THE IMPACT OF CLIMATE CHANGE ON TWO SCENIC RIVERS IN OHIO

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By

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ABSTRACT

In the state of Ohio, most rivers have undergone major modifications due to human activity. Fifteen rivers across the state have retained most of their natural character and are designated as scenic rivers. These rivers are ideal surface water systems to characterize hydrologic shifts caused by changes in climate. This work is an assessment of the impact of climate change on two scenic rivers in northeast and central Ohio, the Grand River and Darby Creek. Discharge and precipitation data over a 31-year period were collected and statistical analyses were conducted using the Mann-Kendall Test to evaluate trends in the data. Annual and monthly trends revealed an increase in annual mean, median, and maximum discharge, and a decrease in annual minimum discharge. Overall, it is evident that river discharge increased from 1990 to 2021. Higher annual maximums and lower minimums suggest an increase in extreme weather events that can cause floods and droughts. Additional statistical analyses conducted on Ohio precipitation revealed a decrease in total precipitation, in contrast with findings from similar research. Data on El Niño Southern Oscillation was collected to investigate the correlation between discharge and short-term climate cycles. The discharge patterns of the Grand River and Darby Creek suggest long-term changes, which may be representative of fluctuating precipitation and climate over time. Along with climate, long-term changes are likely reflective of shifts in land use. These data are important to understand how hydrologic patterns are shifting due to changes in climate, as both environmental and human systems are threatened by increasing erosion changes and flooding events.

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1. INTRODUCTION

Stream water is an important human resource for recreation, irrigation, and domestic use. Many urban areas in Ohio depend on water extracted from rivers and stream for their primary water supply. As humans continue to burn fossil fuels and make landscape changes, carbon dioxide increases in the atmosphere. Because carbon dioxide is a greenhouse gas, its continued accumulation will lead to an increase in global atmospheric and oceanic temperatures (IPCC, 2023). A warming climate could affect precipitation, surface runoff, evaporation, plant utilization, and hence, stream discharge in many ways. It is anticipated that the increased atmospheric temperatures will lead to changes in the global hydrological cycle, impacting both precipitation amounts and intensities. Long-term data suggest that the Midwestern U.S. has gotten warmer and wetter as well as a ~doubling in the frequency of heavy rainfall events (Kucharik et al., 2010; Hayhoe, 2020). These changes in amount and intensity of rainfall events are expected to have observable impacts on watershed water dynamics, especially streamflow. The U.S. EPA has shown that over the past 83 years, seven-day low flows have generally increased in the Midwest with locations in both east-central Ohio and northern Kentucky having increased by more than 50% (U.S. EPA, 2024). Changes in the frequency and intensity of rainfall may also affect the duration of both high and low flows, and not just the total annual discharge. The seasonality of rainfall amounts may also be impacted by the warming induced changing in the local hydrological cycle. Additionally, climate cycles such as El Niño-Southern Oscillation can impact regional weather patterns, and consequently river discharge. Although, there have been efforts to evaluate the outcome of temperature increases on streamflow on a regional scale within the Midwest (Demaria et al., 2016), there have been few investigations that have looked at individual localized watershed behavior.

In this study, I have documented long-term changes in both precipitation and streamflow on an annual as well as monthly basis in order to assess the relationship and variation on both factors as the climate in Ohio has warmed.

2. GOALS AND OBJECTIVES

As the global climate shifts over time, regional hydrologic systems are impacted by changes in weather patterns. The aim of this research is to test the hypothesis that changes in precipitation driven by climate have caused an increase in discharge from two scenic rivers in Ohio. To do this, the following steps were implemented:

- Gather river discharge data for two rivers in Ohio, the Grand River and Darby Creek from 1990 to 2021
- Determine and assess trends in discharge over the study period through annual and monthly groupings
- Compare discharge trends to precipitation patterns to identify a relationship among the two variables

3. STUDY SITES

In Ohio, fifteen rivers are designated scenic, wild, and/or recreational, representative of varying levels of local, state, and federal protection. These rivers are ideal water systems to analyze hydrologic shifts resulting from climate change. The Grand River and Darby Creek are two scenic rivers that have retained most of their natural character.

The Grand River watershed is divided into an upper and lower portion. The upper portion (southern) flows through Ashtabula, Geauga, Portage and Trumbull counties and is dominated by forest, row crop/pasture, and woody wetlands. This portion is designated scenic. The lower (northern) portion of the Grand River watershed flows through Lake, Ashtabula, and Geauga counties and land use transitions from urban/suburban on the western edge to rural and agricultural in the east. This portion is designated wild.

The Darby Creek watershed encompasses the Big Darby Creek and the Little Darby Creek, along with twelve other minor tributaries.

Table 1. Watershed characteristics of each river. Information obtained from ODNR and the Ohio EPA (Big Darby Creek Watershed TMDLs; Grand River Watershed; Grand Scenic River, 2024).

