ways to define a high pulse in this report. Q25 high pulse means a flow rate that is above the 25% percentile. One-SD high pulse means a flow rate that is above one standard deviation of the mean.
	Mean or median duration of high pulses (days)	
5. Rate and frequency of water condition changes	Rise rate	The mean or median of all positive differences between consecutive daily values
	Fall rate	The mean or median of all negative differences between consecutive daily values
	Reversals	Daily flow rate of one day was compared to the flow rate of the previous day to determine if the rate is larger or smaller than the previous day. From two consecutive days, if there is a change from "larger" to "smaller" or "smaller" to "larger", it is considered to be one reversal.

Indicator of Hydrologic Alteration

Indicator of Hydrologic Alteration (IHA) is a software program developed by The Nature Conservancy (Richter et al. 1996), aiming to calculate the characteristics of flow regimes. IHA software can calculate a total of 33 IHA parameters, which could be subdivided into five groups (Table 2.2; modified from The Nature Conservancy 2009). To understand the flow characteristics of the Huron River, daily flow data from the Ann Arbor gauge (10/1/1914 to 9/30/2012) were analyzed using IHA software to calculate IHA parameters from 1914 to 2012. All the IHA parameters in Table 2.2, except for the timing of annual extreme water conditions from Group 3, were calculated. The calculated IHA parameters were then imported to R to complete the Mann-Kendall trend analysis and Sen's slope estimator.

Mann-Kendall Analysis and Sen's Slope Estimator

Mann-Kendall trend analysis and Sen's slope estimator were applied to all the IHA parameters to determine whether there is a significant upward or downward trend and to depict a linear trend line showing the rate of change in terms of time, respectively. Mann-Kendall trend analysis is a non-parametric statistical method for detecting upward or downward trends in monotonic time-series data, which is widely applied in hydrologic time-series analysis (Mann 1945; Helsel and Hirsch 2002). This test reports a P-value, showing whether the pattern is significant, and a Kendall score, showing whether the trend is upward (positive Kendall score) or downward (negative Kendall score) (Helsel and Hirsch 2002). Sen's slope estimator is also a non-parametric method determining a linear trend line (Theil 1950; Sen 1968; Helsel and Hirsch 2002). The Sen's slope is the median of all the slopes calculated using all different coordinates of points in the time-series data, which could indicate the increasing or decreasing rate per unit time in time-series analysis (Helsel and Hirsch 2002).

To conduct the Mann-Kendall trend analysis and Sen's slope estimator, the R package "Kendall" (version 2.2) and R package "zyp" (version 0.10-1) were used, respectively. Finally, IHA parameters were plotted against years using R package "ggplot2".

Repeated Mann-Kendall Analysis

To have a comprehensive understanding of the pattern of flow rate change, the Repeated Mann-Kendall trend analysis, which was proposed by Zhang et al. (2010), was applied for all IHA parameters. This approach applied single Mann-Kendall trend analysis on all the possible subsets with different beginning and ending time in a time-series (Figure 2.3 and Figure 2.5, Appendix 2). The minimum duration of a subset is at least 10 years. The results were documented in two matrices. One matrix recorded the P-value of each trend analysis, and the other matrix recorded the Kendall score. The x-axis and y-axis of these two matrices show the beginning and ending years, respectively. These two matrices were then combined to generate a new matrix, in which each cell contained information whether the trend is significant (S) or non-significant (NS), and whether the trend is upward (U), downward (D), or non-changing (N). Finally, these different outcomes were color-coded to generate a matrix plot. Blue indicates a significant downward trend (S_D), while yellow indicates a significant upward trend (S_U). Light green means although Kendall score is positive, the trend is non-significant (NS_U), while cyan means although Kendall score is negative, the trend is non-significant (NS_D). Black means the trend is non-changing (NS_N). For its application in this project, an R function (Appendix 2) was written to conduct the above-mentioned analysis.

Repeated Mann-Kendall analysis can provide a comprehensive demonstration of the trend pattern in a time-series data. By setting the beginning time on the x-axis of the matrix plot, the trend of different ending time can be inspected. By setting the ending time on the y-axis of the matrix plot, the trend of different beginning time can be inspected. Trend patterns of any subsets with varying beginning and ending years that have durations larger than 10 years can be examined in the matrix plot. Moreover, this method can examine whether the changing pattern of flow rate is an abrupt or a gradual change. If the matrix plot reveals that all of the subset of time-series data, which have a beginning year before a particular period and an ending year after that period, show significant upward or downward trend, the changing pattern within the whole study period could have experienced an abrupt change. If there are no particular periods in which all the subsets show significant change, even though the overall time-series show a significant upward or downward trend, the changing pattern could be gradual. In the following section, Figure 2.3 and Figure 2.5 provide examples on how to interpret the matrix plot.

Results

Exploratory Data Analysis

Trend patterns of annual and monthly mean flow rate from different gauges were highly related (Appendix 2). Take the annual mean flow rate as an example (Figure 2.1). When one gauge shows an increase or a decrease of flow rate in a year, other gauges usually reveal the same trend. Therefore, it is unclear whether the construction of dams had impacts on flow rate pattern, since the trends of flow rate from different gauges usually have the same patterns. In other words, the impact of dam construction may not be evident on annual or monthly mean flow rate.

Table 2.3 Trend analysis of annual and monthly mean flow rate

Month	Mann-Kendall P	Sen's slope
Annual	< 0.001	2.200
January	< 0.001	3.056
February	0.024	2.306
March	0.083	2.156
April	0.904	0.105
May	0.014	2.219
June	0.014	1.853
July	0.011	1.093
August	< 0.001	1.177
September	0.005	0.917
October	0.004	1.225
November	< 0.001	3.416
December	< 0.001	3.287

Table 2.4 Trend analysis of monthly median flow rate

Month	Mann-Kendall P	Sen's slope
January	< 0.001	2.750
February	0.006	2.262
March	0.106	2.077
April	0.980	-0.039
May	0.016	2.125
June	0.012	1.705
July	0.043	0.797
August	0.001	0.821
September	0.020	0.682
October	0.004	1.106
November	< 0.001	3.438
December	< 0.001	3.300

Figure 2.1 Annual mean flow on the main stem of Huron River. Lines indicate the construction year of a dam. Red lines mean the dam locates on the upstream of the gauge. Purple lines mean the dam locates on the downstream of the gauge "Ypsilanti".

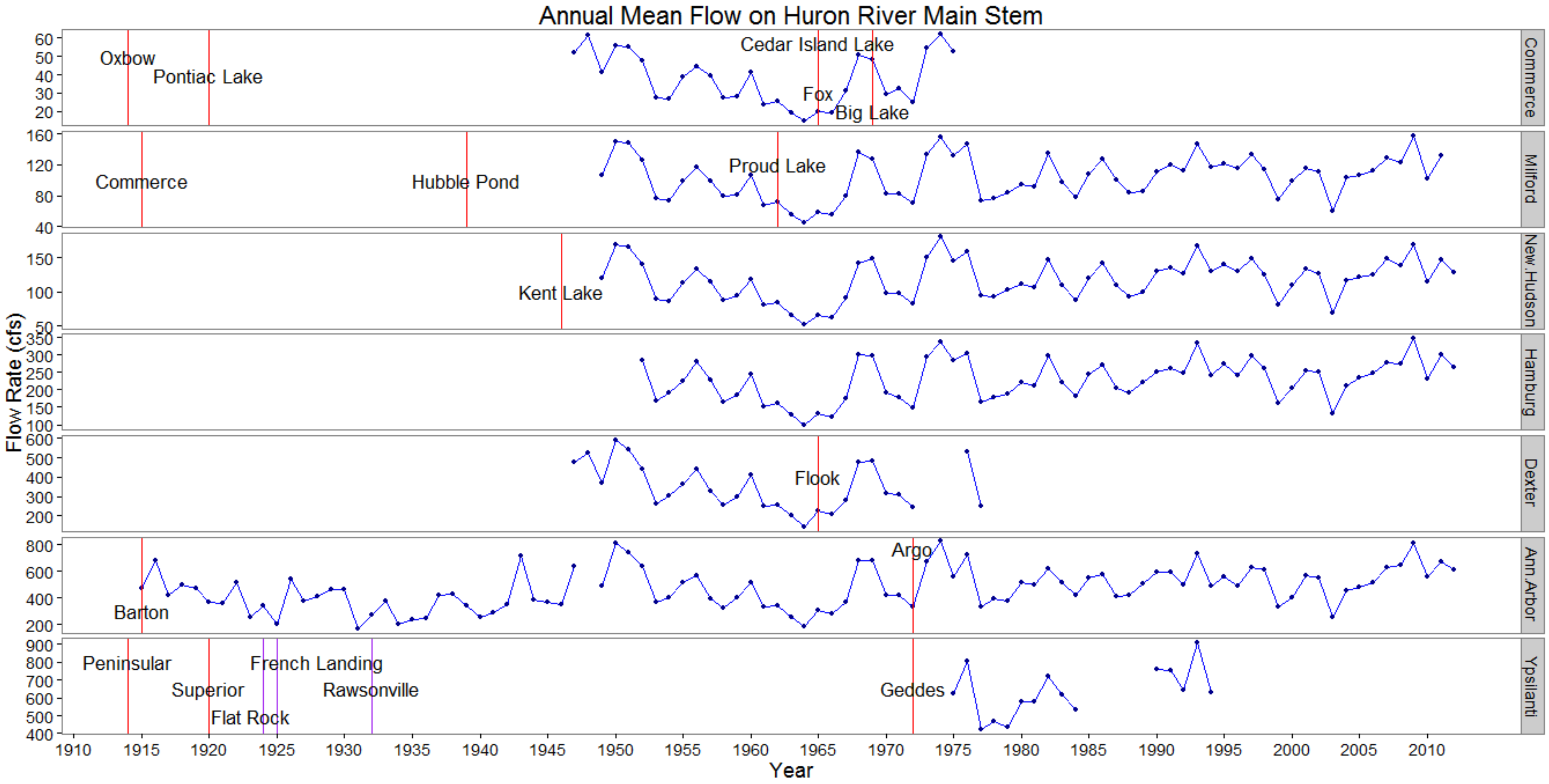


Figure 2.2 Annual mean flow of Huron River near the gauge "Ann Arbor". Red line shows the trend line using Sen's slope estimator.

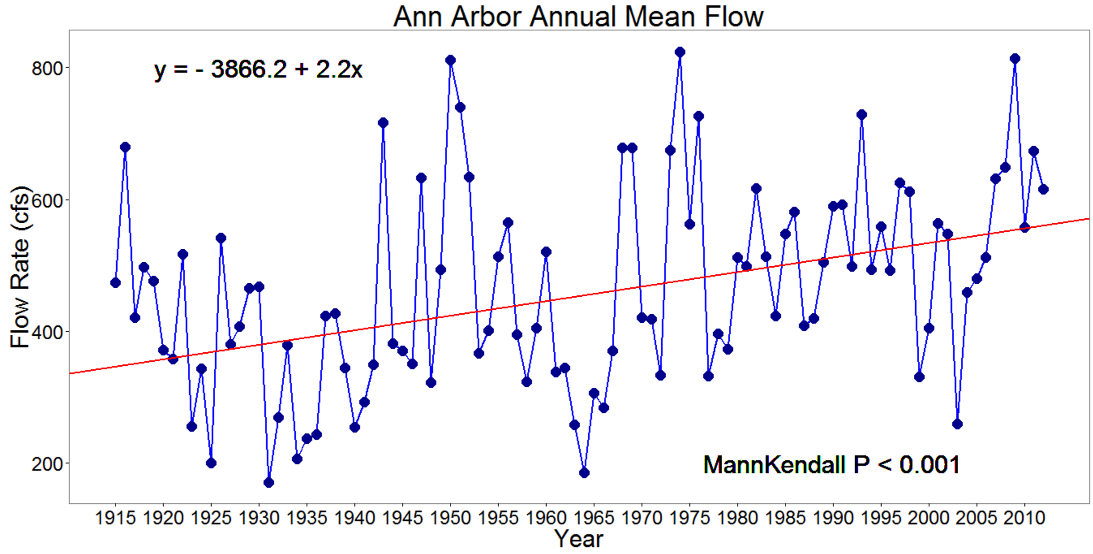


Figure 2.3 Repeated Mann-Kendall analysis on the annual mean flow. S_D indicates a significant downward trend. S_U indicates a significant upward trend. NS_D and NS_U mean an overall downward or upward trend, respectively, but the test result is not significant. NS_N indicates no change in trend. NA means no data.

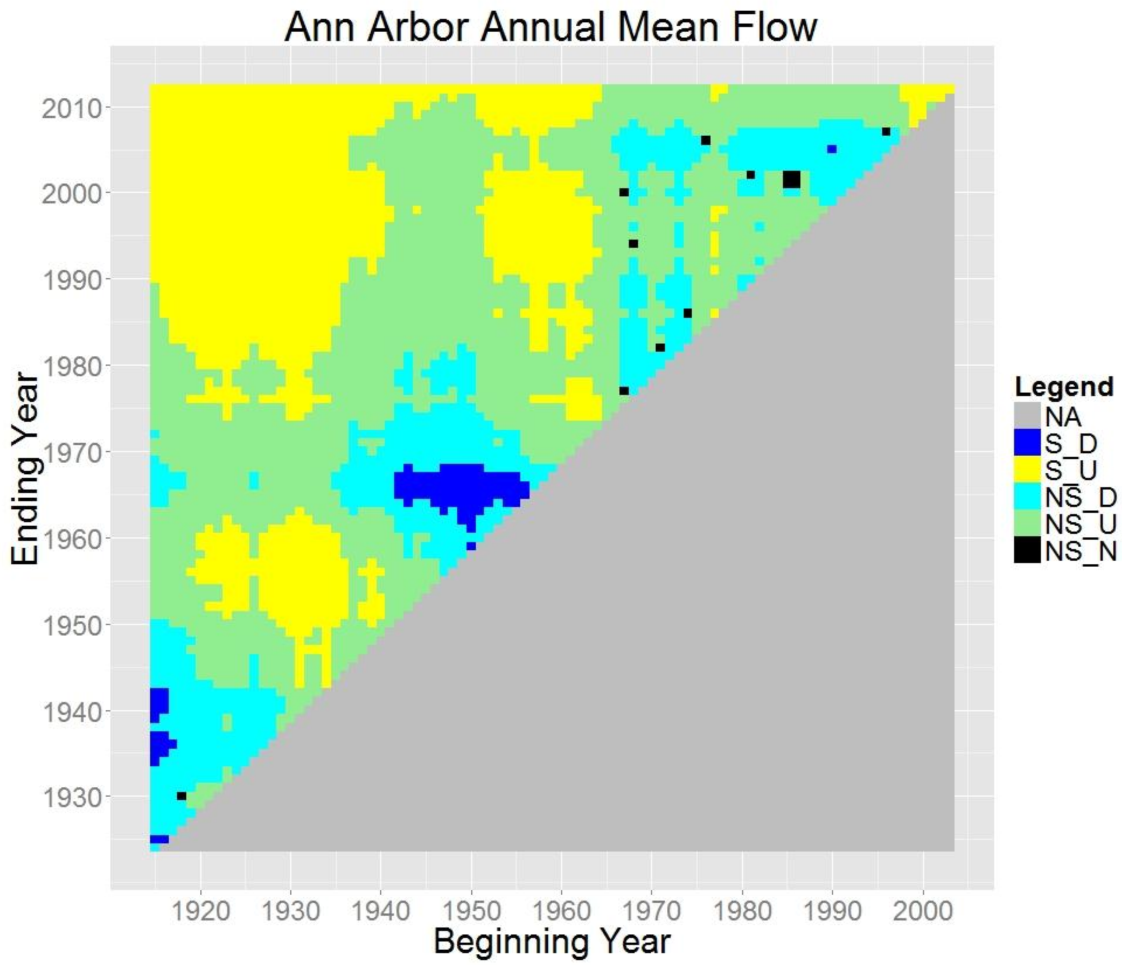


Figure 2.4 Reversals of Huron River near the gauge "Ann Arbor". Red line shows the trend line using Sen's slope estimator.

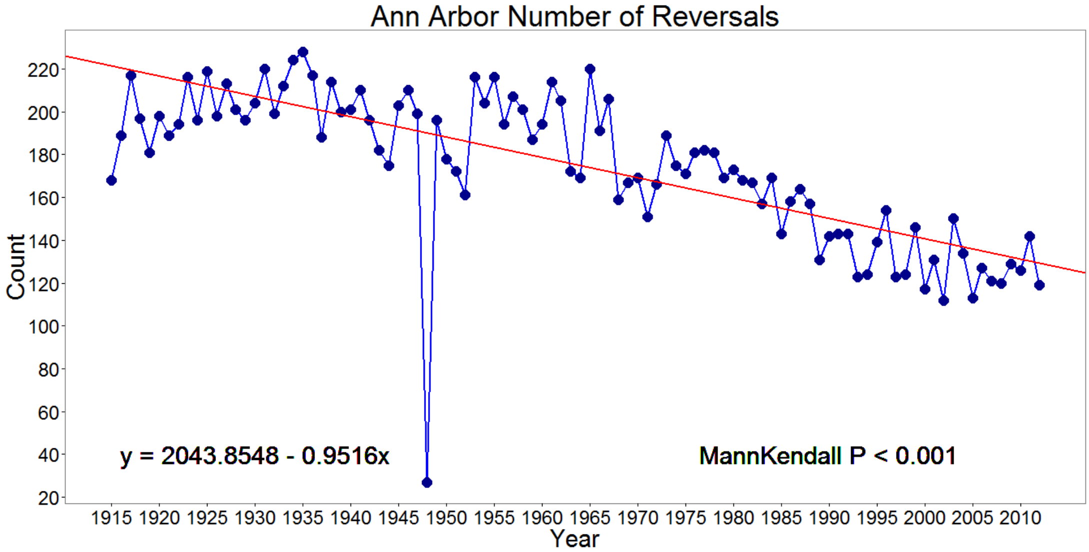
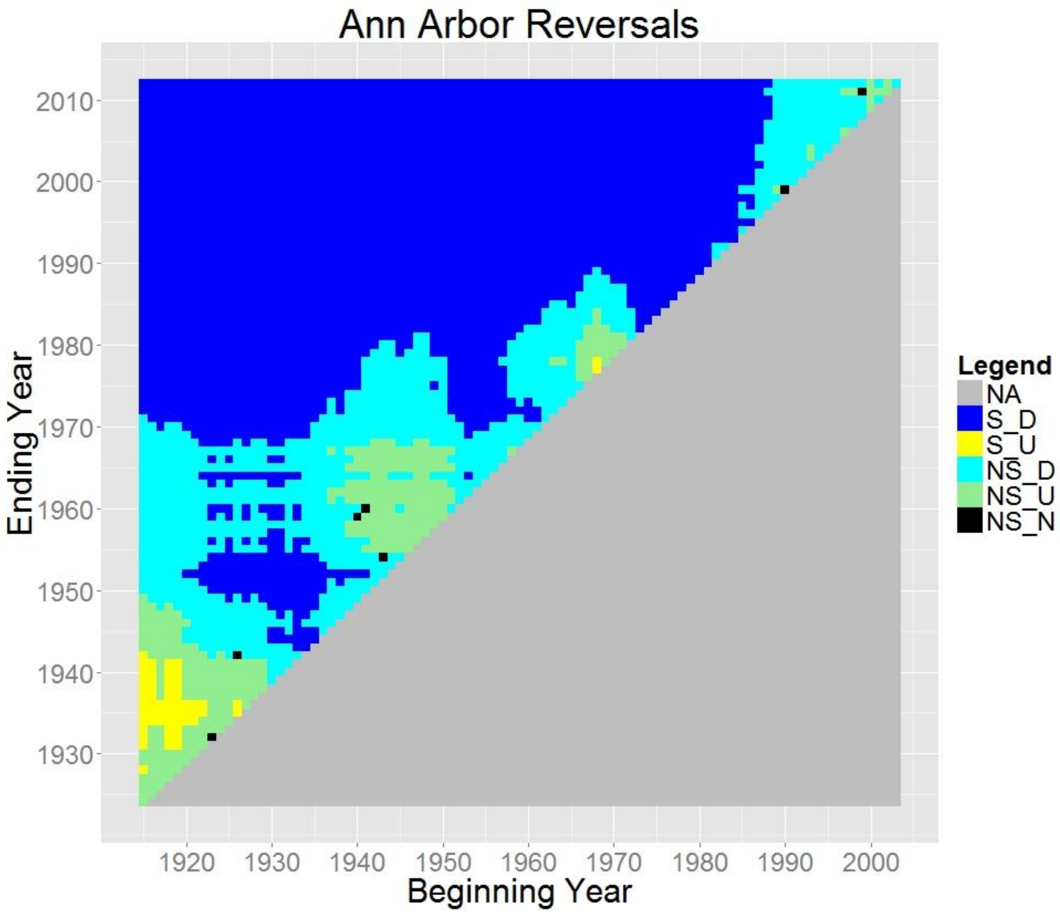


Figure 2.5 Repeated Mann-Kendall analysis on reversals. S_D indicates a significant downward trend. S_U indicates a significant upward trend. NS_D and NS_U mean an overall downward or upward trend, respectively, but the test result is not significant. NS_N indicates no change in trend. NA means no data.



Mann-Kendall Analysis and Sen's Slope Estimator

Table 2.3 and Table 2.4 summarize the result of Mann-Kendall trend analysis and Sen's slope estimator for Group 1 IHA parameters, including annual and monthly mean and median flow rate. All the mean and median values, except mean and median of March and April, show a significantly upward trend (Appendix 2). Annual mean flow shows a 2.2 cfs/year increasing rate based on Sen's slope estimator (Figure 2.2). Among all the calendar months, November shows the highest increasing rate in both mean (3.416 cfs/year) and median (3.438 cfs/year). Table 2.5 shows the result of Group 2 IHA parameters, which are the magnitude and duration of annual extreme water conditions. Most of the minimum magnitudes displayed significantly upward trend (Appendix 2). On the contrary, most of the maximum magnitudes did not display a significant upward trend (Appendix 2). The base flow index did not have significant changes. There were no zero flow days, so we were unable to perform Mann-Kendall trend analysis.

Table 2.6 summarizes the results of Group 4 IHA parameters, which are the frequency and duration of high pulse or low pulse events. The Q25 high pulse count is the number of flows ranked above the 25^{th} percentile. There was a significantly upward trend, while the Q75 low pulse count (number of flows ranked below the 75%) shows a significantly downward trend (Appendix 2). The Standard deviation high pulse count (flows higher than the mean plus one standard deviation) also shows a significantly upward trend, which is consistent with the trend of the Q25 high pulse count (Appendix 2). Other IHA parameters in this group could not be analyzed using Sen's slope estimator because of missing values and/or excessive zero values. Table 2.7 summarizes the result of Group 5 IHA parameters, demonstrating that mean and median rise rate significantly increased, but mean and median fall rate did not change (Appendix 2). The number of reversals (Table 2.2, the number of changes from increasing to decreasing flow rate in two consecutive days within one year), however, shows a significantly downward trend (Figure 2.4).

Repeated Mann-Kendall Analysis

Repeated Mann-Kendall Trend Analysis demonstrates that most of the IHA flow parameters show an upward trend. Moreover, if there is an upward trend it is usually a gradual increase (Appendix 2). Take the annual mean flow as an example. The matrix plot shows that when the beginning year is around 1914 to 1940 and the ending year is around 1980 to 2012, the results of Mann-Kendall Trend Analysis mostly are significant upward trend (Figure 2.3). As a result, comparing the first 30 years to the last 30 years of the study period, mean annual flow rate was significantly increased. Furthermore, we did not find a particular year that causes an abrupt increase in the time-series, suggesting that the increasing trend was probably gradual (Figure 2.3). Most of the other IHA parameters are similar to the annual mean flow, showing a gradual upward trend. The flow rate or parameter of the nearly last 30 years was significantly higher than the flow rate or parameter of the nearly first 30 years.

The number of reversal is one of the few exceptions that did not show a gradual upward trend. Moreover, the matrix plot shows an abrupt downward trend in the time series (Figure 2.5). This is because when a time-series subset has a beginning year before roughly 1970s to 1980s and an ending year after the same period, the results of Mann-Kendall Trend Analysis were mostly significantly decreasing, implying that an event occurred within this period may change the flow system, causing the number of reversal significantly decreased.

Table 2.5 Magnitude and duration of annual extreme water conditions.

Parameters	Mann-Kendall P	Sen's slope
One-day max mean	0.256	3.545
Three-day max mean	0.123	4.157
Seven-day max mean	0.068	4.119
Thirty-day max mean	0.207	1.900
Ninety-day max mean	0.042	2.145
One-day min mean	< 0.001	0.628
Three-day min mean	0.014	0.312
Seven-day min mean	0.111	0.221
Thirty-day min mean	0.022	0.433
Ninety-day min mean	< 0.001	1.195
Zero-flow days	-	-
Base flow index	0.189	0

Table 2.6 Frequency and duration of high and low pulses.

Parameters	Mann-Kendall P	Sen's slope
Q25 high pulse count	< 0.001	0.050
Q75 low pulse count	< 0.001	-0.059
Median of Q25 high pulse duration	0.634	-
Median of Q75 low pulse duration	0.010	0.011
One-SD high pulse count	< 0.001	0.036
One-SD low pulse count	< 0.001	-
Mean One-SD high Pulse Duration	0.921	-
Mean One-SD low Pulse Duration	0.184	-

Table 2.7 Rate and frequency of water condition changes.

Parameters	Mann-Kendall P	Sen's slope
Mean rise rate	0.005	0.216
Mean fall rate	0.754	-0.015
Median rise rate	0.029	0.075
Median fall rate	0.294	0.036
Reversals	< 0.001	-0.952

Discussion

The long term flow analysis show that most of the IHA flow parameters have significantly increased for the past 100 years, suggesting there has been more water on the main stem of the Huron River. We found that the annual mean flow rate and most of the mean and median flow rate of each calendar month show a significant increase for the nearly past 100 years. Among each calendar month, flow in November and December has experienced the largest increase rate, whereas flow in

March and April did not change much (Table 2.3 and Table 2.4). On the other hand, we found that most of the minimum magnitude in flow rate shows a significant increase; however, most of the maximum magnitude in flow rate shows an increase but without statistical significance. These results all suggest that the flow increase is most significant during winter but least significant during spring. Because most of the low flow magnitude occurred during summer, the significant increasing pattern of flow in summer can explain the significant increase of minimum flow magnitude. In contrast, because most of the high flow magnitude occurred during spring, the non-significant trend of flow in spring can explain most of the high flow magnitude does not show significant increase. The increase in flow may indicate a higher probably of flooding in the future.

The Repeated Mann-Kendall Trend Analysis reveals the detailed pattern in time-series; furthermore, it determines the changing patterns of most of the IHA parameters are gradual increase. This could indicate that most of the dam constructions or management on the main stem of Huron River did not contribute to the gradual upward pattern in flow rate. Otherwise, we may observe an abrupt change whose timing matches the time of dam construction or reconstruction. Precipitation may be the potential driving force for the increase in flow (Chapter 3).

The number of reversals is the only IHA parameters that show an abrupt decrease. The timing of this abrupt decrease happened around 1970 to 1980 (Figure 2.5). In 1972, there was a major reconstruction of the Argo Dam, which is on the upstream of the Ann Arbor gauge (Table 1.1). It is thus possible that the reconstruction of Argo Dam may decrease the flow variability in Ann Arbor. However, based on the result of short term flow analysis, the Ann Arbor gauge still has higher flashiness compared to other gauges (Table 4.5 and Table 4.6). We will discuss the short term flow analysis in Chapter 4.

Conclusions and Recommendations

In this section, we applied Mann-Kendall Trend Analysis and Sen's Slope Estimators on different flow parameters to evaluate the long term flow trend. We further used matrix plot to conduct Repeated Mann-Kendall Trend Analysis to determine if the changing pattern is a gradual or abrupt change. We found that most of the flow parameters, such as the annual mean flow, mean flow of each calendar month, and minimum flow magnitudes, demonstrate a significant and gradual upward trend for the nearly past 100 years. Maximum flow magnitudes also show an upward pattern although it is not statistically significant. As a result, we concluded that the flow rate have increased for the nearly past 100 years, which could be driven by the increase in precipitation. If this trend continues to increase, this could mean higher probability of flood events of Huron River in the future. The Huron River Watershed Council may need to focus on the preparation for the potential flood events in the future.

REFERENCES

Helsel, D.R. and R.M. Hirsch, 2002. Statistical Methods in Water Resources. U.S. Geological Survey.

Huron River Watershed Council and Great Lakes Integrated Sciences and Assessments Center, 2013. Climate resilient communities: Improving information access and communication among dam operations of the Huron River main stem.

Mann, H. B., 1945. Nonparametric test against trend. Econometrica 13: 245-259.

Ritcher, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun, 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 63: 1379–1389.

The Nature Conservancy, 2009. Indicators of Hydrologic Alteration Version 7.1 User's Manual.

Theil, H., 1950. A rank-invariant method of linear and polynomial regression analysis, 1, 2, and 3: Ned. Akad. Wentsch Proc., 53, 386-392, 521-525, and 1397-1412.

Zhang Z., A.D. Dehoff, and R.D. Pody, 2010. New Approach to Identify Trend Pattern of Streamflows. Journal of Hydrologic Engineering 15: 244-248

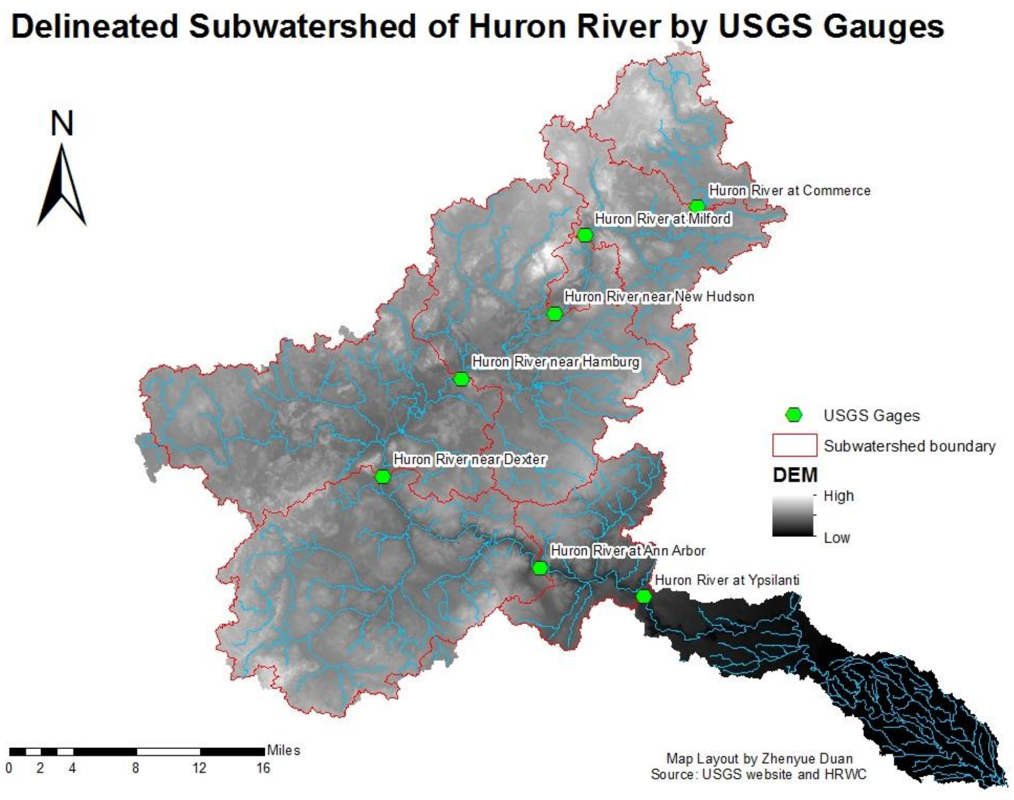
3 Precipitation

Precipitation and runoff are two critical processes in the hydrological cycle. It is significant to analyze the temporal trend of precipitation with runoff for the Huron River watershed during the last hundred years. The main objective of this research is to determine whether there is an evidence of long-term trends of precipitation in Huron River Watershed from 1915 to 2013. Another objective is to investigate relationships between stream flow and precipitation. This research will provide updated information on the effect of climate change and climate variability on water flow in the Huron River Watershed.

Methods

Two types of methods were employed in the trend analyses. (1) For each station, the trend of precipitation was determined by Mann-Kendall test analysis (2) Annual average precipitation for basins and sub basins was calculated using the following procedures: firstly the basin and sub-basin shapes and stations were projected into UTM 17N in ArcGIS; then extracted precipitation from PRISM; lastly the average annual precipitation of basins for each year was determined.

Figure 3.1 Mainstem USGS gauges and delineated subwatershed boundary



Annual total precipitation in the catchment was computed for each of the 7 USGS flow gauges on the main stem of the Huron River based on monthly precipitation data from the PRISM climate group. The 7 USGS gauges are Commerce, Milford, Hamburg, New Hudson, Dexter, Ann Arbor and Ypsilanti (Table 2.1). The PRISM Climate Group gathers climate observations from a wide range of monitoring networks, applies sophisticated quality control measures, and develops spatial climate datasets to reveal short- and long-term climate patterns. The resulting datasets incorporate a variety of modeling techniques and are available at multiple spatial/temporal resolutions, covering the period from 1895 to the present (http://www.prism.oregonstate.edu/). The Huron watershed always has a very cold winter from November to April. During this time, the rainfall usually comes in the form of snow, accumulates and then melts in spring. Thus it is necessary to organize precipitation data into water year in order to match flow data.

The Huron River Watershed has a humid climate influenced by its location in the Great Lakes region, with cooler summers and warmer winters, yet is in the drier portion of Michigan (MDNR 1995, MDNR 2002). The Huron River Watershed shows obvious seasonal change. It has an average of 30 inches of precipitation per year (MDNR 1995). Ann Arbor city which locates on the downstream of the watershed has an average of 30.6 inches of rainfall and 37-38 inches of snowfall per year, based on a 57 year period (MDNR 2002). Based on our research, the average yearly precipitation is 29.89 inches from 1896 to 2013 (Data from PRISM).

The relationship between annual precipitation and flow discharge was evaluated using spearman rank correlation and linear regression. The spearman correlation is a nonparametric measure of statistical dependence between two variables. It assesses how well the relationship between two variables can be described using a monotonic function.

The Rational Formula for runoff coefficient is the most commonly used method of determining rainfall discharges from small basin areas. This method is traditionally used to size storm sewers, channels and other stormwater structures which handle runoff from drainage areas less than 200 acres (Poullain 2012).

The Rational Formula is expressed as

$$Q=C*i*A$$

$$R=Q/A$$

where:

R= subwatershed-scale runoff (mm/yr)

Q = peak rate of runoff in cubic kilometers per year (km^3/yr)

C = runoff coefficient, a dimensionless coefficient

i = average intensity of rainfall in millimeters per year (mm/yr)

A = the watershed area in acres (ac)

The runoff coefficient, C, is expressed as a dimensionless decimal that represents the ratio of runoff to rainfall (Poullain 2012). Except for precipitation, which is accounted for in the formula by using the average rainfall intensity over 1915 to 2012, all other portions of the hydrologic cycle are contained in the runoff coefficient. It was used to explain how much rainfall become surface flow.

Many variables impact runoff coefficient values, including soil type, land use, degree of imperviousness, watershed slope, surface roughness, antecedent moisture condition, interception and surface storage, etc. The more of these variables used to estimate C, the more accurately the rational formula will reflect the actual hydrologic cycle.

Results

Figure 3.2 Ann Arbor annual mean precipitation change from 1915 to 2013

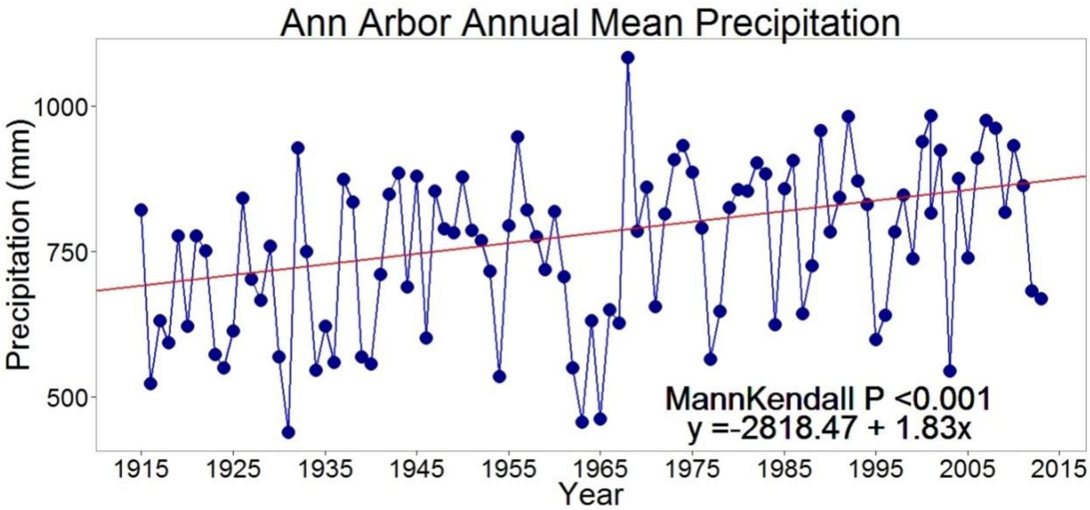


Table 3.1 Annual increasing rate and P-value for all subwatersheds from 1915 to 2013.

Subwatershed	P-value	Increasing rate(mm/10yr)
Commerce	0.002	18.5
Milford	0.091	12.5
New Hudson	0.102	8.2
Hamburg	0.029	13.4
Dexter	0.003	15.6
Ann Arbor	<0.001	18.3
Ypsilanti	0.058	6.4

Table 3.2 Annual average precipitation from 1896 to 2013 for 7 subwatersheds

Subwatersheds	Precipitation(m)
Commerce	0.759
Milford	0.777
Hamburg	0.767
New Hudson	0.757
Dexter	0.760
Ann Arbor	0.757
Ypsilanti	0.740

For Ann Arbor gauge, the average precipitation increased 8% from 1949-1980 period to 1981-2013 period. It is consistent with the result of the Huron River Watershed Council's report. In their report, from the 1951-1980 period to the 1981-2010 period, annual precipitation increased by 11% in southeastern Michigan. Ann Arbor saw a more dramatic increase of 25% over the same time period, but local factors may have played a part (HRWC 2012). Due to the climate change, the rainfall amount has increased at all gauges in recent years.

Ann Arbor annual mean precipitation showed a significant upward trend from 1915 to 2013 (Figure 3.2). In the recent decades, the annual mean rainfall of most years are higher than 750mm. These obvious increasing trends also showed in other sub-watersheds from 1915 to 2013.

Table 3.1 shows the precipitation of Huron River Watershed has showed an upward trend from 1915 to 2013. Based on this table, Ann Arbor area has most significant p-value and Commerce area has largest increasing rate. Five subwatersheds increased more than 12mm rainfall per 10 years.

Table 3.3 showed it has a significant relationship between precipitation and surface flow in the main stem, which means that precipitation may be the main driving force for flow change. However, the Ypsilanti gauge only has data from 1975 to 1994, thus the correlation may be overestimated.

Table 3.3 Spearman's rank correlation for all subwatersheds

Spearman's rank correlation		
Name	**P-value**	**Correlation coefficient**
Commerce	0.002	0.548
Milford	<0.001	0.460
New Hudson	0.005	0.352
Hamburg	<0.001	0.541
Dexter	<0.001	0.640
Ann Arbor	<0.001	0.609
Ypsilanti	0.002	0.750

Table 3.4 Runoff coefficient for all subwatersheds

Gauge	**R^2**	***p***	**Runoff Coef (sd)**	**Time Period**
Commerce	0.315	0.002	0.33 (0.14)	1947-1975
Milford	0.209	<0.001	0.32 (0.09)	1949-2011
New Hudson	0.150	0.002	0.34 (0.08)	1949-2012
Hamburg	0.319	<0.001	0.30 (0.07)	1952-2012
Dexter	0.409	<0.001	0.31 (0.08)	1947-1977
Ann Arbor	0.354	<0.001	0.29 (0.08)	1915-2012
Ypsilanti	0.397	0.012	0.36 (0.07)	1975-1994

After conducting rainfall-runoff coefficient analysis on all gauges, the result showed a value range from 0.3 to 0.4, which is a consistent meaningful correlation between precipitation and flow discharge, while the runoff coefficient did not change significantly over time. This result implies that the increase in precipitation due to climate change is a possible explanation for the increase in flow of discharge.

Figure 3 Mann-Kendall plot for annual mean precipitation from 1915 to 2013

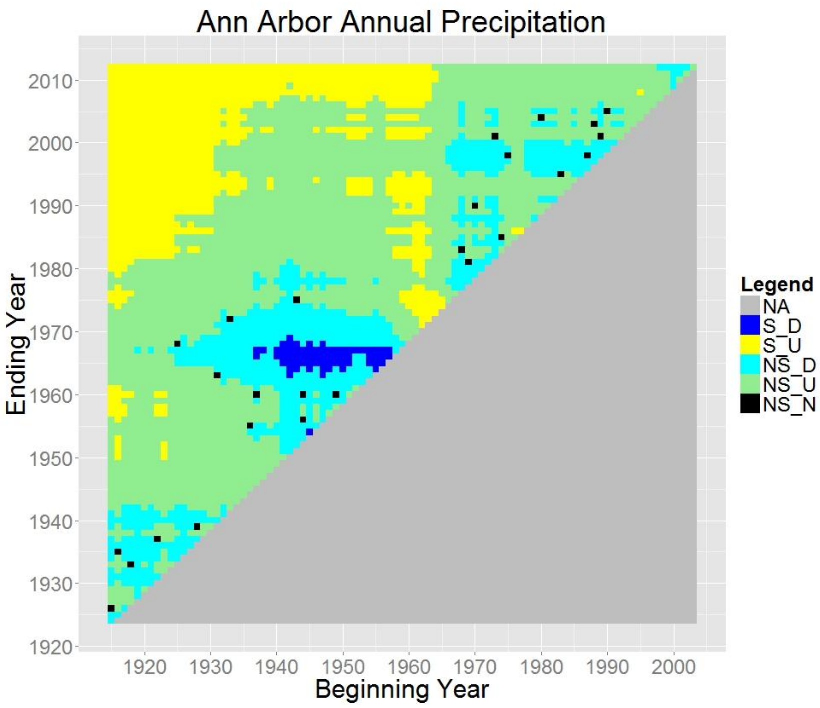
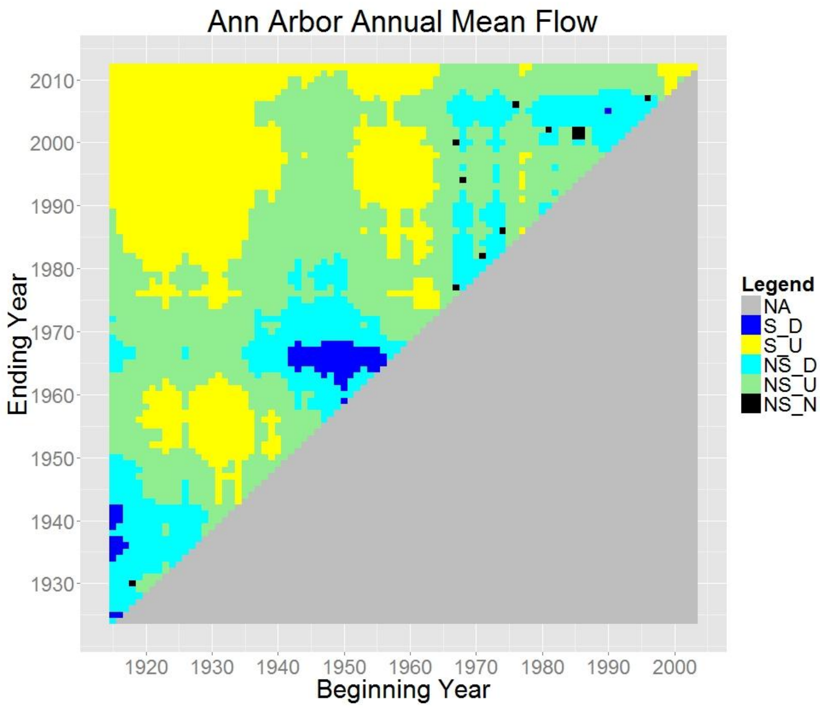


Figure 4 Mann-Kendall plot for annual mean flow from 1915 to 2013



Generally speaking, trends occur in two different ways: a gradual change over time that is consistent in direction (monotonic) or an abrupt shift at a specific point in time (step trend). Because the precipitation data are annual data for several decades and there are no normal distributions, thus it could not be utilized for simple trend analysis. The Mann-Kendall analysis can evaluate whether values tend to increase or decrease over time through what is essentially a nonparametric form of monotonic trend regression analysis. The Mann-Kendall plot shows the trend of change from different starting year and an ending year. When compared to the precipitation Mann-Kendall plot to flow Mann-Kendall plot in different gauges, it shows very similar patterns and has some extent consistency. For instance, both two plots show a significant decreasing from 1910 to 1940 period and display a increasing trend from 1940 to 2010 period (Figure 3.3). Even though there is some extent inconsistency caused by data uncertainty between basin precipitation and runoff trend, it still shows the hydrologic factors impacting runoff change.

Conclusions

It will be helpful that collaborated with regional or local organization to record more detailed climate data. Because the precipitation has a significant increasing trend in recent years, it is necessary to prepare for high flow and high intensity rainfall events. We recommend collecting local/regional precipitation regularly and organizing into database. In this study, we simplified the process and only focus on precipitation and runoff water flow. In order to conduct more realistic and systematic model, it would be useful to have to soil type, slope, temperature and groundwater data.

REFERENCES

Burn, D.H., Elnur, M.A., 2002. Detection of hydrologic trend and variability. Journal of Hydrology 255, 107-122.

E. M. Hay-Chmielewski.,Paul W. Seelbach.,Gary E. Whelan.,Douglas B. Jester Jr.1995.Huron river assessment.

Harry, F., Lins, Slack, J. R., 1999. Streamflow trends in the United States. Geographical research letters vol. 26, No. 2, pages 227-230.

Helsel, D.R., Hirsch, R.M., 1988. Discussion of paper by Montgomery R.H., Loftis,J.C., "Applicability of the t-test for detecting trends in water quality variables," Water Resource Bull. 24, 201-204.

Hirsch, R.M., Slack, J.R., Smith, R.A., 1982. Techniques of trend analysis for monthly water quality data, Water Resource Res.18 (1), 107-121.

Huron River Water Council., 2012. Review of climate impacts to tree species of the Huron River watershed

Huth, R., Pokorna, L., 2004. Parametric versus non-parametric estimates of climatic trends. Theoretical and Applied Climatology 77, 107-112.

John Poullain, PE,.2012.Florida Erosion and Sediment Control Inspector's Manual

Michigan Department of Nature Resource.2002. Huron River Plan.(Livingston, Washtenaw, Oakland, Monroe and Wayne Counties)

Van Belle, G., Hughes, J. P., 1984. Nonparametric tests for trend in water quality. Water Resources Res. 20(1), 127-136.

Zhang, X., Vincent, L.A., Hogg, W.D., Niitsoo A., 2000. Temperature and precipitation trends in Canada during the 20th century. Atmos. Ocean, 38(3),395-429.

4 Short Term Flow Analysis

The purpose of the short term flow analysis is to assess the flashiness (flow variability) of flow rate based on daily or sub-daily flow data. The level of flow variability in a river system can shape the ecological communities and if the level of flashiness is altered by humans, the resulting flows may change the assemblage of fish species (Poff and Allan 1995; Richter et al. 1997; Zimmerman et al. 2010). Therefore, the goal of this study is to identify sites with high flashiness and quantify the level of flashiness.

Daily and sub-daily flow data were downloaded from USGS website (http://waterdata.usgs.gov/mi/nwis/rt). Data was then imported into R to perform exploratory data analysis and flashiness index calculation for the daily and sub-daily level.

Methods

Exploratory Data Analysis

Daily and sub-daily flow data from each gauge station (Table 4.1 and 4.2) were imported into R (http://www.r-project.org/) for exploratory data analysis. In addition to the gauge stations from USGS mentioned in the Long Term Flow Analysis Section, daily and sub-daily flow data from the Ford Lake Dam and the mouth of Allen Creek were also used in short term flow analysis. The Ford Lake Dam is located at Ford Lake, which is a further downstream site of the Ypsilanti gauge. Flow data of Ford Lake Dam were provided by Charter Township of Ypsilanti. The mouth of Allen Creek is near the Argo Dam, which is an upstream site of the Ann Arbor gauge. Although it does not show flow from the main stem of Huron River, the flow data were included in this analysis because it may significantly affect the flashiness of the Ann Arbor gauge. Flow data of the mouth of Allen Creek Flow data of Allen Creek were downloaded from the USGS website (http://waterdata.usgs.gov/mi/nwis/rt).

Two R functions were created to display the daily and sub-daily flow data in time-series for any given time periods. The time-series of daily and sub-daily flow rate were visually inspected using these two R functions to understand the patterns of flow variability of different gauges and different time periods.

Daily Flashiness Index Calculation

To quantify the level of flashiness in daily level, four daily flashiness indices based on Poff and Allan (1995) were calculated. They are Predictability, Baseflow Stability, Daily Flow Coefficient of Variation, and Frequency of Spates (Table 4.3). These four indices are crucial to distinguish "Hydrological Variable Sites" and "Hydrological Stable Sites" in Poff and Allan's study (1995). Daily flow data with a time span of 60 years (10/1/1951 to 9/30/2011) from Milford, New Hudson, Hamburg, and Ann Arbor were analyzed using these indices. The Indicator of Hydrologic Alteration (IHA) was applied to calculate daily flow predictability, while other daily flashiness indices were calculated using R.

Predictability shows whether the daily flow data are predictable or non-predictable. The index was developed by Colwell (1974), which has two components: Constancy and Contingency. Predictability equals to Constancy plus Contingency. All these three indices are ranging from 0 to 1. High value in C means that the temporal variation is relatively small, while high value in P means that there is a high periodicity in daily flow data (Poff and Allan 1995; The Nature Conservancy 2009).

Table 4.1 Daily flow data from these gauge stations were used in exploratory data analysis. Begin date and end date indicate the time span of flow data. Asterisk shows the gauge is still functioning.

USGS Site No.	Site Name	Name Abbreviation	Begin Date	End Date
04169500	Huron River at Commerce	Commerce	3/1/1946	9/30/1975
04170000	Huron River at Milford	Milford	9/23/1948	9/30/2011
04170500	Huron River near New Hudson	New Hudson	8/20/1948	5/12/2013
04172000	Huron River near Hamburg	Hamburg	10/1/1951	5/12/2013
04173000	Huron River near Dexter	Dexter	3/1/1946	10/31/1977
04174500	Huron River at Ann Arbor	Ann Arbor	1/1/1914	5/12/2013
04174800	Huron River at Ypsilanti	Ypsilanti	6/1/1974	9/30/1994

Table 4.2 Sub-daily flow data from these gauge stations were used in exploratory data analysis. Begin time and end time indicate the time span of flow data. Asterisk shows the gauge is still functioning.

USGS Site No.	Site Name (in this report)	Begin Time	End Time
04170000	Milford	10/1/2007 00:00	10/1/2011 00:00
04170500	New Hudson*	10/1/2007 00:00	12/12/2013 11:00
04172000	Hamburg*	10/1/2007 00:00	12/12/2013 11:00
04174490	Allen Creek*	8/5/2011 04:35	12/12/2013 11:00
04174500	Ann Arbor*	10/1/2007 00:00	12/12/2013 11:00
-	Ford Lake Dam*	10/1/2007 00:00	10/1/2013 00:00

Table 4.3 Four Daily flashiness indices based on Poff and Allan (1995).

Index	Definition
Predictability	Predictability (P) is an index developed by Colwell (1974). It has two components: Constancy (C) and Contingency (M). P = C + M. All these three indices are ranging from 0 to 1.
Baseflow Stability	The average of (minimum one-day flow /the annual mean flow)
Daily Flow Coefficient of Variation	(Standard Deviation / Mean) × 100%
Frequency of Spates	Average number of spates per year

Baseflow Stability is defined as the average of the minimum one-day flow divided by the annual mean flow, indicating the level of flow variation between low and mean flow (Table 4.3). Daily Flow Coefficient of Variation is defined as the standard deviation of daily flow over the entire the study period divided by the mean flow over the entire study period, transformed to percentage scale (Table 4.3). This shows the overall variation in daily flow data. Finally, frequency of spate is defined as the average number of spates per year (Table 4.3). Spate is defined as flow events that are larger than the bankfull discharge. The bankfull discharge is determined by the level of flow that occurs once per 1.67 year on average based on the 60 percent of exceedance calculated using HEC-DSS.

Sub-daily Flashiness Index Calculation

To quantify the level of flashiness in sub-daily level, four daily flashiness indices based on Zimmerman et al. (2010) were calculated. They are Reversals, Sub-daily Flow Coefficient of Variation, Percentage of Flow, and Richard-Baker Flashiness Index (Table 4.4). Sub-daily flow data from Milford, New Hudson, Hamburg, Ann Arbor, and Ford Lake Dam were analyzed sing these four flashiness indices. The analysis periods were shown in Table 4.2. All the following calculations were performed using R.

Table 4.4 Four Sub-daily flashiness indices based on Zimmerman et al. (2010).

Index	Definition
Reversals	Number of changes between rising and falling events in the sub-daily flow within one day. One flow measure was compared to the previous flow measure to determine if the rate is larger or smaller. From two consecutive measures, if there is a change from "larger" to "smaller" or "smaller" to "larger", it is considered to be one reversal.
Sub-daily Coefficient of Variation	(Standard Deviation / Mean) × 100%
Percentage of Flow	{(Maximum - Minimum) / Mean} × 100%
Richard-Baker Flashiness Index	$\sum_{i=1}^{n} 0.5(\lvert q_{i+1} - q \rvert + \lvert q - q_{i-1} \rvert) \Big/ \sum_{i=1}^{n} q$ where q is the sub-daily flow

The Reversals is the number of changes between rising and falling events in the sub-daily flow within one day (The Nature Conservancy 2009). All the flow measures were compared to their previous one within one day. If the latter flow measure is larger than the former one, the change is a rising event. If the latter flow measure is smaller than the former one, the change is a falling event. Finally, the number of changes between rising and falling events was counted for each day. This index demonstrates the stability of the flow rate. Low Reversals could mean the flow mostly keeps increasing, decreasing, or steady in one day.

It is important to note that all the USGS gauge stations record sub-daily flow data once every 15 minutes, while Ford Lake Dam records sub-daily flow data once per hour. Therefore, the index Reversals was only calculated for the USGS gauge stations but not for the Ford Lake Dam because the results of Reversals are incomparable when the frequencies of data record are different.

The Sub-daily Flow Coefficient of Variation is defined as the standard deviation of daily flow over one day divided by the mean flow over one day, transformed to percentage scale. This index is the same as the Daily Flow Coefficient of Variation except that the time span is different, which reveals the variability of flow within one day (McKinney et al. 2001).

The Percentage of Flow is defined as the range between maximum flow and minimum flow within one day divided by the mean flow of that day (Table 4.4). In this report, because the different sample size in data record among USGS gauges and Ford Lake Dam, we slightly modified the definition of Percentage of Flow compared to Zimmerman et al.'s (2010), in which Percentage of Flow is defined as the range between maximum flow and minimum flow within one day divided by the total flow of that day. This index shows the range of change in flow within one day.

The Richard-Baker Flashiness Index reveals the level of flow oscillation within one day (Baker et al. 2004). Table 4.4 shows the formula of the Richard-Baker Flashiness Index. The sum of the absolute consecutive sub-daily flow measures was divided the sum of all flow measures.

Results

Exploratory Data Analysis

The exploratory data analysis shows that daily flow rates among each gauge stations are highly correlated. For example, Figure 4.1 is the daily hydrograph from 1/1/2012 to 12/31/2012. Based on this plot it is clear that all gauges show similar flow pattern. The timing of high flow or low flow of each gauge occurred in roughly the same period. However, during April and November, some spikes on the hydrograph are observed only in New Hudson, suggesting flow changes happened only in that location. This pattern of flow change in New Hudson during April and November has been found in many different years, implying that the mechanism causing this pattern could occur every year.

The sub-daily hydrograph further demonstrates the feature of the flow changes in New Hudson during April and November (Figure 4.2 and 4.3). During April, the flow rate in New Hudson has decreased suddenly within a short time period (Figure 4.2). On the other hand, during November, the flow rate has increased suddenly within a short time period (Figure 4.3). After the increase or decrease event occurred, the flow rate in New Hudson gradually returned to the original rate over severally days until another event occurred.

Furthermore, flow rates in Ann Arbor showed high variability (Figure 4.2 and 4.3). There are many spikes on the sub-daily hydrograph of Ann Arbor. This phenomenon can be found in all calendar months. The flow pattern in Ford Lake Dam also showed high variability. On the contrary, the flow patterns in Hamburg and Milford had less variability based on the analysis of the hydrograph.

Figure 4.1 Daily hydrograph from 1/1/2010 to 12/31/2010. Red rectangle shows the spikes in hydrograph during April and November.

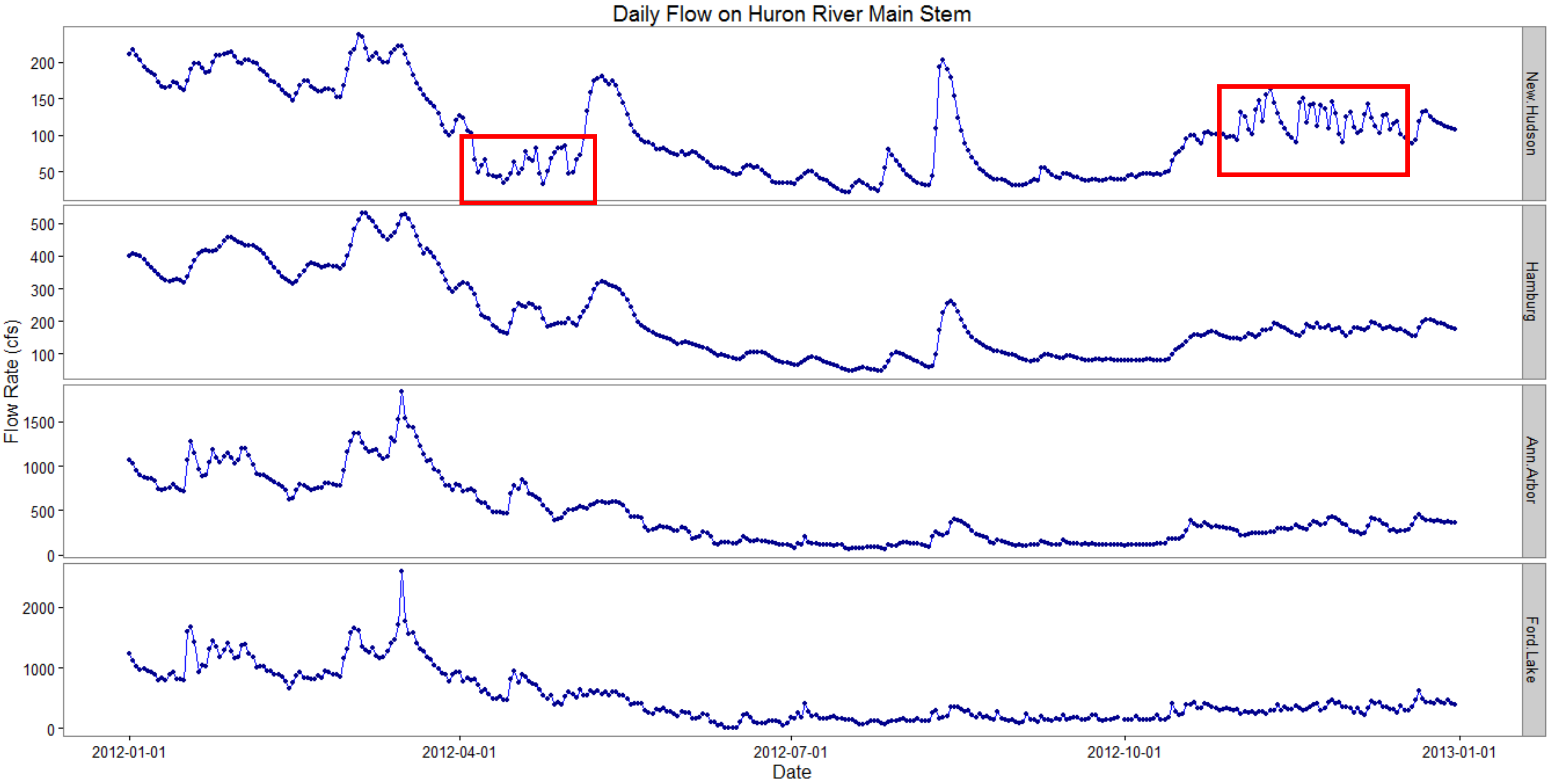


Figure 4.2 Sub-daily hydrograph from 4/1/2012 to 4/30/2012. Allen Creek, represented as an orange hydrograph, is a tributary which has a large impact on the Huron River main stem.

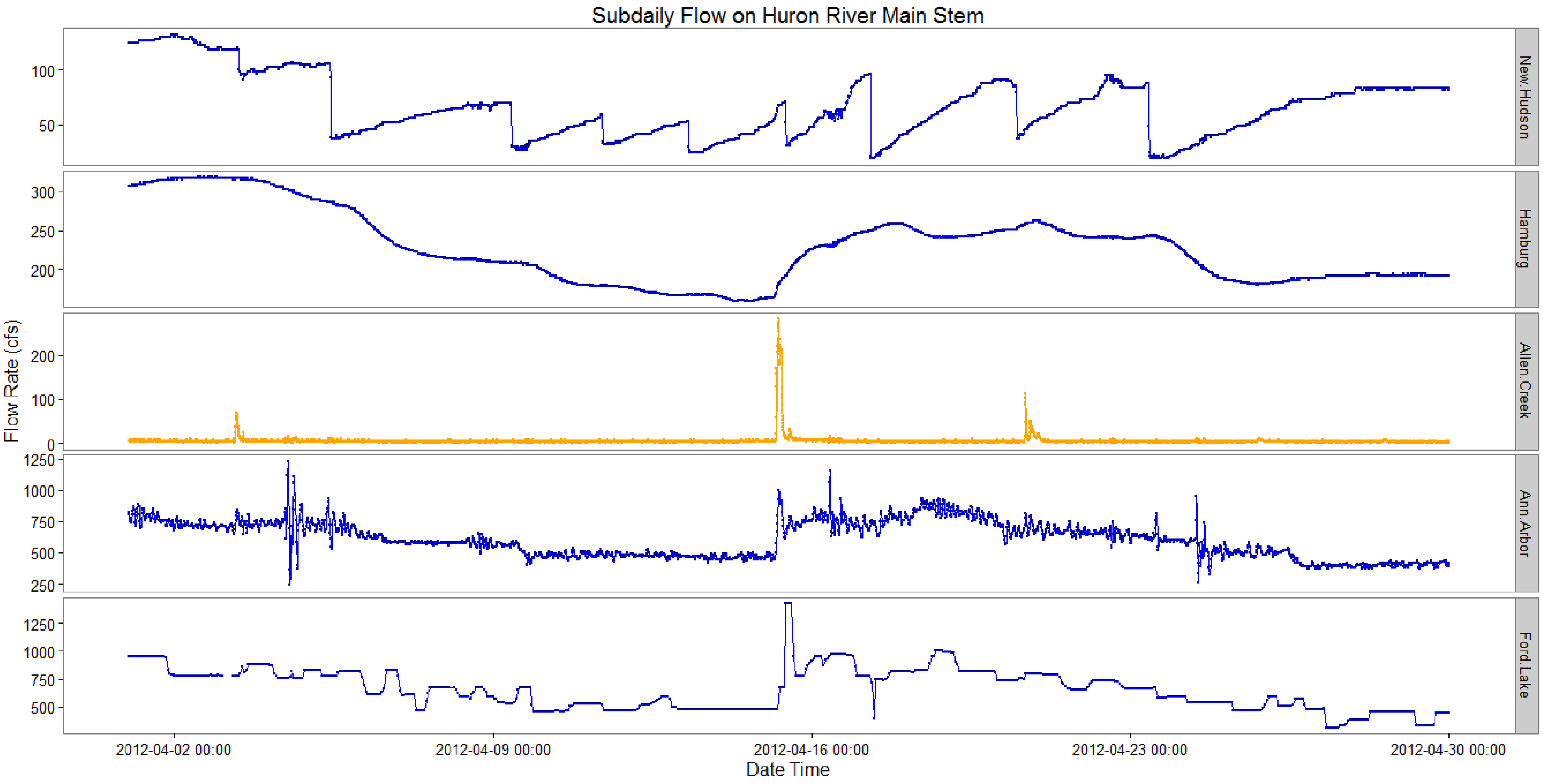
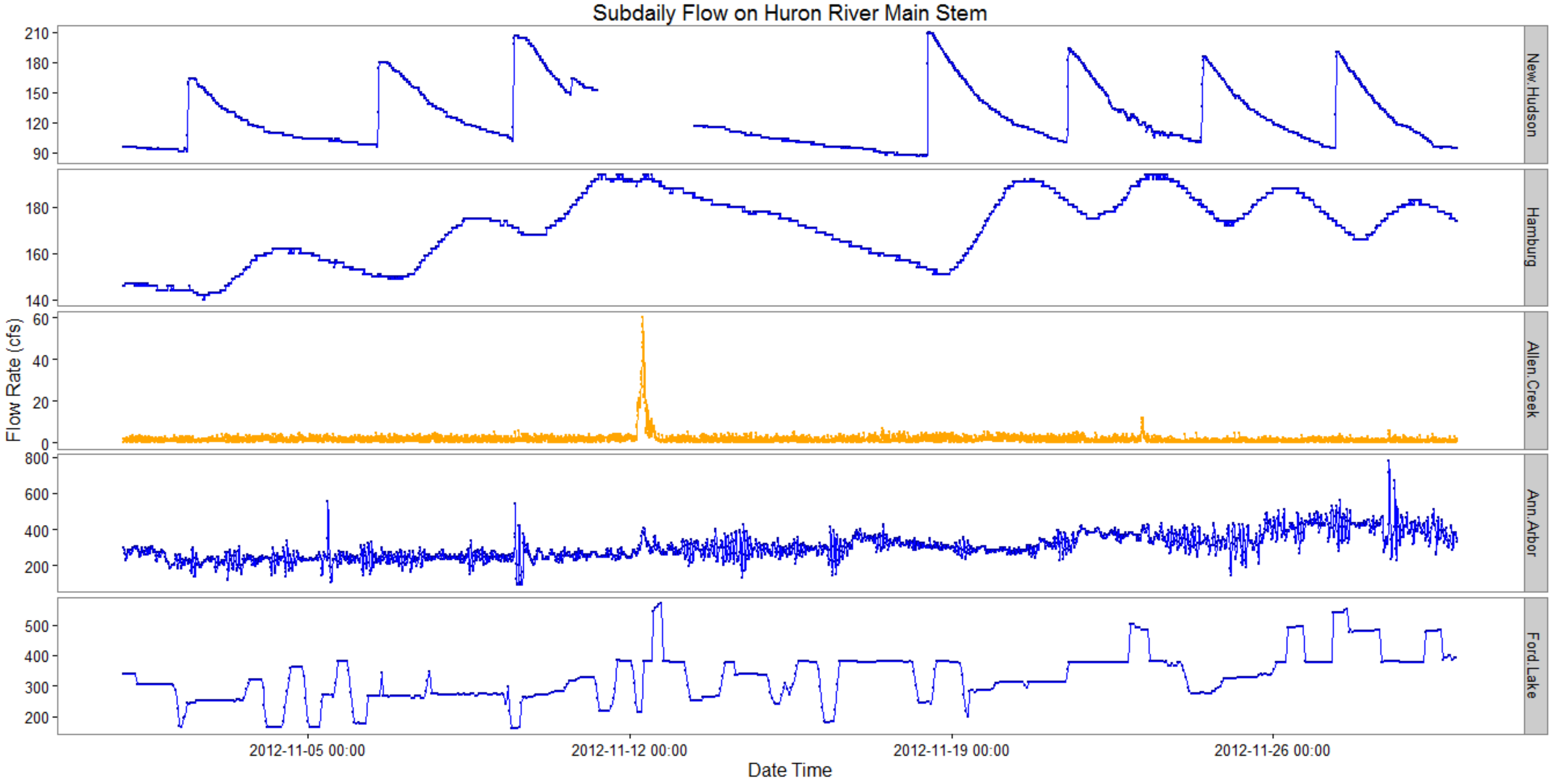


Figure 4.3 Daily hydrograph from 11/1/2012 to 11/30/2012. Allen Creek, represented as an orange hydrograph, is a tributary which has a large impact on the Huron River main stem.



Daily Flashiness Index Calculation

Table 4.5 summarizes the results of daily flashiness index calculation. Ann Arbor had a lower Predictability compared to other gauges; while the other gauges had the same Predictability. Moreover Ann Arbor showed the highest Daily Coefficient of Variation and the lowest Baseflow Stability. The Frequency of Spates is lowest in Hamburg, while other gauges had almost the same values.

Table 4.5 Summary of daily flashiness index calculation

	Milford	**New Hudson**	**Hamburg**	**Ann Arbor**
Predictability	0.55	0.55	0.55	0.49
Constancy	0.462	0.4675	0.462	0.3773
Contingency	0.088	0.0825	0.088	0.1227
Daily Coefficient of Variation (%)	63.15	57.77	62.57	79.34
Baseflow Stability	0.24	0.23	0.30	0.16
Frequency of Spates	0.55	0.53	0.43	0.55

Sub-daily Flashiness Index Calculation

Table 4.6 summarizes the results of sub-daily flashiness index calculation. All four indices showed that Ann Arbor and Ford Lake Dam had higher flashiness when compared to other sites. Box plots (Figure 4.4 to 4.7) also show that there are two groups in terms of flashiness indices. Ann Arbor and Ford Lake Dam had relatively high flow variability, while Milford, New Hudson, and Hamburg had relatively low flow variability. Other than the Reversals index, Hamburg showed the lowest flashiness indices among all the study gauges.

During April and November, New Hudson had high Sub-daily Coefficient of Variation and Percentage of Flows compared to other calendar months, while Reversals and Richard-Baker Flashiness Index were low from December to March (Figure 4.11). Other study sites did not show much seasonal variation, having roughly the same level of each calendar month (Figure 4.8 to 4.10 and Figure 4.12).

Table 4.6 Summary of sub-daily flashiness index calculation. SD means standard deviation

	Mean (SD)	Median
Reversals		
Ann Arbor	11.38 (5.46)	11
Hamburg	5.46 (4.86)	4
New Hudson	3.75 (4.91)	2
Milford	0.90 (1.44)	0
Sub-daily Coefficient of Variation		
Ford Lake	12.42 (12.27)	9.30
Ann Arbor	9.75 (10.00)	6.48
Hamburg	1.81 (1.68)	1.36
New Hudson	4.46 (7.28)	2.44
Milford	3.1 (3.93)	1.97
Percentage of Flows		
Ford Lake	34.00 (35.07)	23.64
Ann Arbor	49.53 (56.74)	31.08
Hamburg	6.14 (5.55)	4.79
New Hudson	13.65 (18.38)	8.43
Milford	10.00 (11.56)	6.66
Richard-Baker Index		
Ford Lake	0.0227 (0.0259)	0.0144
Ann Arbor	0.0317 (0.0323)	0.0217
Hamburg	0.0014 (0.0008)	0.0013
New Hudson	0.0038 (0.0044)	0.0020
Milford	0.0014 (0.0013)	0.0010

Figure 4.4 Box plot of Reversals. Black points indicate outliers in the dataset.

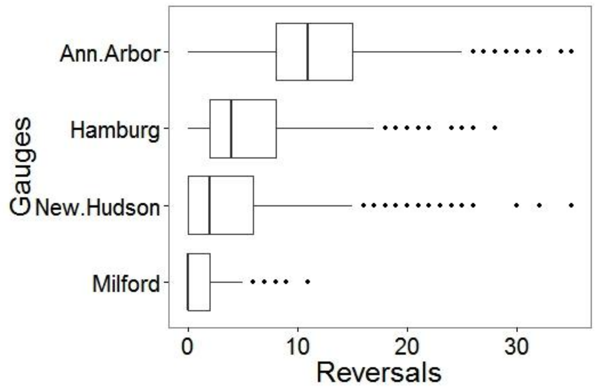


Figure 4.5 Box plot of Sub-daily Coefficient of Variation. Black points indicate outliers in the dataset.

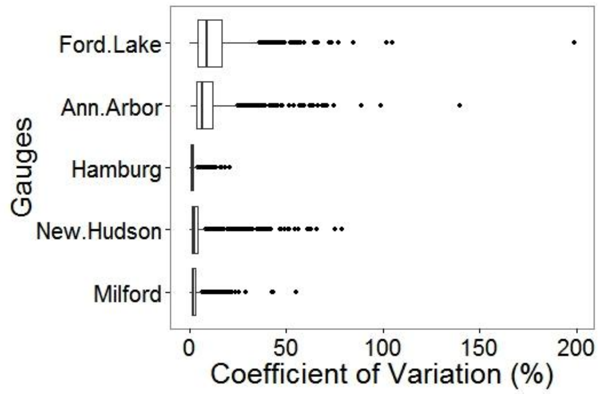


Figure 4.6 Box plot of Percentage of Flows. Black points indicate outliers in the dataset.

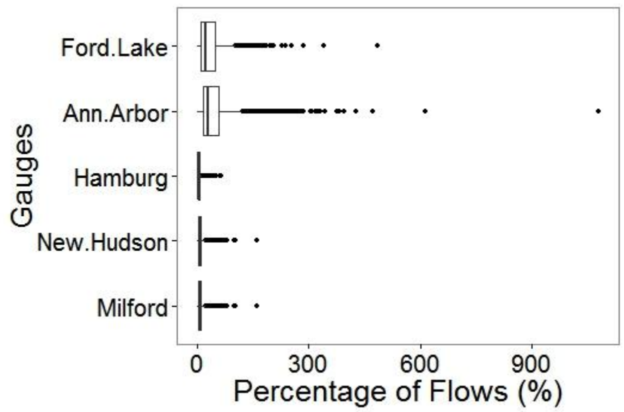


Figure 4.7 Box plot of Richard-Baker Flashiness Index. Black points indicate outliers in the dataset.

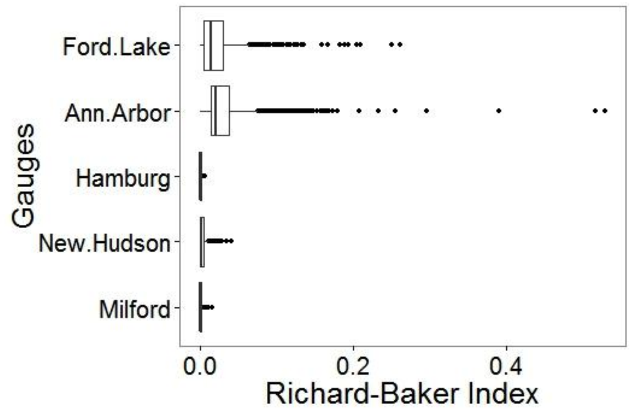
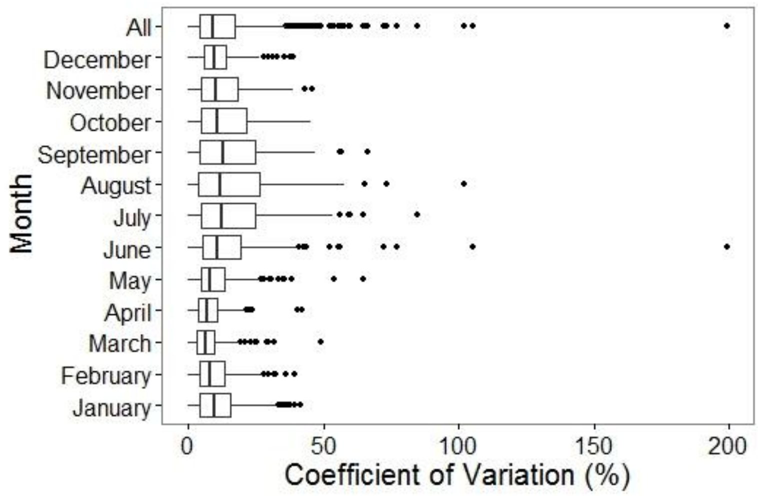
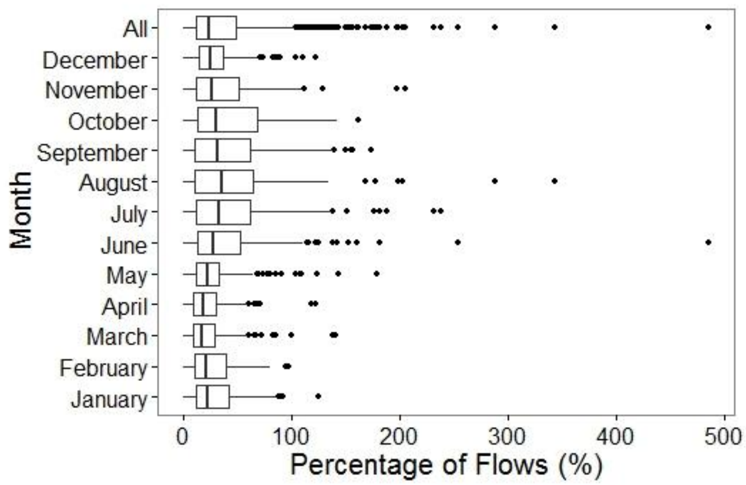


Figure 4.8 Sub-daily flow indices of the whole year and each calendar month in Ford Lake Dam. (a) Sub-daily Coefficient of Variation (b) Percentage of Flows (c) Richard-Baker Flashiness Index.

(a)



(b)



(c)

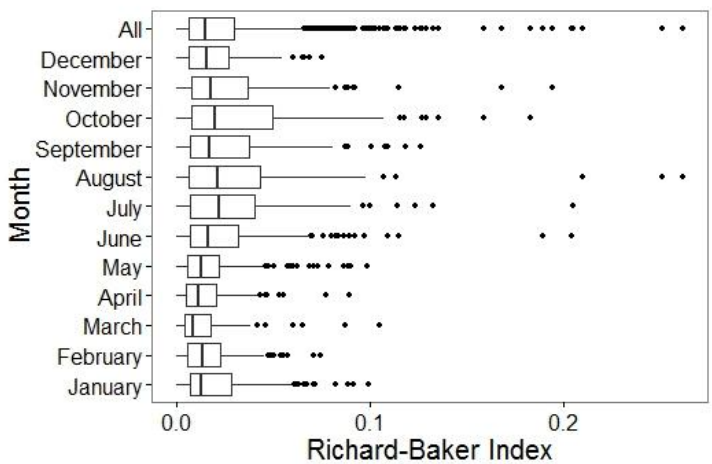


Figure 4.9 Sub-daily flow indices of the whole year and each calendar month in Ann Arbor. (a) Reversals. (b) Sub-daily Coefficient of Variation (c) Percentage of Flows (d) Richard-Baker Flashiness Index.

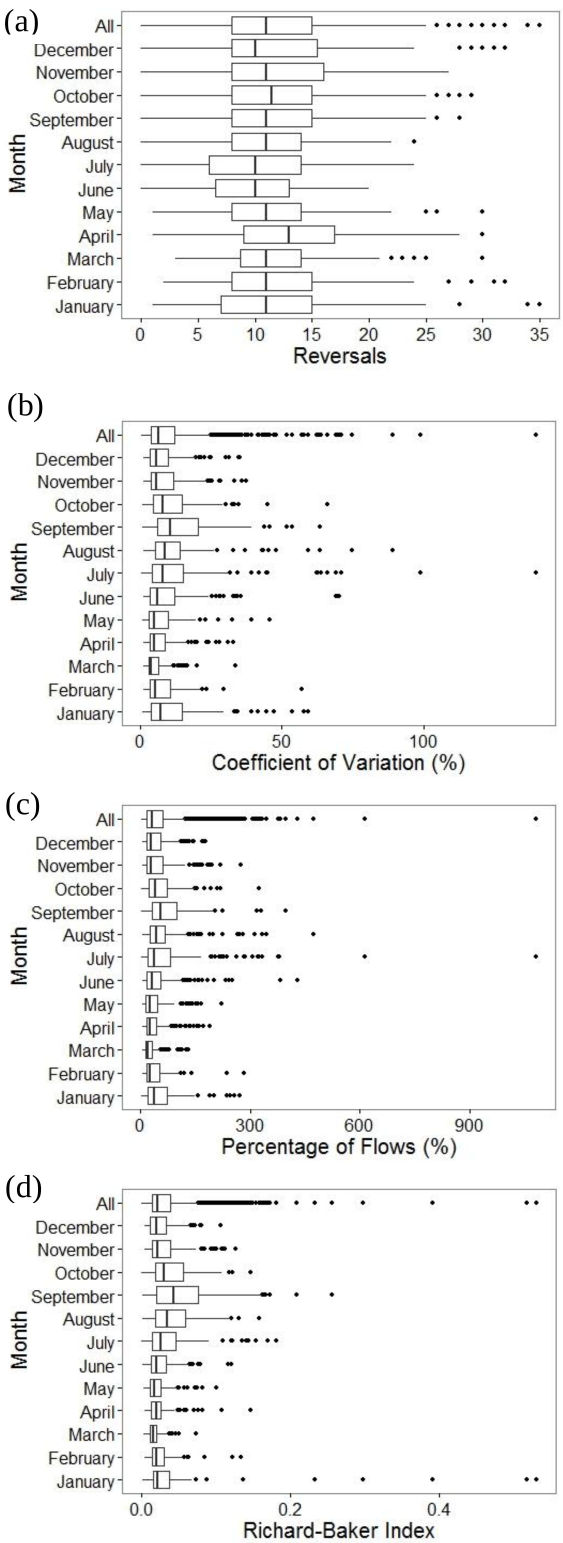


Figure 4.10 Sub-daily flow indices of the whole year and each calendar month in Hamburg. (a) Reversals. (b) Sub-daily Coefficient of Variation (c) Percentage of Flows (d) Richard-Baker Flashiness Index

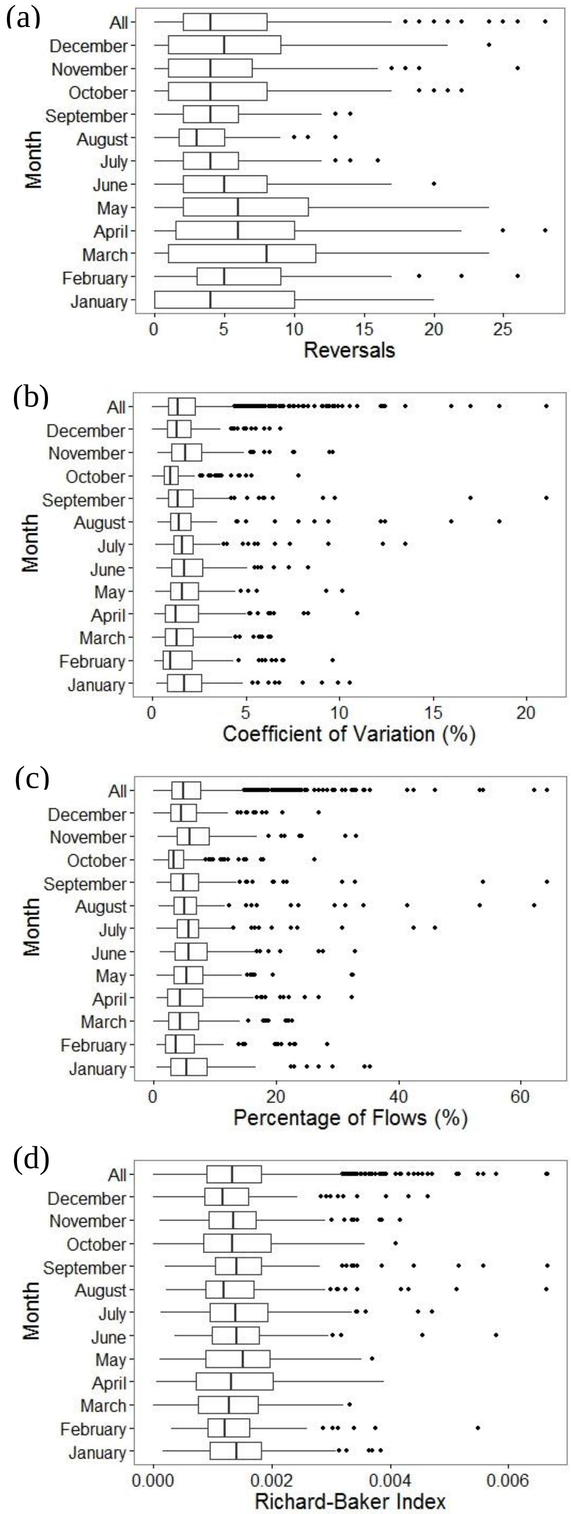


Figure 4.11 Sub-daily flow indices of the whole year and each calendar month in New Hudson. (a) Reversals. (b) Sub-daily Coefficient of Variation (c) Percentage of Flows (d) Richard-Baker Flashiness Index

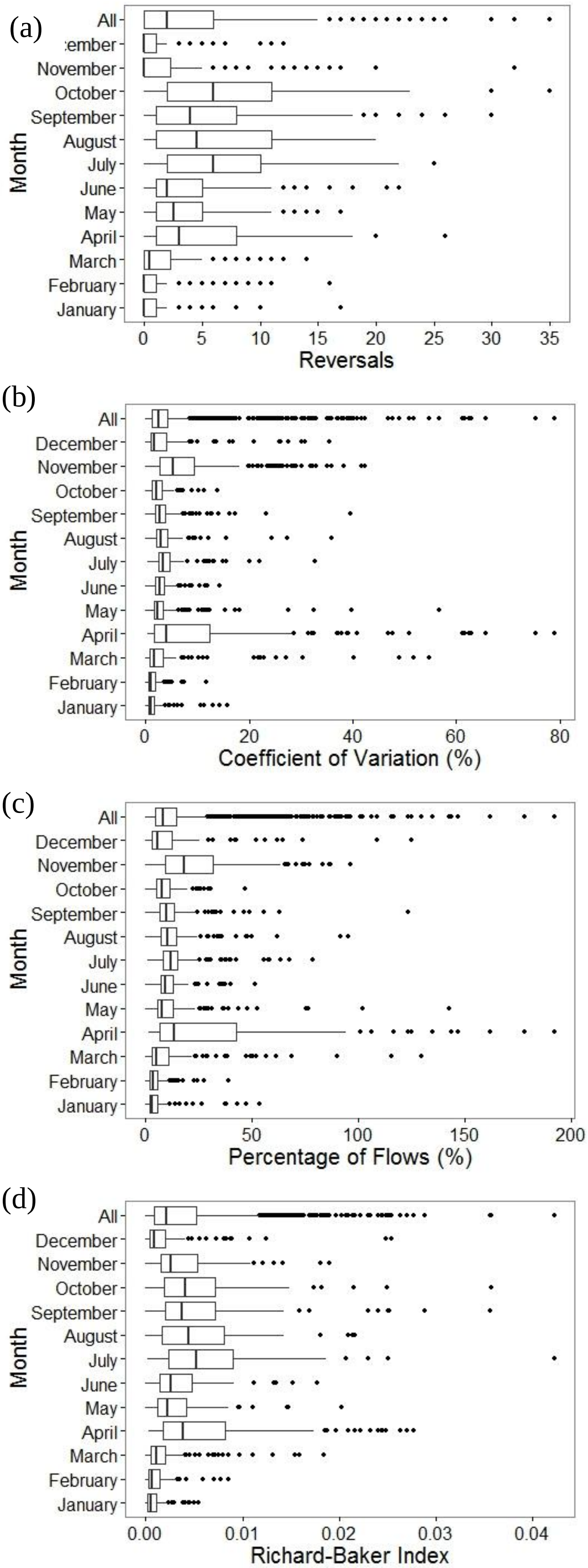
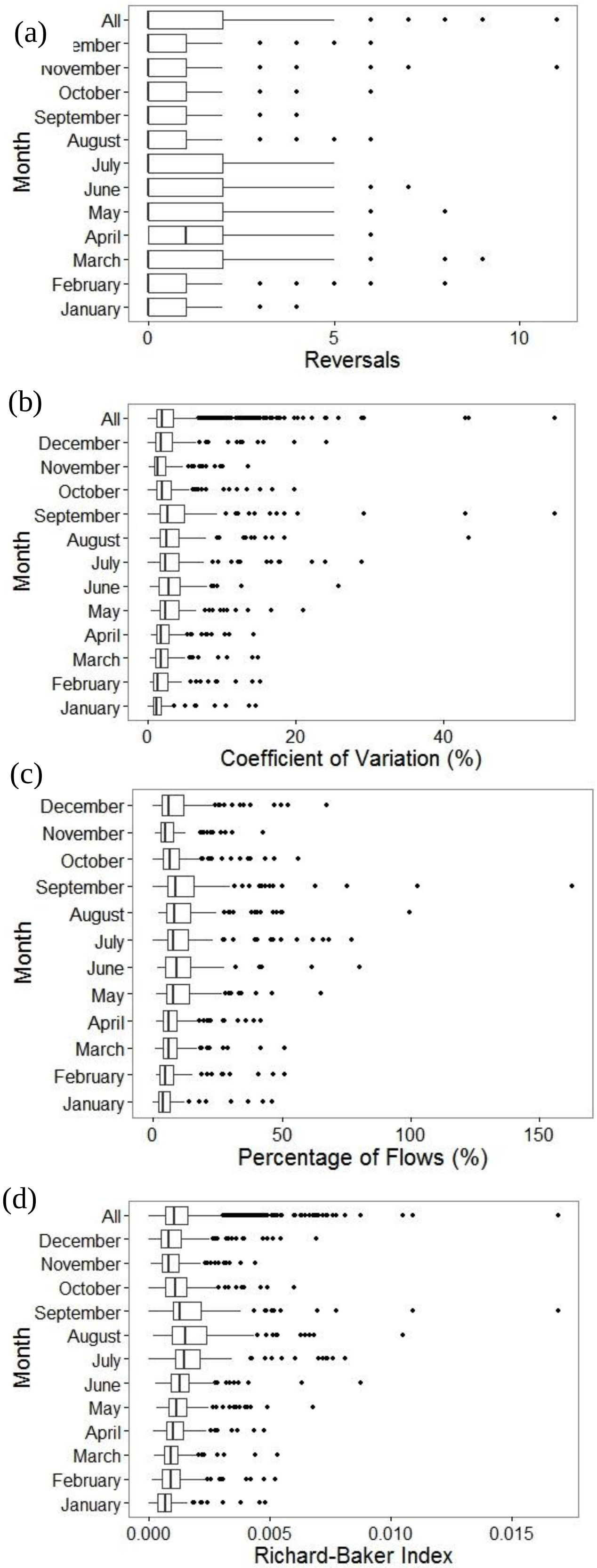


Figure 4.12 Sub-daily flow indices of the whole year and each calendar month in Milford. (a) Reversals. (b) Sub-daily Coefficient of Variation (c) Percentage of Flows (d) Richard-Baker Flashiness Index



Discussion

The analyses demonstrate that dam operation may be affecting the flow pattern in the Huron River, increasing the flashiness. Exploratory data analysis based on daily and sub-daily hydrograph both show that the flow rate in New Hudson had high variability during April and November (Figure 4.1 to 4.3). Furthermore, Ann Arbor and Ford Lake Dam show high flashiness in sub-daily flow rates (Table 4.6; Figure 4.4 to 4.7). These observations are consistent with the results of daily and sub-daily flashiness index calculation. Because the location of New Hudson, Ann Arbor, and Ford Lake Dam are next to or near an upstream dam, dam operation could cause high flow variability from these three study sites. In contrast, the flow variability in Milford and Hamburg could be more similar to the natural condition since these two gauges are not on the downstream of dams, thus may have less impact from dams (Figure 1.3).

