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Recommended Citation
Ialenti, Alexander, "Climate Change's Effect on Flow Regime" (2024). Williams Honors College, Honors Research Projects. 1798.
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Climate Change’s Effect on Flow Regime

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Abstract

Climate change is projected to have broad effects on many ecological components. One of the most supported hypotheses of climate change, aside from an increase in temperature, deals with a shift in precipitation patterns. A mainstream hypothesis regarding precipitation predicts a decrease in frequency and an increase in intensity of rain events. Rain events create water run-off that then drains into different streams with different intensities, thus creating different flow patterns. The flow regime is responsible for creating physical aquascapes and influencing the life histories of the organisms dwelling within the confines of streams. Current literature supports the hypothesis that there will be a decrease in the number of perennial streams over time because of climate change. Many currently perennial streams are projected to shift to non-perennial. Perennial describes streams that have flowing water during all times of year while non-perennial streams dry up for some duration of the year. Changes from a perennial to a non-perennial flow regime can cause a decrease in natural flora, fauna, nutrient cycling, and limit the tributaries flowing to larger bodies of water. The current project utilizes data gathered by the Cleveland Metroparks from 2003-2021. The 130 sampling events covered four reserves across NE Ohio. Analyses of these sampling events revealed that there was a significant increase in the percentage of sites deemed non-perennial that were formerly perennial over time. Analyses also revealed that there was a significant increase in rainfall per event in the latter as compared to the earlier time periods. However, there was no significant increase in days since the last rainfall for this same time comparison, although there was a positive trend. Therefore, the data covering the ~20 years of sampling showed significant support for the predictions concerning climate change’s effects on rain patterns in northeast Ohio.
Introduction

Climate change is hypothesized to bring about not only an increase in yearly average temperature, but also a decrease in precipitation frequency, and an increase in rainfall intensity. These changes include an increase in periods of drought, flooding events, and heavy rain events (Trenberth 2005). Higher annual temperatures should lead to higher evaporation rates (Schneider et al. 2013), meaning that the atmosphere will have a higher water capacity due to climate change (Dore 2005). This greater capacity suggests higher intensity rainfall during rain events. The water-holding capacity of the atmosphere increases by about 7% per 1°C increase in air temperature, as calculated in the Clausius-Clapeyron equation, which relates vapor saturation to temperature (Trenberth 2005). Higher intensity rain events cause a disproportionate change in yearly precipitation on a global scale, meaning that wet environments should become wetter and dry environments should become drier (Dore 2005).

Precipitation percentage, the ratio of snow, sleet, hail, rain, etc. that constitutes that year’s total precipitation, is projected to yield a higher percentage of precipitation falling as rain globally because of increased atmospheric temperatures (Trenberth 2005). Additionally, there should be less frequent yearly snow events and the snow that does fall should melt more quickly (Trenberth and Shea 2005). This increase in the yearly air temperature should make early spring the most susceptible to flooding due to increased rainfall and quickly melting snow. On the contrary, the middle of summer in warm biomes should be the most susceptible to droughts (Trenberth 2005). However, just because the intensity of the rain is projected to be stronger over time, the number of rain events is projected to decrease over time (Dore 2005). This is due to the increased water holding capacity of the atmosphere, which can hold more water at a time, then releasing it as rain with a stronger intensity (Dore 2005).
The intensity and the frequency of rain events can affect the flow of streams. Once the rain falls, there are multiple routes it can take while on the ground. Watersheds are areas of land that act as funnels for the rainwater. Here, the rainwater drains into a collective body of water. In streams, the water comes down the slope and some of it enters the streams. Depending on the intensity and the frequency of rain events, along with other factors such as the ability of soil to hold water, the stream may have a faster or slower flow. If rain events are too infrequent, it can even lead to streams periodically drying out (Schneider et al. 2013). A stream that dries up periodically that previously was always flowing would be an example of a change in its flow regime.

The flow regime (i.e., the overall yearly variability of flow for a body of water) is an important aspect of any stream. Any stream can be classified as one of four flow regimes: intermittent, ephemeral, perennial, or interstitial (Svec et al. 2005). Intermittent flow occurs when a stream only flows for part of the year. Ephemeral flow, which is a type of intermittent flow, occurs following or during a precipitation event that causes a clear path to be made through any ground litter. Perennial flow indicates a stream has flowing water year-round. Lastly, interstitial flow is when there is water under the surface of the stream bed which is termed the “hyporheic zone” (Svec et al. 2005). Ephemeral, intermittent, and interstitial can be grouped under the term “non-perennial” since for at least some portion of the year they do not experience flow. However, the flow regime affects more than how often there is flow: the composition of native vegetation and organisms (e.g., aquatic macroinvertebrates) depends heavily on the flow regime of the water body (Reynolds et al. 2015).