	Grand River	**Darby Creek**
Location	Northeastern Ohio. Composed of Ashtabula, Geauga, Portage, Trumbull, and Lake counties.	Central Ohio. Composed of Union, Madison, Franklin, and Pickaway counties.
River Length	165 km	130 km
Watershed area	1,830 km^2	1,440 km^2
Land use	Forest, agricultural (cultivated crops and pasture and hay lands), urban	Agricultural (row crop), suburban
Designation	Upper portion- Scenic Lower portion- Wild	Ohio State Scenic River National Scenic River

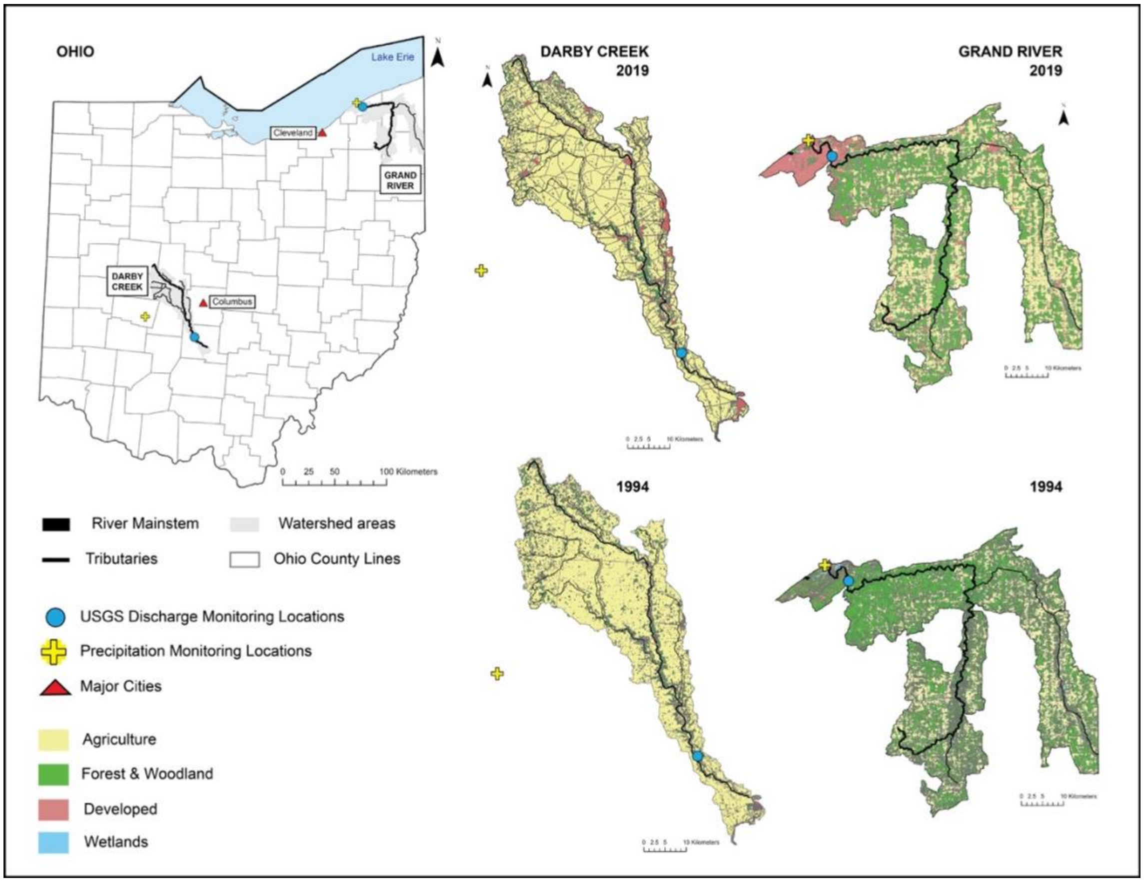

Figure 1. Site map showing the location of each river on a map of Ohio (USGS, 2011, 2023; National Land Cover Database, 2019). The Darby Creek and Grand River watersheds are labeled with the discharge monitoring locations and precipitation monitoring locations.

4. METHODS

4.1. Data Collection

To observe changes over time in discharge of the Grand River and Darby Creek, data was obtained from the U.S. Geological Survey (USGS) database (USGS, 2021). The Grand River USGS station (station #04212100) is located in Lake County near Painesville, Ohio in the upstream basin of the watershed (Figure 1). The Darby Creek USGS station (station #03230500) is located in Darbyville, Ohio at the low end of the upstream basin (Figure 1). At the monitoring sites, discharge values are recorded every fifteen minutes in units of cubic feet per second and are available for public access (USGS, 2021). Discharge values over the period of interest of 1988 to 2021 were downloaded into Microsoft Excel in three subsections: 1988-2000, 2000-2010, and 2010-2021. Each subsection was then condensed into daily average values using PivotTables and converted to SI units of cubic meters per second. The daily average values were used to analyze monthly and annual changes over time. All tables were made using Microsoft Excel.

Although the available discharge data goes back to 1988, reported measurements are not consistent until October of 1990. For this reason, the analyses were conducted from 1990 to 2021. Despite removal of discharge data from 1988 to 1990, there are still inconsistent temporal ranges in the earlier years of this data set that cause periods of scatter.

Table 2. Data Availability. Total days per year with available discharge (Q) and precipitation (P) data.

