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SI 305 | Introduction to Information Analysis
Final Report

Summary

Ann Arbor, Michigan has been subject to changes in climate and weather patterns that have led to a recent change in precipitation levels over the last ten years. This change in precipitation has been noticeable in Ann Arbor, whose raised levels are much higher than the most recent Atlas-14 estimates would indicate. Despite the higher levels, Ann Arbor has not suffered an increasing amount of water main breaks. However, there are certain Ann Arbor neighborhoods that are experiencing higher frequency and costs related to water main breaks that are worth monitoring in the future.

Problem Diagnosis

Global temperatures have continued to rise in recent decades causing more moisture to be in the air and therefore more frequent extreme weather events. Throughout the United States, this increase in storm frequency has been costly as there were a record 22 weather events that cost at least $1 billion in damages during the year 2020.[1]

Concerned by the high costs, many state governments have begun frantically trying to determine whether their current precipitation estimates are accurate and if infrastructure reinforcements are needed. Although different methods of doing so have led to varying results, there is a general consensus that the NOAA's Atlas 14 estimates, the most commonly used in the United States, are not currently accurate or reliable. Without this previously exogenous information, local governments must decide for themselves what level of precipitation to expect and how to adjust water infrastructure accordingly.

Specifically, "the NOAA is substantially underestimating the risk of severe rain in some of the nation's largest cities" while "in other areas, including those east of the Sierra Nevada and Cascade Range, First Street finds that NOAA is overestimating the likelihood of intense rain."[2] It is important that local governments have an accurate estimate of future rainfall so they do not

[1] Morrison, Jim. "As Rainstorms Grow More Severe and Frequent, Communities Fail to Prepare for Risks." The Washington Post, April 12, 2021. https://www.washingtonpost.com/climate-environment/2021/04/09/climate-change-rainfall/.

[2] Zhong, Raymond. "Intensifying Rains Pose Hidden Flood Risks across the U.S." The New York Times, June 26, 2023. https://www.nytimes.com/2023/06/26/climate/rainstorms-hidden-flood-risk.html#:~:text=The%20calculations%20suggest%20that%20one,might%20be%20designed%20to%20drain.

[3] "How Heavy Rain Can Increase Pressure on Pipes." High Efficiency LLC, September 23, 2021. https://high-efficiencyllc.com/how-heavy-rain-can-increase-pressure-on-pipes/#:~:text=Shift%20Underground%20Pipes,and%20a%20change%20in%20pressure.

[4] "NOAA Atlas 14 Precipitation Frequency Volume 8 Version 2.0." National Oceanic and Atmospheric Administration, 2013. https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume8.pdf

waste anywhere from thousands to billions of dollars on infrastructure that is not designed to meet the actual needs of the region.

One example of such water infrastructure are water mains, the underground pipes that help water flow in and out of residential and commercial buildings. With higher rainfall, the soil surrounding the water mains softens which can lead to the pipes becoming dislodged and cracking open.[3] Obviously, these situations require the water mains to be repaired which cost thousands of dollars depending on the materials, labor, and type of work needed. This money comes from local governments and taxpayers, who would both prefer to effectively reduce these costs by replacing water mains in an efficient and effective manner that is sufficient for the expected amount of precipitation the region will incur.

The City of Ann Arbor and the state of Michigan are no different than the majority of US regions, as they are undergoing climate changes without any updates to their Atlas 14 estimates calculated in 2012.[4] Addressing the ongoing weather changes and infrastructure reactions is vital to ensuring that Michigan taxpayers do not waste money on unnecessary or impactless solutions.

Research Questions

1. Are the Atlas 14 estimates for Ann Arbor, Michigan accurate and if not, are they understating or overstating the actual precipitation trends in Ann Arbor?
2. How do changes in rainfall over consistent time periods relate to the frequency of water main breaks?
3. Are water mains in certain areas breaking more frequently than others and are the upkeep costs in these areas more expensive on a per-replacement basis than the typical water main replacement cost?

Analysis for Research Question 1

Findings

There is a significant difference between the expected rainfall determined by the Atlas 14 estimations and the actual rainfall experienced by Ann Arbor, Michigan over the last 10 years with the estimates typically underestimating the amount of precipitation during both short and long time periods. Even when the Atlas-14 90% confidence interval upper estimate was used to calculate expected storms, there was a very low correlation between the estimates and the actual rainfall in Ann Arbor. For example, some 1-year storms were witnessed hundreds and thousands times more than would be expected. When analyzing this relation in Figure 1, it was clear that this trend was particularly relevant in the 1 and 2-year storm estimates as well as during longer rainfall periods (24+ hours), as shown by the spikes in the graphs. This overall trend continued to be noticeable in Figure 2 where there is an overall upward trend in percentage over estimate for each of the three categories (1, 2, and 5-year storm estimates). However, the key difference is that the 1-year and 2-year estimates spike to values over 4,000%, clearly indicating that the

Atlas-14 measures used for predicting the actual rainfall are inaccurate and underestimating Ann Arbor rainfall. Despite these trends, there are limitations in the analysis as there could have been a series of storms over the span of roughly one week that could have altered this data in a significant way.