The pattern of flow variability in New Hudson during April and November could be explained by the operations at Kent Lake Dam. The New Hudson gauge is on the downstream of the Kent Lake Dam, which creates an impoundment of about 1050 surface acres. The water level of the impoundment is controlled by a drum gate running a spillway on the Kent Lake Dam. The dam operator (Huron-Clinton Metropark) needs to lower the water level in the winter to minimize shoreline erosion, which typically starts around November 1 and lasts for several weeks. On the other hand, in the spring around April the dam operator raises the drum gate to increase the water level. After that the dam operator maintains the level of the drum gate until November (Personal communication with Huron-Clinton Metroparks). As a result, the flow rates during April and November may suddenly decrease or increase, respectively (Figure 4.2 to 4.3), leading to high flashiness during these two time period (Figure 4.11).

In addition to New Hudson, we also found evidence to show that dams may increase flashiness in Ford Lake Dam and Ann Arbor. The sub-daily flashiness indices of each calendar month were all high in Ford Lake Dam; and there were no obvious seasonal variations in flashiness (Figure 4.8), which is in accordance with the dam operation pattern in Ford Lake Dam. The dam operators of Ford Lake Dam (Charter Township of Ypsilanti) regulate the dam to maintain the impoundment level of the entire year. There could be multiple times of adjustment each day or no changes in flow for days (Personal communication with the Charter Township of Ypsilanti), which could lead to flow variations of the downstream sites.

Flow variability was also high and without obvious seasonal variation in Ann Arbor. It is interesting to point out that Ann Arbor gauge is downstream of Argo Dam. The City of Ann Arbor operates the Argo Dam as “run of river” (Personal communication with the City of Ann Arbor). “Run of river” is a dam operation type meaning that the dam has little or no control of the level of water release, having less impact on flow regime compared to “storage” dam with active regulation (Poff and Hart, 2002). Therefore, we would expect that the flashiness in Ann Arbor would be as low as the flashiness in other upstream gauge stations that are relatively far from dams, such as Hamburg or Milford. However, sub-daily flashiness indices show that the pattern of flow variability was more similar to the pattern in Ford Lake Dam; while daily flow flashiness indices also reveal that Ann Arbor has high flashiness, suggesting that the flow pattern in Ann Arbor could be significantly different from the natural condition.

We identified two causes that may contribute to the high flashiness condition in Ann Arbor. The first one is the inflow from Allen Creek, which is a tributary of Huron River. The mouth of Allen Creek is near the downstream of Argo Dam and on the upstream of the Ann Arbor gauge. The watershed of Allen Creek is mainly covered by urbanized areas. As a result, Allen Creek has a low buffering time when precipitation occurs, indicating that a precipitation event may cause a sudden increase of flow into the Huron River. As was shown in Figure 4.2 and 4.3, there are several peaks in the sub-daily hydrograph of Allen Creek, which could indicate a precipitation event. This sudden increase in flow would increase the flashiness of the downstream Ann Arbor gauge. However, based on the sub-daily hydrograph, it is clear that Allen Creek cannot explain all the flow variability in Ann Arbor.

The second cause is the flow from the Argo Dam and the cascade, which may be affected by dam regulations. There is an automatic regulation system to control the gate of Argo Dam. It is possible that this system did not respond the actual timing of inflow from Huron River, leading to excess release of water. On the other hand, the cascade may also increase the flow variability. Therefore, it is important to study the automatic regulation system in Argo Dam and evaluate its impact together with the cascade.

As was mentioned in the long term flow analysis, the number of reversals in Ann Arbor gauge has significantly decreased compared to the time period prior to the 1970s (Figure 2.3a and 2.3b), which could be due to the reconstruction of Argo Dam in 1972. However, the flashiness in Ann Arbor is still higher than other sites. The pattern in Ann Arbor has a large contrast compared to the pattern in Hamburg, which we assumed that the overall condition has the highest similarity to the natural state of the Huron River because Hamburg is relatively far from any upstream or downstream dams. Hamburg has the highest Baseflow Stability and lowest Frequency of Spates (Table 4.5), implying good buffering capacity. In the future, Huron River Watershed Council may want to collaborate with the City of Ann Arbor to reduce the impact of Argo Dam or other dams causing high flashiness, which could improve the quality of the environment to a more natural condition, like Hamburg.

The entire Huron River Watershed may have less flashiness compared to other studies. In Poff and Allan's (1995) study, they calculated the daily flashiness indices for both "Hydrological Variable Sites" and "Hydrological Stable Sites" for 34 sites in Wisconsin and Minnesota. The values of indices are higher in "Hydrological Variable Sites" than in "Hydrological Stable Sites". In our study, although the Ann Arbor gauge has high flashiness compared to other gauges, only the Baseflow Stability of Ann Arbor (0.16) was similar to the mean Baseflow Stability of "Hydrological Variable Sites" (0.16) in Poff and Allan's (1995) study. The Predictability, Daily Coefficient of Variation, and Frequency of Spate of Ann Arbor were all similar to or less than the means of "Hydrological Stable Sites" in Poff and Allan's (1995) study. In other words, in our study, even the site with the highest flashiness, Ann Arbor, may be classified as "Hydrological Stable Sites" using Poff and Allan's (1995) approach. Similarly, when comparing the sub-daily flashiness indices in our studies to Zimmerman's et al.'s (2010) study, which focused on Connecticut River, we found that most of our indices were below the their flashiness threshold, only the mean of Reversals (11.38) was higher than the Reversals threshold (9) in Zimmerman's et al.'s (2010) paper. It is possible that rivers from different region may have different ranges of these indices. Future studies should conduct a massive comparison of flashiness indices from different regions to study the association between flashiness indices and biological community in details.

Conclusions and Recommendations

Our daily and sub-daily flashiness calculations show that the Ann Arbor gauge and Ford Lake Dam have a higher flashiness compared to other gauges. In addition, New Hudson shows high flashiness during April and November. Dam operations could cause the high flashiness for these three sites. The Ann Arbor gauge is of particular interest because it is on the downstream site of Argo Dam. We believed that although the inflow from Allen Creek, which is largely affected by precipitation, could partially explain the high flashiness in the Ann Arbor gauge, most of the flow variability is resulted from in the Argo Dam and the cascade. Although the Argo Dam is operated as “run of river”, the automatic control system may still significantly increase the flashiness of its downstream sites. Therefore, Huron River Watershed Council may collaborate with the City of Ann Arbor to examine the automatic control system in Argo Dam. Future studies should identify the cause of flashiness and the impact for local biological community.

REFERENCES

Baker, D. B., R. P. Richards, T. T. Loftus, J. W. Kramer. 2004. A new flashiness index: characteristics and applications to Midwestern rivers and streams. Journal of the American Water Resources Association 40: 503–522.

Colwell, R. K. 1974. Predictability, constancy, and contingency of periodic phenomena. Ecology 55:1148-1153.

McKinney, T., D. W. Speas, R. S. Rogers, W. Persons, 2001. Rainbow trout in a regulated river below Glen Canyon Dam, Arizona, following increased minimum flows and reduced discharge variability. North American Journal of Fisheries Management 21: 216–222.

Poff , N. L. , J. D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76: 606–627.

Richter, B. D., J. V. Baumgartner, R. Wigington, D. P. Braun, 1997. How much water does a river need? Freshwater Biology 37: 231–249.

The Nature Conservancy, 2009. Indicators of Hydrologic Alteration Version 7.1 User's Manual.

Zimmerman, J. K. H., B. H. Letcher, K. N. Nislow, K. A. Lutz, and F. J. Magilligan, 2010. Determine the effects of dams on subdaily variation in river flows at a whole-basin scale. River Research Application 26: 1246-1260.

5 Land Cover Change

Change in land cover from pre-settlement to its current state has had a definite impact on the hydrology of the Huron River watershed. Because impact on flows is of primary interest for this assessment, the change in runoff due to land cover change was studied. In order to determine the impacts that land cover change has had on the hydrology of the Huron River main stem, the SCS Runoff Curve Number (CN) method was used as it is outlined in the United States Department of Agriculture (USDA) Technical Release 55 "Urban Hydrology for Small Watersheds" (SCS 1986). This method is a simple, efficient method for determining the estimated amount of runoff from a rainfall event in a given area based on its soil and land cover characteristics. The SCS CN method is further described in detail in NEH-4 (SCS 1986). The CN method was used to estimate runoff in the Huron River watershed for three different time periods.

Methods

A CN was developed for three different years: pre-1800, 1992, and 2006. These years were chosen because of the availability of land use/cover data. Two basic datasets were necessary to complete the CN analysis: soils and land cover. State Soil Geographic (STATSGO) data was used as the baseline soil condition for all three dates for which the CN analysis was completed. It was assumed that soil conditions would not have changed enough over 200+ years to influence the analysis. Land cover data was obtained for pre-1800 conditions, as well as 1992, and 2006. Because data was available in similar formats, a reasonable comparison was be made between the three dates. The site locations for which the catchment areas were calculated correspond to the locations of the USGS stream gage sites at the following locations from upstream to downstream: Commerce, Milford, New Hudson, Hamburg, Dexter, Ann Arbor, and Ypsilanti.

To evaluate the influence soil and land cover conditions on river flow, estimated runoff was computed for a range of possible rainfall events using the equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where

Q = runoff (in)

P = rainfall (in)

S = potential maximum retention after runoff begins (in)

I_a = initial abstraction, $I_a = 0.2S$

In calculating runoff (Q), land cover and soils contribute to the determination of S. In the case that initial abstraction (I_a) is a constant, S is the only variable that needs to be calculated in order to determine Q. S is related to the soil and land cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10$$

Table 5.1 CNs for soil/land cover type

Land Cover Type	Hydrologic Soil Group (HSG)			
	A	B	C	D
Beech-Sugar Maple Forest	-	55	70	77
Black Ash Swamp	-	78	-	-
Black Oak Barren	35	56	70	77
Grassland	-	58	-	-
Lake/River	100	100	100	100
Mixed Conifer Swamp	78	78	78	78
Mixed Hardwood Swamp	78	78	78	78
Mixed Oak Forest	-	55	70	77
Mixed Oak Savanna	-	58	-	79
Muskeg/Bog	-	78	-	78
Oak-Hickory Forest	30	55	70	77
Shrub Swamp/Emergent Marsh	-	78	-	78
Wet Prairie	30	58	71	78
Commercial/Industrial/Transportation	81	88	91	93
Deciduous Forest	36	60	73	79
Emergent Herbaceous Wetlands	78	78	78	78
Evergreen Forest	36	60	73	79
Grassland/Herbaceous	49	69	79	84
High Intensity Residential	77	85	90	92
Low Intensity Residential	51	68	79	84
Mixed Forest	36	60	73	79
Open Water	100	100	100	100
Pasture/Hay	49	69	79	84
Quarries/Strip Mines/Gravel Pits	76	85	89	91
Row Crops	67	78	85	89
Transitional Barren	48	67	77	83
Urban/Recreational Grasses	49	69	79	84
Woody Wetlands	78	78	78	78
Barren Land (Rock/Sand/Clay)	72	82	87	89
Cultivated Crops	67	78	85	89
Developed, High Intensity	77	85	90	92
Developed, Low Intensity	51	68	79	84
Developed, Medium Intensity	57	72	81	86
Developed, Open Space	49	69	79	84
Shrub/Scrub	35	56	70	77

A specific CN is appointed to any given area with a similar land cover type and hydrologic soil group (HSG). Soils are classified into four HSG's (A, B, C, and D) according to their minimum infiltration rate. Using GIS, STATSGO data was reclassified to reflect the HSG for every soil within the Huron River Watershed. The HSG data was then intersected with the land cover data to create a dataset which possessed both soil group information and land cover information, with each combination represented separately. Based on the soil and land cover combinations, a CN was applied to each area of a given soil/land cover type. The CN for each soil/land cover type can be seen in Table 5.1. For each of the seven catchment areas of interest an area weighted CN was determined by taking the sum of the CN multiplied by the area and dividing it by the total area of the catchment.

To compare the CNs between the three years, as well as between the different catchments, runoff (Q) per rainfall (P) event was calculated for events ranging from P = 0 inches to P = 10 inches. These results were plotted as a curve for comparison.

Results

CN calculations for the seven catchment locations along the Huron River main stem for the three time periods are shown in Table 5.2.

Table 5.2 Area weighted CNs

Site	**Runoff Curve Number (CN)**		
	Pre-1800	**1992**	**2006**
Commerce	68.9462	76.9811	75.5322
Milford	67.7390	76.6709	75.2512
New Hudson	66.6689	76.1786	74.7312
Hamburg	63.8990	74.6898	73.2193
Dexter	63.4646	74.2598	72.9458
Ann Arbor	62.1250	73.5468	72.5372
Ypsilanti	62.3848	73.7753	72.7720

Predicted runoff (Q) in inches was calculated across precipitation (P) events in inches (Appendix 5) and are shown in Figures 5.1-5.3 for pre-1800, 1992, and 2006, and for the two sites within the reach of interest, Ann Arbor and Ypsilanti, (Figures 5.4-5.5).The results of this study indicate that there has been a clear increase in CN from pre-1800 conditions. This means that there will be more runoff per precipitation event in current day conditions as compared with pre-settlement times. This is due to the reduction of surface infiltration caused by conversion from pervious surfaces to impervious ones. Between pre-1800 and 1992 there was roughly an 18 % increase in CN throughout the watershed. From 1992 to 2006 there was an overall decrease in CN of roughly 1 %. Although this number is small, it indicates that the long term trend of increasing CN may be turning around.

Discussion

There is no doubt that a change of land cover from pre-settlement conditions to current conditions has had a large impact on the flow regime throughout the Huron River watershed and the Huron River main stem. Although changes have been seen in infiltration, evapotranspiration, and storage within the watershed, the greatest influence on flow regime has been caused by increased runoff. The conversion of the land from wetlands and woodlands to agricultural urban lands has had an impact on both quality and quantity of the water in the Huron River. These changes have increased the overall flashiness of the system, increasing peak flows associated with precipitation events and decreasing low flows associated with natural drought. In quantifying these impacts the SCS Runoff

Curve Number method was used.

Figure 5.1 Pre-1800 CN

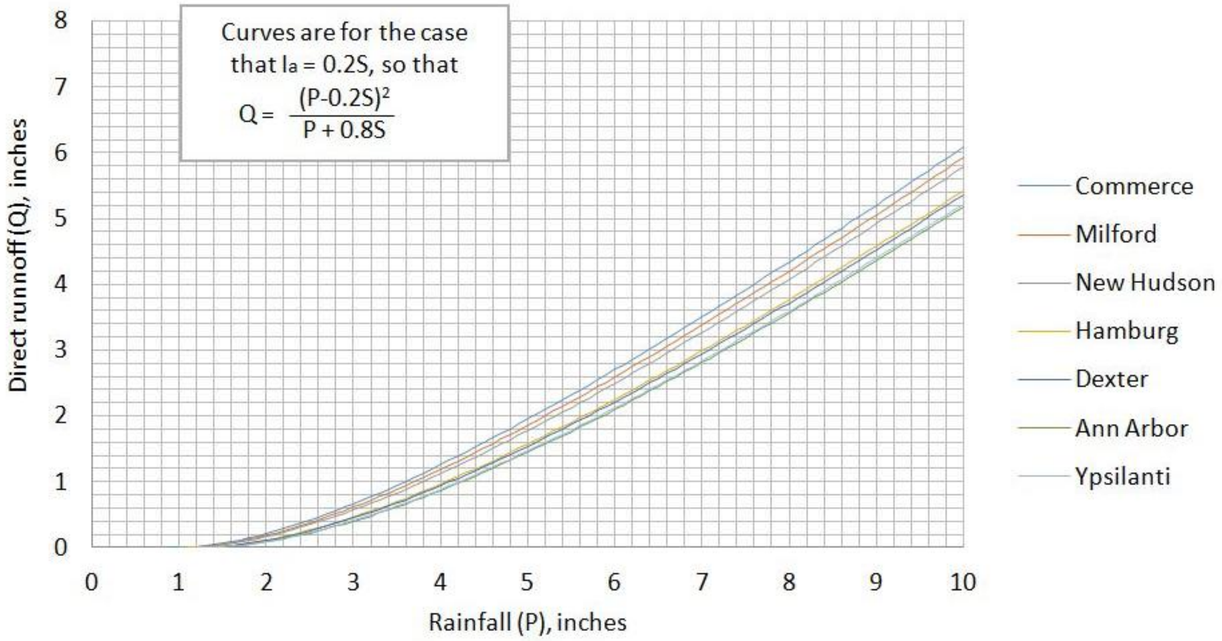


Figure 5.2 1992 CN

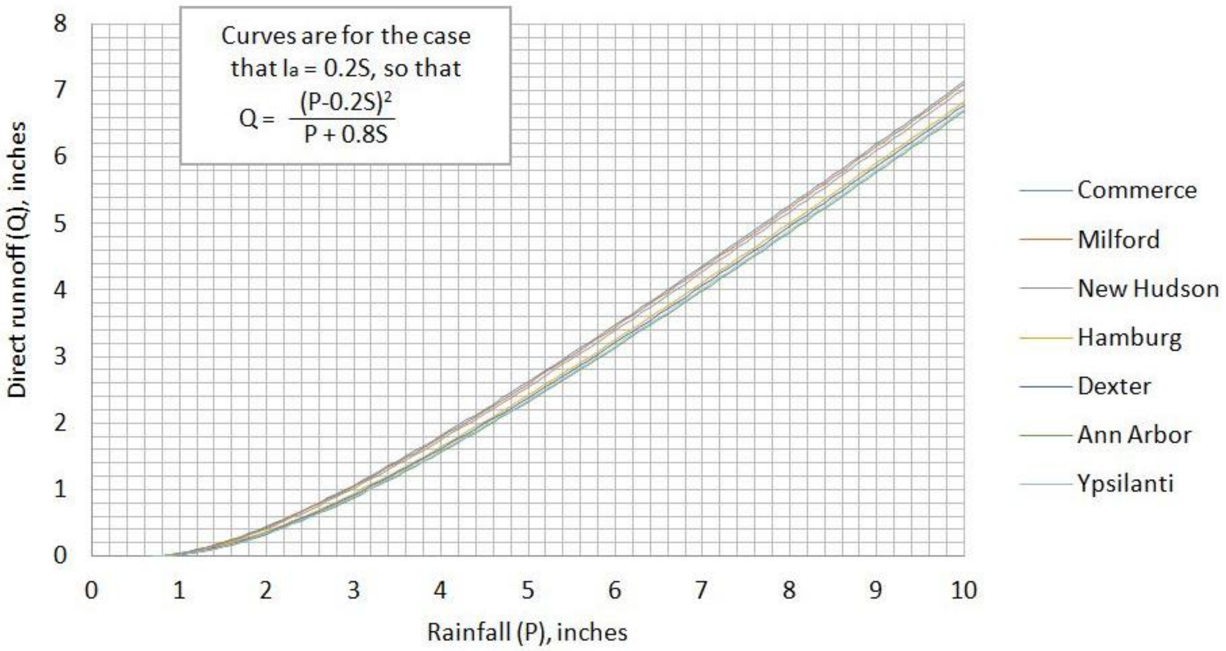


Figure 5.3 2006 CN

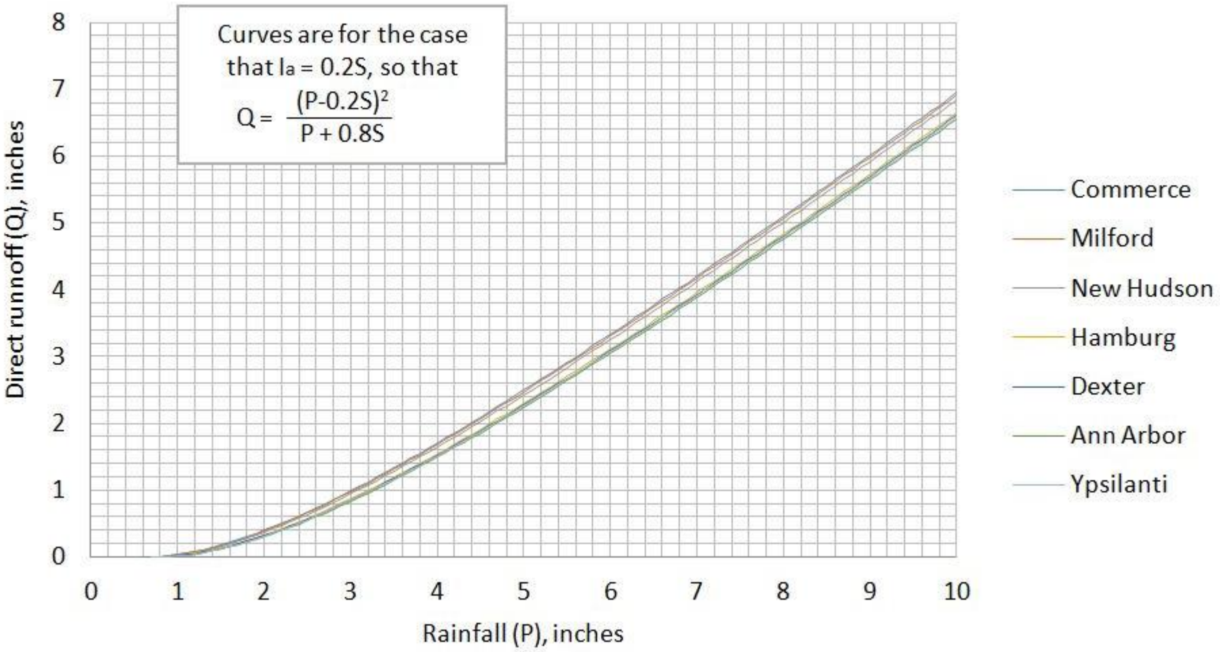


Figure 5.4 Ann Arbor CN

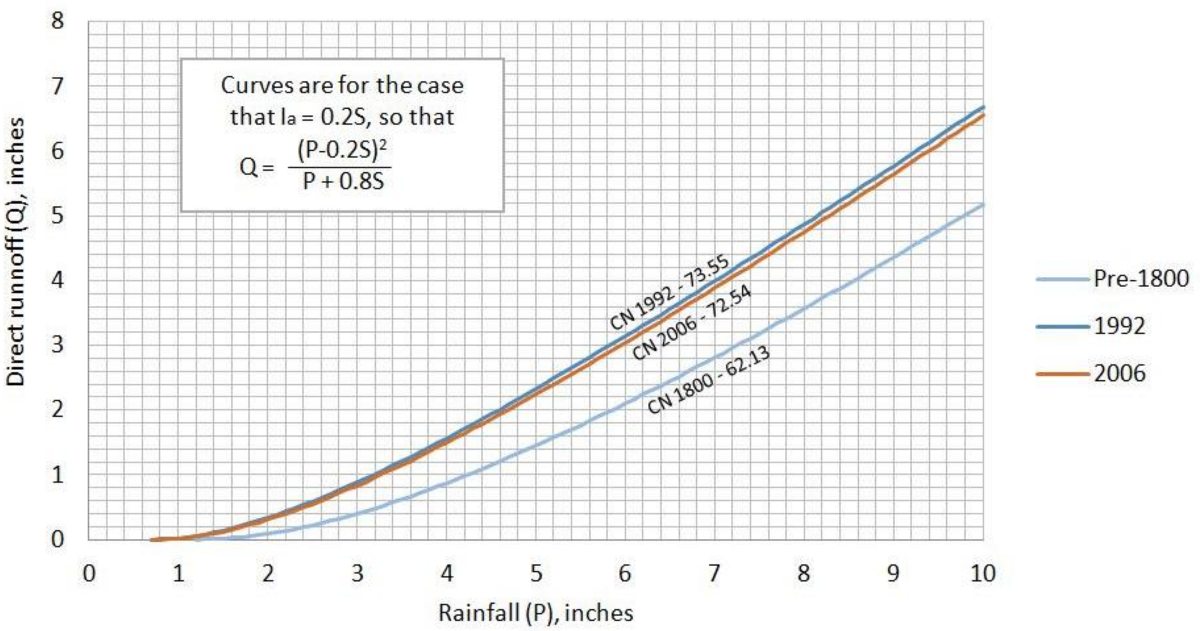
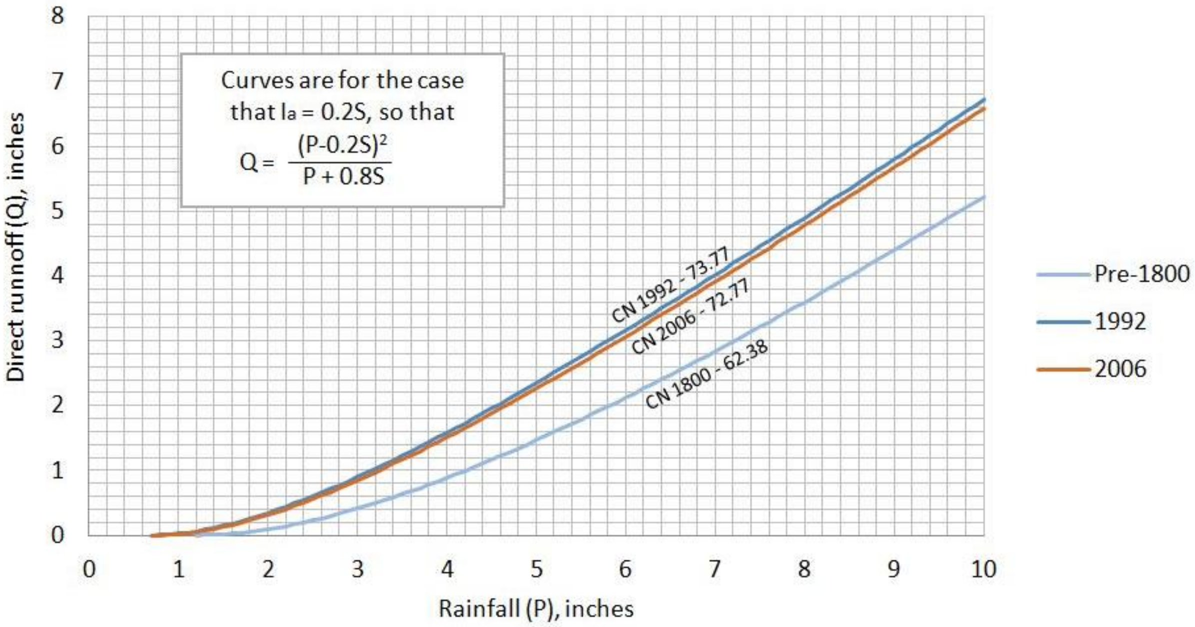


Figure 5.5 Ypsilanti CN



Best management practices for agricultural and urban lands as well as the reforestation of lands throughout the watershed may be the cause of the decreased CN between 1992 and 2006. Although it is but a fraction of the increase from pre-settlement conditions, this trend is significant in understanding the potential influence of land cover change on the flow regime of the Huron River in the coming years.

Although the application of the SCS Runoff Curve Number was useful in quantifying the potential runoff per precipitation event it cannot accurately determine the change in quantity of flow contributing the Huron River main stem. The CN method provides a coarse estimate of runoff which can be used to compare relative flow and how change in land cover may be affecting flow. To more accurately predict the change in flow due to land cover change, factors such ground water flow, evapotranspiration, and constructed and natural storage must be considered.

Conclusions

With continued implementation of urban and agricultural BMPs as well as the conversion of agricultural lands back to forested or wetland cover, runoff per precipitation event should begin to return to pre-settlement conditions to some extent. Although in recent years land cover is becoming less influential on surface water processes of the Huron River watershed, it is clear that that the overall increase in runoff curve number has increased the flashiness of the system as a whole. This has had an impact on the short term flow trends and also influences biological communities by decreasing water quality as well as changing the overall flow regime.

REFERENCES

Soil Conservation Service. 1986. Urban hydrology for small watersheds. US Soil Conservation Service. Technical release, 55.

Soil Conservation Service. 1985. National engineering handbook. Section 4-Hydrology. Washington, DC.

6 Benthic Macroinvertebrates and Stream Habitat

Benthic macroinvertebrates are frequently used as indicators of stream habitat and water quality. With land use change in the watershed, stream habitats were probably impaired by altered hydrologic routing, sediment and pollutant load. The following analysis examined the relationship between land use in drainage area, stream habitat quality and benthic macroinvertebrate communities to find evidence and explanations of the impact of land use change on aquatic biotic communities.

Methods

Survey on benthic macroinvertebrate communities have been carried out by HRWC with volunteers every spring (April or early May) since 1994 and by Michigan Department of Environmental Quality (MDEQ) in the summers of 1997, 2002, 2007, and 2008. Sampling of benthic invertebrates was aimed at identifying all existing families at the sample sites, while abundance was not considered. HRWC and MDEQ also provided corresponding habitat assessment results for all sample sites following the MDEQ protocols (MDEQ 2008). The study sites included in this analysis were selected from the HRWC and MDEQ sites with the following criteria: 1) located on the main stem of the Huron River; 2) categorized as a riffle-run stream (glide-pool stream has different habitat quality metrics); and 3) habitat assessment and invertebrate sample were taken within the same year.

Three measures were used to characterize benthic macroinvertebrate samples: total family richness, percentage of low tolerant families, and EPT taxon richness. Low tolerant families were identified as having a Hilsenhoff tolerance rank value less than 4 (Hilsenhoff 1988, Bouchard et al. 2004). EPT taxa are the macroinvertebrates from 3 sensitive orders, i.e. Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). Habitat quality was evaluated with 11 metrics, and a higher score indicated higher habitat quality (See appendix for detailed description of habitat assessment metrics). Since the MDEQ protocols changed over the years, the highest possible score for some metrics varied from 10 to 20. All habitat scores were rescaled to 0-20 in further analysis.

The catchment of each study site was delineated based on a 30m-resolution Digital Elevation Model (DEM) of the Huron River watershed using the ArcGIS Hydrology toolbox in ArcGIS 10. Percentage of different land use categories were calculated for each catchment based on land use data of year 2000 provided by Southeast Michigan Council of Governments (SEMCOG). Land use was classified as agriculture, wetland, grassland, forest, residential, and commercial. Total developed land (urban) was calculated as the sum of residential and commercial land.

Pearson's correlation coefficient was calculated between benthic macroinvertebrate assemblage characteristics, habitat quality scores, and percentage of different land use categories, in order to detect the impact of land use on stream habitat quality and aquatic organisms. Pearson's correlation coefficient was also calculated between all land use categories to determine their intercorrelation.

Results

Not all habitat quality metrics were significantly correlated with invertebrate assemblages. Habitat quality metrics explaining variation in invertebrate assemblages are embeddedness, velocity/depth regime, sediment deposition, channel alteration, frequency of riffles (or bends), vegetative protection and riparian vegetation zone width (Table 6.1). In other words, the differences in invertebrate assemblage condition in our study sites were driven by the 7 metrics mentioned above.

Table 6.1 Pearson's correlation coefficient between habitat quality metrics and benthic macroinvertebrate assemblage characteristics

HABITAT QUALITY METRIC	Family richness	% Low tolerant	EPT families
Substrate and In-stream Cover			
Epifaunal Substrate / Available Cover	-0.030	0.222	-0.068
Embeddedness	0.290*	0.069	0.270*
Velocity/Depth Regime	0.258*	0.293**	0.177
Channel Morphology			
Sediment Deposition	0.481***	-0.521***	0.301**
Maintained Flow Volume	-0.101	0.093	-0.206
Flashiness	-0.248	0.229	-0.275
Channel Alteration	0.346	0.090	0.376*
Frequency of Riffles	0.547***	-0.178	0.350**
Riparian and Bank Structure			
Bank Stability	-0.072	-0.043	-0.153
Vegetative Protection	-0.069	0.503***	-0.172
Riparian Vegetation Zone Width	-0.118	0.566***	-0.080

Note: 1) Significance code: 0 *** 0.01 ** 0.05 * 0.1
2) Habitat quality metrics are all scored 0~20, 20 being excellent habitat quality.

Table 6.2 Pearson's correlation coefficient between % land use and benthic macroinvertebrate assemblage characteristics

Land use	Richness	% Low tolerant	EPT families
Agricultural	0.163	-0.173	0.143
Wetland	-0.144	0.806***	0.008
Forest	-0.029	0.607***	-0.008
Grassland	0.423***	0.103	0.394***
Residential	-0.098	-0.456***	-0.170
Commercial	-0.594***	0.043	-0.494***
Total Developed (commercial + residential)	-0.199	-0.410***	-0.246*

Note: Significance code: 0 *** 0.01 ** 0.05 * 0.1

Except for agriculture, all other land use categories showed significant correlation with invertebrate assemblages (Table 6.2). Land use was also significantly correlated with all habitat metrics related to benthos excluding channel alteration (Table 6.3). These correlations indicated that different catchment land use patterns contributed to the variation in habitat quality of the study sites. Residential land use contributed more to total area and variation of developed land in the watershed compared to commercial land (Table 6.4). However, commercial land use had a broader impact on stream habitat quality, as it was significantly correlated with more habitat metrics (Table 6.3).

Our study sites had an average of 35.2% total developed area in their catchments, consisting of 27.1% residential and 8.2% commercial land. The highest urbanized catchment held 47.5% developed area with 37.9% residential and 9.6% commercial. Agricultural lands ranged from 5.1% to 24.8% and averaged 18.4% for all sites. As shown in the intercorrelation results for all land use categories, developed area was highly correlated with all other land use (Table 6.4). Although agricultural land was also significantly correlated with habitat metrics, it showed an unexpected positive impact on habitat quality (Table 6.3). Considering the negative correlation between developed and agricultural land, the correlation between agricultural land and habitat metrics was a reflection of less impact from developed area rather than the impact of agriculture. Therefore, urbanization is a characteristic anthropogenic stressor in this watershed.

Table 6.3 Pearson's correlation coefficient between % land use and habitat metrics

HABITAT QUALITY METRIC	TDVLP	RESID	COMM	AGRI	WETL	FOREST	GRASS
Epifaunal Substrate / Available Cover	-0.559***	-0.550***	-0.292**	0.458***	0.205	0.520***	-0.013
Embeddedness	-0.581***	-0.532***	-0.499***	0.349**	0.297**	0.428***	0.202
Velocity/Depth Regime	-0.620***	-0.577***	-0.487***	0.304**	0.377***	0.565***	0.239
Sediment Deposition	-0.176	-0.132	-0.299**	0.398***	-0.355**	-0.138	0.243
Maintained Flow Volume	-0.226	-0.166	-0.384*	0.147	0.069	0.501**	-0.081
Flashiness	-0.136	-0.158	0.031	-0.036	0.316*	0.259	-0.003
Channel Alteration	-0.178	-0.161	-0.164	-0.007	0.189	0.067	0.344
Frequency of Riffles	-0.347**	-0.266*	-0.557***	0.248*	-0.009	0.192	0.329*
Bank Stability	-0.084	-0.136	0.221	0.117	0.070	0.072	-0.072
Vegetative Protection	-0.197	-0.262	0.185	-0.220	0.659***	0.337*	0.154
Riparian Vegetation Zone Width	-0.099	-0.165	0.240	-0.298	0.621***	0.252	0.146

Note: 1) Significance code: 0 *** 0.01 ** 0.05 * 0.1
2) Land use: TDVLP - Total developed (Commercial + Residential); RESID - Residential; COMM - Commercial; AGRI-Agricultural; WETL- Wetland; FOREST- Forest; GRASS- Grassland
3) Habitat quality metrics are all scored 0~20, 20 being excellent habitat quality.

Table 6.4 Intercorrelation between percentages of land use

Total Developed						
0.517***	Commercial					
0.985***	0.363**	Residential				
-0.603***	-0.318**	-0.593***	Agricultural			
-0.570***	-0.062	-0.609***	-0.251*	Wetland		
-0.779***	-0.453***	-0.757***	0.298**	0.677***	Forest	
-0.343**	-0.313**	-0.311**	-0.244	0.433***	0.018	Grassland

Note: Significance code: 0 *** 0.01 ** 0.05 * 0.1

Discussion

Urban land use in the drainage area of the study sites corresponds to 7~20% impervious area. Studies across numerous watersheds have shown that the response threshold of aquatic invertebrates to impervious cover is usually between 5-15% (Morse et al. 2003, Stanfield and Kilgour 2006, Bazinet et al. 2010, Fitzgerald et al. 2012). Some studies with high resolution land use analysis even found response thresholds as low as 1% (Ourso and Frenzel 2003, Utz et al. 2009). With regard to agricultural land, its impact on stream habitat and aquatic organisms is highly dependent on the type of crop and management practices. In other words, agricultural land does not necessarily have a negative impact on aquatic invertebrates. Moreover, if a negative impact was observed, the response threshold is usually above 20% agricultural cover (Utz et al. 2009, Riseng et al. 2011, Waite 2013, 2014). This explained why the impact of developed land was found more prominent than agricultural land in this watershed.

Channel alteration was not correlated with catchment land use, but it was largely affected by land use patterns near the river. Most channel alteration was seen in urban and agricultural areas for flood control or irrigation purposes. Compared to naturally meandering streams, channelized streams provide fewer and less diverse habitats for aquatic flora and fauna (Simon 1989b, a, Barbour and Stribling 1991, Hupp 1992). Channelization also alters the flow regime since it changes the stream structure and linkage to ground water. Channelized streams are likely to have a higher rate of drying in late summer and early fall (Beugly and Pyron 2010).

Higher percentage of commercial and residential land in catchments was associated with lower habitat diversity in terms of velocity/depth regime and frequency of riffles (Table 6.3). This result indicated that even if apparent channel alteration was not found, land development in the catchment might have led to gradual change in stream structure, resulting in loss of high-quality habitat and diverse fauna (Hawkins et al. 1982, Osborne and Herricks 1983, Platts et al. 1983, Brown and Brussock 1991, Gordon et al. 2004).

Urbanization also decreased natural buffer zones for the river, which was reflected in the quality of vegetative protection and riparian zone. An undisturbed riparian zone with diverse plant community and water storage capability can prevent pollutants from runoff, help stop bank erosion, provide stream shading and source of materials for biotic communities (Gregory et al. 1991, Hupp and Simon 1991, Naiman et al. 1993, Collier et al. 2009). While urbanization decreased natural space for the river, the habitat health was impaired both in terms of water quality and ecological functions.

Increase of fine sediment input is common with increased urban land use (Paul and Meyer 2001). The habitat metric embeddedness measures the extent to which fine substrate covers rocks and snags (Burton and Harvey 1990, Barbour and Stribling 1991, Osborne et al. 1991). As embeddedness increases (i.e., metric score decreases), there are less available surface for macroinvertebrates and fish for shelter, spawning and egg incubation (Reice 1980, Hawkins et al. 1982, Benke et al. 1984, Clements 1987). Sediment deposition metric estimates the magnitude and frequency of sediment accumulated in pools. High deposition rate or frequency (i.e., low metric score) usually indicates unstable environment which is not ideal for many aquatic organisms. Input of fine sediment also impact aquatic invertebrates through oxygen depletion as its organic components decay. Moreover, sediment from urban land is often associated with chemical pollutants, making it even more undesirable for aquatic invertebrates (Wagenhoff et al. 2012, Von Bertrab et al. 2013). The sediment deposition metric is evaluated in pools or bends where the stream slows down, while embeddedness is evaluated at riffles where most sensitive invertebrate families live (MDEQ 2008). Therefore, low-tolerant invertebrate families are likely to show a lower response level to sediment deposition than the whole invertebrate community. That explains why we observed higher percentage of low tolerant families of macroinvertebrates as sediment deposition increased (Table 6.1, negative correlation coefficient between % low tolerant and metric score).

In addition to more fine sediment in runoff, urbanization also changes the routing of runoff. With urbanization, or more specifically, increase of impervious area, the stream sees increased response to precipitation events with higher peak flows. Flashy streams are more likely to hold unstable habitat, thus become unsuitable for aquatic organisms (Cushman 1985, Gislason 1985, Hicks et al. 1991). No strong correlation between land use, flow status and macroinvertebrate assemblages was found in this study, but it remains a question whether flow flashiness based on actual flow measurement will give different results compared to flow flashiness scores based on visual assessment of habitat conditions.

Conclusions and Recommendations

Urbanization is a major stressor on benthic macroinvertebrates and in-stream habitat in this watershed. Higher percentage of developed land in drainage area was correlated with higher input of fine sediment, lower habitat diversity and degraded riparian zone. Flow status based on visual habitat assessment was not correlated with the quality of macroinvertebrate assemblages. To examine the relationship between flow flashiness and macroinvertebrate assemblages, flow flashiness measurements at specific sample sites are needed.

REFERRENCES

Barbour, M. T., and J. Stribling. 1991. Use of habitat assessment in evaluating the biological integrity of stream communities. Biological Criteria: Research and Regulation. US Environmental Protection Agency, Washington, DC EPA-440/5-91-005:25-38.

Bazinet, N. L., B. M. Gilbert, and A. M. Wallace. 2010. A Comparison of Urbanization Effects on Stream Benthic Macroinvertebrates and Water Chemistry in an Urban and an Urbanizing Basin in Southern Ontario, Canada. Water Quality Research Journal of Canada 45:327-341.

Benke, A. C., T. C. Vanarsdall, D. M. Gillespie, and F. K. Parrish. 1984. INVERTEBRATE PRODUCTIVITY IN A SUB-TROPICAL BLACKWATER RIVER - THE IMPORTANCE OF HABITAT AND LIFE-HISTORY. Ecological Monographs 54:25-63.

Beugly, J., and M. Pyron. 2010. Variation in Fish and Macroinvertebrate Assemblages Among Seasonal and Perennial Headwater Streams. American Midland Naturalist 163:2-13.

Bouchard, R. W., L. C. Ferrington, and M. L. Karius. 2004. Guide to aquatic invertebrates of the upper midwest.

Brown, A. V., and P. P. Brussock. 1991. COMPARISONS OF BENTHIC INVERTEBRATES BETWEEN RIFFLES AND POOLS. Hydrobiologia 220:99-108.

Burton, T. A., and G. W. Harvey. 1990. Estimating intergravel salmonid living space using the cobble embeddedness sampling procedure. Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Bureau.

Clements, W. H. 1987. THE EFFECT OF ROCK SURFACE-AREA ON DISTRIBUTION AND ABUNDANCE OF STREAM INSECTS. Journal of Freshwater Ecology 4:83-91.

Collier, K. J., B. Aldridge, B. J. Hicks, J. Kelly, A. Macdonald, B. J. Smith, and J. Tonkin. 2009. Ecological values of Hamilton urban streams (North Island, New Zealand): constraints and opportunities for restoration. New Zealand Journal of Ecology 33:177-189.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American journal of fisheries Management 5:330-339.

Fitzgerald, E. P., W. B. Bowden, S. P. Parker, and M. L. Kline. 2012. Urban Impacts on Streams are Scale-Dependent With Nonlinear Influences on Their Physical and Biotic Recovery in Vermont, United States. Journal of the American Water Resources Association 48:679-697.

Gislason, J. C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel flow patterns. North American journal of fisheries Management 5:39-46.

Gordon, N. D., T. A. McMahon, B. L. Finlayson, C. J. Gippel, and R. J. Nathan. 2004. Stream hydrology: an introduction for ecologists. John Wiley & Sons.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. AN ECOSYSTEM PERSPECTIVE OF RIPARIAN ZONES. Bioscience 41:540-551.

Hawkins, C. P., M. L. Murphy, and N. H. Anderson. 1982. EFFECTS OF CANOPY, SUBSTRATE COMPOSITION, AND GRADIENT ON THE STRUCTURE OF MACROINVERTEBRATE COMMUNITIES IN CASCADE RANGE STREAMS OF OREGON. Ecology 63:1840-1856.

Hicks, B. J., R. L. Beschta, and R. D. Harr. 1991. LONG-TERM CHANGES IN STREAMFLOW FOLLOWING LOGGING IN WESTERN OREGON AND ASSOCIATED FISHERIES IMPLICATIONS. Water Resources Bulletin 27:217-226.

Hilsenhoff, W. L. 1988. RAPID FIELD ASSESSMENT OF ORGANIC POLLUTION WITH A FAMILY-LEVEL BIOTIC INDEX. Journal of the North American Benthological Society 7:65-68.

Hupp, C. R. 1992. RIPARIAN VEGETATION RECOVERY PATTERNS FOLLOWING STREAM CHANNELIZATION - A GEOMORPHIC PERSPECTIVE. Ecology 73:1209-1226.

Hupp, C. R., and A. Simon. 1991. BANK ACCRETION AND THE DEVELOPMENT OF VEGETATED DEPOSITIONAL SURFACES ALONG MODIFIED ALLUVIAL CHANNELS. Geomorphology 4:111-124.

MDEQ. 2008. Qualitative Biological and Habitat Survey Protocols for Wadeable Streams and Rivers.in M. D. o. E. Quality, editor., Michigan.

Morse, C. C., A. D. Huryn, and C. Cronan. 2003. Impervious surface area as a predictor of the effects of urbanization on stream insect communities in Maine, USA. Environmental Monitoring and Assessment 89:95-127.

Naiman, R. J., H. Decamps, and M. Pollock. 1993. THE ROLE OF RIPARIAN CORRIDORS IN MAINTAINING REGIONAL BIODIVERSITY. Ecological Applications 3:209-212.

Osborne, L. L., B. Dickson, M. Ebbers, R. Ford, J. Lyons, D. Kline, E. Rankin, D. Ross, R. Sauer, P. Seelbach, C. Speas, T. Stefanavage, J. Waite, and S. Walker. 1991. STREAM HABITAT ASSESSMENT PROGRAMS IN STATES OF THE AFS NORTH CENTRAL DIVISION. Fisheries 16:28-35.

Osborne, L. L., and E. E. Herricks. 1983. Streamflow and velocity as determinants of aquatic insect distribution and benthic community structure in Illinois. University of Illinois at Urbana-Champaign, Water Resources Center.

Ourso, R. T., and S. A. Frenzel. 2003. Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska. Hydrobiologia 501:117-131.

Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333-365.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions.

Reice, S. R. 1980. THE ROLE OF SUBSTRATUM IN BENTHIC MACROINVERTEBRATE MICRO-DISTRIBUTION AND LITTER DECOMPOSITION IN A WOODLAND STREAM. Ecology 61:580-590.

Riseng, C. M., M. J. Wiley, R. W. Black, and M. D. Munn. 2011. Impacts of agricultural land use on biological integrity: a causal analysis. Ecological Applications 21:3128-3146.

Simon, A. 1989a. A MODEL OF CHANNEL RESPONSE IN DISTURBED ALLUVIAL CHANNELS. Earth Surface Processes and Landforms 14:11-26.

Simon, A. 1989b. THE DISCHARGE OF SEDIMENT IN CHANNELIZED ALLUVIAL STREAMS. Water Resources Bulletin 25:1177-1188.

Stanfield, L. W., and B. W. Kilgour. 2006. Effects of percent impervious cover on fish and benthos assemblages and instream habitats in Lake Ontario tributaries. Pages 577-599 in R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Landscape Influences on Stream Habitats and Biological Assemblages. Amer Fisheries Soc, Bethesda.

Utz, R. M., R. H. Hilderbrand, and D. M. Boward. 2009. Identifying regional differences in threshold responses of aquatic invertebrates to land cover gradients. Ecological Indicators 9:556-567.

Von Bertrab, M. G., A. Krein, S. Stendera, F. Thielen, and D. Hering. 2013. Is fine sediment deposition a main driver for the composition of benthic macroinvertebrate assemblages? Ecological Indicators 24:589-598.

Wagenhoff, A., C. R. Townsend, and C. D. Matthaei. 2012. Macroinvertebrate responses along broad stressor gradients of deposited fine sediment and dissolved nutrients: a stream mesocosm experiment. Journal of Applied Ecology 49:892-902.

Waite, I. R. 2013. Development and Application of an Agricultural Intensity Index to Invertebrate and Algal Metrics from Streams at Two Scales. Journal of the American Water Resources Association 49:431-448.

Waite, I. R. 2014. Agricultural disturbance response models for invertebrate and algal metrics from streams at two spatial scales within the U.S. Hydrobiologia 726:285-303.

7 Fish Community Assemblage Analysis

The purpose of this analysis was to determine how present flow regimes in the Huron River impact fish with regard to habitat preferences and tolerance to environmental conditions. Fish taxa and population data along a reach with hydrologically different segments (riverine and impoundments) were examined to identify fish communities. The goal of this effort was to characterize the existing fish communities at sites along a particular reach of the Huron River, so that the results could be compared to expected communities. The expected communities were based on the habitat suitability model developed for Michigan's Water Withdrawal Tool (Zorn et al. 2012) and is addressed in the following section entitled "Habitat Suitability Model".

Methods

A reach of the Huron River from North Territorial Road to Belleville Lake (Figure 1.3), was selected for the following reasons: existing hydrologic variability, sufficient available data, site accessibility for habitat assessment, proximity to the HRWC's area of concern, and time constraints. Fish sampling along this reach had been conducted by the Michigan Department of Natural Resources (MDNR) from 1995 to 2011 and compiled by the Michigan Fish Atlas and was accessed from HRWC's interactive Google map layer and Microsoft access database. For the purpose of this study, fish sampling sites were named with respect to their location: Hudson Mills Metropark, Mill Creek, Barton Pond, Argo Pond, Geddes Pond, Ypsilanti, Ford Lake, and Belleville Lake (Figure 1.3). Additional fish sampling data from mainstem river sites collected in 2006 was provided by the Michigan Department of Environmental Quality (MDEQ)/MDNR. These Huron River mainstem sites included: North Territorial Road, Mast Road, Zeeb Road, Fuller Road, and Forest Street (Figure 1.3).

Sampling methods and effort, collection periods, and taxonomic resolution differed at each site (Table 7.1); therefore, the analysis was limited to fish species presence/absence metrics. However, these metrics provided an appropriate ecological data grain size for assessing fish assemblies. Additionally, since the focus of this analysis was identification of potential fish communities within the reach, targeted and full community sample data was composited for sites in close proximity and with similar hydrologic conditions (i.e. impoundment or riverine). The following were composited: four sites at Belleville Lake within 1.80 river miles, three sites along Hudson Mills Metropark within 0.75 river miles, two dates in Mill Creek (same location), two sites in Barton pond within 0.52 river miles, two sites (three dates) in Ypsilanti within 0.39 river miles, and two dates in Ford Lake (same location) (Table 7.1; Figure 1.3).

Using an existing Access database of ecological fish characteristics (housed in M.J. Wiley lab, created by C.M. Riseng and others (Wiley and Riseng 2009)), each sampled fish species was linked with its characteristics and habitat preferences. For each fish species in the database, the following categories were examined: Identification (11 characteristics, e.g. common name), Water Temperature Preference (3 characteristics, e.g. cold water), Tolerance Preference (7 characteristics, e.g. Intolerant), River Size Preference (6 characteristics, e.g. Small River), Substrate Preference (4 characteristics, e.g. rock/gravel), Flow Velocity Preference (4 characteristics, e.g. slow flow), Trophic Preference (4 characteristics, e.g. piscivore), and Additional Information (4 categories; e.g. lithophilic spawner)

(Table 7.2).

Table 7.1 All fish sample sites with corresponding location, date, and collection methods.

SITE NAME	WATERBODY	LOCATION	DATE	COMMUNITY SAMPLE	METHOD	EFFORT	COLLECTOR
Hudson Mills Metropark	Huron River	North Territorial Road	1/24/2006	Unknown	Unknown	6750 ft^2	MDEQ
	Huron River	Hudson Mills Metropark	8/31/2011	Targeted	Towbarge electroshocking	1000 feet and on each bank, total of 80 minutes	MDNR
	Huron River	Huron River at south end of Hudson Mills Metropark	7/6/1995	Presence Data Only	Unknown	Unknown	Mi Fish Atlas
Mast Road	Huron River	Mast Road	1/24/2006	Unknown	Unknown	8000 ft^2	MDEQ
Mill Creek	Mill Creek	Shield Road	8/31/2010	Full Community	Stream Shocker	377 ft, 2026 seconds	MDNR
	Mill Creek	Shield Road	7/23/2008	Full Community	Stream Shocker	2039 seconds, 377 feet	MDNR
Zeeb Road	Huron River	Zeeb Road	1/24/2006	Unknown	Unknown	13500 ft^2	MDEQ
Barton Pond	Barton Pond	Washtenaw County	1996	Full Community	Trap Net	8 trap nets	MDNR
	Barton Pond	Washtenaw County	4/28/2010	Targeted- most smaller species ignored	Boom Shocker	20 minutes	MDNR
Argo Pond	Argo Pond	Washtenaw County	2000	Full Community	Trap Net	8 trap nets	MDNR
Fuller Road	Huron River	Fuller Road	1/24/2006	Unknown	Unknown	15000 ft^2	MDEQ
Geddes Pond	Geddes Pond	Washtenaw County	1996	Full Community	Trap Net	4 trap nets	MDNR
Ypsilanti	Huron River	Between Forest and LaForge Roads, Ypsilanti	05/13/1992	Presence Data Only	Unknown	Unknown	Mi Fish Atlas
	Huron River	Forest Street	1/24/2006	Unknown	Stream Shocker	36500 ft^2, 25 min	MDEQ
	Huron River	Forest Street	1/24/2006	Unknown	Unknown	4500 ft^2	MDEQ
Ford Lake	Ford Lake	Washtenaw County	Summer 2006	Targeted	Creel Survey	Unknown	MDNR
	Ford Lake	Washtenaw County	5/15/06 through 5/19/06, and 6/14/06	Full Community	Trap nets, fyke nets, gill nets, boom shocker, seine	Many efforts over several day period	MDNR
Belleville Lake	Belleville Lake	Wayne County	1992	Full Community	Trap Net, Fyke Net	Unknown	MDNR
	Belleville Lake	Wayne County	1997	Full Community	Trap Net, Inland Gill Net	Unknown	MDNR
	Belleville Lake	Wayne County	1999	Full Community	Trap Net, Inland Gill Net	Unknown	MDNR
	Belleville Lake	Wayne County	Summer 2005	Targeted	Creel Survey	Unknown	MDNR

Tolerance level, which was included in the original database, was expanded upon in this analysis and examined in two ways: 1) using the MDNR list of tolerant, intolerant, and unknown tolerance species, and 2) updated using other published IBI categorizations (Karr 1981, OhioEPA 1987, Lyons 1992, Lyons et al. 2001, OhioEPA 2013) to parse species into tolerant, mid-tolerant, and intolerant categories. The original database was also augmented with additional data for lithophilic spawner, benthic forager, and lake dweller (Becker 1983, Hubbs et al. 2004, Froese and Pauly 2014).

Two relevant fish preference categories were added to the original database: Flow Velocity Preference (slow, medium, fast, all) and Trophic Preference (omnivore, piscivore, insectivore/aquatic invertebrates, and plankton) (Becker 1983, Hubbs et al. 2004, Froese and Pauly 2014) (Table 7.2). Trophic preference was categorized using the principal diet of the adult fish as reported in the literature (Becker 1983, Hubbs et al. 2004, Froese and Pauly 2014). Overlap in diet categories was addressed by setting boundaries based on the relative frequency of food items with the most frequent food type being categorized as dominant and therefore preferred. Association with aquatic macrophytes, MDNR stocking history (MDNR 2005), and MDNR regulated species (MDNR 2014) were added to the original database through literature (Becker 1983, Hubbs et al. 2004, Froese and Pauly 2014) and MDNR communication, respectively (Table 7.2). The association of a particular fish species with aquatic vegetation was not as methodically robust as the other categories due to analysis being constrained to only broad anecdotal evidence in the literature.

Table 7.2 Fish database metadata explaining preference characteristics and additional species information. Category defines data: identification, preferences, or additional information. Characteristics: added to the dataset (bold) or modified (italics). Sources: Lit = primary literature (specified in text), MDNR = Michigan Department of Natural Resources literature or website, DNR = MI and surrounding regional DNRs (Ohio, Wisconsin) literature or websites, IBI = Index of Biotic Integrity literature (specified in text), Fish Base = online fish database, and NA = not applicable. Data Type is the form of data: Classified = grouped due to shared characteristics, Designated = officially bestowed description/title, Research = primary literature observation and data, Expert Opinion = expert observation, Reported = personal communication, and NA = not applicable.

Category	Characteristic	Meaning	Data Type	Source
Identification	Common Name	Common name	NA	MDNR, Fish Base
	Scientific Name	Scientific name	NA	MDNR, Fish Base
	Family	Scientific family name	NA	MDNR, Fish Base
	Family_common	Common family name	NA	MDNR, Fish Base
	Native	Native to Michigan	Classified	MDNR, Lit
	Status	Rare, Threatened, Endangered, Declining	Designated	MDNR, IBI, Lit
	F_game	Game fish	Designated	MDNR, Lit
	Reg_sp	MDNR regulated fish species	Designated	MDNR
	Stock_His	MDNR stocking history	Reported	MDNR
	Darters	Darter species	Classified	MDNR, IBI
	Brk_trt	Brook trout	Classified	NA
Water Temperature Preference	Cold Water	Prefer cold water (<22 C)	Research	Lit, DNR, Fish Base
	Cool Water	Prefer cool water (22 - 24 C)	Research	Lit, DNR, Fish Base
	Warm Water	Prefer warm water (>24 C)	Research	Lit, DNR, Fish Base
Tolerance Preference	*Tol*	Tolerant of physical/chemical perturbation	Classified/Research	IBI, Lit
	Mtol	Mid-tolerant of physical/chemical perturbation	Classified/Research	IBI, Lit
	Intol	Intolerant of physical/chemical perturbation	Classified/Research	IBI, Lit
	Unk_tol	Unknown tolerance of physical/chemical perturbation	Classified/Research	IBI, Lit
	MDNR_tol	Tolerant of physical/chemical perturbation	Classified	MDNR
	MDNR_intol	Intolerant of physical/chemical perturbation	Classified	MDNR
	MDNR_unk_tol	Unknown tolerance of physical/chemical perturbation	Classified	MDNR
River Size Preference	Lo_sm	Lotic, small river	Research	Lit, DNR, Fish Base
	Lo_sm_med	Lotic, small to medium sized river	Research	Lit, DNR, Fish Base
	Lo_med	Lotic, medium sized river	Research	Lit, DNR, Fish Base
	Lo_med-lg	Lotic, medium to large sized river	Research	Lit, DNR, Fish Base
	Lo_lg	Lotic, large sized river	Research	Lit, DNR, Fish Base
	Lo_all	Lotic, any sized river	Research	Lit, DNR, Fish Base
Substrate Preference	Substr_rock/grav	Predominantly found on rock and gravel substrate	Research	Lit, DNR, Fish Base
	Substr_sand	Predominantly found on sand substrate	Research	Lit, DNR, Fish Base
	Substr_mud/silt	Predominantly found on mud/silt substrate	Research	Lit, DNR, Fish Base
	Substr_gen	Substrate generalist	Research	Lit, DNR, Fish Base
Flow Preference	**Slow_Flow**	Predominantly found in oxbows, ponds, low current	Research	Lit, DNR, Fish Base
	Med_Flow	Predominantly found in pools or riffles	Research	Lit, DNR, Fish Base
	Fast_Flow	Predominantly found in swift riffles or quick current	Research	Lit, DNR, Fish Base
	All_Flow	Flow generalist	Research	Lit, DNR, Fish Base
Trophic Preference	**Pisicivore**	Primarily fish diet	Research	Lit, DNR, Fish Base
	Insect/Aqua_Inverts	Primarily insect or invertebrate diet	Research	Lit, DNR, Fish Base
	Plankton	Primarily plankton diet	Research	Lit, DNR, Fish Base
	Omnivore	Primarily mix of insects, plants, occasionally fish	Research	Lit, DNR, Fish Base
Additional Information	*Lith_sp*	Lithophillic spawner	Classified	MDNR, IBI, Lit
	Ben_forag	Benthic forager (bottom feeders)	Research	Lit, DNR, Fish Base
	Aqua_Veg	Predominantly found with aquatic macrophytes	Expert Opinion	Lit, DNR, Fish Base
	Lake	Commonly found in lentic habitats	Research/Expert Opinion	Lit, DNR, Fish Base

At each site, the percent of the fish taxa exhibiting a particular characteristic was calculated and compared to other sites along the Huron River. Therefore, for a site with 10 species, the proportion matching the category characteristic was calculated. For example, if 4 out of 10 species had a preference for “gravel/rock” substrate under the “Substrate Preference” category, then .4 or 40% of fish species were categorized as preferring gravel at a particular site. In most cases all subcategory scores summed to 1.00; however, for characteristics in the “Identification” and “Additional Information” categories, this was not always applicable. For example, at some sites, not all fish in a sample were native; therefore, the “Native” characteristic did not sum to 1.

To compare fish communities, the percent taxa and raw numbers were used to determine if preferences changed longitudinally (upstream to downstream) or varied between riverine and impoundment habitats. No trend was identified in the former; therefore, the resulting analyses from the latter will be focused on in the results section. Hence, from this analysis, eighteen riverine-only species (i.e. species that did not occur at impoundment sites), fifteen impoundment-only species (i.e. species that did not occur at riverine sites), and twenty-two overlap species (i.e. species that occurred at both riverine and impoundment sites) were identified. These lotic vs. lentic habitat preferences were then compared using the same analysis as above - the percentage of fish taxa displaying a particular preference in the riverine, impoundment, and over-lap were compared using bar charts in Microsoft Excel.

Several approaches were used to assess existing habitat at the fish sample sites. The most recent raw habitat assessment data collected by the HRWC during volunteer insect collection days from 2008-2012 was used to provide details on riverine habitats at the following sites: Zeeb Road (2008), Bell Road (2012), Mill Creek at Jackson Road (2010), and Huron River at Cross Street (2009). The habitat data included: General Characteristics (e.g. flow patterns, shade, trash, etc.), Riparian Zone and Plant Community, Stream Substrate and Sediment, Bank Stability, Transects and Stream Bank Measurements, and MDEQ metrics for Riffle-Run and Pool/Glide. Insect collections do not occur at impoundments; therefore, there was no raw habitat data available for those sites. In addition, only the HRWC habitat data from Zeeb Road overlapped spatially with the fish sampling sites. The habitat data from Bell Road was also considered since the site was relatively close (approximately 1.8 river miles) to the most northern Hudson Mills Metropark fish sampling site (North Territorial Road). Ground-truthing habitat assessments were attempted at three sites (Zeeb Road, Barton Pond, and Argo Pond) using Ohio EPA’s Qualitative Habitat Evaluation Index (QHEI); however, cold temperatures and snow and ice on the river and floodplain made analysis of substrate type and pool/glide and run-riffle quality difficult (OhioEPA 2006).

Table 7.3 Riverine sites used in the MDEQ Procedure 51 to evaluate riverine habitat.

Site Name	Location	Year	No. Taxa	No. Individuals	Collector
Hudson Mills Metropark	North Territorial Road	2006	11	140	MDEQ
Mast Road	Mast Road	2006	9	79	MDEQ
Zeeb Road	Zeeb Road	2006	12	61	MDEQ
Fuller Road	Fuller Road	2006	10	59	MDEQ
Ypsilanti	Forest Street	2006	10	86	MDEQ

The MDEQ Procedure 51 was also used to perform an indirect approximation of habitat conditions from the sampled fish population at the following riverine sites: Hudson Mills Metropark, Mast Road, Zeeb Road, Fuller Road, and Ypsilanti (MDEQ 1996, Creel et al. 2000). Due to missing information on the width of the stream, which is integral to the calculation, Mill Creek could not be included.

For all other sites, the most recent fish sampling date that included average width of the stream and species numbers was utilized in the calculation (Table 7.3). For Ypsilanti, the sample with the largest total number of individuals was used.

Table 7.4 Impoundment sites used in the MDNR IBI for lakes (impoundments).

Site Name	Year	No. Taxa	No. Individuals	Collector	Score
Barton Pond	1996	14	98	MDNR	35
Argo Pond	2000	18	280	MDNR	34
Geddes Pond	1996	11	137	MDNR	32
Ford Lake	2006	27	3234	MDNR	36

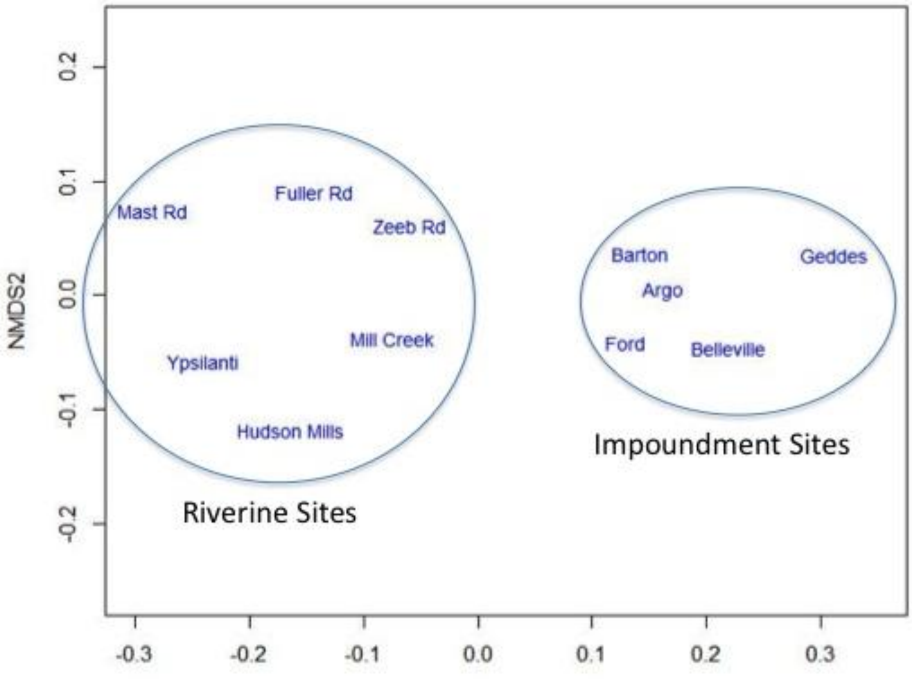
To assess impoundment habitats, an IBI developed by the MDNR that uses fish as indicators for lake habitat quality assessment (Schneider 2002) was utilized for: Barton Pond, Argo Pond, Geddes Pond, and Ford Lake. Habitat at Belleville Lake was not assessed due to a lack of fish stocking data, which was important for accurate assessment. The IBI included the following metrics: Native fish fauna, Winterkill, Acidity, Thermocline/hypolimnion DO, Productivity/enrichment, Turbidity, Silt, Macrophytes, Edge modification, Level stabilization, and Predation/Competition. The metrics sometimes required that numbers of a particular fish species be available; therefore, instead of using consolidated presence/absence data, the most recent date of full community sampling was used to calculate these metrics (Table 7.4). Important to note, the “Native fish fauna” metric required information about the stocking history of a particular lake or impoundment. Fish that were not native to that particular lake (i.e. stocked), but had established reproducing populations were negative counts. This had two important implications for the calculation of the IBI: 1) if a fish species was stocked in an impoundment prior to the sampling date and also found on the sampling date, it was included as a reproducing or self-sustaining population and 2) given that these fish species were assumed to be reproducing, it was logically concluded that the habitat was suitable and, therefore, these species were included in calculating the remaining metrics of the IBI. Given that the IBI was developed for lakes and not impoundments, other caveats will be discussed in the results section.

Results

The fish presence/absence data (percent of the sample taxa) for riverine and impoundment sites showed marked differences in the following: game species, darter species, Tolerance Preference, Flow Velocity Preference, Substrate Preference, River Size Preference, lake dwellers, and Trophic Preference (Figures 1-10 in Appendix 7.1). Differences between riverine and impoundment sites were not distinct for the following preferences or characteristics: Water Temperature Preference, association with macrophytes, and lithophilic spawners (Figures 11-13 in Appendix 7.1). Benthic foragers displayed an interesting trend of first increasing from upstream to downstream riverine sites and then continuing a downward trend in the impoundments (Figure 14 in Appendix 7.1).

An NMDS analysis confirmed and illustrated the differentiation of two fish guilds – riverine and impoundment – by means of clustering sites with similar fish species preferences or characteristics (Figure 7.1). The stress of this ordination result, a measure of how well the plotted distance represents the calculated distance, is 0.056. A stress < 0.1 is usually considered good, while < 0.05 is considered excellent.

Figure 7.1 NMDS cluster analysis. Sites with more similar fish sample taxa preferences are closer together. The stress of this ordination result, a measure of how well the plotted distance represents the calculated distance, is 0.056. A stress < 0.1 is usually considered good, while < 0.05 is considered excellent.



From these results, eighteen fish species found solely in riverine sites and 15 fish species found solely in impoundment sites were identified (Table 7.5 and Table 7.6). Twenty-two fish were identified as overlapping between riverine and impoundment sites (Table 1 in Appendix 7.2).

Distinct differences between the riverine only guild (ROG) and the impoundment only guild (IOG) were found for the following preferences and characteristics: status of species, game species, darter species (Figure 7.2), Tolerance Preference, lake dwellers, River Size Preference, Substrate Preference, Flow Velocity Preference (Figure 7.3), and Trophic Preference (Additional Figures 1-5 in Appendix 7.3; Table 7.7, Table 7.8). Differences between the ROG and IOG were not distinct for the following preferences/characteristics: Water Temperature Preference, association with macrophytes, and lithophilic spawners (Figures 6-8 in Appendix 7.3). Additionally, an increasing trend of gravel/rock Substrate Preference, benthic foragers, and lithophilic spawners was observed in the riverine sites, which was not consistent for the impoundment guild (Figure 7.4).

Figure 7.2 Characteristics of fish, as percent of the taxa, found in the identified riverine or impoundment guilds. Species of "Status" are classified as rare, declining, endangered, or threatened.

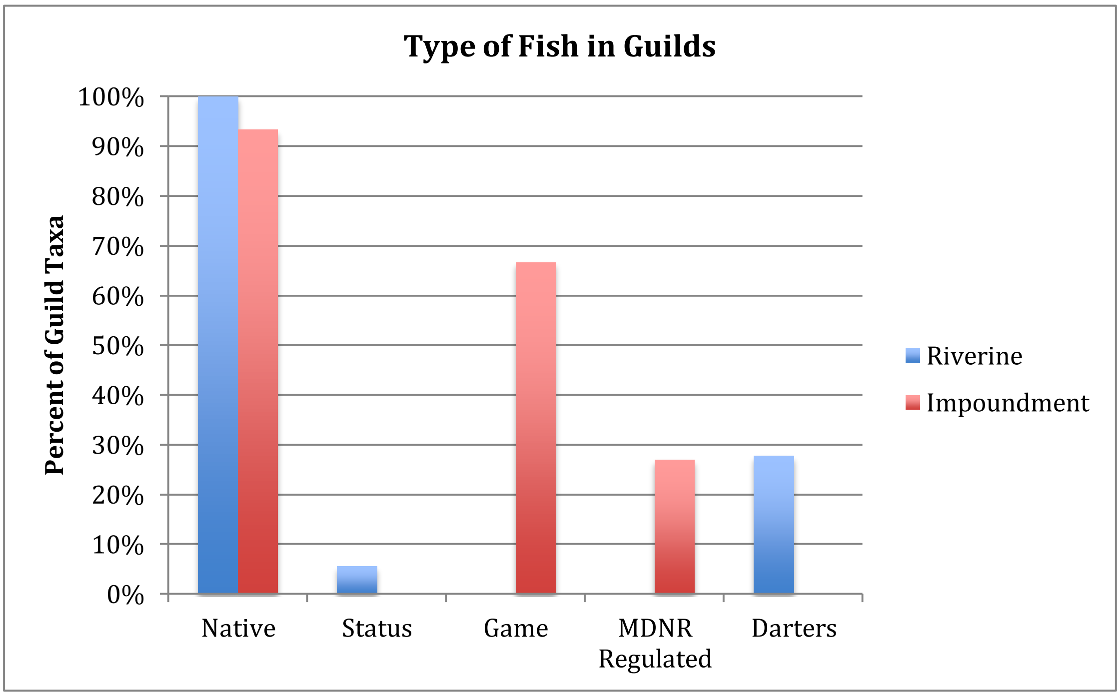


Figure 7.3 Flow velocity preferences of fish in riverine and impoundment guilds as a percent of taxa for riverine and impoundment guilds.

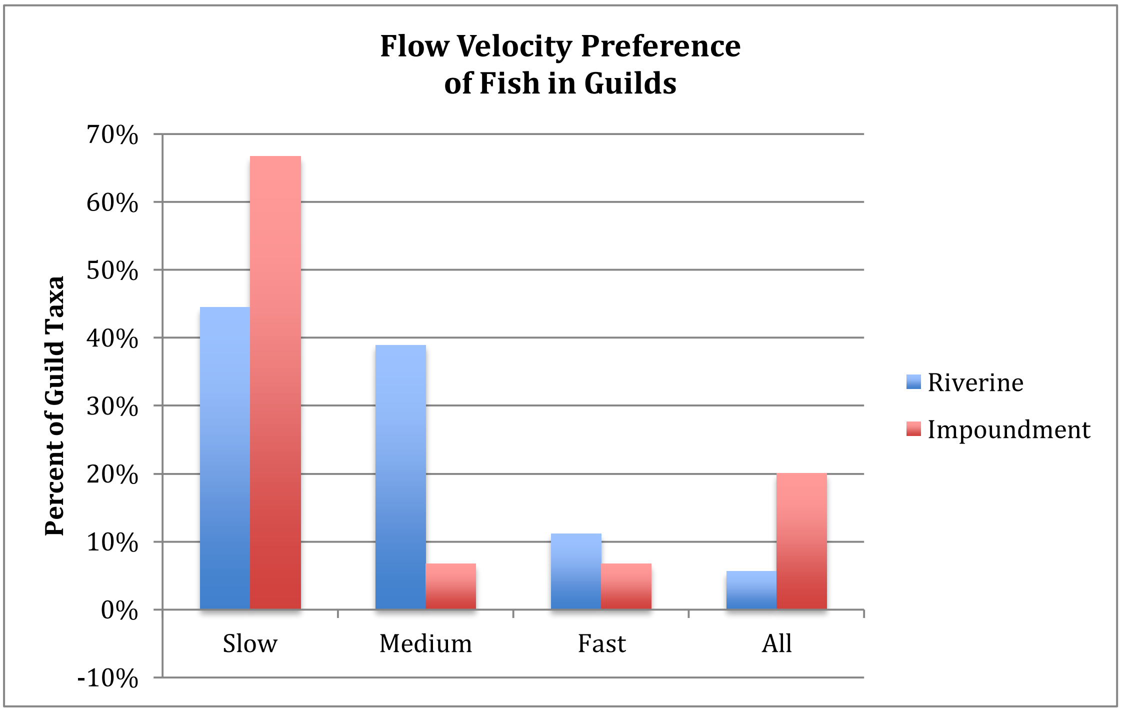
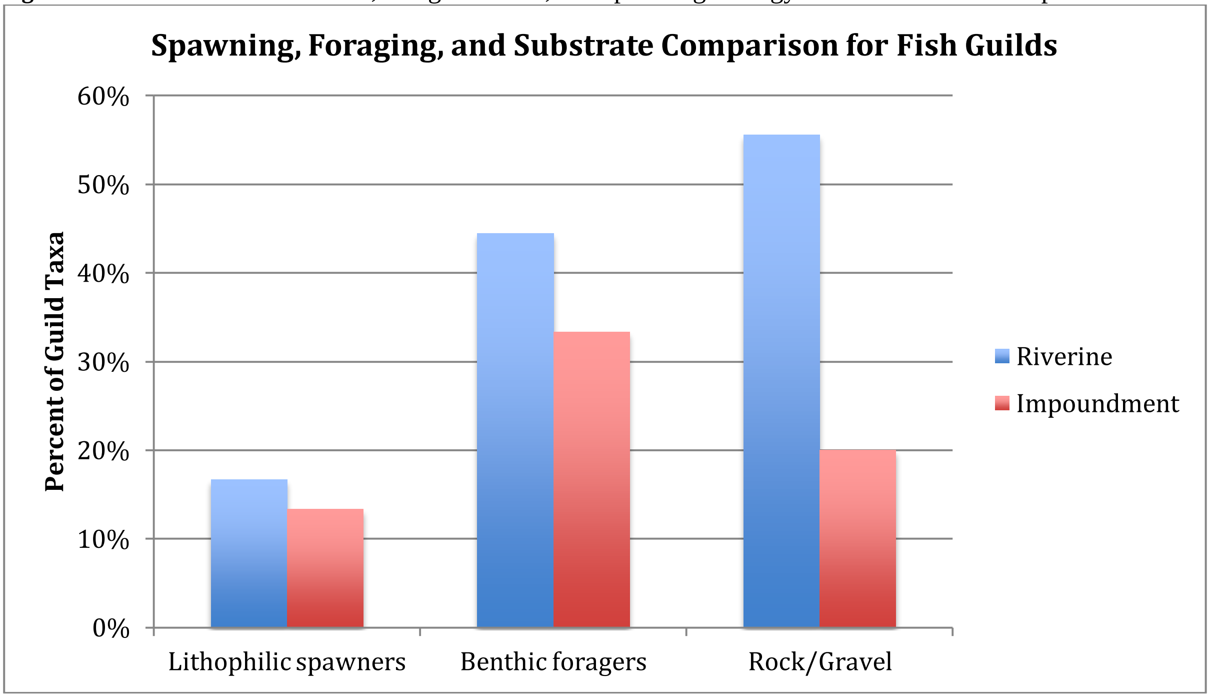


Figure 7.4 Trend between substrate, forage location, and spawning strategy within riverine and impoundment sites.



With regard to the habitat analysis, the MDEQ Procedure 51 (Table 1 in Appendix 7.4) provided an indirect approximation of habitat conditions using fish sampled at riverine sites (Creel 2000, MDEQ 1996). Using this procedure, a score of +5 or higher is categorized as an excellent site, while a score of -5 or lower is categorized as a poor site. The scores for riverine sites arranged in downstream order were as follows: Hudson Mills Metropark (4), Mast Road (-2), Zeeb Road (2), Fuller Road (4), and Ypsilanti (1) (Table 7.9). The HRWC habitat and insect data at Bell Road (approximately 1.8 river miles north of North Territorial Road, which is the northern most fish sample site in Hudson Mills Metropark) was rated as “Good”, which is equivalent to the IBI score of 4. A qualitative summary of HRWC’s raw habitat data at Bell Road is as follows: very stable substrate, available instream cover, low embeddedness (low siltation), variable current velocity and stream depth, consistent flow volume, low flashiness, and decent riparian width. The corresponding HRWC habitat and insect data at Zeeb Road rated the site as “Good”, which is also equivalent to the IBI score of 2. In general, the scores for Zeeb Road were similar to, but slightly less than, Bell Road in the previous categories (i.e. slightly higher levels of impairment) (Example HRWC Stream Habitat Assessment Packet in Appendix 7.4).

An IBI developed by the MDNR for lakes (Schneider 2002) was used to assess habitat at impoundment sites. For lakes in MI, a typical best possible score is 50, but the best score for an extremely shallow lake is 31. The scores for the impoundment sites arranged in downstream order are as follows: Barton Pond (35), Argo Pond (34), Geddes Pond (32), and Ford Lake (36) (Table 7.10; Example score card in Appendix 7.4).

Table 7.5 List of species only found at sample sites classified as riverine.

Riverine Only Guild (ROG)	
Common Name	**Scientific Name**
Banded killifish	*Fundulus diaphanus*
Blacknose dace	*Rhinichthys atratulus*
Central mudminnow	*Umbra limi*
Central Stoneroller	*Campostoma anomalum*
Creek chub	*Semotilus atromaculatus*
Fantail darter	*Etheostoma flabellare*
Fathead minnow	*Pimephales promelas*
Grass pickerel	*Esox americanus vermiculatus*
Greenside darter	*Etheostoma blennioides*
Hornyhead chub	*Nocomis biguttatus*
Iowa darter	*Etheostoma exile*
Least darter	*Etheostoma microperca*
Mimic shiner	*Notropis volucellus*
Mottled Sculpin	*Cottus bairdii*
Northern brook lamprey	*Ichthyomyzon fosser*
Rainbow darter	*Etheostoma caeruleum*
Sand shiner	*Notropis stramineus*
Spotfin shiner	*Cyprinella spiloptera*

Table 7.6 List of species only found at sample sites classified as impoundment.

Impoundment Only Guild (IOG)	
Common Name	**Scientific Name**
Black bullhead	*Ameiurus melas*
Blackstripe topminnow	*Fundulus notatus*
Bowfin	*Amia calva*
Brown bullhead	*Ameiurus nebulosus*
Channel catfish	*Ictalurus punctatus*
Emerald Shiner	*Notropis atherinoides*
Golden shiner	*Notemigonus crysoleucas*
Longnose gar	*Lepisosteus osseus*
Shorthead redhorse	*Moxostoma macrolepidotum*
Spottail shiner	*Notropis hudsonius*
Walleye	*Sander viterus*
Warmouth	*Lepomis gulosus*
White bass	*Morone chrysops*
White perch	*Morone americana*
Yellow perch	*Perca flavescens*

Table 7.7 Percent taxa and raw number with particular preferences or characteristics in the IOG.

IOG (15 total species)		Percent Taxa	Raw Numbers
Native		93	14
Status		0	0
Game		67	10
MDNR Regulated Species		27	4
Darters		0	0
Water Temp	**Cold**	0	0
	Cool	20	3
	Warm	80	12
Tolerance	**Tolerant**	47	7
	Mid	67	10
	Intolerant	0	0
MDNR Tolerance	**Tolerant**	13	2
	Intolerant	20	3
	Unknown	67	10
Lithophilic Spawners		13	2
River Size	**Small**	0	0
	Small-Med	7	1
	Medium	7	1
	Med-Large	33	5
	Large	33	5
	All	13	2
Lake Dwelling		27	4
Benthic Forager		33	5
Substrate	**Rock/Gravel**	20	3
	Sand	7	1
	Mud/Silt	33	5
	Generalist	40	6
Flow Velocity	**Slow**	67	10
	Medium	7	1
	Fast	7	1
	All	20	3
Macrophyte Association		40	6
Trophic	**Piscivore**	47	7
	Aquatic Inverts	27	4
	Plankton	7	1
	Omnivore	20	3

Table 7.8 Percent taxa and raw number with particular preferences or characteristics in the ROG.

ROG (18 total species)		Percent Taxa	Raw Numbers
Native		100	18
Status		6	1
Game		0	0
Darters		28	5
Water Temp	Cold	6	1
	Cool	22	4
	Warm	72	13
Tolerance	Tolerant	22	4
	Mid	39	7
	Intolerant	39	7
MDNR Tolerance	Tolerant	22	4
	Intolerant	33	6
	Unknown	44	8
Lithophilic Spawners		17	3
River Size	Small	11	2
	Small-Med	50	9
	Medium	11	2
	Med-Large	17	3
	Large	0	0
	All	11	2
Lake		0	0
Benthic Forager		44	8
Substrate	Rock	56	10
	Sand	22	4
	Mud	17	3
	Generalist	6	1
Flow Velocity	Slow	44	8
	Medium	39	7
	Fast	11	2
	All	6	1
Aqua Veg		44	8
Trophic	Piscivore	6	1
	Aquatic Inverts	61	11
	Plankton	11	2
	Omnivore	22	4

Table 7.9 List of riverine sites evaluated using MDEQ Procedure 51 for habitat quality. A score of +5 or higher is excellent, while a score of -5 or lower is poor.

Site Name	Year	No. Taxa	No. Individuals	Collector	Score
Hudson Mills Metropark	2006	11	140	MDEQ	4
Mast Road	2006	9	79	MDEQ	-2
Zeeb Road	2006	12	61	MDEQ	2
Fuller Road	2006	10	59	MDEQ	4
Ypsilanti	2006	10	86	MDEQ	1

Table 7.10 List of impoundment sites evaluated using a MI Lake IBI as proposed by MDNR for habitat quality.

Site Name	Year	No. Taxa	No. Individuals	Collector	Score
Barton Pond	1996	14	98	MDNR	35
Argo Pond	2000	18	280	MDNR	34
Geddes Pond	1996	11	137	MDNR	32
Ford Lake	2006	27	3234	MDNR	36

Discussion

The impoundment and riverine presence/absence bar graph data and the NMDS cluster analysis confirmed two hypotheses: 1) that fish sampled at impoundment sites generally have different preferences or characteristics than fish sampled at riverine sites and 2) that the preferences or characteristics of fish in either site type – impoundment or riverine – are likely to be more similar to another site of the same type. Hence, it was justified to categorize species along a divide of preference into two guilds: 1) fish species that prefer impoundment habitats and 2) fish species that prefer riverine habitats.

From the spatial arrangement of the NMDS, impoundment sites – Barton Pond, Argo Pond, Geddes Pond, Ford Lake, and Belleville Lake – were very similar to one another, while the riverine sites – Hudson Mills Metropark, Mill Creek, Zeeb Road, Mast Road, Fuller Road, and Ypsilanti – displayed more variability between sites. This is reasonable given that altered flow regimes, like impoundments, tend to have less habitat diversity than natural riverine sites. Naturally diverse habitat provides more fundamental ecological niches (Kroes 1977, Colwell and Rangel 2009), which may also explain why more species were identified in the riverine only guild (ROG) as compared to the impoundment only guild (IOG) (18 versus 15 species, respectively).

The NMDS analysis separated fish into two groups based on: status, game species, darter species, benthic foragers, lake dweller, Trophic Preference, Tolerance Preference (MDNR and compiled), River Size Preference, Substrate Preference, and Flow Velocity Preference. There were two species of "Status" (i.e. endangered, declining, threatened, or rare): 1) the rare Northern brook lamprey, which was restricted to the ROG and 2) the declining Black Redhorse, which was found in both riverine and impoundment sites and, therefore, was not included in either guild. However, it should be noted that the Black Redhorse was only found in the most upstream impoundment (Barton Pond) and two adjacent riverine sites (Zeeb Road and Hudson Mills Metropark). Neither species of "Status" was found at the Fuller Road or Ypsilanti riverine sites (the only two riverine sites located between and within close proximity to impoundments within the reach of interest) and both species were only found at Hudson Mills Metropark albeit on two different sampling occasions. These results are not unexpected given that the species share similar characteristics and preferences – intolerance, lithophilic spawners, rock/gravel substrate, and fast velocity flows – and are likely declining or rare due to anthropogenic alterations to the habitat, flow regime, and/or water quality.

Additionally, game species in the IOG constitute approximately 67% of the taxa, but 0% in the ROG. However, it is important to note that the game species characteristic included all fish that are caught by anglers according to two sources: the online MDNR list and angler surveys used to populate the original database. The narrower “MDNR regulated” species characteristic was defined by MDNR’s list of regulated game fish ((MDNR 2014), personal communication). MDNR regulated species were found to comprise 27% of the taxa in the IOG, but 0% in the ROG. Therefore, the large portion of game fish in impoundments is partly a consequence of MDNR regulation and stocking.

Darter species in the ROG constitute about 28% of the taxa, but 0% in the IOG. Darters, benthic species requiring gravel and high oxygen concentrations, are generally highly intolerant of environmental degradation, and thus are good indicators of compromised habitat (Lyons 1992). Therefore, it would be unlikely to find a darter species in the IOG, since that would mean it was not found at any riverine site. However, it should be noted that two impoundments, Barton Pond and Ford Lake, had 10% and 4% darter taxa, respectively. As mentioned previously, Barton Pond is the most upstream impoundment in the reach of interest and therefore, most likely to have cross-over species from nearby riverine sites (Zeeb Road, Mast Road, Mill Creek, Hudson Mills). Ford Lake is the first impoundment downstream of the riverine Ypsilanti site and therefore, may also have species cross-over. The fact that these two impoundment sites are spatially connected to adjacent riverine sites further strengthens the result of the analysis: darter species in these hydrologically connected areas made up a larger portion of the taxa at riverine sites, therefore, indicating a preference for those sites.

The trophic preference guild characteristics distinguished a strong difference between taxa in the IOG (47% piscivores) and species in the ROG (61% insectivores). At least part of this divergence can be explained by MDNR fish regulation and stocking, which increases the taxa and number of piscivores at impoundment sites. Conversely, it is logical that insectivores would more likely be found in riverine areas, where gravel is present and kept free of insect smothering sediment by faster flows. Additionally, lithophilic spawners, fish that require clean gravel for spawning, generally need areas of moderate flow to increase oxygen circulation around eggs, but not wash them downstream (Grabowski and Isely 2007, Diana 2014). In support of these assertions, a proportionally increasing trend was identified between lithophilic spawners, benthic foragers, and rock/gravel substrate in riverine systems, while this trend did not hold for impoundments.

The tolerance preference results, MDNR and updated, communicated similar messages although the trends differed slightly. For the ROG, species demonstrated a broader tolerance range (for both MDNR and updated) as compared to the IOG. For the MDNR tolerance, the ROG had more tolerant and intolerant taxa than the IOG. This is not surprising since an environment that can support intolerant species might also support a high number of tolerant species. Regardless, the percentage of “Unknown Tolerance” was very large for both impoundment (67%) and riverine (44%) guilds, which inspired the literature search to parse species into Tolerant, Mid-tolerant, and Intolerant categories (i.e. the creation of the updated tolerance). The resulting updated tolerance revealed species in the IOG to be better categorized as Tolerant or Mid-tolerant, while the ROG had species in all categories. This result confirmed that impoundments were not supportive of sensitive species. However, it is important to note, this does not mean that no intolerant species were found in impoundments (percent taxa ranged from 10% to 0% across the sites), but that they were crossover species, and thus, were not included in either guild. With respect to impoundment sites, Barton Pond, the most upstream and riverine connected impoundment, had the highest percent of updated intolerant taxa (2 or 10%) and the second highest MDNR intolerant taxa (4 or 20%; Ford Lake had 6 or 22%). It is also important to note that the definition of intolerance was very broad and included both physical and chemical perturbations. The main message from this analysis is the following: impoundment habitats are not as supportive as riverine environments for intolerant species (such as the Black Redhorse and Northern brook lamprey, which are also species of status).

The results from river size preference and lake dweller characteristics were not unexpected. The ROG's preference for small to small-medium rivers was likely not skewed by including Mill Creek, which is actually the largest tributary of the Huron River. There was only one unique species, the Central stoneroller (*Campostoma anomalum*), at the Mill Creek sample site and the majority of upstream riverine sites (Mast Road, Zeeb Road, Hudson Mills Metropark) were within close enough proximity that a similar species list due to migration across sites was expected. The IOG's preference for medium-large and large rivers and lakes was also not unexpected given that the MDNR stocks some game species (e.g. Largemouth bass and Walleye), which prefer those habitat types (MDNR 2005).

Over half the taxa species in the ROG preferred gravel/rock, while almost half of the taxa species in the IOG were generalists and a high percentage preferred mud/silt. These results are not unexpected given that the stagnant flow in impoundments often causes substantial sediment deposit and faster flows in riverine sites, which may be sediment "hungry" if water is coming from an impoundment, would likely remove most of the bottom silt. The Fuller Road riverine site, which is located between Argo Pond and Geddes Pond had 0 species that prefer sand or mud/silt. The Ypsilanti riverine site, which is located between Geddes Pond and Ford Lake had the highest percent sample taxa of the riverine sites for both sand and mud/silt (11% for both). This is an example of where "ground-truthing" sites with habitat evaluations could help determine if those fish were simply missed in the sample collected at Fuller Road, or if Ann Arbor's dam operations might be influencing the substrate downstream. If the upstream riverine sites are used as references for typical substrate, than some habitats with either sand or mud/silt substrate would be expected as part of natural habitat diversity (exception, Mast Road also had 0 species with those preferences).

Species in the IOG preferred slow currents or had no preference (i.e "All"). Species in the ROG displayed greater preference for medium and fast flows as compared to the IOG, as well as a wider variety of preferences. These conclusions are reasonable given that there is likely a wider variety of habitat type (riffles, pools, runs, backwaters) in natural riverine sites as compared to manmade impoundments. However, without baseline (prior to dam installation) fish sampling data, these results cannot determine how artificial flow regime from dam construction and operations has impacted fish communities in riverine systems. However, the flow preferences at riverine sites surrounded by impoundments (i.e. Fuller Rd and Ypsilanti) are more similar to upstream riverine sites, which have 15.7 river miles between mainstem dams, as compared to impoundment sites. One explanation is that all riverine sites may be similarly impacted by flow alteration due to dam operation, but the impacts are not being captured by the present data. This could be occurring for several reasons: 1) there is no baseline data by which to compare historic riverine fish populations/taxa and their flow preferences to those of current populations/taxa, 2) sample dates missed important life cycle events or missed the recovery period of fish populations/taxa due to changes in dam operation, or 3) presence/absence is not a fine enough grain and estimates of fish spawning success, movement, or other parameters are necessary. It is also possible that Argo Dam and Geddes Dam are operated in such a fashion that they do not cause sufficient impact with respect to fish flow preferences at the Fuller Road and Ypsilanti sites, respectively. However, the flashy hydrograph at Ann Arbor gage, located downstream of Argo Dam, likely discounts this theory and encourages further inspection and analysis.