Year	**Darby Creek total P (cm)**	**Days with data**	**Grand River total P (cm)**	**Days with data**	**Grand River total Q (m^3)**	**Days with data**	**Darby Creek total Q (m^3)**	**Days with data**
1991	71.93	**364**	178.18	**364**	6791.50	**353**	742.18	**250**
1992	95.61	**365**	188.16	**365**	10140.13	**353**	3733.89	**317**
1993	110.95	**364**	224.79	**333**	10177.21	**291**	5698.82	**277**
1994	100.28	**364**	210.16	**364**	8018.58	**314**	3513.57	**324**
1995	138.00	**364**	177.11	**364**	7278.55	**266**	5509.11	**311**
1996	173.43	**365**	263.04	**365**	15293.87	**322**	7668.99	**325**
1997	108.89	**364**	155.17	**364**	10273.72	**351**	4749.67	**337**
1998	67.64	**364**	110.74	**364**	6684.77	**359**	5216.24	**355**
1999	48.72	**364**	200.66	**364**	6846.26	**338**	3093.41	**338**
2000	112.65	**365**	239.45	**365**	7948.51	**331**	4532.63	**363**
2001	56.67	**234**	157.89	**364**	5654.52	**329**	2883.07	**234**
2002	136.45	**342**	188.47	**364**	7516.67	**340**	5950.38	**342**
2003	134.21	**364**	212.39	**364**	11287.55	**273**	8714.93	**364**
2004	95.91	**178**	198.27	**365**	11264.95	**322**	7785.91	**178**
2005	109.80	**361**	202.82	**364**	12589.19	**331**	4756.54	**361**
2006	28.10	**142**	176.86	**364**	13243.04	**334**	2288.82	**142**
2007	36.10	**109**	242.60	**364**	10161.39	**307**	1859.22	**109**
2008	92.04	**365**	320.27	**365**	12782.20	**333**	2543.50	**364**
2009	69.99	**364**	162.89	**364**	7323.51	**342**	742.76	**87**
2010	80.54	**363**	136.27	**364**	6989.11	**292**	4196.54	**296**
2011	125.07	**364**	155.65	**364**	16520.69	**307**	10258.0	**319**
2012	77.75	**365**	108.46	**365**	8817.86	**359**	3506.68	**363**
2013	94.28	**363**	155.47	**364**	12021.31	**345**	4854.27	**331**
2014	89.43	**363**	153.80	**364**	8780.73	**297**	4621.48	**312**
2015	108.25	**363**	151.77	**364**	7216.27	**287**	5165.15	**286**
2016	88.52	**364**	163.40	**365**	7597.05	**317**	3711.91	**342**
2017	111.18	**363**	235.84	**364**	11504.78	**362**	6400.20	**363**
2018	119.00	**358**	147.78	**364**	13688.37	**364**	9023.52	**356**
2019	81.79	**352**	149.45	**364**	13540.25	**364**	7244.10	**348**
2020	108.99	**365**	77.34	**365**	11165.82	**365**	4975.03	**331**
2021	74.35	**363**	102.95	**364**	9952.92	**364**	5005.15	**362**

Precipitation data for the Grand River and Darby Creek was obtained from the NOAA National Weather Service (NOAA Online Weather Data, 2024) and the Ohio State CFAES Past Weather Information System (CFAES Weather System, 2024), respectively. The Grand River precipitation monitoring site is located in Painesville, Ohio. The Darby Creek precipitation monitoring site is located in South Charleston, Ohio. Daily rainfall and snowfall measurements were summarized to calculate total daily precipitation values. The daily total precipitation values were analyzed for monthly and annual changes over the study period and were analyzed in conjunction with the daily average discharge values.

To investigate potential correlations between El Niño Southern Oscillation (ENSO) and fluctuations in precipitation and discharge, ENSO data was obtained from the Oceanic Niño Index, or ONI (NOAA, 2024; Null, 2024). The ONI tracks average sea-surface temperatures and is the NOAA's primary indicator for monitoring ENSO anomalies. Based on ONI temperature anomalies, each time period is classified as either El Niño, La Niña, or a neutral period. El Niño and La Niña periods are further categorized into weak (0.5 to 0.9 temperature anomaly), moderate (1.0 to 1.4), strong (1.5 to 1.9), and very strong events (≥2.0). These classifications were used to align the strong and very strong events with total annual discharge and precipitation values. This comparison helps to analyze how global climate patterns influence regional water systems.

4.2. Data Analyses

Discharge data was organized by month over the 1990 – 2021 study period. For this research, the Mann-Kendall (MK) test was used as a statistical assessment to identify if the linear slope describing the monthly discharge trends was significantly different from zero (Fatichi, 2024; Meals et al., 2011). A monthly MK analysis acted as a direct method of reducing seasonality in discharge data while identifying a trend (Kendall, 1975; Mann, 1945). An alpha value of 0.05 was implemented, indicating a significance level of 95%. The Mann-Kendall Trend Test (MK) is a statistical assessment that can recognize an upward or downward trend in a variable. The MK test compares each value to the value preceding it, finding that a trend is present if the variable is constantly increasing or constantly decreasing. It is a non-parametric analysis that can compute a trend for measurements that are not normally distributed. The null hypothesis for the MK test is that there is not a monotonic trend in the series. If the null hypothesis is rejected, it signifies that a positive or negative trend is present.

For both the Grand River and the Darby Creek, the MK test was conducted on monthly data sets for discharge and precipitation. This revealed the absence or presence of a trend for each month over the time series (e.g., every January from 1990 to 2021). A monthly MK test was conducted to determine seasonal trends in the data. Since the variables looked at in this analysis fluctuate based on local weather patterns and seasonal changes, the MK test is suitable for determining whether or not there is a trend in discharge and precipitation patterns over the 31-year time period.