Not only does the flow regime play a role in determining the composition of flora, fauna, and physical characteristics of a water body, it also shapes the habitat of the stream itself:
different flow regimes cause different erosion patterns in a stream channel (Bunn and Arthington 2002). This additionally creates microhabitats best fit for different organisms with different niches (Bunn and Arthington 2002). A change in flow regime could negatively affect multiple species. An animal species that has evolved to live in perennial streams has a high likelihood of dying in a dried-out stream whereas species naturally living in non-perennial streams will likely survive. Similarly, plants commonly use streams to disperse their seeds. If the stream is not flowing while the seeds are being produced, the dispersal event can be much smaller (Bunn and Arthington 2002). Additionally, only some plants have a high germination rate while submerged (Bunn and Arthington 2002). Some plant species are successful reproducing in non-perennial streams, their seeds being able to germinate in a dried-out stream bed. It is expected that these types of plants’ seeds would have a harder time persisting in a perennial stream (Bunn and Arthington 2002).

In addition to increased temperature and evaporation rate, longer, drier summers and changes in precipitation rates will likely cause more perennial streams to shift to non-perennial (Reynolds et al. 2015). This trend is projected to continue due to climate change and human land use (Messager et al. 2021). The current project uses data from the Cleveland Metroparks across four different nature reserves in Northeastern Ohio to test whether the percentage of non-perennial streams, the duration between rain events and the amount of rain per event should increase over time in streams in Northeast Ohio due to climate change.

**Methods**

The Cleveland Metroparks sampled streams from four nature reservations, all located in Northeastern Ohio: Bedford, Brecksville, Hinckley, and North Chagrin. This project utilized 65
independent streams over the course of 18 years (2003-2021). Not every stream was used for analysis since some streams were missing data. Every sampling event provided stream name, site number, flow regime, sample date, amount of last rain, and days since last rain. All streams used in the project had a minimum of two sampling events. If a stream was sampled more than twice, the earliest and the most recent sampling events were utilized. The minimum interval between a first and last sampling event was 6 years. That provided a total of 130 total samplings that included flow regime, 116 sampling events that included the amount of last rain, and 128 sampling events that included days since last rain. This made for 65 flow regime data points, 58 data points for last rain amount, and 64 data points for days since last rain. These data were separated by different time frames: “< 11” for sites sampled less than 11 years apart (sampled on average 8.1 years apart) and “>14” for sites sampled more than 14 years apart (sampled on average 17.1 years apart). There were 36 sites for “<11” and 29 sites for the “>14” timeframe of the data set comparing flow regimes. The amount of rain data set had 35 sites in the “<11” timeframe and 23 sites for the “>14” group. Lastly, there were 36 sites for the “<11” group and 28 sites were sampled more than 14 years apart for the data set observing days since last rain. All data pairs were categorized by flow regime (Fig. 1): sites that did not experience a change in flow regime (1), sites that shifted from perennial flow to non-perennial flow (2), and sites that shifted from non-perennial flow to perennial flow (3). Similarly, the amount of last rain (Fig. 2) and days since last rain (Fig. 3) were categorized as more, less, or the same, depending on the value of the most recent sampling event compared to the first.

A nominal logistic test was run using JMP to test for significant changes in the two tested time frames (<11 vs >14). A nominal logistic test was used rather than a typical chi-square since
some categories had less than five data points to provide more accurate p-values for all three comparisons.

Results

The prediction that more streams will shift from perennial to non-perennial would be higher in the comparisons over a longer period (>14 years’ time frame) relative to the shorter comparisons (<11 years) was indeed found and significant (green in Fig. 1; $\chi^2_{(2)} = 6.67$ P= 0.0355). The increase was from 2.78% to 6.90%, an increase of 4.12%. There was also a significant decrease in streams that were at first non-perennial that became perennial (blue) in the >14 years comparison compared to <11 years comparison. A decrease from 13.89% to 0% over time. Lastly, there was a significant increase in the percentage of streams that did not change flow regime in the > 14 years’ timeframe. An increase from 83.33% to 93.10%, an increase of 9.77%. These combined data supported the hypothesis that the number of perennial streams will decrease over time and more will continue to shift to non-perennial.