With respect to habitat, the MDEQ Procedure 51 and MDNR Lake IBI gave some further indications of quality at each site with respect to what is typical in Michigan and allowed for relative rankings between sites. Two of the five riverine sites received high scores (4 for both Hudson Mills Metropark and Fuller Road), which translates qualitatively to a "Good" site. It was unexpected that Fuller Road, situated between Argo Pond and Geddes Pond, would score the same as the most upstream site, but it is possible that high quality habitat may mitigate some of the negative impacts of flow alteration. Also unexpected, the lowest scoring site was Mast Road, an upstream site. It is possible that Mast Road actually had poor quality habitat, but more likely, the single fish sample may have poorly represented the actual fish population or there may be a third factor, such as a wastewater treatment plant outlet.

The MDNR Lake IBI determined that impoundments along the Huron River were generally more akin to shallow MI lakes as compared to typical high quality lakes in the state. Since the impoundments along the Huron River would not be described as shallow, it is clear that other factors are impacting the quality of the habitat. First, impoundments are not actually lakes and therefore, receive inputs from the river system, which may influence the accuracy of the IBI. Second, impoundments are man-made structures, which often lack variability in habitat as seen in natural formations. Although impoundments cannot support the same assemblage of species found at riverine sites, habitat improvements may increase the number of crossover species that could benefit from both types of environment.

However, the fish samples, which were inherently different due to disparities in sampling procedures, were still the basis of these habitat analyses. Although their usage here may be more accurate (given that only the most recent year of full community data was used for each site and this was generally collected by the same organization), habitat assessment in the field would give a more complete picture of the quality of the site. Additionally, these samples are only a snapshot of the population in time and should be updated for all sites given that the most recent full community data at sites were 1996 and 2006. Also, the MDNR Lake IBI was not developed for the evaluation of impoundment habitat and; therefore, results should not be taken at face value. Therefore, more research should be conducted before management recommendations are implemented.

Conclusions

Overall, this analysis confirms that preferences and characteristics of fish in riverine guilds differ from those in impoundment guilds. Thus, current impoundments are not supporting fish species characteristic of a more natural flow regime. However, alterations to dam characteristics, such as flow through alterations to dam operations, might be able to further encourage fish taxa and populations belonging to a ROG or another desired guild. However, habitat characteristics, which are also partly shaped by flow, are also responsible for the differentiation in guilds; therefore, flow regime amendment alone might not be enough to encourage the desired fish populations. Although impoundment sites cannot support the ROG, habitat improvements may support a larger population or taxonomic range of crossover species. For impoundments that have little chance of removal, whether due to energy or cultural demands, the adjustment of flow and improvement of in-stream habitat may be a beneficial compromise for both parties.

It should be recognized that the analysis also revealed significant limitations. With respect to the actual fish samples, the analysis was restricted by the discrepancies in methodology among and within sites that may not have captured the entire fish community and lack of comparable habitat data for all locations. Time series data that includes population numbers and life stages would help to identify how populations, at sites in close and far proximity from impoundments, are changing over time. With more information about dam operations and the corresponding temporal gage data, how specific dam operations are impacting biota could be more precisely identified. Also, this analysis did not have time to formally address critical swimming speed of fish, which is directly related to a species ability to persist in a particular flow rate. Flow velocity preference, with characteristics of slow, medium, fast, and all, was a more general estimate of adult fishes flow tolerance and should be further researched. In addition, “ground-truthing” the habitat at each site is essential to determining how flow conditions indirectly impact the biota through environmental change. Standardizing the methodologies employed and selecting riverine and impoundment sites at which to perform fish sampling, invertebrate sampling, and habitat assessment would allow for multiple lines of evidence to address how flow impacts a particular site and its biotic assemblages.

Recommendations

Although further analysis is recommended, this study does have implications for management. Given that flow velocity impacts fish guild assemblage both directly (flow velocity preference) and indirectly (e.g. substrate preference), collaboration with dam operators to amend operations could encourage the establishment of specific fish taxa and populations. Given the unusual hydrograph at Ann Arbor gage (located below Argo Dam) and its close proximity to the HRWC and the UM, this would likely be an interesting place to implement a pilot program examining fish, invertebrates, and habitat on a synchronized and regular interval. It is possible that the UM may have classes, thesis students, or another Master’s Project team interested in creating the design and implementing the first collection stage for this field intensive project. Additionally, at socially or fiscally entrenched impoundment sites, habitat enhancement should be considered after further investigation into potential benefits.

REFERENCES

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin, Madison.

Colwell, R. K., and T. F. Rangel. 2009. Hutchinson's duality: The once and future niche. Proceedings of the National Academy of Sciences of the United States of America 106:19651.

Creel, W., S. Hanshue, S. Kosek, M. Oemke, and M. Walterhouse. 2000. Manual of Fisheries Survey Methods II:Chapter 25B: GLEAS Procedure 51 Metric Scoring and Interpretation.in S. W. Q. D. Michigan Department of Environmental Quality, editor.

Diana, J. 2014. Lecture on Fish Spawning and Restoration Projects in Michigan.in S. Roberts, editor. School of Natural Resources and Environment, University of Michigan, Ann Arbor.

Froese, R., and D. Pauly. 2014. FishBase.

Grabowski, T. B., and J. J. Isely. 2007. Effects of Flow Fluctuations on the Spawning Habitat of a Riverine Fish. Southeastern Naturalist 6:471-478.

Hubbs, C. L., K. F. Lagler, and G. Ray. 2004. Fishes of the Great Lakes Region. University of Michigan, Ann Arbor.

Karr, J. R. 1981. Assessment of Biotic Integrity Using Fish Communities. Fisheries 6:21.

Kroes, H. W. 1977. The niche structure of ecosystems. Journal of Theoretical Biology 65:317-326.

Lyons, J. 1992. Using The Index Of Biotic Integrity (IBI) To Measure Environmental Quality In Warmwater Streams of Wisconsin.in F. S. United States Department of Agriculture, North Central Forest Experiment Station, editor.

Lyons, J., R. R. Piette, and K. W. Niermeyer. 2001. Development, Validation, and Application of a Fish-Based Index of Biotic Integrity for Wisconsin's Large Warmwater Rivers. Transactions of the American Fisheries Society 130:1077.

MDEQ. 1996. Update of GLEAS Procedure 51 Metric Scoring and Interpretation.in S. W. Q. D. Michigan Department of Environmental Quality, editor.

MDNR. 2005. Fish Stocking Database.

MDNR. 2014. Regulated Fish Species List.in C. Riseng and S. Roberts, editors.

OhioEPA. 1987. Biological Criteria for the Protection of Aquatic Life: Volume II: Users Manual for Biological Field Assessment of Ohio Surface Waters.in D. o. W. Q. P. a. Assessment, editor., Columbus, Ohio.

OhioEPA. 2006. Methods for Assessing Habitat in Flowing Waters: Using the Qualitative Habitat Evaluation Index (QHEI).

OhioEPA. 2013. 2013 Updates to Biological Criteria for the Protection of Aquatic Life: Volume II and Volume II Addendum. Users Manual for Biological Field Assessment of Ohio Surface Waters.in D. o. S. W. Ohio EPA, Ecological Assessment Section, editor.

Schneider, J. C. 2002. Fish as Indicators of Lake Habitat Quality and a Proposed Application.in F. D. Michigan DNR, editor.

Wiley, M., and C. Riseng. 2009. Unpublished Database of Fish Ecological Characteristics. University of Michigan, Ann Arbor.

Zorn, T. G., P. W. Seelbach, and E. S. Rutherford. 2012. A REGIONAL-SCALE HABITAT SUITABILITY MODEL TO ASSESS THE EFFECTS OF FLOW REDUCTION ON FISH ASSEMBLAGES IN MICHIGAN STREAMS. Journal of the American Water Resources Association 48:871-895.

8 Fish Habitat Suitability

The habitat suitability model, developed by Zorn et al. (2008) for the Michigan Department of Natural Resources, was intended to be used in establishing low flow criteria for 11 stream types throughout Michigan using the expected fish community. In order to calibrate the regional-scale model to the Huron River, criteria specific to the Huron River were used in executing the model. Utilizing the criteria and methodology outlined by Zorn et al. (2008), low flow criteria were determined for seven sites throughout the Huron River using the following process: 1) Determine catchment area (CA), 2) Calculate July mean water temperature (JMT) 3) Calculate Index Flow (50% exceedence flow for low flow month), 4) Execute the model, 5) Construct Community Response Curve, and 6) Determine when an Adverse Resource Impact (ARI), to the fish community, will occur. In order to test the applicability of this regional-scale model to the Huron River, a test of the predictive power of the model was conducted using a Receiver Operating Characteristic Plot. In addition to the determination of an ARI, the model was used to propose suitable and preferred flow ranges for various fish communities of the Huron River.

Methods

This habitat suitability model was developed for application within the state of Michigan and was intended for use at the regional scale. Habitat suitability was based on fish assemblages sampled throughout the state and was divided into regions of Lower and Upper Peninsula. The model uses habitat criteria for nearly 70 species to predict assemblage structure and characteristic fish assemblages in individual river segments under a range of base flow conditions (Zorn et al. 2008). The model makes use of three input parameters, catchment area (CA), July mean water temperature (JMT), and base flow yield (BFY) to determine expected fish communities throughout the state of Michigan. These three defining characteristics of catchment and flow have been found to be significant in impacting fish metabolism, survival, reproductive success, distribution, and abundance (Poff and Ward 1989; Sellbach et al. 1997; Zorn et al. 2002; Wherly et al. 2003; Zorn et al. 2004; Zorn et al. 2008). Based on surveys throughout the State of Michigan, the model indicates which fish species, comprising a fish community, are most likely to inhabit a given stream or river based on the site's CA, JMT, and BFY. In predicting the response of fish communities to flow reduction, the model runs under the assumption that if there is a change in CA, JMT, or BFY, the fish community will change to accurately represent a community which occupies those conditions elsewhere in the State of Michigan.

There is some uncertainty in determining expected fish communities on a watershed to watershed basis, but for this study, results were compared to fish samples to ensure proper application for the Huron River. The habitat suitability model has previously been used in the Water Withdrawal Assessment Tool (WWAT) to estimate the likely impact of water withdrawal on streams and rivers throughout Michigan. This model is used as the key component in identifying low flow conditions for the Huron River main stem.

Choice of Sites

The habitat suitability model was used to predict expected fish communities and their associated low flow criteria at a total of seven sites on the Huron River main stem. These seven sites were selected based on the availability of flow data. The sites are each representative of a location where a USGS stream gauge is either continuously recording or has previously recorded flow data. Because flow data is critical to the accuracy of the model, these sites serve to represent conditions of an increasing flow as they are organized from headwaters to estuary along the Huron River. In order from upstream to downstream the seven sites are: Commerce (CM), Milford (ML), New Hudson (NH), Hamburg (HM), Dexter (DX), Ann Arbor (AA), and Ypsilanti (YP). Because the USGS stream gauges at these sites collected data at different periods of time, an ideal comparison between the sites is not obtainable; however, this does not impact the predictive capability of the model. Table 8.1 summarizes the location, data range, and temperature data availability for each of the seven sites.

Table 8.1 Location and data information for USGS stream gauge sites used for the habitat suitability model

Site Name	USGS Gauge ID	Site Location		Data Range	Temperature Data
		Latitude	Longitude		
Commerce	04169500	42 °35'28"	83 °28'59"	03/01/1946 - 09/30/1975	No
Milford	04170000	42 °34'44"	83 °37'36"	09/23/1948 - 09/30/2011	Yes
New Hudson	04170500	42 °30'46"	83 °40'35"	08/20/1948 - 12/31/2013	No
Hamburg	04172000	42 °27'55"	83 °48'00"	10/01/1951 - 12/31/2013	No
Dexter	04173500	42 °18'01"	83 °53'54"	03/01/1946 - 10/31/1977	No
Ann Arbor	04174500	42 °17'13"	83 °44'02"	01/01/1914 - 12/31/2013	Yes
Ypsilanti	04174800	42 °14'57"	83 °36'45"	06/01/1974 - 09/30/1984 10/01/1989 - 09/30/1994	No

In order to test the predictive capability of the habitat suitability model for the Huron River, the expected fish communities produced by the model were compared to fish communities that have been sampled in the Huron River. Because fish sample sites do not align exactly with USGS stream gauge sites, fish sample sites were grouped based on location near the USGS gauges. Not every site had a fish community sample that could be compared to the model output, but for those that did, a comparison was made between the expected fish community and the sampled fish community. Table 8.2 summarizes the sites that had associated fish sample sites and the details about collection method.

Choice of Season

In conjunction with the assumptions of Zorn et al. (2008), low flow conditions were modeled in the summer. The habitat suitability model is designed to predict fish communities based on maximum water temperature and minimum flow condition criteria. Low flow conditions, resulting from natural drought or from management decisions, are most likely to occur during summer months when precipitation is low and water use is high. Because of the low flow and high temperature conditions, these periods tend to be the most stressful for aquatic biology and are of particular significance when it comes to managing for ecological well-being. To simulate low flows in summer months, the habitat suitability model used July mean water temperature and the 50% exeedence flow for the low flow month (August) as model inputs.

Model Inputs

The habitat suitability model used to determine fish communities in the Huron River requires three basic inputs, and provides an indicator of expected presence or absence of 67 fish species commonly found in Michigan. The three required inputs to run the model are: catchment area (square miles), July mean water temperature (degrees Fahrenheit), and the base flow yield which is the index flow (August 50% exceedence flow) divided by the catchment area (cubic feet per second / square miles).

Table 8.2 Fish sample sites associated with each USGS stream gauge site

Site	Fish Sample Site	Sample Site Location		Location Relative to Gauge	Sample Type
		Latitude	Longitude		
Commerce	F1	42 °43'14.77"	83 °31'8.58"	Upstream	Full Community
	F2	42 °39'50.63"	83 °27'3.31"	Upstream	Full Community
	F3	42 °37'49.40"	83 °28'51.78"	Upstream	Full Community
Milford	NA	NA	NA	NA	NA
New Hudson	F4	42 °31'47.35"	83 °38'33.78"	Upstream	Targeted
	F5	42 °30'6.56"	83 °42'49.21"	Downstream	Full Community
	F6	42 °29'47.00"	83 °43'33.93"	Downstream	Targeted
Hamburg	NA	NA	NA	NA	NA
Dexter	F7	42 °23'13.00"	83 °54'40.00"	Downstream	NA
	F8	42 °23'0.16"	83 °54'54.53"	Downstream	Targeted
	F9	42 °22'25.73"	83 °54'56.50"	Downstream	NA
	F10	42 °21'58.21"	83 °54'17.10"	Downstream	Targeted
	F11	42 °20'28.20"	83 °52'46.40"	Downstream	NA
	F12	42 °19'43.36"	83 °51'39.08"	Downstream	NA
	F13	42 °19'22.79"	83 °50'26.26"	Downstream	Targeted
Ann Arbor	F15	42 °19'0.48"	83 °45'55.08"	Upstream	Full Community
	F16	42 °18'45.97"	83 °45'23.19"	Upstream	Targeted
	F17	42 °17'43.80"	83 °44'36.24"	Upstream	Full Community
	F18	42 °16'13.44"	83 °41'7.80"	Downstream	Full Community
Ypsilanti	F20	42 °15'14.64"	83 °36'58.76"	Upstream	NA
	F21	42 °13'4.86"	83 °35'56.77"	Downstream	Targeted
	F22	42 °13'4.86"	83 °35'56.77"	Downstream	Full Community

Note: 1) Fish sample site are named in conjunction with the summary map.
2) NA means no data available for that sample or site.

Catchment area is used to determine fish response to flow alterations because it is generally accepted that streams and rivers with a smaller catchment are more susceptible to unnatural alterations in flow regime (Zorn et al. 2008). In larger catchments, the sheer increase in quantity of water flowing through a site is expected to dampen out impacts caused by flow management to a certain degree. Catchment area determines river size which influences the composition of the fish community as it would be expected to find different species in the headwaters as compared to the lower Huron River. Catchment area for each of the seven sites was determined using ArcGIS 10. These values were used as catchment area parameter inputs for the habitat suitability model.

Water temperature data is only available for two of the seven sites on the Huron River, Milford and Ann Arbor. For these two sites the July mean water temperature was calculated using HEC-DSSvue and used as a direct input into the model. To calculate the July mean water temperature for these two sites, temperature values were extracted for the month of July for all years on record and averaged. For the remaining five sites, July mean temperature was extrapolated based on the lower recorded temperature (Milford) and the higher recorded temperature (Ann Arbor). For the four sites upstream from Ann Arbor (Dexter, Hamburg, New Hudson, and Commerce) July mean temperature was extrapolated by subtracting the lower recorded temperature (Milford) from the higher recorded temperature (Ann Arbor), and dividing by the distance, in linear miles, between Milford and Ann Arbor. This product was then multiplied by the distance from Ann Arbor to the respective site, and subtracted from the July mean water temperature at Ann Arbor. The remaining site, Ypsilanti, lies below Ann Arbor and may be influenced by surface or base flow processes that cannot be represented by recorded temperatures at either of the Milford or Ann Arbor sites. Although there may be some influence on water temperature by tributaries and the Ann Arbor Wastewater Treatment Plant, which contribute water downstream from the Ann Arbor site, the model was run under the assumption that water temperature at Ypsilanti can be extrapolated using the same method as the sites upstream from Ann Arbor. For the Ypsilanti site, July mean temperature was extrapolated by subtracting the Milford from the Ann Arbor temperatures, and dividing by the distance, in linear miles, between Milford and Ann Arbor. This product was then multiplied by the distance from Ann Arbor to the Ypsilanti site, and added to the July mean water temperature at Ann Arbor.

In order to calculate the base flow yield, two parameters were required: index flow and catchment area. Because catchment area had previously been calculated, index flow was the only value that needed to be determined for each of the seven sites. Index flow was defined as the 50% exceedence flow for the low flow month which, in the case of all seven USGS stream gauge stations on the Huron River, was August (Zorn et al. 2008). Index flow was calculated using HEC-DSSvue and serves as a baseline low flow condition for the habitat suitability model. For every site, the associated flow data at the USGS stream gauge for the history of the gauge was imported into HEC-DSSvue. Using HEC-DSSvue a monthly duration analysis was completed and the 50% exceedence flow for the month of August in cubic feet per second (cfs) was recorded. This process was used to calculate the index flow for all seven sites. After both index flow and catchment area were determined for each site, the base flow yield for each site was calculated by taking the index flow and dividing by the catchment area.

Model Execution

The habitat suitability model was executed in Microsoft Excel and uses three input parameters to predict whether an individual fish species will be present or absent in the given site. The model makes use of catchment area (CA), July mean water temperature (JMT), and base flow yield (BFY), to compare site characteristics to suitable habitats for individual fish species. Each of the 67 fish species has an optimal suitability for the three site characteristics and the comparison between the optimal suitable range and site characteristics determines whether the fish will be present or absent at the site. The expected fish community for the site is therefore, the accumulation of all predicted present species.

The habitat suitability model references six criteria in order to determine whether a fish will be present at the site and be classified as characteristic, or whether the fish will be present at the site and be classified as thriving. Zorn et al. (2008) classify a characteristic species as those "expected to be abundant at that segment compared to other segments with less suitable habitat conditions." A species was determined to be a characteristic species if the values for CA, JMT, and BFY were within 1.5 standard deviations of the species' optimal value (Zorn et al. 2008). For thriving species, the CA, JMT, and BFY were near optimal, with all three values being within 1 standard deviation of the optimal value. According to Zorn et al. (2008), thriving species are expected "to show high abundance, multiple age classes, and good reproduction." Using the habitat suitability model, these optimal habitat criteria were compared with the input site CA, JMT, and BFY parameters to produce either a presence or absence prediction as to whether the species would be characteristic or thriving at the given site. The total number of predicted present fish species was used to calculate the total expected fish community.

Testing Model Performance

Because the model developed by Zorn et al. was designed to predict how different fish assemblages throughout the entirety of Michigan would respond to flow reduction (Zorn et al. 2008), the predictive power of the model may be limited within any one watershed. In order to test the applicability of the habitat suitability model in successfully predicting fish communities in various locations within the Huron River, a comparison was made using actual collected fish samples. In testing the predictive capability of the model, the overall prediction success was determined as well as examining comparisons between sites using receiver operating characteristic (ROC) plots. In comparing sampled populations to the model results, a high prediction success indicates that the present fish community is similar to a fish community in unaltered flow conditions. If the prediction success is low, this indicates that the fish community does not represent a community that would be expected in unaltered flow conditions given the CA, JMT, and BFY for that site.

Table 8.3 Matrices of confusion

		Actual	
		+ (Present)	- (Absent)
Predicted	+ (Present)	*a*	*b*
	- (Absent)	*c*	*d*

Table 8.4 Measures of model performance

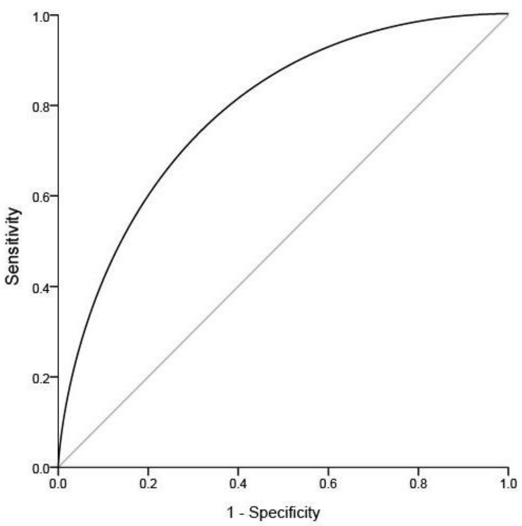
Performance measure	Definition	Formula
Overall prediction success	Percentage of all cases correctly predicted (S)	$a + d / n$
Sensitivity	Percentage of true positives correctly predicted (Sn)	$a / (a + c)$
Specificity	Percentage of true negatives correctly predicted (Sp)	$d / (b + d)$

The evaluation of the model for each site first required the derivation of matrices of confusion that identified true positive (*a*), false positive (*b*), false negative (*c*), and true negative (*d*) cases predicted by the model (Table 8.3) (Manel et al. 2001). From the values of the matrix of confusion, three significant performance measures were calculated: 1) overall predictive success, which is one way of comparing model performance between sites, 2) sensitivity, and 3) specificity (Table 8.4). The calculations of sensitivity and specificity were then used to construct the ROC plots.

Receiver operating characteristic (ROC) plots provide an index of accuracy by demonstrating the limits of a model's ability to discriminate between predicted outcomes over the complete spectrum of potential outcomes (Zweig and Campbell 1993). An ROC curve is plotted using the sensitivity and specificity values calculated in the matrix of confusion. Sensitivity is defined as the percentage of the true positives correctly predicted where specificity is defined as the percentage of true negatives correctly predicted (Manel et al. 2001). The ROC plot was obtained by plotting sensitivity on the *y* axis against the equivalent (1 - specificity) on the *x* axis, as shown in Figure 8.1 (Fielding and Bell 1997; Manel et al. 2001). Predictive capability of the model and similarity to expected conditions, based on CA, JMT, and BFY, is determined by measuring the area under the curve (AUC) of the ROC plot. Because the habitat suitability model and fish samples are compared using presence and absence data, the ROC plot for the sites include only three points: 0,0 ; (1- specificity), sensitivity ; and 1,1. Good model performance is characterized by a curve that maximizes sensitivity for low values of (1 - specificity), where the curve passes close to the upper left corner of the plot (Robertertson et al. 1983; Manel et al. 2001). High performance models are indicated by large AUC and represent a community potentially unaffected by flow alterations. For the habitat suitability model predictability, AUC values of 0.5 - 0.7 indicate low accuracy, values of 0.7 - 0.9 indicate

useful applications, and values of > 0.9 indicate high accuracy (Manel et al. 2001; Swets 1988).

Figure 8.1 Typical ROC plot



<u>Determining Optimal, Preferred, and Suitable Flow Values</u>

After comparing the predictive performance of the habitat suitability model amongst the 5 sites, it was necessary to determine what drives the difference in performance for each site. In order to interpret the model results - true positive (*a*), false positive (*b*), and false negative (*c*) - values from the matrices of confusion were compared for each site. Each value of *a, b,* and *c* was derived from a specific species list: species that were expected by the model and also found to be present in fish samples (*a*), species that were expected by the model and not present in fish samples (*b*), and species that were not expected by the model but were present in fish samples (*c*). These values were compared for each site to determine: 1) the difference in flow preference for each community (*a,b,* and *c*) at each site; 2) which species were driving the flow preferences for each community; and 3) if the "model" fish community better represented riverine flow conditions. For the sake of this report, Model community is defined as species group *b*; species that were expected by the model and not present in fish samples.

In order to estimate the optimal low flow value as well as preferred and suitable ranges for each species within the three fish communities, flow values were derived from the habitat suitability model for each site by dissecting the values for BFY. In doing this, CA and JMT remain constant while CA is removed from the BFY equation (index flow divided by CA) to result in optimal values for index flow. Because the model executes BFY as a log10-transformed BFY, the value for BFY was derived and multiplied by the CA resulting in an optimal flow value in cfs. A "preferred flow" range was determined by using the values associated with 1 standard deviation above and below BFY. This provided a maximum and minimum value associated with a given species' preferred flow range. A "suitable flow" range was determined by deriving the value of 1.5 standard deviations of the BFY. This provided a minimum and maximum value associated with a given species' suitable flow range. A "preferred flow" range aligns with the Zorn et al. (2008) definition of a "Thriving Species" and the "suitable flow" range aligns with the definition of a "Characteristic Species".

For each species within the three communities, an optimal value, a preferred range, and a suitable range were derived. The overall community ranges were driven by species with the highest low flow values and/or the lowest high flow values for "preferred flow" and "suitable flow" ranges. The mean values for low and high preferred and suitable ranges were compared between the *a, b,* and *c* communities in order to determine if flow is a driving factor in community composition. This comparison was done using an Analysis of Variance (ANOVA) test reporting p-values to determine if there was a significant difference between the *a, b,* and *c* communities.

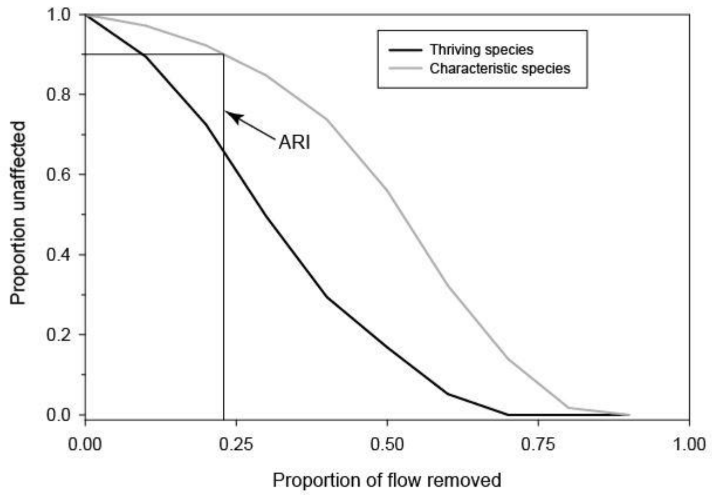
Determining Adverse Resource Impact

After using the habitat suitability model to predict expected fish communities in the Huron River, the model results were then used to determine low flow criteria for the seven sites. An adverse resource impact (ARI) is the standard by which low flow criteria for the Huron River is established. The State of Michigan Public Act 33 of 2006 defines an adverse resource impact as "decreasing the flow of a stream by part of the index flow such that the stream's ability to support characteristic fish populations is functionally impaired" (Michigan Legislature 2006). According to the Michigan Groundwater Conservation Advisory Council (GWCAC), an ARI is characterized by the characteristic species, which are the species expected by the model, declining by 10% from their abundance at the index flow (Zorn et al. 2008). Strata-specific, fish response curves were used to identify stream flow reduction levels resulting in ARIs to characteristic fish populations.

Fish assemblage response curves were created for each of the seven sites on the Huron River using the habitat suitability model. The response curves were constructed by plotting proportion of unaffected fish characteristic community on the y axis against proportion of index flow removed on the x axis, as seen in Figure 8.2. To create the fish response curve, the number of characteristic species that was expected to be present at the index flow for the given site was predicted by the habitat suitability model. This number of species serves as the baseline for the curve. The model was then used to predict the number of characteristic species at intervals of 10% reduction in flow from the index flow. The resulting percentage of species and flow reduction were plotted to complete the fish community response curve. An ARI was found to occur where the fish community was reduced by 10%. The associated flow value (cfs) was then determined to produce a low flow recommendation for each of the seven sites on the Huron River.

An analysis of historical ARI occurrences was completed to understand the patterns of when and where low flows have occurred in the past 100 years in the Huron River. In doing this, an overview of ARI occurrence year and month was created. To determine historic ARI occurrences, HEC-DSSvue was used to identify past flows that fell below the determined ARI flow value for each USGS stream gauge site. For the yearly trend analysis, discharge in cfs was plotted against year using the ARI flow value as the cutoff. A tally of total occurrences for each month of the year was created to understand during which months low flows have commonly occurred in the Huron River.

Figure 8.2 Typical fish assemblage response curve



Analyzing trends in historic ARI flows requires more than just an assessment of yearly and monthly occurrences because it is necessary to understand the cause of the low flows. Because we are interested in low flows which are associated with river management processes, low flows caused by natural conditions needed to be isolated and noted. It is expected that flow management has had exacerbated drought flows in the Huron River but to identify areas of highest concern non-drought flows were of primary interest. Presence of drought has a significant influence on the hydrology of the Huron River and was considered when describing low flows. To account for historic occurrences of drought, the Palmer Hydrological Drought Severity Index (PHDI) was used to identify months when Southeast Michigan experienced various degrees of drought. The PHDI uses a water balance assessment including a soil model to apply stringent criterion for the elimination of a drought or wet spell, resulting in a gradual response seen in the hydrological regime in the receiving waters of the watershed (Keyantash and Dracup 2002). Using data provided on the *National Oceanic and*

Atmospheric Administration (*NOAA*) website, historic occurrences of a hydrological drought were recorded from 1914 to 2013 for the geographical region of Southeast Michigan. The index reports drought severity in 7 categories: extreme drought, severe drought, moderate drought, mid-range, moderately moist, very moist, and extremely moist. For the purpose of this study, the following categories were considered a drought: extreme drought, severe drought, and moderate drought. Drought values for each month were compared to the historic ARI flow results and those flows which occurred during non-drought months were identified.

Establishing Target Community Flow Ranges

The habitat suitability model was used to target individual species or an aggregate of species composing a fish community. Optimal flow values, and "preferred flow" and "suitable flow" ranges were derived from the habitat suitability model for a given species, and in turn, entire communities. There are three major tasks involved in establishing criteria for management of flow regimes based on target communities: 1) Establish sites at which target communities can be managed, 2) Develop criteria for selecting which individual species will comprise the target communities, and 3) Derive preferred and suitable ranges for each community of interest. This process was completed for several sites between Barton Pond and Ford Lake, a section of the reach of interest on the Huron River.

Sites to target fish communities for flow management were selected based on their location within the reach of interest as well as the ability for flow to be managed at a particular location. Because dams introduce a means by which the flow regime is altered and controlled, sites with dams were selected to model target fish communities. At these dammed sites, there is a mechanism by which flow regimes may be altered in a way that can realistically manage for target fish communities downstream of the dams. The infrastructure at these sites provide realistic opportunities to influence flows for biological management below these sites. The selected sites are listed in Table 8.5.

Table 8.5 Dams targeted for flow management recommendations.

Dam Name	Site Location		Catchment Area (sq mi)
	Latitude	Longitude	
Barton Dam	42°18'29.61"	83°45'15.84"	719.89
Argo Dam	42°17'25.62"	83°44'44.38"	721.94
Geddes Dam	42°16'15.41"	83°40'16.25"	755.51
Superior Dam	42°15'54.91"	83°38'40.29"	788.76
Peninsular Paper Dam	42°15'21.78"	83°37'26.76"	791.69
Rawsonville Dam	42°12'21.80"	83°33'27.42"	803.23

In selecting target fish communities, there are many methods by which to determine the individual species that comprise a community. Target fish communities may represent either a biologically meaningful community or a community of interest to local stakeholders. The process for choosing a community of interest is somewhat arbitrary so, for the sake of this study, two target fish communities were selected: 1) expected species from the habitat suitability model and 2) game species listed, but not necessarily regulated, by the Michigan Department of Natural Resources (MDNR). By selecting these two target communities, a comparison was made between an ecologically fit fish community (Model) and a fish community desired by fishermen and the public for recreational purposes (Game).

After the sites were selected and the species comprising the target fish communities were determined, the habitat suitability model was used to derive "'preferred flow" and "suitable flow" ranges for the two target communities for each of the six selected sites. Following the previously mentioned methodology used to compare the habit suitability model results for sites along the Huron River main stem, the habitat suitability model was used to determine flow ranges for Model and Game fish communities. Catchment area is the only necessary input when deriving flow ranges from BFY. The catchment areas for each site were input into the model in order to derive the flow values. From the value of the log10-transformed BFY, the value for BFY was derived and multiplied by the CA resulting in an optimal flow value in cfs for each species comprising the target community. The "preferred flow" range, for each species, was derived by using the values associated with 1 standard deviation above and below BFY. The species' "suitable flow" ranges were determined by deriving the value of 1.5 standard deviation of the BFY. This provided a minimum and maximum value associated with a given species' flow range. This process was repeated for each species comprising both the Model and Game. To identify the preferred and suitable low and high flow values for each target community, the species with the highest low flow and lowest high flow values were identified. These values represent the lows and highs of the flow range at which each full community can exist in either preferred or suitable conditions. This process was completed separately for the Model and Game communities in order to yield independent results.

Results

Table 8.6 Model input parameters

Site	CA (sq mi)	JMT (deg F)	Index Flow (cfs)
Commerce	58.41	73.77	12
Milford	154.36	74.65	46
New Hudson	161.78	75.23	54
Hamburg	338.59	76.32	106
Dexter	524.14	77.27	120
Ann Arbor	728.00	78.83	151
Ypsilanti	797.58	78.98	235

Table 8.7 Species predicted by the habitat suitability model

	Ann Arbor	Ypsilanti
Predicted Species	Black Crappie	Black Crappie
	Bluntnose Minnow	Bluntnose Minnow
	Bowfin	Bowfin
	Brook Silverside	Brook Silverside
	Brown Bullhead	Brown Bullhead
	Carp	Carp
	Channel Catfish	Channel Catfish
	Freshwater Drum	Freshwater Drum
	Mimic Shiner	Mimic Shiner
	Northern Hogsucker	Quillback
	Quillback	
	Silver Redhorse	
	Striped Shiner	

The use of the habitat suitability model to determine low flow criteria for given sites in the Huron River was dependent upon the calculation of three input parameters: catchment area (CA), July mean water temperature (JMT), and index flow. These parameters were calculated for each of the seven sites correlated with USGS stream gauges along the Huron River main stem. Although the reach of interest for this project includes the Ann Arbor and Ypsilanti sites, it was necessary to summarize the findings for each of the seven sites to determine the applicability of the model for the Huron River. Table 8.6 summarizes the three input parameters as calculated for the seven sites.

To predict community composition, the habitat suitability model was executed for each site using the three input parameters. Based on the preference and suitability of the site's size, water temperature, and low flow characteristics, the model predicted which fish species would be present in a "characteristic" condition and those which would be present in a "thriving condition". At the Ann Arbor site, the habitat suitability model was used to predict the presence of 13 fish species classified as characteristic species and 0 species as thriving (Table 8.7). For the Ypsilanti site, 11 species were predicted to be present as characteristic species and 0 species were predicted to be thriving species (Table 8.7). The limiting factors for species in these two sites were catchment size and thermal criteria. A full table of model results for all 7 sites can be reviewed in Appendix 8.1.

Table 8.8 Habitat suitability model prediction success

Site	Prediction Success (%)
Commerce	76.47
Milford	NA
New Hudson	77.94
Hamburg	NA
Dexter	51.47
Ann Arbor	63.24
Ypsilanti	60.29

Note: Prediction Success indicates that the model accurately predicted fish communities at the Commerce and New Hudson sites and that fish communities at the Dexter, Ann Arbor, and Ypsilanti sites were different that what the model expected.

Table 8.9 ROC plot results

Site	AUC	Std. Error	Asypmtotic Sig.	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Commerce	0.734	0.064	0.001	0.609	0.860
New Hudson	0.790	0.057	0.000	0.678	0.902
Dexter	0.510	0.075	0.896	0.362	0.658
Ann Arbor	0.550	0.072	0.485	0.409	0.691
Ypsilanti	0.549	0.070	0.488	0.411	0.687

Model Performance

To determine whether the model could be used to set low flow criteria based on model fish communities, it was necessary to test the habitat suitability model's capacity to predict fish communities in the Huron River. This was determined by comparing the model fish communities to actual fish communities sampled near the site locations. Overall prediction success was derived from the matrices of confusion for each site and compared amongst five sites with fish sample data (Table

8.8). To determine the applicability of the model, the area under the curve for a receiver operating characteristic (ROC) plot was calculated. The following result value ranges indicate low accuracy (0.5 -0.7), "useful applications" (0.7 - 0.9), or high accuracy (> 0.9) (Manel et al. 2001; Swets 1988). The model results (Table 8.9) are reported with the AUC, standard error, asymptotic significance, and asymptotic 95% confidence intervals. Comparison amongst the five test sites is reported as an ROC plot in Figure 8.3 and the comparison of AUCs is reported in Figure 8.4.

The results of the ROC plot indicate that the habitat suitability model is more accurate in predicting the fish community in the upper reaches of the Huron River main stem including the Commerce and New Hudson sites. This also indicates that these two sites have a fish community which represents an expected community that is present in unaltered flow conditions. The Commerce and New Hudson sites report asymptotic significances of 0.001 and 0.000, respectively, indicating that these areas are significantly different than the null hypothesis that the true area = 0.5, which represents a model with no predictive capability. The Dexter, Ann Arbor, and Ypsilanti sites report low accuracy for the predictive capability of the habitat suitability model, but not significantly different from AUC = 0.5. This indicates that these sites have fish communities which are different than an expected fish community that is present in unaltered flow conditions.

Figure 8.3 Comparison of ROC plots

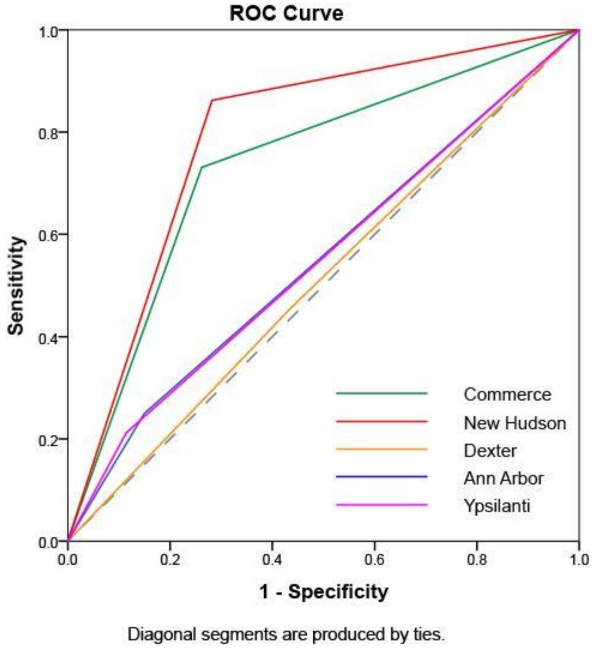
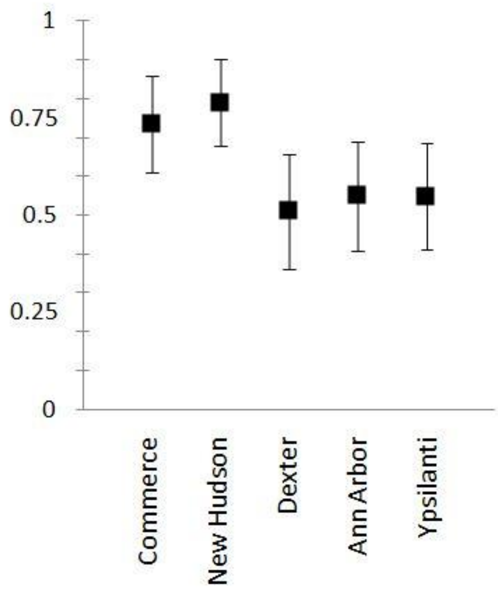


Figure 8.4 Comparison of area under the curve (AUC) for ROC plots



Comparison of Community Flow Preferences

The habitat suitability model was used to determine the optimal flow value, and "preferred flow" and "suitable flow" ranges for each fish species in the following communities: (*a*) predicted by the model and found in fish samples, (*b*) predicted by the model and not present in fish samples, or (*c*) not predicted by the model, but present in fish samples. In turn, values for mean minimum and mean maximum preferred and suitable flow, were calculated for each of the three fish communities (*a*, *b*, and *c*). These values were calculated for each community at each site along the Huron River main stem (Commerce, New Hudson, Dexter, Ann Arbor, and Ypsilanti) as a means to compare expected model communities to fish communities currently present in the river (Table 8.10). A table including each fish species comprising the various communities for each site is located in Appendix 8.2.

When comparing Model (*b*) and Present (*c*) fish communities for the Commerce and New Hudson sites, the fish comprising the three communities have similar low and high flow preferences. The Dexter, Ann Arbor, and Ypsilanti sites show trends that the Present (*c*) fish communities have a higher high flow and lower low flow value than the Model (*b*) community. Additionally, the Model and Present fish communities are more similar in the upstream sites (Commerce and New Hudson) and more different in the downstream sites (Dexter, Ann Arbor, and Ypsilanti). The results of the Analysis of Variance (ANOVA) test, which supports these trends can be seen in Table 8.11 and in graphic form in Figure 8.5.

Table 8.10 Mean high and low suitable and preferred values

Site	Community	Mean Flow Value (cfs)			
		Suitable Low	**Preferred Low**	**Preferred High**	**Suitable High**
Commerce	Present & Model (*a*)	0.91	1.78	26.69	53.03
	Model (*b*)	1.05	1.95	29.87	64.39
	Present (*c*)	2.05	3.19	27.54	51.94
New Hudson	Present & Model (*a*)	4.80	7.79	70.93	132.68
	Model (*b*)	7.20	11.22	83.71	150.45
	Present (*c*)	7.07	11.05	87.71	159.29
Dexter	Present & Model (*a*)	17.97	27.33	193.51	340.16
	Model (*b*)	23.56	34.87	201.62	328.50
	Present (*c*)	8.95	17.18	267.61	553.22
Ann Arbor	Present & Model (*a*)	21.85	34.67	279.79	500.38
	Model (*b*)	33.81	49.33	277.52	447.15
	Present (*c*)	21.74	34.31	312.00	605.32
Ypsilanti	Present & Model (*a*)	22.43	36.16	308.10	555.33
	Model (*b*)	43.31	59.63	250.88	371.64
	Present (*c*)	26.93	42.30	337.77	614.91

Table 8.11 ANOVA table comparing *a, b,* and *c* fish communities for each site

Site	ANOVA p-values			
	Suitable Low	**Preferred Low**	**Preferred High**	**Suitable High**
Commerce	0.5972	0.5518	0.1338	0.0898
New Hudson	0.3496	0.3054	0.3483	0.6005
Dexter	0.0136*	0.0148*	0.0380*	0.0033**
Ann Arbor	0.4982	0.4988	0.5549	0.2552
Ypsilanti	0.3378	0.4373	0.2700	0.1210

Note: 1) Significance code: 0 *** 0.01 ** 0.05 * 0.1

Figure 8.5 Comparison of preferred and suitable flow conditions for modeled and sampled fish communities for Commerce, New Hudson, Dexter, Ann Arbor, and Ypsilanti sites.

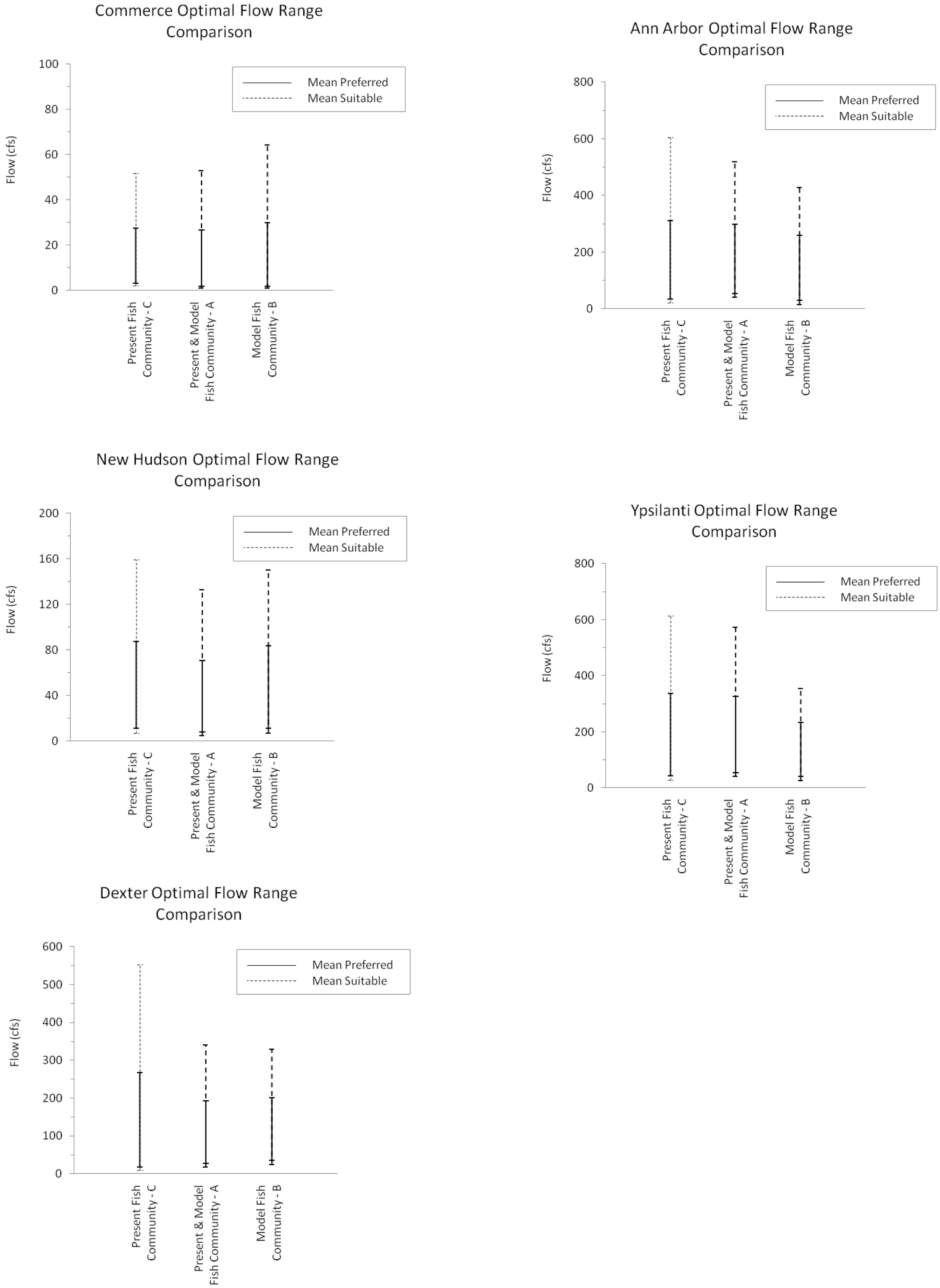


Figure 8.6 Fish community response curve for Ann Arbor

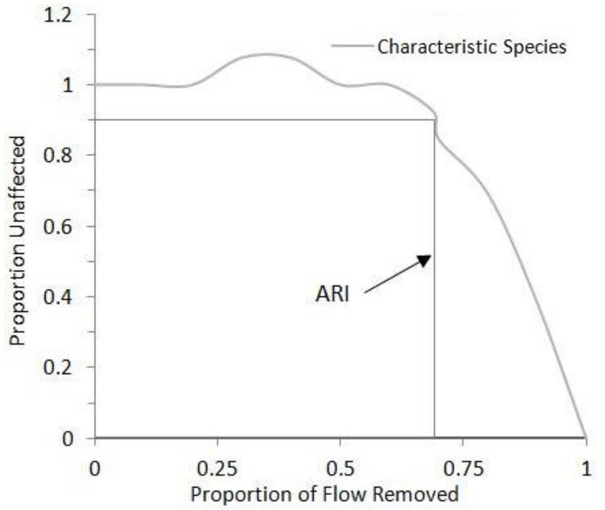


Figure 8.7 Fish community response curve for Ypsilanti

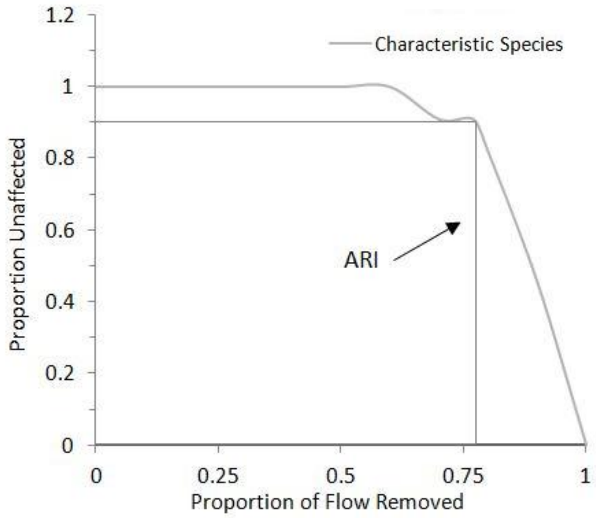


Figure 8.8 Historic ARI causing flows for the USGS stream gauge in Ann Arbor

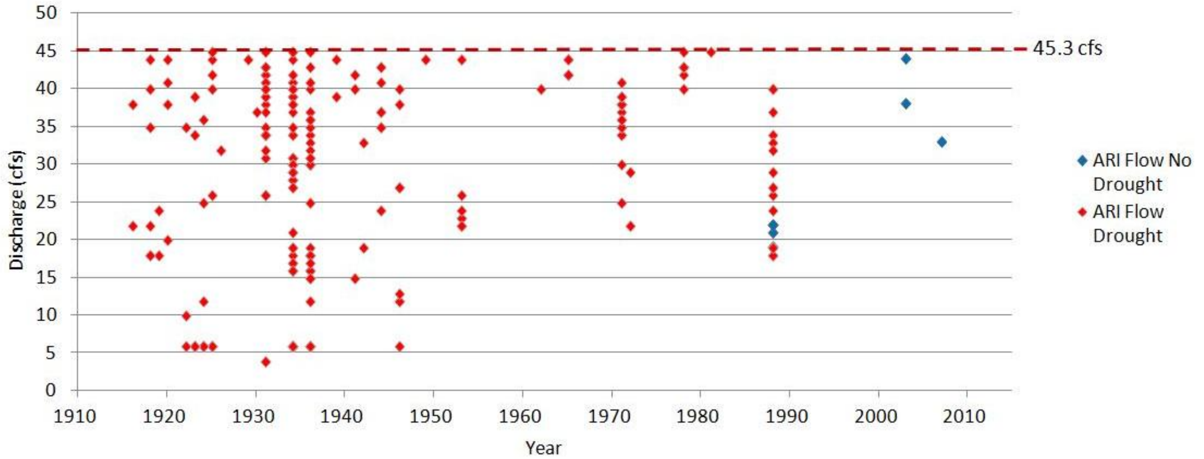
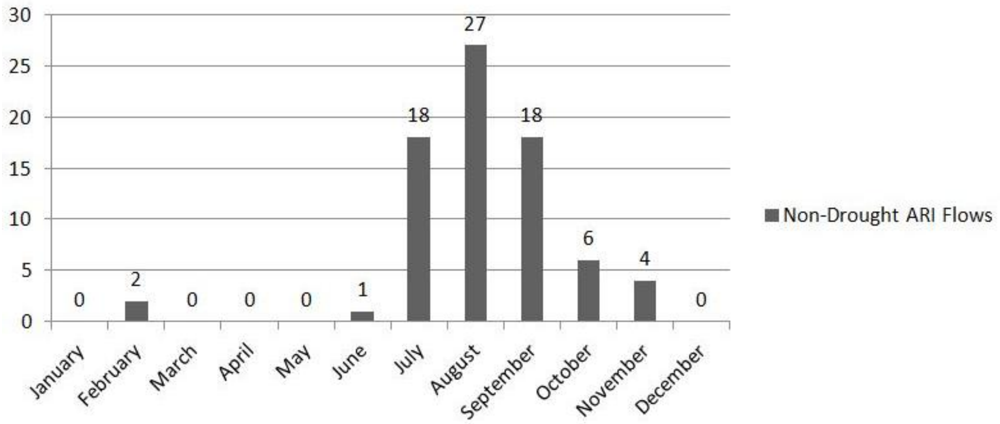


Figure 8.9 Monthly distribution of non-drought ARI causing flows for the USGS stream gauge in Ann Arbor



Adverse Resource Impact

The flow at which an Adverse Resource Impact (10% decline in characteristic species) occurs was determined based on the species predicted by the model for each site. In plotting proportion of species unaffected against proportion of flow removed, a low flow condition was targeted for the expected fish community. The resulting plot (Figure 8.6 and Figure 8.7) shows the decline in the number of characteristic fish species as a response to flow reduction at the Ann Arbor and Ypsilanti sites. Using this method, it was found that an ARI occurs at 45.3 cfs for the Ann Arbor site and at 51.7 cfs for the Ypsilanti site. The fish community response curves and flows causing ARI for the seven sites along the Huron River main stem is summarized in Appendix 8.3.

Historic flow data was analyzed to determine when flows causing ARIs have occurred in the past. In determining historic low flow conditions, ARI causing flows which occurred during non-drought months were noted. At the Ann Arbor site an ARI causing flow, below 45.3 cfs, has occurred a total of 287 times, with a total of 61 occurrences during non-drought months (Figure 8.8). The most recent ARI causing flows occurred in 2003 and 2007, with the flow dropping to 44, 38, and 33 cfs. The majority of these 61 non-drought ARI flows were distributed in the latter half of the calendar year with only 3 occurrences before the month of July (Figure 8.9). For the Ypsilanti site, there were 0 overall ARI causing flow occurrences (below 51.7 cfs) in the history of the USGS gauge. A summary of historic drought and non-drought ARI occurances is summarized in Appendix 8.4.

Target Community Flow Ranges

Table 8.12 Target Community Composition

Target Community	**Species**	
	Common Name	**Scientific Name**
Model	Black Crappie	Pomoxis nigromaculatus
	Bluntnose Minnow	Pimephales notatus
	Bowfin	Amia calva
	Brook Silverside	Labidesthes sicculus
	Brown Bullhead	Ameiurus nebulosus
	Channel Catfish	Ictalurus punctatus
	Mimic Shiner	Notropis volucellus
	Northern Hogsucker	Hypentelium nigricans
	Silver Redhorse	Moxostoma anisurum
	Striped Shiner	Luxilus chrysocephalus
Game	Black Crappie	Pomoxis nigromaculatus
	Bluegill	Ictalurus punctatus
	Bowfin	Amia calva
	Brown Bullhead	Ameiurus nebulosus
	Channel Catfish	Ictalurus punctatus
	Largemouth Bass	Micropterus salmoides
	Northern Pike	Esox lucius
	Rock Bass	Ambloplites rupestris
	Smallmouth Bass	Micropterus dolomieu
	Walleye	Sander vitreus
	White Sucker	Catostomus commersonii
	Yellow Perch	Perca flavescens

Note: 1) Target Community Composition. Carp, Quillback, and Freshwater Drum were removed from the Model community because they are either non-native or are migratory species which need unimpeded waters to fulfill their lifecycle requirements.
2) Carp, Muskellunge, and White Bass were removed from the Game community because they were not included in the habitat suitability model for the State of Michigan.

In order to inform site specific management practices, the habitat suitability model was used to determine low and high "preferred flow" and "suitable flow" range recommendations for each dam from Barton Pond to Ford Lake. This includes recommendations for the following dams, from upstream to downstream: Barton Dam, Argo Dam, Superior Dam, Peninsular Paper Dam, and Rawsonville Dam. To provide a meaningful application of the habitat suitability model, two target communities were established as a means to provide flow recommendations. The first, the Model community, is comprised of species predicted for the site by the habitat suitability model, but not found in samples. The second, the Game community, is comprised of game species, as classified (but not necessarily regulated) by MDNR, and is important for recreational purposes. Table 8.12 lists the individual species that comprise the two target communities. The "preferred flow" and "suitable flow" ranges for each site, based on these two target communities are reported in Table 8.13.

Table 8.13 Preferred and suitable flow ranges for model and game communities

Site	Community	Flow Value (cfs)			
		Suitable Low	**Preferred Low**	**Preferred High**	**Suitable High**
Barton Dam	Model	78.93	94.90	189.35	238.38
	Game	47.56	62.70	189.35	249.61
Argo Dam	Model	79.16	95.17	189.89	239.06
	Game	47.70	62.88	189.89	250.32
Geddes Dam	Model	82.84	99.60	198.72	250.17
	Game	49.92	68.90	198.72	261.96
Superior Dam	Model	86.49	103.98	207.47	261.18
	Game	52.11	71.94	207.47	273.49
Peninsular Paper Dam	Model	86.81	104.37	208.24	262.15
	Game	52.31	72.20	208.24	274.51
Rawsonville Dam	Model	88.07	105.89	211.27	265.97
	Game	53.07	73.26	211.27	278.51

Discussion

The environmental flows assessment makes use of long term and short term flow trend analyses as well as assessments of the biological conditions of the Huron River to provide meaningful insight into how the flows of the river should be managed for the greatest ecological benefit. Connecting the observed hydrological patterns to the surveyed biological conditions is the final step towards understanding how the river is functioning as a system. Since flow data is not available prior to dam construction and biological samples were only completed in the last few decades, it is not possible to know the exact impacts that have occurred due to human alterations of the Huron River. However, there are methods by which it is possible to quantify the physical and ecological conditions of the Huron River as to promote recommendations towards a more ecologically beneficial flow regime for the river.

Habitat suitability models are one method by which historic and current flow conditions and biological communities are used to assess flow regime quality. As with all models, there is some degree of error expected, and biological communities used for management are subjective. While the model that was applied to produce flow management recommendations is extremely useful in its assessment of the Huron River, limitations have been noted.

The habitat suitability model used for this assessment was developed by Zorn et al. (2008) and was initially designed for its use in the Water Withdrawal Assessment Tool (WWAT) (Hamilton and Seelbach 2011). This habitat suitability model is used to provide river managers and decision makers a means to assess the impacts of water withdrawal during low flow periods on rivers throughout the state of Michigan. For the Huron River, biological assessments include in depth studies of invertebrate and fish communities, however the habitat suitability model only makes use of fish data in establishing recommendations for the desired flow regime. It has been established that fish are accurate and effective indicators of the ecological integrity of rivers and streams, supporting the use of this habitat suitability model for the Huron River (Zorn et al. 2008; Fausch et al. 1990; Simon 1999).

Model Function

The habitat suitability model was developed at a regional-scale, but applied at the watershed scale for the Huron River. The model made use of ecologically relevant indicator flows and explored relationships between flow reduction and biologic impairment to develop environmental flow standards. Because low flow and peak water temperature conditions occur primarily in summer months, the model is best applied to flows during this season. During these periods, low flow and high temperature conditions can act as stressors on many fish species and the exacerbation of such conditions by flow management decisions can cause increased mortality resulting in unhealthy populations or local extinction (Zorn et al. 2008). In addition to increased vulnerability to changing conditions, summer months are the growing season for most fish and changes in flow regime may inhibit proper metabolism, feeding, and growth (Brett 1979; Elliott 1981; Zorn and Nuhfer 2007; Zorn et al. 2008). In addition to the biological requirements of fish during the summer season, the majority of fish surveys throughout the State of Michigan were conducted during these months when the conditions were prime for collecting samples.

Model Performance

Since the model was developed at a regional-scale, based on data collected throughout the State of Michigan, it was important to test the applicability of the model at the scale of the Huron River watershed. Additionally, because the model incorporates fish species that are not native to the local conditions of the Huron River, the model may not be able to accurately predict local fish communities. The only unsuitable fish species predicted by the model for the Huron River were those that do not occur in the river because of human impacts, such as dams, which have limited migration from headwaters to estuary. The Quillback (*Carpiodes cyprinus*) and the Freshwater Drum (*Aplodinotus grunniens*) were excluded from target community flow recommendations because, although they could survive in the Huron River based on CA, JMT, and BFY, the structures on the river prevent essential life cycle migrations, thus they would not be expected to survive in the Huron River.

After taking note of those species which were not expected to be present in the Huron River, the model was tested for its power in predicting present and absent fish species. In testing the model, four outcomes were expected: (*a*) species predicted by the model and found in fish samples, (*b*) species predicted by model and absent in fish samples, (*c*) species not predicted by the model, but present in fish samples, and (*d*) not predicted by the model and absent in fish samples. Results *a* and *d* represent a correct prediction by the model. Results *b* and *c* represent an incorrect prediction by the model. Prediction success was determined in two ways: overall prediction success, and area under the curve (AUC) for the receiver operating characteristic (ROC) plot.

The calculations of the prediction success of the model and the as well as the AUC indicate that the model has useful applications and is fairly accurate in predicting fish communities for the upstream sites at Commerce and New Hudson. The results for the ROC plot show that the modeled fish community agrees with the sampled fish community for the two upstream sites and but not for the Dexter, Ann Arbor, and Ypsilanti sites. One explanation for this is that the upstream sites are less impacted by human controlled flow regimes than that of the downstream sites. It has been noted that the dam operations at Kent Lake have a heavy influence on the flow regime downstream of the dam. These impacts, as well as impacts from other dam operations may be altering the flow regime enough to influence the present fish communities.

It must also be considered that fish sample methodology, be it targeted or a community sample, may have an impact on model performance. The larger the sample size, the greater the probability that the sample accurately reflects the fish population. Since there are only a handful of fish samples for each site, the low number of sampled fish may be influencing the accuracy of the model predictions. However, there are a number of full community samples for each site that was tested, so lack of sample size is likely not the only reason for the gradient of model performance. Because the model does not accurately predict the fish species in the downstream sites, either CA, JMT, BFY or a combination of the variables is negatively influencing the fish communities at these sites. A comparison between community flow preferences was analyzed to determine whether flow is influencing the present fish community

Comparison of Community Flow Preferences

For each of the sites, a high and low mean suitable and preferred flow value was compared for the three communities (either modeled, sampled, or the combination). For each of the sites, a high and low mean suitable and preferred flow value was compared for the three communities: Present and Model (*a*), Model (*b*), and Present (*c*). A comparison between flow preferences of these fish communities was made in order to establish whether flow is impacting which fish species are present at the selected sites.

For the two upstream sites, Commerce and New Hudson, flow preferences for the Model (b) and Present (c) communities were similar. There is no distinct difference between the high and low suitable and preferred flow values. On the other hand, the downstream sites, Dexter, Ann Arbor, and Ypsilanti, show a definite trend: the suitable high flow values for present fish communities are much higher and the low flows lower than the model communities. Although only the Dexter site shows a significant difference, the trend indicates that altered flow regimes may be driving the fish communities at these three downstream sites.

Adverse Resource Impact

Since the habitat suitability model proved useful in predicting fish communities in the Huron River, it has been applied to establish flow criteria. Summer low flow criteria were defined by the occurrence of an adverse resource impact (ARI).

Due to available flow data at USGS stream gauges, these sites are best suited to provide flow recommendations. In the reach of interest, low flow recommendations were calculated for the Ann Arbor and Ypsilanti sites corresponding to the USGS stream gauges. After constructing fish community response curves to determine how modeled fish communities would respond to flow reduction, ARI causing flows were determined. For the Ann Arbor site an ARI would occur at a low flow of 45.3 cfs. For the Ypsilanti site an ARI would occur at a low flow of 51.7 cfs. These values represent the base flow that must be maintained in order to avoid the occurrence of an ARI, which may disrupt the ecological integrity of the river.

An assessment of the historic ARI occurrences was conducted for each of the seven sites on the main stem of the Huron River. Historical records informed to what extent and how often these low flow ARI conditions occurred in the past. For example, a high occurrence of low flow ARI conditions, not associated with regional drought, would indicate that human impact, including dam operations, were the driving factor. Ann Arbor has the highest number of ARI causing flows in the history of the gauge indicating that human impacts may have a drastic influence on the flow regime at this site.

Target Community Flow Ranges

To further hone in on flow recommendations for the Huron River, a finer scale analysis was conducted for each dam within the reach of interest. Using the habitat suitability model, target summer flow ranges were established for the following dams: Barton Dam, Argo Dam, Geddes Dam, Superior Dam, Peninsular Paper Dam, and Rawsonville Dam. Since historic ARI records have confirmed that human impacts from dam management are influencing the flow regime within this reach of the Huron River, flow management must occur at this scale.

Suitable and preferred low flow and high flow values were derived for individual fish species in each community. To provide realistic recommendations yet set forth standards to enhance ecological functioning of the river, two target fish communities were selected for the establishment of management decisions. These two communities are subjective and the process of targeting a flow regime remains the same regardless of the selected target community. The first target community, Model, represents fish species which should thrive in the Huron River, yet do not because of flow management practices. The second target community, Game, includes fish species which the MDNR lists as desirable for recreational fishing purposes. These two communities embody likely management scenarios based on the priorities of different stakeholders involved in the management of the Huron River.

“Suitable flow” recommendations represent conditions in which fish species could survive and maintain viable populations. “Preferred flow” recommendations represent flow conditions in which fish should show high abundance, multiple age classes, and good reproductive capability.

Management for a preferred flow range is ideal in terms of ecological functioning, but sometimes unobtainable, in which case a suitable flow range will provide adequate conditions for the species to remain stable. These target flows could be used as the standard ranges within which low and high summer base flows should be maintained. It is important to note, if flow management were to be based on the Game community, low flows could be much lower and somewhat higher than if flow management was based on the Model community. Since the Model community represents a fish community that should exist in the Huron River, not including non-native and game species, the flow range in which these species can survive and thrive is tighter than other potential target communities.

Limitations

The habitat suitability model can establish criteria for low flow events which may harm fish species within any given reach of the Huron River as well as describe suitable and preferred flow ranges for any given fish species or fish community. Although the application of the model for the environmental flows assessment has proven very useful, there are a number of limitations which need to be considered when applying the results to management decisions.

Developed specifically for summer low flow conditions, the model does not accurately represent conditions outside of low flow or summer conditions. Since the model was created based on biological surveys, it relies on the data collected during the surveyed time periods. The majority of stream and river surveys throughout the State of Michigan occur during the summer months when the waters are accessible. The number of surveys that occur outside of the low flow season are not substantial enough to justify model application during those periods. Therefore, the model cannot be used to predict flow thresholds for fish species or communities outside of the summer months.

In addition to the seasonal restrictions, the model provides flow recommendations for what is considered base flow. The definition of base flow does not include a temporal component which should be considered when implementing management recommendations. The recommendations proposed through the use of the model, the low flow criteria based on adverse resource impact and the suitable and preferred flow ranges for fish communities, is a recommendation for the management of base flow as derived from the base flow yield equation in the model. Zorn et al. (2008) selected the 50% August exceedence flow to define base flow, but it is not discussed how long these flows can be maintained. If a recommendation specifies that flow cannot drop below a certain level without an ARI occurring, it is unknown for what time period this is true. Certain species will be able to survive below these thresholds for various lengths of time, but the temporal threshold is unclear.

Finally, the model was designed for application throughout the state, meaning that further study is necessary to hone the model to the watershed scale. The model, solely relies on the variables of catchment area, July mean water temperature, and base flow yield and disregards all other factors influencing fish populations. Physical conditions such as habitat quality or water quality cannot be incorporated, so the model should be used to complement ground studies of the river reach or site of interest. Some species may be able to seek refuge in tributaries or other habitat structures during low or high flow conditions, allowing them to survive even though the flow drops below the critical threshold proposed by the model. The model must be used in conjunction with habitat surveys as well as physical channel surveys to determine the specific capacity of the channel to support various fish species and communities.

Conclusions and Recommendations

Having noted the limitations and associated implications of the habitat suitability model for flow management, the model is a useful first step in characterizing the impacts of flows on the biology of the Huron River. A number of conclusions and recommendations can be drawn from the use of this model as it is applied to the Huron River:

1) Fish communities around Ann Arbor and Ypsilanti are not in agreement with predicted model communities given the catchment size, July mean water temperature, and base flow yield.

2) Present fish communities prefer a flow range with a higher upper bound for high flows and lower for low flows relative to model communities at the Ann Arbor and Ypsilanti sites.

3) An adverse resource impact (ARI) occurs in Ann Arbor at a low flow of 45.3 cfs and in Ypsilanti of 51.7 cfs.

4) Ann Arbor has the highest amount of historic ARI causing flow occurrences throughout the Huron River, indicating that it is necessary to prioritize associated dam operations.

5) Suitable and preferred flow ranges were determined for Model and Game target fish communities for each dam from Barton Pond to Ford Lake as a means to manage flows influenced by these dams.

REFERENCES

Brett, J. R. 1979. Environmental factors and growth. Pages 599–675 in W.S. Hoar, D.L. Randall, and J. R. Brett, editors. Fish physiology volume VIII. Academic Press.

Elliott, J. M. 1981. Some aspects of thermal stress on freshwater teleosts. Pages 209–245 in A. D. Pickering, editor. Stress and fish. Academic Press, New York.

Fausch, K. D., J. Lyons, J. R. Karr, and P. L. Angermeier. 1990. Fish communities as indicators of environmental degradation. Pages 123–144 in S. M. Adams, editor. Biological indicators of stress in fish. American Fisheries Society, Symposium 8, Bethesda, Maryland.

Fielding, A. H., & Bell, J. F. (1997). A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental conservation, 24(1), 38-49.

Hamilton, D. A., & Seelbach, P. W. (2011). Michigan's water withdrawal assessment process and internet screening tool. Michigan Department of Natural Resources, Fisheries Special Report, 55.

Keyantash, J., & Dracup, J. A. (2002). The quantification of drought: an evaluation of drought indices. Bulletin of the American Meteorological Society,83(8), 1167-1180.

Manel, S., Williams, H. C., & Ormerod, S. J. (2001). Evaluating presence–absence models in ecology: the need to account for prevalence. Journal of applied Ecology, 38(5), 921-931.

Michigan Legislature, 2006, Public Acts of 2006, Act No. 33: 93rd Legislature, Regular Session of 2006. Available: http://www.legislature.mi.gov/documents/2005-2006/publicact/pdf/2006-PA-0033.pdf. (September 2013).

Poff, N. L., and J. V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Canadian Journal of Fisheries and Aquatic Sciences

46:1805–1818.
Robertson, E.A., Zweig, M.H. & Van Steirteghem, M.D. (1983) Evaluating the clinical accuracy of laboratory tests. American Journal of Clinical Pathology, 79, 78–86.
Seelbach, P. W., M. J. Wiley, J. C. Kotanchik, and M. E. Baker. 1997. A landscape-based ecological classification system for river valley segments in lower Michigan (MI-VSEC version 1.0). Michigan Department of Natural Resources, Fisheries Research Report 2036, Ann Arbor.
Simon, T. P. 1999. Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, Florida.
Swets, J.A. (1988) Measuring the accuracy of diagnostic systems. Science, 240, 1285–1293.
Wehrly, K. E., M. J. Wiley, and P. W. Seelbach. 2003. Classifying regional variation in thermal regime based on stream fish community patterns. Transactions of the American Fisheries Society 132:18–38.
Zorn, T. G., P. W. Seelbach, and M. J. Wiley. 2002. Distributions of stream fishes and their relationship to stream size and hydrology in Michigan's Lower Peninsula. Transactions of the American Fisheries Society 131:70–85.
Zorn, T. G., P. W. Seelbach, and M. J. Wiley. 2004. Utility of species-specific, multiple linear regression models for prediction of fish assemblages in rivers of Michigan’s Lower Peninsula. Michigan Department of Natural Resources, Fisheries Research Report 2072, Ann Arbor.
Zorn, T. G., P. W. Seelbach, E. S. Rutherford, T. C. Wills, S.-T. Cheng, and M. J. Wiley. 2008. A regional-scale habitat suitability model to assess the effects of flow reduction on fish assemblages in Michigan streams. Michigan Department of Natural Resources, Fisheries Research Report 2089, Ann Arbor.
Zorn, T. G., and A. J. Nuhfer. 2007. Influences on brown trout and brook trout population dynamics in a Michigan river. Transactions of the American Fisheries Society 136:691–705.
Zweig, M. H., & Campbell, G. (1993). Receiver-operating characteristic (ROC) plots: a fundamental evaluation tool in clinical medicine. Clinical chemistry, 39(4), 561-577.

9 Conclusions

The flow rate of the Huron River has increased over the past nearly 100 years. Specifically, major flow parameters related to flow magnitude (e.g. annual mean flow, monthly mean flow, baseflow, etc.) demonstrated significant increasing trends for the past nearly 100 years. The magnitude of high flows also showed an upward pattern although it was not statistically significant.

The long-term flow rate rise could be driven by the increase of precipitation (averaged 1.3mm/yr from 1915 to 2013) within the watershed. Annual precipitation in the watershed showed a similar increasing trend to that of flow discharge and significant correlations were found between precipitation and flow discharge. With respect to current climate change trajectories, the trend of more water running into the river is likely to continue, which means higher probability of flood events of the Huron River in the future.

The daily and sub-daily flashiness calculations revealed some evidence of flow alteration by dams. The Ann Arbor USGS gauge and Ford Lake Dam have generally higher flashiness compared to other gauges. In addition, New Hudson USGS gauge (Kent Lake Dam) showed high flashiness during April and November. Dam operations likely caused the high flashiness for these three sites. The Ann Arbor gauge is of particular interest because it is downstream from the Argo Dam. The inflow from Allen Creek, which is largely affected by stormwater runoff, could partially explain the high flashiness in the Ann Arbor gauge, while most of the flow variability resulted from the Argo Dam and the cascade. Although the Argo Dam is operated as run of the river, the automatic control system may still significantly increase the flashiness of its downstream reach.

With respect to indirect affects on flow alteration, the analysis on land cover proved it influential, although perhaps less so in the future, within the Huron River watershed. For the bulk of the watershed, the SCS Runoff Curve Number increased by roughly 18% between pre-1800 conditions and 1992 land cover conditions, and decreased by 1% from 1992 to 2006. This result indicated that land cover change from pre-settlement conditions has had a large direct influence on the amount of water running into the Huron River per precipitation event, but that the trend is changing. With continued implementation of urban and agricultural BMPs as well as the conversion of agricultural lands back to forest or wetland cover, runoff per precipitation event should continue decreasing. Although in recent years land cover is becoming less influential on surface water processes of the Huron River watershed, it is clear that that the overall increase in runoff curve number has increased the flashiness of the system as a whole.

With respect to the biotic communities, comparison between benthic macroinvertebrate samples and site habitat quality along the main stem of the Huron River revealed urbanization to be a major stressor. A higher percentage of developed land, or more specifically impervious area, was correlated with lower habitat diversity and higher input of fine sediments into the stream. Since land cover change is often associated with increased flow flashiness, aquatic invertebrate assemblages may also suffer from this impact. However, more flow gauge data is needed to confirm this relationship at sites along the Huron River main stem.

Presence/absence data of fish samples, along the hydrologically variable reach of interest in the

Huron River, allowed for the identification of two guilds - riverine and impoundment - based on distinct preferences and characteristics. Eighteen species comprised the riverine only guild (ROG), 15 species comprised the impoundment only guild (IOG), and 22 species were found in both riverine and impoundment sites (cross-over or overlap species). This analysis was also a precursor to the use of a habitat suitability model, which compared existing and expected fish communities.

The MDEQ Procedure 51 and a MDNR developed IBI for lakes were used to assess habitat quality at riverine and impoundment sites, respectively. The riverine sites were generally of "Good" quality, but there were a few anomalies that require further investigation. The impoundments were generally of poorer quality with respect to typical MI lakes. Although impoundments cannot support the same assemblage of species found at riverine sites, habitat improvements may increase the number of crossover species that could benefit from both types of environment. However, given that the same fish data was used for the MDEQ Procedure 51 and MDNR lake IBI to analyze habitat, ground-truthed data is necessary to verify scores and determine to what degree differences in habitat may be driving fish assemblages as well as the potential benefits of improving impoundment habitat.

Following the analysis of the long and short term flow trends, as well as the analysis of the invertebrate and fish communities of the Huron River, it was necessary to develop a method to connect these patterns to better inform management decisions. Connecting the observed hydrological patterns to the surveyed biological conditions is the final step understanding how the river is functioning as a system. This connection was made using an existing habitat suitability model developed based on fish communities throughout the state of Michigan. The habitat suitability model made use of key characteristics influencing fish habitat for various sites (catchment area, July mean water temperature, and base flow yield). Based on analysis of model results and fish samples throughout the Huron River, the flow regimes of various sites could be better understood. In addition, low flow recommendations were proposed for sites throughout the Huron River main stem.

Based on the model results, it was determined that fish communities around Ann Arbor and Ypsilanti are not representative of model communities for the catchment size, July mean water temperature, and base flow yield for which they exhibit. These existing communities do not resemble model communities because they prefer a flow range with a higher upper bound relative to those model communities. In order to maintain model communities, which represent an ecologically fit community, low flow levels must be maintained above 45.3 cfs in Ann Arbor and above 51.7 cfs in Ypsilanti. In addition to low flow requirements, recommendations were made based on two target communities which were selected based on potential stakeholder interest. This model has a number of limitations but is a first step in creating more informed flow management decisions. With the addition of site specific physical studies, the habitat suitability model can serve as a management tool for various stakeholders within the Huron River watershed.

10 Recommendations

Areas of further action and study have been identified by the analyses in this report and are recommended to ensure the effectiveness of management decisions.

HRWC can collaborate with the City of Ann Arbor to determine the cause of the flashy hydrograph at Ann Arbor gauge and its subsequent impact on the biotic community. Additionally, the number of historic flows causing an adverse resource impact (ARI) is considerably higher at the Ann Arbor gauge compared to other locations along the Huron River. Therefore, if significant impacts to the biotic community are occurring due to altered flows, this site presents the best opportunity to capture and quantify the impact.

Following further investigation, habitat improvement at impoundment sites may support a larger population or diversity of crossover species (i.e. not ROG or IOG). For impoundments that have little chance of removal, whether due to energy requirements or cultural demands, the improvement of habitat may be a beneficial compromise for all involved stakeholders.

Utilizing the habitat suitability model provided in this study, an ideal and suitable low flow and high flow range for desired fish communities can be determined. Thus HRWC can collaborate with dam owners to encourage desired fish communities through amendments to operations.

The future potential increase in flow rate and/or flood events due to climate change need to be further studied. Collaboration with dam owners and residents, especially those living near the Huron River, to prepare for possible future flood events is encouraged.

As mentioned in the fish and invertebrate analysis, it is possible that flow alteration impacts were not captured in the available data, whether due to discrepancies between collection methodology at sites, a temporal mismatch between data collection and vulnerable life cycle events, or a spatial mismatch between flow characteristics and biotic assemblages. More field measurements and analysis are needed to confirm the flow conditions on specific sites and the response of biotic communities.

Appendix

Table of Contents

Appendix 2 - Long Term Flow Analysis

This appendix contains three kinds of plots. The first kind shows the annual or monthly mean flow rate of each USGS gauge on the Huron River main stem as time series. The year of dam construction or the most recent reconstruction for each dam was marked on the time-series plots using colored lines. Red lines indicate dams located upstream of the gauge station, while purple lines indicate dams located downstream of the gauge station “Ypsilanti”.

The second kind is time-series plot showing the level of each Indicator of Hydrologic Alteration (IHA) parameter. Red line shows the trend line using Sen’s slope estimator. Some plots have no trend lines because we were unable to perform Sen’s slope estimator due to missing values (no data) in the time series. The equation of the trend line and the p value of Mann-Kendall Trend Analysis were labeled on the plot.

The third kind is a matrix plot showing the result of Repeated Mann-Kendall Trend Analysis of each IHA parameter. The x-axis and y-axis demonstrate the beginning and ending year of each subset of time-series data. S_D (blue) indicates a significant downward trend. S_U (yellow) indicates a significant upward trend. NS_D (cyan) and NS_U (green) mean an overall downward or upward trend, respectively, but the test result is not significant. NS_N (black) indicates no change in trend. NA (grey) means no data.

Table of Contents

Figure 1 Annual mean flow on the main stem of Huron River.

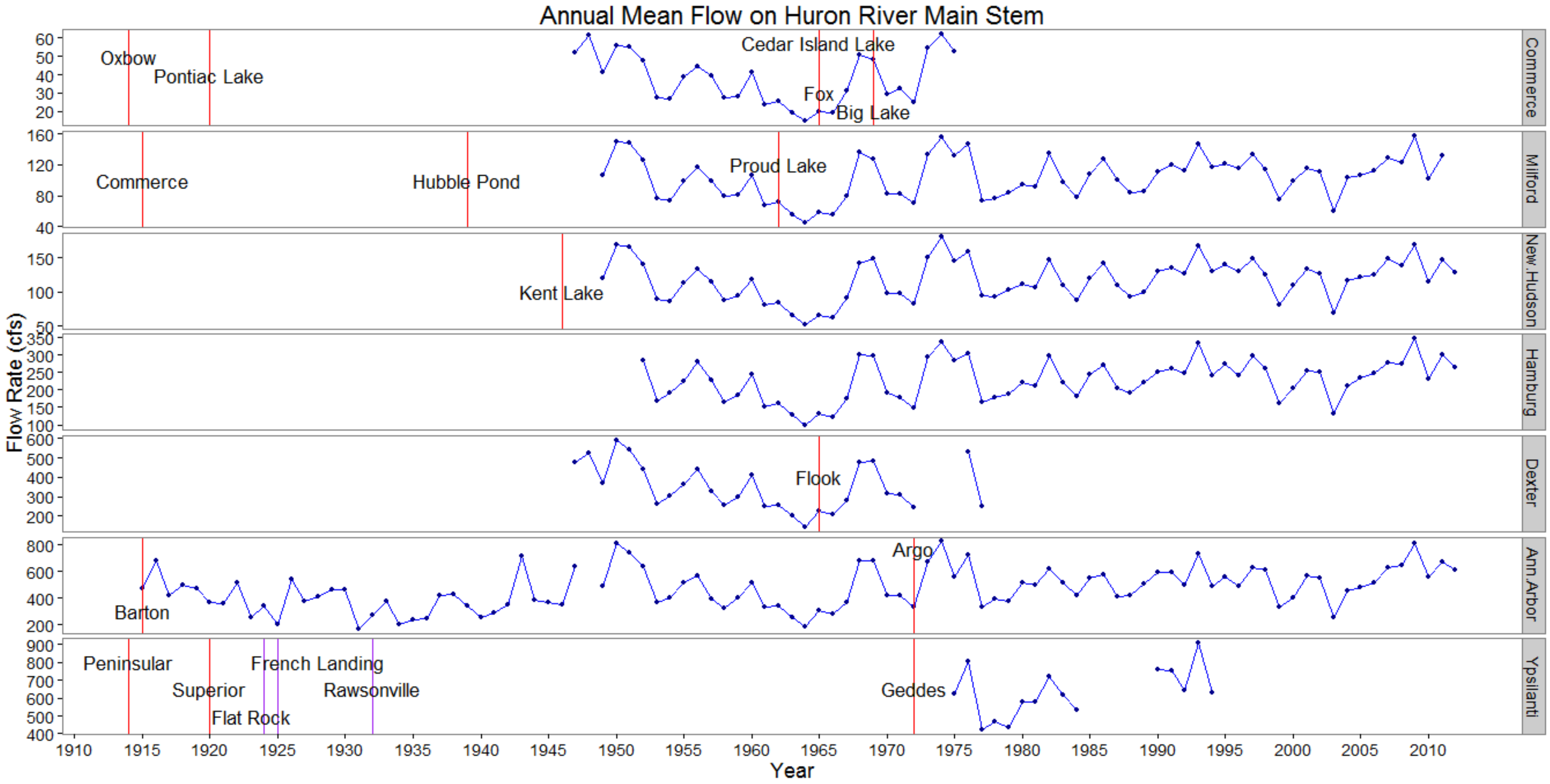


Figure 2 Mean January flow on the main stem of Huron River.

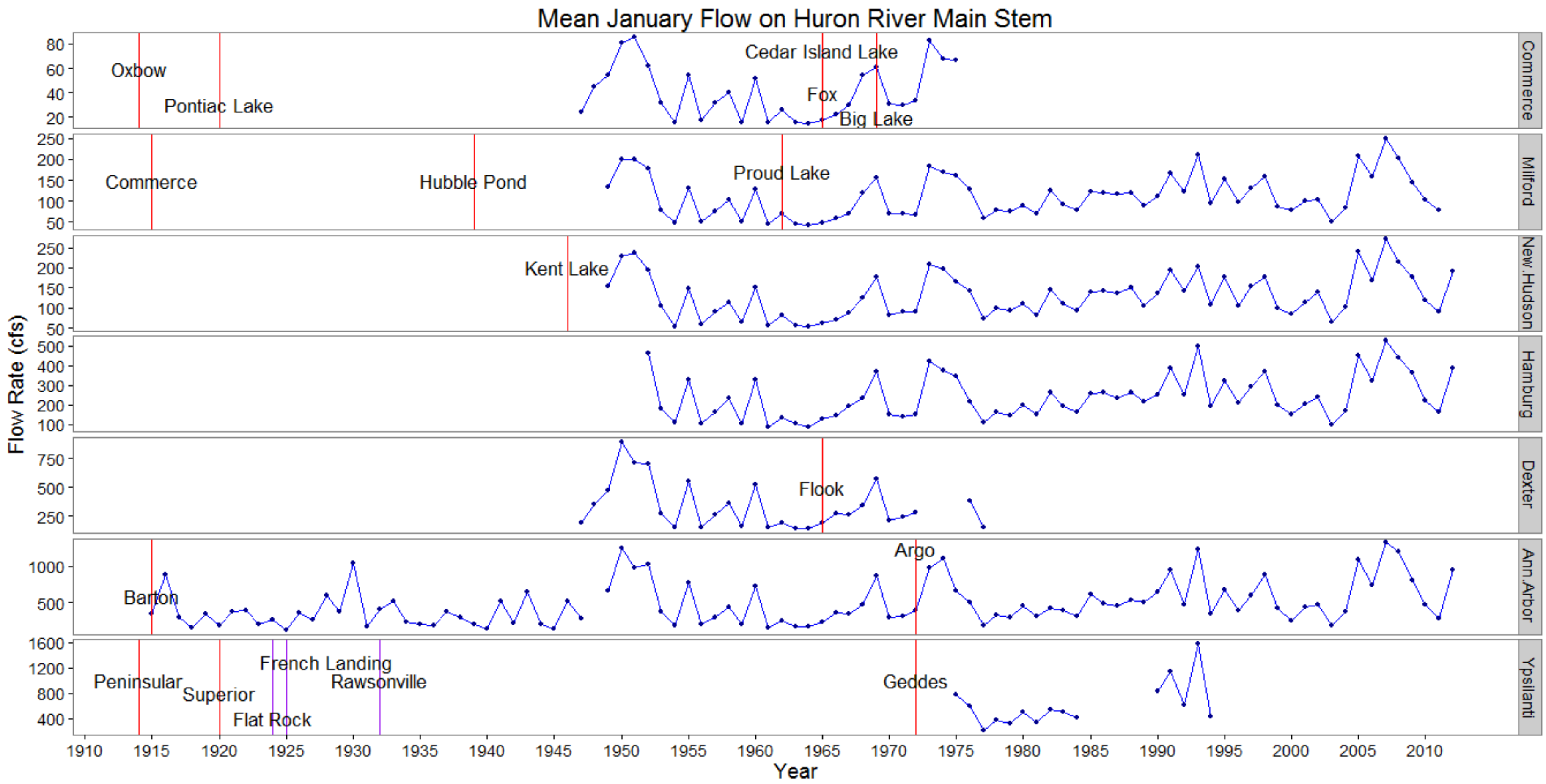


Figure 3 Mean February flow on the main stem of Huron River.

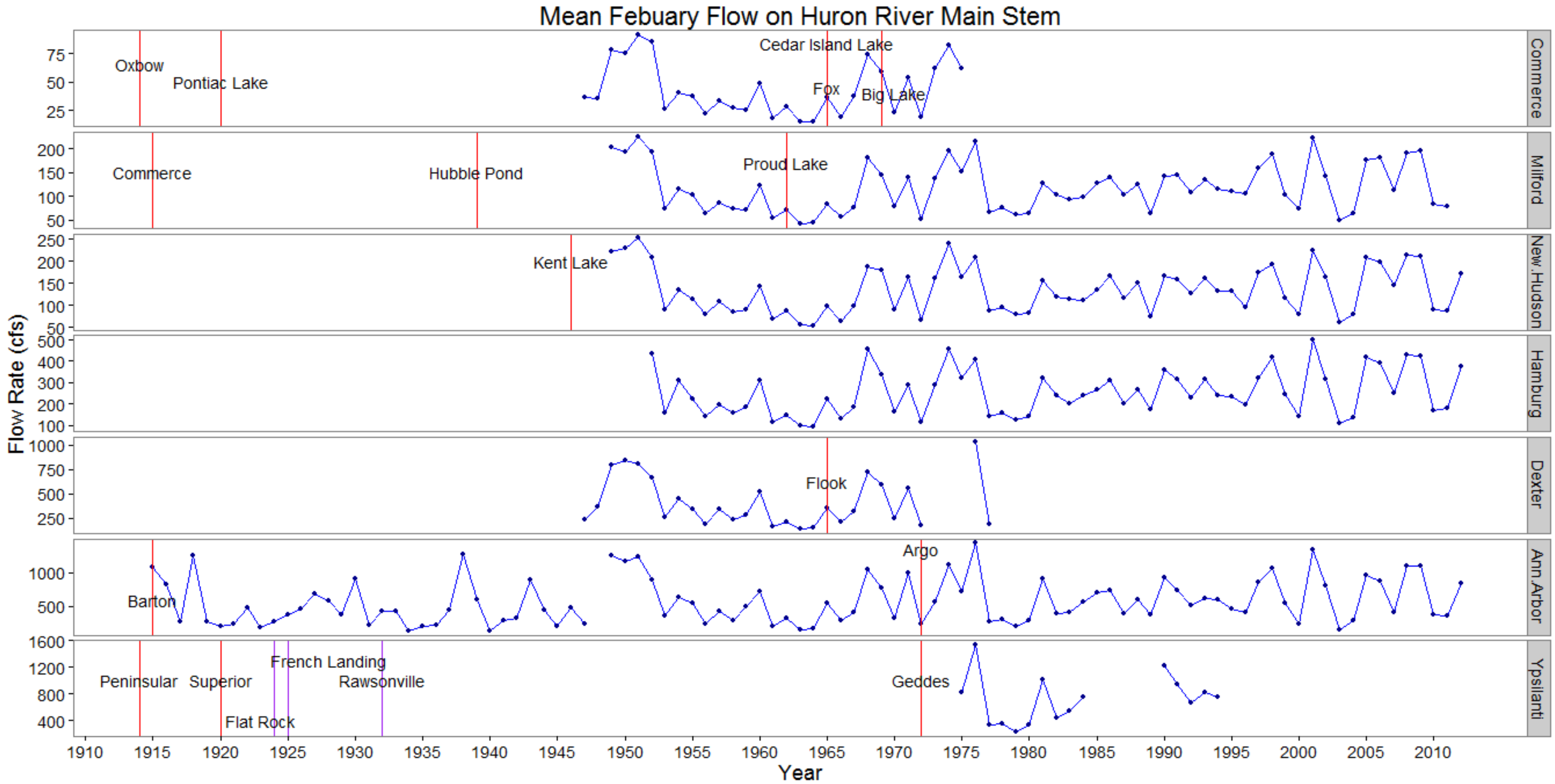


Figure 4 Mean March flow on the main stem of Huron River.