Additionally, monthly linear discharge trends from 1990 – 2021 were calculated for the two rivers and the MATLAB Curve Fitter was utilized to find linear coefficients for trendlines of each month (Table 2, 3).

5. RESULTS

5.1. Precipitation and Discharge Annual Trends

According to an analysis of discharge and precipitation levels from 1990 to 2021, there was an increase in average daily discharge for both the Grand River and Darby Creek (Table 1). Precipitation daily totals showed a decrease between 1990 and 2021 for both rivers, although there is correlation between interannual fluctuations of discharge and precipitation (Figure 4, 5). The summary tables of precipitation and discharge trends revealed positive trends for the mean, median, and maximum discharge values for both rivers, and negative trends for the minimum discharge values (Table 1). These trends indicated that there were higher annual maximum values and lower annual minimum values for discharge of both rivers. Precipitation trends for the two watersheds differed and did not always match discharge patterns. The Grand River mean and maximum precipitation values decreased, while the Darby Creek mean and maximum values increased over time. Overall, there are higher annual maximum values and lower annual minimum values for discharge of both rivers.

Table 3. Summary of discharge and precipitation annual trend results.

Grand Discharge	Trend Results
Mean	Increasing
Median	Increasing
Maximum	Increasing
Minimum	Decreasing

Darby Discharge	Trend Results
Mean	Increasing
Median	Increasing
Maximum	Increasing
Minimum	Slightly Decreasing

Grand Precipitation	Trend Results
Mean	Slightly Decreasing
Maximum	Decreasing
Total	Decreasing

Darby Precipitation	Trend Results
Mean	Slightly Increasing
Maximum	Increasing
Total	Decreasing

5.2. Monthly MK

The MK test was used to analyze monthly trends for discharge in the Grand River and Darby Creek, and for precipitation in the correlating areas. For a majority of months out of the year, discharge increased from 1990 to 2021 for both the Grand River and Darby Creek. Based on this statistical analysis, Darby Creek showed a significant positive trend in discharge in the spring months of March – June and in December. Precipitation data collected in the Darby Creek watershed had a significant trend only for the month of October. Discharge in the Grand River had a significant positive trend from May – October and December, and a significant negative trend in November. Precipitation in the watershed showed a significant trend in January, April, and November. It is apparent that there have been significant changes in discharge since 1990, particularly for the Grand River where significant increasing trends were observed for 7 months of the year. Precipitation showed a significant change in only a few months of the year since 1990 for both rivers. Between the two rivers, the significance of discharge and precipitation trends over time varied and did not demonstrate a clear pattern in variation.

Table 4. Monthly MK Test Discharge results for Darby Creek and Grand River from 1990 - 2021. H_0 is the null hypothesis, representing no significant trend. H_1 is a rejection of the null hypothesis, representing the presence of a significant trend, as indicated by the highlighted cells. A p-value greater than alpha (0.05) indicates insufficient evidence to reject the null hypothesis.

Mann-Kendall Discharge from 1990-2021				
	Darby Creek		Grand River	
Month	H	P	H	P
January	0	0.26	0	0.07
February	0	0.07	0	0.49
March	1	0.00	0	0.87
April	1	0.02	0	0.21
May	1	0.00	1	0.00
June	1	0.00	1	0.00
July	0	0.97	1	0.00
August	0	0.55	1	0.00
September	0	0.48	1	0.00
October	0	0.76	1	0.00
November	0	0.17	1	0.00
December	1	0.00	1	0.00

Table 5. Monthly MK Test Precipitation results for stations in or near the Darby Creek and Grand River watersheds. H_0 is the null hypothesis, representing no significant trend. H_1 is a rejection of the null hypothesis, representing the presence of a significant trend, as indicated by the highlighted cells. A p-value greater than alpha indicates insufficient evidence to reject the null hypothesis.

Mann-Kendall Precipitation from 1990-2021				
	Darby Creek		Grand River	
Month	H	P	H	P
January	0	0.28	1	0.04
February	0	0.72	0	0.08
March	0	0.41	0	0.16
April	0	0.54	1	0.01
May	0	0.56	0	0.99
June	0	0.45	0	0.82
July	0	0.97	0	0.70
August	0	0.41	0	0.61
September	0	0.23	0	0.17
October	1	0.00	0	0.18
November	0	0.11	1	0.00
December	0	0.85	0	0.07

5.3. Monthly Trends

The Darby Creek monthly discharge linear trends indicated an increase over time particularly in the spring months (February – June), as well as the months of September, November, and December (Fig. 2,3). All trends that were significant according to the MK test are months that showed an increase in discharge, though not all increasing trends were significant.

The Grand River monthly discharge linear trends indicated an increase over time particularly in summer and fall months (May – October), and in the months of March and December. Each of the trends that were significant besides November were increasing trends, and all increasing trends besides March were significant.