There was also a significant increase in the amount of rainfall per most recent event over time. For the data sampled greater than 14 years apart, there was significantly more rainfall per event than the data less than 11 years apart (Fig. 2; $\chi^2_{(1)} = 8.57$ and P=0.0034). The longer the time between the sampling events, the higher chance that the more recent rain event was larger than the first measured rain event (Fig. 2). This supports the hypothesis of climate change causing more rain to fall per rain event in recent compared to previous rain events.

The data for days since last rain did not have a significant difference over time (Fig. 3; $\chi^2_{(2)} = 3.08$ and P= 0.2141). There was a trend of a higher percent of sites where the later sampling event had a longer time between rain events for the >14-year time frame (Fig. 3).
However, these data did not reveal significant support for the hypothesis that climate change increases the duration of time between rain events.

Figure 1. Mosaic plot for flow regime. <11 is assigned to samples taken less than 11 years apart at the same site and >14 is assigned to samples taken greater than 14 years apart. Red (1) illustrates sites that did not exhibit a change in flow, green (2) illustrates sites that exhibit a change in flow from perennial to non-perennial, and blue (3) illustrates sites that exhibited a change from non-perennial flow to perennial flow. Total N sites for <11=36, for >14=29.
Figure 2. Mosaic plot for last rain amount. The time period is the same as in Fig. 1. Red (less) indicates a lower level of rain in the more recent compared to the later sampling event of each comparison per site. Blue (more) indicates the opposite: a higher level of rain in the more recent compared to the later sampling of each site. Total N sites for <11=35, for >14=23.

Figure 3. Mosaic plot for days since last rain. The time periods are the same as Figs. 1 & 2. Red (less) indicates a shorter time between rains in the most recent sampling event compared to the earlier measurement at each site Green (more) indicates the opposite: a longer time between rains in the most recent compared to the earlier measurement at each site. Blue (same) indicates the number of days between rain events did not change between samples. Total N sites for <11=36, for >14=28.
Discussion

Climate change is predicted to increase atmospheric temperatures, thus increasing evaporation rates and the ability of the atmosphere to hold more moisture. Due to these increasing temperatures, a higher percentage of yearly precipitation is projected to fall as rain. These rain events are hypothesized to occur less frequently and with a higher intensity of rainfall per event. These variations in yearly precipitation are projected to cause more streams to periodically dry (i.e., become non-perennial) over time. To test these predictions using the rainfall data set from the Cleveland Metroparks, three mosaic plots were created to illustrate comparisons between two timeframes: sites sampled <11 years apart and sites sampled >14 years apart.

Climate change is expected to cause many former perennial streams to become non-perennial streams over time. I found that there was a significant increase of 4.12% in the percentage of streams labeled as non-perennial over time for the streams sampled in northeast Ohio. This increase stemmed from both an increase in the number of formerly perennial stream sites shifting to non-perennial and originally fewer non-perennial sites shifting to perennial over time (<11 years apart compared to >14 years apart; Fig. 1). Additionally, there was an increase in the percentage of streams that did not change flow regime during the >14-year time frame versus the <11-year time frame. These combined results supported the hypothesis that climate change has resulted in more perennial streams in Northeast Ohio becoming non-perennial over time (Reynolds et al. 2015). If this trend continues, the proportion of non-perennial streams would increase at the expense of perennial streams, which could cause a decrease in both native flora and fauna. These native organisms play key roles in nutrient breakdown in their respective food
webs. This could increase the risk of extinction for species that are unable to adapt to periodically dried out streams (Bunn and Arthington 2002).

The current findings are like a study from the Upper Colorado River Basin that showed an increase of streams experiencing no-flow days due to climate change (Reynolds et al., 2015). Reynolds et al. utilized 115 streams located in the Upper Colorado River Basin. Many of these sites were sampled across 36 years in the latter half of the 20th century, however the total data set used streams gauged between 8-83 years. They also tested the prediction that as temperatures are projected to continue to increase, the percentage of non-perennial streams are also projected to increase. They found that a decrease in annual rainfall led to a decrease in minimum flow, which increased the number of zero flow days in non-perennial streams and could cause perennial streams to become non-perennial. Some perennial streams in their data set showed increased variation in mean flow and minimum flow average. These streams are projected to have a higher risk of becoming non-perennial in the future. These findings, as well as the findings of the current project, show that climate change is causing more streams to become non-perennial and already non-perennial streams to have more days of no flow. This is likely to cause a decline in perennial streams’ habitats and increased periods of drought.