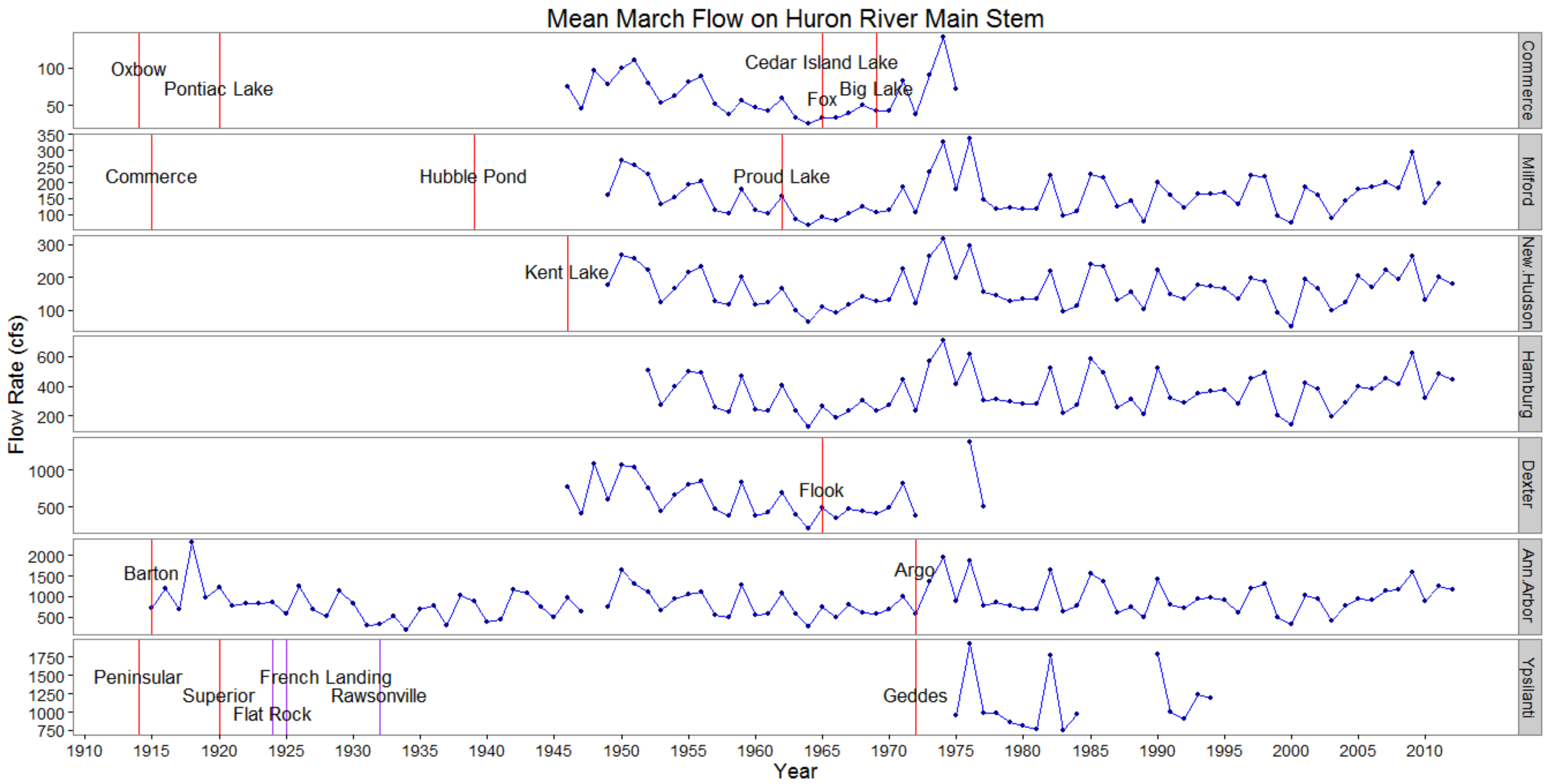


Figure 5 Mean April flow on the main stem of Huron River.

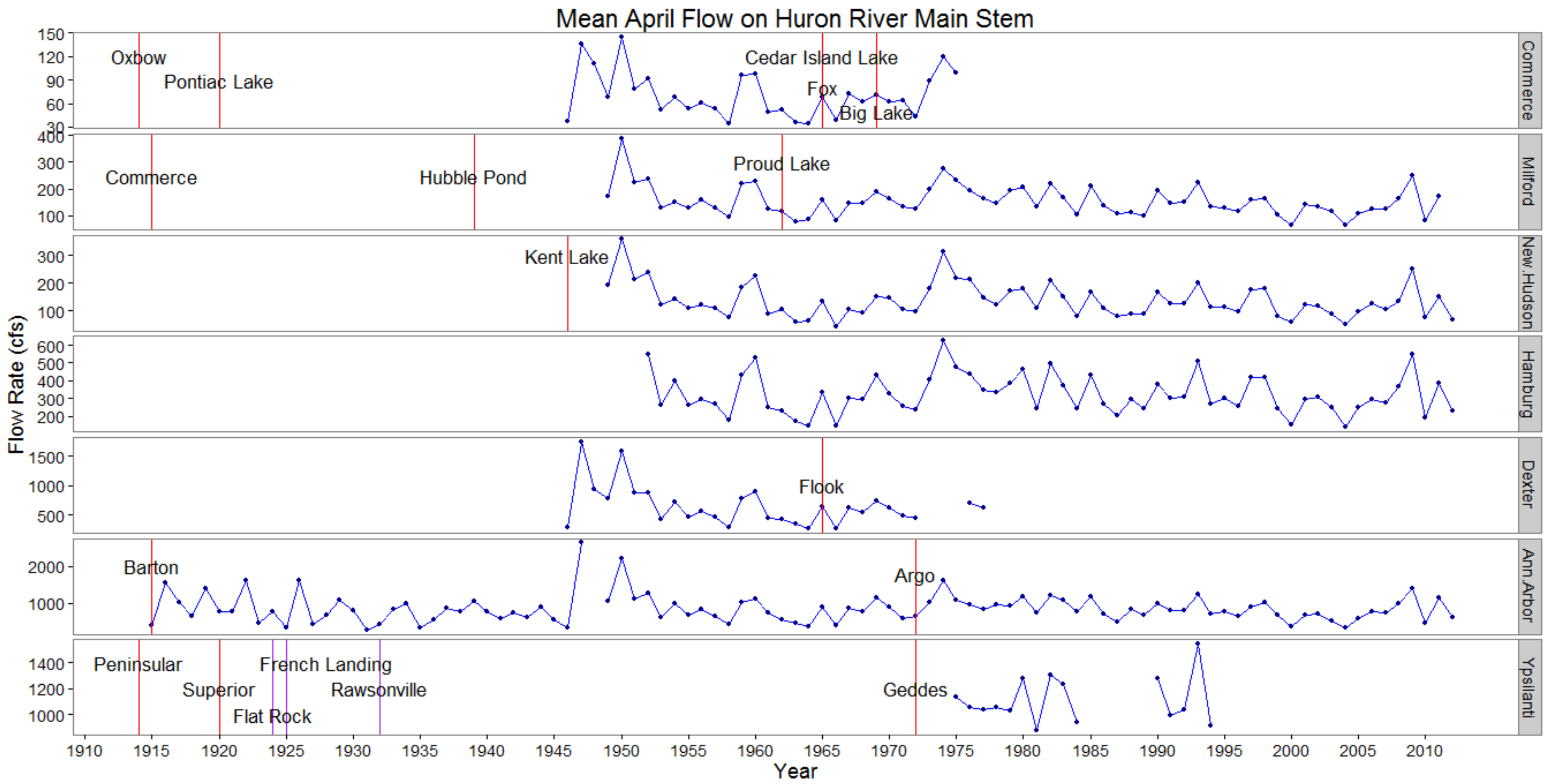


Figure 6 Mean May flow on the main stem of Huron River.

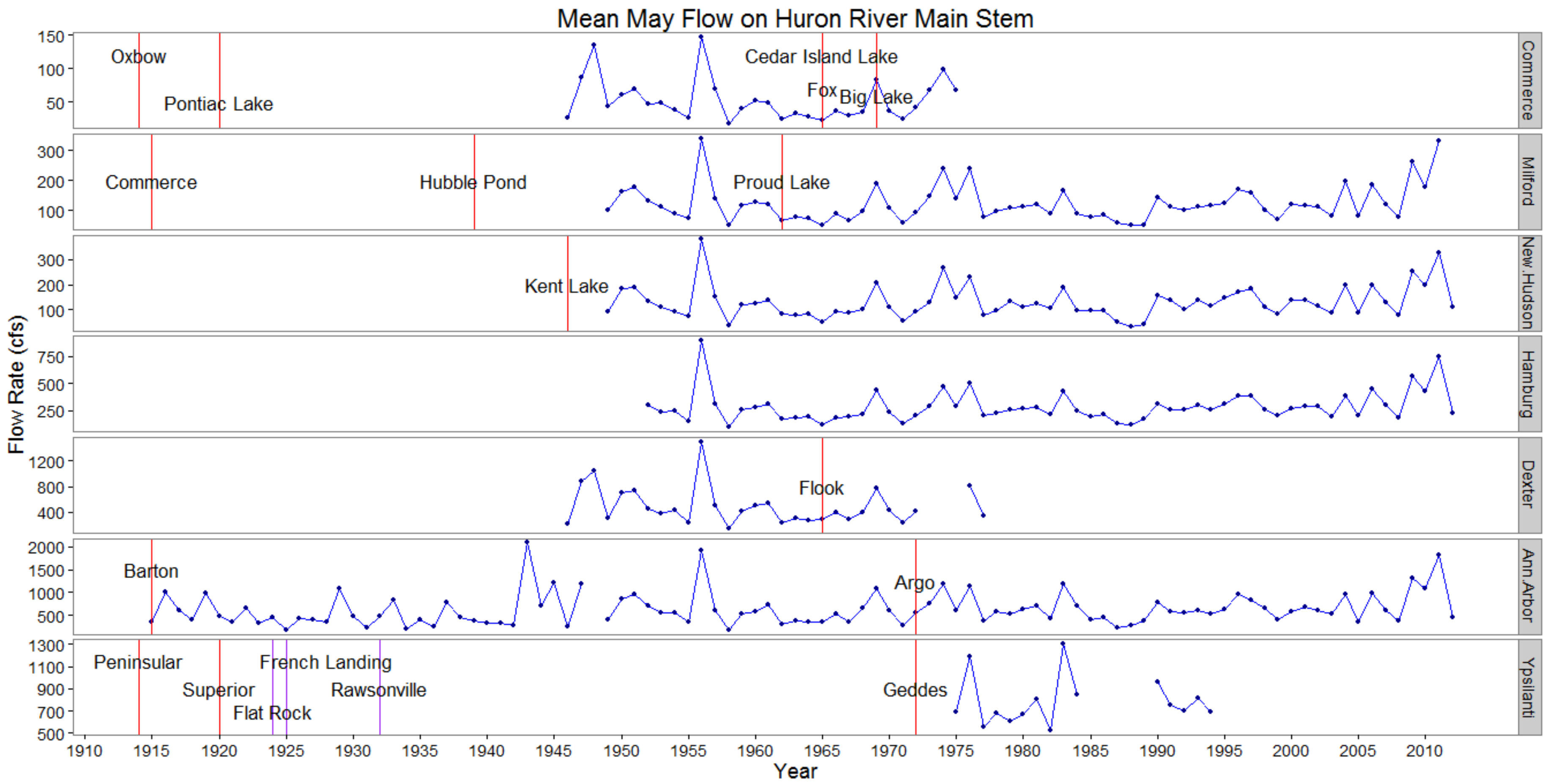


Figure 7 Mean June flow on the main stem of Huron River.

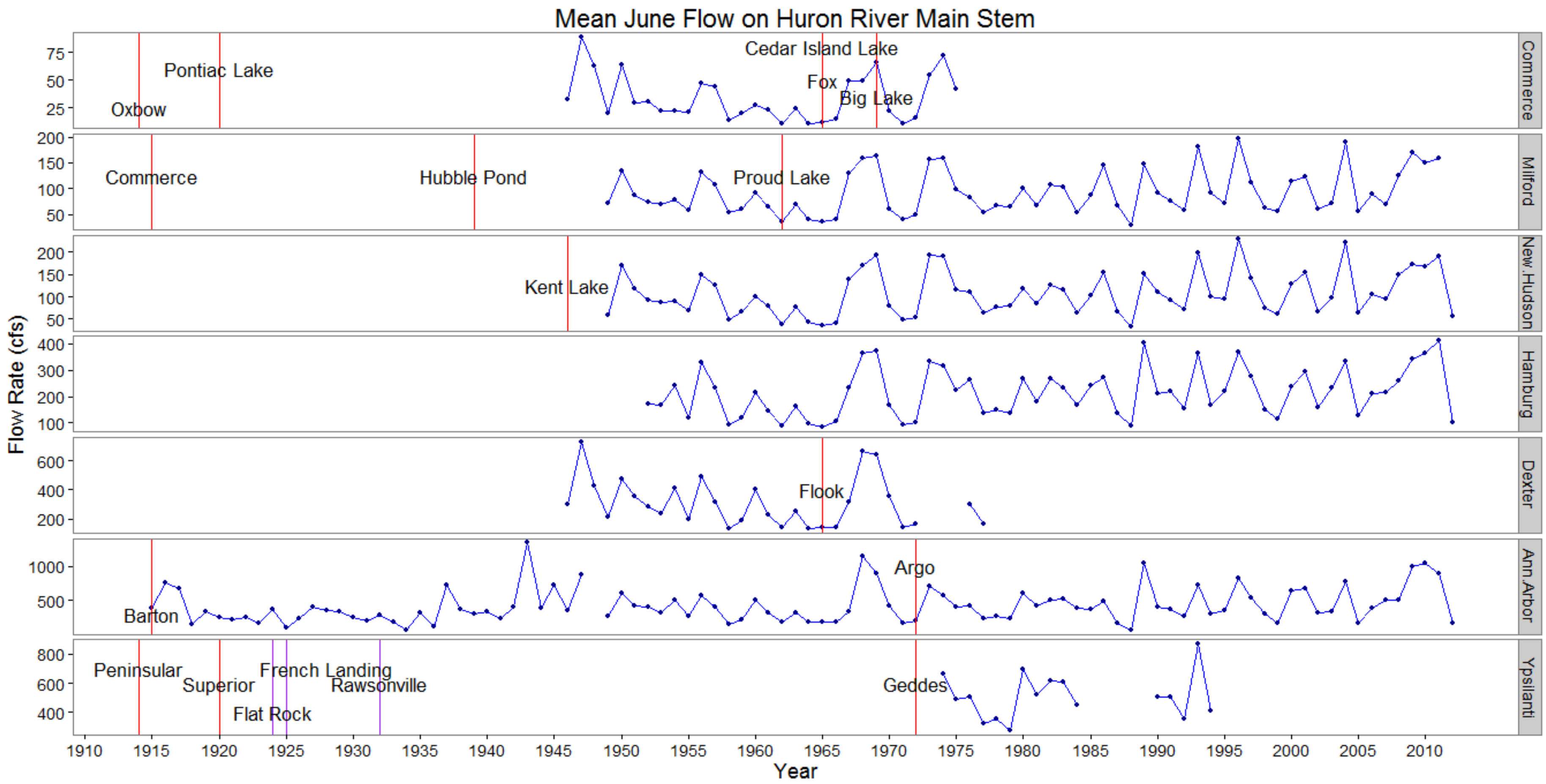


Figure 8 Mean July flow on the main stem of Huron River.

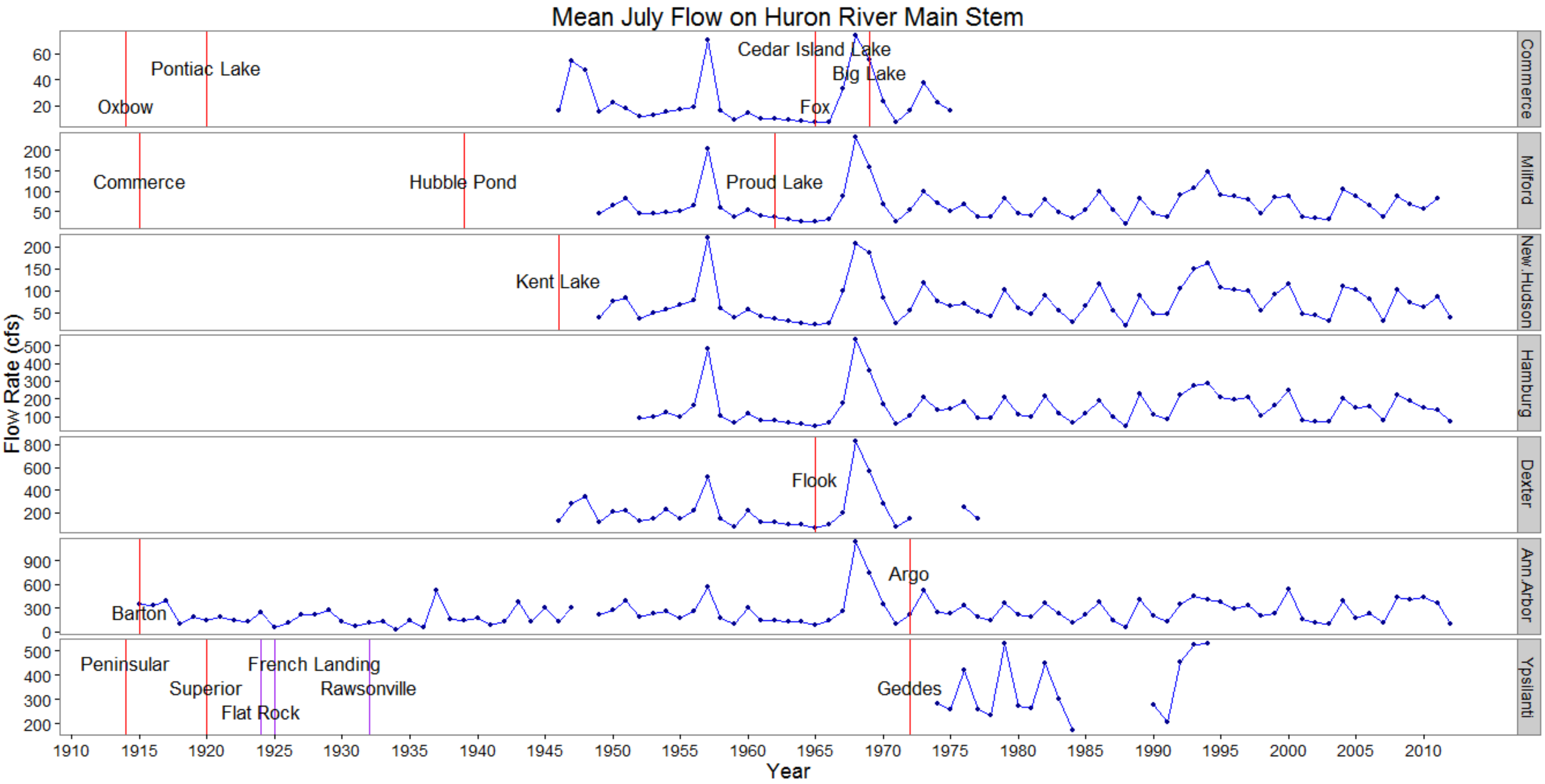


Figure 9 Mean August flow on the main stem of Huron River.

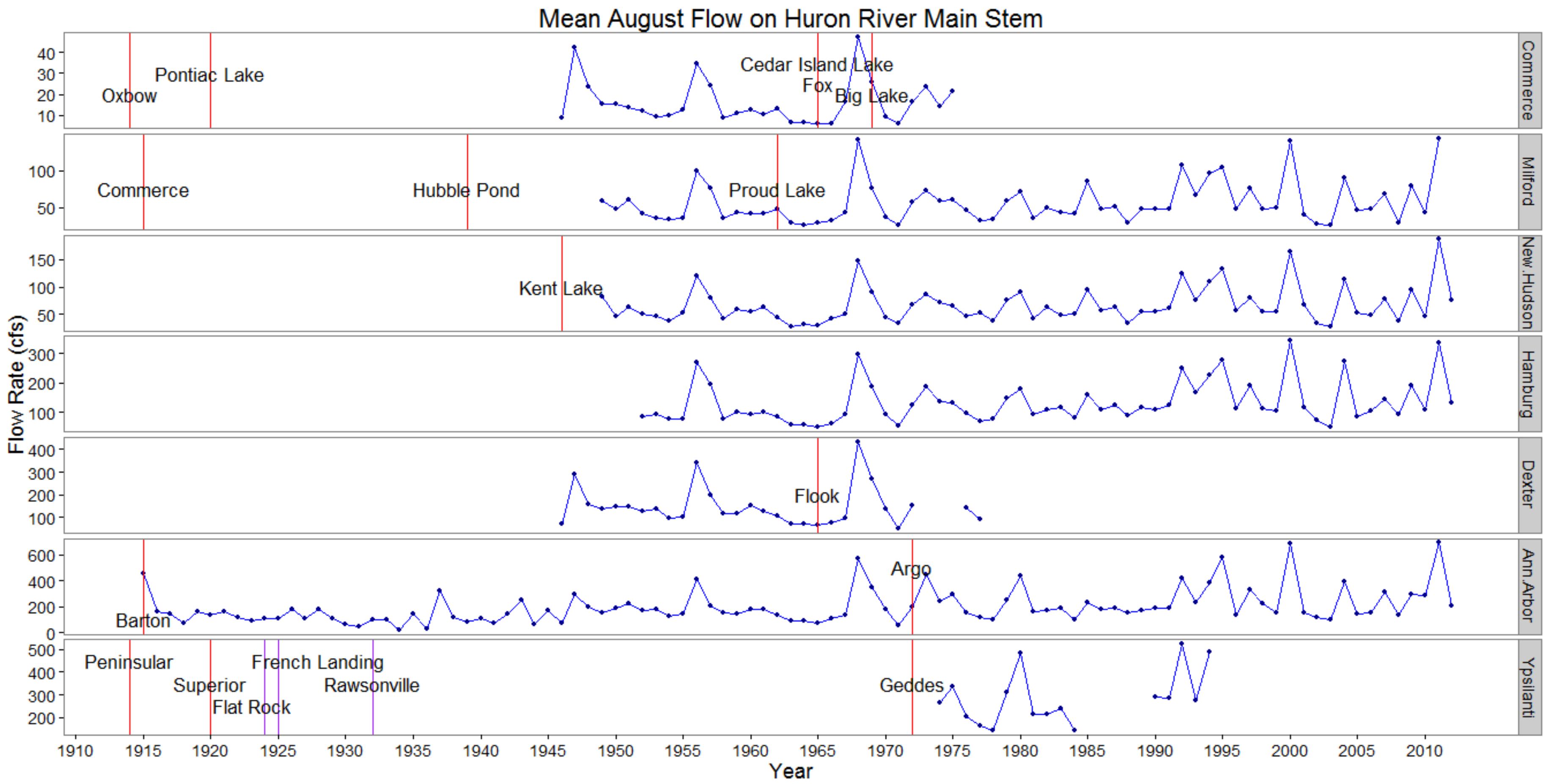


Figure 10 Mean September flow on the main stem of Huron River.

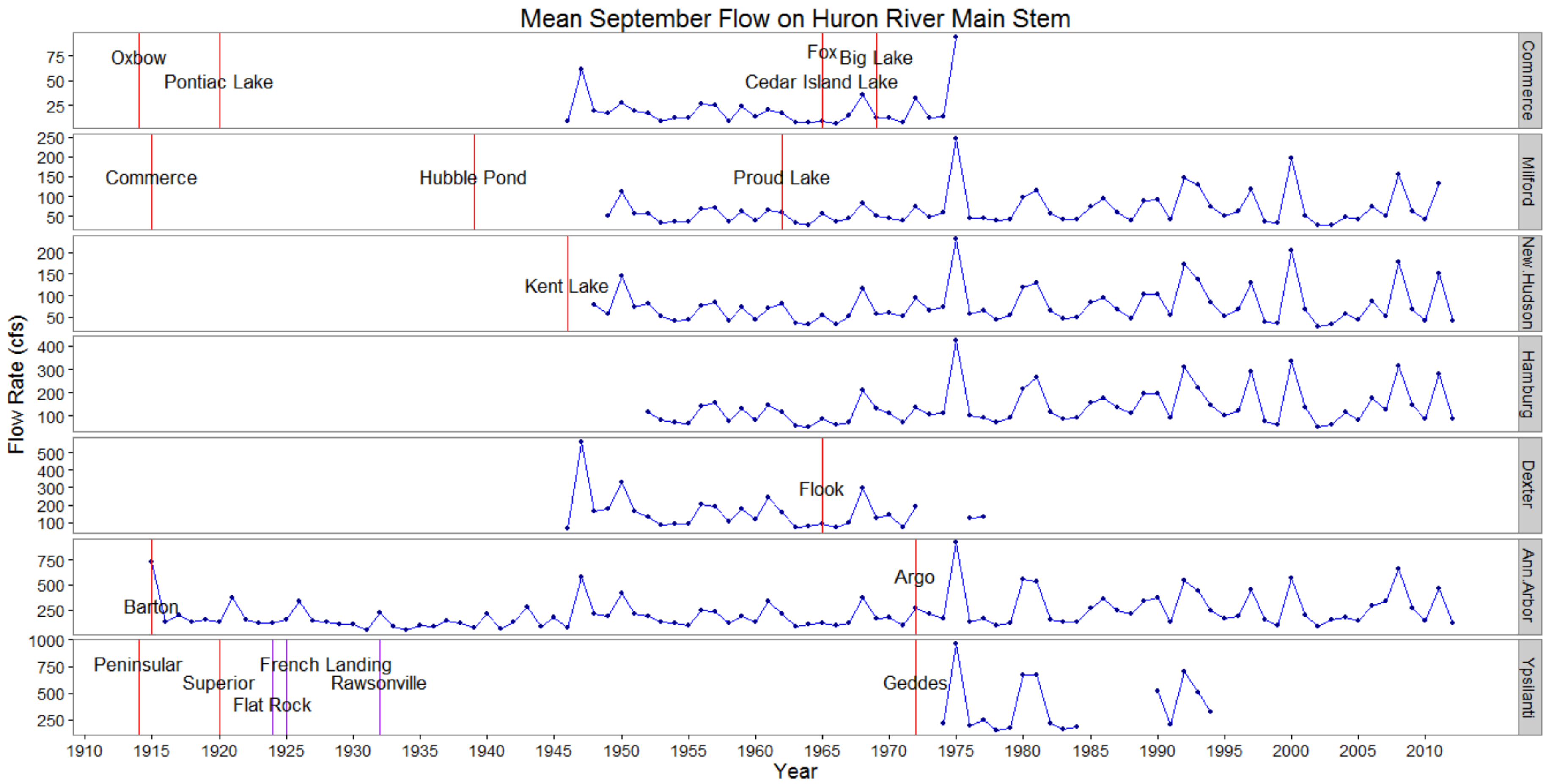


Figure 11 Mean October flow on the main stem of Huron River.

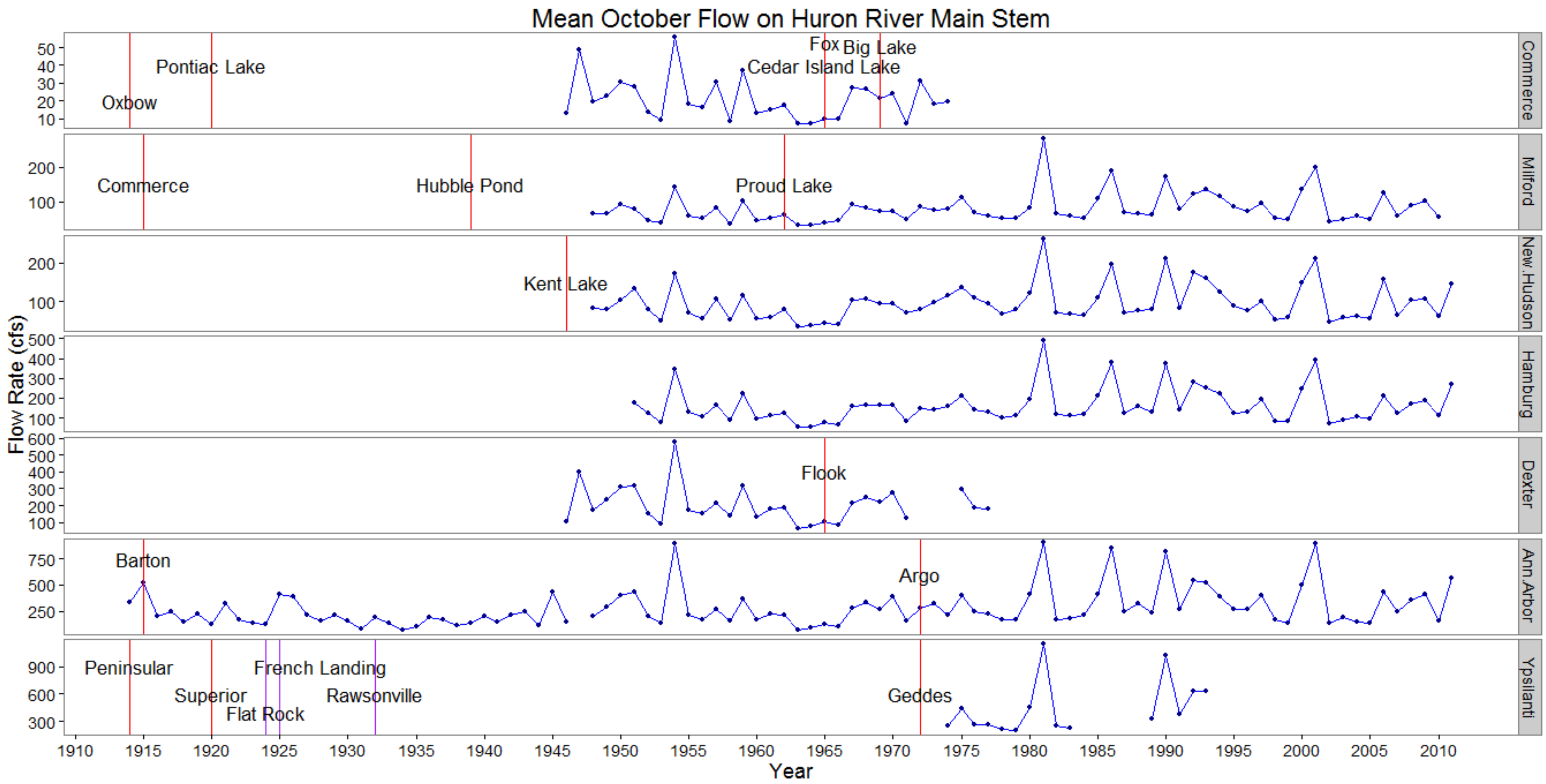


Figure 12 Mean November flow on the main stem of Huron River.

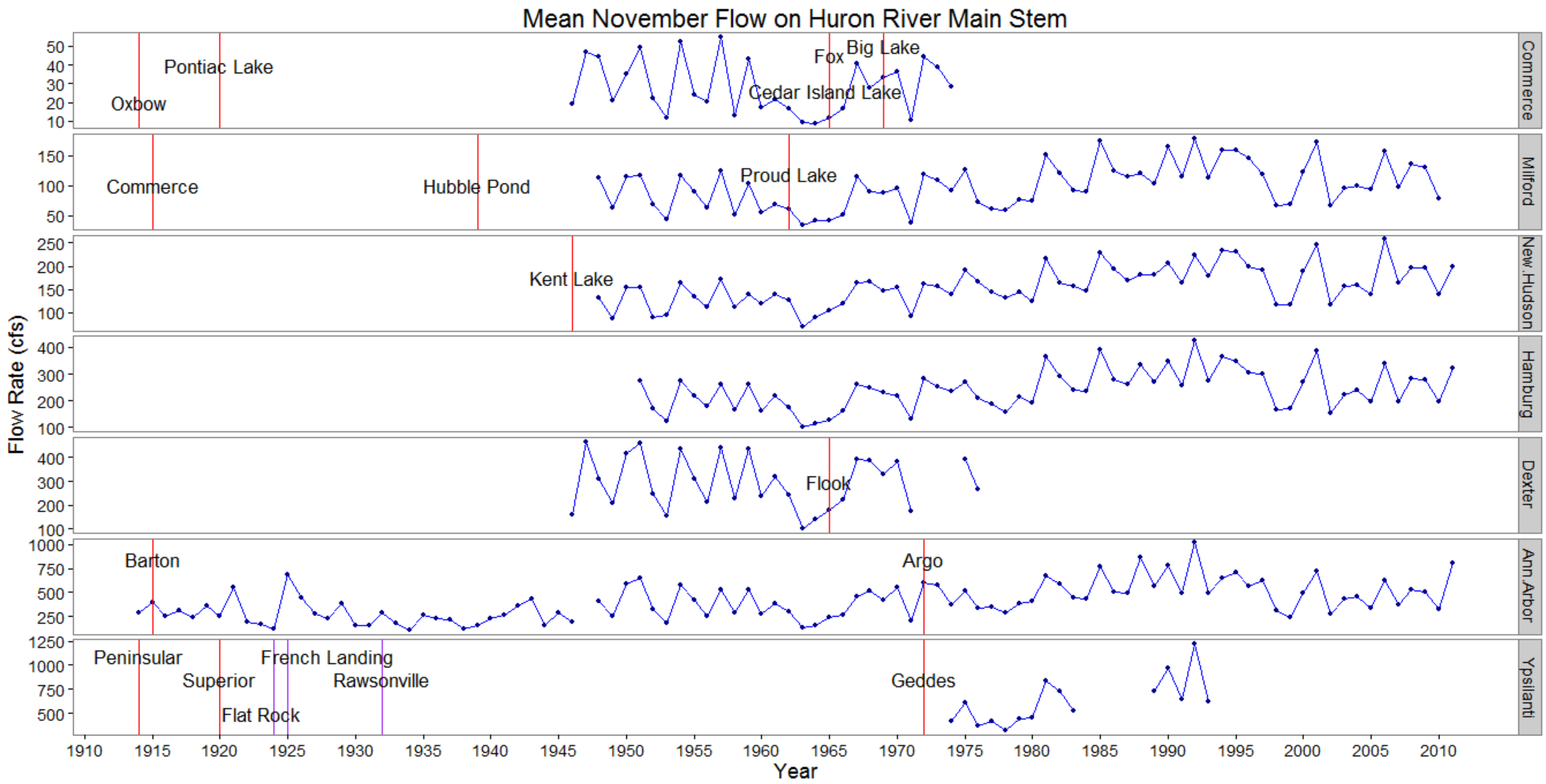


Figure 13 Mean December flow on the main stem of Huron River.

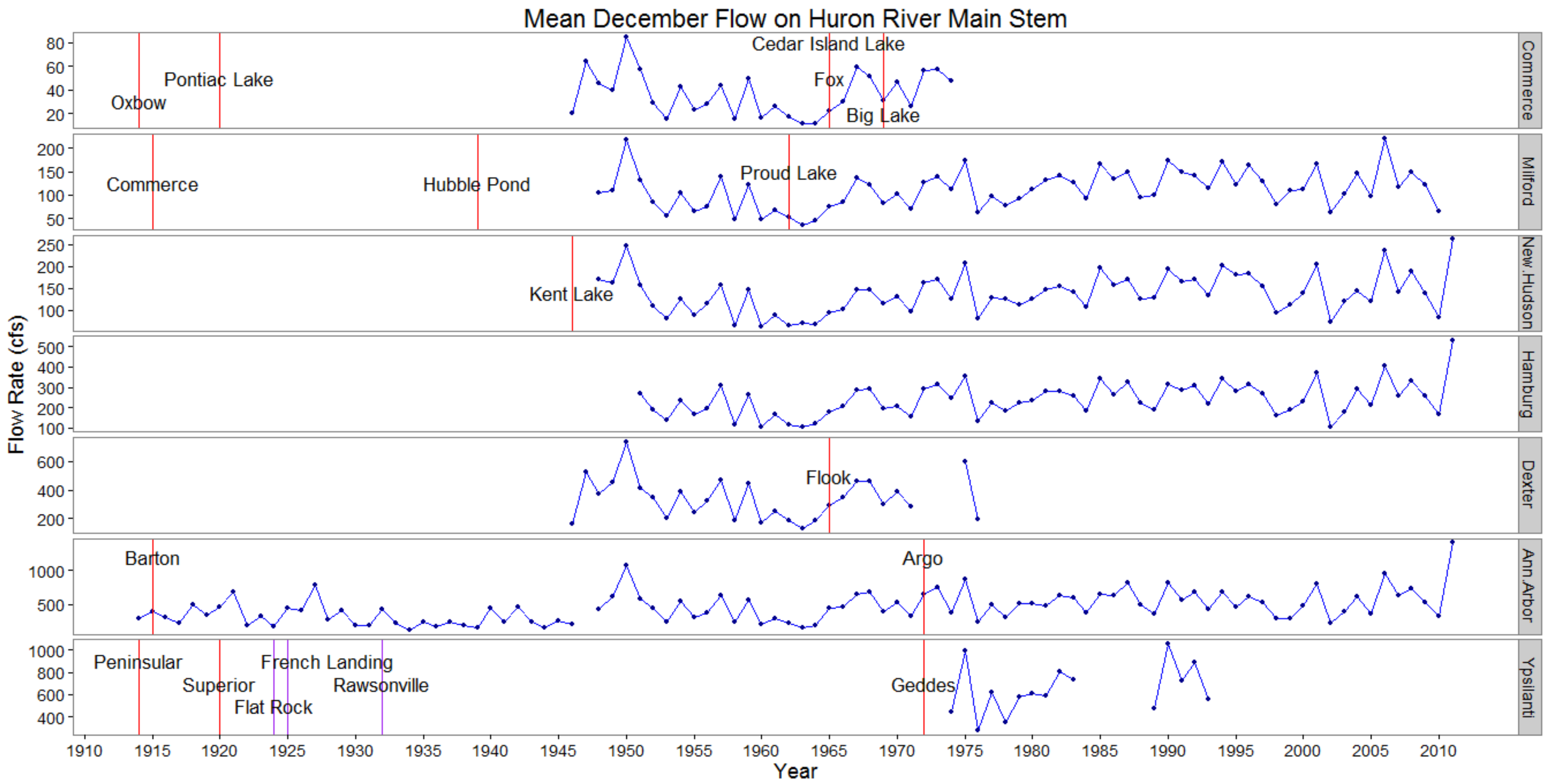


Figure 14 Annual mean flow of the gauge “Ann Arbor”.

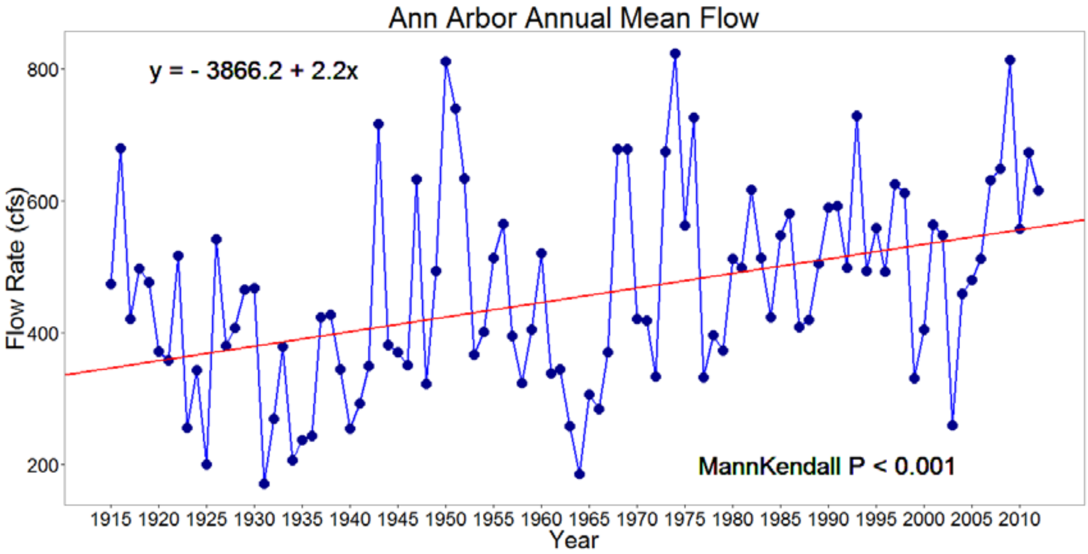


Figure 15 Repeated Mann-Kendall Analysis on the annual mean flow of the gauge “Ann Arbor”.

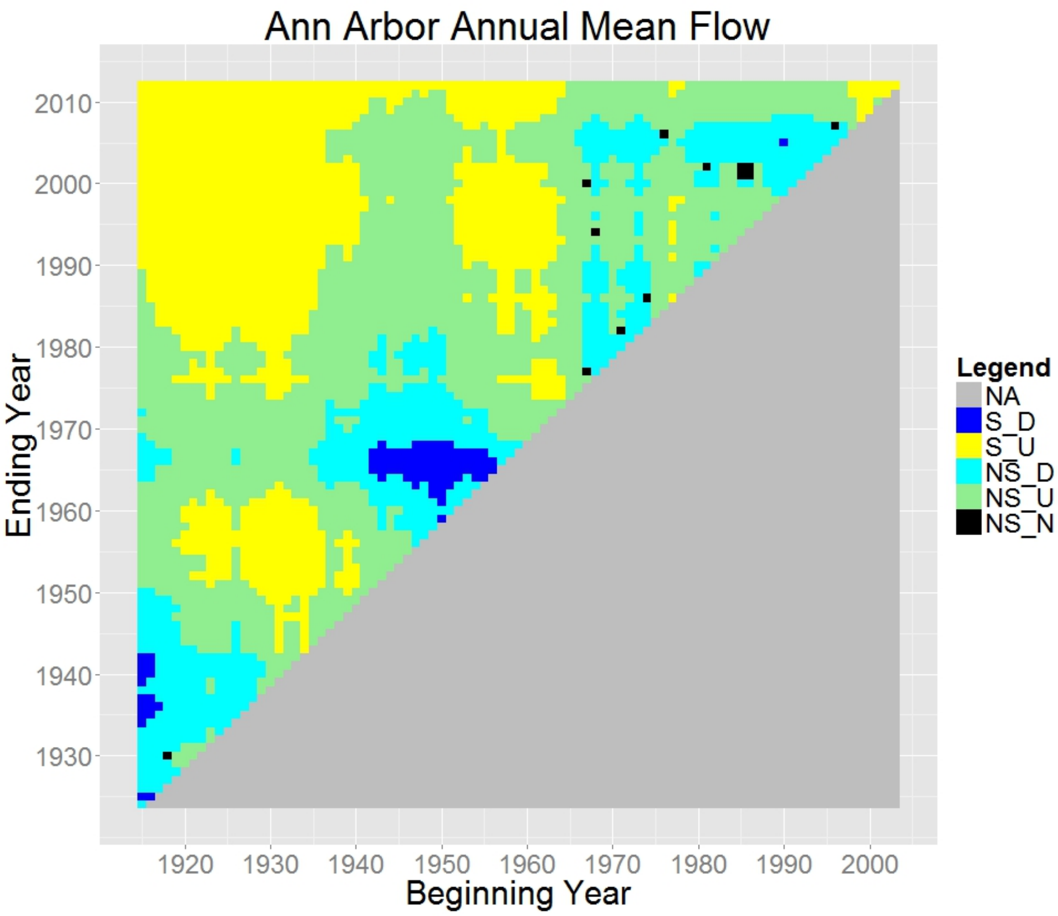


Figure 16 January mean flow of the gauge “Ann Arbor”.

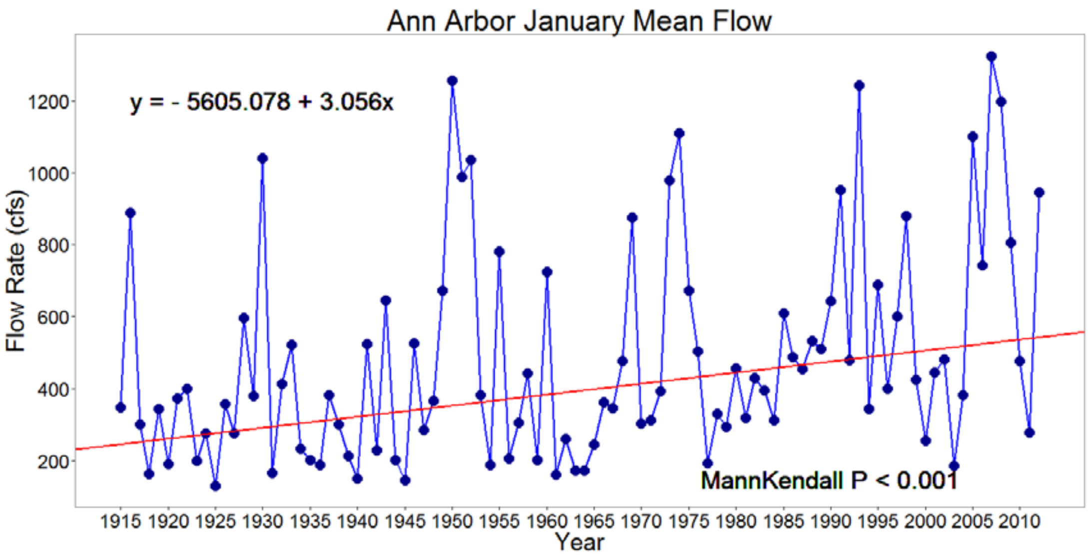


Figure 17 Repeated Mann-Kendall Analysis on the January mean flow of the gauge “Ann Arbor”.

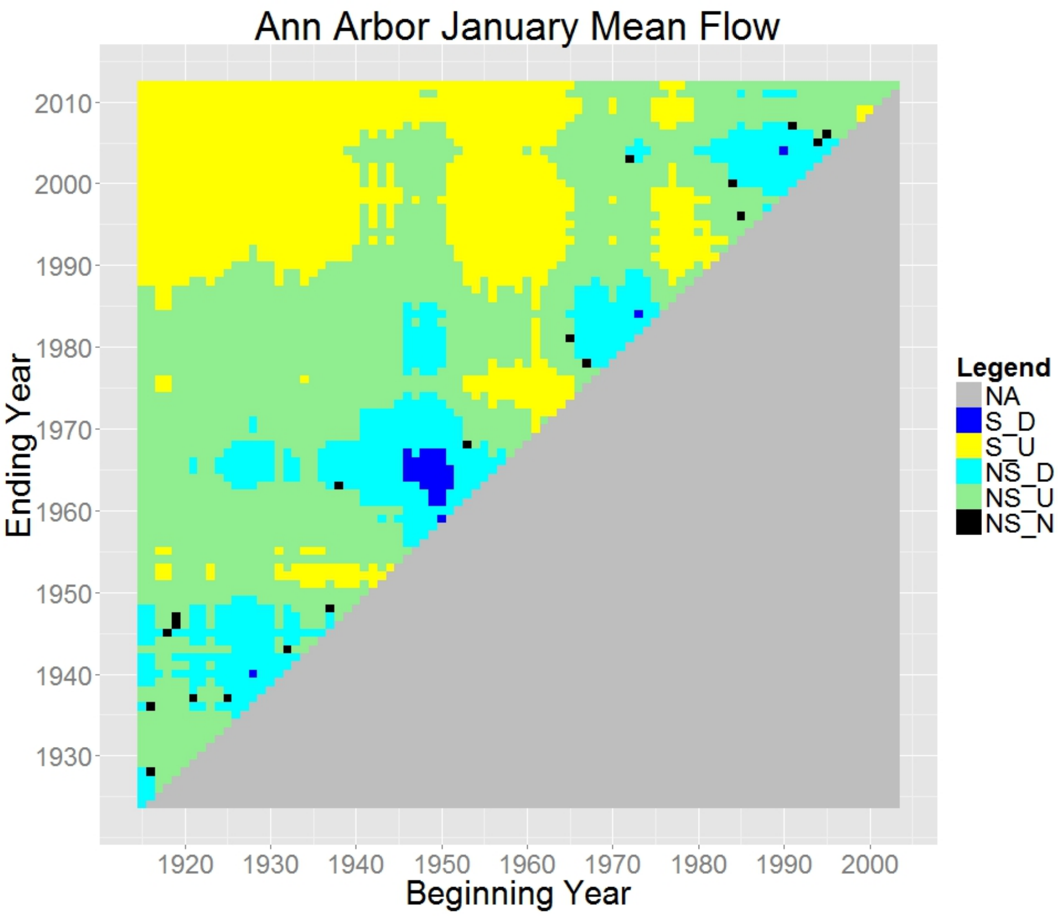


Figure 18 January median flow of the gauge "Ann Arbor".

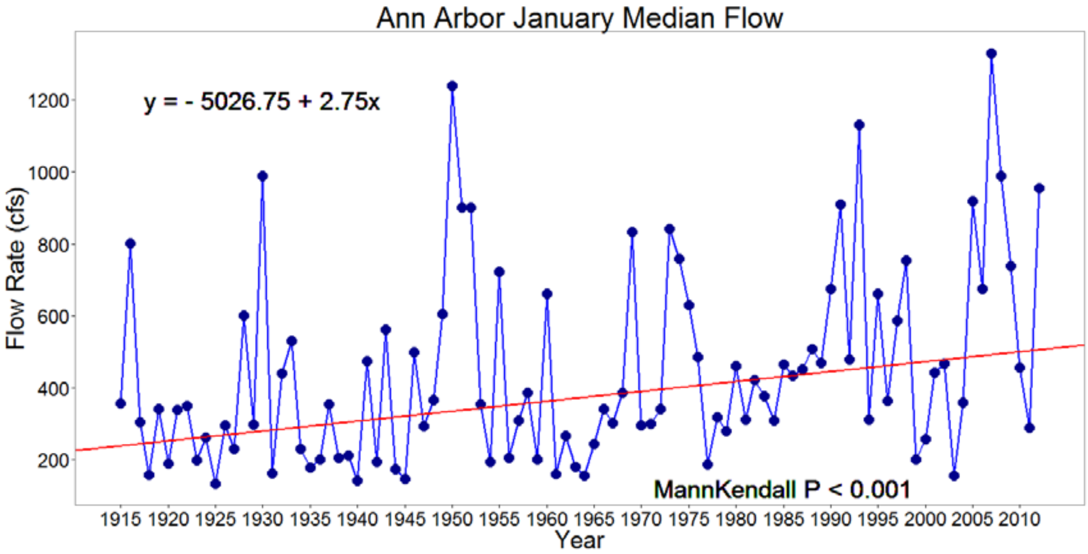


Figure 19 Repeated Mann-Kendall Analysis on the January median flow of the gauge "Ann Arbor".

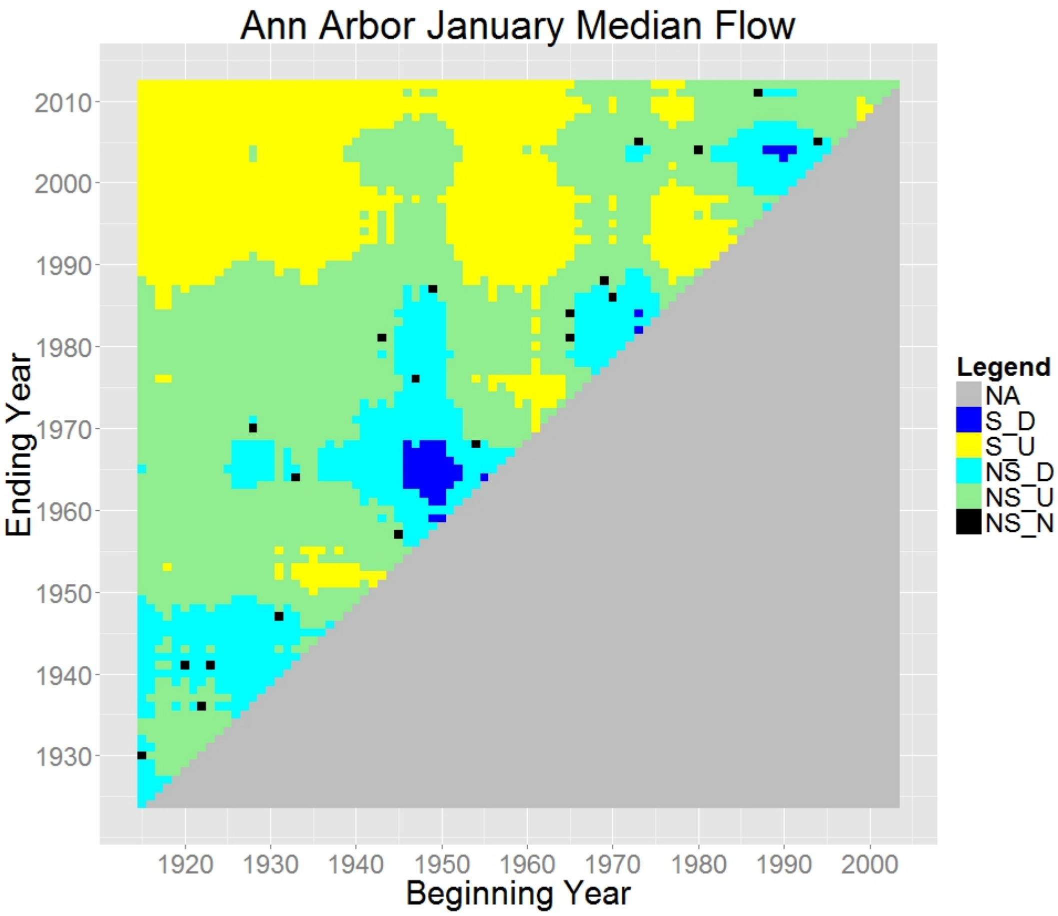


Figure 20 February mean flow of the gauge "Ann Arbor".

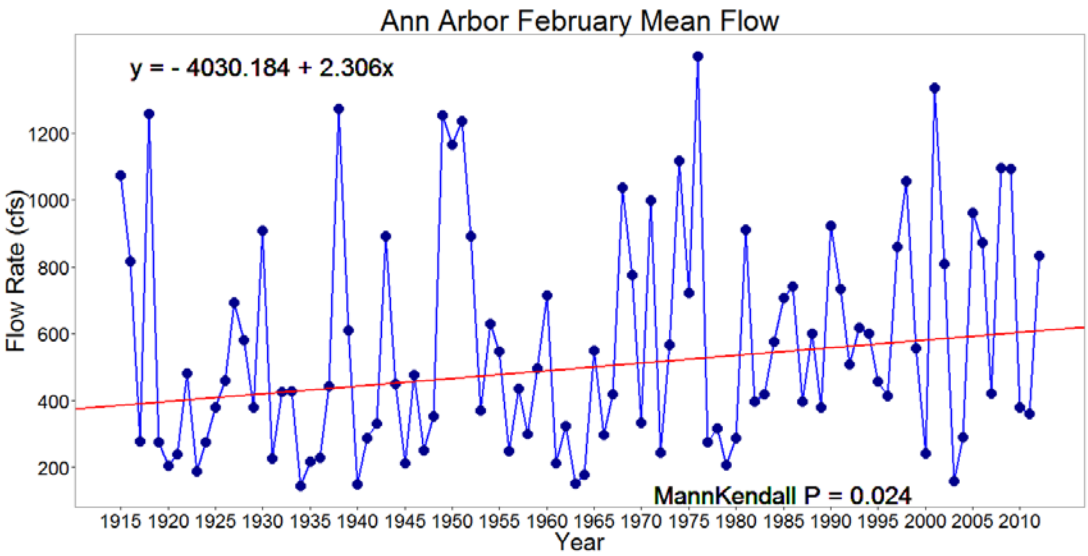


Figure 21 Repeated Mann-Kendall Analysis on the February mean flow of the gauge "Ann Arbor".

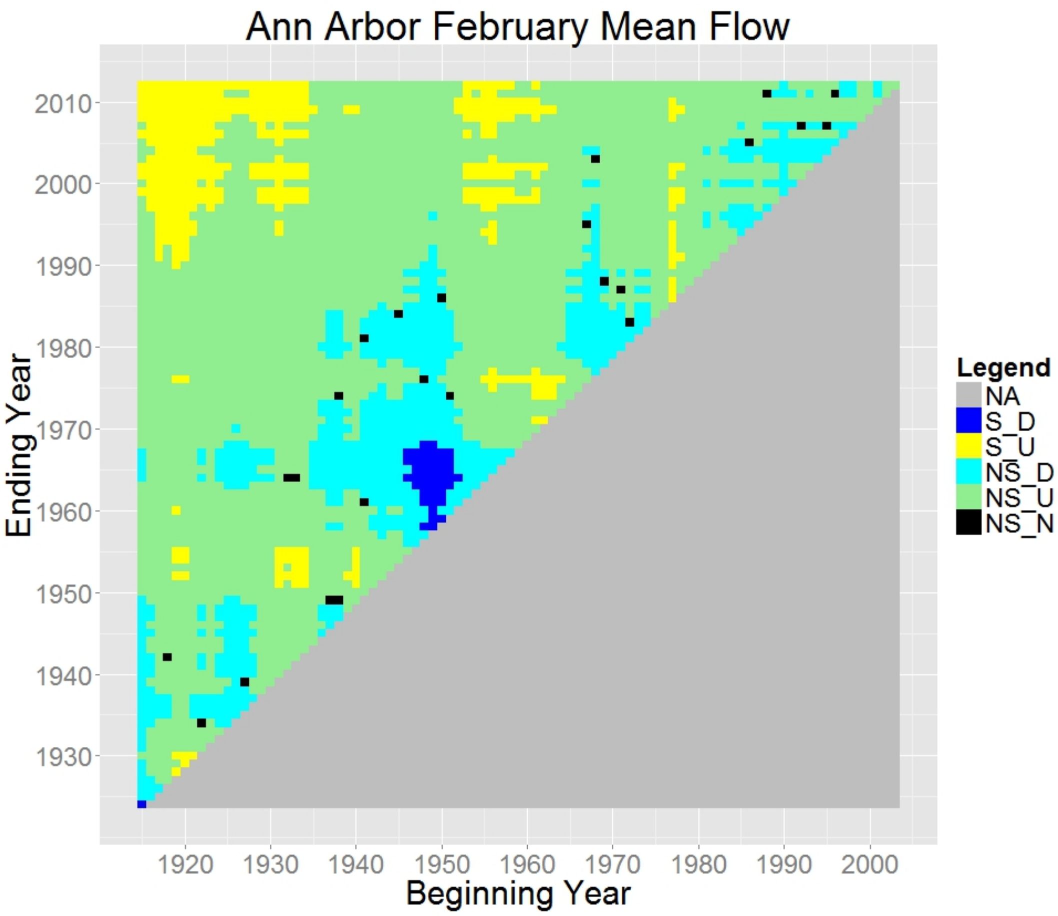


Figure 22 February median flow of the gauge "Ann Arbor".

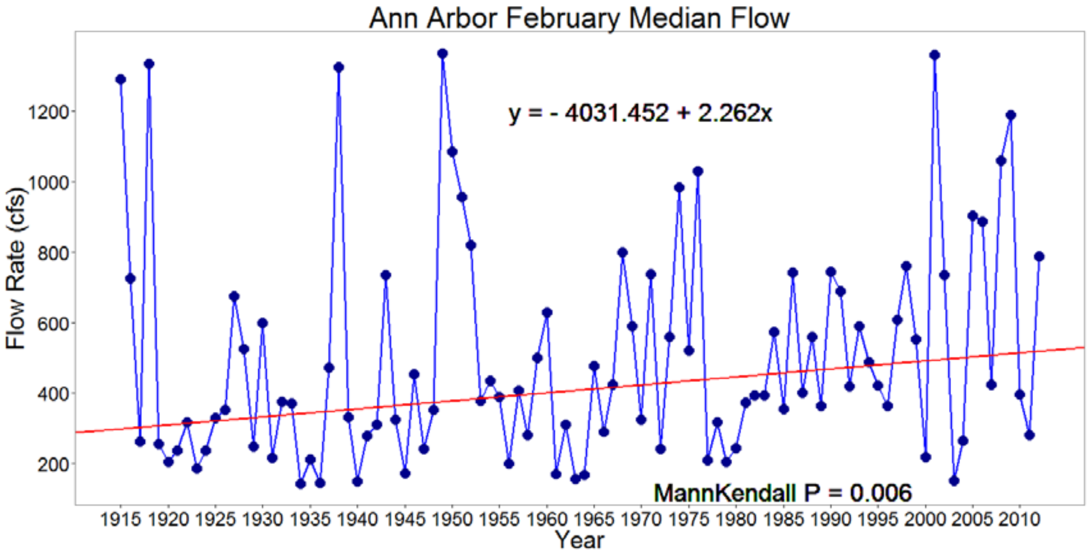


Figure 23 Repeated Mann-Kendall Analysis on the February median flow of the gauge "Ann Arbor".

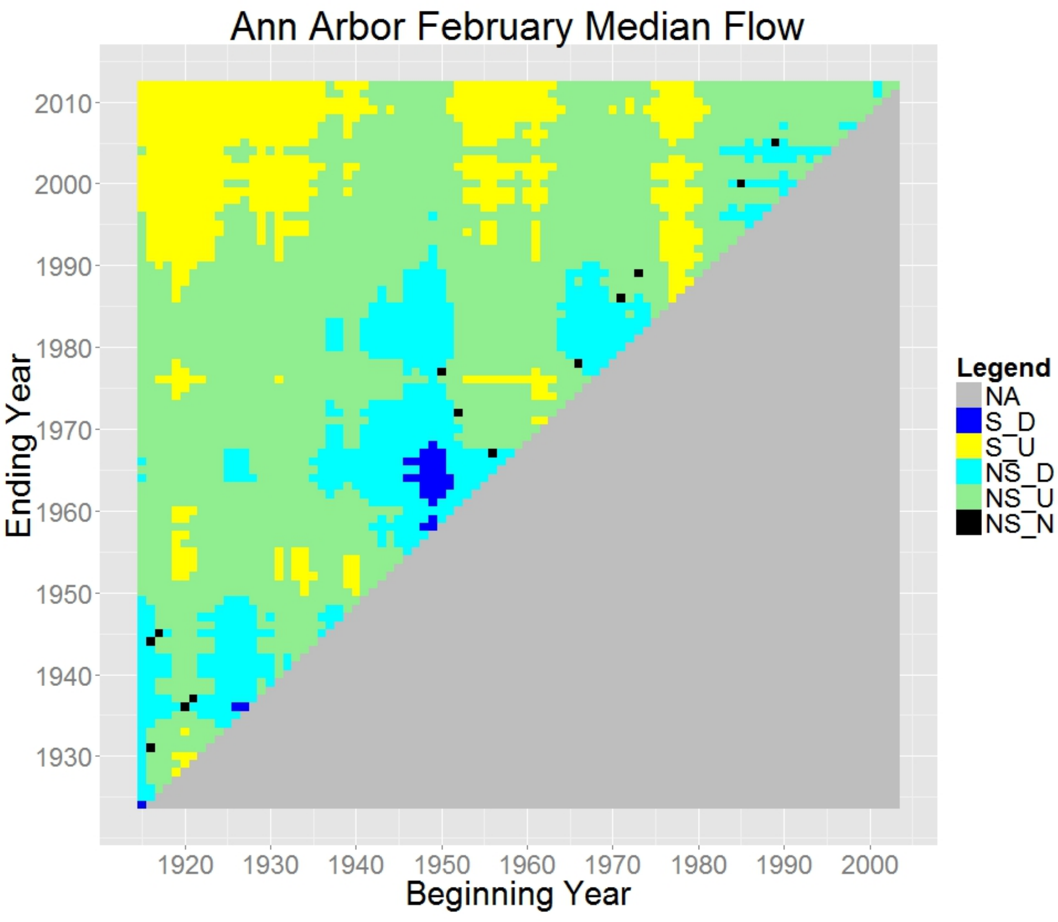


Figure 24 March mean flow of the gauge "Ann Arbor".

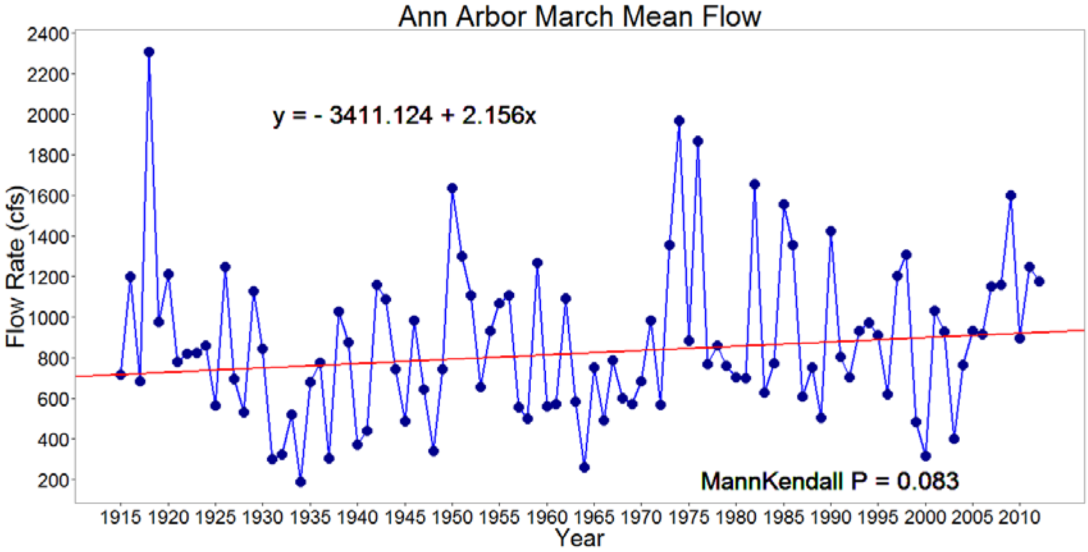


Figure 25 Repeated Mann-Kendall Analysis on the March mean flow of the gauge "Ann Arbor".

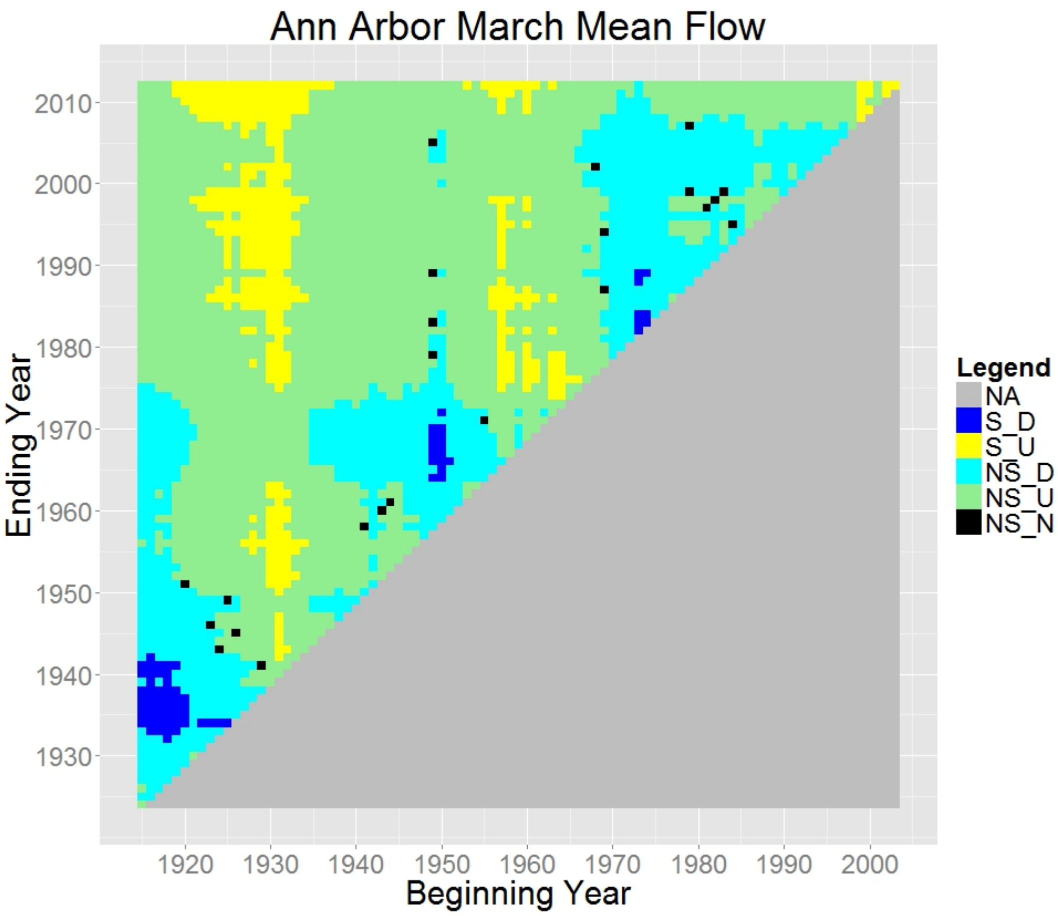


Figure 26 March median flow of the gauge “Ann Arbor”.

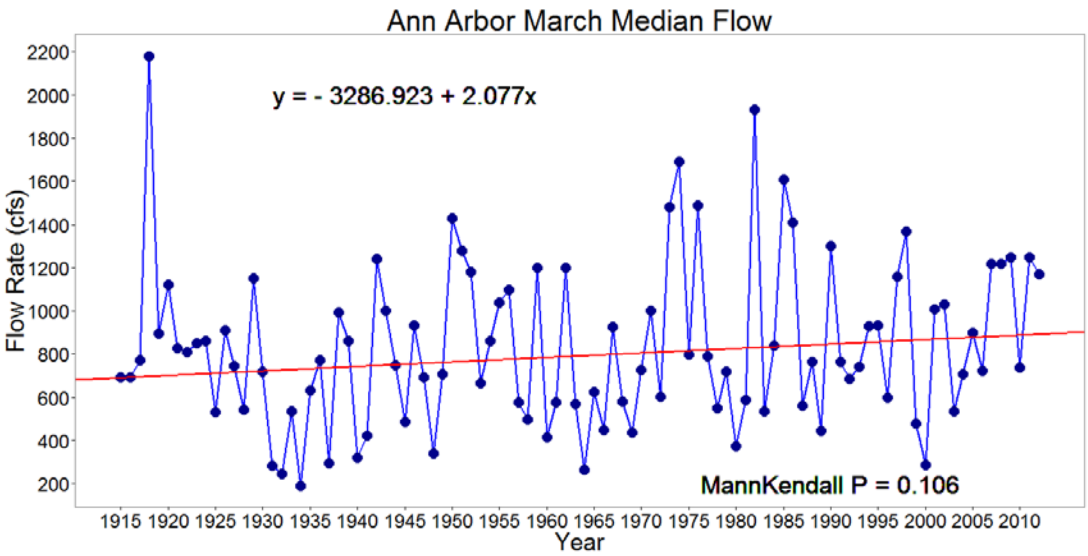


Figure 27 Repeated Mann-Kendall Analysis on the March median flow of the gauge “Ann Arbor”.

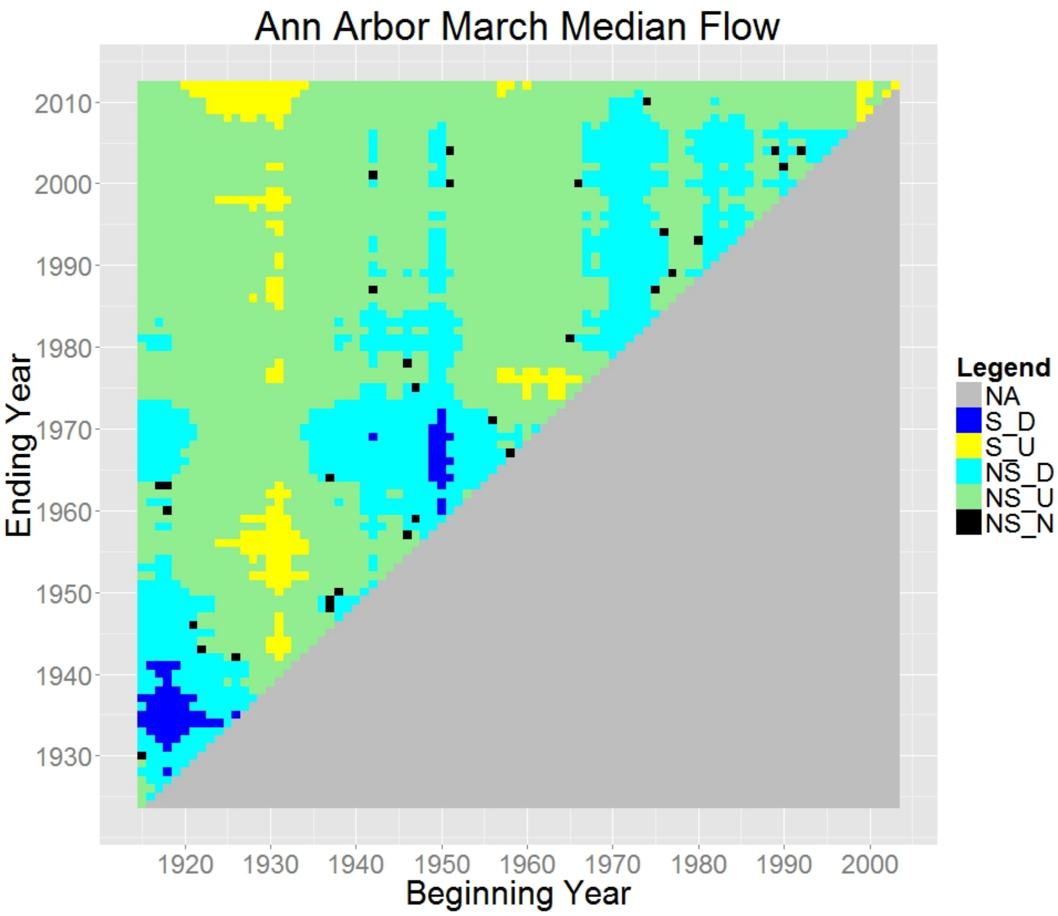


Figure 28 April mean flow of the gauge "Ann Arbor".

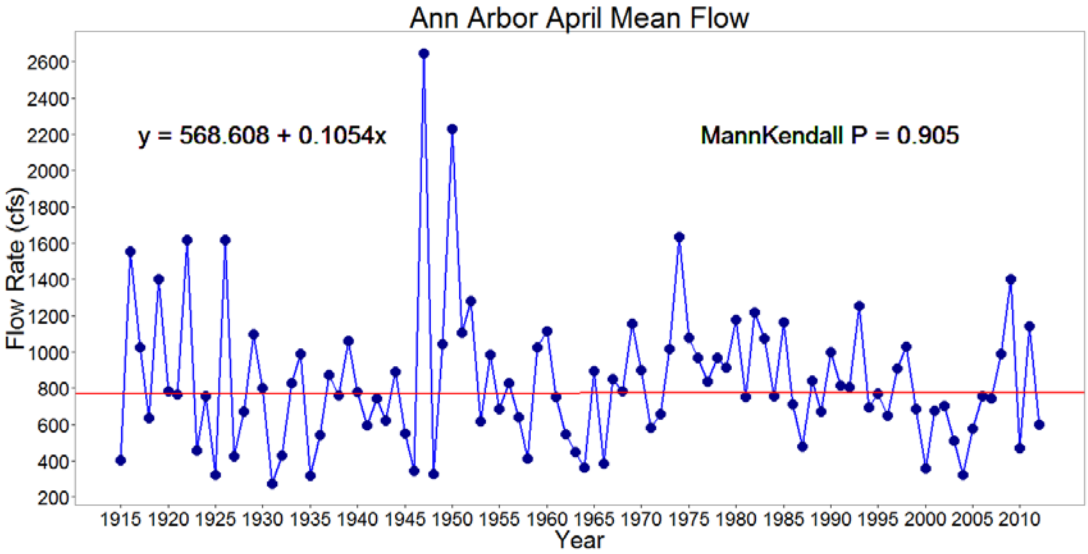


Figure 29 Repeated Mann-Kendall Analysis on the April mean flow of the gauge "Ann Arbor".

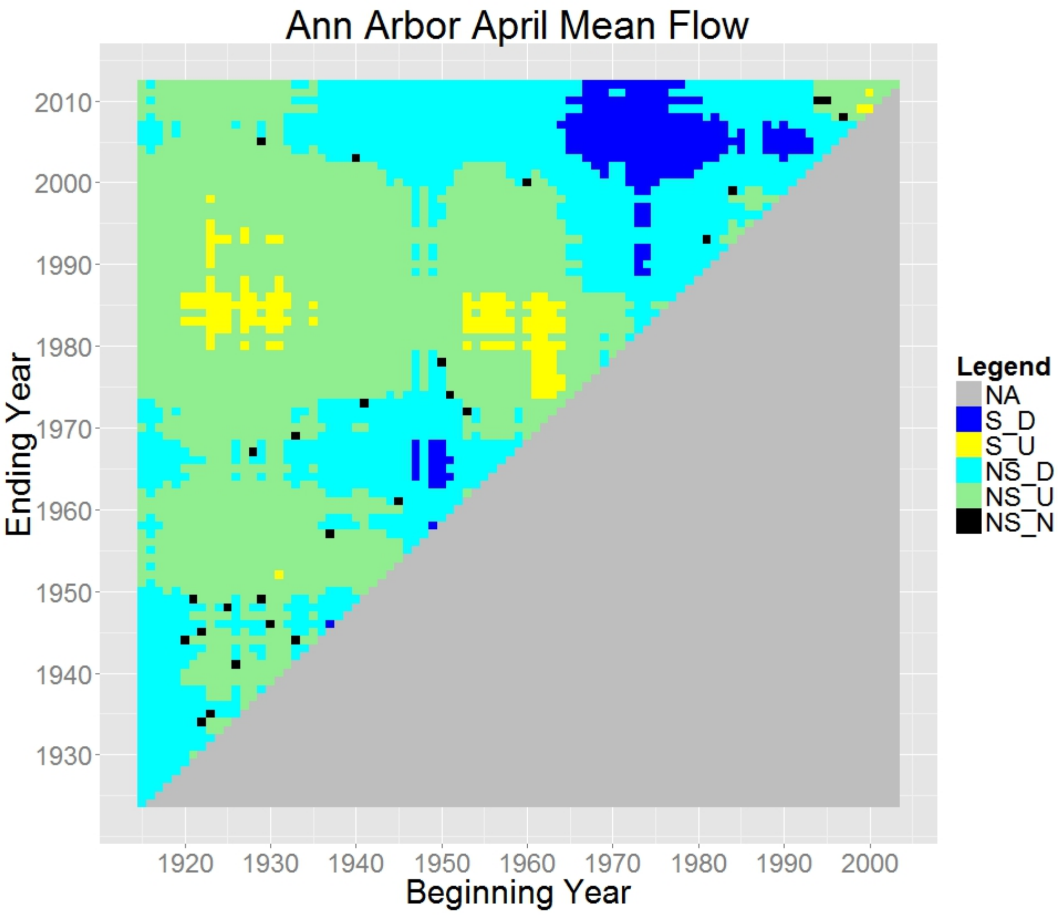


Figure 30 April median flow of the gauge "Ann Arbor".

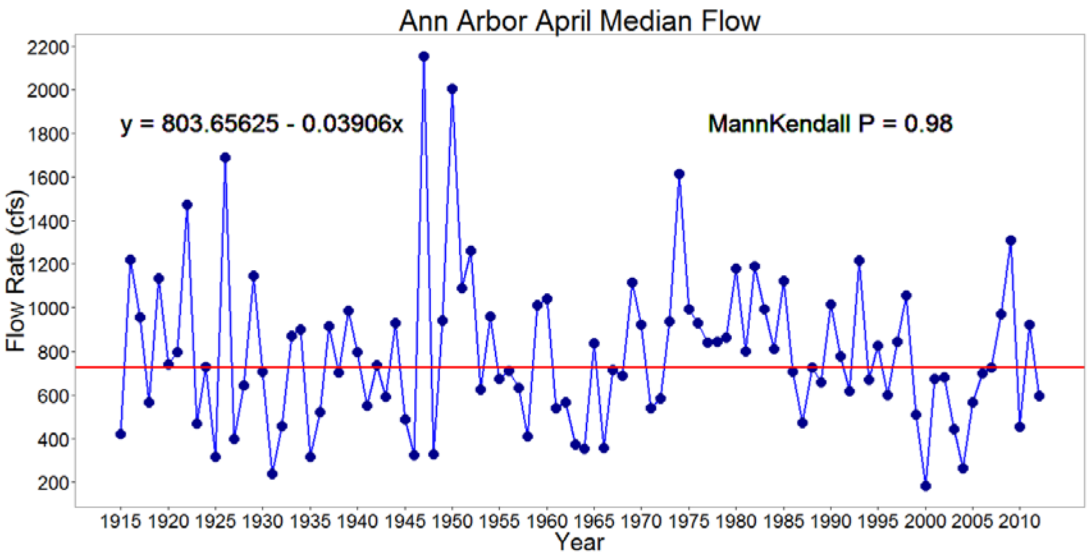


Figure 31 Repeated Mann-Kendall Analysis on the April median flow of the gauge "Ann Arbor".

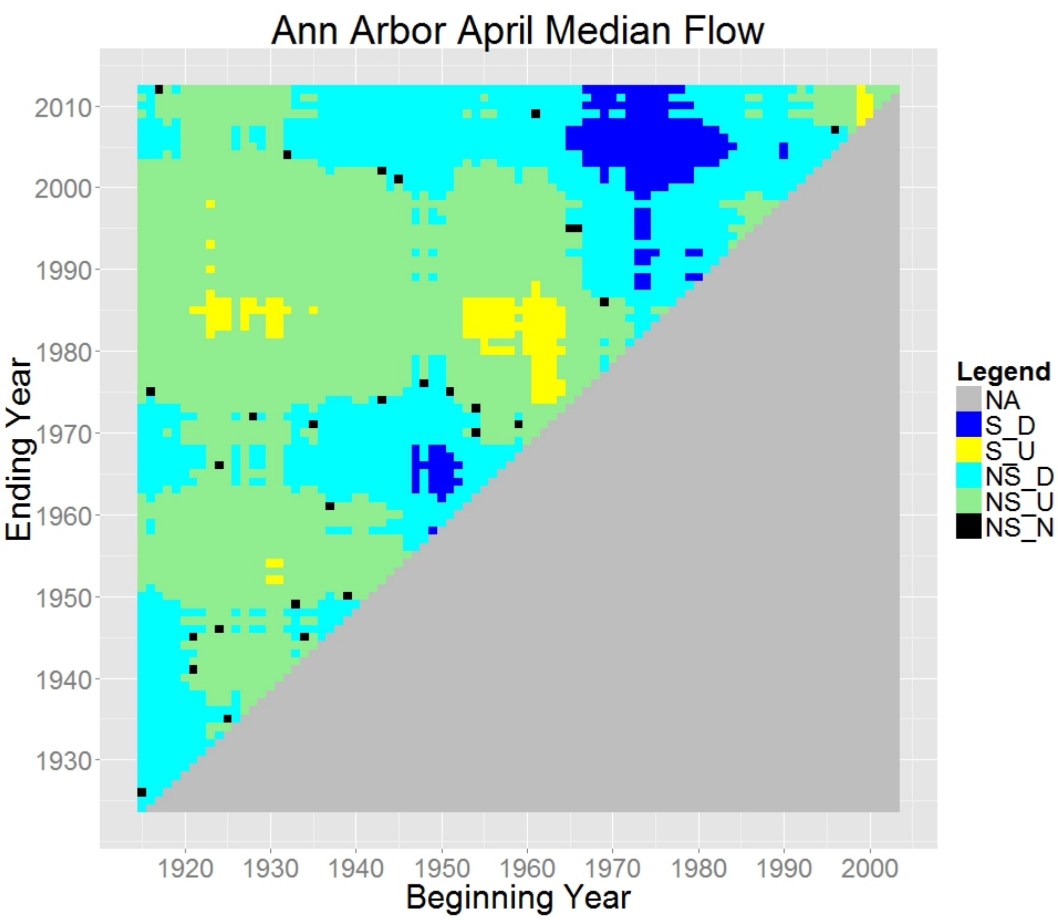


Figure 32 May mean flow of the gauge "Ann Arbor".

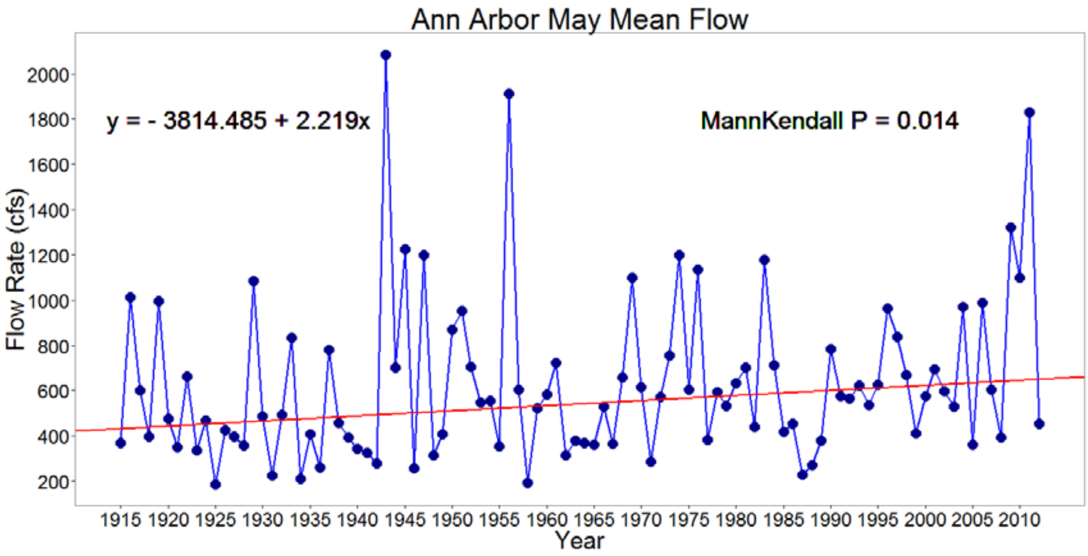


Figure 33 Repeated Mann-Kendall Analysis on the May mean flow of the gauge "Ann Arbor".

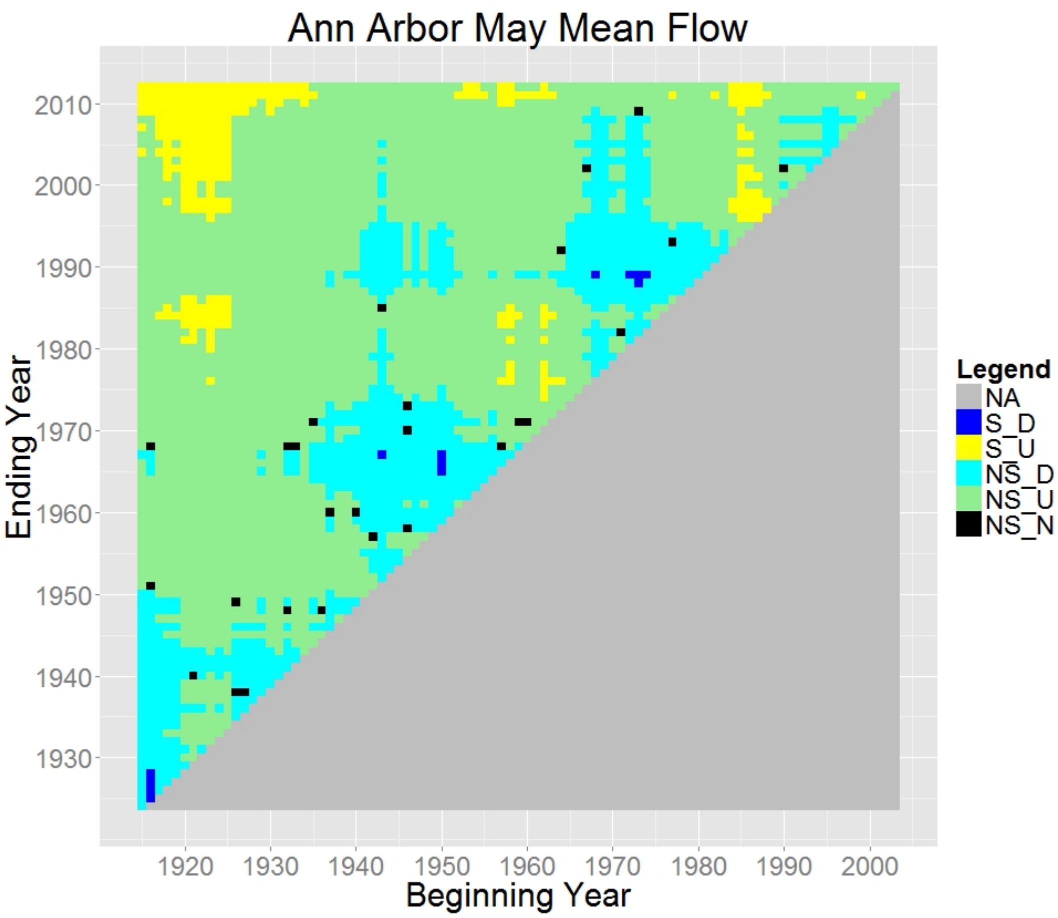


Figure 34 May median flow of the gauge “Ann Arbor”.

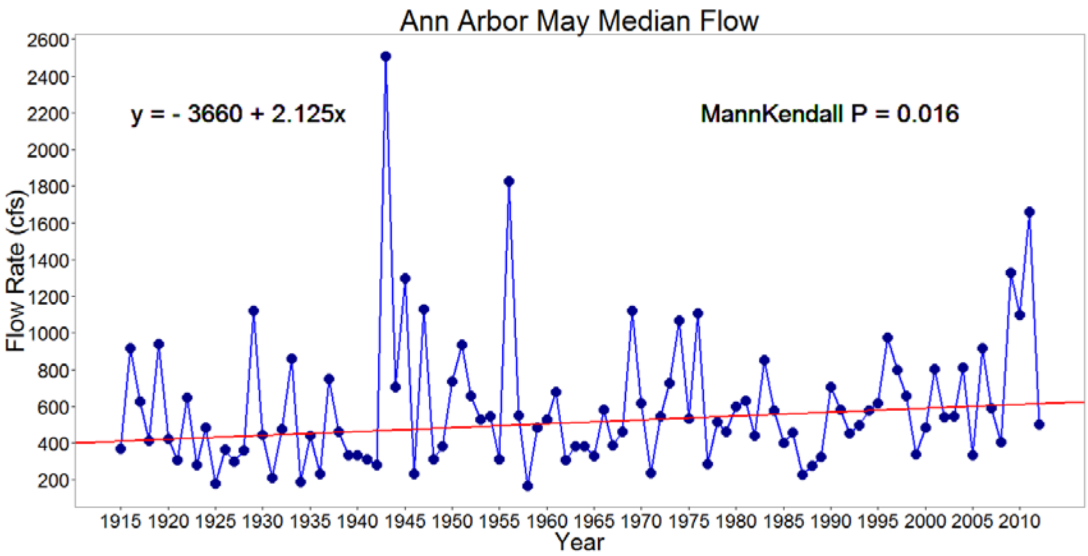


Figure 35 Repeated Mann-Kendall Analysis on the May median flow of the gauge “Ann Arbor”.