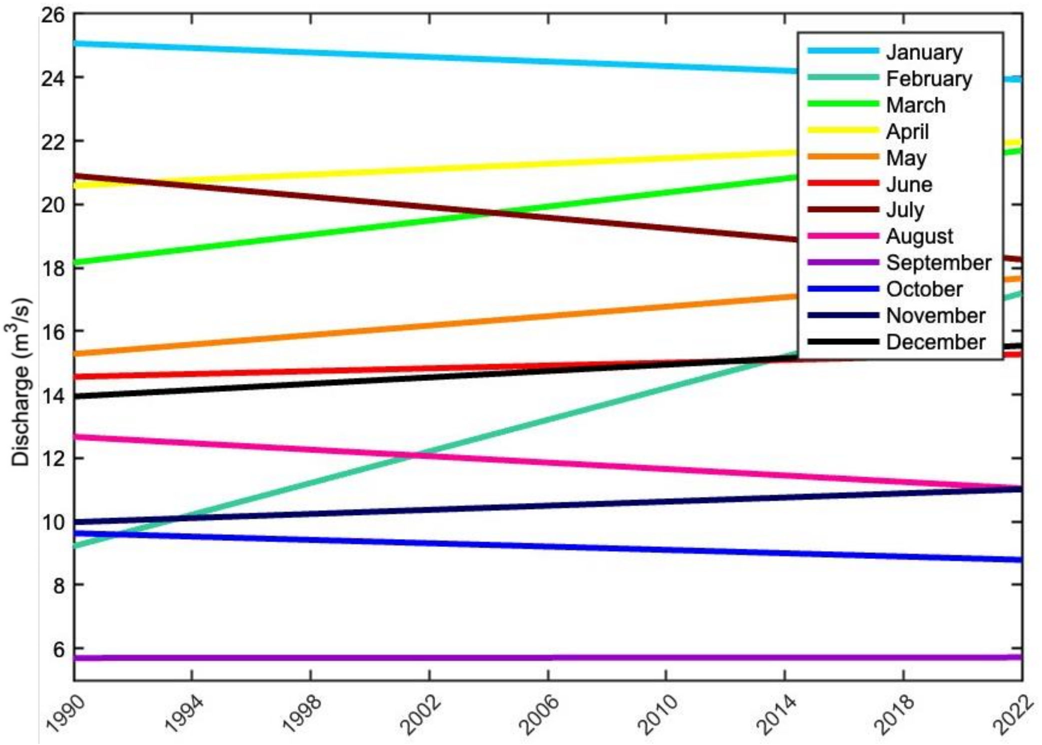

Figure 2. Darby Creek monthly discharge linear trends from 1990 to 2021 (USGS, 2021).

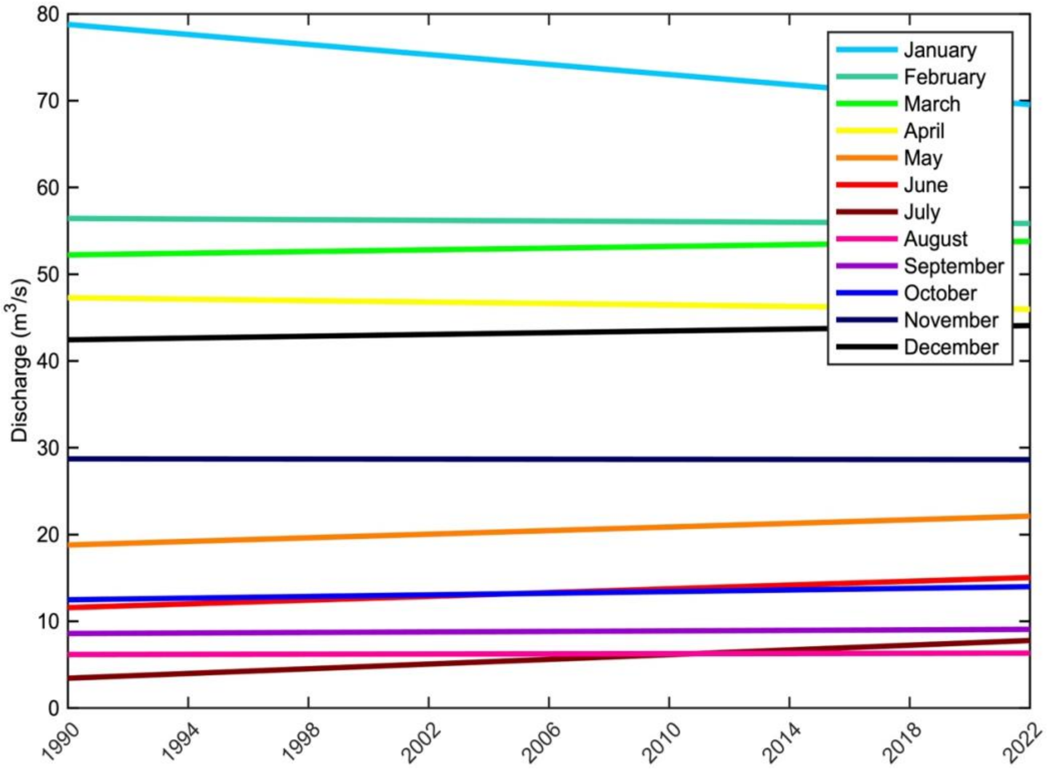

Figure 3. Grand River monthly discharge linear trends from 1990 to 2021 (USGS, 2021).