I also tested the prediction that the amount of rainfall per event would increase over time. In this study, the average rainfall per event for sites sampled greater than 14 years apart was significantly greater than the rainfall per event for sites sampled less than 11 years apart (Fig. 2). This increased rainfall per event could cause flooding in areas that were previously experiencing drought. These flash floods often are followed by periods of extended drought, which in turn can be followed by heavy rains (Trenberth 2005). These heavy rains have become more common since the yearly total precipitation is projected to remain approximately the same while the total
number of rain events decrease over time. As temperatures continue to increase, the water capacity of the atmosphere increases and therefore increases the probability of a heavy rain event. These heavy rains could also cause a decrease in nutrient breakdown as potential nutrients are sent downstream via flash floods prior to being fully broken down (Bunn and Arthington 2002).

The current finding of increased rainfall per event is in accordance with a review paper that noted precipitation across the world has increased the proportion of rain events classified as “heavy rains” (i.e., rain events in the upper ten percent of rainfall) over time due to climate change (Dore 2005). Dore showed there was between a 10 and 45% increase in “heavy rain” events in many Australian regions from 1910 to 1995. In Serbia, despite a decrease of <1% in yearly precipitation between the years of 1936 and 1994 and a decrease in the number of days with precipitation, there was nearly a 2% increase in “heavy rains” per decade. These findings, as well as the results of this project, suggest that as temperatures continue to increase, the average amount of rainfall per event will increase. The correlation of an increased frequency of periods of drought and flash flood events is predicted to increase over time. These irregular precipitation events should therefore cause more perennial streams to shift to non-perennial.

The interval between rain events is also hypothesized to increase over time due to climate change (Dore 2005). Even though the trend in time between rain events did show there was a higher percentage of “more” in the sites sampled more than 14 years apart in the current study (Fig. 3), this trend was not found to be significantly different than the sites sampled less than 11 years apart. These longer periods without rain are what cause the higher number of non-perennial streams. When rain becomes too infrequent, this can cause periods of drought, which are then punctuated by heavy rain events (Trenberth 2005). Like the non-significant trend in the number
of days since the last rain found in this project, Reynolds et al. (2015) found an increase in the number of zero flow days and a decrease in precipitation events in the Upper Colorado River Basin. Reynolds et al. (2015) projected that this pattern would continue as atmospheric temperature continues to increase thus increasing the span in between rain events. Many non-perennial streams are experiencing an increase in days without flow. This in turn is causing more perennial streams to have days with minimum flow. Reynolds et al. (2005) projects the continued increase in temperatures will increase the atmospheric water capacity. These extended periods of no rainfall will result in more days with little to no flow and cause some formerly perennial streams to temporarily dry. Increased times between rains can cause periods of drought, streams to dry, and have negative ramifications on stream-dwelling organisms.

The current project did have some limitations. One is that the study was over a relatively short window for a study of climate change. It would have been beneficial if the sampling was conducted over a period longer than 2003-2021, for example across 30 or more years (e.g., similar to the Australian and Serbian studies noted above). This would have not only allowed for a larger sample size, but also more time to notice the effects of climate change on flow regime and rain events. Additionally, not every site was sampled the same number of times or were the same amount of time apart. Had this been done, the data set would have had greater statistical power. These amendments to the methodology would allow for a more accurate view on the effects of climate change for northeastern Ohio.

**Conclusion**

This project supported the three previously stated predictions of climate change in northeast Ohio. I expected to find the percent of perennial streams becoming non-perennial, the amount of rain per event, and the time in between rain events to all increase over time. This
project supported all these predictions. These findings support the idea that climate change is impacting rain patterns and streams in northeast Ohio.

In addition to the changes in rain patterns and their effects on stream flow, climate change is predicted to have a broader effect on Earth’s environment and weather patterns. Increasing temperatures are predicted to melt the ice caps and glaciers resulting in the ocean levels rising, flooding coastline areas and damaging infrastructure. All these changes in weather patterns caused by increased temperatures are predicted to decrease biodiversity. Plants and animals not able to adapt to such changes are at risk of declining. Further studies concerning climate change will be required to better understand the potential effects and potential remedies to minimize damage.
Bibliography


Appendix

The data for this project was provided by the Cleveland Metroparks. The data was analyzed, cleaned, and manipulated using both JMP and Excel. Attached is the original excel file containing the raw data of the 488 sampling events. C:\Users\alexi\OneDrive\Desktop\Cleveland metropark raw data.xlsx

Attached is the JMP journal which contains the data sets for Figures 1,2 and 3 as well as their associated nominal logistic tests. C:\Users\alexi\OneDrive\Desktop\Ialenti Honors Project JMP Journal.jrn