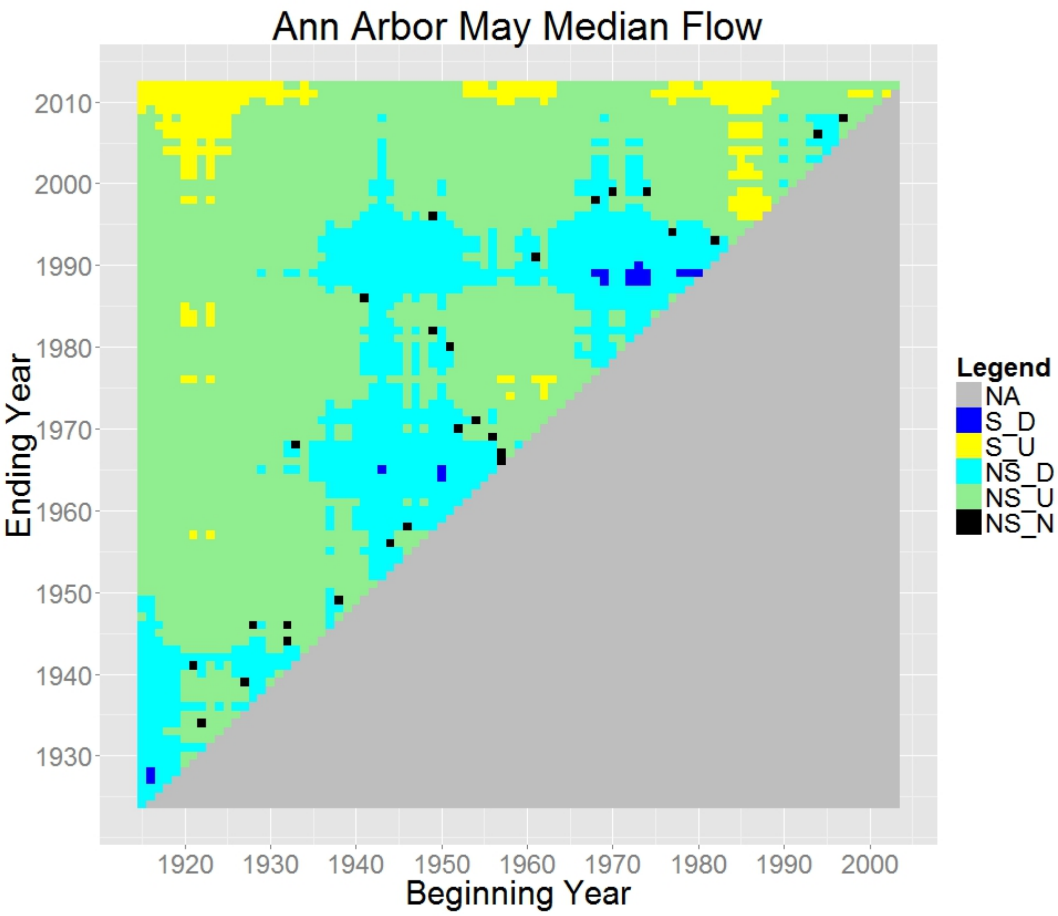


Figure 36 June mean flow of the gauge “Ann Arbor”.

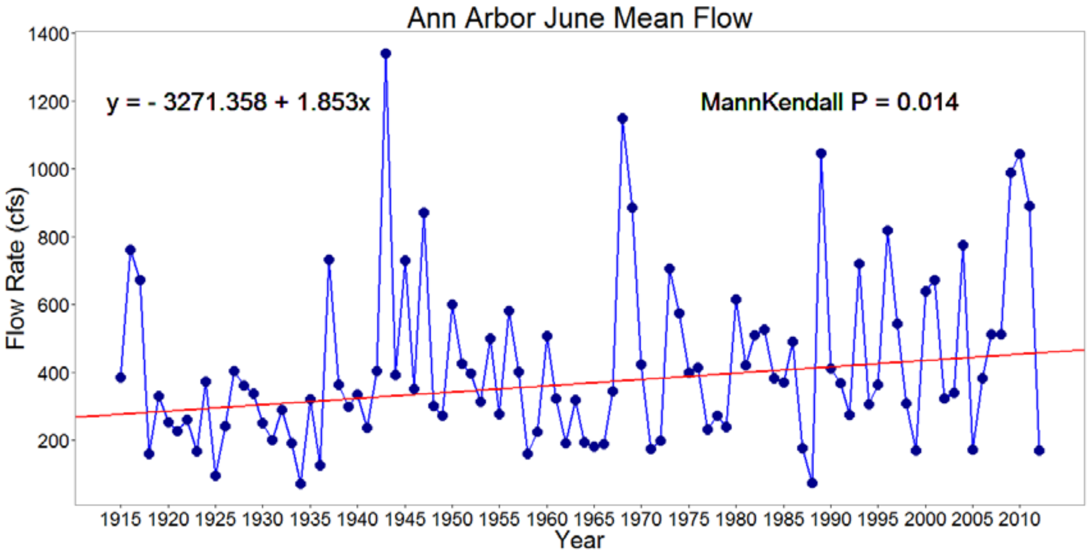


Figure 37 Repeated Mann-Kendall Analysis on the June mean flow of the gauge “Ann Arbor”.

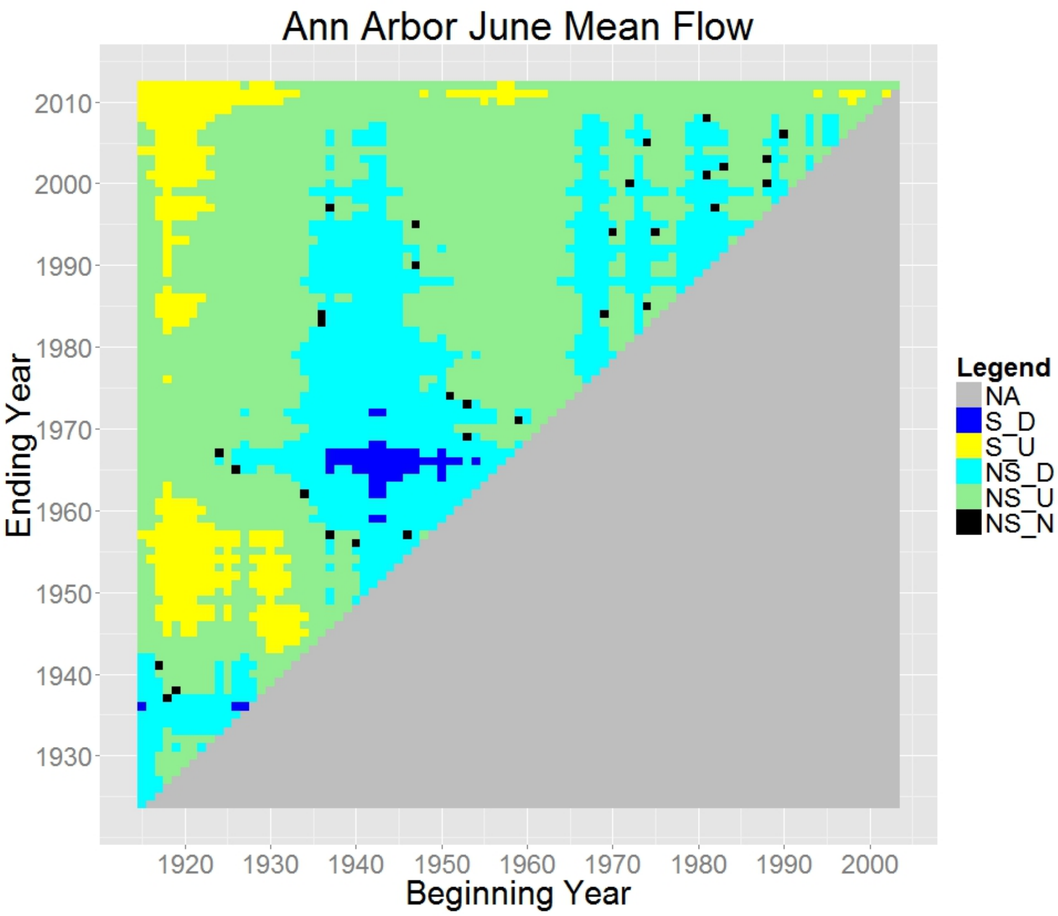


Figure 38 June median flow of the gauge “Ann Arbor”.

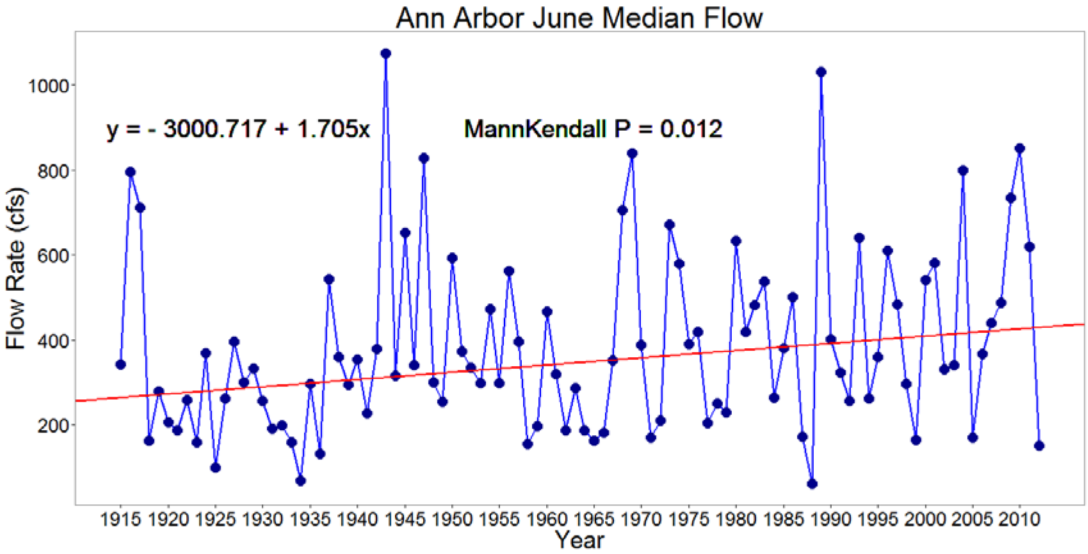


Figure 39 Repeated Mann-Kendall Analysis on the June median flow of the gauge “Ann Arbor”.

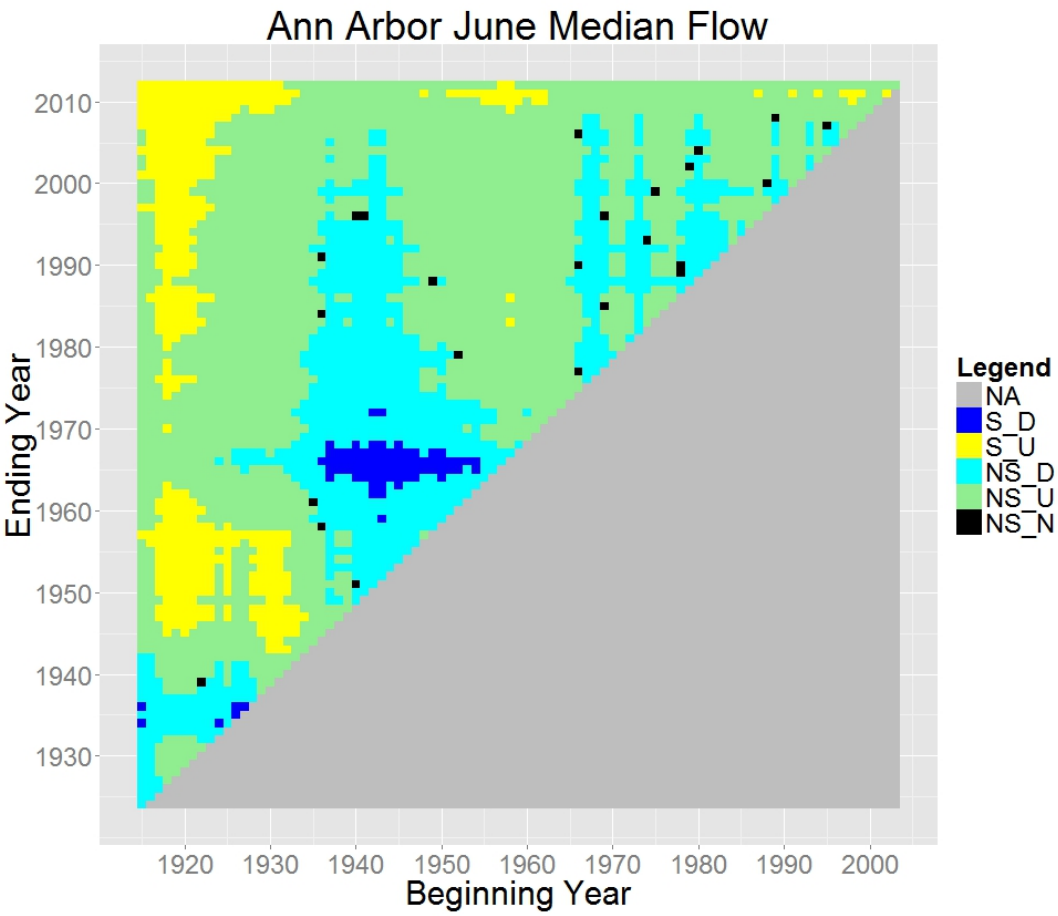


Figure 40 July mean flow of the gauge "Ann Arbor".

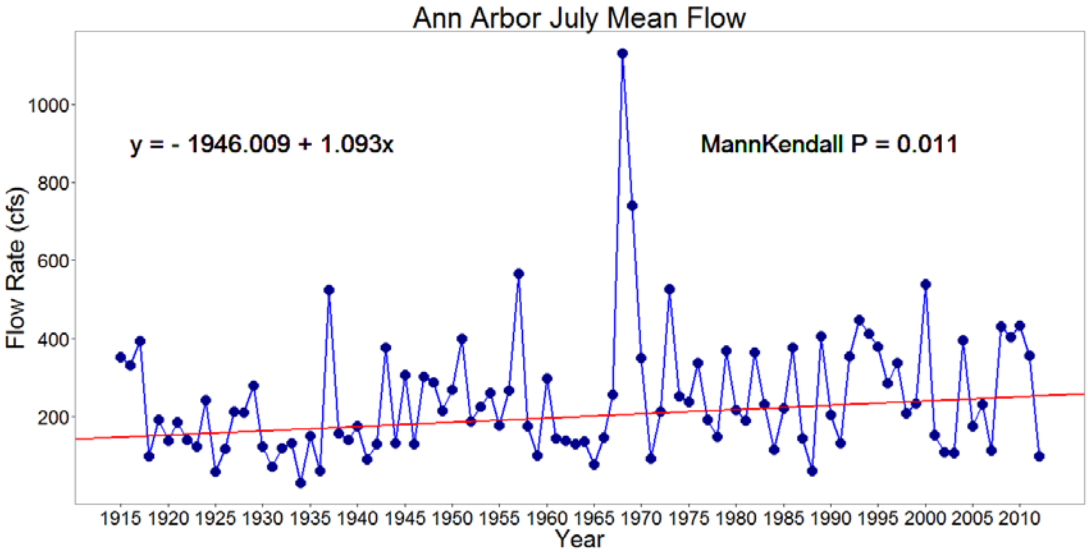


Figure 41 Repeated Mann-Kendall Analysis on the July mean flow of the gauge "Ann Arbor".

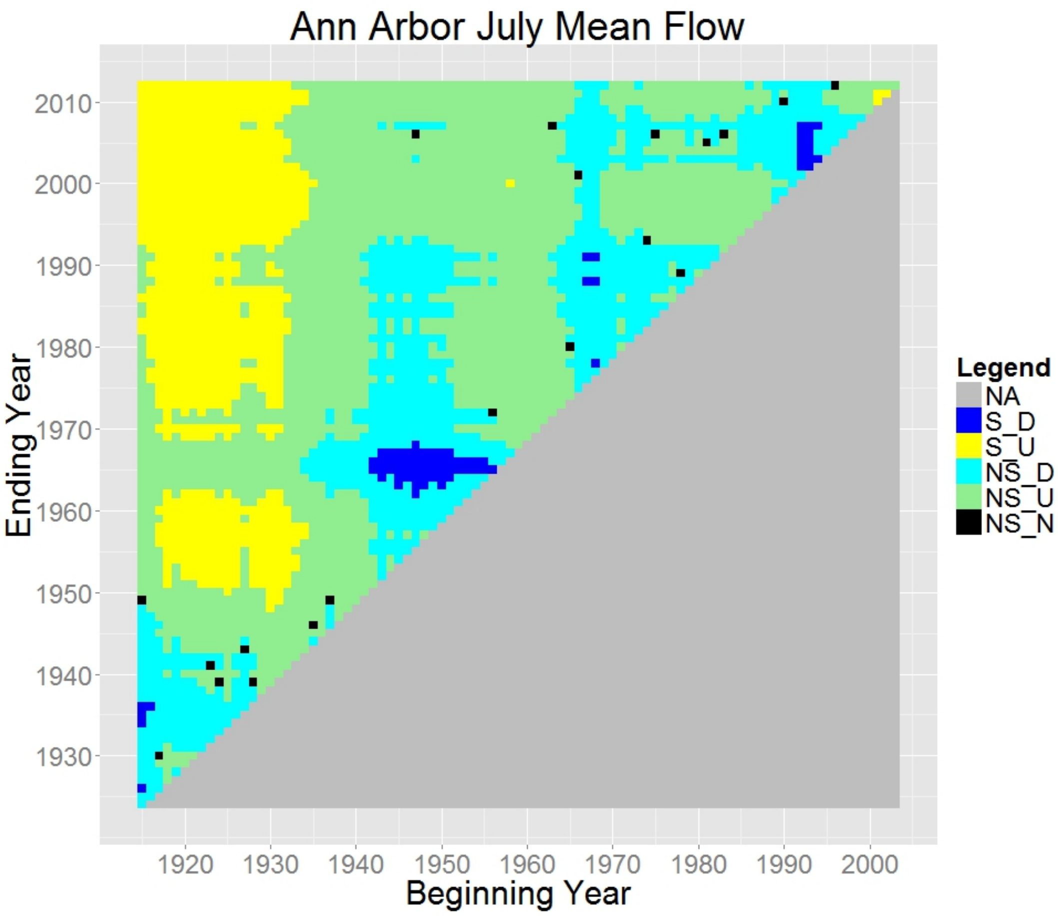


Figure 42 July median flow of the gauge "Ann Arbor".

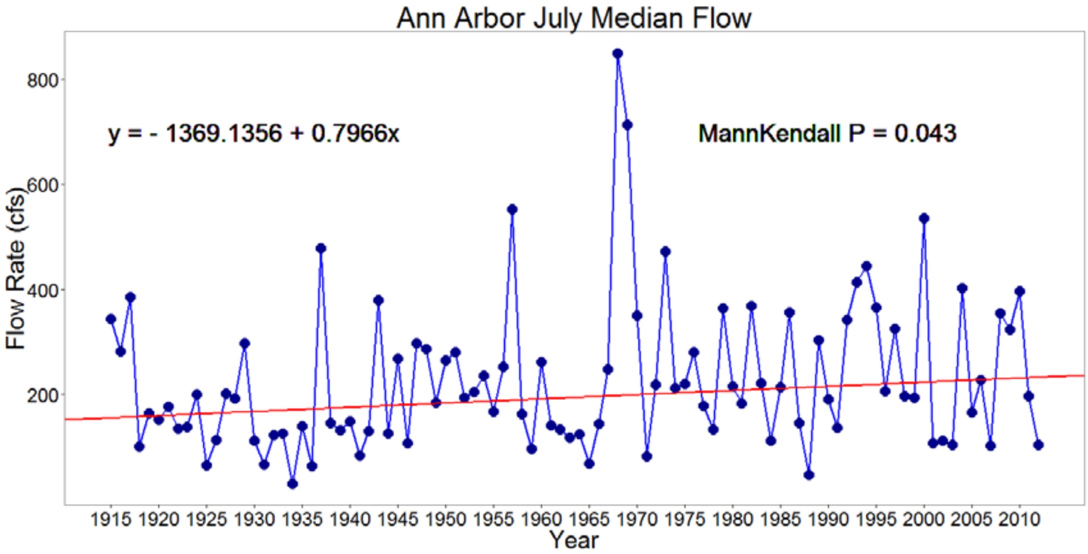


Figure 43 Repeated Mann-Kendall Analysis on the July median flow of the gauge "Ann Arbor".

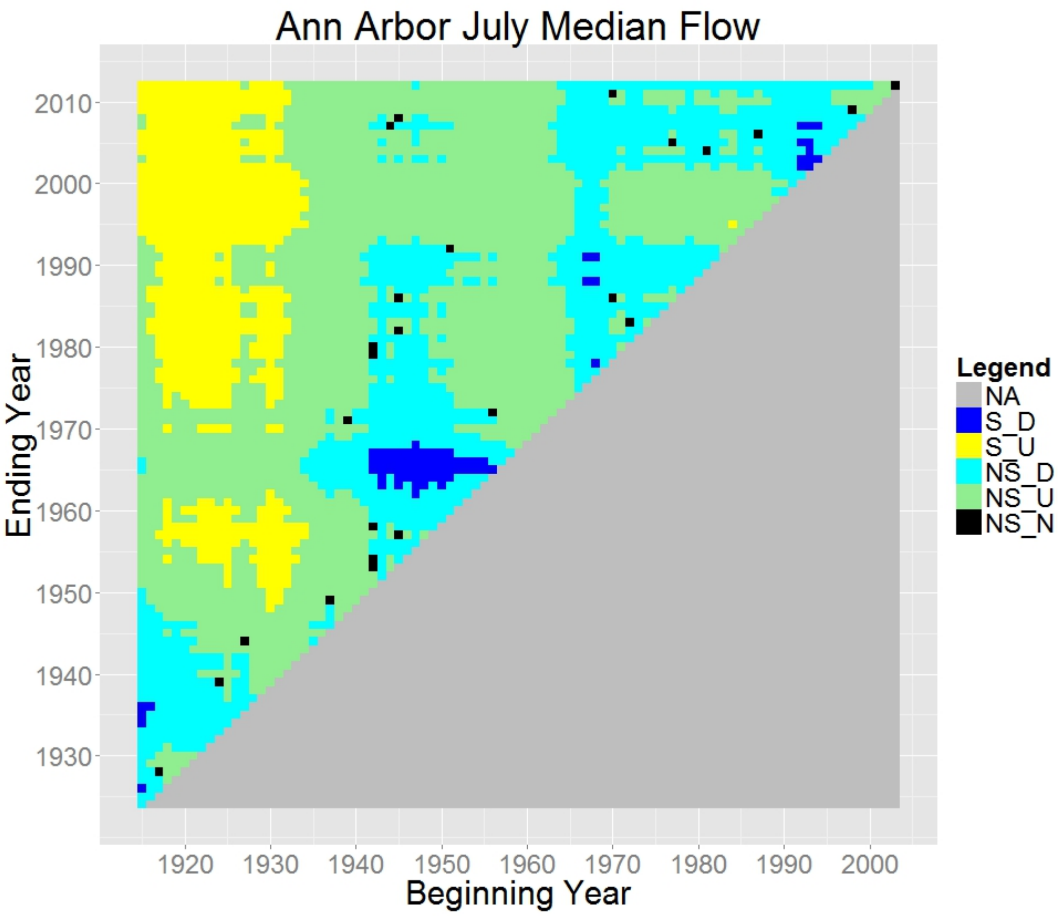


Figure 44 August mean flow of the gauge “Ann Arbor”.

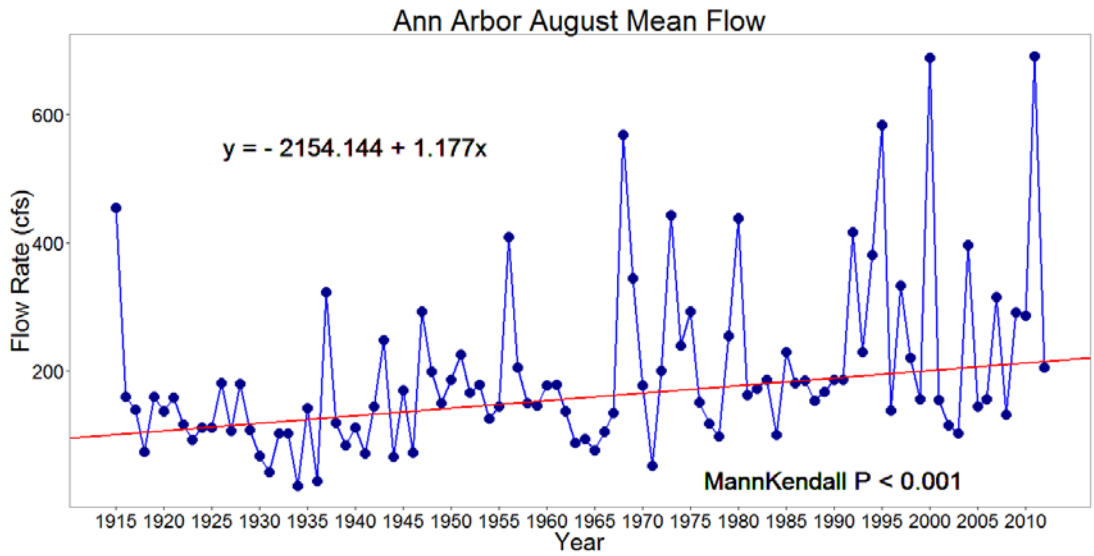


Figure 45 Repeated Mann-Kendall Analysis on the August mean flow of the gauge “Ann Arbor”.

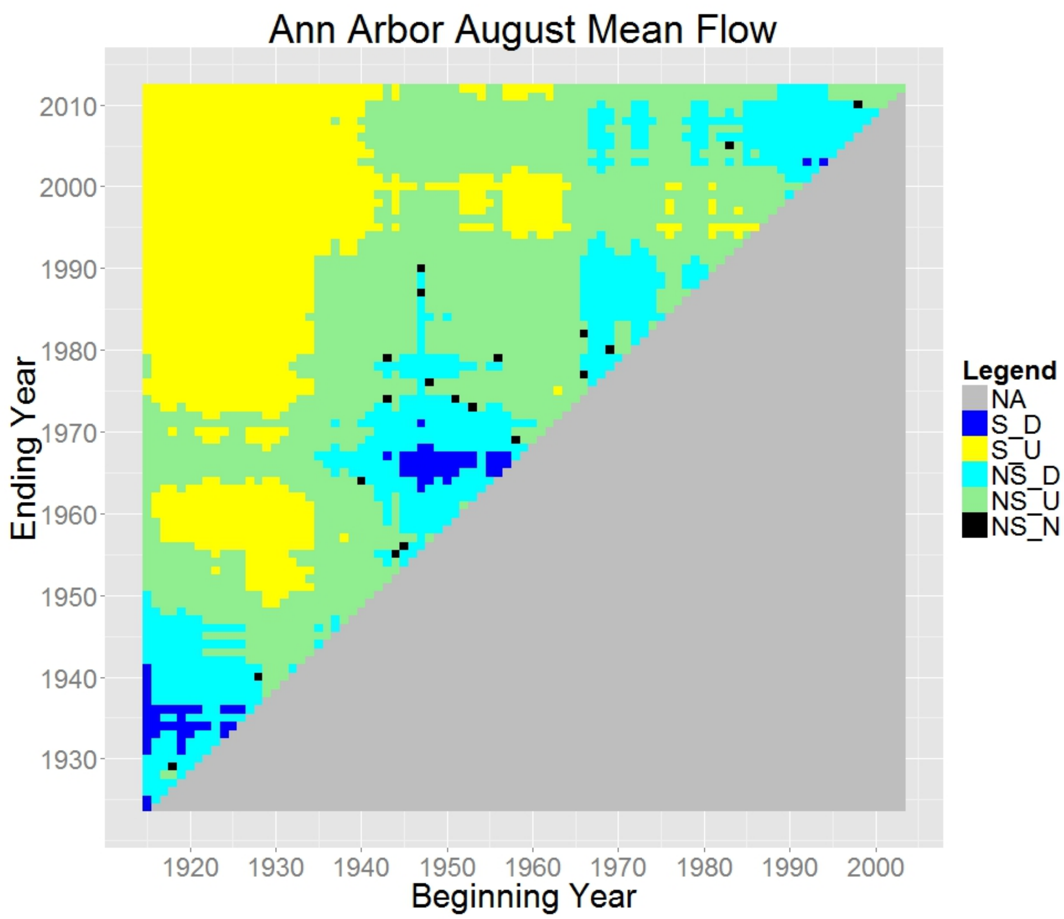


Figure 46 August median flow of the gauge "Ann Arbor".

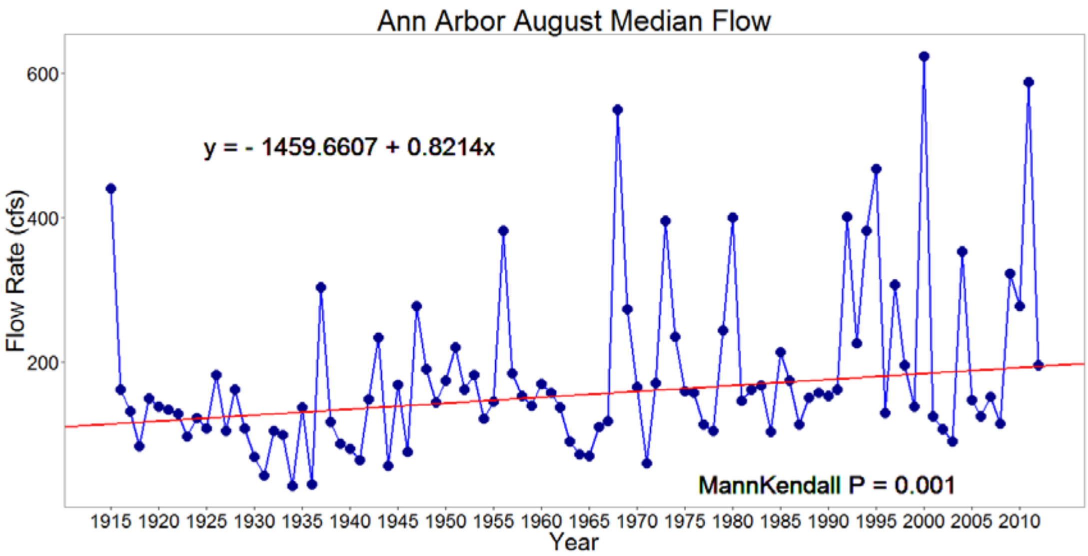


Figure 47 Repeated Mann-Kendall Analysis on the August median flow of the gauge "Ann Arbor".

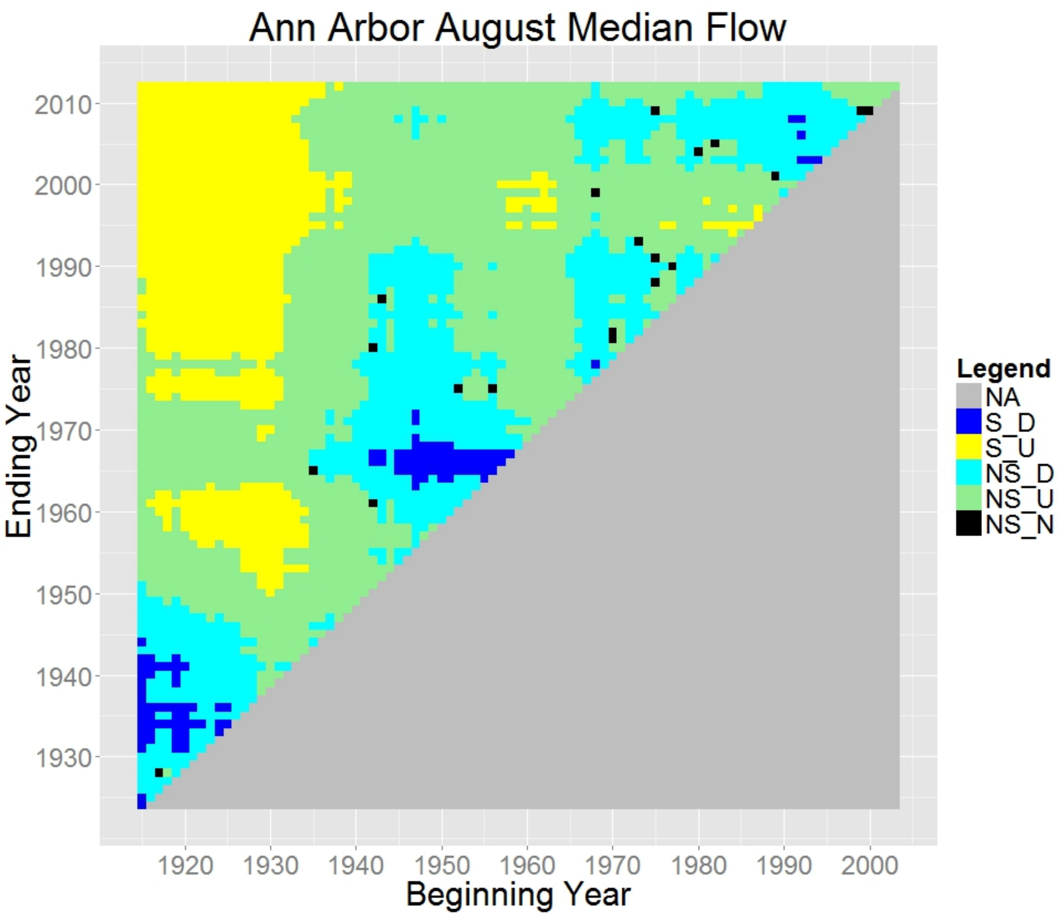


Figure 48 September mean flow of the gauge “Ann Arbor”.

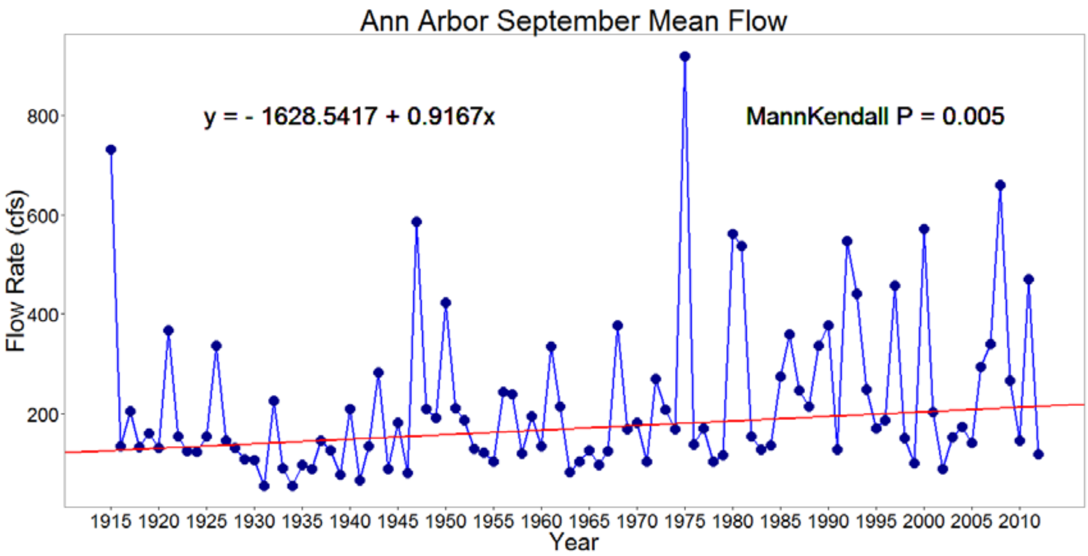


Figure 49 Repeated Mann-Kendall Analysis on the September mean flow of the gauge “Ann Arbor”.

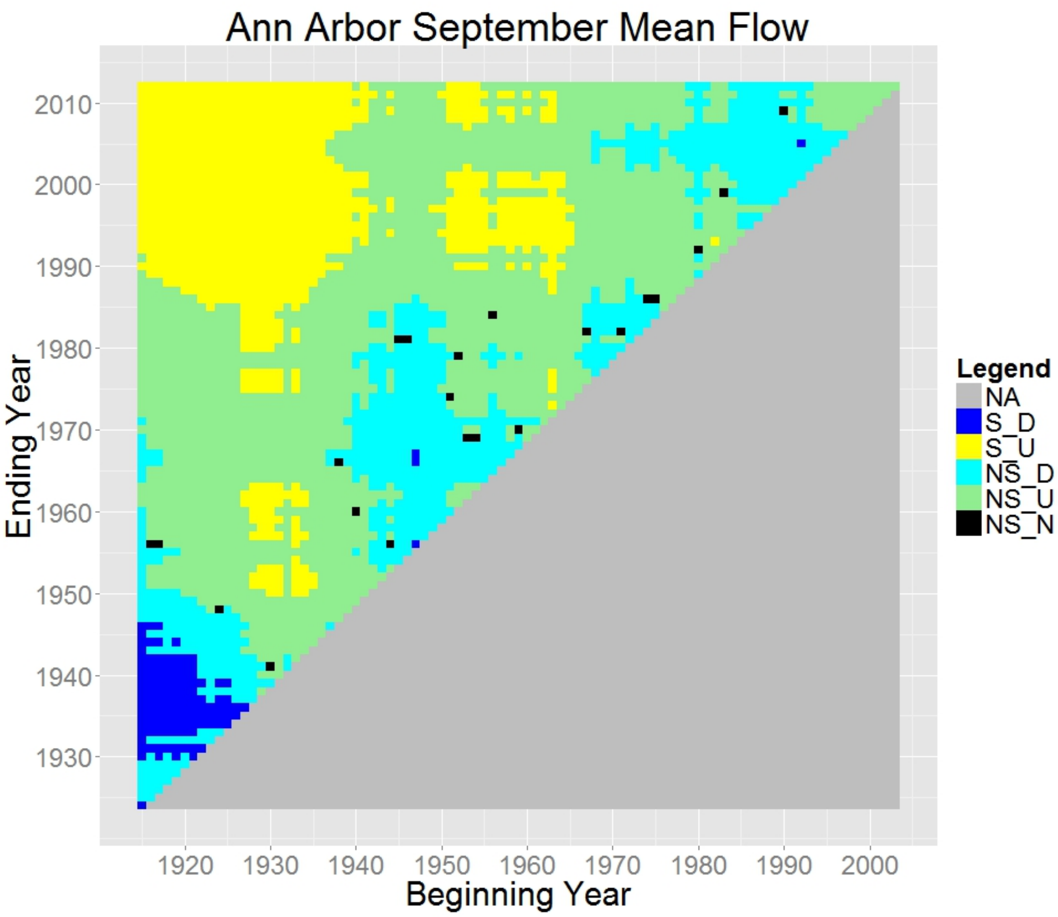


Figure 50 September median flow of the gauge "Ann Arbor".

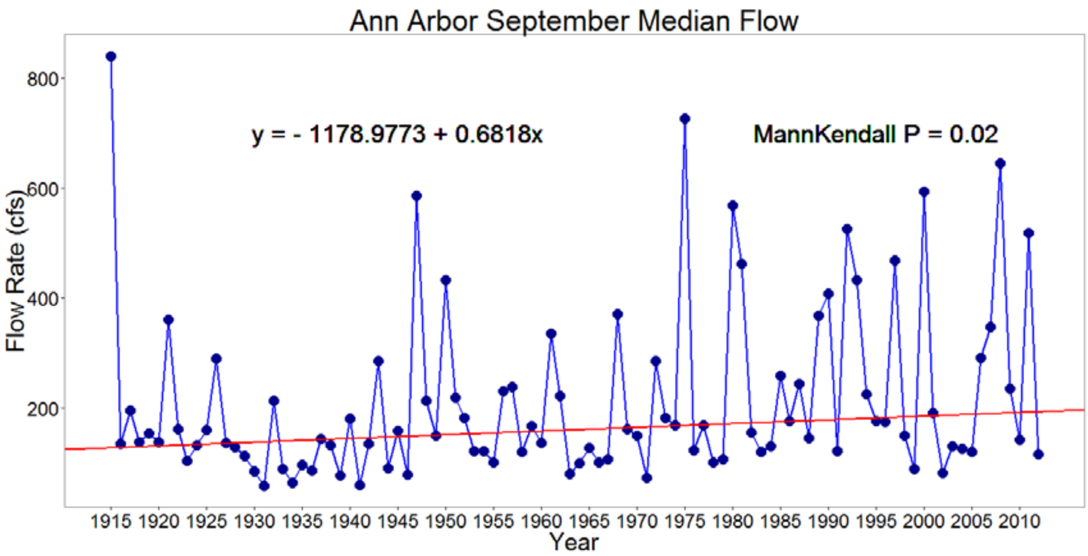


Figure 51 Repeated Mann-Kendall Analysis on the September median flow of the gauge "Ann Arbor".

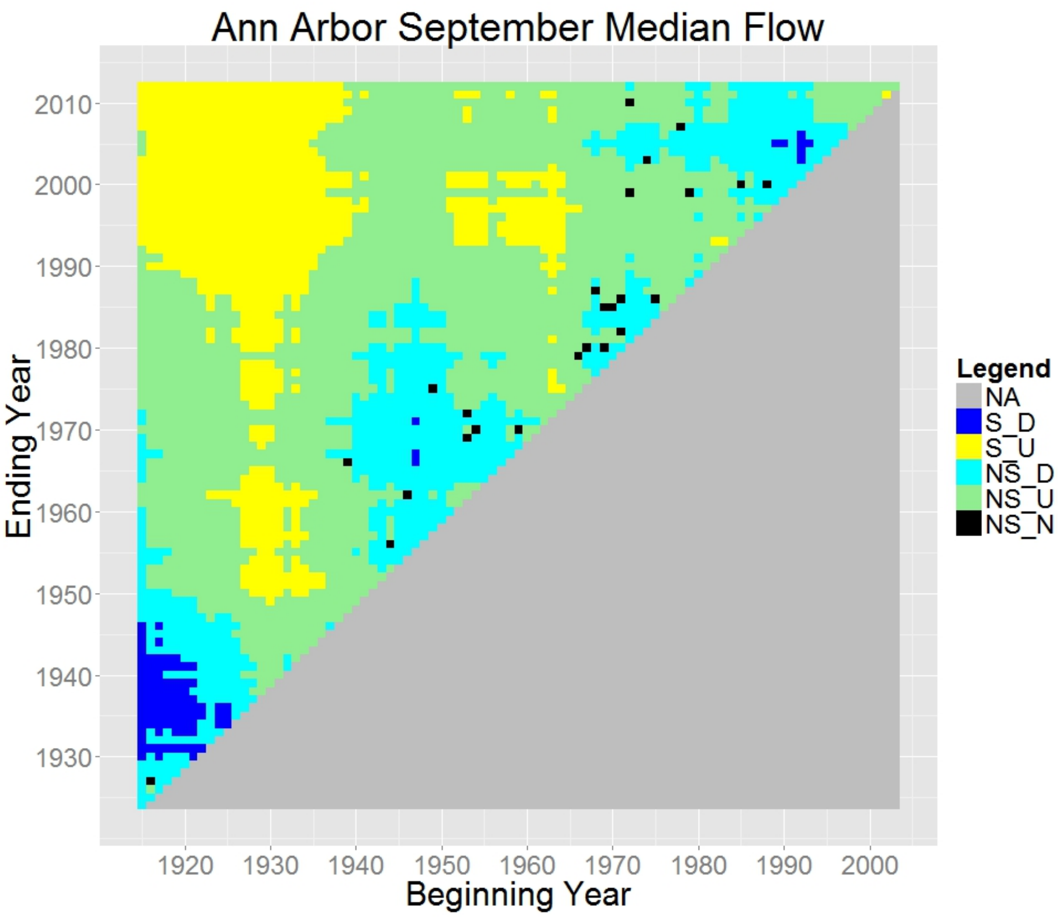


Figure 52 October mean flow of the gauge "Ann Arbor".

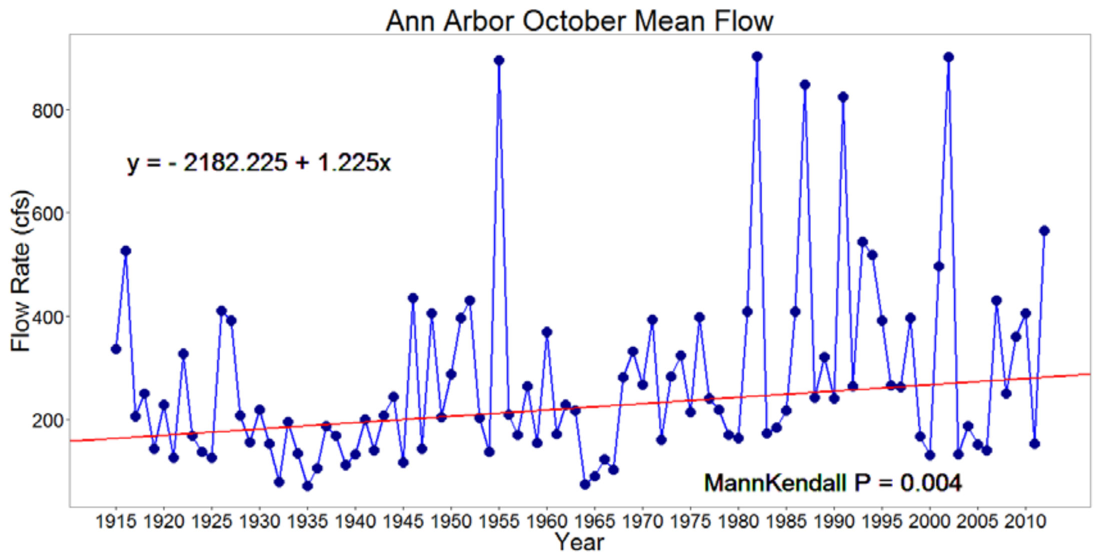


Figure 53 Repeated Mann-Kendall Analysis on the October mean flow of the gauge "Ann Arbor".

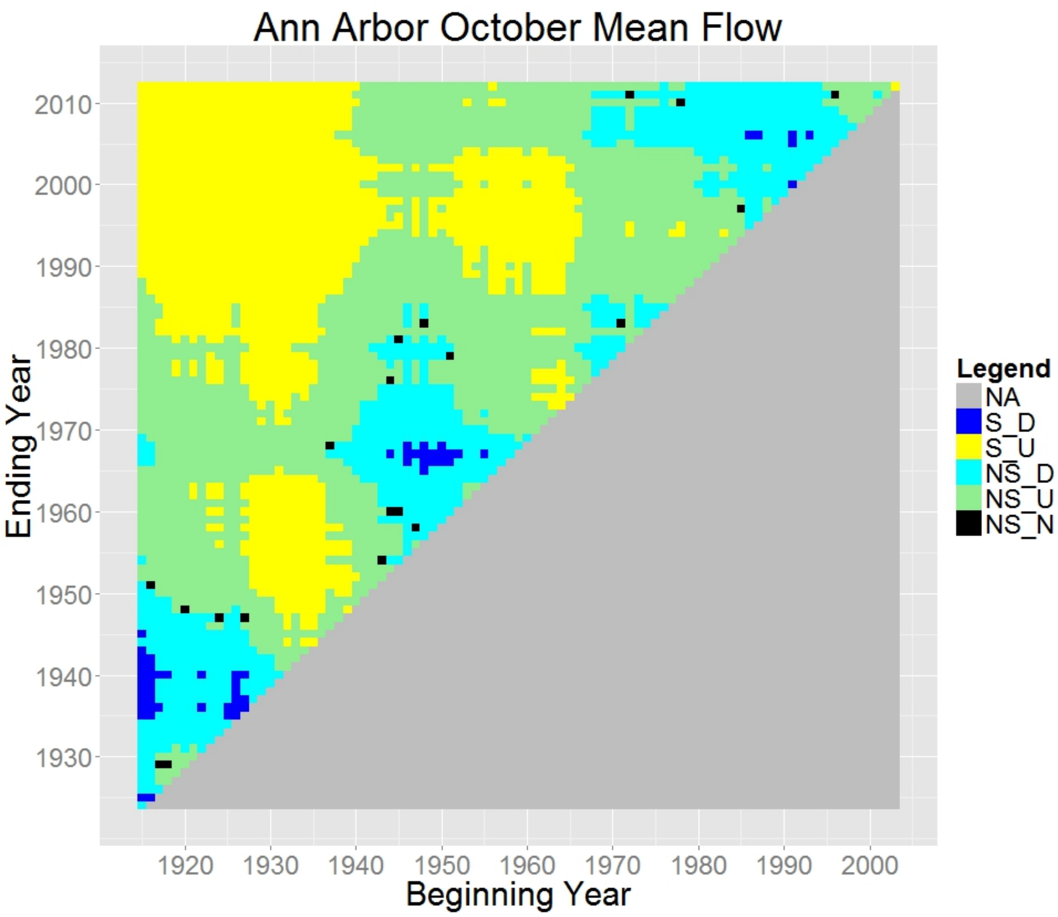


Figure 54 October median flow of the gauge “Ann Arbor”.

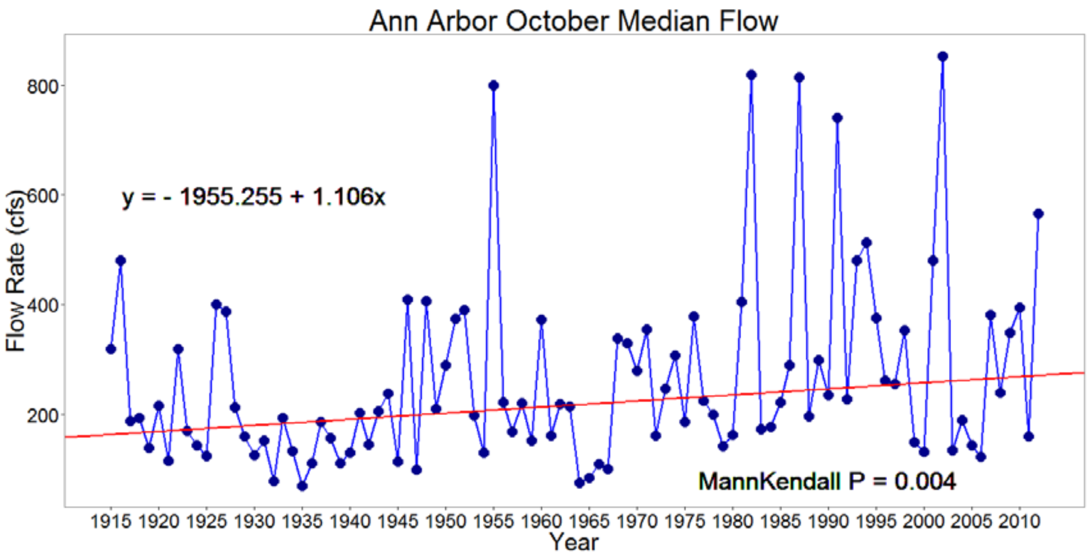


Figure 55 Repeated Mann-Kendall Analysis on the October median flow of the gauge “Ann Arbor”.

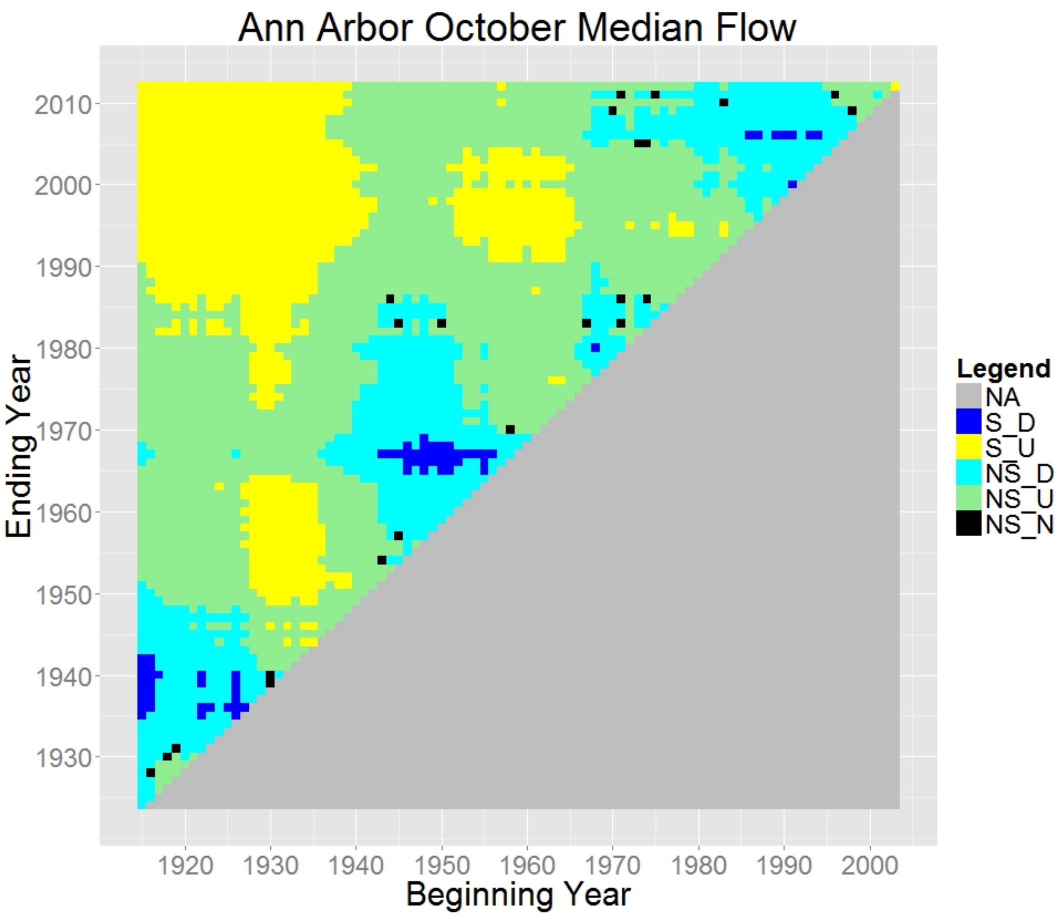


Figure 56 November mean flow of the gauge "Ann Arbor".

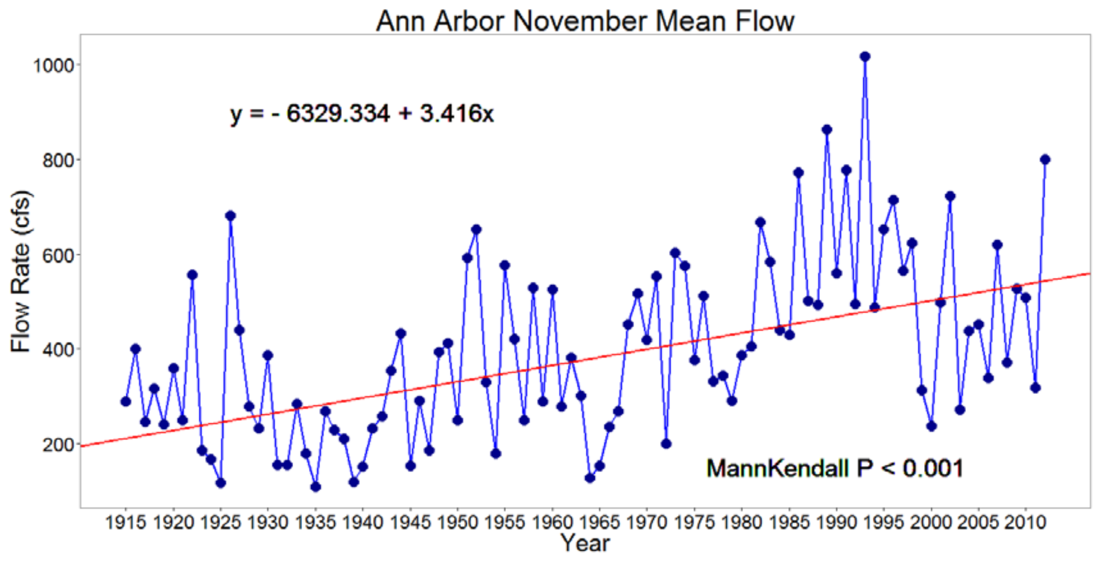


Figure 57 Repeated Mann-Kendall Analysis on the November mean flow of the gauge "Ann Arbor".

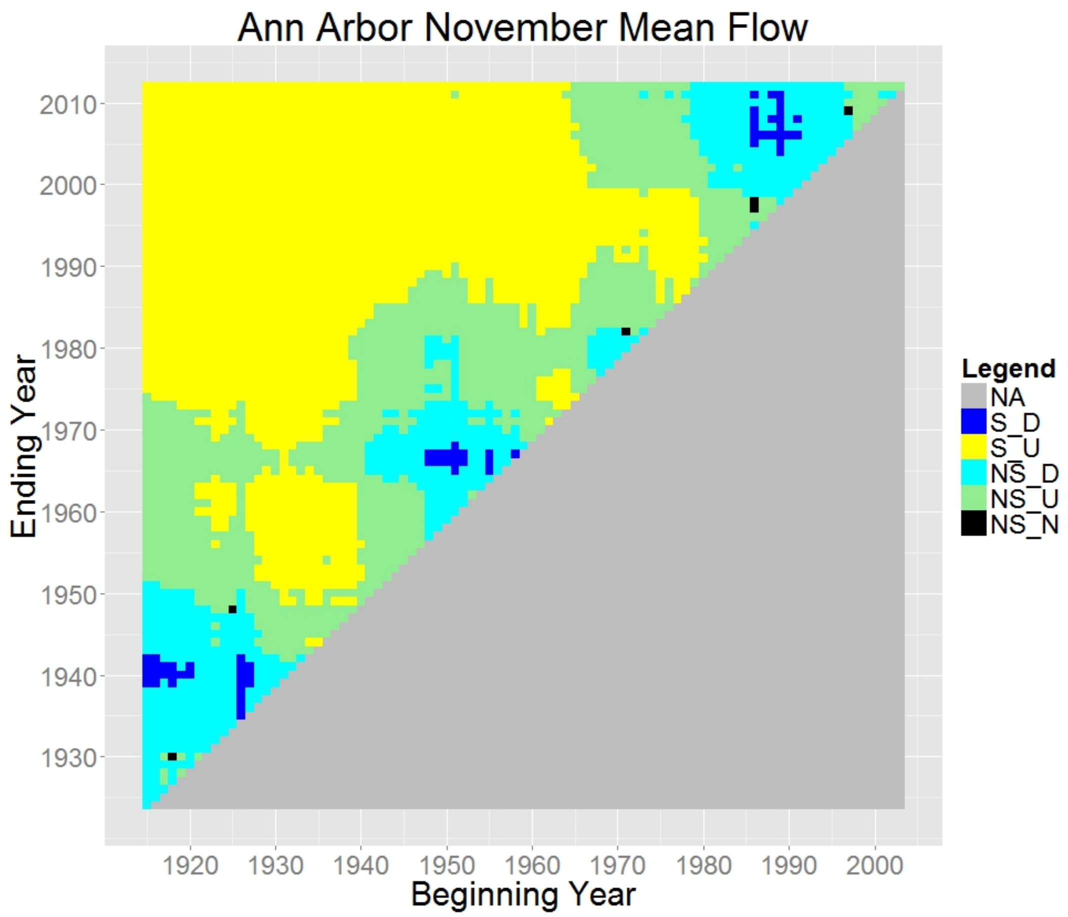


Figure 58 November median flow of the gauge "Ann Arbor".

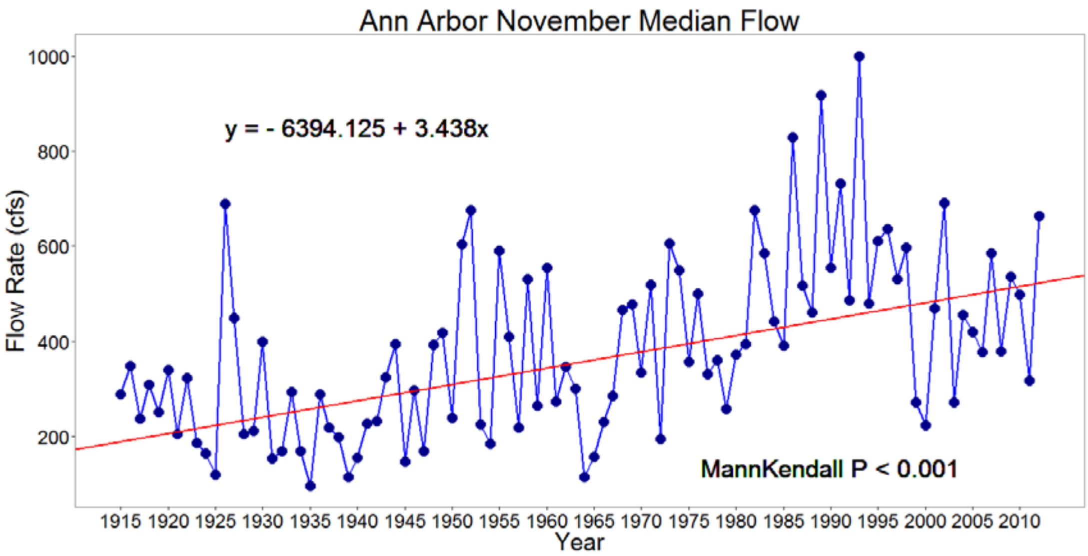


Figure 59 Repeated Mann-Kendall Analysis on the November median flow of the gauge "Ann Arbor".

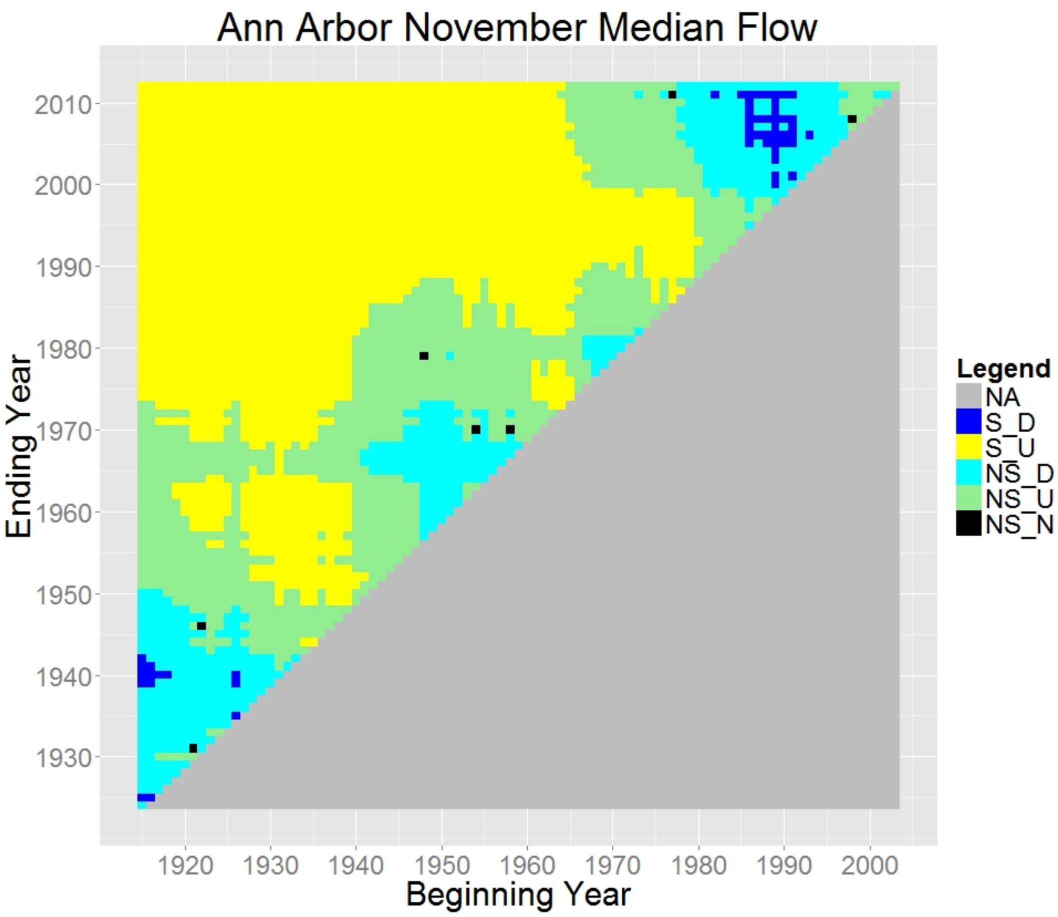


Figure 60 December mean flow of the gauge “Ann Arbor”.

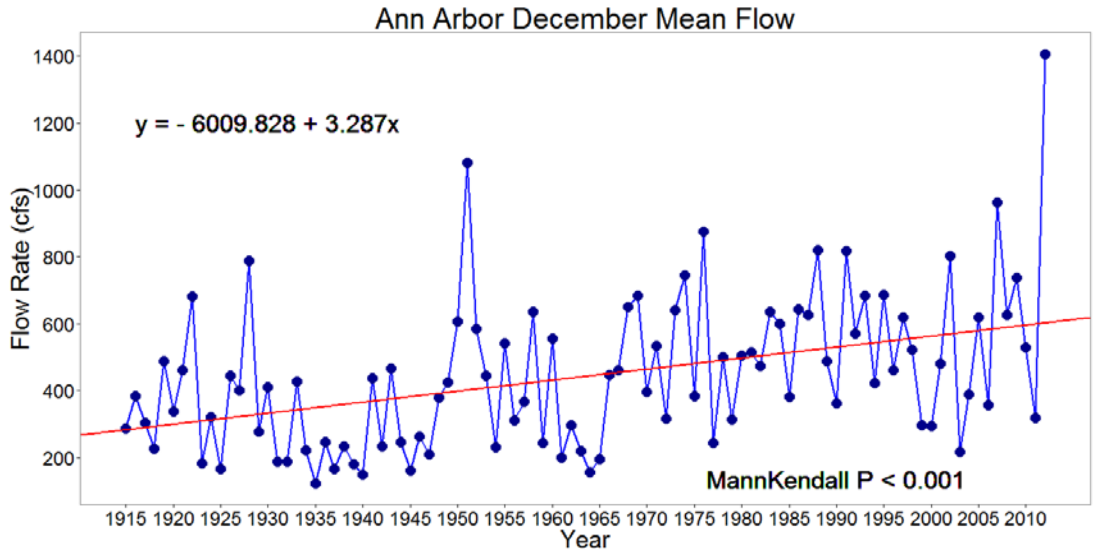


Figure 61 Repeated Mann-Kendall Analysis on the December mean flow of the gauge “Ann Arbor”.

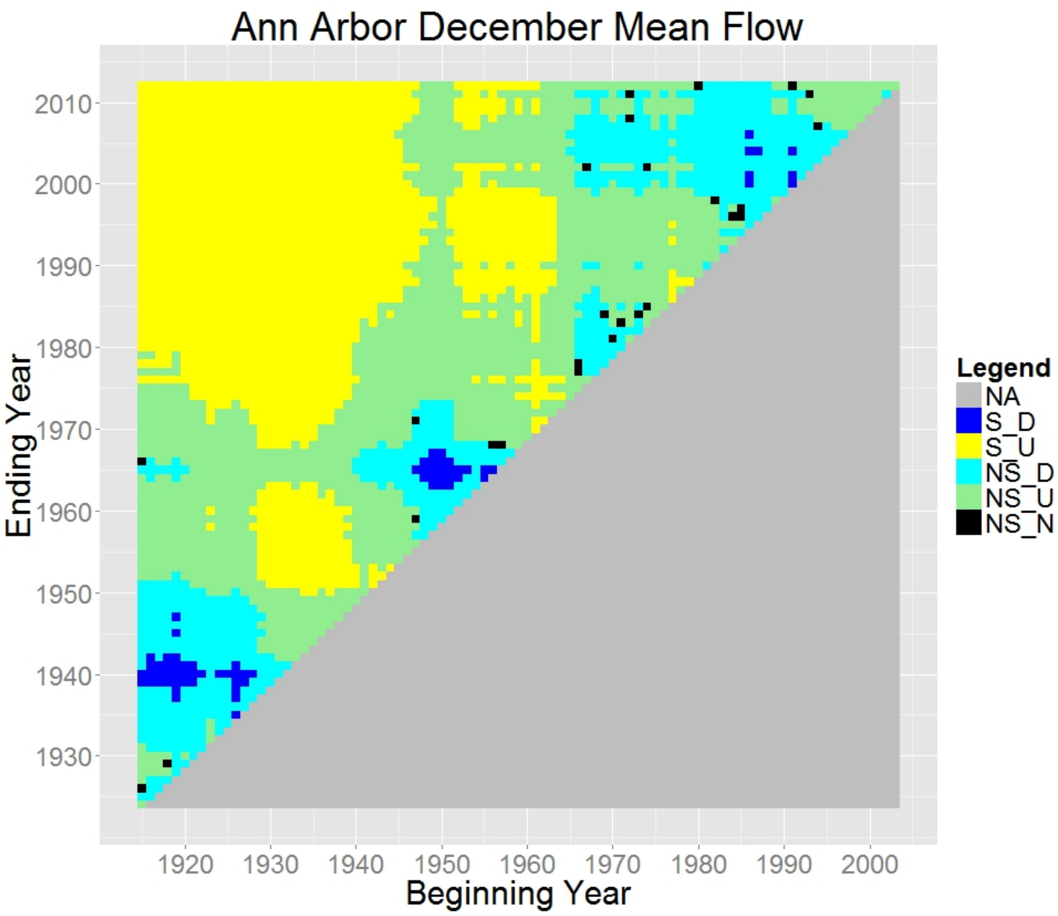


Figure 62 December median flow of the gauge “Ann Arbor”.

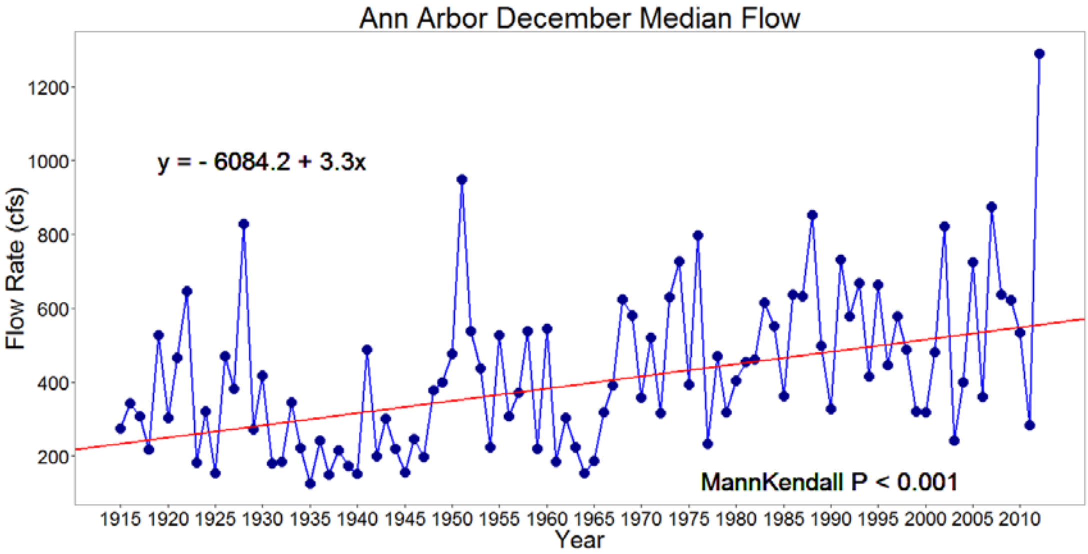


Figure 63 Repeated Mann-Kendall Analysis on the December median flow of the gauge “Ann Arbor”.

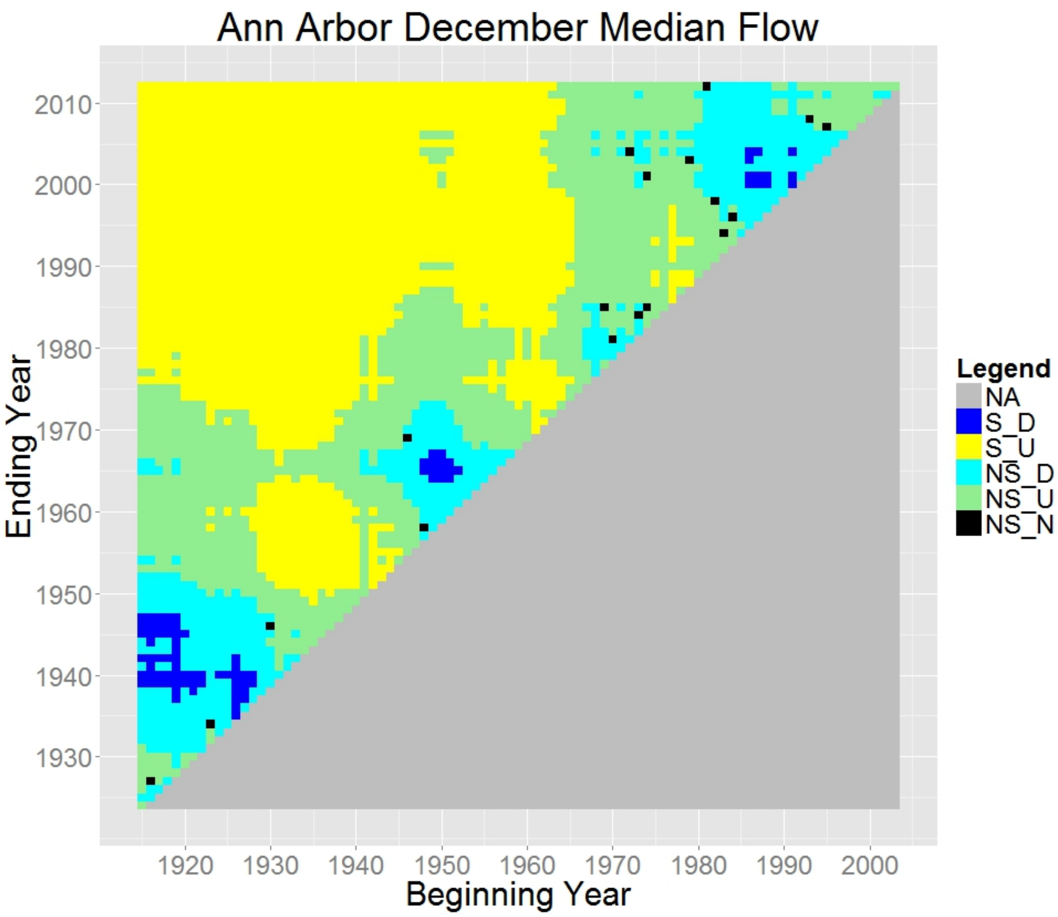


Figure 64 Annual maximum 1-day mean flow of the gauge “Ann Arbor”.

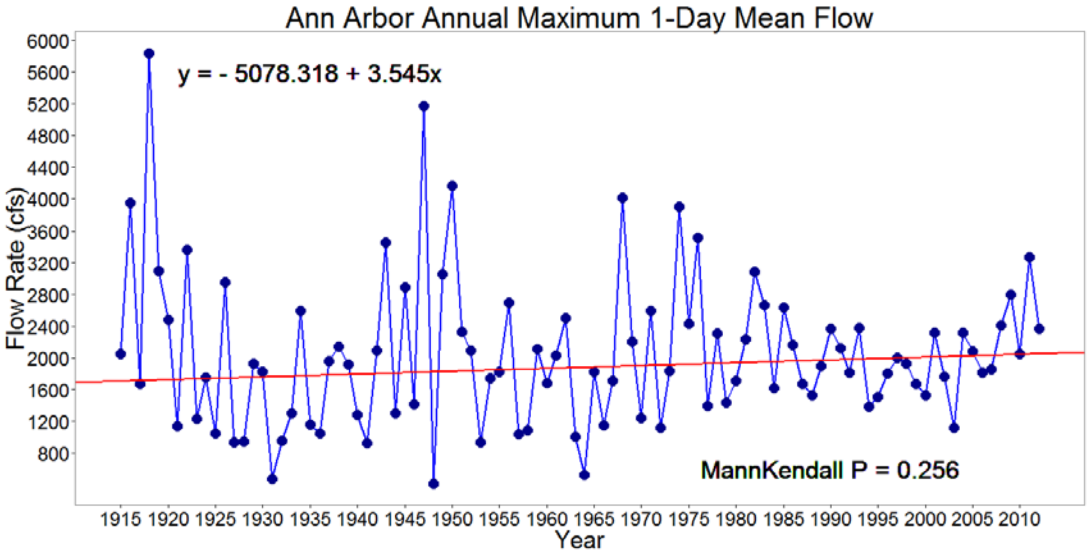


Figure 65 Repeated Mann-Kendall Analysis on the annual maximum 1-day mean flow of the gauge “Ann Arbor”.

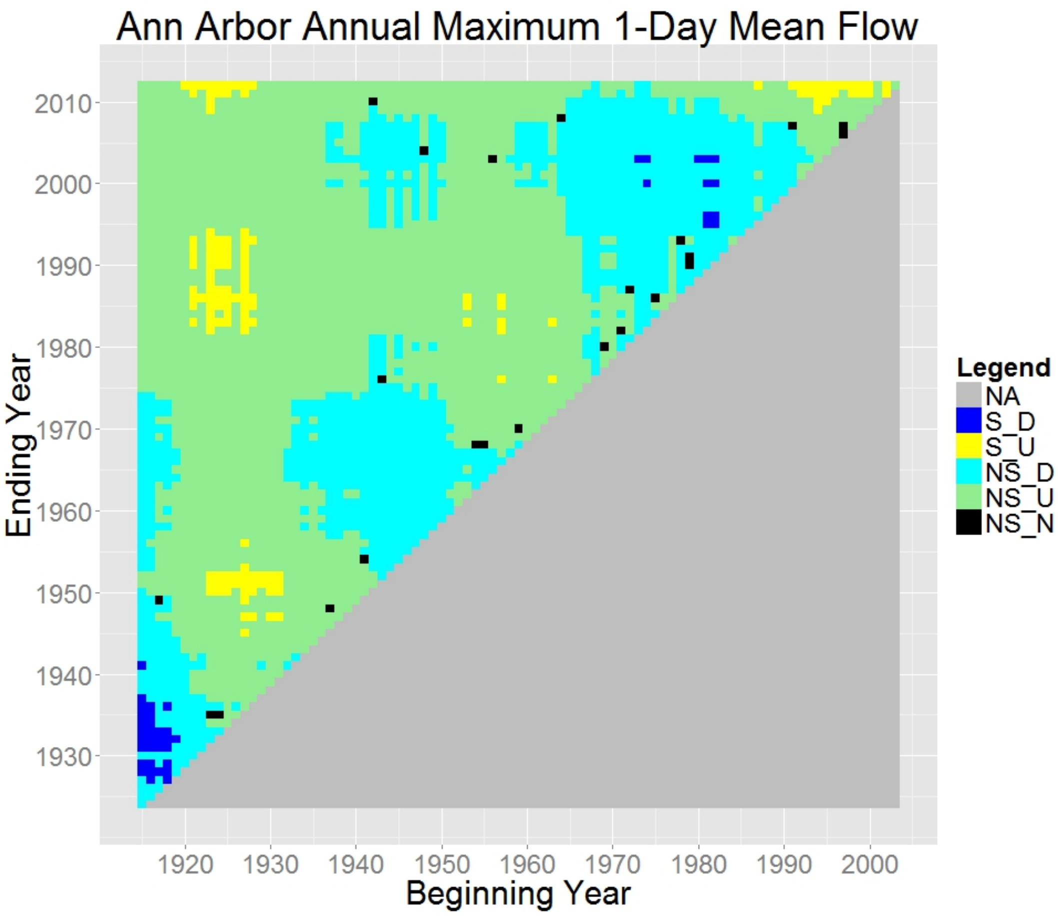


Figure 66 Annual maximum 3-day mean flow of the gauge “Ann Arbor”.

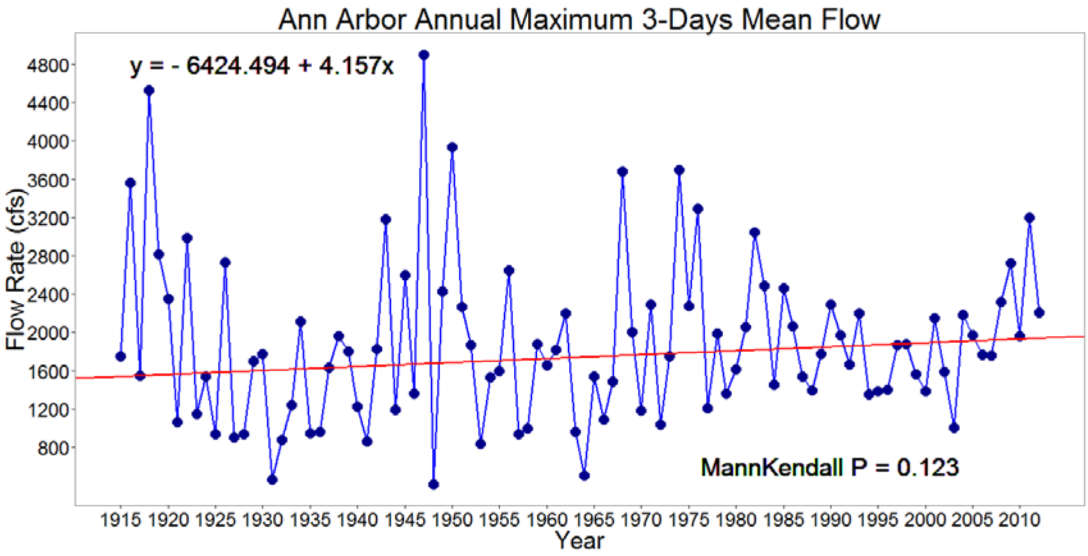


Figure 67 Repeated Mann-Kendall Analysis on the annual maximum 3-day mean flow of the gauge “Ann Arbor”.

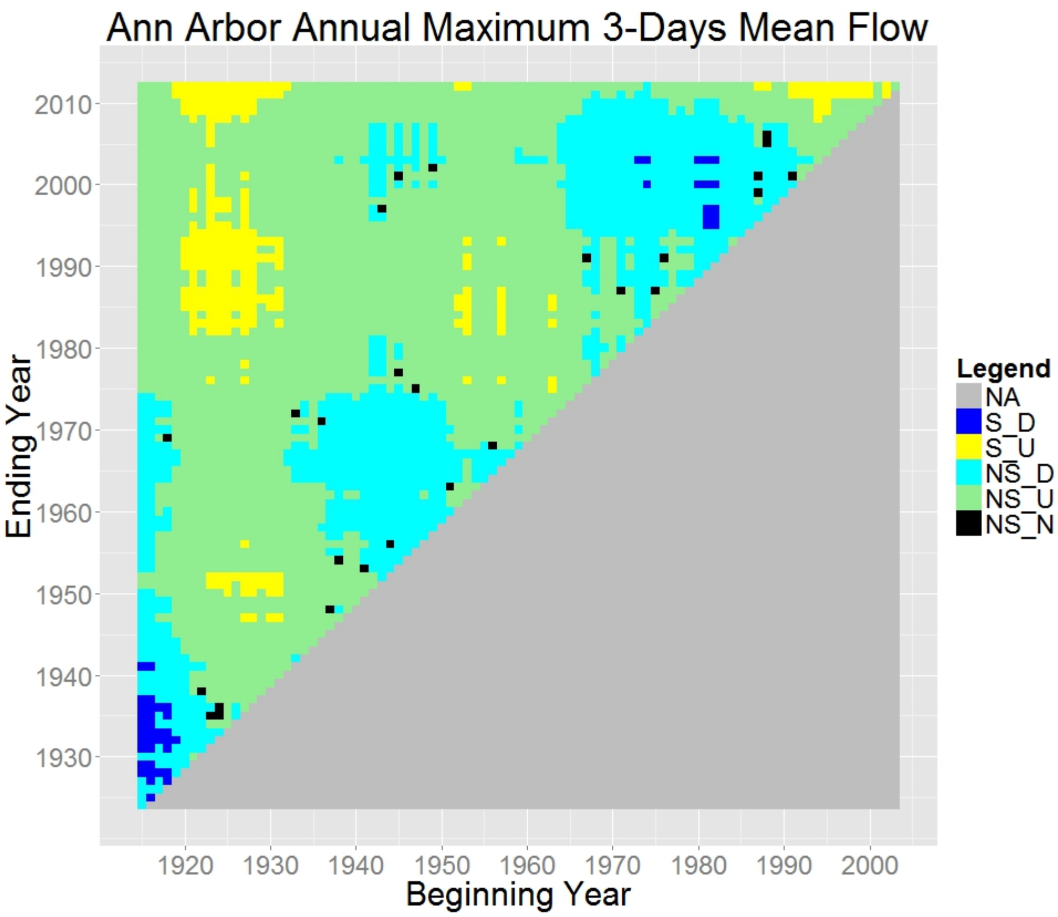


Figure 68 Annual maximum 7-day mean flow of the gauge “Ann Arbor”.

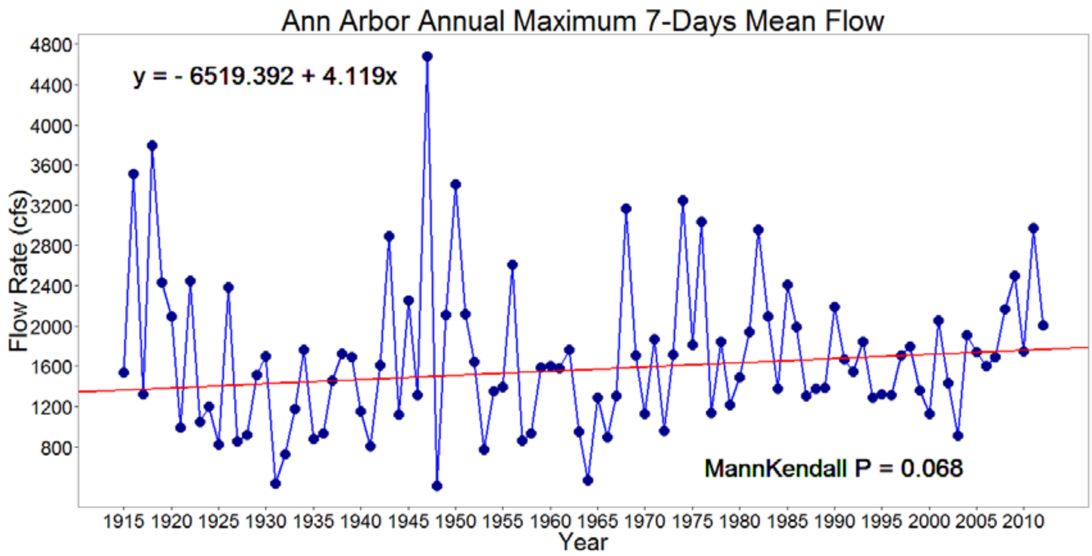


Figure 69 Repeated Mann-Kendall Analysis on the annual maximum 7-day mean flow of the gauge “Ann Arbor”.

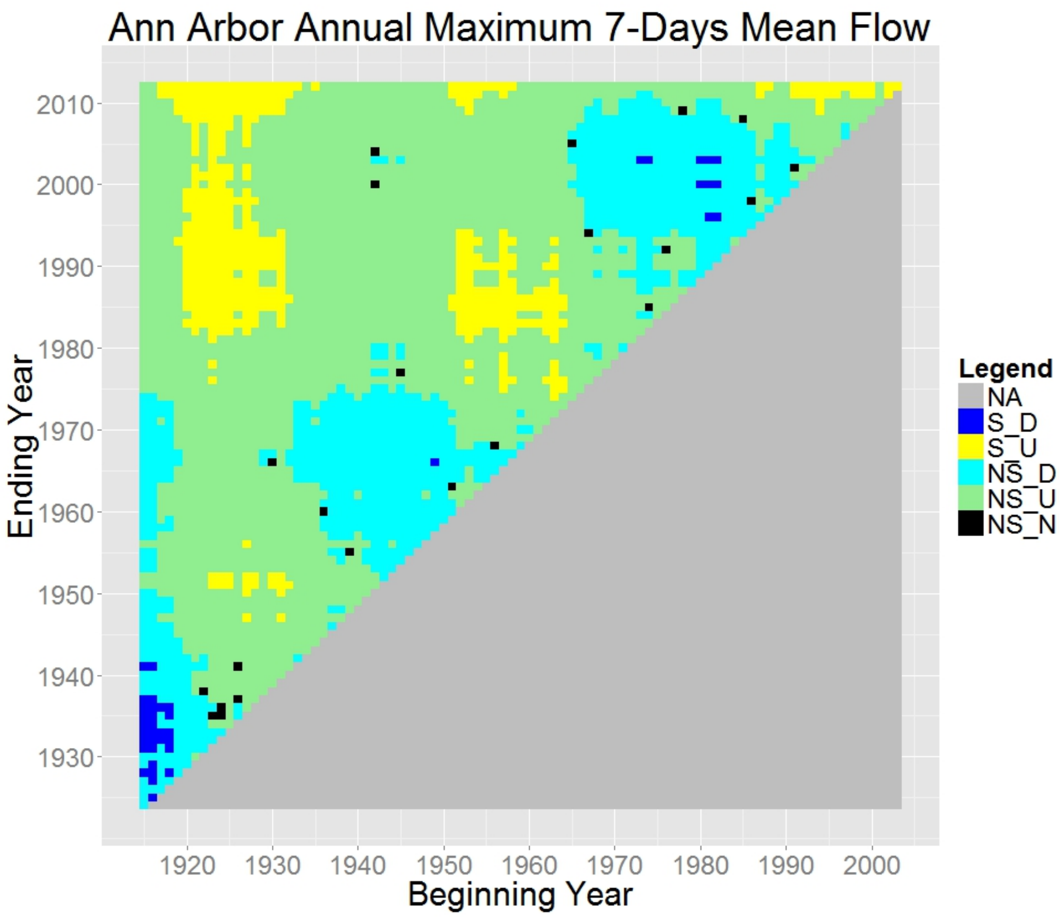


Figure 70 Annual maximum 30-day mean flow of the gauge "Ann Arbor".

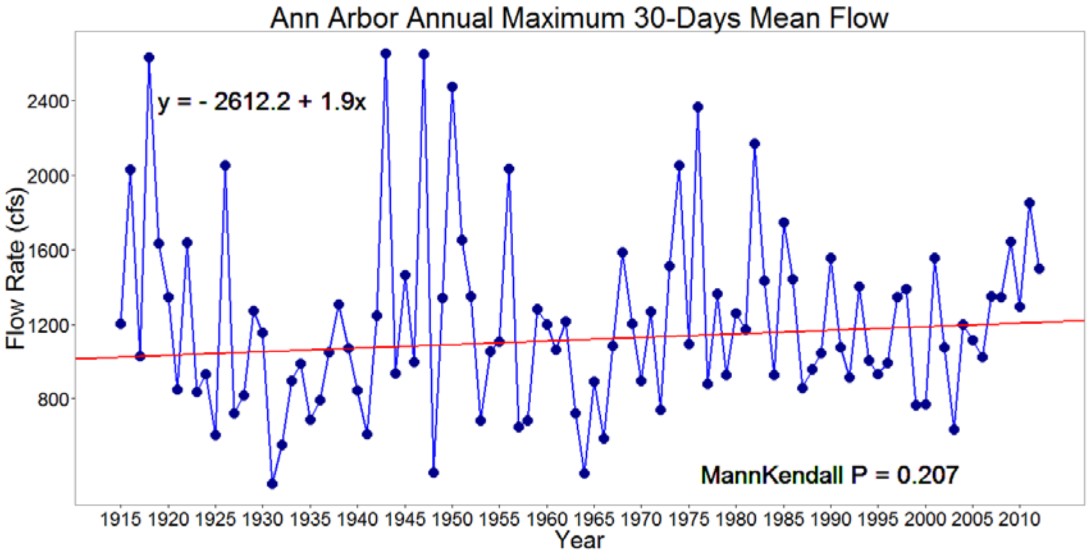


Figure 71 Repeated Mann-Kendall Analysis on the annual maximum 30-day mean flow of the gauge "Ann Arbor".