5.4. ENSO

The analyses of daily total precipitation and discharge for both the Grand River and Darby creek showed correlation with ENSO patterns. During strong El Niño years, there were lower levels of precipitation, correlating with lower discharge. Conversely, La Niña years generally aligned with peaks in both precipitation and discharge. Although, the strongest El Niño years (1997-1998, 2015-2016) do not coincide with the lowest precipitation and discharge values. The strong La Niña years of 2010-2011 coincide with the highest peak in discharge, but not the highest peak in precipitation. Based on visual analysis, ENSO trends appear to be indistinctly correlated with precipitation and discharge trends.

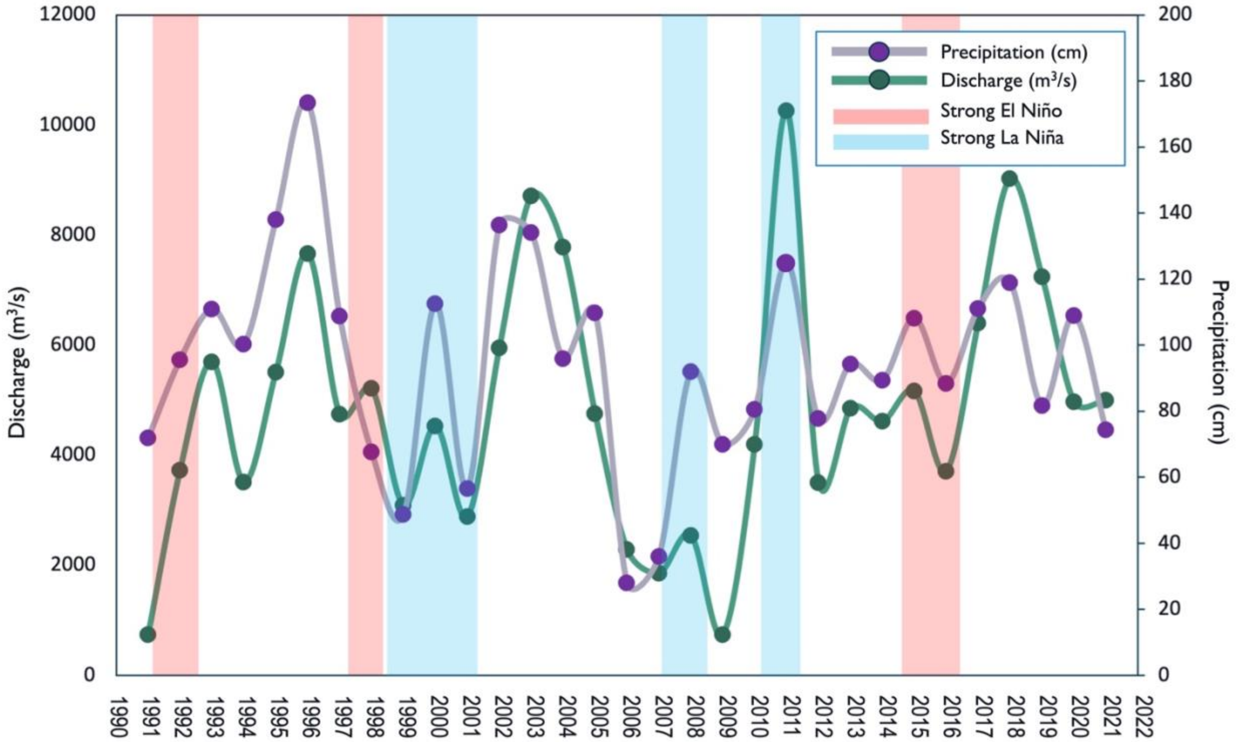

Figure 4. Darby Creek total annual discharge and precipitation from 1991to 2021. Shaded areas show ENSO periods of strong anomalies. Precipitation trendline equation is y=-0.3841x+865.52. Discharge trendline equation is y=54.626x-104710.

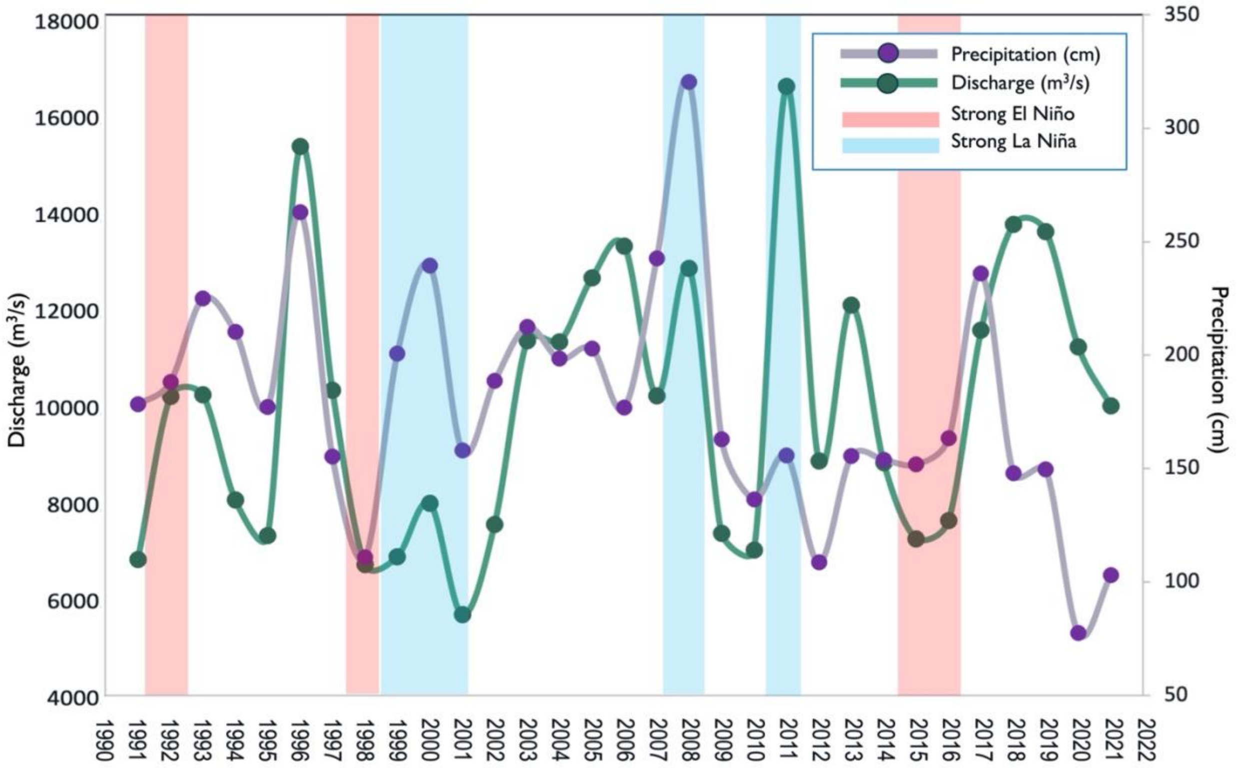

Figure 5. Grand River total annual discharge and precipitation from 1991 to 2021. Shaded areas show ENSO periods of strong anomalies. Precipitation trendline equation is y=-2.2708x+4734.2. Discharge trendline equation is y=86.567x-163683.

6. DISCUSSION

6.1. Land Use Impacts

The increases in discharge seen in both the Grand River and Darby Creek are reflective of both climate related changes and land use changes. From 1994 to 2019, the areas surrounding each watershed experienced urbanization. A shift from forest and woodland to urban areas and agricultural land increases impervious surfaces, leading to less infiltration and amplifying runoff from precipitation events (Stets, 2020). Studies throughout the Midwestern U.S. show that artificial drainage, which has increased since 1935, can amplify discharge as well due to increased hydrologic efficiency (Kelly et al., 2017).

Throughout the U.S., precipitation and discharge changes over time vary by region (Coopersmith et al., 2014). Studies on the Mississippi River basin show that precipitation is positively correlated with discharge (Stets, 2020). With small increases in precipitation, land use changes can cause disproportionately large increases in discharge. Further, there is evidence that changes in precipitation patterns from 1990 to 2021 are largely due to changes in the frequency of extreme weather events on regional scales (Costa, 2017). Precipitation is reported to experience the most drastic changes in summer months (Frans et al., 2013), which aligns with the increased discharge in summer months for the two rivers studied.

It is likely that the land development in each watershed had an impact on discharge patterns. Based on data from the Grand River and Darby Creek, there is not a direct relationship between precipitation and discharge, rather it is a complex relationship with many variables. For the Grand River, there was an increase in discharge despite a decrease in precipitation in the watershed area. Similarly, the Darby River increased in discharge and decreased in precipitation in the watershed. A possible reason for this disconnect is that the total precipitation trends do not accurately reflect the change in intensity and seasonality of precipitation events. Increasing impervious surfaces may increase the amount of water going into rivers through runoff and baseflow, which is another explanation for the trends found that is consistent with studies throughout the Midwest (Ayers et al., 2018).

6.2. Precipitation / Discharge Relationship

Increasing trends for the median, mean, and maximum discharge values and decreasing trends for the minimum discharge values for the Grand River and Darby Creek are reflective of various changes in climate and land use. These annual trends reveal that the rivers are reaching higher discharge rates more often, and that the river discharge was higher, on average, in 2021 than it was in 1990. Agricultural intensification and increased hydrologic efficiency due to land use changes can cause water to reach the rivers at faster rates, possibly explaining an increase in maximum discharge rates. Increasing annual trends are also consistent with impacts from climate change in the Midwest. As the climate warms, extreme weather events happen more frequently, resulting in higher precipitation in a shorter time frame (Byun et al., 2019, Clarke et al., 2022).

6.3. Monthly Trends

Monthly trends for the Grand River and Darby Creek are representative of seasonal discharge patterns, giving a closer look than annual trends. The MK test results revealed positive significant monthly trends for both rivers, largely in spring and summer. These patterns are likely reflective of seasonal factors, such as snowmelt and storms, and align with patterns throughout the Midwest that show seasonal changes due to climate change (Frans et al., 2013). Analysis of monthly trends is important in regions like Ohio where the weather changes drastically throughout the year. Monthly trends were represented graphically in order to visualize the discharge fluctuation throughout the seasons (Figure 2, 3). The lowest flow rates are seen in the summer and early autumn months, while the highest flow is seen in the winter and spring months.