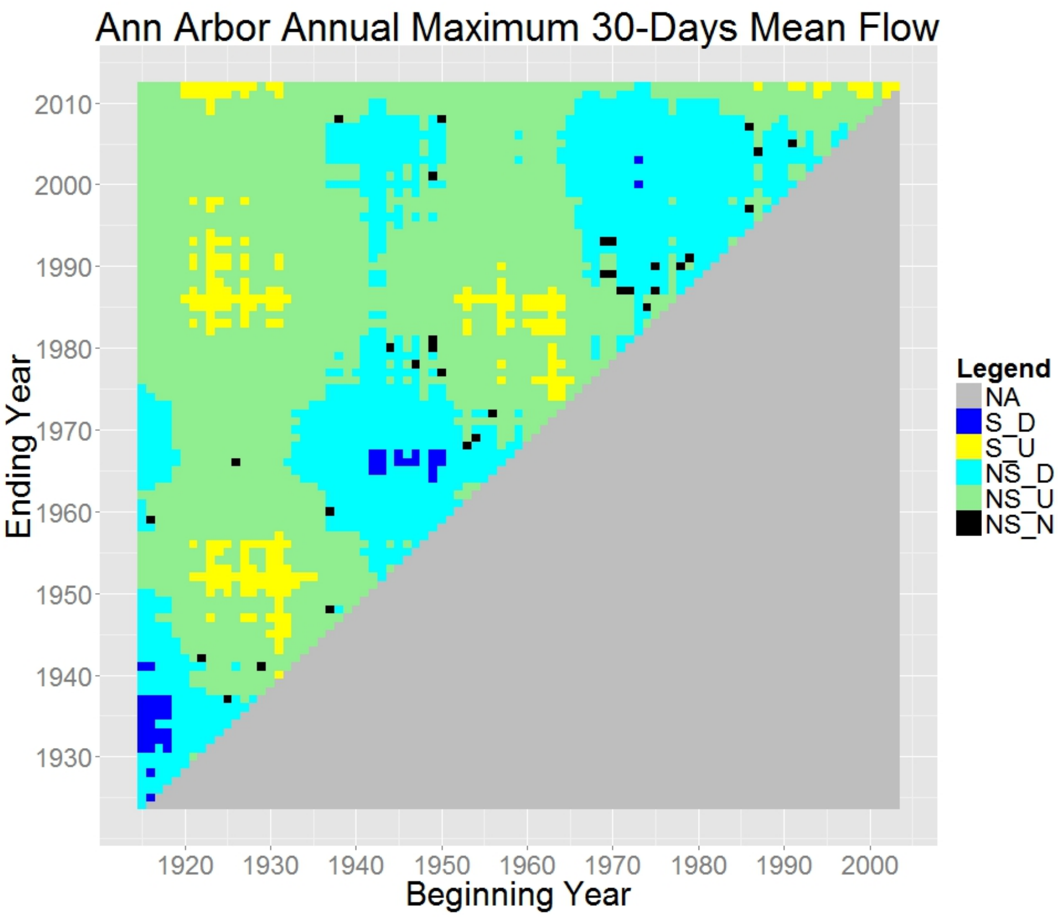


Figure 72 Annual maximum 90-day mean flow of the gauge "Ann Arbor".

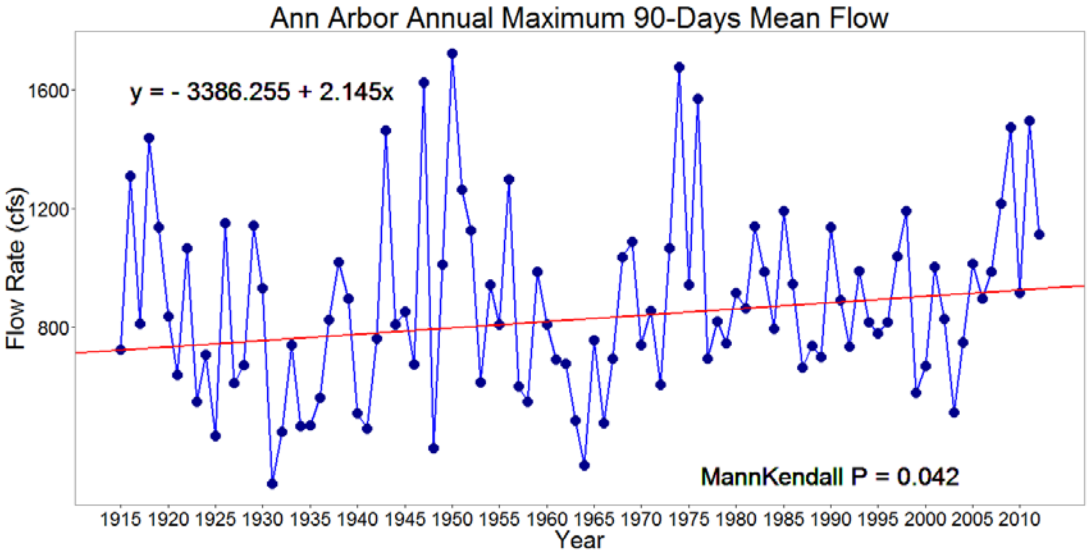


Figure 73 Repeated Mann-Kendall Analysis on the annual maximum 90-day mean flow of the gauge "Ann Arbor".

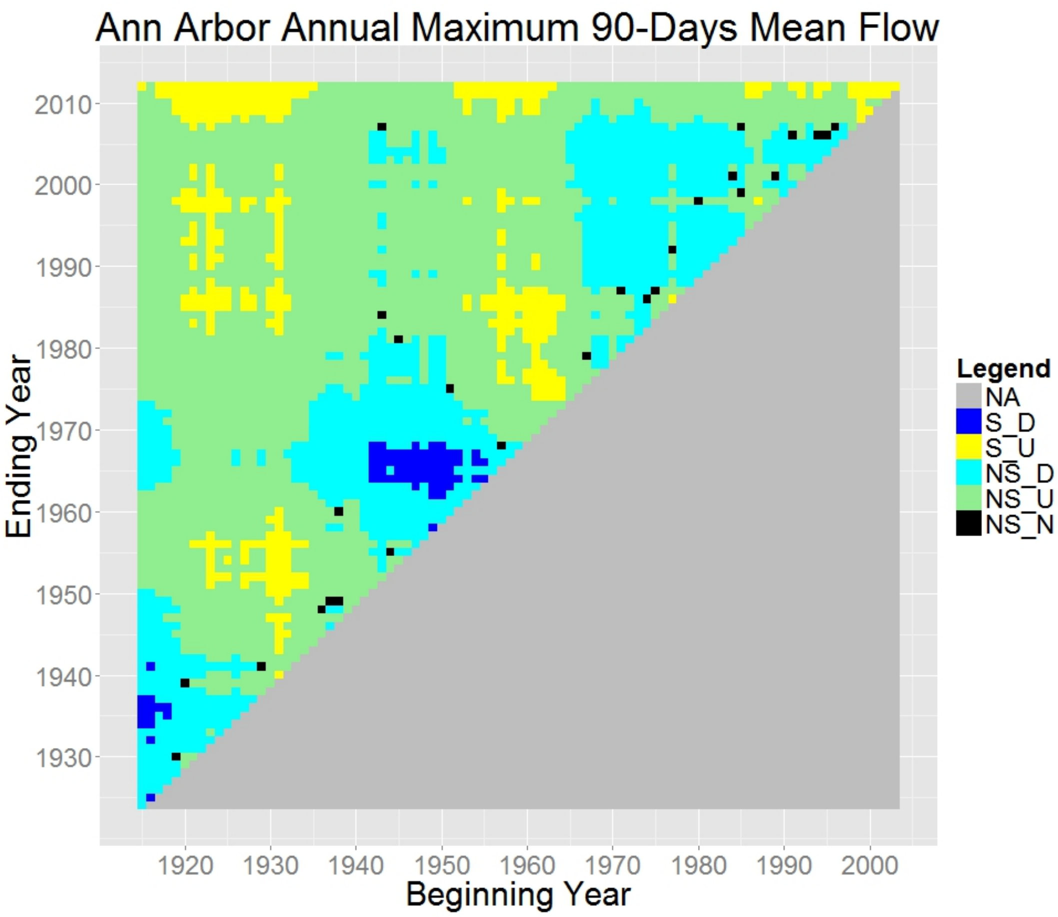


Figure 74 Annual minimum 1-day mean flow of the gauge "Ann Arbor".

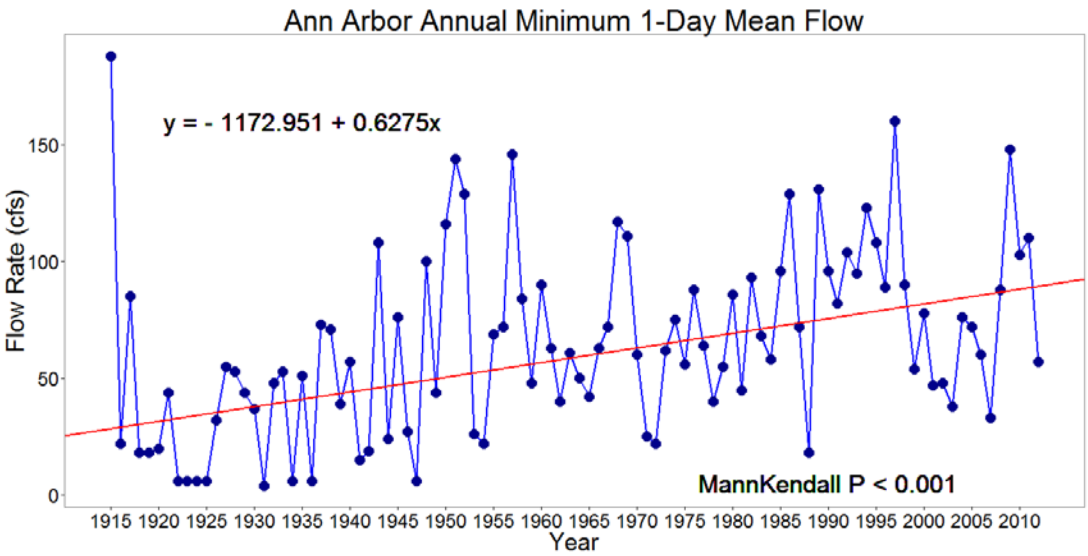


Figure 75 Repeated Mann-Kendall Analysis on the annual minimum 1-day mean flow of the gauge "Ann Arbor".

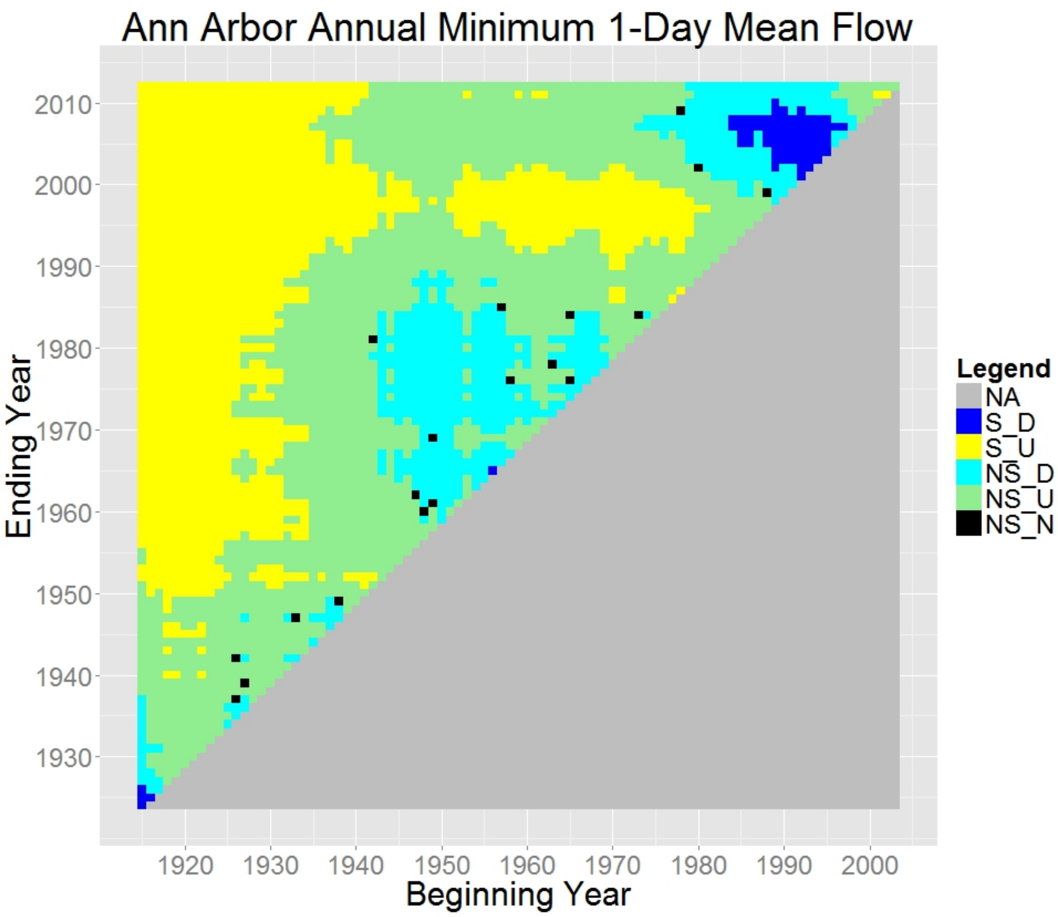


Figure 76 Annual minimum 3-day mean flow of the gauge “Ann Arbor”.

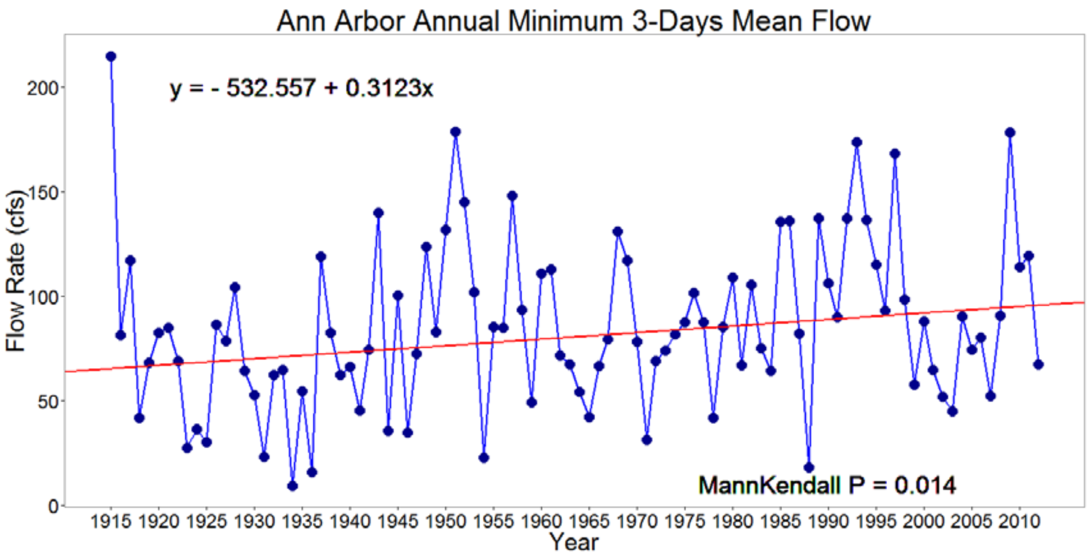


Figure 77 Repeated Mann-Kendall Analysis on the annual minimum 3-day mean flow of the gauge “Ann Arbor”.

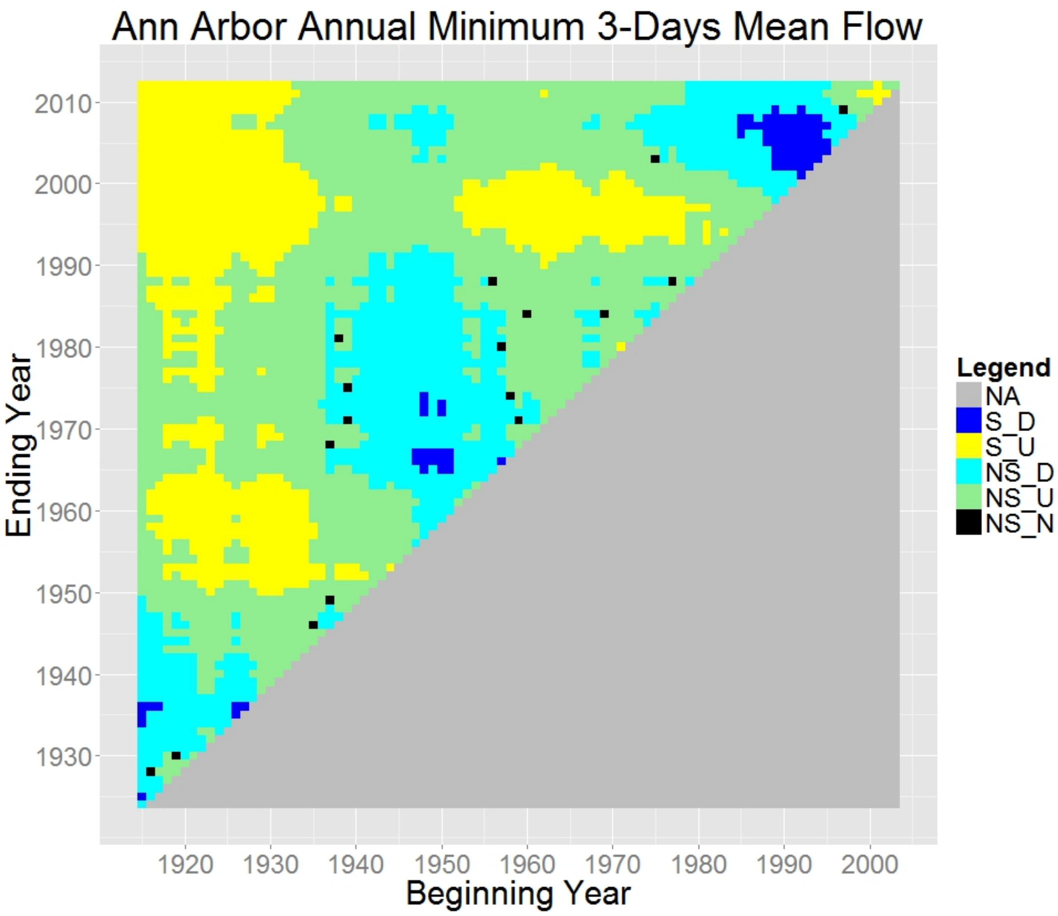


Figure 78 Annual minimum 7-day mean flow of the gauge "Ann Arbor".

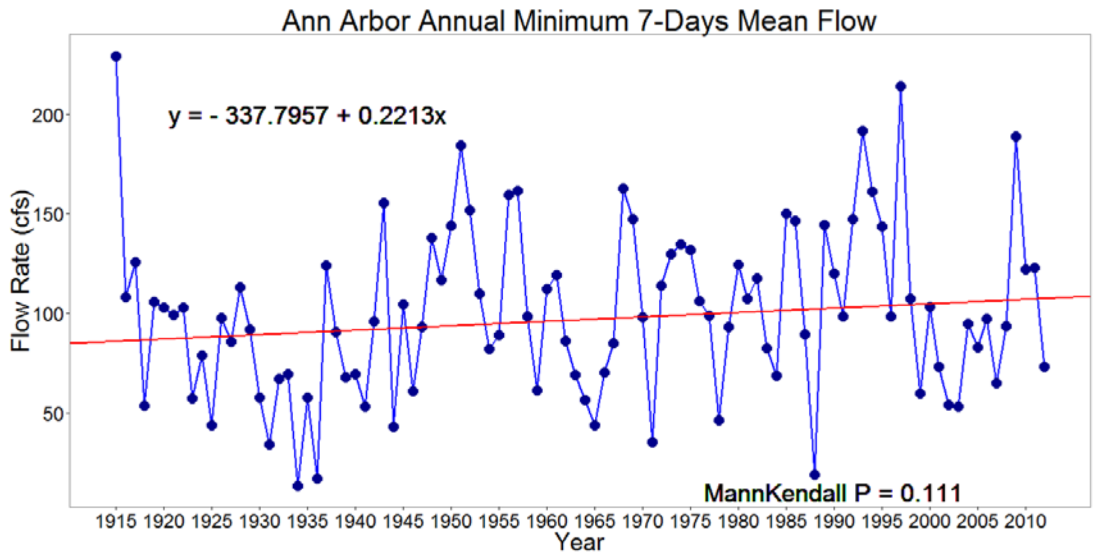


Figure 79 Repeated Mann-Kendall Analysis on the annual minimum 7-day mean flow of the gauge "Ann Arbor".

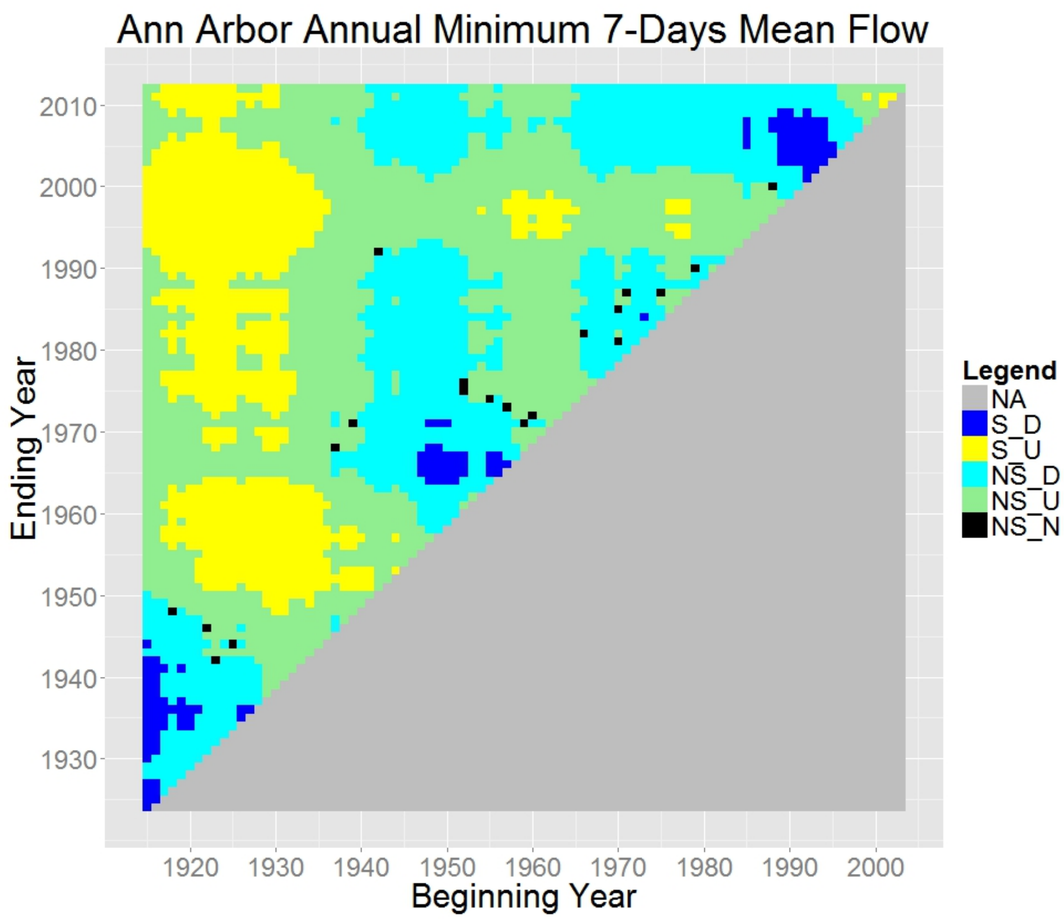


Figure 80 Annual minimum 30-day mean flow of the gauge “Ann Arbor”.

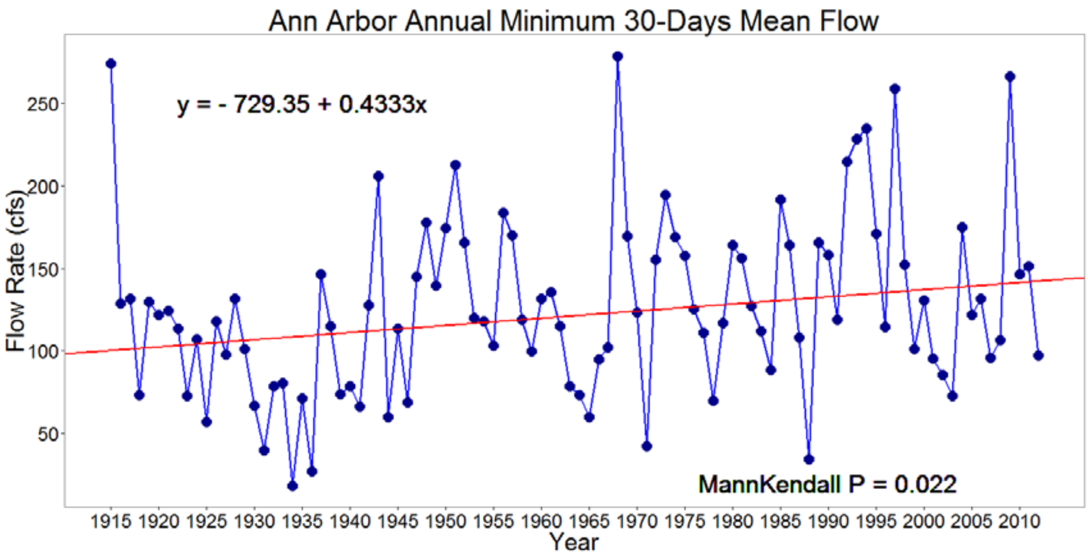


Figure 81 Repeated Mann-Kendall Analysis on the annual minimum 30-day mean flow of the gauge “Ann Arbor”.

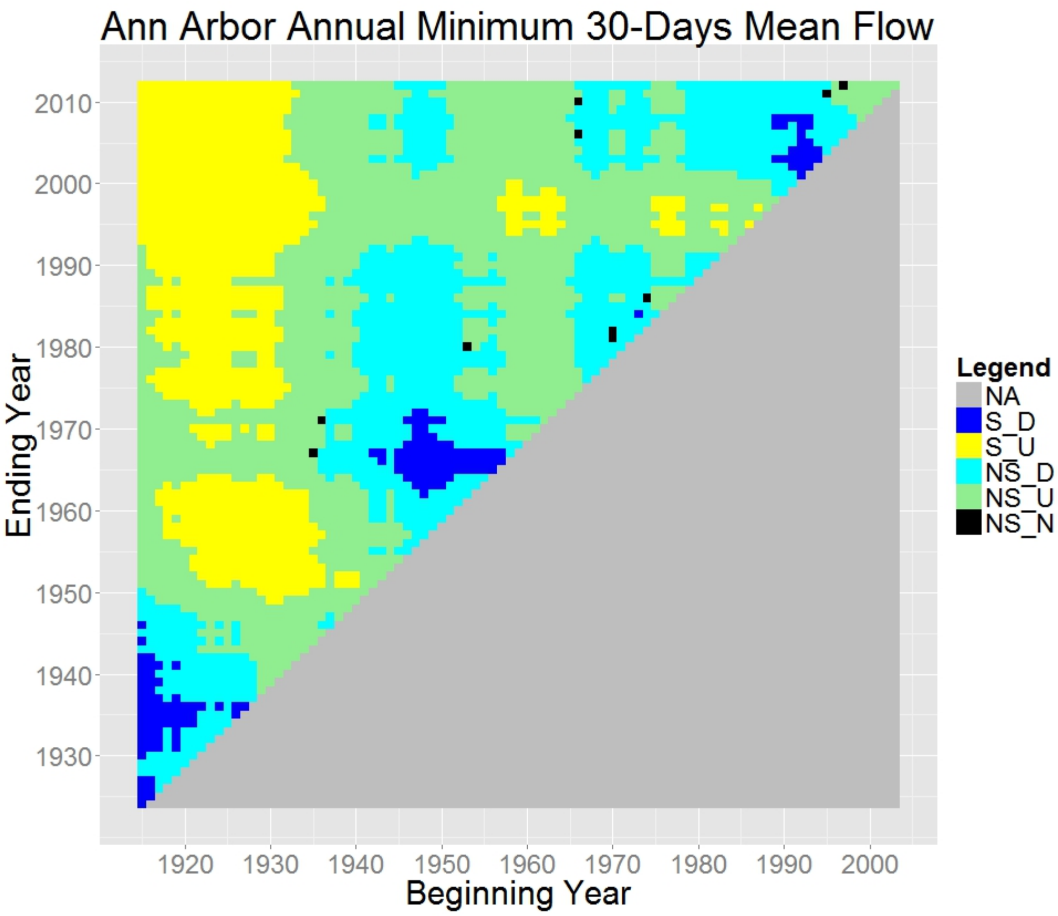


Figure 82 Annual minimum 30-day mean flow of the gauge “Ann Arbor”.

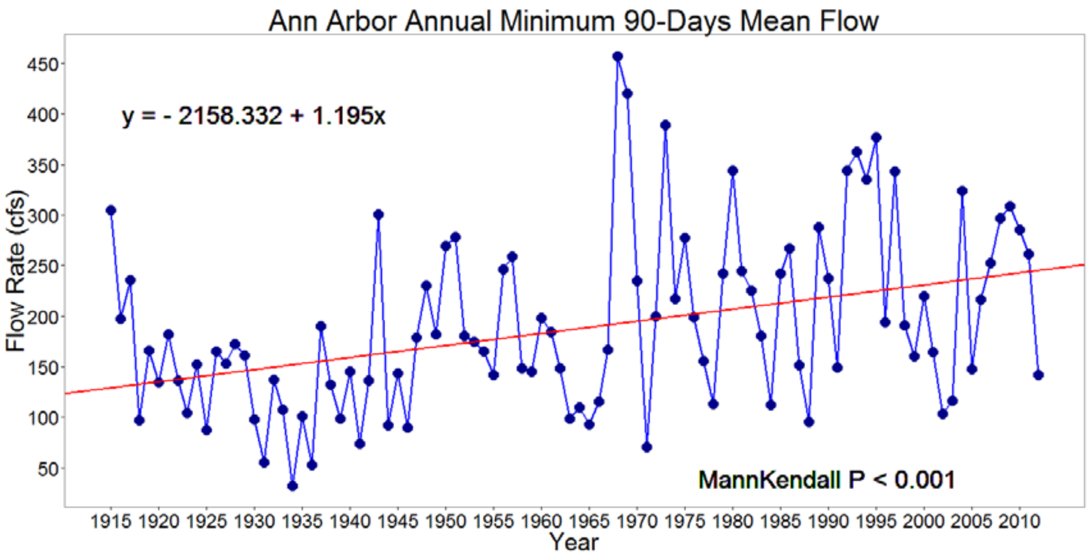


Figure 83 Repeated Mann-Kendall Analysis on the annual minimum 30-day mean flow of the gauge “Ann Arbor”.

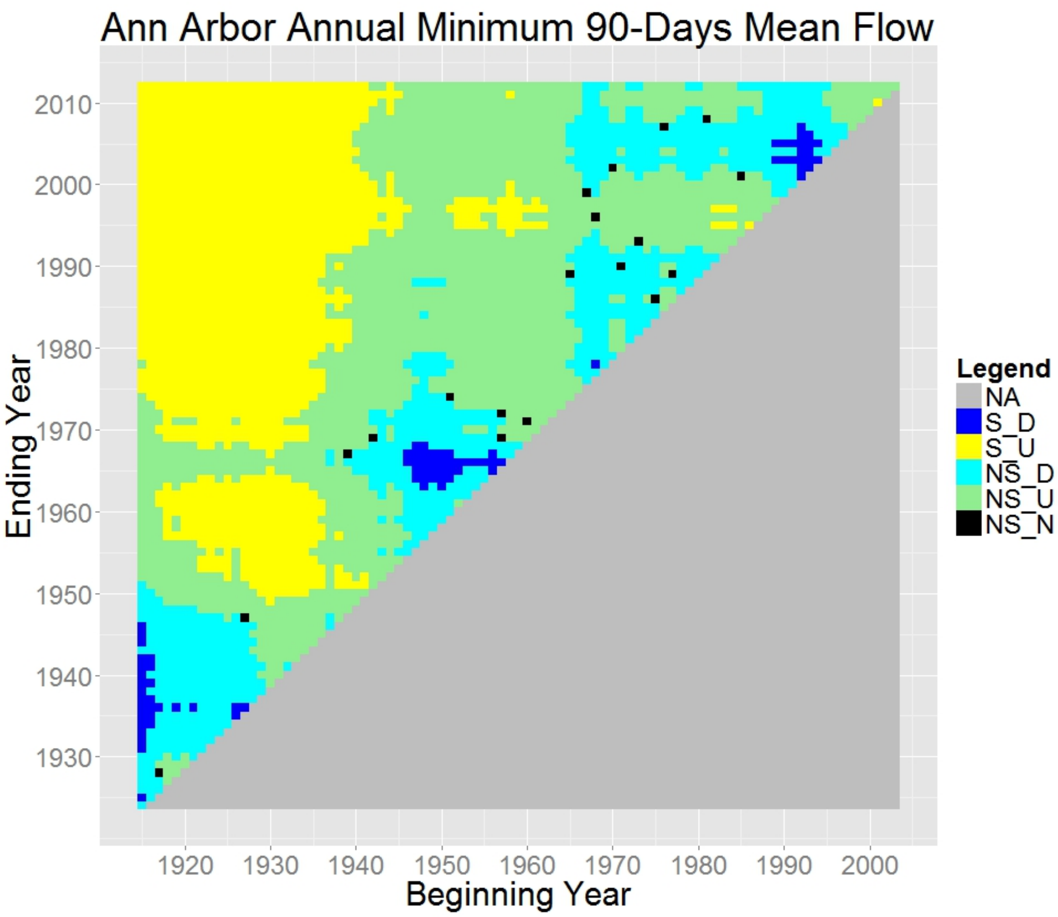


Figure 84 Annual base flow index (7-day minimum flow/annual mean flow) of the gauge “Ann Arbor”.

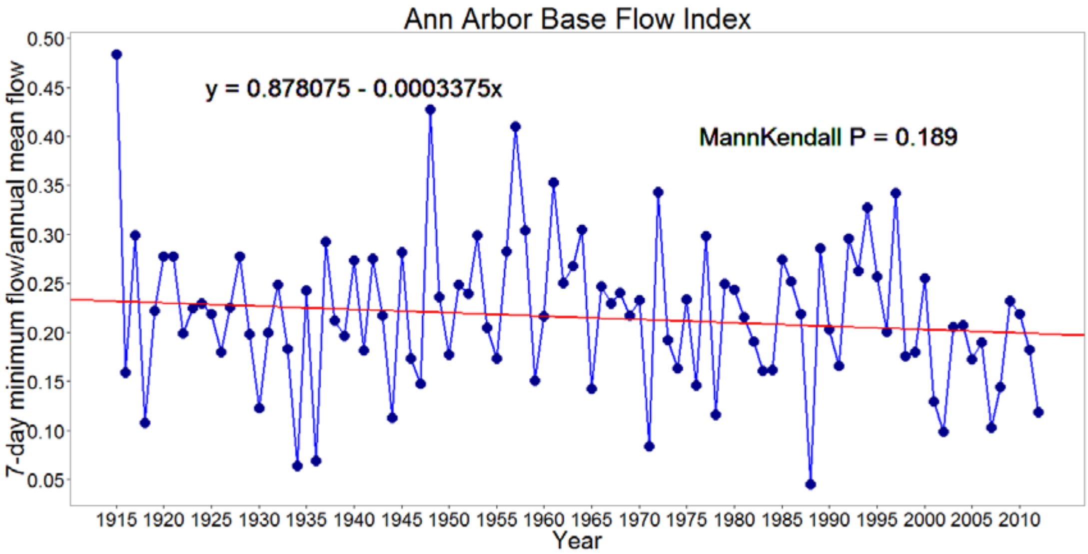


Figure 85 Repeated Mann-Kendall Analysis on the Q25 high pulse count of the gauge “Ann Arbor”.

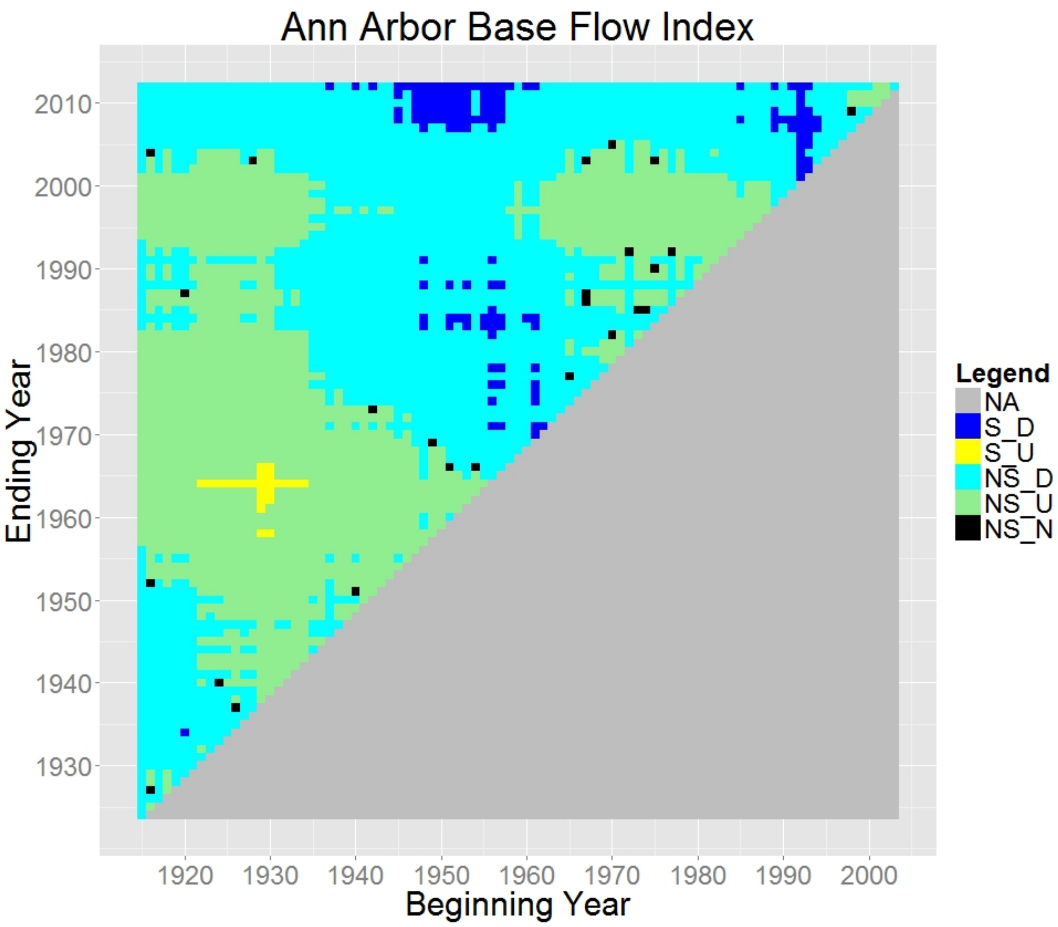


Figure 86 Q25 high pulse count of the gauge “Ann Arbor”.

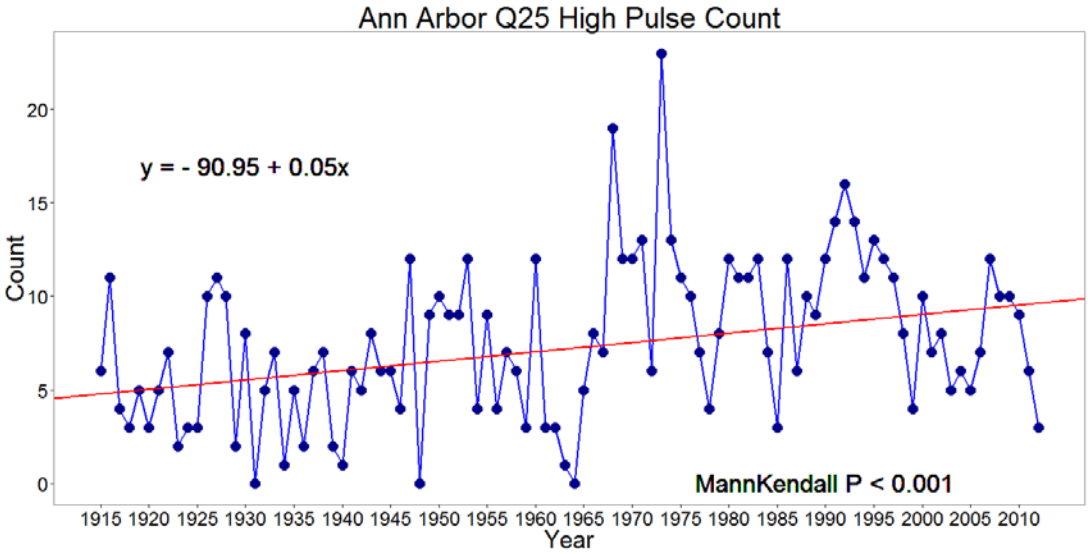


Figure 87 Repeated Mann-Kendall Analysis on the Q25 high pulse count of the gauge “Ann Arbor”.

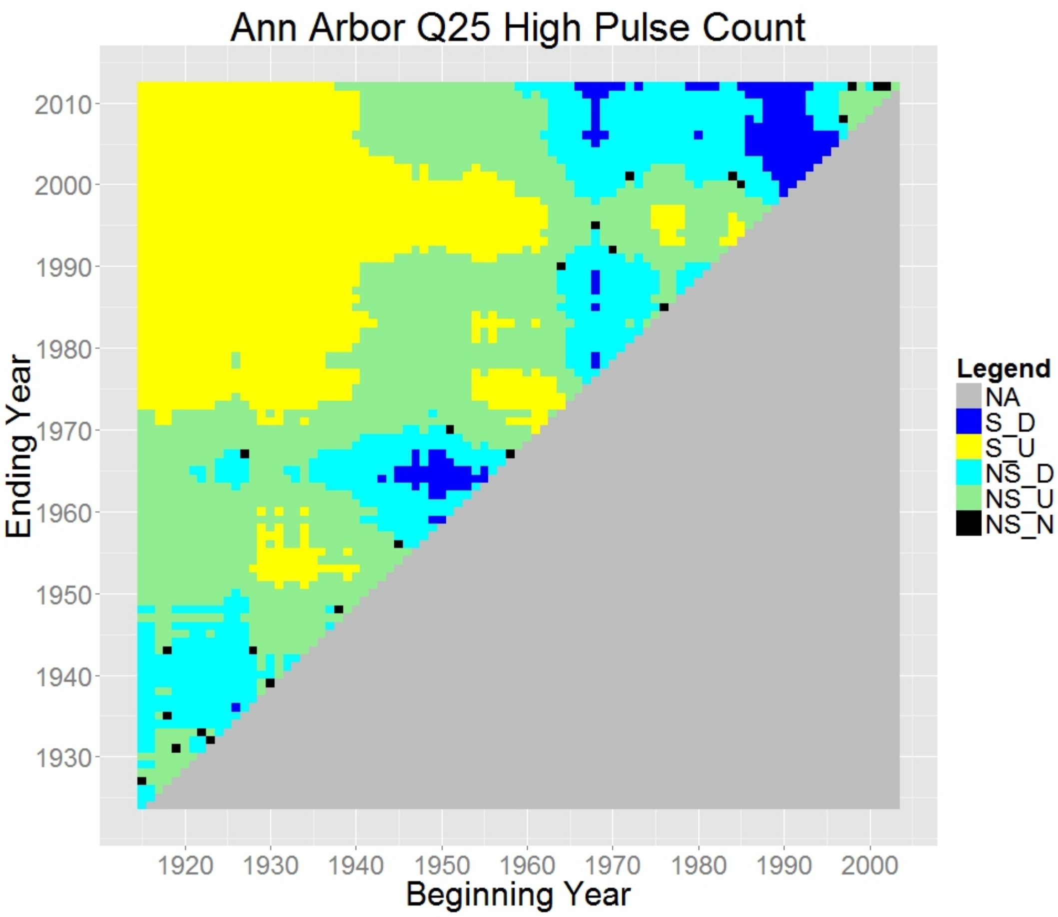


Figure 88 Q75 low pulse count of the gauge "Ann Arbor".

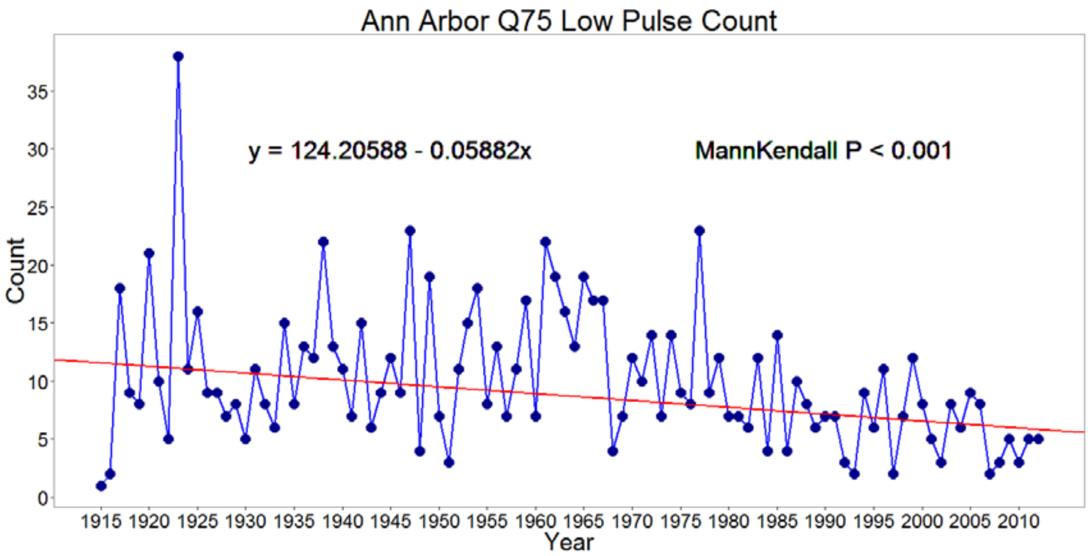


Figure 89 Repeated Mann-Kendall Analysis on the Q75 low pulse count of the gauge "Ann Arbor".

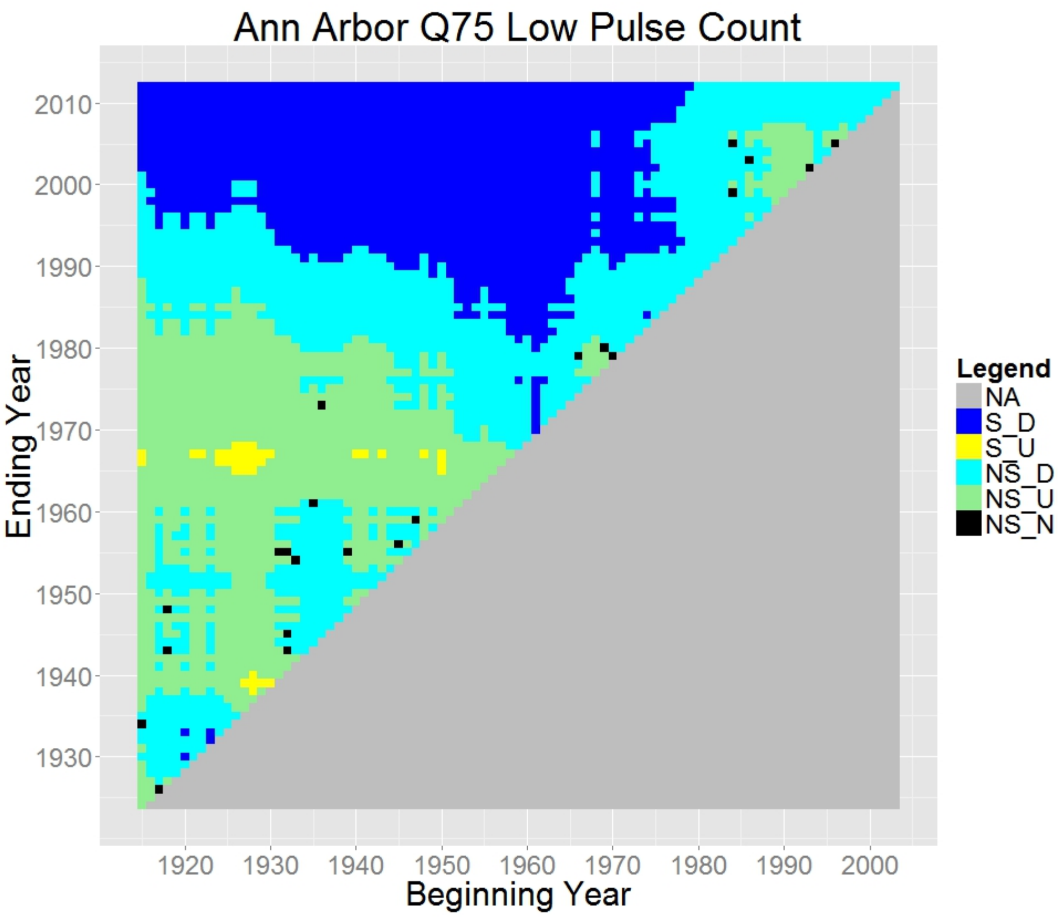


Figure 90 Q25 high pulse median duration of the gauge “Ann Arbor”.

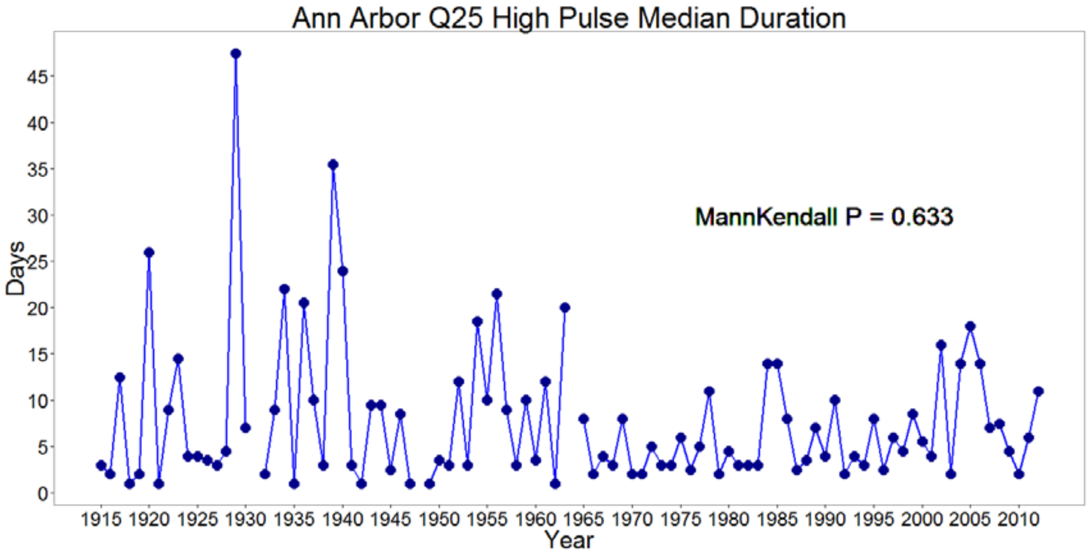


Figure 91 Repeated Mann-Kendall Analysis on the Q25 high pulse median duration of the gauge “Ann Arbor”.

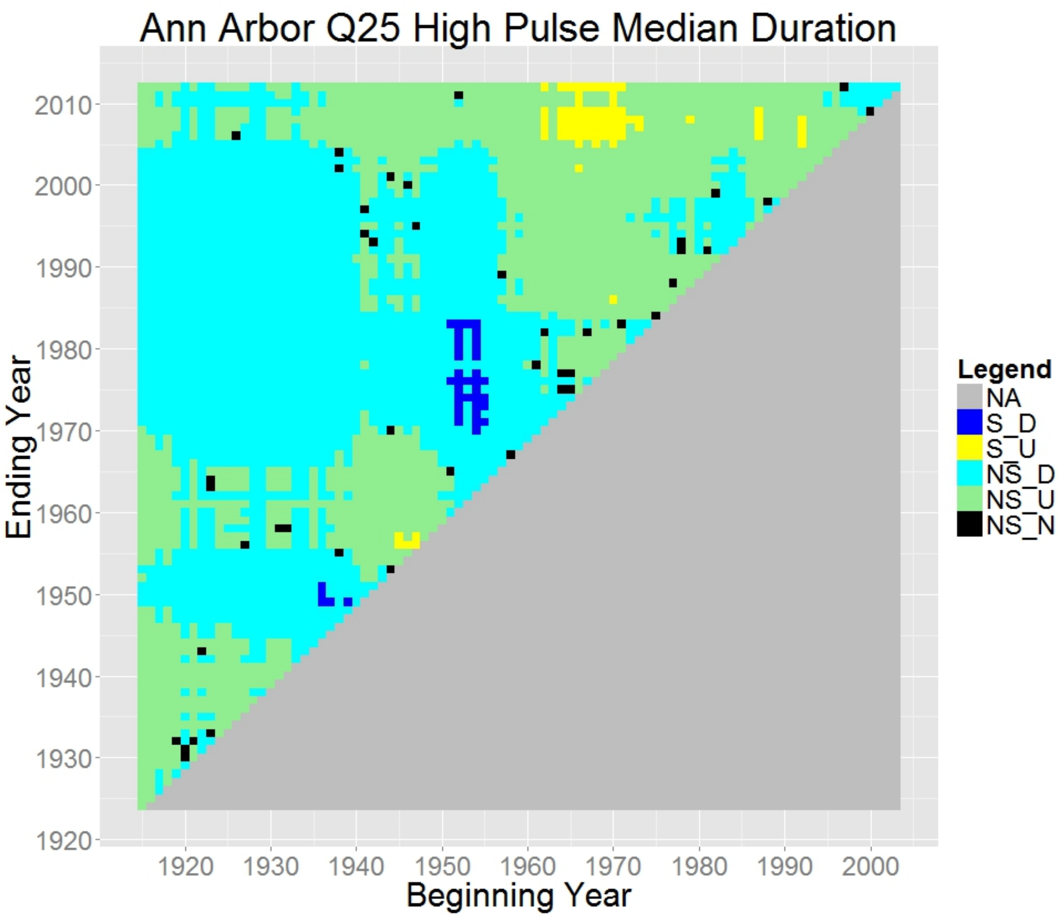


Figure 92 Q75 low pulse median duration of the gauge “Ann Arbor”.

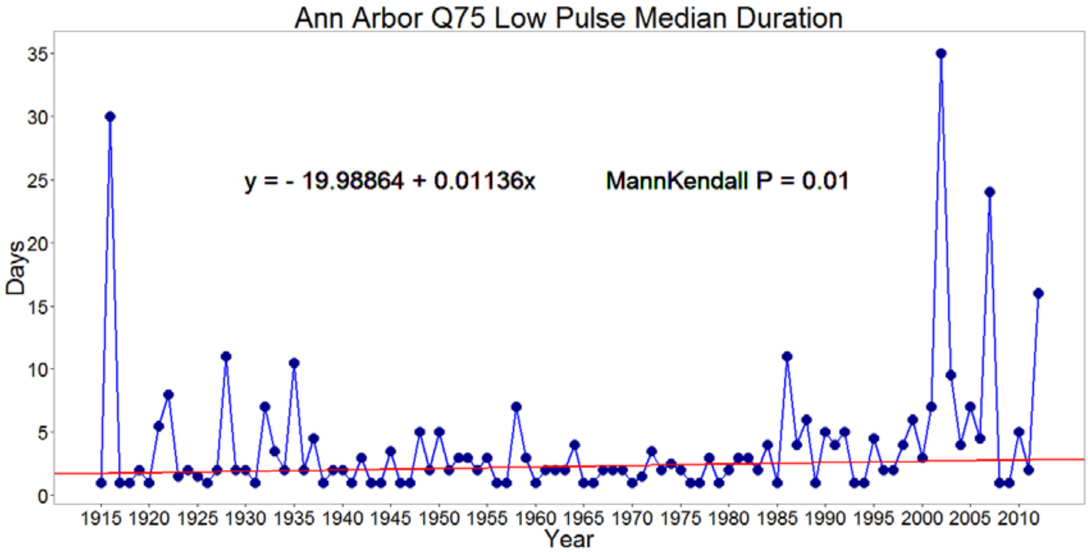


Figure 93 Repeated Mann-Kendall Analysis on the Q75 low pulse median duration of the gauge “Ann Arbor”.

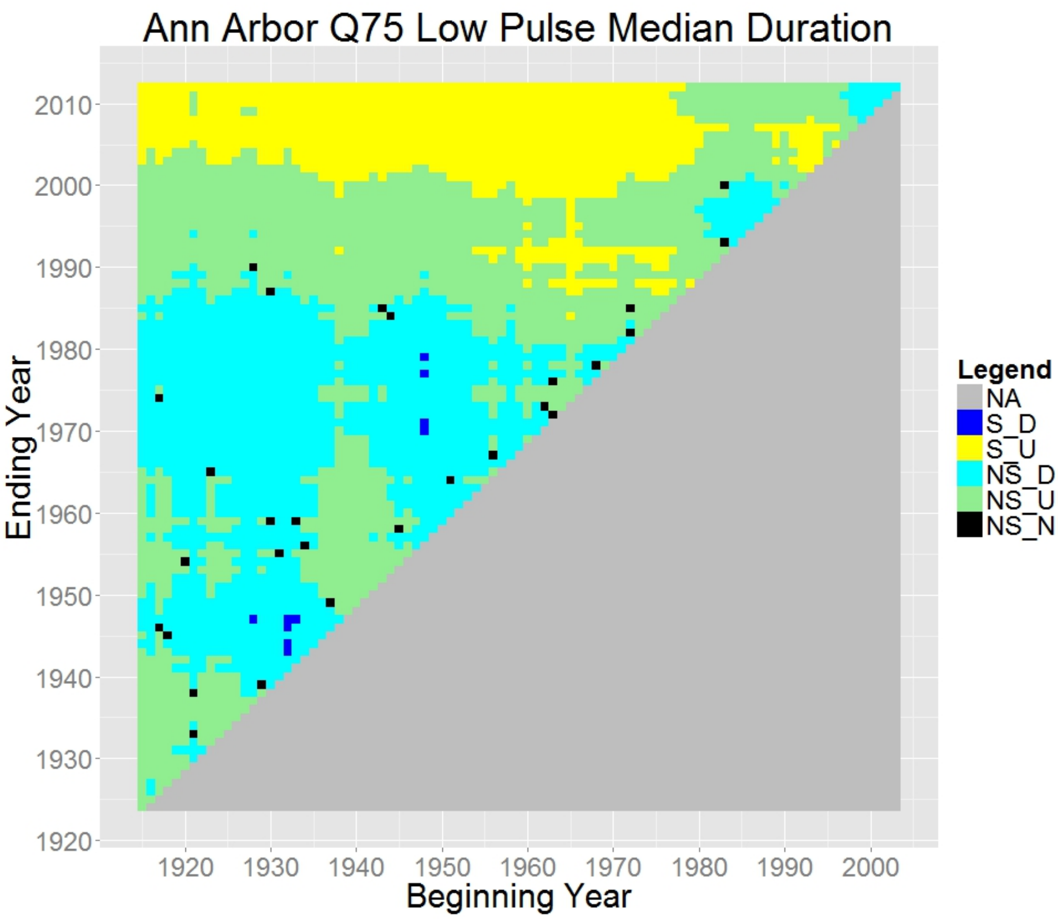


Figure 94 One standard deviation (1-SD) high pulse count of Huron River near the gauge "Ann Arbor".

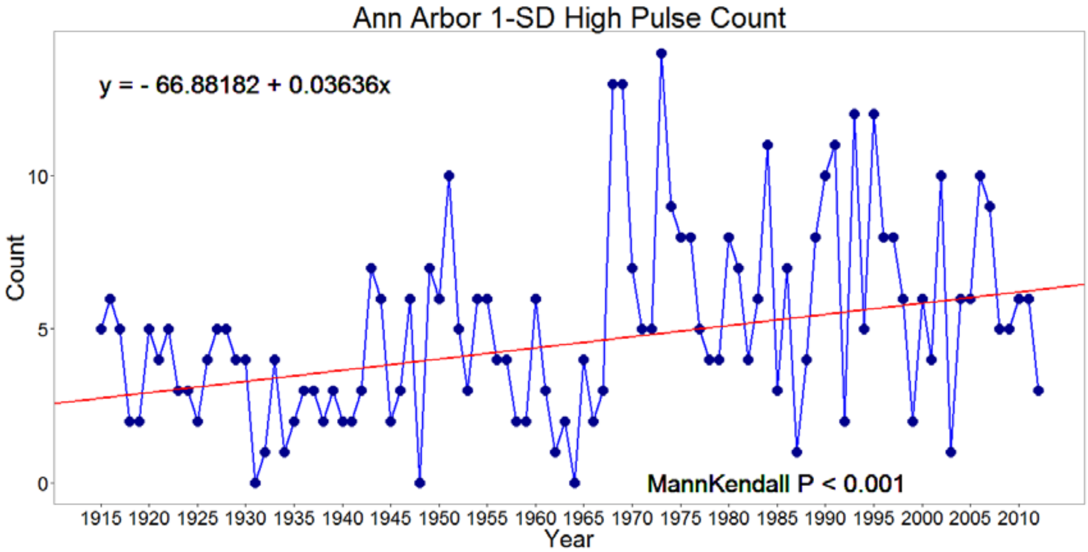


Figure 95 Repeated Mann-Kendall Analysis on the one standard deviation (1-SD) high pulse count of the gauge "Ann Arbor".

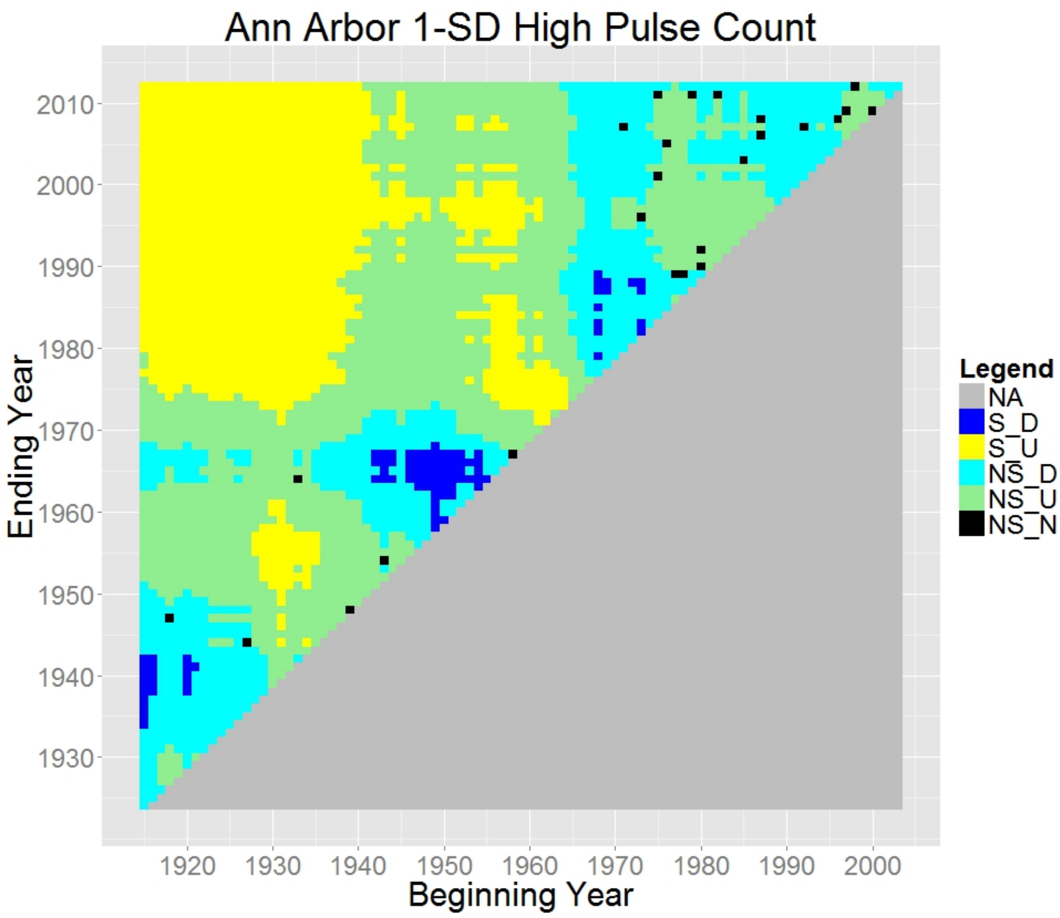


Figure 96 One standard deviation (1-SD) low pulse count of the gauge “Ann Arbor”.

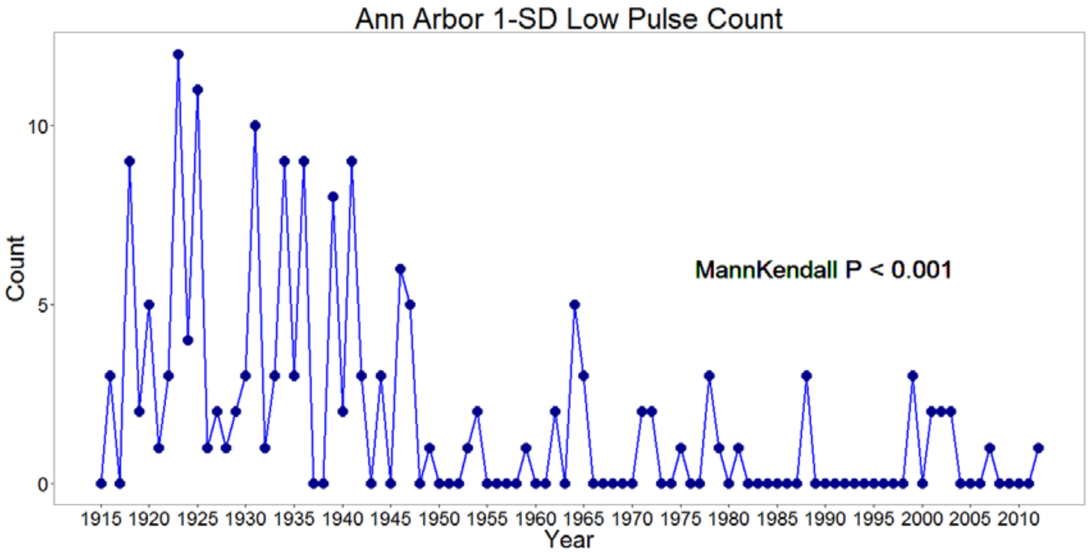


Figure 97 Repeated Mann-Kendall Analysis on the one standard deviation (1-SD) low pulse count of the gauge “Ann Arbor”.

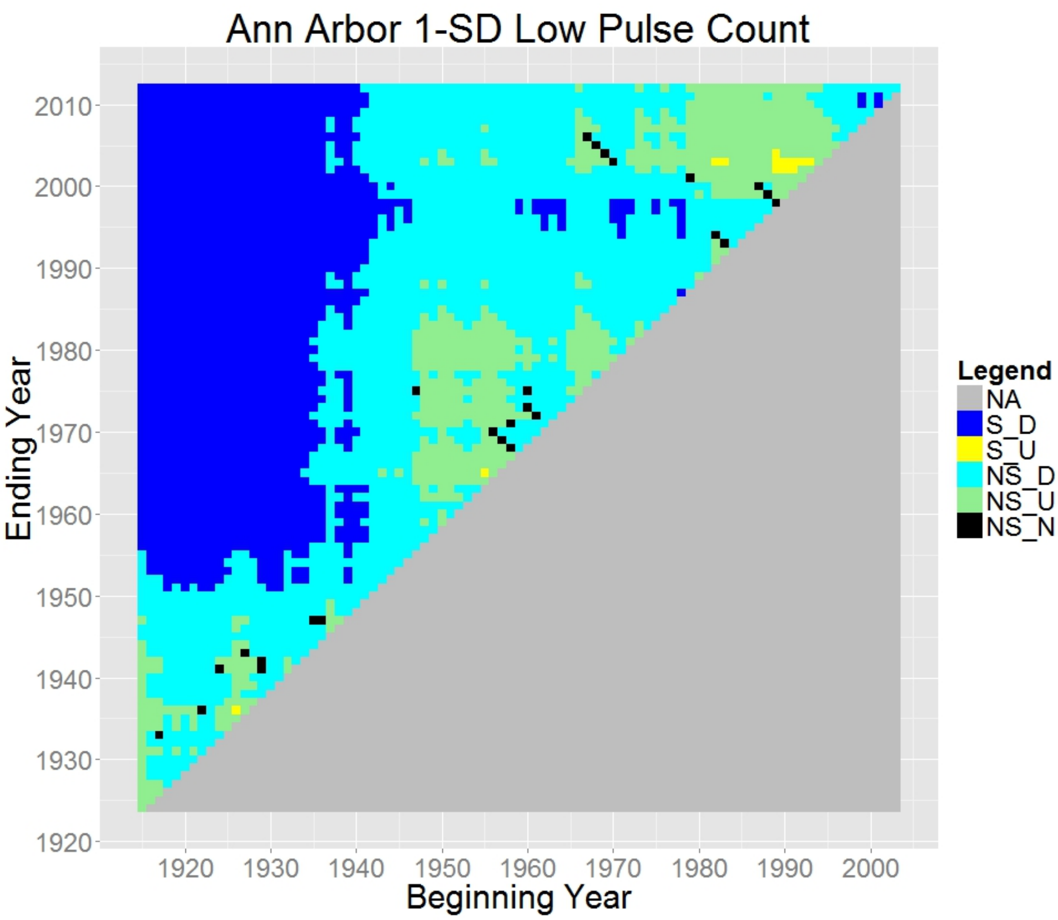


Figure 98 One standard deviation (1-SD) high pulse mean duration of the gauge “Ann Arbor”.

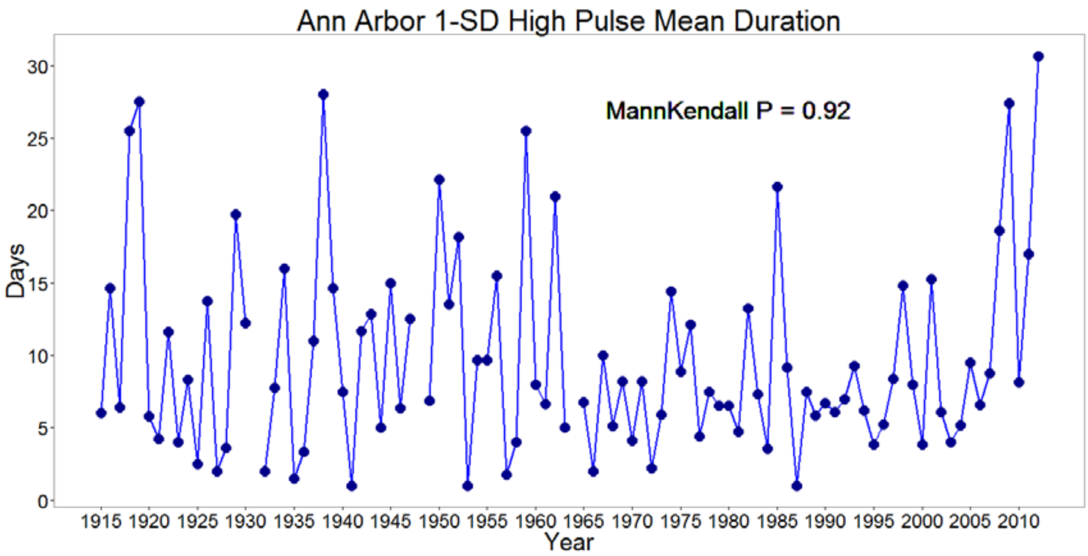


Figure 99 Repeated Mann-Kendall Analysis on the one standard deviation (1-SD) high pulse mean duration of the gauge “Ann Arbor”.

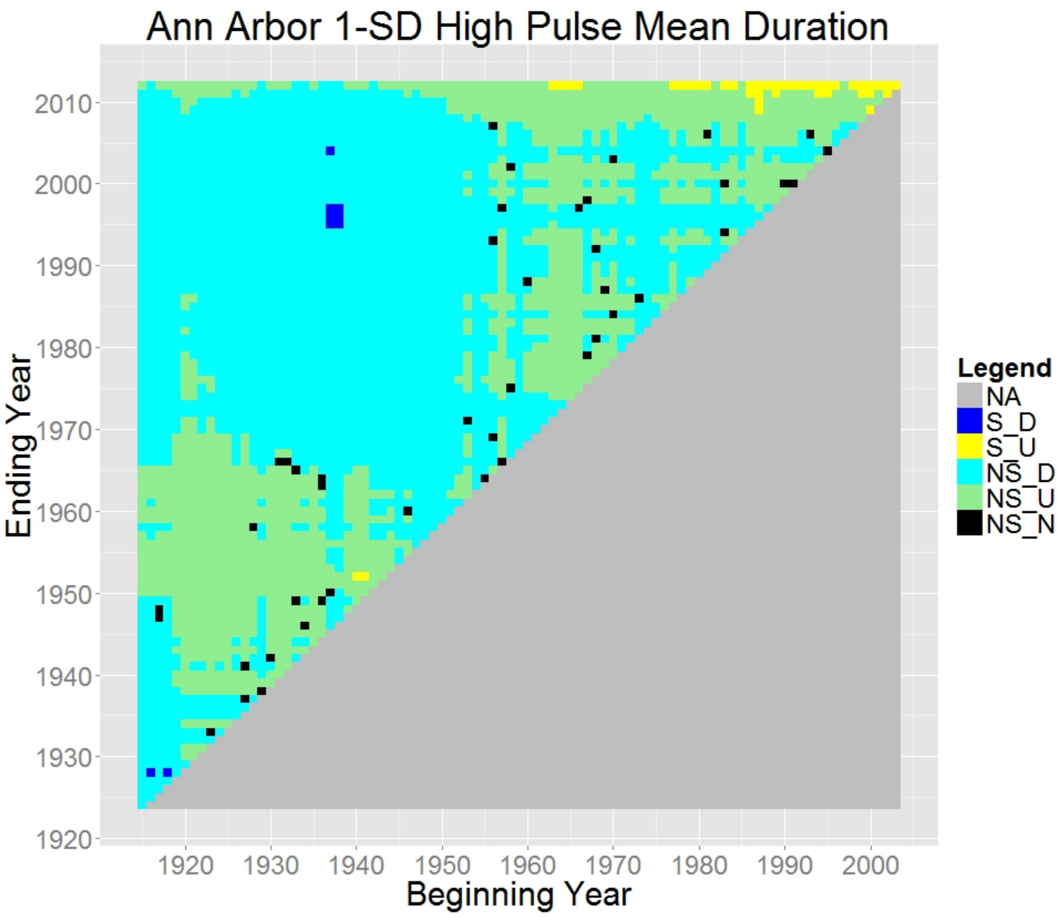


Figure 100 One standard deviation (1-SD) low pulse mean duration of the gauge “Ann Arbor”.

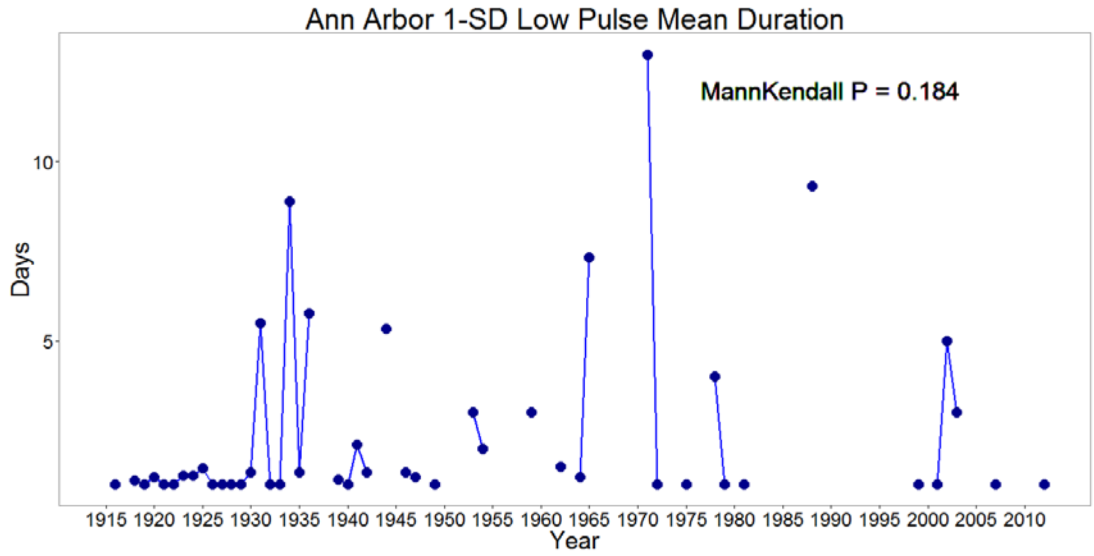


Figure 101 Repeated Mann-Kendall Analysis on the one standard deviation (1-SD) low pulse mean duration of the gauge "Ann Arbor".

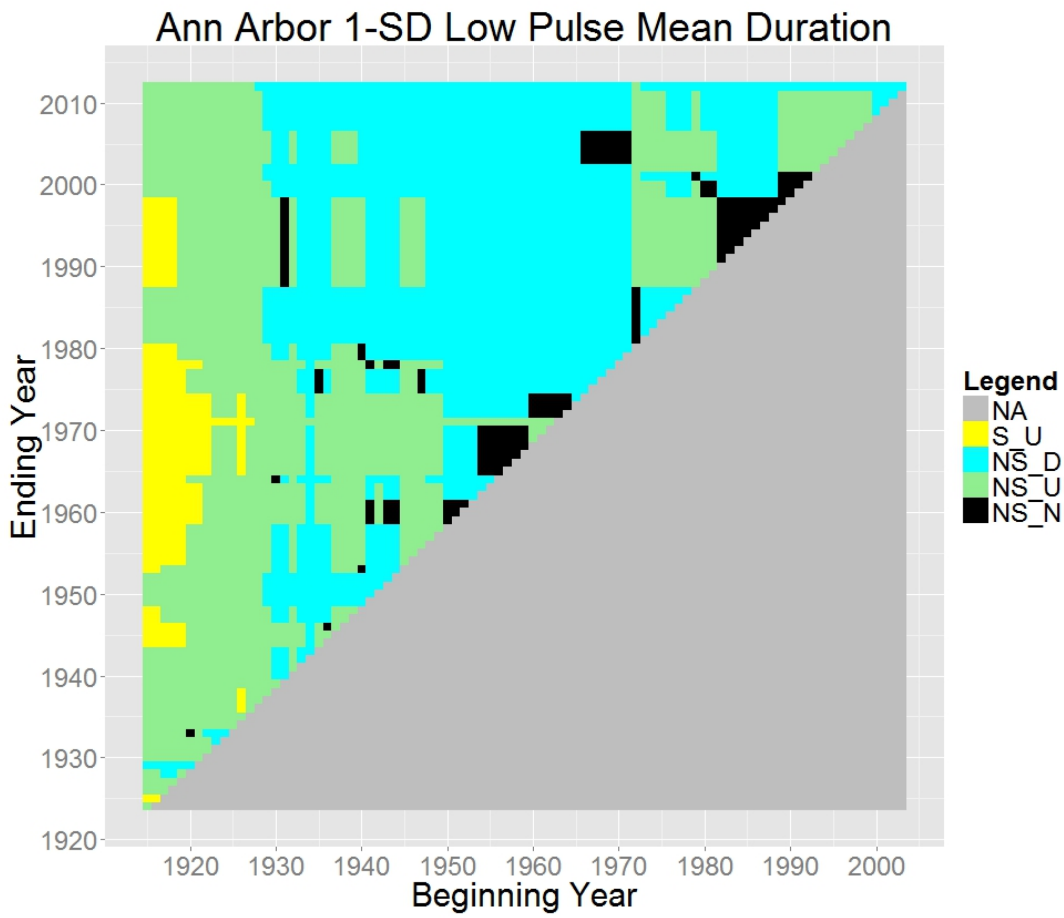


Figure 102 Mean rise rate of the gauge "Ann Arbor".

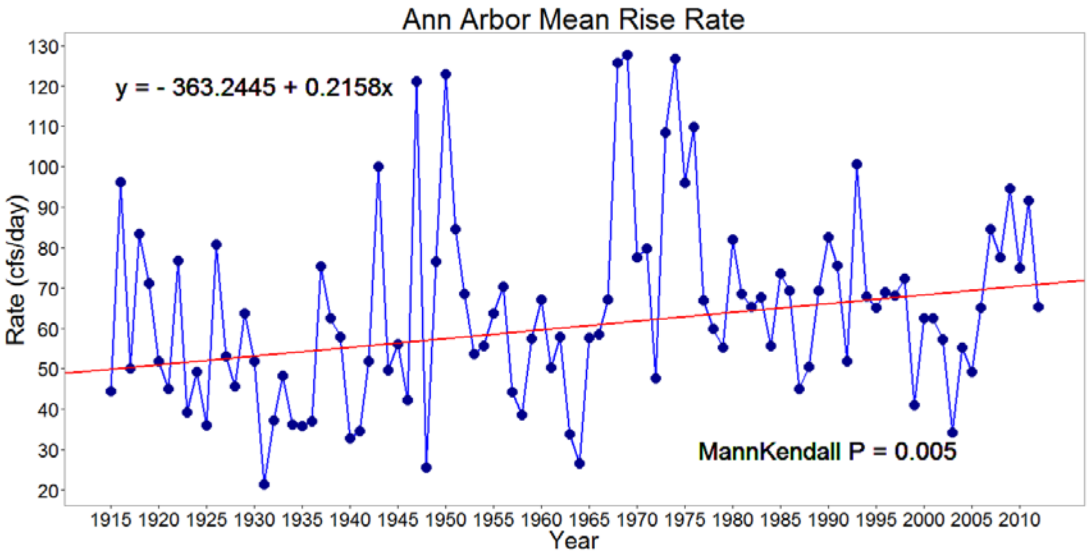


Figure 103 Repeated Mann-Kendall Analysis on the mean rise rate of the gauge "Ann Arbor".

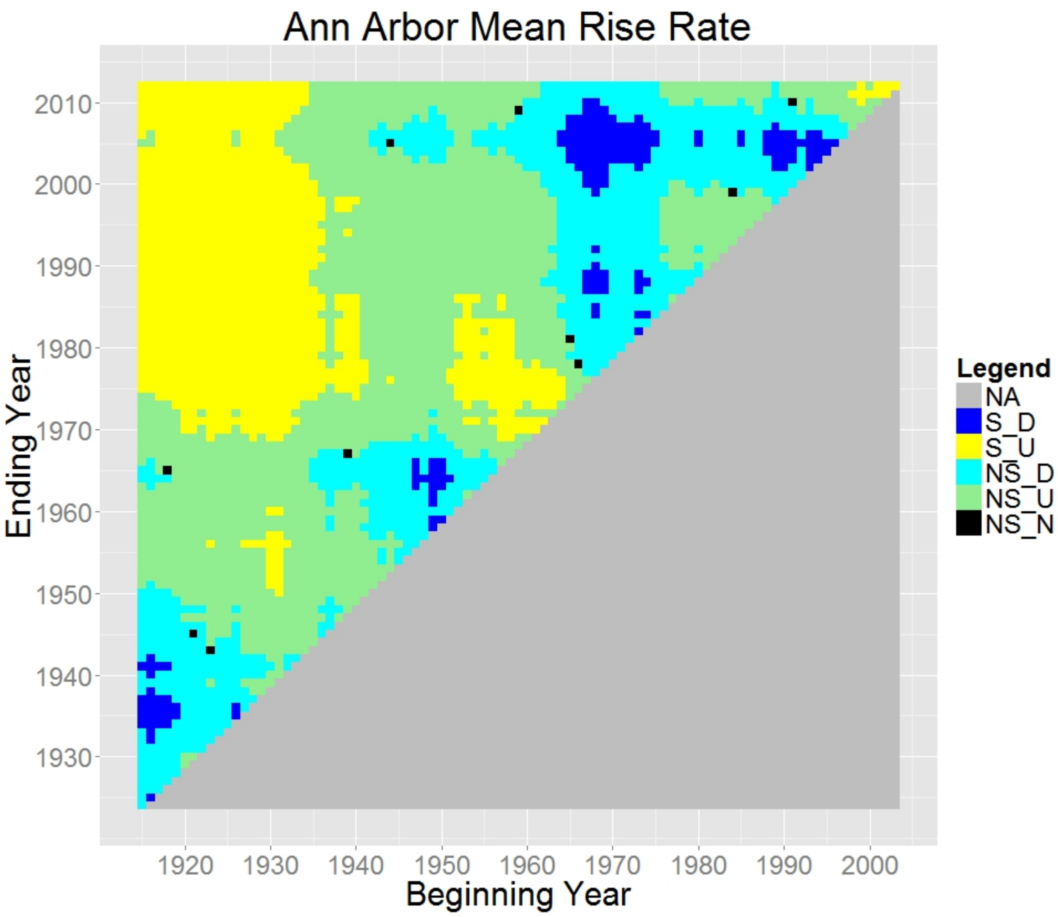


Figure 104 Mean fall rate of the gauge "Ann Arbor".

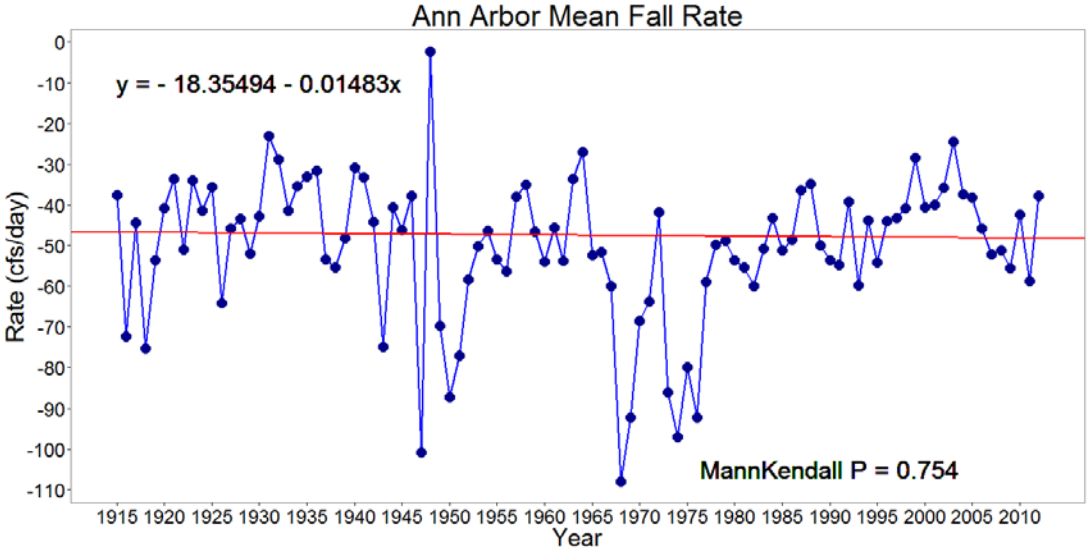


Figure 105 Repeated Mann-Kendall Analysis on the mean fall rate of the gauge "Ann Arbor".

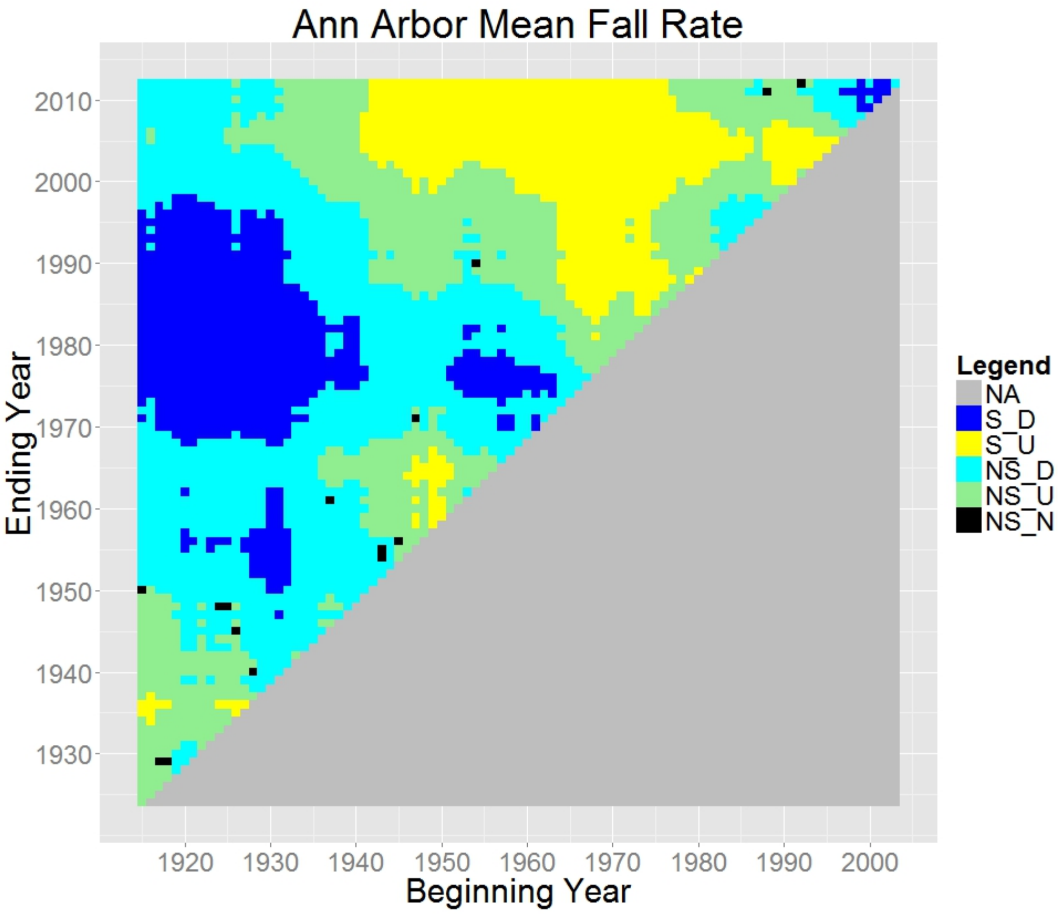


Figure 106 Median rise rate of Huron Riverof the gauge "Ann Arbor".

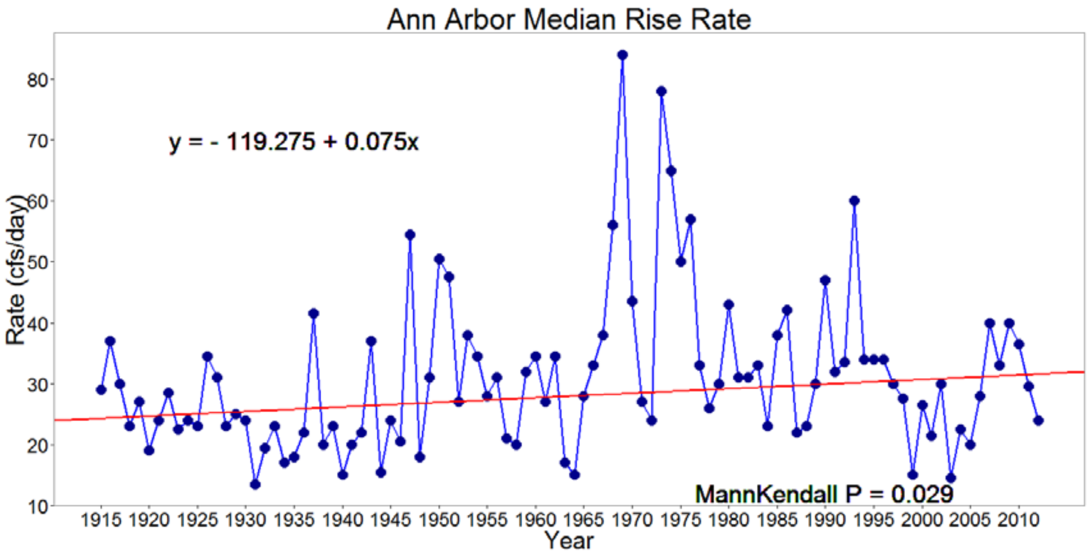


Figure 107 Repeated Mann-Kendall Analysis on the median rise rate of the gauge "Ann Arbor".

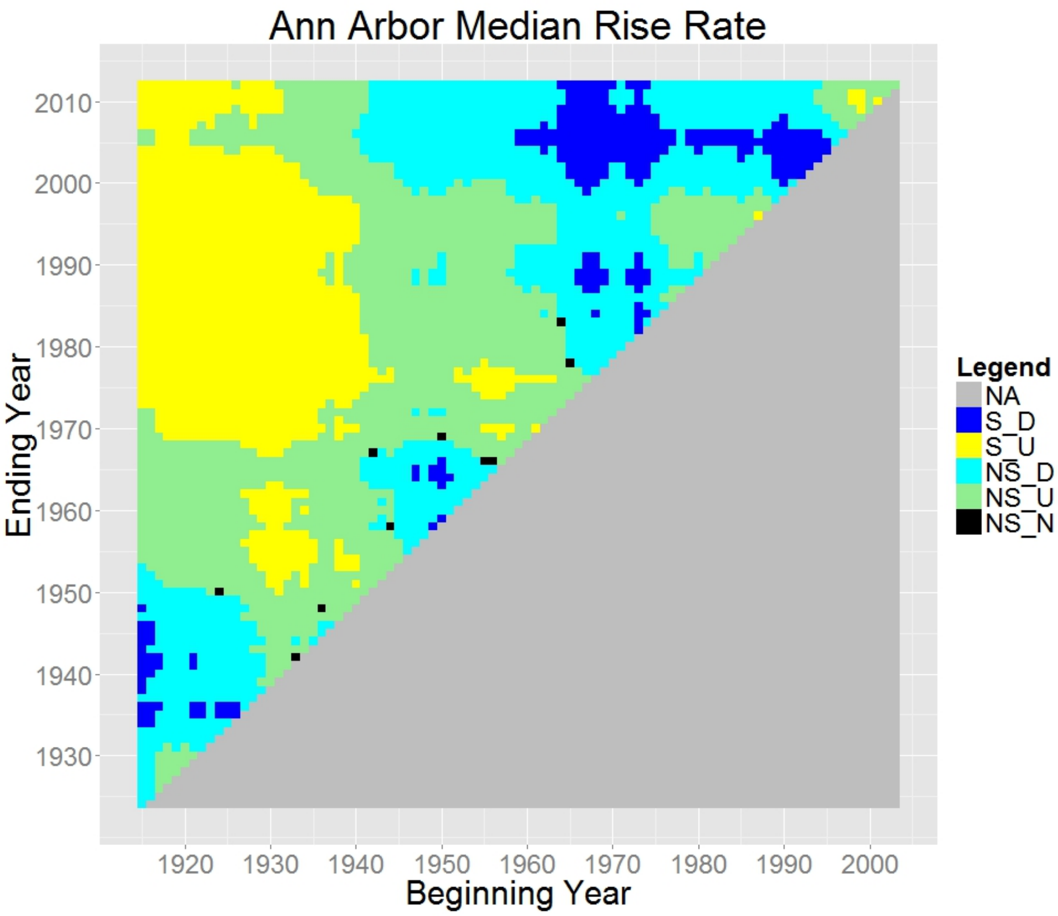


Figure 108 Median fall rate of the gauge “Ann Arbor”.

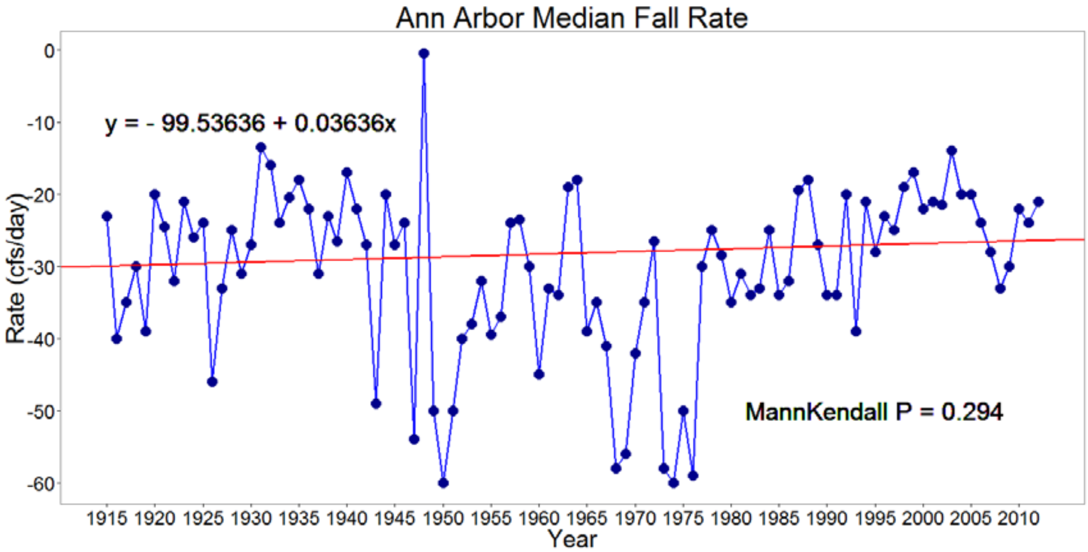


Figure 109 Repeated Mann-Kendall Analysis on the median fall rate of the gauge “Ann Arbor”.

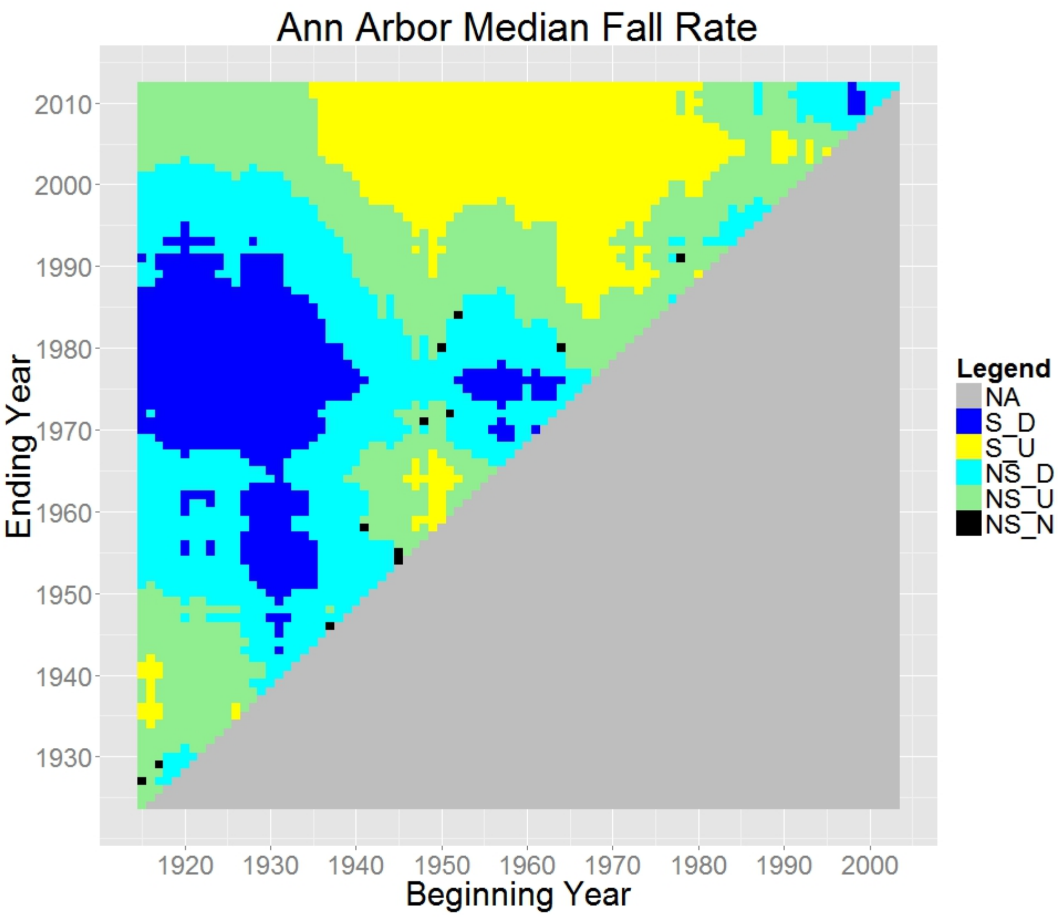


Figure 110 Reversals of the gauge “Ann Arbor”.

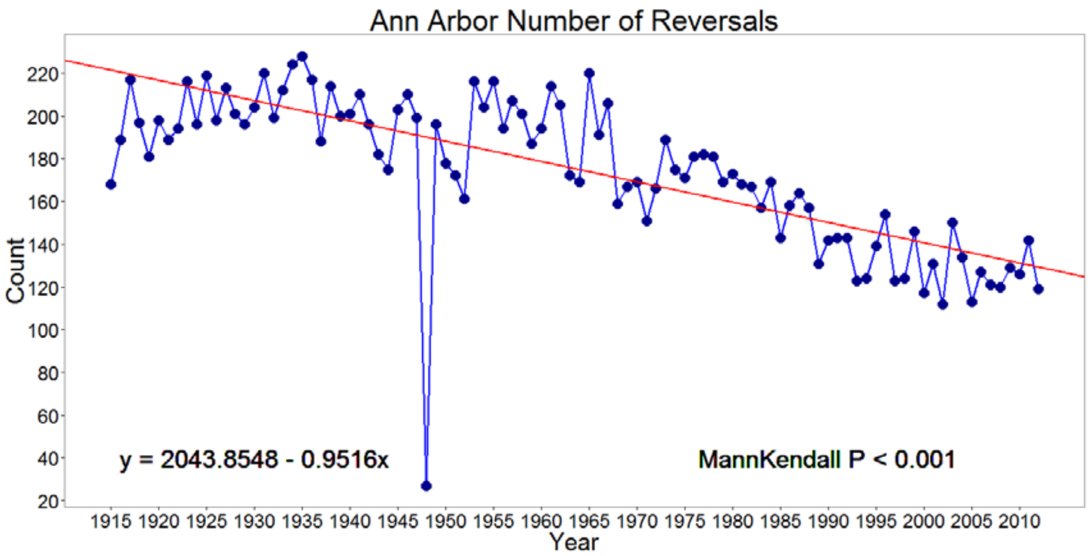
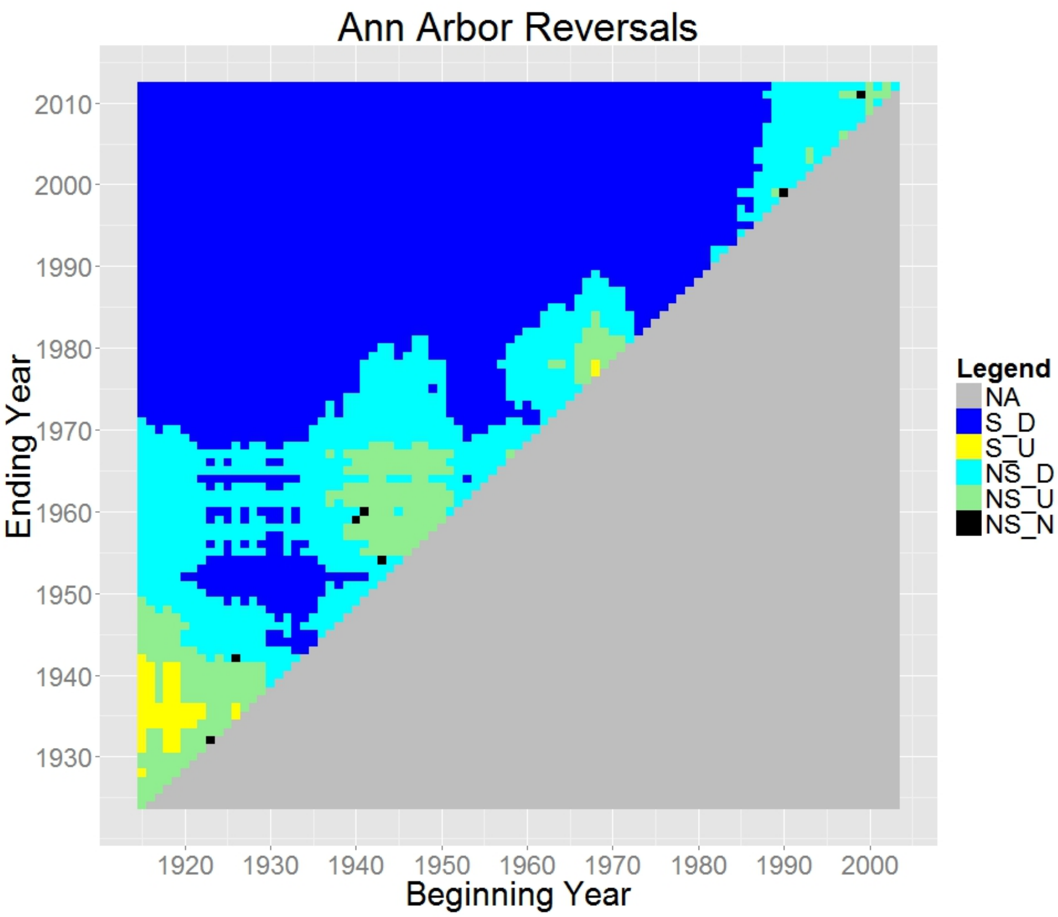


Figure 111 Repeated Mann-Kendall Analysis on reversals of the gauge “Ann Arbor”.



Appendix 3 - Precipitation

Figure 1 Mann-Kendall plot for annual mean precipitation from 1895 to 2013 (Commerce)

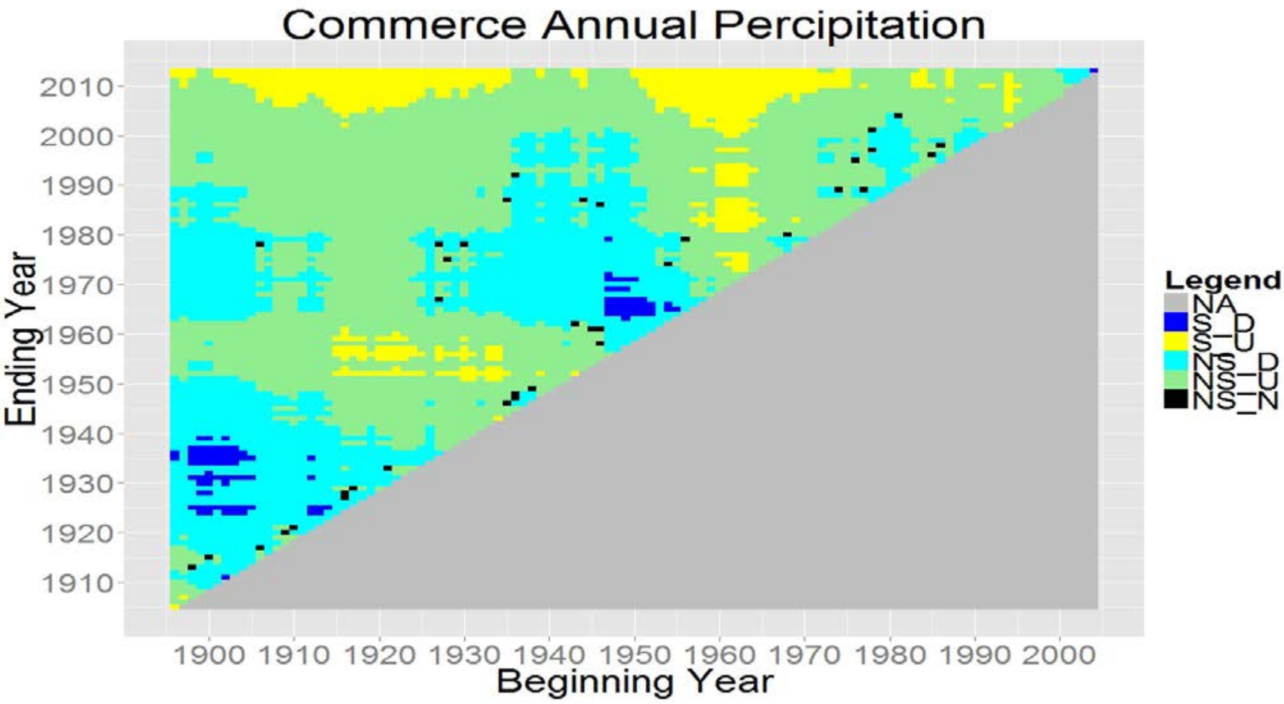


Figure 2 Commerce annual mean precipitation change from 1915 to 2013

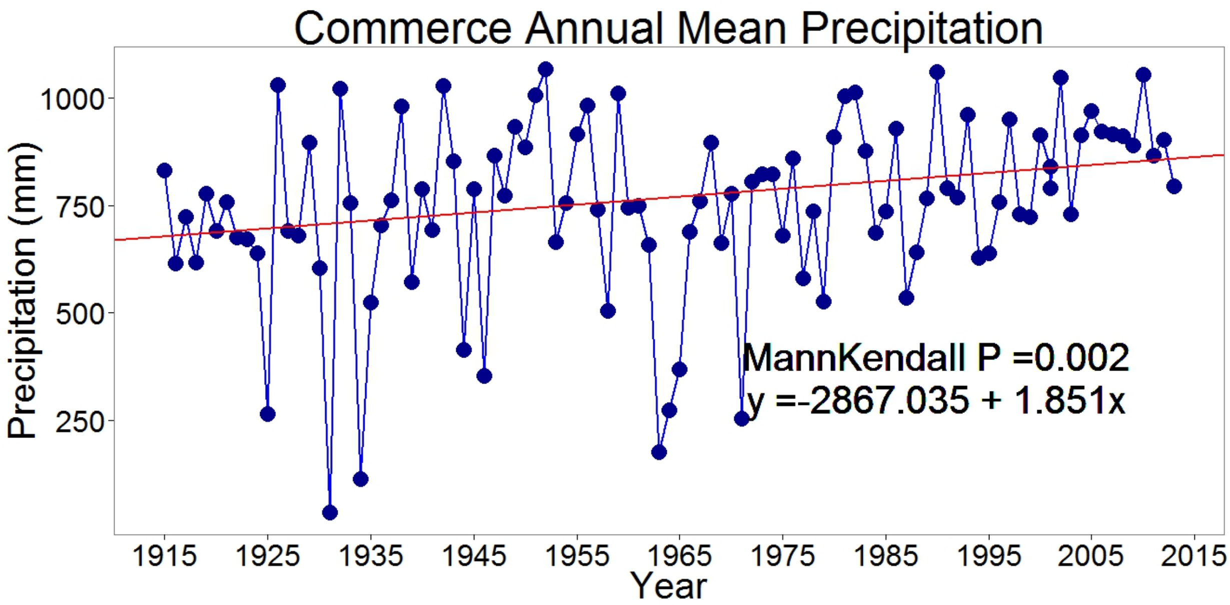


Figure 3 Mann-Kendall plot for annual mean precipitation from 1895 to 2013 (Milford)

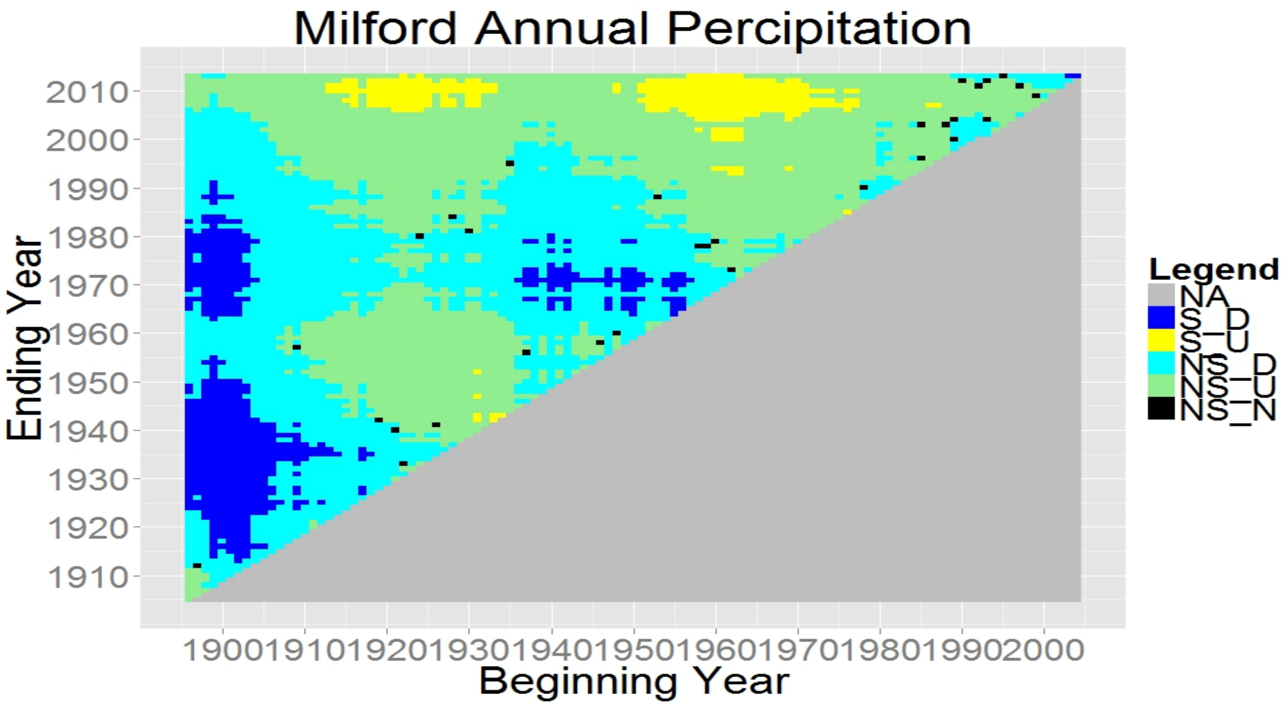


Figure 4 Milford annual mean precipitation change from 1915 to 2013

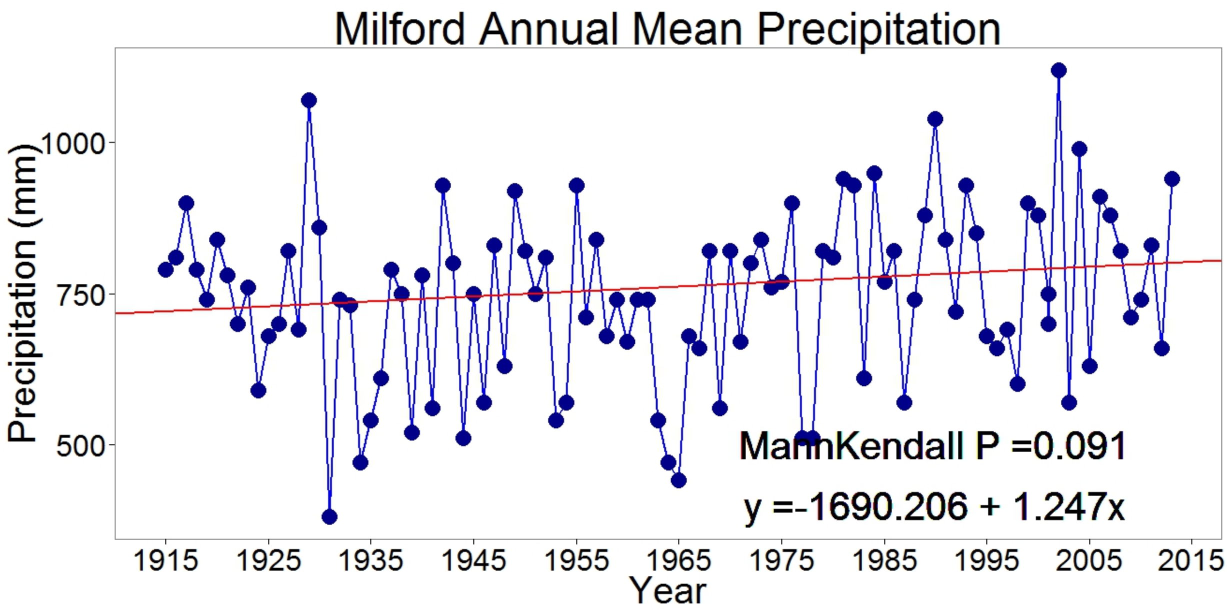


Figure 5 Mann-Kendall plot for annual mean precipitation from 1895 to 2013 (New Hudson)

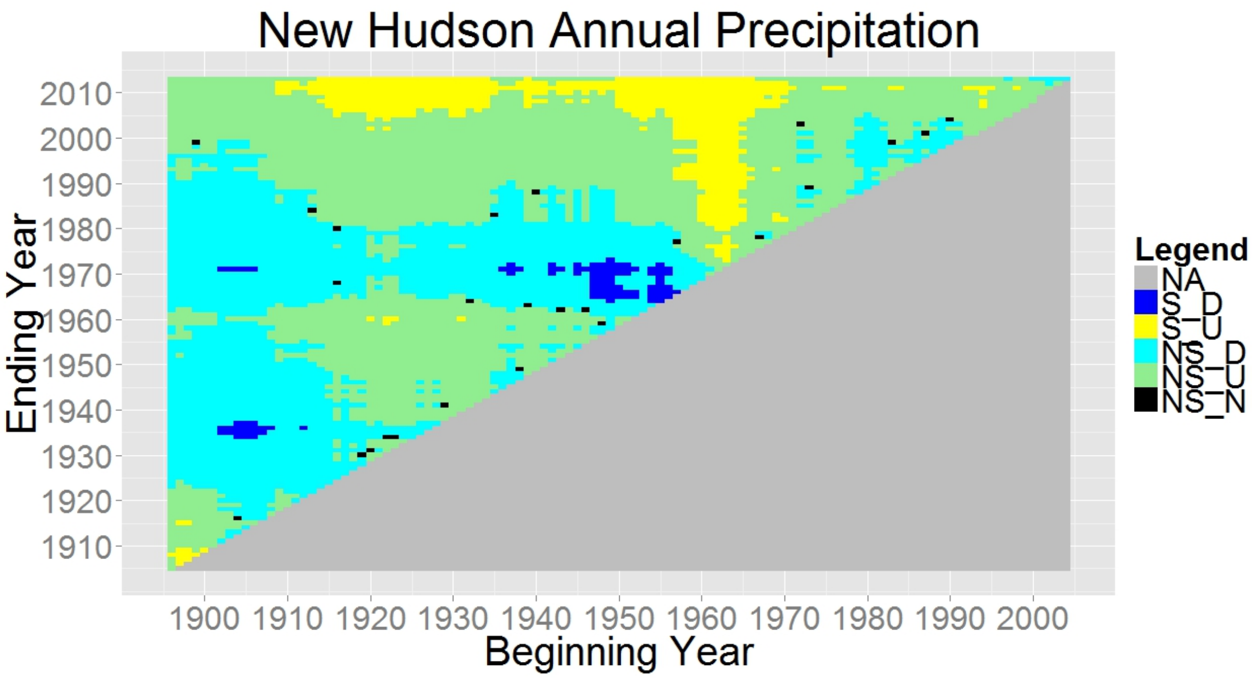


Figure 6 New Hudson annual mean precipitation change from 1915 to 2013

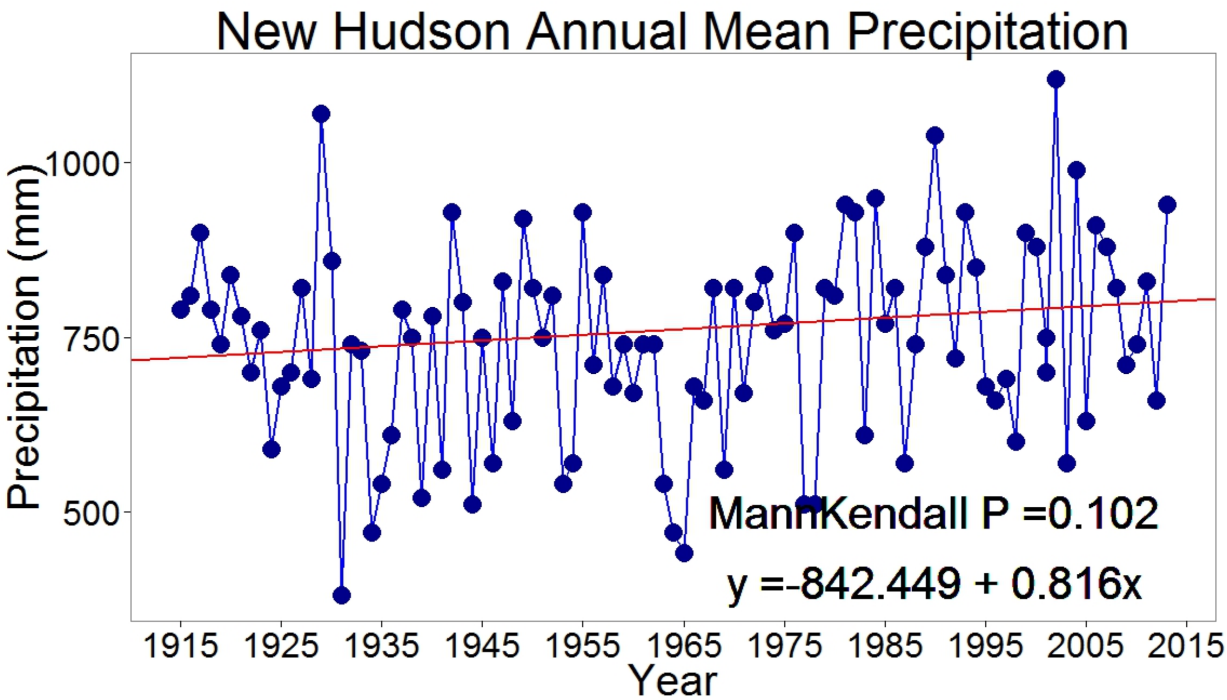


Figure 7 Mann-Kendall plot for annual mean precipitation from 1895 to 2013 (Hamburg)

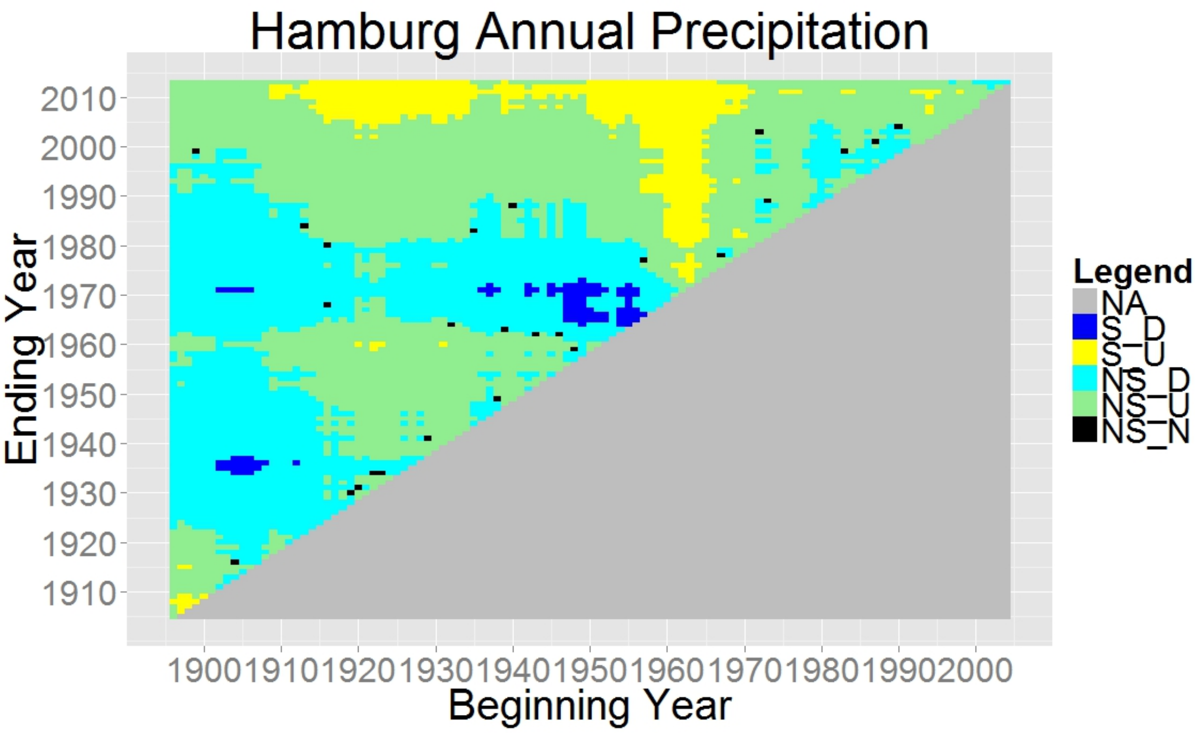


Figure 8 Hamburg annual mean precipitation change from 1915 to 2013

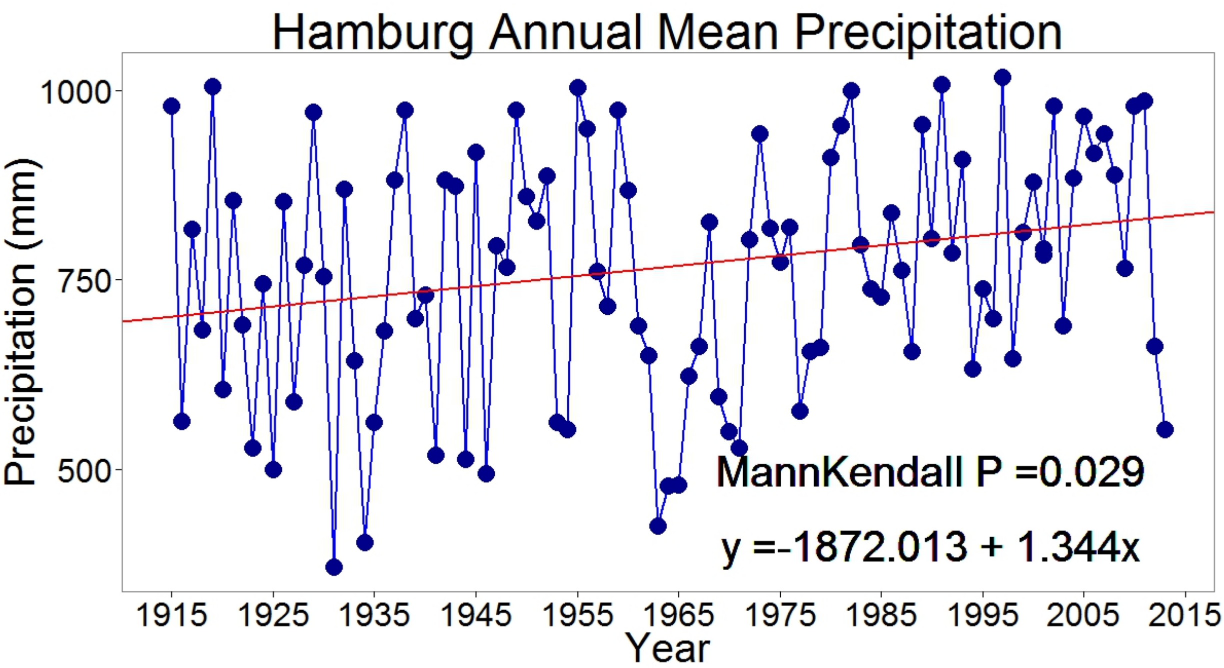


Figure 9 Mann-Kendall plot for annual mean precipitation from 1895 to 2013 (Dexter)

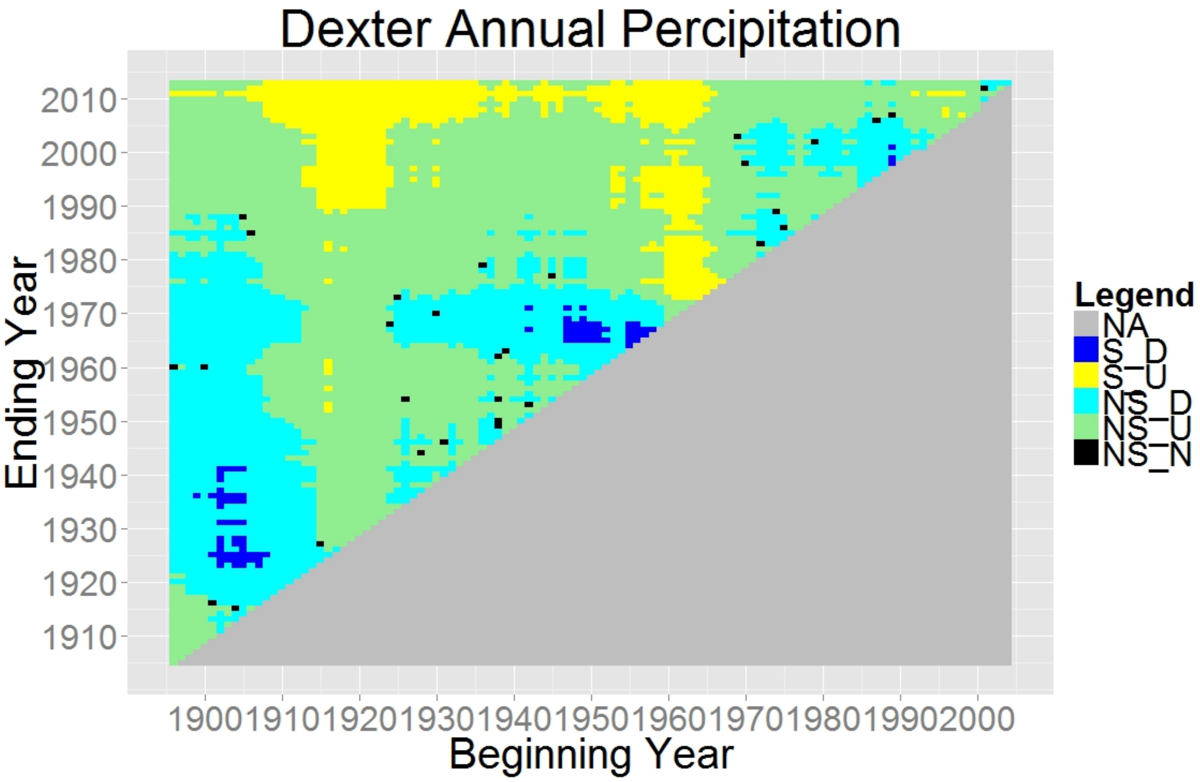


Figure 10 Dexter annual mean precipitation change from 1915 to 2013

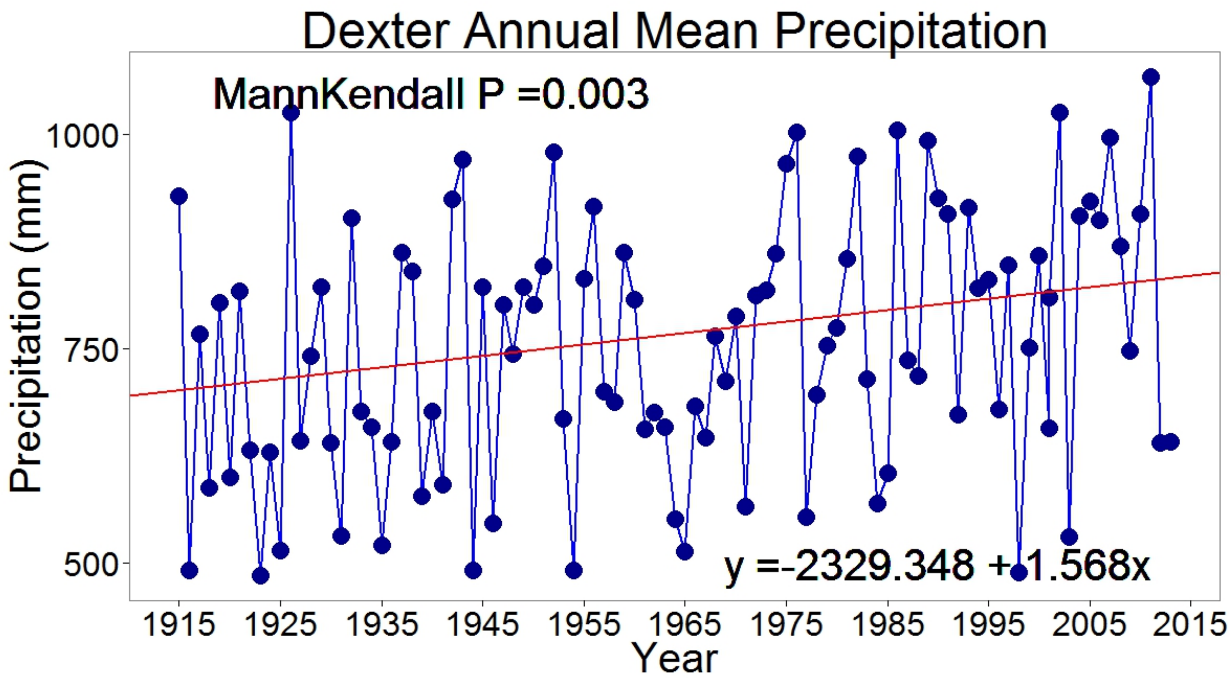


Figure 11 Mann-Kendall plot for annual mean precipitation from 1895 to 2013 (Ypslanti)

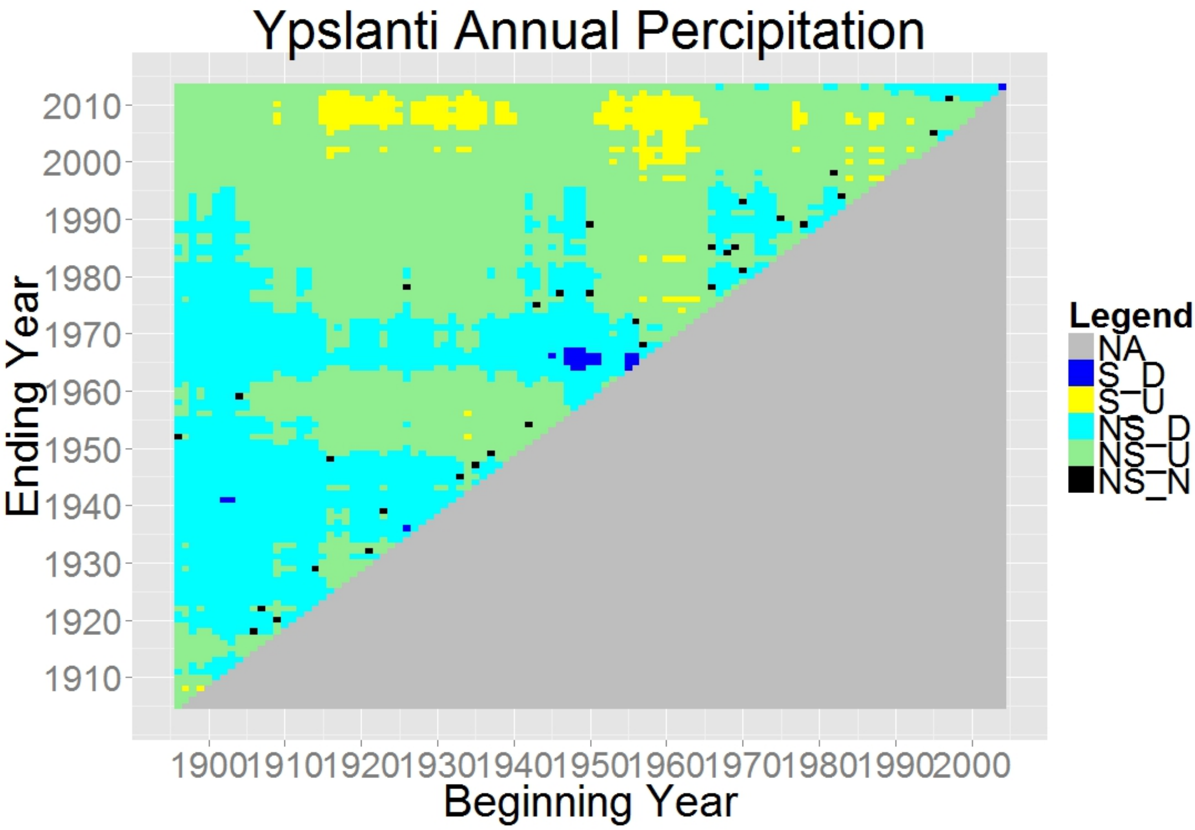
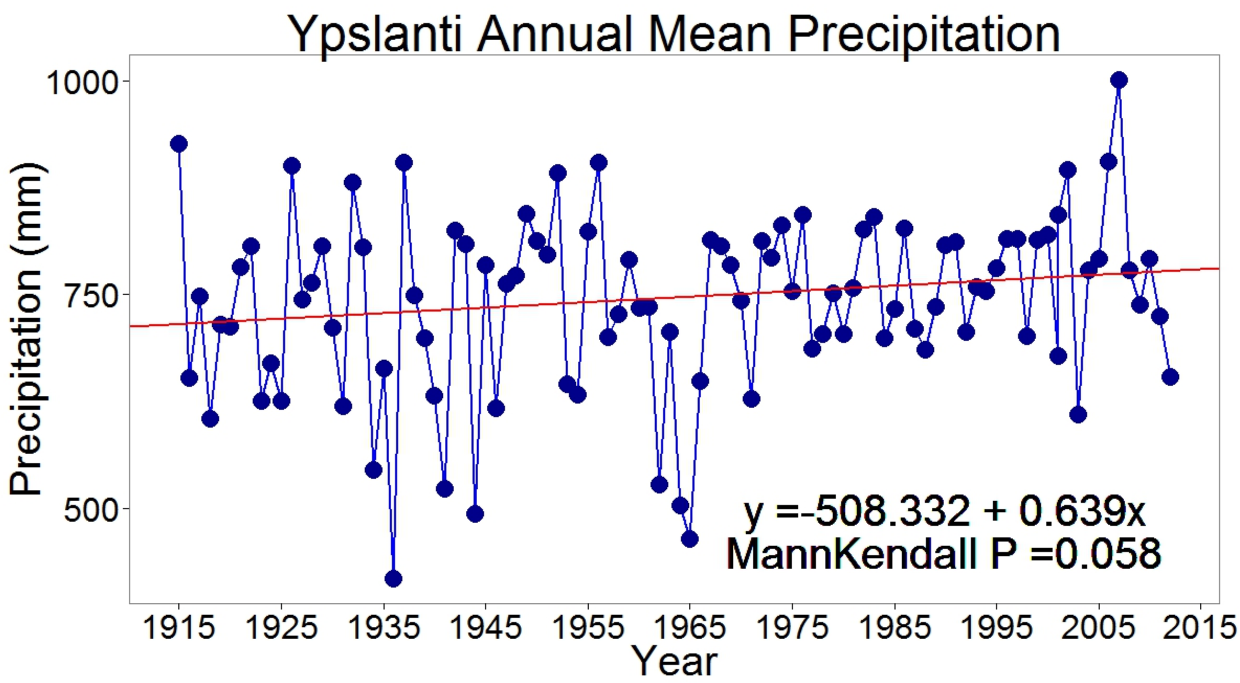


Figure 12 Ypslanti annual mean precipitation change from 1915 to 2013



Appendix 5 – Land Cover Change

Table 1 Pre-1800 Land Cover Conditions

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	**Milford**	**New Hudson**	**Hamburg**	**Dexter**	**Ann Arbor**	**Ypsilanti**
0.1	0.173173	0.185873	0.197537	0.229617	0.234912	0.251718	0.248401
0.2	0.129137	0.141213	0.152358	0.183227	0.188347	0.204638	0.201419
0.3	0.092481	0.103592	0.113932	0.142912	0.147758	0.163241	0.160174
0.4	0.062653	0.072509	0.081799	0.108301	0.112787	0.127202	0.124337
0.5	0.039152	0.047509	0.055538	0.079053	0.083102	0.096223	0.093603
0.6	0.021528	0.028177	0.034768	0.054853	0.058401	0.070026	0.06769
0.7	0.009371	0.014138	0.019138	0.035413	0.0384	0.048355	0.046336
0.8	0.002308	0.005045	0.008326	0.020463	0.022839	0.03097	0.029298
0.9	1.47E-07	0.000585	0.002037	0.009756	0.011477	0.017649	0.01635
1	0.002137	0.000469	1.97E-09	0.003059	0.004087	0.008184	0.007281
1.1	0.008436	0.00443	0.001965	0.00016	0.000462	0.002382	0.001894
1.2	0.018636	0.012226	0.007701	0.000858	0.000407	6.14E-05	5.8E-06
1.3	0.032499	0.02363	0.016994	0.004969	0.003741	0.001054	0.001446
1.4	0.049805	0.038435	0.029647	0.01232	0.010294	0.005201	0.006053
1.5	0.070352	0.056449	0.045476	0.022749	0.019908	0.012354	0.013677
1.6	0.093953	0.077494	0.064312	0.036105	0.032435	0.022374	0.024177
1.7	0.120435	0.101404	0.085995	0.052248	0.047737	0.03513	0.037421
1.8	0.149639	0.128028	0.11038	0.071044	0.065683	0.050499	0.053285
1.9	0.181415	0.157221	0.137328	0.09237	0.086152	0.068366	0.071652
2	0.215626	0.188852	0.166711	0.116109	0.109028	0.088621	0.092411
2.1	0.252145	0.222796	0.198409	0.142153	0.134206	0.111162	0.115459
2.2	0.290851	0.258939	0.232311	0.170397	0.161582	0.135892	0.140698

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
2.3	0.331634	0.297172	0.268312	0.200746	0.191061	0.16272	0.168036
2.4	0.37439	0.337394	0.306312	0.233108	0.222554	0.191558	0.197386
2.5	0.419021	0.379511	0.346221	0.267397	0.255975	0.222326	0.228666
2.6	0.465438	0.423434	0.38795	0.303532	0.291244	0.254945	0.261797
2.7	0.513555	0.469079	0.431419	0.341436	0.328285	0.289343	0.296705
2.8	0.563293	0.51637	0.476551	0.381037	0.367027	0.32545	0.333321
2.9	0.614576	0.565231	0.523273	0.422266	0.407401	0.3632	0.371578
3	0.667335	0.615594	0.571518	0.465058	0.449342	0.402531	0.411414
3.1	0.721503	0.667394	0.62122	0.509351	0.492791	0.443383	0.452768
3.2	0.777018	0.720569	0.67232	0.555088	0.537689	0.485699	0.495584
3.3	0.833823	0.775061	0.724759	0.602213	0.583981	0.529426	0.539808
3.4	0.891861	0.830815	0.778484	0.650673	0.631615	0.574513	0.585389
3.5	0.95108	0.887781	0.833444	0.700418	0.68054	0.62091	0.632277
3.6	1.011432	0.945907	0.889588	0.751401	0.730711	0.668573	0.680426
3.7	1.07287	1.005149	0.946872	0.803577	0.782082	0.717455	0.729791
3.8	1.135349	1.065462	1.005251	0.856902	0.834609	0.767516	0.780331
3.9	1.198828	1.126804	1.064683	0.911336	0.888253	0.818715	0.832005
4	1.263268	1.189136	1.12513	0.96684	0.942974	0.871013	0.884774
4.1	1.328632	1.252421	1.186554	1.023376	0.998736	0.924374	0.938602
4.2	1.394883	1.316623	1.248918	1.080909	1.055502	0.978763	0.993453
4.3	1.461988	1.381707	1.31219	1.139405	1.11324	1.034146	1.049294
4.4	1.529915	1.447642	1.376336	1.198832	1.171916	1.09049	1.106093
4.5	1.598634	1.514396	1.441325	1.259158	1.231499	1.147766	1.163818

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
4.6	1.668115	1.581942	1.507129	1.320354	1.291961	1.205943	1.22244
4.7	1.738332	1.65025	1.573719	1.382392	1.353272	1.264994	1.281931
4.8	1.809257	1.719294	1.641069	1.445245	1.415406	1.324891	1.342265
4.9	1.880866	1.789049	1.709152	1.508887	1.478337	1.385608	1.403414
5	1.953135	1.859491	1.777944	1.573292	1.54204	1.44712	1.465354
5.1	2.026042	1.930596	1.847423	1.638437	1.606491	1.509405	1.528061
5.2	2.099564	2.002342	1.917565	1.7043	1.671666	1.572437	1.591512
5.3	2.173681	2.074709	1.988349	1.770858	1.737545	1.636196	1.655685
5.4	2.248372	2.147676	2.059754	1.83809	1.804106	1.700661	1.720559
5.5	2.32362	2.221223	2.131762	1.905976	1.871329	1.76581	1.786114
5.6	2.399406	2.295333	2.204353	1.974497	1.939194	1.831625	1.852329
5.7	2.475712	2.369987	2.277509	2.043633	2.007683	1.898086	1.919187
5.8	2.552522	2.445169	2.351213	2.113368	2.076777	1.965175	1.986668
5.9	2.629821	2.520862	2.425448	2.183684	2.14646	2.032875	2.054756
6	2.707592	2.59705	2.500198	2.254565	2.216714	2.101169	2.123434
6.1	2.785821	2.67372	2.575449	2.325993	2.287525	2.17004	2.192685
6.2	2.864494	2.750855	2.651185	2.397955	2.358875	2.239474	2.262494
6.3	2.943598	2.828442	2.727392	2.470435	2.430751	2.309454	2.332846
6.4	3.02312	2.906469	2.804056	2.543419	2.503138	2.379967	2.403726
6.5	3.103047	2.984922	2.881165	2.616894	2.576022	2.450998	2.47512
6.6	3.183368	3.063788	2.958706	2.690845	2.649391	2.522534	2.547015
6.7	3.264071	3.143057	3.036667	2.765261	2.72323	2.594562	2.619398
6.8	3.345144	3.222717	3.115036	2.840129	2.797528	2.667069	2.692257

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
6.9	3.426578	3.302757	3.193802	2.915437	2.872273	2.740042	2.765578
7	3.508363	3.383165	3.272954	2.991173	2.947453	2.813471	2.83935
7.1	3.590487	3.463933	3.352481	3.067328	3.023057	2.887344	2.913563
7.2	3.672943	3.545051	3.432374	3.143889	3.099075	2.961649	2.988204
7.3	3.75572	3.626508	3.512623	3.220847	3.175495	3.036376	3.063264
7.4	3.838811	3.708296	3.593219	3.298191	3.252309	3.111515	3.138732
7.5	3.922206	3.790406	3.674152	3.375912	3.329505	3.187056	3.214598
7.6	4.005897	3.87283	3.755414	3.454001	3.407075	3.262988	3.290852
7.7	4.089877	3.955559	3.836996	3.532449	3.485009	3.339304	3.367486
7.8	4.174138	4.038586	3.91889	3.611247	3.5633	3.415993	3.44449
7.9	4.258673	4.121902	4.001089	3.690386	3.641937	3.493047	3.521855
8	4.343474	4.205501	4.083584	3.769858	3.720913	3.570457	3.599573
8.1	4.428535	4.289376	4.166369	3.849655	3.800221	3.648215	3.677637
8.2	4.513849	4.373519	4.249436	3.929771	3.879851	3.726314	3.756037
8.3	4.59941	4.457923	4.332778	4.010196	3.959797	3.804745	3.834766
8.4	4.685211	4.542584	4.416389	4.090925	4.040052	3.883501	3.913817
8.5	4.771247	4.627493	4.500262	4.171949	4.120608	3.962574	3.993182
8.6	4.857512	4.712646	4.584391	4.253263	4.201458	4.041958	4.072855
8.7	4.944	4.798036	4.66877	4.334859	4.282597	4.121646	4.152828
8.8	5.030706	4.883658	4.753393	4.416732	4.364016	4.201631	4.233096
8.9	5.117625	4.969506	4.838255	4.498875	4.445711	4.281906	4.313651
9	5.204751	5.055575	4.923349	4.581282	4.527675	4.362466	4.394487
9.1	5.29208	5.14186	5.008671	4.663948	4.609902	4.443304	4.475599

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
9.2	5.379607	5.228356	5.094216	4.746866	4.692387	4.524414	4.55698
9.3	5.467327	5.315057	5.179978	4.830031	4.775123	4.60579	4.638624
9.4	5.555236	5.40196	5.265952	4.913438	4.858106	4.687428	4.720527
9.5	5.64333	5.48906	5.352134	4.997082	4.94133	4.76932	4.802683
9.6	5.731604	5.576353	5.438519	5.080958	5.024791	4.851463	4.885085
9.7	5.820054	5.663833	5.525104	5.16506	5.108482	4.933851	4.967731
9.8	5.908677	5.751497	5.611882	5.249385	5.192401	5.016479	5.050613
9.9	5.997468	5.839341	5.698851	5.333927	5.27654	5.099342	5.133728
10	6.086424	5.927362	5.786006	5.418681	5.360897	5.182436	5.217071

Table 2 1992 Land Cover Conditions

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
0.1	0.09953	0.102053	0.106108	0.118744	0.1225	0.128837	0.12679186
0.2	0.061121	0.063364	0.066986	0.078406	0.081834	0.087648	0.085767915
0.3	0.032995	0.03482	0.037796	0.04739	0.050323	0.055347	0.05371569
0.4	0.014046	0.015346	0.01751	0.024797	0.027102	0.031118	0.029805429
0.5	0.003323	0.004016	0.00524	0.009839	0.01141	0.014247	0.013306637
0.6	1.28E-06	2.41E-05	0.000208	0.001825	0.002578	0.004097	0.003573666
0.7	0.003362	0.002668	0.001738	0.000145	1.31E-05	0.000105	3.37483E-05
0.8	0.012778	0.011333	0.009233	0.004257	0.00319	0.001768	0.002176992
0.9	0.027696	0.025476	0.022166	0.01368	0.011638	0.008639	0.009547984
1	0.047631	0.044619	0.040072	0.027984	0.02494	0.020313	0.021738704

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
1.1	0.072151	0.068338	0.062538	0.046786	0.042719	0.036428	0.038382517
1.2	0.100874	0.096255	0.089192	0.06974	0.064636	0.056658	0.059149053
1.3	0.133458	0.128033	0.119705	0.096536	0.090388	0.080707	0.083739835
1.4	0.169597	0.163369	0.15378	0.126893	0.119698	0.108307	0.111884517
1.5	0.209018	0.201993	0.19115	0.160558	0.152318	0.139215	0.143337649
1.6	0.251474	0.243659	0.231574	0.197301	0.188018	0.17321	0.177875878
1.7	0.296742	0.288147	0.274833	0.236911	0.226594	0.210088	0.215295508
1.8	0.344621	0.335258	0.320731	0.279199	0.267856	0.249665	0.255410394
1.9	0.394929	0.384809	0.369087	0.323991	0.311632	0.291772	0.298050083
2	0.4475	0.436635	0.419737	0.371126	0.357764	0.336253	0.343058201
2.1	0.502182	0.490586	0.472533	0.420459	0.406107	0.382964	0.390291025
2.2	0.558839	0.546525	0.527336	0.471855	0.456528	0.431775	0.439616231
2.3	0.617342	0.604325	0.584022	0.525191	0.508903	0.482563	0.490911783
2.4	0.677578	0.663871	0.642475	0.580353	0.563119	0.535216	0.544064956
2.5	0.739439	0.725057	0.70259	0.637236	0.619072	0.58963	0.598971462
2.6	0.802828	0.787784	0.764268	0.695743	0.676664	0.645708	0.655534678
2.7	0.867655	0.851964	0.82742	0.755783	0.735806	0.703362	0.71366495
2.8	0.933836	0.917512	0.891961	0.817274	0.796415	0.762507	0.773278978
2.9	1.001296	0.984352	0.957816	0.880137	0.858412	0.823067	0.834299267
3	1.069963	1.052413	1.024912	0.944301	0.921726	0.884968	0.896653621
3.1	1.139771	1.121627	1.093182	1.009698	0.986289	0.948144	0.960274707
3.2	1.210659	1.191935	1.162566	1.076266	1.052038	1.012533	1.025099647
3.3	1.282569	1.263278	1.233005	1.143946	1.118916	1.078074	1.091069657

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	**Milford**	**New Hudson**	**Hamburg**	**Dexter**	**Ann Arbor**	**Ypsilanti**
3.4	1.35545	1.335604	1.304446	1.212685	1.186867	1.144713	1.158129717
3.5	1.42925	1.408862	1.376839	1.282429	1.255839	1.212398	1.226228278
3.6	1.503926	1.483006	1.450136	1.353133	1.325786	1.281081	1.295316992
3.7	1.579433	1.557994	1.524295	1.424751	1.396661	1.350716	1.365350464
3.8	1.655731	1.633784	1.599274	1.49724	1.468422	1.421261	1.436286034
3.9	1.732782	1.710338	1.675034	1.570562	1.541029	1.492675	1.508083571
4	1.810551	1.787621	1.75154	1.644678	1.614445	1.56492	1.58070529
4.1	1.889005	1.8656	1.828758	1.719555	1.688635	1.637961	1.654115584
4.2	1.968113	1.944242	1.906656	1.795159	1.763565	1.711763	1.728280865
4.3	2.047845	2.023519	1.985204	1.871459	1.839204	1.786296	1.803169429
4.4	2.128174	2.103402	2.064373	1.948425	1.915523	1.861529	1.87875132
4.5	2.209074	2.183866	2.144138	2.02603	1.992492	1.937433	1.954998216
4.6	2.29052	2.264884	2.224472	2.104248	2.070087	2.013981	2.031883314
4.7	2.37249	2.346435	2.305352	2.183054	2.14828	2.091148	2.109381236
4.8	2.454961	2.428496	2.386757	2.262424	2.22705	2.168911	2.187467929
4.9	2.537912	2.511047	2.468663	2.342336	2.306373	2.247245	2.266120583
5	2.621325	2.594066	2.551052	2.422769	2.386229	2.326129	2.345317553
5.1	2.70518	2.677537	2.633905	2.503703	2.466596	2.405543	2.425038282
5.2	2.789461	2.76144	2.717202	2.585119	2.547455	2.485466	2.505263235
5.3	2.874151	2.84576	2.800928	2.666999	2.628789	2.56588	2.585973838
5.4	2.959233	2.93048	2.885066	2.749326	2.710579	2.646768	2.667152418
5.5	3.044694	3.015585	2.9696	2.832084	2.79281	2.728112	2.748782148
5.6	3.130519	3.101061	3.054516	2.915256	2.875465	2.809895	2.830847

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
5.7	3.216693	3.186894	3.1398	2.998828	2.958529	2.892104	2.913331695
5.8	3.303206	3.273071	3.225438	3.082787	3.041989	2.974723	2.99622166
5.9	3.390043	3.35958	3.311419	3.167118	3.12583	3.057738	3.079502993
6	3.477195	3.446409	3.397729	3.251809	3.210039	3.141135	3.163162415
6.1	3.564648	3.533546	3.484357	3.336847	3.294604	3.224903	3.247187245
6.2	3.652394	3.620981	3.571293	3.422221	3.379514	3.309028	3.331565363
6.3	3.740422	3.708704	3.658525	3.50792	3.464756	3.393499	3.416285175
6.4	3.828723	3.796706	3.746045	3.593933	3.550319	3.478304	3.501335594
6.5	3.917286	3.884975	3.833842	3.680249	3.636194	3.563434	3.586706004
6.6	4.006104	3.973505	3.921906	3.76686	3.722371	3.648878	3.67238624
6.7	4.095167	4.062285	4.010231	3.853754	3.808839	3.734625	3.758366563
6.8	4.184469	4.151308	4.098806	3.940925	3.89559	3.820667	3.844637637
6.9	4.274001	4.240567	4.187624	4.028362	3.982615	3.906995	3.931190512
7	4.363756	4.330054	4.276678	4.116059	4.069906	3.993599	4.018016598
7.1	4.453727	4.419761	4.36596	4.204006	4.157454	4.080472	4.105107653
7.2	4.543906	4.509681	4.455463	4.292196	4.245252	4.167606	4.192455762
7.3	4.634289	4.599809	4.54518	4.380622	4.333292	4.254992	4.280053324
7.4	4.724868	4.690137	4.635104	4.469277	4.421567	4.342624	4.367893032
7.5	4.815637	4.78066	4.72523	4.558154	4.51007	4.430494	4.455967863
7.6	4.906591	4.871373	4.815552	4.647247	4.598795	4.518596	4.544271065
7.7	4.997725	4.962268	4.906063	4.73655	4.687735	4.606923	4.632796138
7.8	5.089032	5.053341	4.996759	4.826056	4.776885	4.695468	4.721536829
7.9	5.180508	5.144587	5.087633	4.91576	4.866238	4.784226	4.810487118

Rainfall (P) (in)	Runoff (Q) (in)						
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
8	5.272149	5.236001	5.178681	5.005656	4.955788	4.873191	4.899641206
8.1	5.363948	5.327578	5.269899	5.095739	5.045531	4.962356	4.988993506
8.2	5.455903	5.419313	5.36128	5.186004	5.135461	5.051718	5.078538633
8.3	5.548008	5.511203	5.452821	5.276446	5.225572	5.141269	5.168271397
8.4	5.640259	5.603242	5.544517	5.367059	5.315861	5.231006	5.258186792
8.5	5.732653	5.695426	5.636364	5.457841	5.406322	5.320924	5.348279986
8.6	5.825185	5.787753	5.728357	5.548785	5.496951	5.411017	5.43854632
8.7	5.917852	5.880217	5.820494	5.639888	5.587743	5.501281	5.528981294
8.8	6.010649	5.972815	5.91277	5.731145	5.678694	5.591712	5.619580562
8.9	6.103575	6.065544	6.005182	5.822553	5.7698	5.682305	5.710339928
9	6.196624	6.1584	6.097725	5.914108	5.861057	5.773057	5.801255336
9.1	6.289795	6.25138	6.190397	6.005806	5.952462	5.863963	5.892322868
9.2	6.383083	6.34448	6.283194	6.097643	6.04401	5.95502	5.983538733
9.3	6.476486	6.437699	6.376114	6.189616	6.135698	6.046224	6.074899267
9.4	6.570001	6.531031	6.469152	6.281722	6.227523	6.137571	6.166400926
9.5	6.663625	6.624476	6.562306	6.373957	6.319481	6.229058	6.25804028
9.6	6.757355	6.71803	6.655573	6.466318	6.411569	6.320681	6.349814009
9.7	6.851189	6.811689	6.748951	6.558803	6.503783	6.412437	6.441718899
9.8	6.945125	6.905453	6.842437	6.651407	6.596122	6.504324	6.533751838
9.9	7.039158	6.999317	6.936027	6.744129	6.688582	6.596338	6.625909813
10	7.133289	7.09328	7.02972	6.836965	6.781159	6.688475	6.718189901

Table 3 2006 Land Cover Conditions

Rainfall (P) (in)	Runoff (Q) (in)								
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti	YP- CI	
0.1	0.111524	0.113913	0.118385	0.131793	0.134285	0.138045	0.135879	0.057283	0.216713
0.2	0.071858	0.074018	0.078079	0.090373	0.092675	0.096158	0.09415	0.025554	0.170776
0.3	0.041853	0.043669	0.047111	0.05772	0.059734	0.062796	0.061028	0.00716	0.13117
0.4	0.020539	0.021921	0.024579	0.033043	0.034689	0.037213	0.035753	0.000173	0.097491
0.5	0.007073	0.007949	0.009693	0.015645	0.016858	0.018747	0.01765	0.00302	0.069369
0.6	0.000718	0.001033	0.00176	0.004906	0.005634	0.00681	0.006121	0.014406	0.046466
0.7	0.000825	0.000535	0.000166	0.000274	0.000476	0.000878	0.000632	0.033252	0.028468
0.8	0.006823	0.005896	0.004368	0.001259	0.0009	0.000478	0.000704	0.058653	0.015087
0.9	0.018206	0.016617	0.013886	0.007419	0.006475	0.00519	0.00591	0.089847	0.006059
1	0.034523	0.032256	0.028288	0.01836	0.01681	0.014632	0.015864	0.126184	0.001136
1.1	0.055375	0.052417	0.047189	0.033725	0.031555	0.02846	0.030217	0.167108	9.21E-05
1.2	0.080401	0.076746	0.070244	0.053192	0.050391	0.046364	0.048656	0.212141	0.002715
1.3	0.10928	0.104924	0.097141	0.076471	0.073032	0.068061	0.070894	0.260868	0.008809
1.4	0.141723	0.136667	0.127599	0.103296	0.099216	0.093294	0.096672	0.312929	0.018192

Rainfall (P) (in)	Runoff (Q) (in)								
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti	YP- CI	
1.5	0.177469	0.171713	0.161365	0.133428	0.128704	0.121829	0.125753	0.368009	0.030694
1.6	0.21628	0.20983	0.198209	0.166648	0.16128	0.153452	0.157923	0.425831	0.046156
1.7	0.257943	0.250805	0.237919	0.202754	0.196746	0.187966	0.192983	0.486153	0.064431
1.8	0.302263	0.294444	0.280307	0.241564	0.234919	0.225193	0.230753	0.548757	0.085381
1.9	0.349062	0.34057	0.325196	0.282911	0.275633	0.264967	0.271067	0.613454	0.108877
2	0.398178	0.389024	0.372428	0.326638	0.318734	0.307137	0.313771	0.680071	0.134797
2.1	0.449464	0.439656	0.421856	0.372605	0.364081	0.351561	0.358725	0.748456	0.163029
2.2	0.502783	0.492332	0.473347	0.42068	0.411543	0.398111	0.405798	0.818473	0.193465
2.3	0.558011	0.546927	0.526775	0.470742	0.461001	0.446667	0.454872	0.889998	0.226005
2.4	0.615032	0.603328	0.582029	0.522679	0.512341	0.497119	0.505834	0.962921	0.260557
2.5	0.673742	0.661428	0.639002	0.576388	0.565462	0.549363	0.558582	1.03714	0.29703
2.6	0.734042	0.721129	0.697596	0.631772	0.620267	0.603303	0.613019	1.112565	0.335341
2.7	0.795844	0.782343	0.757723	0.688742	0.676667	0.658852	0.669057	1.189114	0.375412
2.8	0.859062	0.844985	0.819299	0.747216	0.734579	0.715926	0.726612	1.26671	0.417169
2.9	0.923619	0.908978	0.882245	0.807114	0.793926	0.774448	0.785608	1.345286	0.460542

Rainfall (P) (in)	Runoff (Q) (in)								
	Commerce	**Milford**	**New Hudson**	**Hamburg**	**Dexter**	**Ann Arbor**	**Ypsilanti**	**YP- CI**	
3	0.989444	0.97425	0.946491	0.868367	0.854635	0.834345	0.845973	1.424778	0.505463
3.1	1.056471	1.040733	1.011968	0.930905	0.91664	0.895552	0.907638	1.505129	0.551871
3.2	1.124636	1.108366	1.078615	0.994666	0.979877	0.958004	0.970541	1.586286	0.599706
3.3	1.193881	1.177091	1.146373	1.059591	1.044287	1.021643	1.034623	1.6682	0.648912
3.4	1.264154	1.246853	1.215186	1.125625	1.109815	1.086413	1.099829	1.750827	0.699436
3.5	1.335402	1.317601	1.285005	1.192717	1.176409	1.152262	1.166106	1.834125	0.751226
3.6	1.407579	1.389288	1.355782	1.260816	1.24402	1.219141	1.233407	1.918056	0.804235
3.7	1.48064	1.46187	1.42747	1.329879	1.312603	1.287005	1.301684	2.002586	0.858418
3.8	1.554545	1.535304	1.50003	1.399862	1.382115	1.35581	1.370896	2.08768	0.91373
3.9	1.629253	1.609552	1.57342	1.470724	1.452514	1.425516	1.441001	2.173309	0.97013
4	1.704729	1.684576	1.647604	1.542427	1.523763	1.496084	1.51196	2.259444	1.02758
4.1	1.780938	1.760343	1.722546	1.614936	1.595826	1.567477	1.583739	2.34606	1.086042
4.2	1.857847	1.836819	1.798215	1.688217	1.668669	1.639662	1.656302	2.433131	1.14548
4.3	1.935427	1.913973	1.874578	1.762237	1.742259	1.712605	1.729618	2.520635	1.20586
4.4	2.013648	1.991778	1.951606	1.836966	1.816566	1.786278	1.803655	2.60855	1.267149

Rainfall (P) (in)	Runoff (Q) (in)								
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti	YP- CI	
4.5	2.092483	2.070205	2.029273	1.912376	1.891561	1.860649	1.878386	2.696856	1.329318
4.6	2.171907	2.149229	2.10755	1.988439	1.967217	1.935693	1.953782	2.785535	1.392335
4.7	2.251895	2.228825	2.186414	2.06513	2.043508	2.011382	2.029817	2.874569	1.456174
4.8	2.332424	2.30897	2.265842	2.142425	2.120409	2.087692	2.106468	2.963942	1.520806
4.9	2.413474	2.389643	2.34581	2.2203	2.197898	2.1646	2.18371	3.053638	1.586206
5	2.495023	2.470822	2.426299	2.298733	2.275952	2.242084	2.261522	3.143643	1.652349
5.1	2.577051	2.552488	2.507287	2.377703	2.354549	2.320121	2.339882	3.233943	1.719212
5.2	2.659541	2.634622	2.588757	2.457191	2.433671	2.398692	2.41877	3.324525	1.786772
5.3	2.742474	2.717207	2.670689	2.537178	2.513299	2.477777	2.498168	3.415377	1.855007
5.4	2.825835	2.800225	2.753068	2.617645	2.593413	2.557359	2.578056	3.506488	1.923896
5.5	2.909607	2.883661	2.835875	2.698577	2.673996	2.63742	2.658418	3.597846	1.993419
5.6	2.993775	2.9675	2.919097	2.779955	2.755034	2.717942	2.739237	3.689442	2.063557
5.7	3.078325	3.051726	3.002718	2.861765	2.836508	2.798911	2.820497	3.781266	2.134292
5.8	3.163243	3.136327	3.086724	2.943992	2.918406	2.880311	2.902184	3.873308	2.205606
5.9	3.248517	3.221289	3.171102	3.026622	3.000711	2.962128	2.984282	3.965561	2.277482

Rainfall (P) (in)	Runoff (Q) (in)								
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti	YP- CI	
6	3.334133	3.306599	3.255839	3.109641	3.083411	3.044348	3.066778	4.058016	2.349903
6.1	3.42008	3.392246	3.340923	3.193036	3.166493	3.126957	3.14966	4.150664	2.422854
6.2	3.506347	3.478218	3.426341	3.276795	3.249944	3.209943	3.232914	4.243499	2.49632
6.3	3.592923	3.564504	3.512084	3.360907	3.333752	3.293294	3.316528	4.336514	2.570285
6.4	3.679798	3.651093	3.598139	3.445359	3.417906	3.376997	3.400491	4.429702	2.644737
6.5	3.766961	3.737977	3.684498	3.530141	3.502395	3.461043	3.484792	4.523057	2.719662
6.6	3.854404	3.825144	3.77115	3.615242	3.587208	3.545421	3.56942	4.616572	2.795046
6.7	3.942116	3.912587	3.858085	3.700653	3.672335	3.630119	3.654366	4.710242	2.870878
6.8	4.030091	4.000296	3.945296	3.786364	3.757766	3.715129	3.739619	4.804061	2.947144
6.9	4.118319	4.088263	4.032773	3.872366	3.843493	3.800441	3.82517	4.898025	3.023834
7	4.206792	4.176479	4.120508	3.958649	3.929507	3.886045	3.91101	4.992127	3.100936
7.1	4.295503	4.264938	4.208493	4.045207	4.015798	3.971934	3.997131	5.086364	3.178439
7.2	4.384445	4.353632	4.29672	4.13203	4.102359	4.058099	4.083524	5.180731	3.256334
7.3	4.473611	4.442553	4.385184	4.21911	4.189181	4.144532	4.170181	5.275224	3.334609
7.4	4.562993	4.531695	4.473875	4.306441	4.276258	4.231225	4.257095	5.369838	3.413255

Rainfall (P) (in)	Runoff (Q) (in)								
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti	YP- CI	
7.5	4.652586	4.621052	4.562788	4.394015	4.363582	4.318171	4.344259	5.464569	3.492262
7.6	4.742383	4.710617	4.651916	4.481825	4.451146	4.405362	4.431665	5.559414	3.571623
7.7	4.832378	4.800383	4.741253	4.569865	4.538943	4.492792	4.519307	5.654368	3.651326
7.8	4.922566	4.890346	4.830793	4.658127	4.626966	4.580454	4.607177	5.74943	3.731365
7.9	5.01294	4.9805	4.920531	4.746606	4.71521	4.668342	4.69527	5.844594	3.811731
8	5.103497	5.070838	5.01046	4.835296	4.803669	4.75645	4.78358	5.939859	3.892416
8.1	5.19423	5.161357	5.100575	4.924192	4.892336	4.844772	4.872101	6.03522	3.973413
8.2	5.285135	5.252051	5.190872	5.013287	4.981206	4.933301	4.960827	6.130675	4.054713
8.3	5.376207	5.342915	5.281345	5.102576	5.070273	5.022033	5.049752	6.226221	4.136309
8.4	5.467442	5.433945	5.37199	5.192054	5.159533	5.110962	5.138872	6.321856	4.218195
8.5	5.558834	5.525136	5.462802	5.281717	5.24898	5.200083	5.228181	6.417577	4.300364
8.6	5.65038	5.616484	5.553776	5.371559	5.33861	5.289392	5.317675	6.51338	4.382809
8.7	5.742077	5.707984	5.644909	5.461575	5.428417	5.378882	5.407348	6.609265	4.465524
8.8	5.833918	5.799634	5.736195	5.551762	5.518398	5.46855	5.497196	6.705228	4.548503
8.9	5.925902	5.891428	5.827632	5.642115	5.608547	5.558392	5.587215	6.801268	4.631739

Rainfall (P) (in)	Runoff (Q) (in)								
	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti	YP- CI	
9	6.018024	5.983363	5.919215	5.73263	5.698861	5.648402	5.677401	6.897382	4.715228
9.1	6.110281	6.075436	6.010941	5.823302	5.789336	5.738577	5.767749	6.993568	4.798962
9.2	6.20267	6.167642	6.102806	5.914128	5.879967	5.828913	5.858255	7.089824	4.882938
9.3	6.295186	6.25998	6.194806	6.005105	5.970751	5.919406	5.948916	7.186148	4.967148
9.4	6.387827	6.352444	6.286939	6.096227	6.061684	6.010051	6.039727	7.282539	5.051589
9.5	6.48059	6.445033	6.3792	6.187493	6.152763	6.100846	6.130685	7.378994	5.136256
9.6	6.573471	6.537743	6.471587	6.278898	6.243983	6.191787	6.221788	7.475512	5.221143
9.7	6.666469	6.630572	6.564097	6.370439	6.335343	6.28287	6.31303	7.572091	5.306245
9.8	6.759579	6.723516	6.656727	6.462114	6.426837	6.374092	6.404409	7.66873	5.391559
9.9	6.8528	6.816572	6.749474	6.553918	6.518464	6.46545	6.495922	7.765427	5.477079
10	6.946128	6.909738	6.842335	6.645848	6.610219	6.55694	6.587565	7.862181	5.562802

Appendix 6 - Benthic Macroinvertebrates and Stream Habitat

Modified from *Qualitative Biological and Habitat Survey Protocols for Wadeable Streams and Rivers* (SWAS procedure 51), Michigan Department of Environmental Quality.

The following metrics are for riffle/run streams, which characteristically:

- Demonstrate a regular (repeating) riffle/run sequence.
- Have substrate primarily composed of coarse sediment particles (i.e., course sand/gravel or larger particle sizes in high velocity reaches of the stream).
- Tend to have moderate to high gradient landscape.

Table 1 Habitat Assessment Metrics

Habitat Parameter	**Condition Category**			
	Excellent **(20~16)**	**Good** **(15~11)**	**Marginal** **(10~6)**	**Poor** **(5~0)**
1. Epifaunal Substrate/ Available Cover	Greater than 70% of substrate are free from sedimentation/siltation and favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/ snags that are not new fall and not transient).	40-70% mix of stable habitat; free from sedimentation/siltation and well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed, removed, or covered by sediment/silt.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
2. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-70% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.

Habitat Parameter	Condition Category			
	Excellent (20~16)	**Good (15~11)**	**Marginal (10~6)**	**Poor (5~0)**
3. Velocity/ Depth Regimes	All 4 velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (slow is <1.0 f/s, deep is >1.5 ft.)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/depth regime (usually slow-deep).
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
5a. Channel Flow Status - Maintained Flow Volume	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
5b. Channel Flow Status - Flashiness	Vegetation along the stream banks is complete nearly to the water's edge. Little or no evidence of frequent changes in discharge and/or frequent high water events that scour streambank vegetation. Large woody debris (if present) stable and extending laterally across the stream channel.	Some evidence of bank scour approximately 4-8 inches above the water's surface. Large woody debris (if present) mostly stable and extending partially into the active stream channel.	Bank scour evident 9-18 inches above the water's surface. Large woody debris (if present) tend to lay more against the streambank rather than extending into the active channel.	Bank scour severe (>20 inches) along the stream channel. Large woody debris is generally absent from the active channel and/or may exist as woody debris jams along the streambank above the active channel.

Habitat Parameter	Condition Category			
	Excellent **(20~16)**	**Good** **(15~11)**	**Marginal** **(10~6)**	**Poor** **(5~0)**
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization is continuous but not recent (> 5 years); embankments without mature trees and dominated by grasses and shrubs.	Stream reach has been recently channelized (<5 years). OR Banks shored with gabion, rock, cement or bare earth. Instream habitat greatly altered or removed entirely. Bank vegetation moderately dense to absent
7. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 and 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 and 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
8. Bank Stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.

Habitat Parameter	Condition Category			
	Excellent **(20~16)**	**Good** **(15~11)**	**Marginal** **(10~6)**	**Poor** **(5~0)**
9. Vegetative Protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zones covered by vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by vegetation, but 1 class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >150 feet; dominated by vegetation, including trees, understory shrubs, or nonwoody macrophytes or wetlands; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally. Human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 75-150 feet; human activities have impacted zone only minimally.	Width of riparian zone 10-75 feet; human activities have impacted the composition of the vegetation a great deal.	Width of riparian zone <10 feet: little or no riparian vegetation due to human activities.

Appendix 7 - Fish Community Assemblage Analysis

7.1

These figures show the fish presence/absence data (percent of the sample taxa) for riverine and impoundment sites. Figures 1 through 10 show marked differences between riverine and impoundment sites, while figures 11 through 14 do not.