6.4. ENSO

The observed changes in the Grand River and Darby Creek watersheds are reflective of how large-scale climate patterns like ENSO can impact regional hydrology. The Grand River and Darby Creek showed fluctuations in both discharge and precipitation that align with strong ENSO phases (figure 4, 5). This is consistent with studies across the Ohio River watershed, where precipitation increased during La Niña years, and drought conditions were prevalent during El Niño years (Costa, 2008). Analyzing the impact of ENSO on small water systems like local river watersheds is essential to understand how climate fluctuations influence weather patterns. Future work could look deeper into the relationships between precipitation, discharge, and ENSO cycles, and work to better predict them.

7. CONCLUSIONS

The purpose of this study was to determine the impact of climate change on the discharge of the Grand River and Darby Creek from 1990 to 2021. In summary, the climate plays a key role in hydrologic changes, along with many other regional factors. The major findings were as follows.

- Data analysis revealed that the Grand River and Darby Creek showed increasing trends for mean, median, and maximum discharge values. Minimum discharge values decreased.
- Total precipitation levels decreased for each river watershed, in contrast with outside studies revealing an increase in precipitation in similar regions
    - Mean and maximum precipitation values increased for Darby Creek, and decreased for the Grand River
- The MK test revealed significant positive trends for a majority of months out of the year for both rivers, largely in spring and summer.
- Along with climate, changes in discharge are likely reflective of shifts in land use (from forest/woodland to urban/agricultural)
- Global climate fluctuations like ENSO have an impact on regional systems

8. FUTURE WORK

This study provides an in-depth analysis on discharge changes over time for the Grand River and Darby Creek. However, further research would enhance understanding of the factors that drive river discharge changes, such as climate fluctuations, land usage, and anthropogenic impact.

Visual analysis provided an introductory look into the relationship between ENSO and river discharge, although statistical analysis could reveal further insight into global climate fluctuations. Alongside discharge and precipitation trends, a comprehensive analysis of climate trends (in addition to seasonal and monthly weather changes) could help to enhance understanding of climate impacts on regional systems.

Precipitation data could be investigated more closely. The two monitoring locations provided sufficient data for this study, though an addition of regional monitoring sites would allow for a more broad, complete understanding of precipitation patterns in Ohio. This could also help to understand the contrast between the collected data and the consensus from other sources on precipitation changes.

In addition, many more aspects of regional land use changes such as damming, base flow, and human impact on water systems could be explored to gain insight on how these factors impact hydrology over time.

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APPENDIX

El Niño				La Niña		
Weak	**Moderate**	**Strong**	**Very Strong**	**Weak**	**Moderate**	**Strong**
2004-05	**1994-95**	**1991-92**	**1997-98**	**2000-01**	**1995-96**	**1998-99**
2006-07	**2002-03**		**2015-16**	**2005-06**	**2011-12**	**1999-00**
2014-15	**2009-10**			**2008-09**	**2020-21**	**2007-08**
2018-19				**2016-17**	**2021-22**	**2010-11**
				2017-18		
				2022-23		

Table 6. ENSO events categorized as Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4), Strong (1.5 to 1.9) or Very Strong (≥ 2.0). Events based on Oceanic Niño Index, documented by the NOAA.

Monthly Discharge Trends						
	Darby Creek			**Grand River**		
Month	**P1**	**P2**	**R^2**	**P1**	**P2**	**R^2**
January	-0.006	25.1	<0.01	-0.046	78.8	0.012
February	0.040	9.22	0.039	-0.003	56.4	<0.01
March	0.018	18.2	0.015	0.008	52.2	<0.01
April	0.007	20.6	<0.01	-0.007	47.3	<0.01
May	0.01	15.3	<0.01	0.017	18.8	0.014
June	0.004	14.6	<0.01	0.017	11.6	0.014
July	-0.013	20.9	<0.01	0.022	3.44	0.025
August	-0.008	12.7	<0.01	<.001	6.17	<0.01
September	<.001	5.70	<0.01	0.002	8.59	<0.01
October	-0.004	9.63	<0.01	0.008	12.5	<0.01
November	0.005	9.98	<0.01	<0.001	28.7	<0.01
December	0.008	13.9	<0.01	0.008	42.4	<0.01

Table 7. Monthly discharge trends. P1 and P2 make up the linear coefficients, where P1 is the slope and P2 is the y-intercept. A positive P1 value indicates a trend with a positive slope (highlighted cells).

Discharge				
	Darby Creek		Grand River	
	Linear Equation	R^2	Linear Equation	R^2
Mean	y= 0.1065x-197.3	0.017	y= 0.202x-375.1	0.038
Median	y= 0.0277x-48.46	0.006	y= .1172x-221.4	0.018
Maximum	y= 0.7854x-1348	0.004	y= 0.7206x-1158	0.005
Minimum	y= -.003433x+7.812	0.002	y= -.04018x+81.55	0.044

Precipitation				
	Darby Creek		Grand River	
	Linear Equation	R^2	Linear Equation	R^2
Mean	y= .0006959x-1.135	0.011	y= -.001684x+3.812	0.013
Median	NA	NA	NA	NA
Maximum	y= .001164x+3.19	<0.001	y= -.02437x+64.93	<.001
Minimum	NA	NA	NA	NA
Total	y = -0.3841x + 865.52	NA	y= -2.2708x + 4734.2	NA

Table 8. Annual statistics.