Figure 1 Percent of the Game and MDNR regulated taxa in each site sample

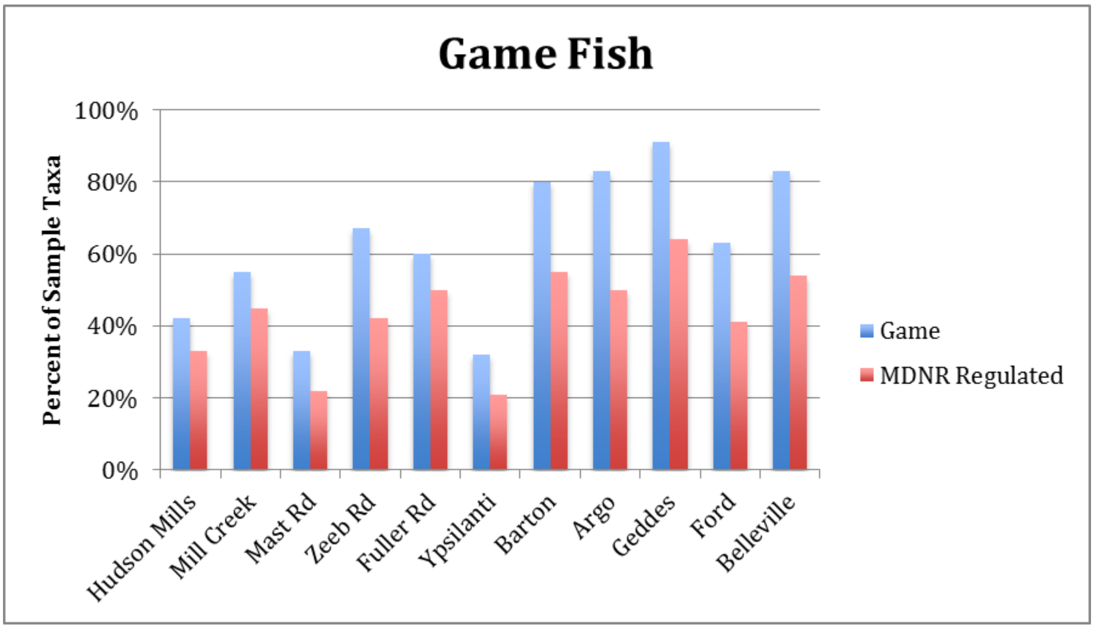


Figure 2 Percent of the Darter taxa in each site sample

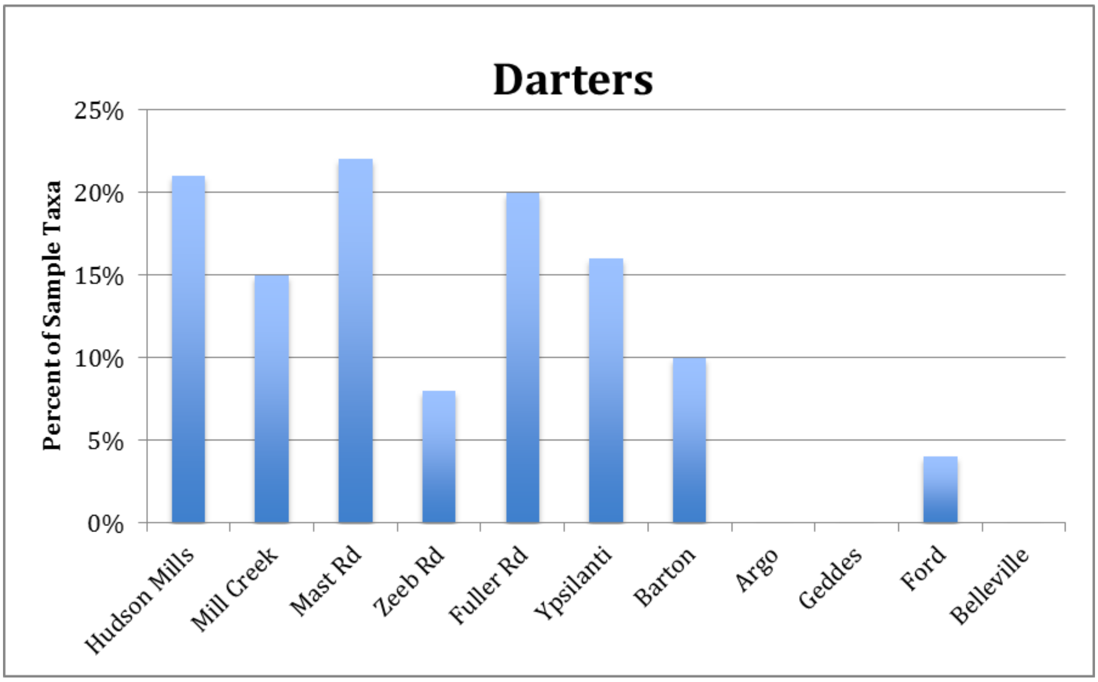


Figure 3 Percent taxa with MDNR designated tolerances in each site sample

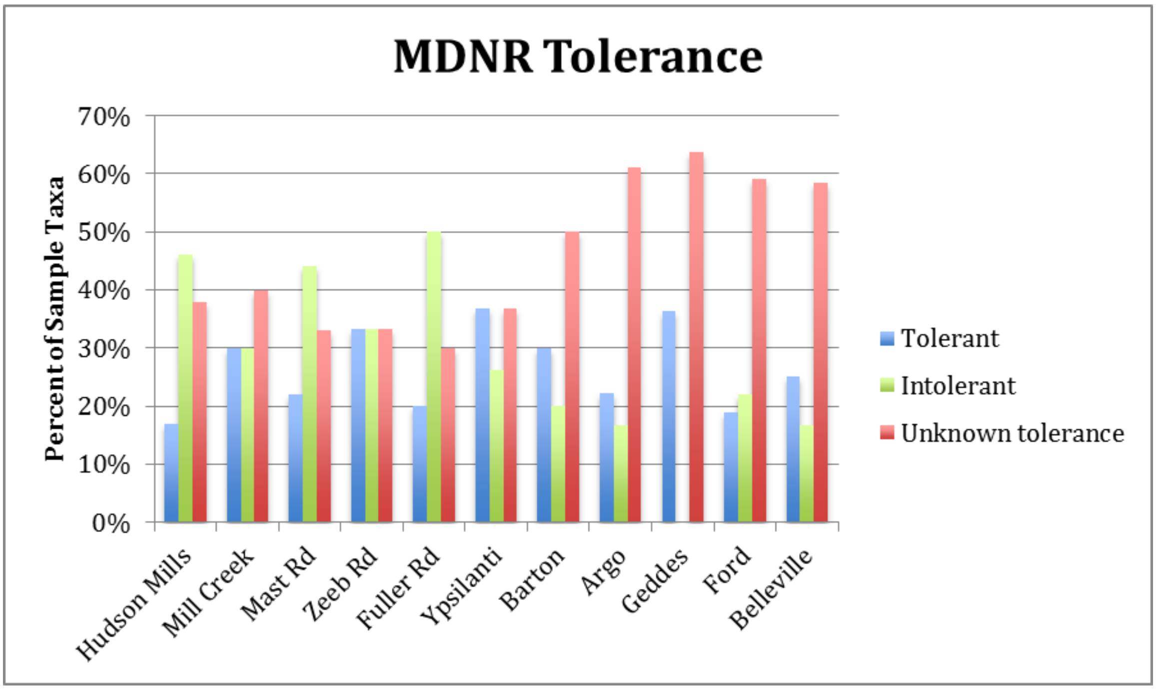


Figure 4 Percent taxa with updated tolerances in each site sample

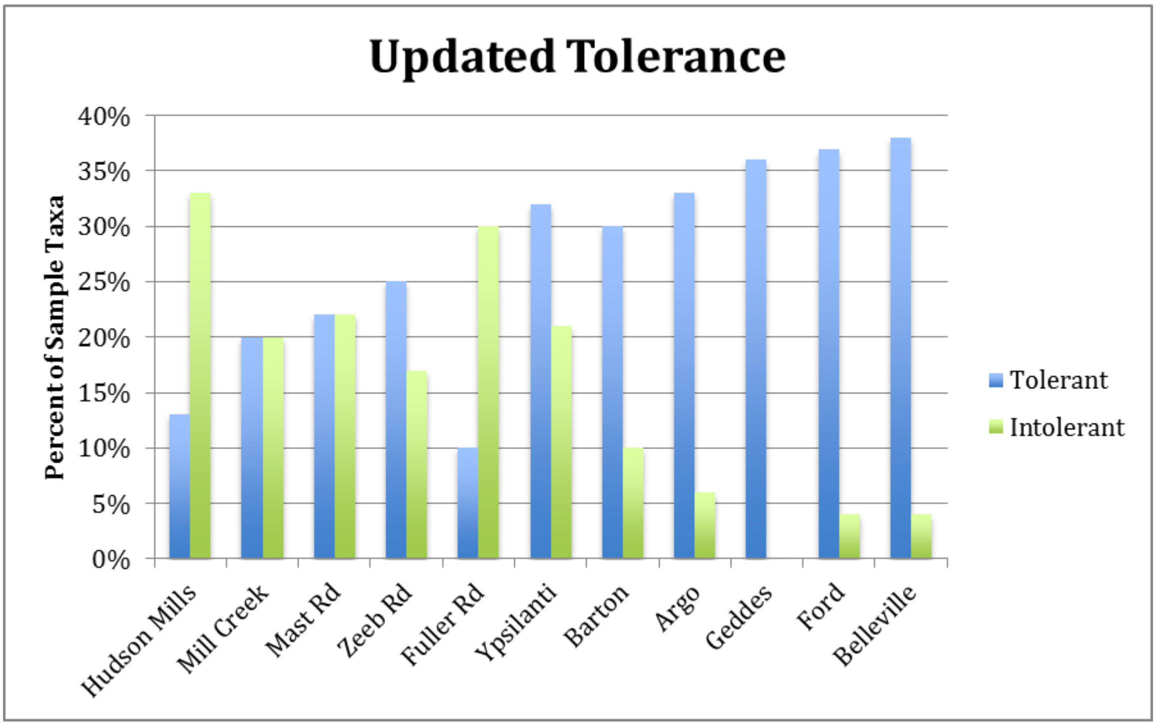


Figure 5 Percent taxa flow velocity preferences in each site sample

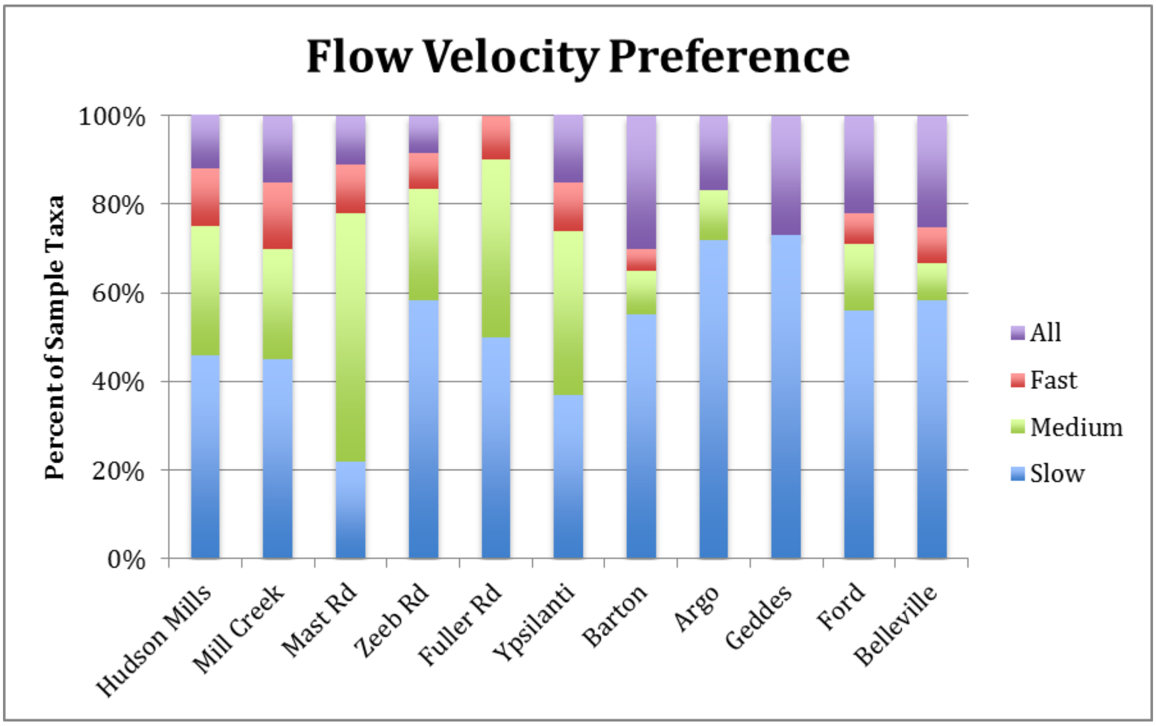


Figure 6 Percent taxa substrate preferences in each site sample

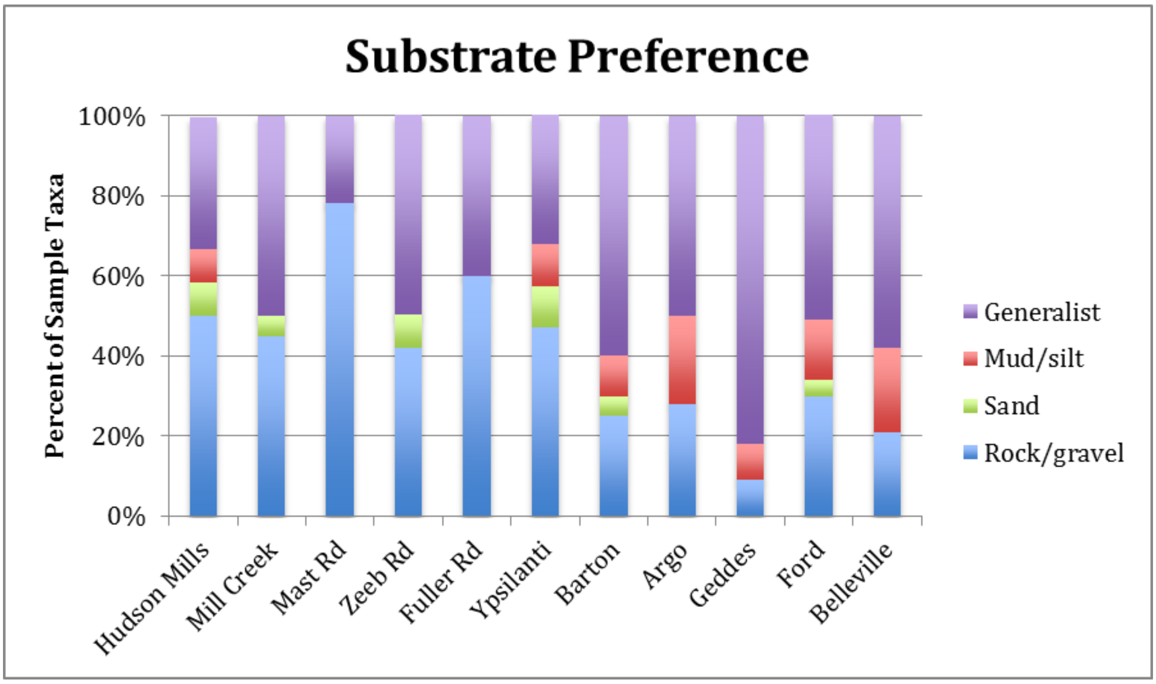


Figure 7 Percent taxa river size preferences in each site sample

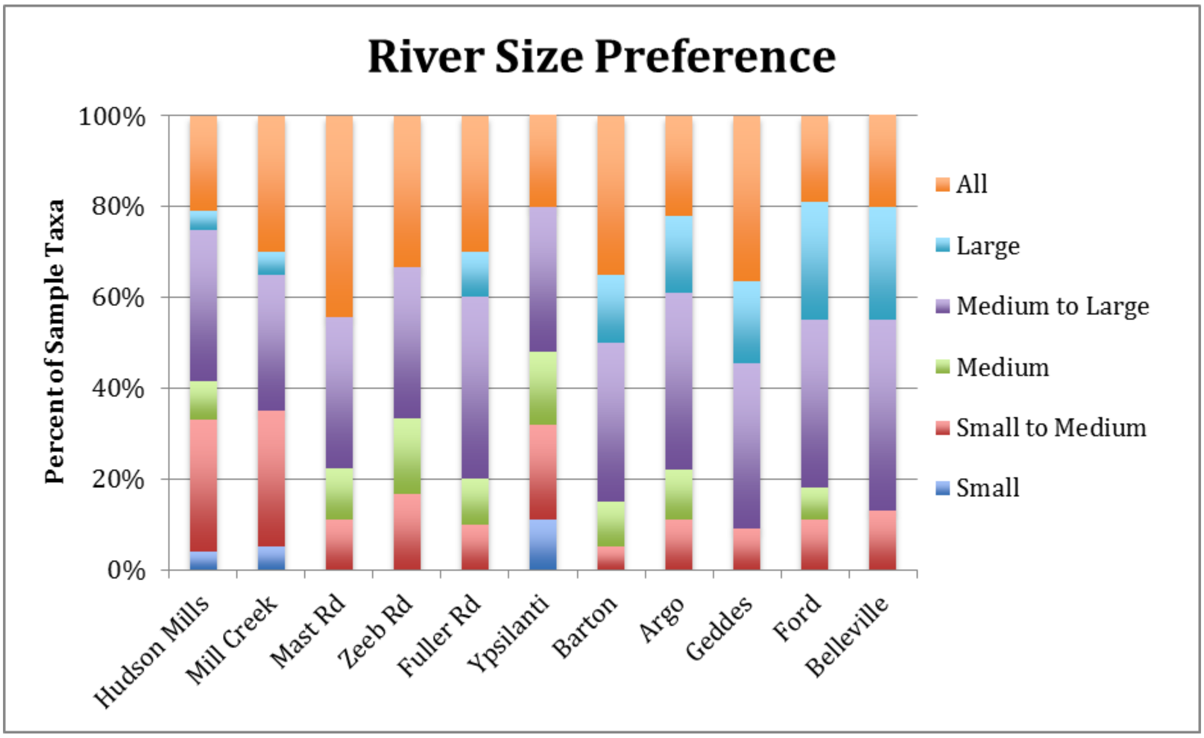


Figure 8 Percent of taxa in each site sample that are lake dwellers (typically found in/strong preference)

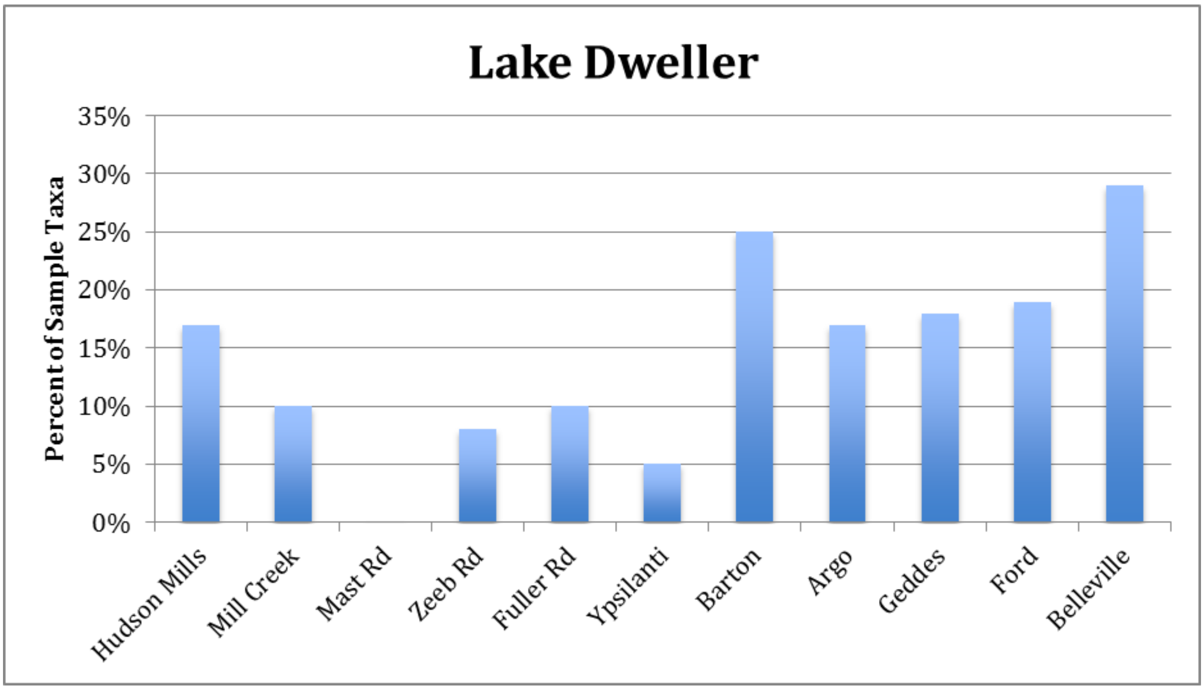


Figure 9 Percent taxa with full range of trophic preferences in each site sample

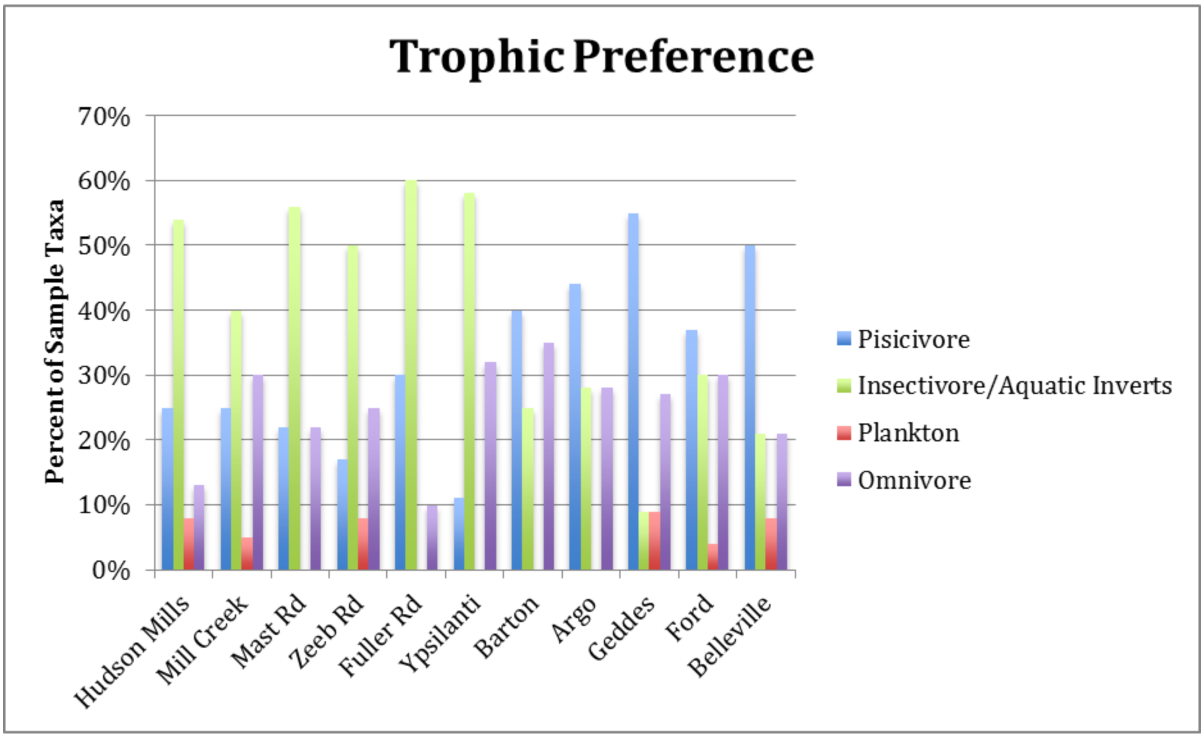


Figure 10 Percent taxa with two trophic preferences in each site sample

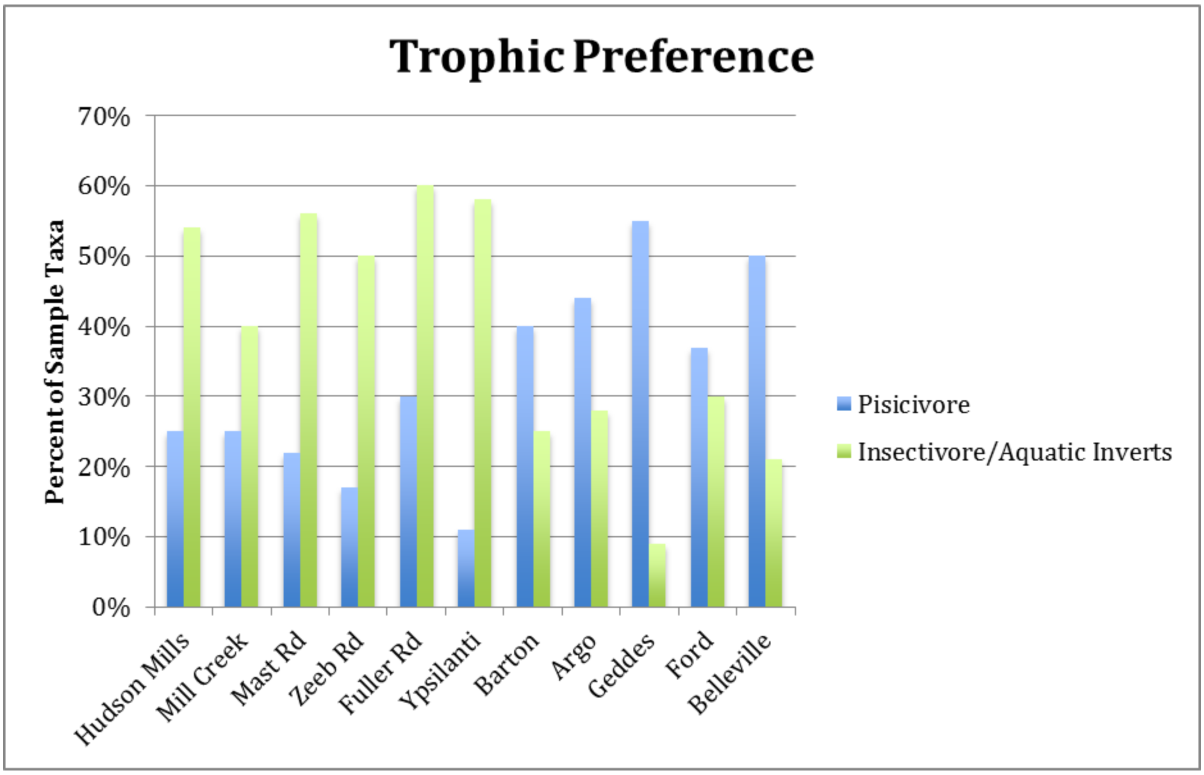


Figure 11 Percent taxa water temperature preferences in each site sample

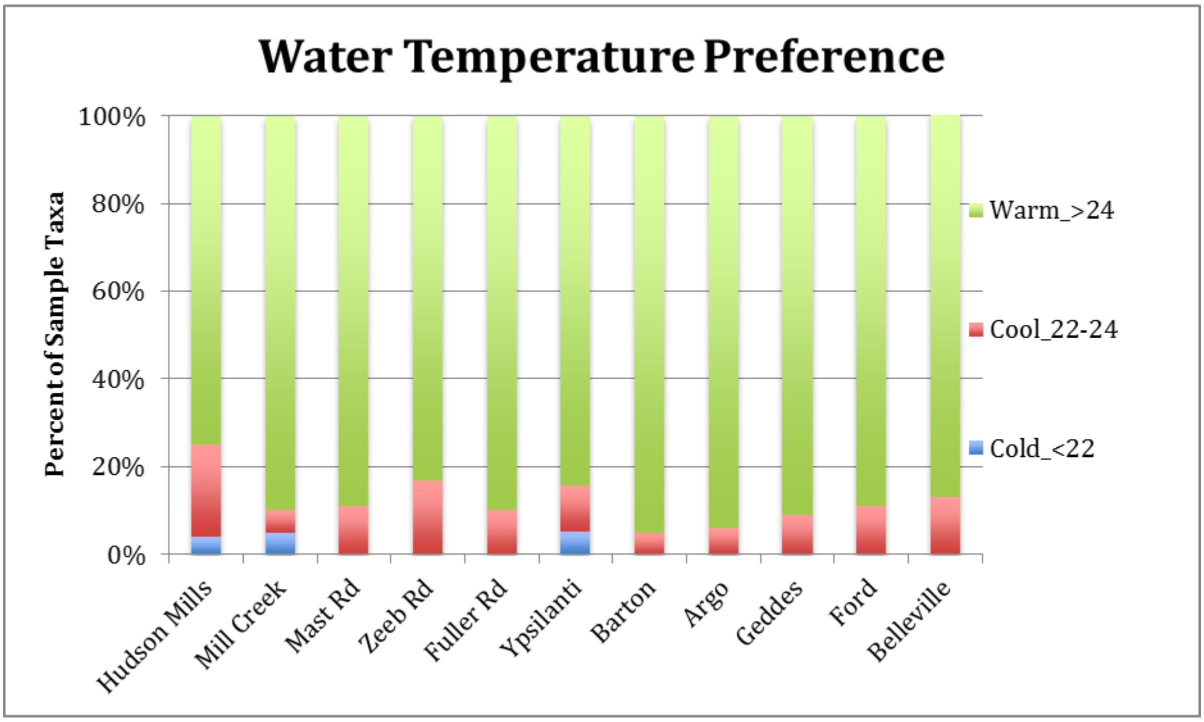


Figure 12 Percent taxa that have a preference for macrophytes at each sample site

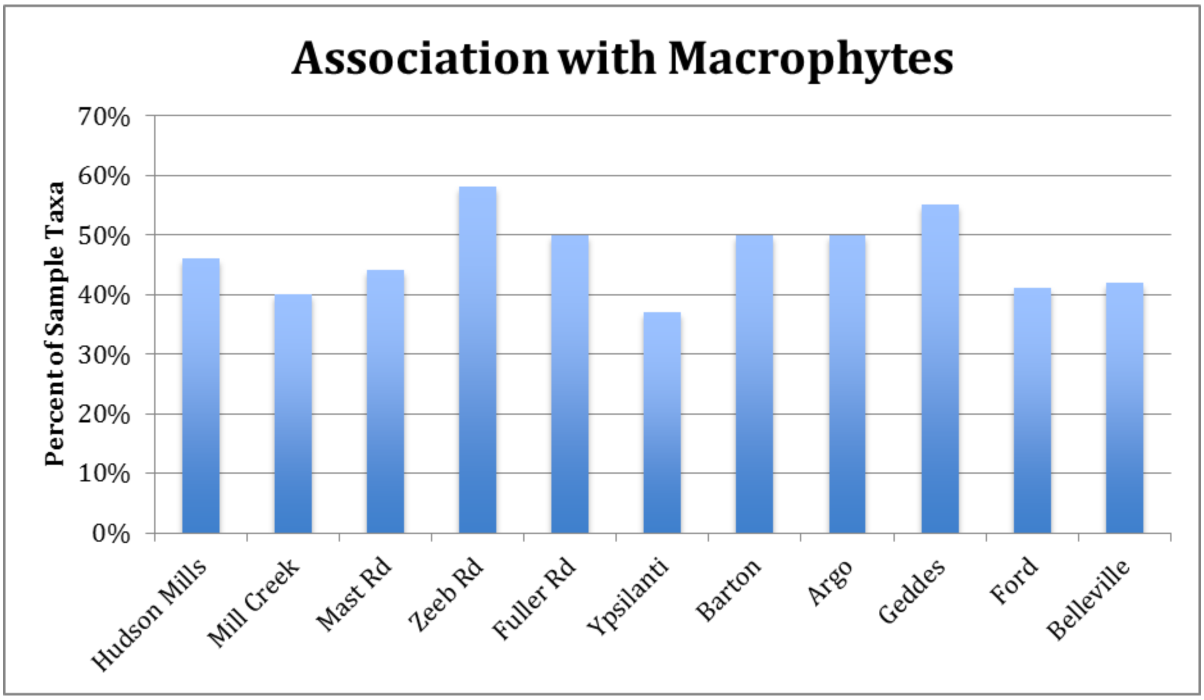


Figure 13 Percent taxa that are lithophilic spawners at each sample site

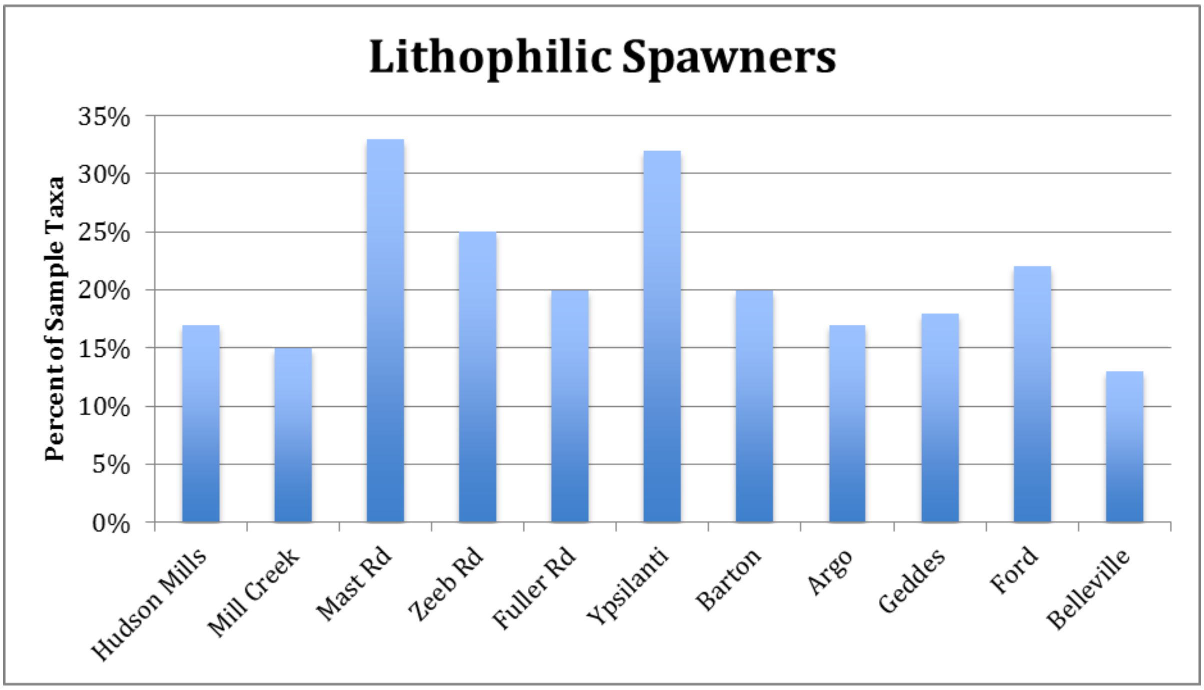
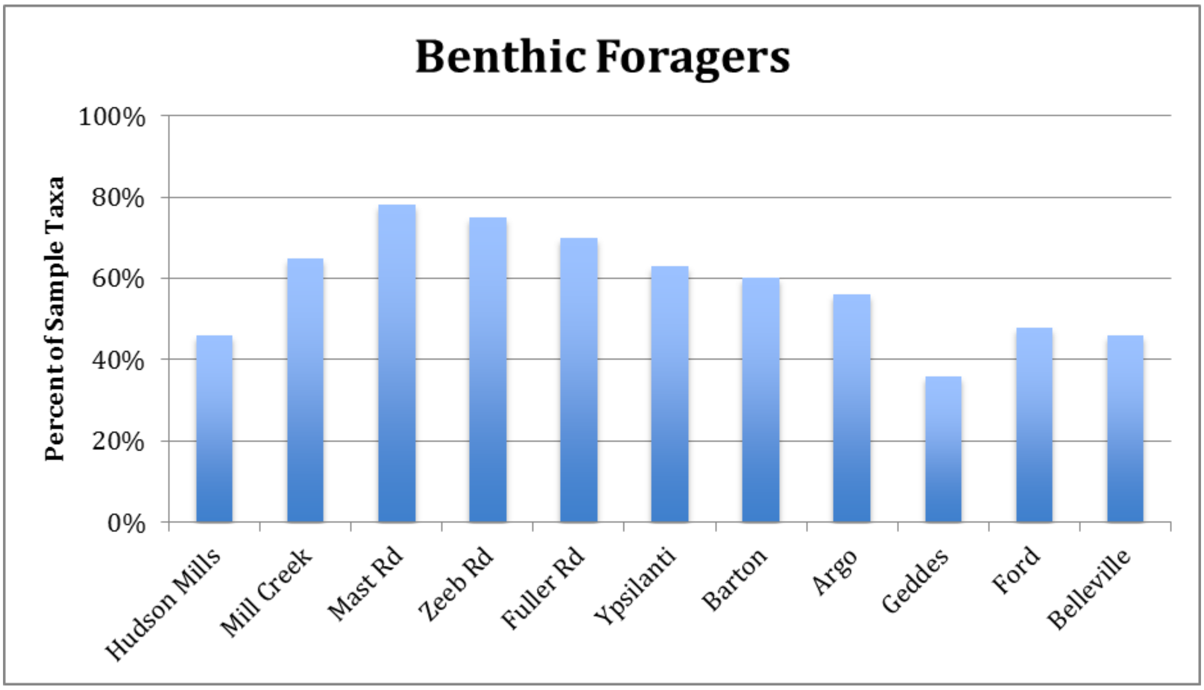


Figure 14 Percent taxa that are benthic foragers at each sample site



7.2

Table 1 Cross-over species (found in both riverine and impoundment sites)

Cross-Over Species	
Common Name	**Scientific Name**
Black crappie	*Pomoxis nigromaculatus*
Black redhorse	*Moxostoma duquesnei*
Bluegill	*Lepomis macrochirus*
Bluntnose Minnow	*Pimephales notatus*
Common carp	*Cyprinus carpio*
Gizzard shad	*Dorosoma cepedianum*
Golden redhorse	*Moxostoma erythrurum*
Green sunfish	*Lepomis cyanellus*
Hybrid Sunfish	*Lepomis spp.*
Johnny darter	*Etheostoma nigrum*
Largemouth bass	*Micropterus salmoides*
Logperch	*Percina caprodes*
Longear sunfish	*Lepomis megalotis*
Muskellunge	*Esox masquinongy*
Northern hogsucker	*Hypentelium nigricans*
Northern pike	*Esox lucius*
Pumpkinseed	*Lepomis gibbosus*
Rock bass	*Ambloplites rupestris*
Smallmouth bass	*Micropterus dolomieui*
Stonecat	*Noturus flavus*
White sucker	*Catostomus commersoni*
Yellow bullhead	*Ameiurus natalis*

7.3

Additional figures for the riverine only guild (ROG) and impoundment only guild (IOG). Figures 1 through 5 show distinct differences between ROG and IOG, while Figures 6 through 8 do not.

Figure 1 Percent MDNR tolerances of ROG and IOG taxa

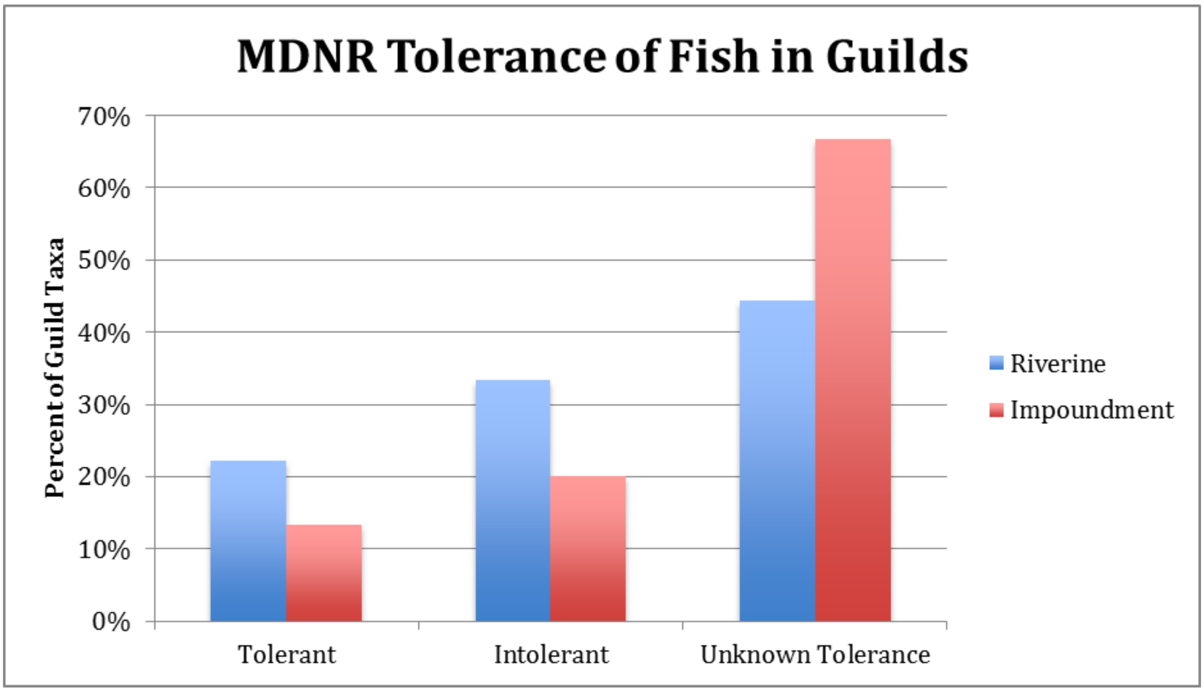


Figure 2 Percent updated tolerances of ROG and IOG taxa

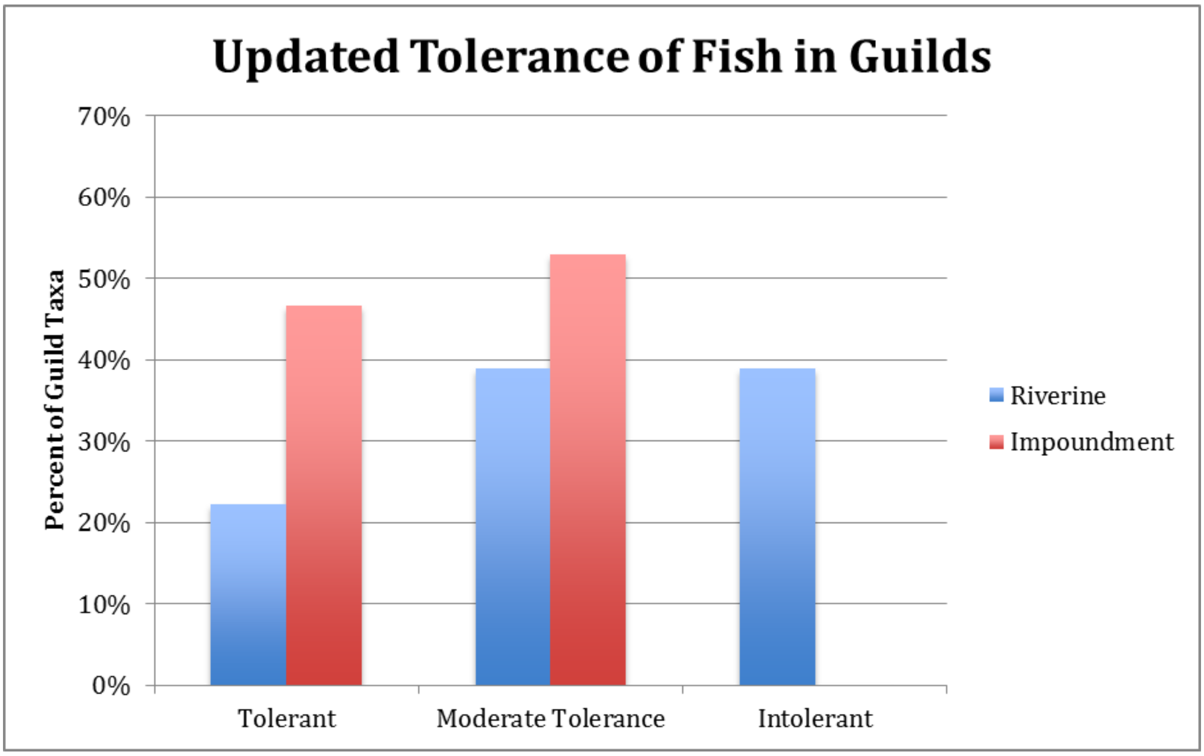


Figure 3 Percent river size and lake dweller preference of ROG and IOG taxa

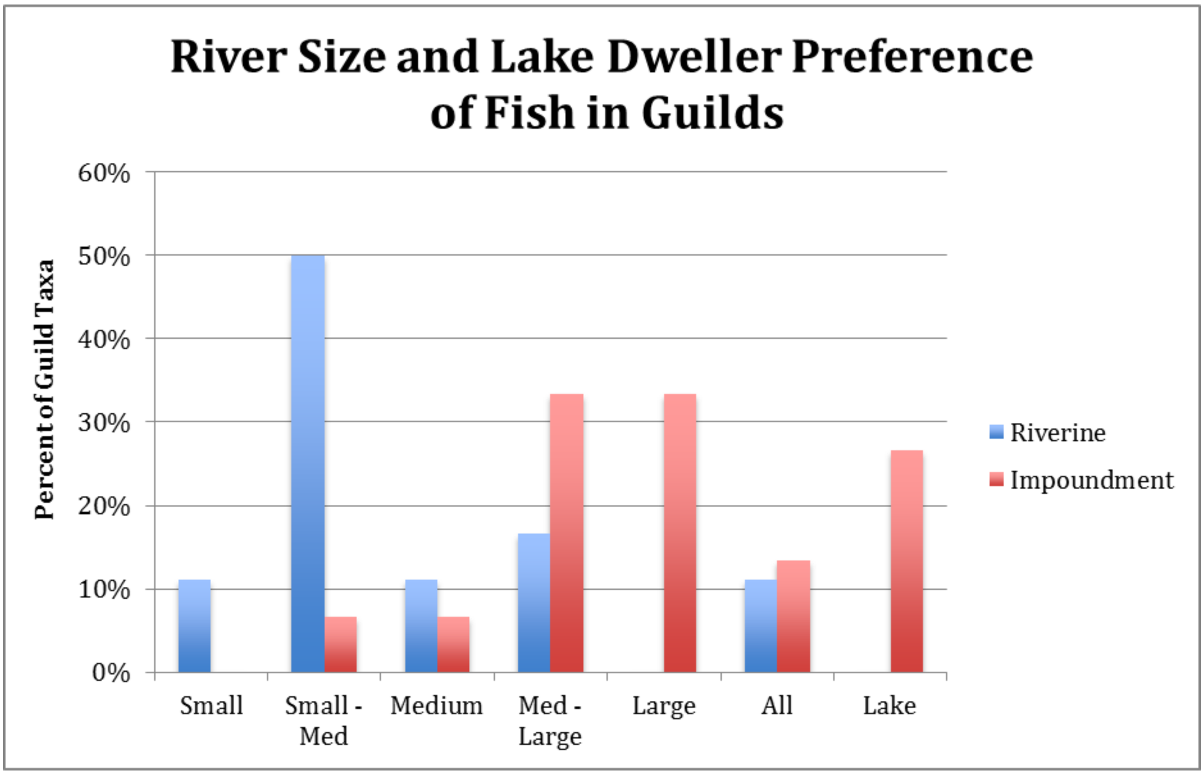


Figure 4 Percent substrate preference of ROG and IOG taxa

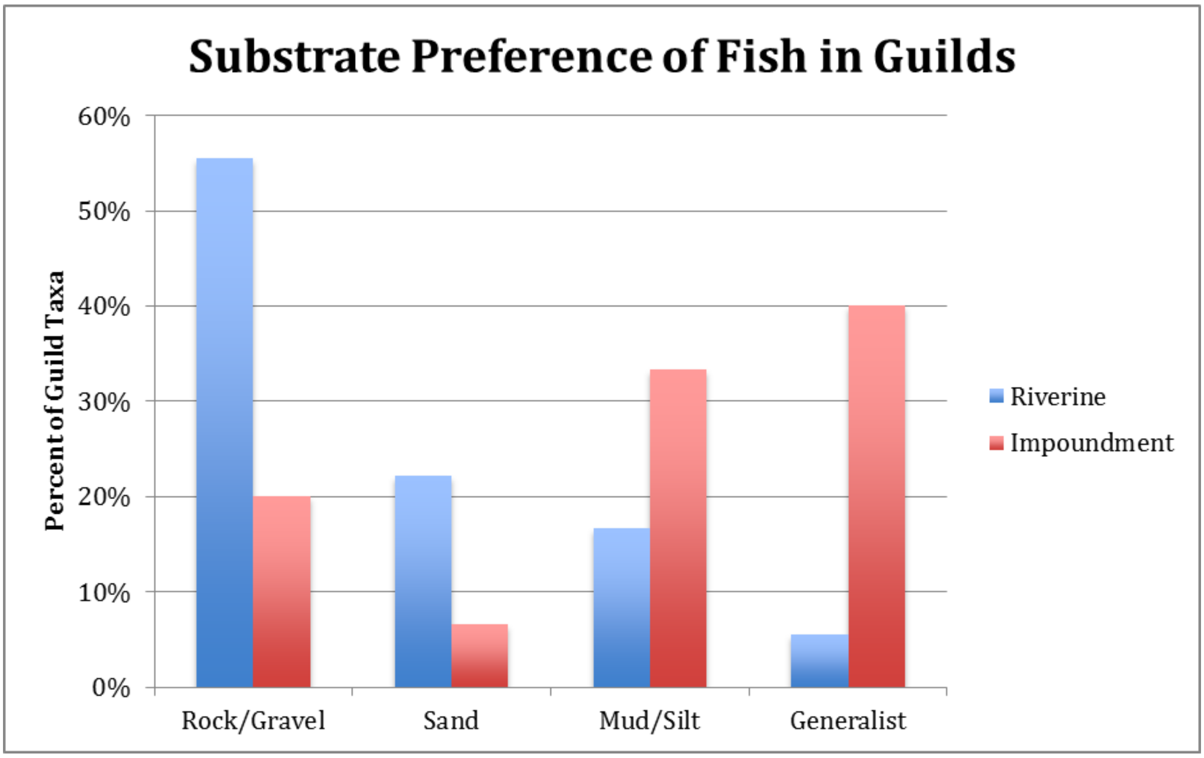


Figure 5 Percent trophic preference of ROG and IOG taxa

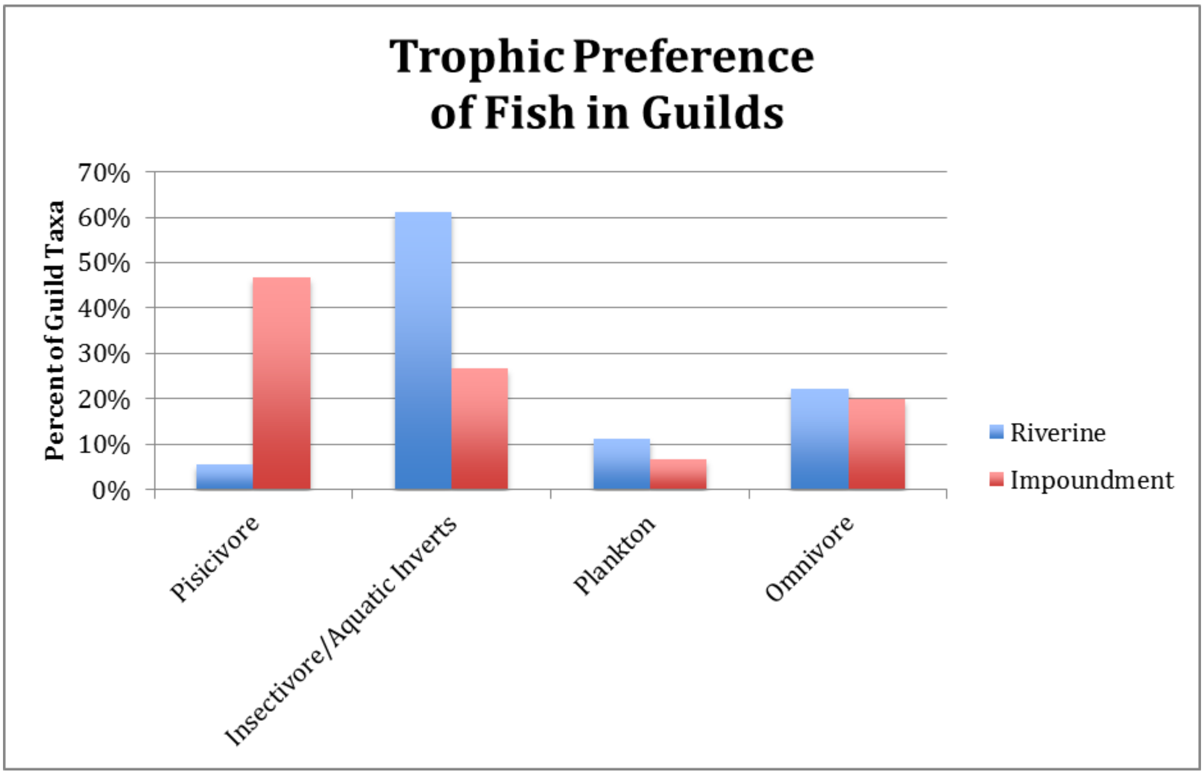


Figure 6 Percent water temperature preference of ROG and IOG taxa

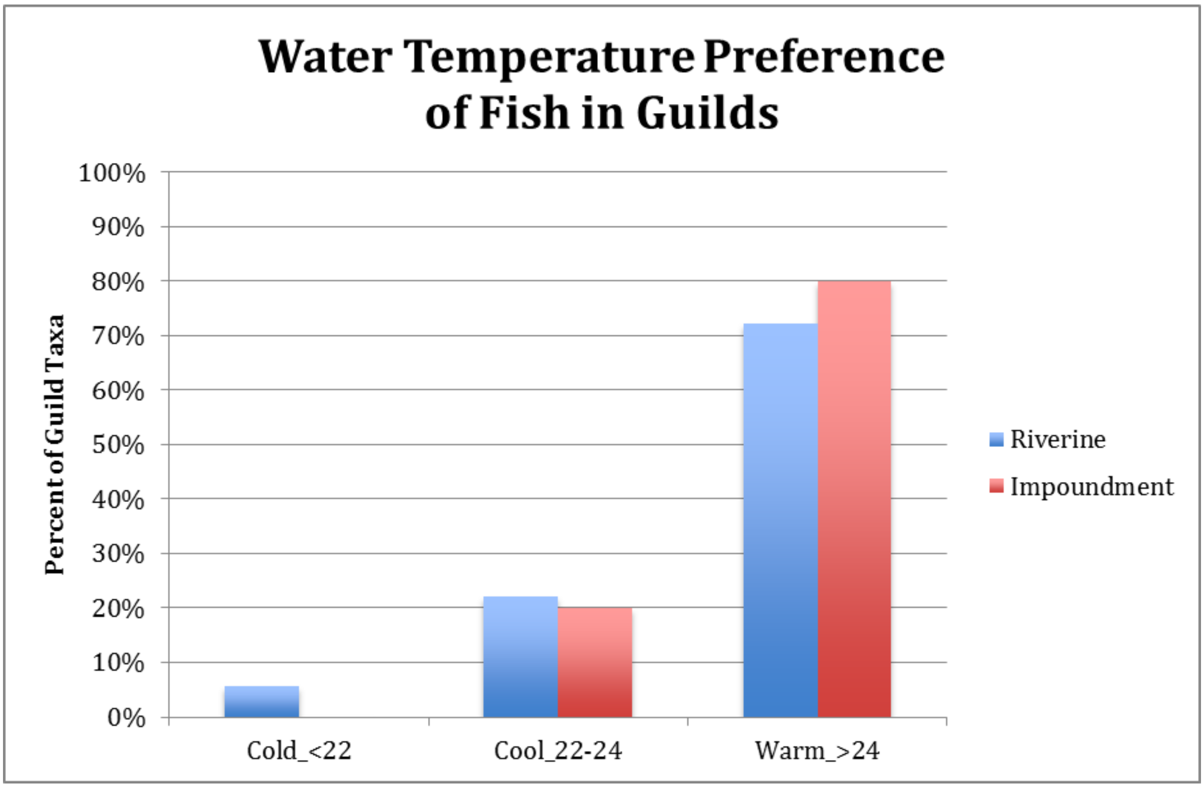


Figure 7 Percent aquatic vegetation preference of ROG and IOG taxa

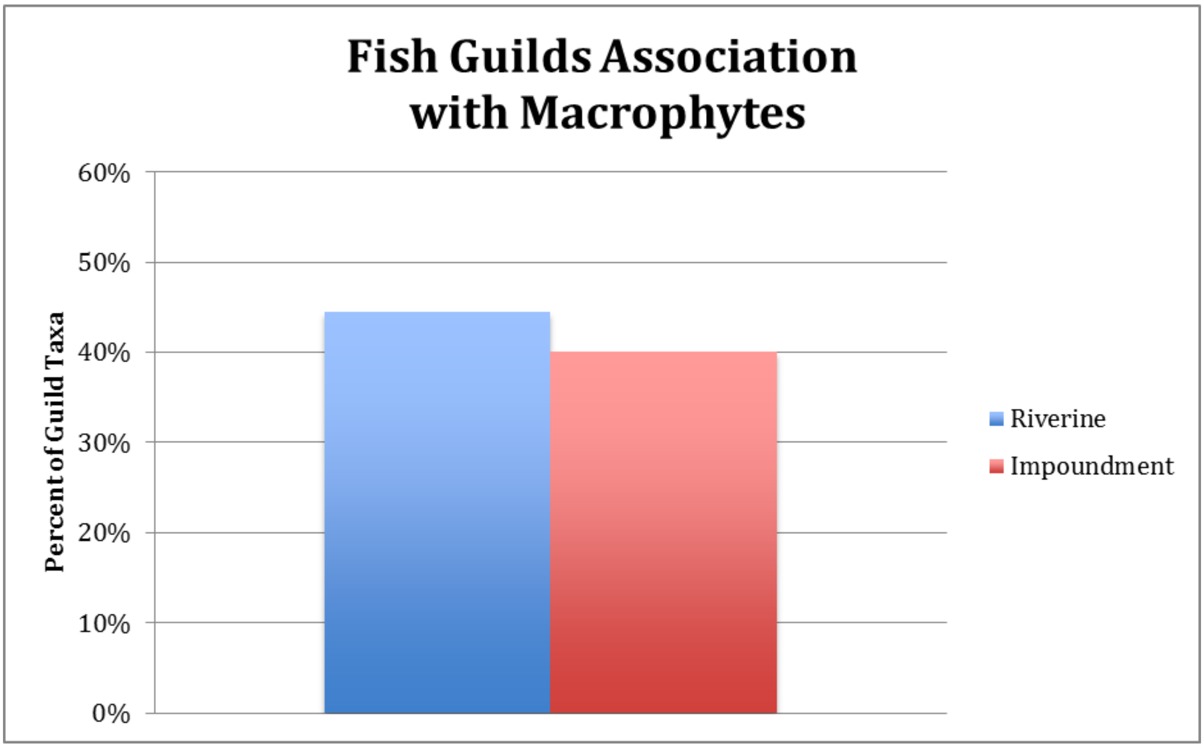
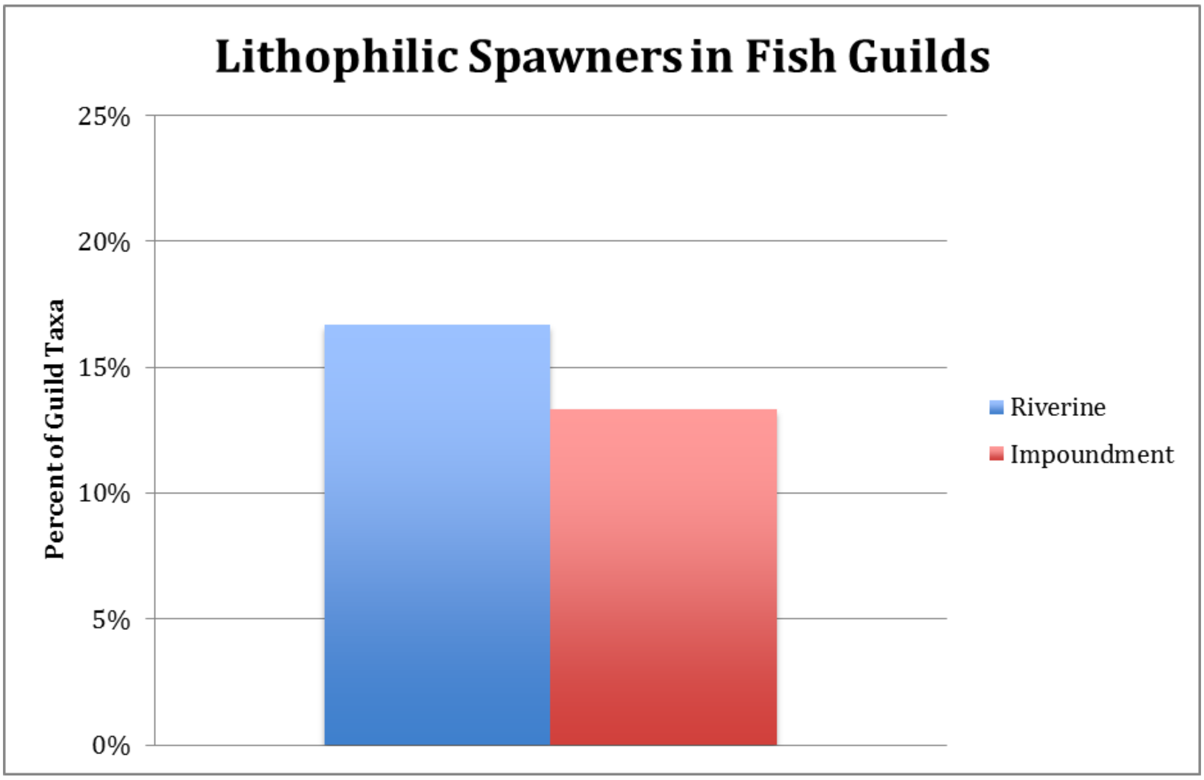


Figure 8 Percent lithophilic spawners in ROG and IOG taxa



7.4

Habitat quality assessment using MDEQ Procedure 51, HRWC Stream Habitat Assessment Packet, and MDNR IBI for Lakes

Table 1 MDEQ Procedure 51 (MDEQ 1996, Creel 2000) score table for the SMNITP Ecoregion

Table 1. Summary of Warmwater Fish Metric Scores for Wadable Streams

Ecoregion: SMNITP

Metric	Stream Width (ft)	+1	0	-1
1. Total Taxa	<15	>.92w	0.6w-0.92w	<0.60w
	≥15	>13	10-13	<10
2. Darter Taxa	<17	>.23w	.11w-.23w	<.11w
	≥17	>3	2-3	<2
3. Sunfish Taxa	<15	>.22w	.11w-.22w	<.11w
	≥15	>3	2-3	<2
4. Sucker Taxa	<18	>.15w	.074w-.15w	<.074w
	≥18	>2	2	<2
5. Intolerant Taxa	<21	>.23w	.14w-.23w	<.14w
	≥21	>4	3-4	<3
6. % Tolerant	All	<20	20-53	>53
7. % Omnivore	All	<16	16-46	>46
8. % Insectivore	All	>64	64-31	<31
9. % Piscivore	All	>14	14-1	<1
10. % Simple Lithophilic Spawners	All	>41	41-2	<2

w = average stream width in feet

Table 2 Example HRWC Stream Habitat Assessment Packet

STREAM HABITAT ASSESSMENT

Huron River Watershed Council

If you need to reach us, our number at the office is (734) 769-5123 x 601, Paul's home (734) 709-6589.

Site ID #: ____________________ Date: ____________________ Starting Time: ____________________

Stream Name: ____________________ Location: ____

Names: ____

Did it rain in the past 3 days? ________ If so, when and how much (approximately)? ____________________

IMPORTANT NOTE: When determining the left/right side of a stream, please face the downstream direction.

I. Transects and Stream Bank Measurements

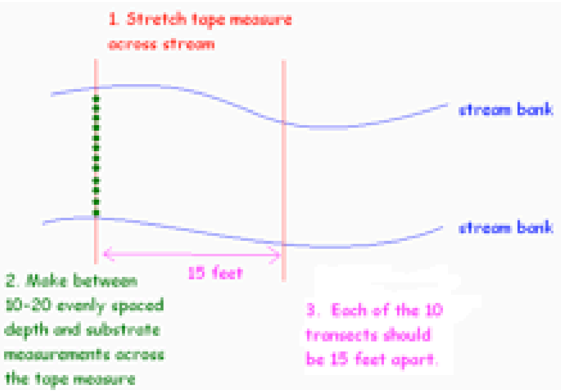
A. TEN TRANSECTS

1) Stretch the tape measure perpendicular across the stream. Measure the active channel width and the water's edge width (see diagram below)
2) Use the rod to measure depth (D) and substrate (S) at more than 10 but less than 20 regular intervals along the entire transect. (For streams less than 10 feet wide, measure approximately every 1/2 foot, for streams greater than 10 feet wide, measure every foot, etc.)
3) At every depth measurement, identify the single piece of substrate that the rod lands on (If it lands on two pieces, please pick one of them).
4) For every measurement, enter the number on the tape measure, the depth measurement, and the substrate type on the data sheet (see back pages).

B. BANK ANGLES

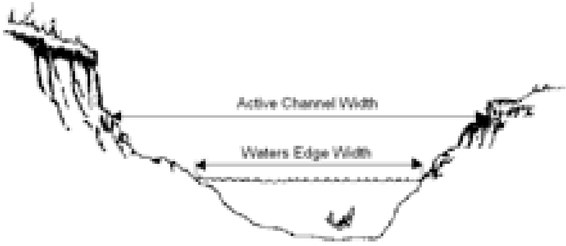
Vertical banks can be unstable, while banks with an overhang provide good habitat for fish and insects. While doing transects, record the angle of the bank (right, acute, obtuse) as indicated on the data sheet. Also, if the bank angle is acute (undercut), record its undercut width.

What is a transect?



What is the active edge and active channel?

The active edge is usually the bottom edge of vegetation. This is the border of the *active channel*, where water flows under normal conditions (not too dry, not too flooded).



Stream Name ____________________ Location __________________________ Date _________________

II. General Characteristics **All of these measurements & judgment calls are made on the 300 foot stream segment.**

A. FLOW PATTERNS
Please observe the POOLS (deep and slow), and RIFFLES (shallow and faster). You should estimate and not measure for the observations below.

POOLS: Number:______________________ Average Depth:_____________ Maximum Depth:_____________

RIFFLES: Length of feet in the study site that could be called a riffle:____________ Average Riffle Depth:_______

B. BENDS
Is the stream perfectly straight? _________ How many bends are in the 300' stretch of creek?________

C. STREAM FLOW
Estimate the current stream flow (circle one): Dry/Stagnant Low Medium High

D. SHADE
Stand in the middle of the stream and look overhead (assume the sun is directly above you).
What percentage of the stream could be shaded by the vegetation?_______%

E. COOL AREAS
Did you find any spots where the water has a localized cool area?________
This may be difficult to notice with waders on.

Did you notice any springs or seeps along the stream bank? ________

Did an orange-yogurt-like substance accompany these any springs or seeps? ________
(This is a natural iron-containing substance produced by some types of bacteria.)

F. TRASH
Does trash need to be removed from the stream? ________ If so, please describe the kinds and amounts, or note if you decide to remove it yourself.

G. APPEARANCE OR ODOR
Does the water have an unusual appearance or odor? _________ If so, please describe.

Is there foam on the water? _________ If yes, is it gritty? (probably natural) ________
Or is it soapy? (probably not natural) ________

Is there a sheen on the surface of the water? ________ Does it break up when poked? (probably natural) ________
Does it come back together after being poked? (not natural) ____

H. PIPES
Are pipes present? ________ Does the opening extend over the water? ________

Do the areas around or behind the pipes show signs of erosion? ________

Are there any problems that the Watershed Council needs to know about?

Sheet Checked By:

Stream Name ____________________ Location _________________________ Date ________________

III. Riparian Zone and Plant Community

A. Riparian Zone

Right/Left banks are identified by looking downstream

1. Left Bank

Circle those land-use types that you can see from this stream segment.

Wetlands | Forest | Residential Lawn | Park | Shub, Old Field | Agriculture

Construction | Commercial | Industrial | Highways | Golf Course | Other__________

2. Right Bank

Circle those land-use types that you can see from this stream segment.

Wetlands | Forest | Residential Lawn | Park | Shub, Old Field | Agriculture

Construction | Commercial | Industrial | Highways | Golf Course | Other__________

3. Summarize the size and quality of the riparian zone along each bank separately on a scale of 1 through 10, by circling a value below.

Excellent	Good	Marginal	Poor
Width of riparian zone >150 feet, dominated by vegetation, including trees, understory shrubs, or non-woody macrophytes or wetlands; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	Width of riparian zone 75-150 feet, human activities have impacted zone only minimally.	Width of riparian zone 10-75 feet; human activities have impacted zone a great deal.	Width of riparian zone ,10 feet; little or no riparian vegetation due to human activities.
LEFT BANK 10 - 9	LEFT BANK 8 - 7 - 6	LEFT BANK 5 - 4 - 3	LEFT BANK 2 - 1 - 0
RIGHT BANK 10 - 9	RIGHT BANK 8 - 7 - 6	RIGHT BANK 5 - 4 - 3	RIGHT BANK 2 - 1 - 0

B. Plant Community

Using the given scale, estimate the relative abundance of the following:

Plants in the stream:		*Plants on the bank/ riparian zone:*	
Algae on Surfaces of Rocks or Plants	Filamentous Algae (Streamers)	Shrubs	Trees
Macrophytes (Rooted Herbaceous Plants)	**0= Absent 1= Rare 2= Common 3= Abundant 4= Dominant**	Grasses	**0= Absent 1= Rare 2= Common 3= Abundant 4= Dominant**
Identified species (optional)		Identified species (optional)	

Sheet Checked By:

3

Stream Name ______________________ Location ____________________________ Date ___________________

IV. Stream Substrate and Sediment

A. STABLE HABITAT (HIDING PLACES)

Circle the objects that make up the hiding places for insects, fish and other critters:

Large rocks grocery carts submerged logs undercut banks other (please describe)

B. SEDIMENT AND ROCKS BEYOND THE TRANSECTS

Please check whether the substrate on the bottom of the stream **beyond** the area of transects contains more, less, or a similar amount of **fine sediment** than you saw in the transects (Circle one):

Much more Much less A similar amount

Please check whether the substrate on the bottom of the stream **beyond** the area of transects contains more, less, or a similar amount of **rocks, gravel, and cobble** than you saw in the transects (Circle one):

Much more Much less A similar amount

C. SEDIMENT DEPOSITION

Did you see:
Islands with little vegetation? _______
Deposition along the inside of bends? _______
Deposition along obstructions? _______

D. SOFT BOTTOM

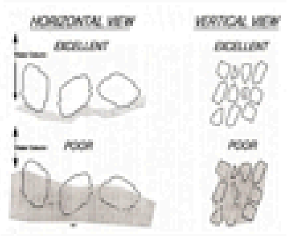
Was a soft bottom common in shallow areas? _______
Was a soft bottom only found in pools? _______
In the soft bottom areas, was the muck deep (did you sink in above the tops of your feet)? _______

E. EMBEDDEDNESS

Estimate the extent to which gravel, cobble and boulder particles are surrounded by fine sediment. Look in the upstream or central portions of **riffles** or **cobble** substrate. Circle One:

<25% (clean; excellent) 25-50% (somewhat silted) 50-75% (silty but a little loose)

>75% (firmly lodged; poor) No gravel, cobble, or boulder particles are present



Other Comments:

Sheet Checked By:

4

Stream Name ____________________ Location ________________________ Date ________________

V. Bank Stability

A. BARE BANKS

What percent of the banks (above the active edge) are bare (showing either soil or sand)? Bank areas covered by rocks, rip-rap, or anything else should not be considered "bare". If percent is difficult to estimate, use words.

__________%

If any, estimate the percent of bank covered in cement or unnatural rock (human influenced bank stability)

_________%

B. BANK STABILITY

Summarize the extent of erosion along each bank separately on a scale of 1 through 10, by circling a value below.

Excellent	Good	Marginal	Poor
Banks Stable. No evidence of erosion or bank failure. Little potential for problems during floods. < 5% of bank affected.	Moderately stable. Small areas of erosion. Slight potential for problems in extreme floods. 5-30% of bank in reach has areas of erosion.	Moderately unstable. Erosional areas occur frequently and are somewhat large. High erosion potential during floods. 30-60% of banks in reach are eroded.	Unstable. Many eroded areas. > 60% banks eroded. Raw areas frequent along straight sections and bends. Bank sloughing obvious.
LEFT BANK 10 - 9 RIGHT BANK 10 - 9	LEFT BANK 8 - 7 - 6 RIGHT BANK 8 - 7 - 6	LEFT BANK 5 - 4 - 3 RIGHT BANK 5 - 4 - 3	LEFT BANK 2 - 1 - 0 RIGHT BANK 2 - 1 - 0

Please use the space below to record any additional observations about this stream site or your experience today:

CONGRATULATIONS!
You've completed a challenging job!
Please check that you have answered all questions on all pages and initial each box that says "Sheet Checked By".

Stop Time: ____________

Sheet Checked By:

5

Stream Name ____________________ Location __________________________ Date _________________

B: Boulder -- more than 10" (Adult head)
C: Cobble -- 2.5 - 10" (Fist→ Small head)
R: Rock -- 1 - 2.5" (Small fingers→ Small fist)
G: Gravel -- up to about an inch (Fingernails)
S: Sand -- fine particles, all about the same tiny size, gritty
F: Clay or Muck -- finer than sand and not gritty
Rt: Root or Woody Debris
I: Island V: Vegetation

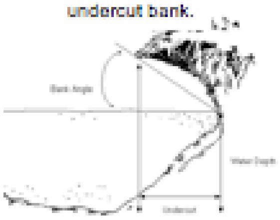
T= Reading on tape
D = Depth
S = Substrate

	EXAMPLE			Transect #1			Transect #2			Transect#3		
Active Channel Width	18.6											
Water's Edge Width	13.3											
	T	D	S	T	D	S	T	D	S	T	D	S
Beginning Water's Edge:	1.5											
1	2.5	0.4	G									
2	3.5	0.4	G									
3	4.5	0.4	G									
4	5.5	0.2	C									
5	6.5	0	S									
6	7.5	0.6	S									
7	8.5	0.7	S									
8	9.5	0.7	G									
9	10.5	0.6	C									
10	11.5	0.7	B									
11	12.5	0.4	G									
12	13.5	0.3	G									
13	14.5	0.2	Rt									
14												
15												
16												
17												
18												
19												
Ending Water's Edge	14.8											
Bank Side	L	R		L	R		L	R		L	R	
Does the bank have an undercut?	N	Y										
If so, how wide is it?		1 ft										
Bank Angles: Sketch												

Sketch examples:

Undercut (Acute) Obtuse Right

Example of an undercut bank.



6

Sheet Checked By:

Table 3 Score card from MDNR IBI for Lakes (Schneider 2002) with the example of Argo Pond

Lake Name: Argo Pond

Sampling Date: 2000 (Full Community)

Metric	Score ⑤		④		③		②		①	
1. Native fish fauna	○	○	○	○	○	○	○	○	✖	1
2. Winterkill	✖		○		○		○		○	5
3. Acidity	○				✖		○		○	3
4. Thermocline/hypolimnion DO	○		○		✖		○		○	3
5. Productivity/enrichment	○		✖		○		○		○	4
6. Turbidity			○		✖		○		○	3
7. Silt			✖		○		○		○	4
8. Macrophytes	○				✖		○		○	3
9. Edge modification	○		○		○		✖		○	2
10. Level stabilization	○		○		○		○		✖	1
11. Predation/competition	✖				○		○			5
									Total Score	34

Appendix 8 - Fish Habitat Suitability

8.1 - Habitat Suitability Model Results

Table 1 The results of habitat suitability model

	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
Predicted Species	Black Bullhead	Black Crappie	Black Crappie	Black Crappie*	Black Crappie*	Black Crappie	Black Crappie
	Blackside Darter	Black Redhorse	Black Redhorse	Black Redhorse*	Black Redhorse	Bluntnose Minnow	Bluntnose Minnow
	Bluegill*	Blackside Darter	Bluegill*	Bluegill	Bluegill	Bowfin	Bowfin
	Bluntnose Minnow*	Bluegill*	Bluntnose Minnow	Bluntnose Minnow	Bluntnose Minnow	Brook Silverside	Brook Silverside
	Bowfin*	Bluntnose Minnow	Bowfin*	Bowfin*	Bowfin	Brown Bullhead	Brown Bullhead
	Brook Silverside	Bowfin*	Brown Bullhead*	Brook Silverside	Brook Silverside*	Carp	Carp
	Brown Bullhead*	Brook Silverside	Carp	Brown Bullhead*	Brown Bullhead*	Channel Catfish	Channel Catfish
	Burbot	Brown Bullhead*	Common Shiner	Carp*	Carp*	Freshwater Drum	Freshwater Drum
	Common Shiner*	Burbot	Golden Redhorse	Channel Catfish	Channel Catfish*	Mimic Shiner	Mimic Shiner
	Fathead Minnow	Carp*	Golden Shiner	Flathead Catfish	Flathead Catfish*	Northern Hogsucker	Quillback
	Golden Shiner	Common Shiner	Grass Pickerel	Freshwater Drum	Freshwater Drum	Quillback	
	Grass Pickerel*	Golden Redhorse	Green Sunfish	Gizzard Shad	Gizzard Shad	Silver Redhorse	
	Green Sunfish*	Golden Shiner	Greenside Darter	Golden Redhorse	Golden Redhorse	Striped Shiner	
	Greenside Darter	Grass Pickerel	Hornyhead Chub	Greenside Darter	Greater Redhorse		
	Hornyhead Chub*	Green Sunfish	Largemouth Bass*	Hornyhead Chub	Largemouth Bass		
	Lake Chubsucker	Greenside Darter	Log Perch*	Largemouth Bass*	Log Perch		
	Largemouth Bass*	Horneyhead Chub*	Longear Sunfish*	Log Perch	Mimic Shiner*		
	Log Perch	Largemouth Bass*	Mimic Shiner*	Longear Sunfish	Northern Hogsucker		

	Commerce	Milford	New Hudson	Hamburg	Dexter	Ann Arbor	Ypsilanti
Predicted Species	Longear Sunfish*	Log Perch*	Northern Hogsucker	Mimic Shiner*	Quillback		
	Longnose Dace	Longear Sunfish*	Northern Pike	Northern Hogsucker*	Sand Shiner		
	Mimic Shiner	Mimic Shiner*	Pumpkinseed*	Northern Pike	Shorthead Redhorse		
	Northern Pike *	Northernhog Sucker	Rainbow Darter	Pumpkinseed	Silver Redhorse*		
	Pumpkinseed*	Northern Pike*	River Chub	River Chub	Smallmouth Bass		
	Rainbow Darter*	Pumpkinseed*	Rock Bass*	Rock Bass	Spotfin Shiner		
	Rock Bass*	Rainbow Darter	Rosyface Shiner*	Rosyface Shiner	Spotted Sucker		
	Striped Shiner	River Chub*	Sand Shiner*	Sand Shiner	Stonecat		
	Tadpole Madtom	Rock Bass*	Shorthead Redhorse	Shorthead Redhorse	Striped Shiner		
	White Sucker	Rosyface Shiner	Smallmouth Bass*	Silver Redhorse*	Tadpole Madtom		
	Yellow Bullhead*	Sand Shiner	Spotted Sucker*	Smallmouth Bass*	Yellow Bullhead		
	Yellow Perch*	Shorthead Redhorse	Stonecat	Spotfin Shiner	Yellow Perch		
		Smallmouth Bass*	Striped Shiner*	Spotted Sucker*			
		Spotted Sucker*	Tadpole Madtom	Tadpole Madtom			
		Stonecat	Walleye	Walleye			
		Striped Shiner*	White Sucker	Yellow Bullhead*			
		Tadpole Madtom	Yellow Bullhead*	Yellow Perch			
		Walleye	Yellow Perch*				
		White Sucker					
		Yellow Bullhead*					
		Yellow Perch					

Note: 1. Listed are species which the habitat suitability model expected to be present in characteristic numbers at each site given the site's CA, JMT, and BFY.
2. * Indicates species which the habitat suitability model expected to be present in thriving numbers.

8.2 - Species Comprising Fish Communities

Table 1 Species comprising fish communities in Commerce

	Present & Model (*a*)	Model (*b*)	Present (*c*)
Species	Black Bullhead	Blackside Darter	Black Crappie
	Bluegill	Burbot	Carp
	Bluntnose Minnow	Common Shiner	Sand Shiner
	Bowfin	Greenside Darter	Smallmouth Bass
	Brook Silverside	Hornyhead Chub	Spotfin Shiner
	Brown Bullhead	Lake Chub	Walleye
	Flathead Minnow	Longear Sunfish	
	Golden Shiner	Rainbow Darter	
	Grass Pickerel	Striped Shiner	
	Green Sunfish	Tadpole Madtom	
	Largemouth Bass		
	Log Perch		
	Longnose Dace		
	Mimic Shiner		
	Northern Pike		
	Pumpkinseed		
	Rock Bass		
	White Sucker		
	Yellow Bullhead		
	Yellow Perch		

Table 2 Species comprising fish communities in New Hudson

	Present & Model (*a*)	Model (*b*)	Present (*c*)
Species	Black Crappie	Bowfin	Blackside Darter
	Black Redhorse	Common Shiner	Johnny Darter
	Blugill	Golden Shiner	Rainbow Trout
	Bluntnose Minnow	Hornyhead Chub	Spotfin Shiner
	Brown Bullhead	River Chub	
	Golden Redhorse	Rosyface Shiner	
	Grass Pickerel	Sand Shiner	
	Green Sunfish	Shorthead redhorse	
	Greenside Darter	Spotted Sucker	
	Largemouth Bass	Striped Shiner	
	Log Perch	Tadpole Madtom	
	Longear Sunfish		
	Mimic Shiner		
	Northern Hogsucker		
	Northern Pike		
	Pumpkinseed		
	Rainbow Darter		
	Rock Bass		
	Smallmouth Bass		
	Stonecat		
	Walleye		
	White Sucker		
	Yellow Bullhead		
	Yellow Perch		

Table 3 Species comprising fish communities in Dexter

	Present & Model (*a*)	**Model (*b*)**	**Present (*c*)**
Species	Black Redhorse	Black Crappie	Common Shiner
	Bluegill	Bowfin	Grass Pickerel
	Bluntnose Minnow	Brook Silverside	Green Sunfish
	Carp	Brown Bullhead	Greenside Darter
	Gizzard Shad	Channel Catfish	Hornyhead Chub
	Golden Redhorse	Flathead Catfish	Longear Sunfish
	Largemouth Bass	Freshwater Drum	Mottled Sculpin
	Northern Hogsucker	Greater Redhorse	Northern Pike
	Smallmouth Bass	Log Perch	Pumpkinseed
	Yellow Bullhead	Mimic Shiner	Rainbow Darter
		Quillback	Rock Bass
		Sand Shiner	White Sucker
		Shorthead Redhorse	
		Silver Redhorse	
		Spotfin Shiner	
		Spotted Sucker	
		Stonecat	
		Striped Shiner	
		Tadpole Madtom	
		Yellow Perch	

Table 4 Species comprising fish communities in Ann Arbor

	Present & Model (*a*)	**Model (*b*)**	**Present (*c*)**
Species	Black Crappie	Brook Silverside	Black Bullhead
	Bluntnose Minnow	Freshwater Drum	Black Redhorse
	Bowfin	Mimic Shiner	Bluegill
	Brown Bullhead	Quillback	Golden Shiner
	Carp	Silver Redhorse	Green Sunfish
	Channel Catfish	Striped Shiner	Greenside Darter
	Northern Hogsucker		Johnny Darter
			Largemouth Bass
			Longear Sunfish
			Longnose Dace
			Northern Pike
			Pumpkinseed
			Rainbow Darter
			Rock Bass
			Shorthead Redhorse
			Smallmouth Bass
			Stonecat
			Walleye
			White Sucker
			Yellow Bullhead
			Yellow Perch

Table 5 Species comprising fish communities in Ypsilanti

	Present & Model (*a*)	**Model (*b*)**	**Present (*c*)**
Species	Black Crappie	Brook Silverside	Black Bullhead
	Bluntnose Minnow	Freshwater Drum	Blacknose Dace
	Bowfin	Quillback	Bluegill
	Brown Bullhead	Silver Redhorse	Common Shiner
	Carp		Creek Chub
	Channel Catfish		Flathead Minnow
	Mimic Shiner		Golden Redhorse
			Golden Shiner
			Green Sunfish
			Greenside Darter
			Largemouth Bass
			Log Perch
			Longnose Dace
			Mottled Sculpin
			Northern Hogsucker
			Pumpkinseed
			Rainbow darter
			Rock Bass
			Sand Shiner
			Smallmouth Bass
			Spotfin Shiner
			Walleye
			White Sucker
			Yellow Perch

8.3 - Fish Community Response Curve

Table 1 ARI causing flow in each study site

Site	ARI causing flow (cfs)
Commerce	5.04
Milford	9.20
New Hudson	9.72
Hamburg	23.32
Dexter	36.00
Ann Arbor	53.30
Ypsilanti	51.70

Figure 1 Fish community response curve in Commerce

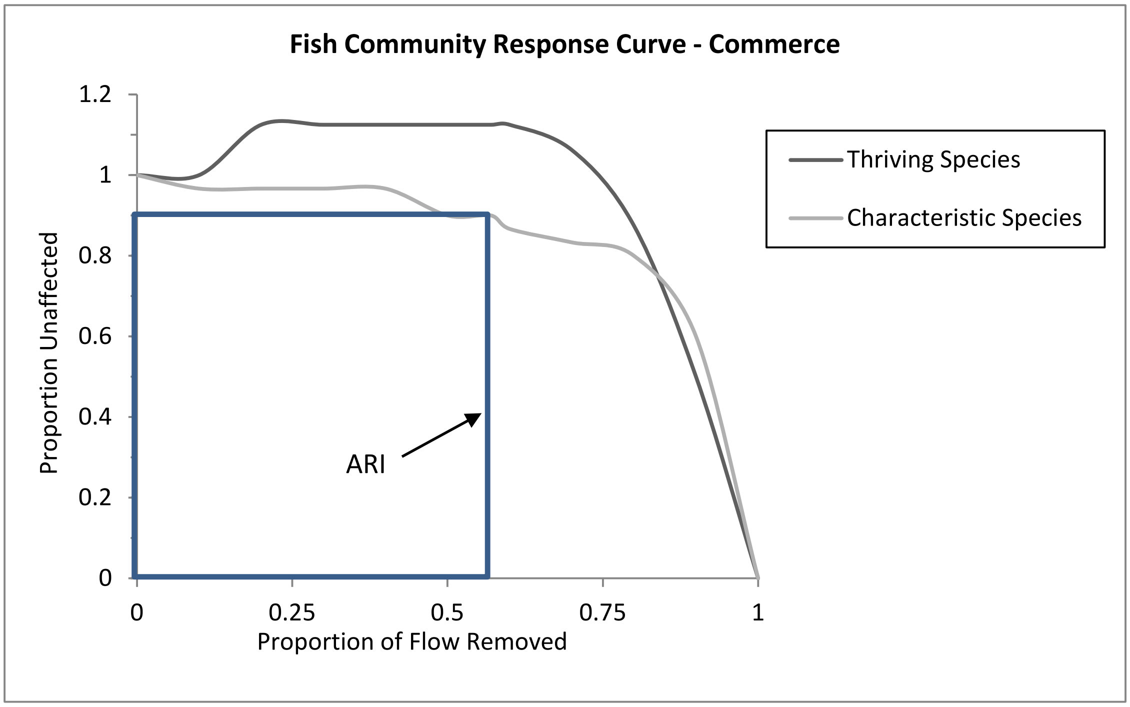


Figure 2 Fish community response curve in Milford

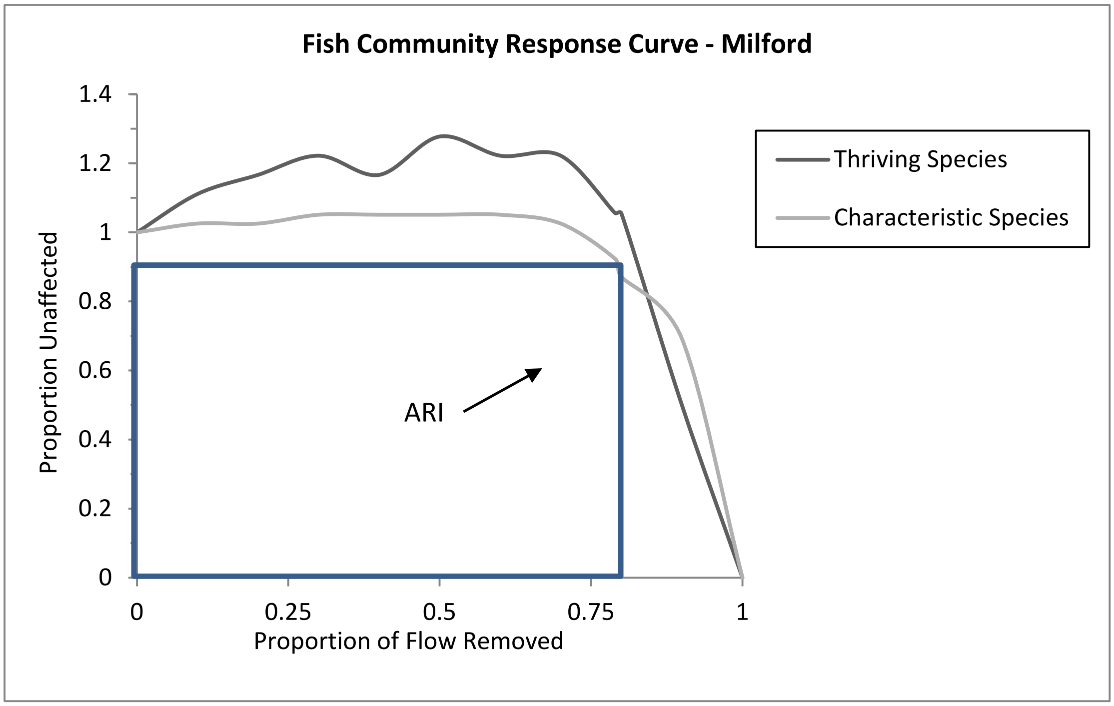


Figure 3 Fish community response curve in New Hudson

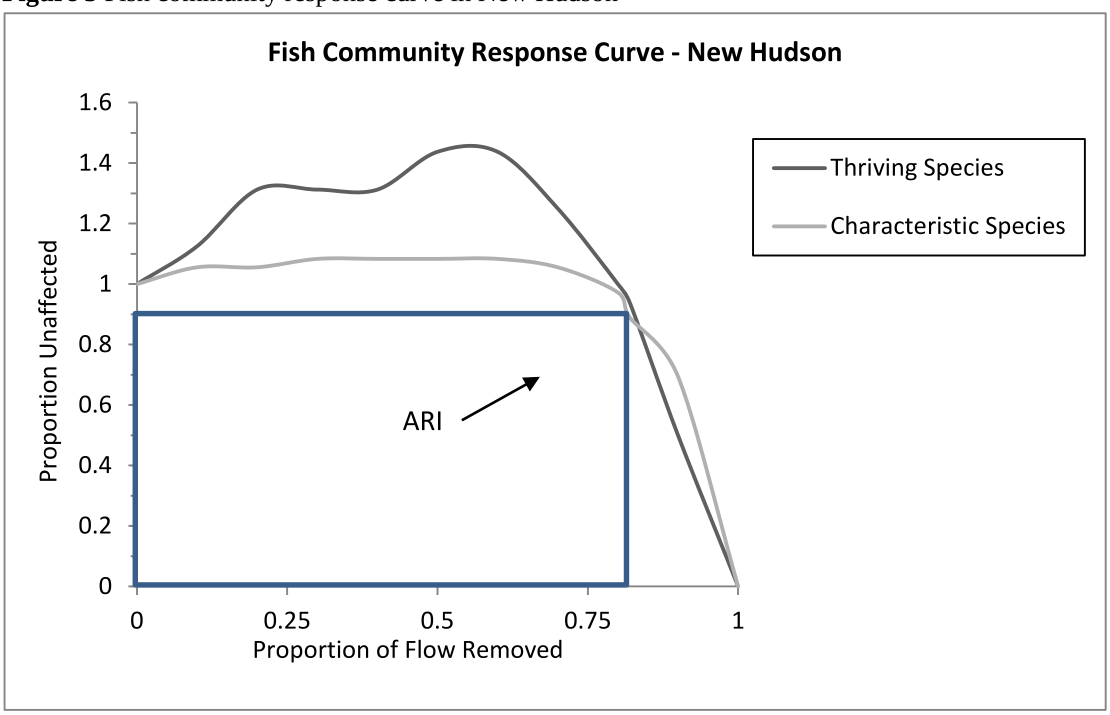


Figure 4 Fish community response curve in Hamburg

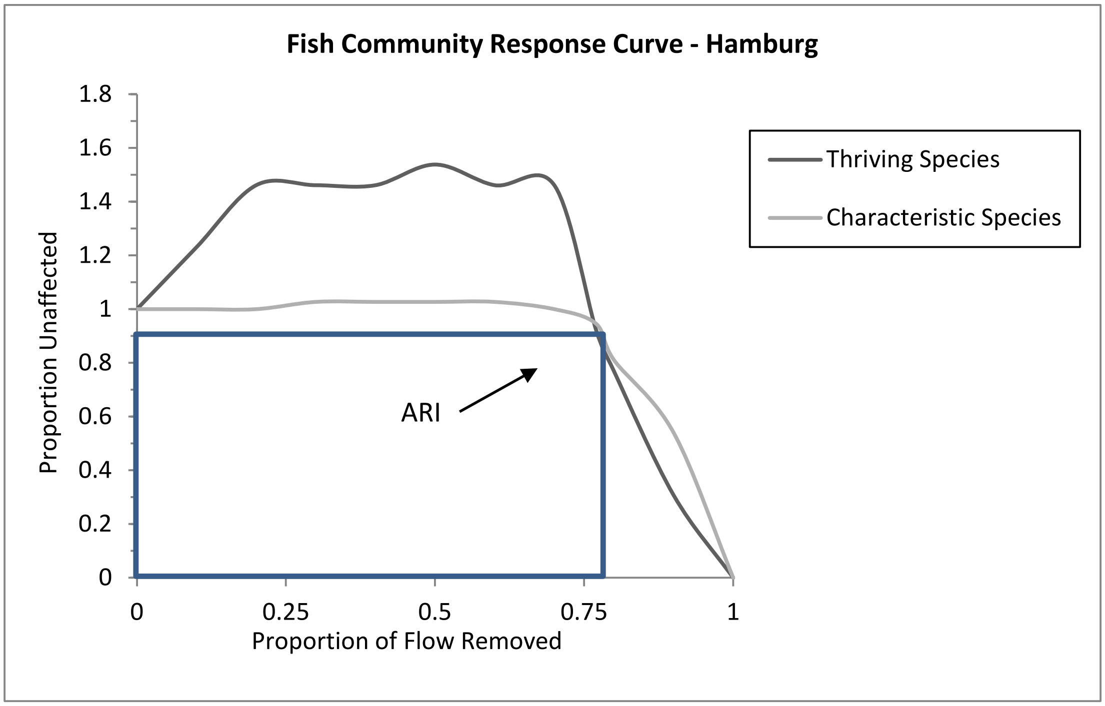


Figure 5 Fish community response curve in Dexter

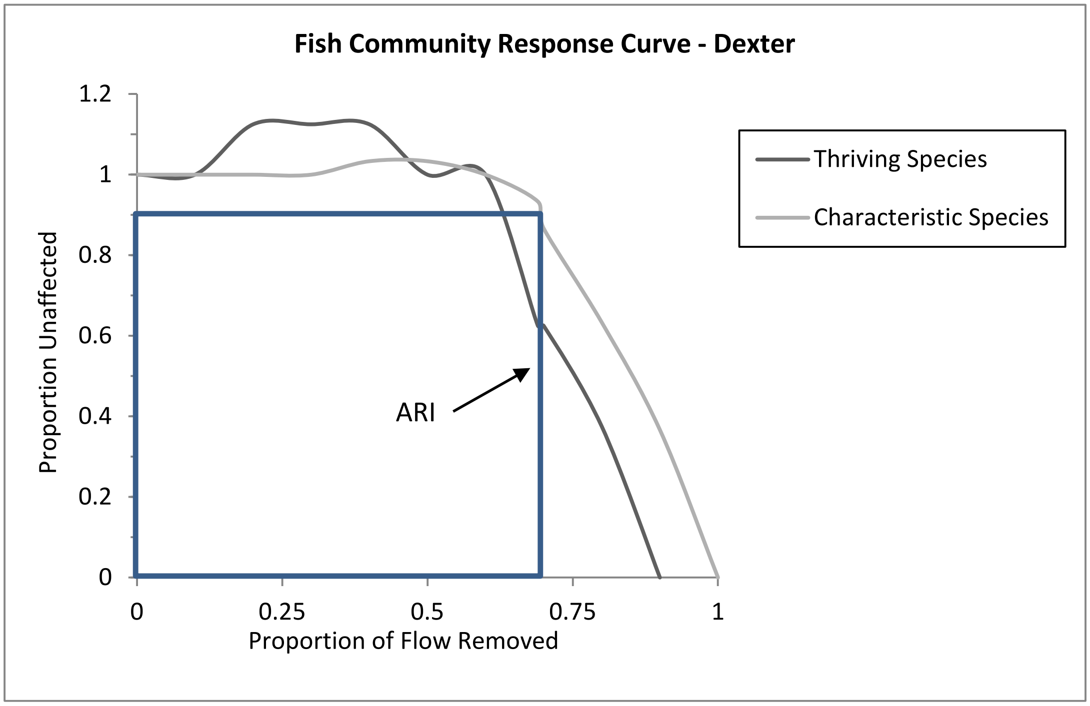


Figure 6 Fish community response curve in Ann Arbor

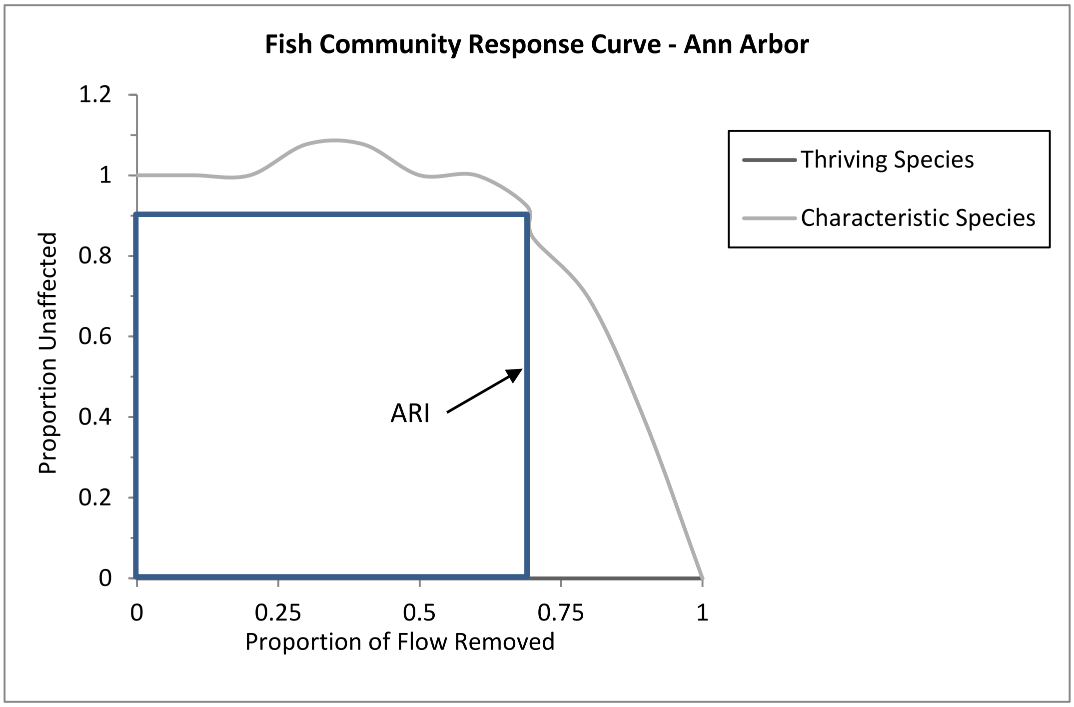
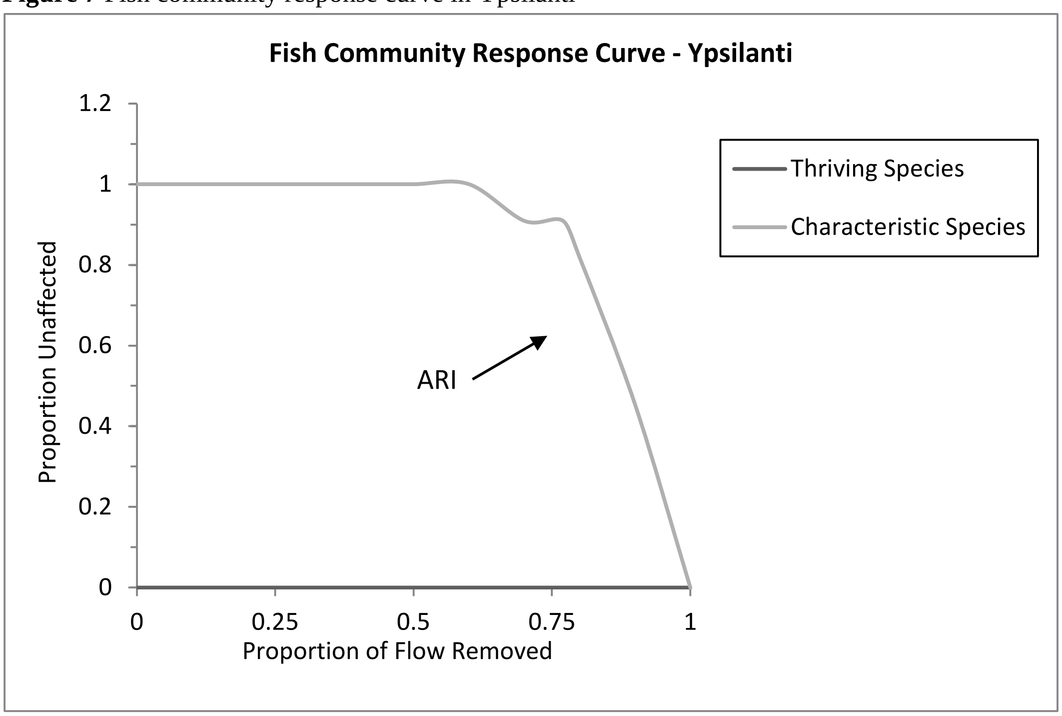


Figure 7 Fish community response curve in Ypsilanti



8.4 - Historic Drought and Non-Drought ARI Occurrences

Table 1 Historic drought and non-drought ARI occurrences

Site	Number of Occurrences		
	Drought	Non-Drought	Total
Commerce	27	26	53
Milford	17	1	18
New Hudson	3	4	7
Hamburg	0	0	0
Dexter	0	0	0
Ann Arbor	226	61	287
Ypsilanti	0	0	0