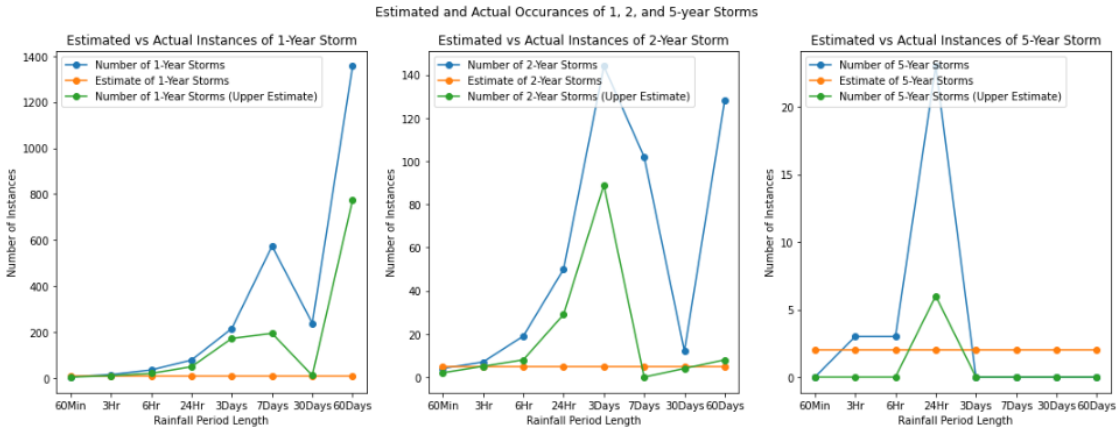

Figure 1: Line graphs showing number of actual and estimated storms based on rainfall period length.

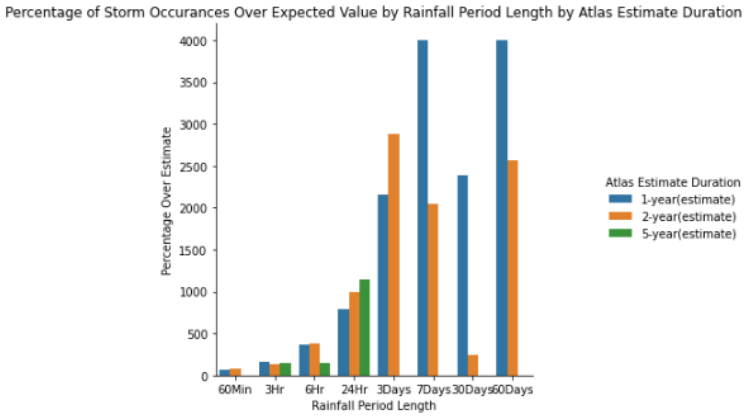

Figure 2: Grouped bar chart showing the percentage of storm occurrences over the expected value by Atlas-14 estimate durations.

Interpretation of Findings

This analysis indicates that many of the Atlas 14 estimates used by the city of Ann Arbor may be significantly underestimating the amount of water the Ann Arbor area expects to get over 1 and 2 year periods. The lack of correlation between the actual and expected instances of certain storms prove that these estimates have not been very accurate over the last decade. However, with no new estimates in place, the city runs the risk of costing taxpayers anywhere from hundreds to millions of dollars on unnecessary or feeble repairs to water infrastructure such as water mains. With more recent and accurate estimates, the city would be able to save their taxpayers significant amounts of money or use that money for more pressing and important causes. This

relationship is compared further in Research Question 2, which analyzes rainfall accumulation and water main breakage frequency on a monthly basis. So, looking at the rainfall accumulation data collected from RQ1 will be very useful in determining if the water main breaks spike during periods of higher precipitation.

Analysis for Research Question 2

Findings

There is very little correlation between the rainfall experienced in Ann Arbor and the frequency of water main breakages reported. To explore the relationship between these two variables, it was important to utilize common time intervals of one month periods. From January 2014 through August 2023, both statistics were measured and plotted in Figure 3. From the graph, it was apparent there was no clear relationship between the monthly rainfall and the number of water main breaks reported as both lines appeared to follow their own individual series of fluctuations. For example, when monthly precipitation was spiking higher or lower than its usual amount, there was no similar change in water main break frequency. This relationship is further explored in Figure 4, which shows a scatter plot of the variables with its linear regression line and confidence interval as well. The data is distributed relatively uniformly throughout, indicating there is little correlation. This is supported by the slightly negative linear trend and larger confidence interval surrounding it.

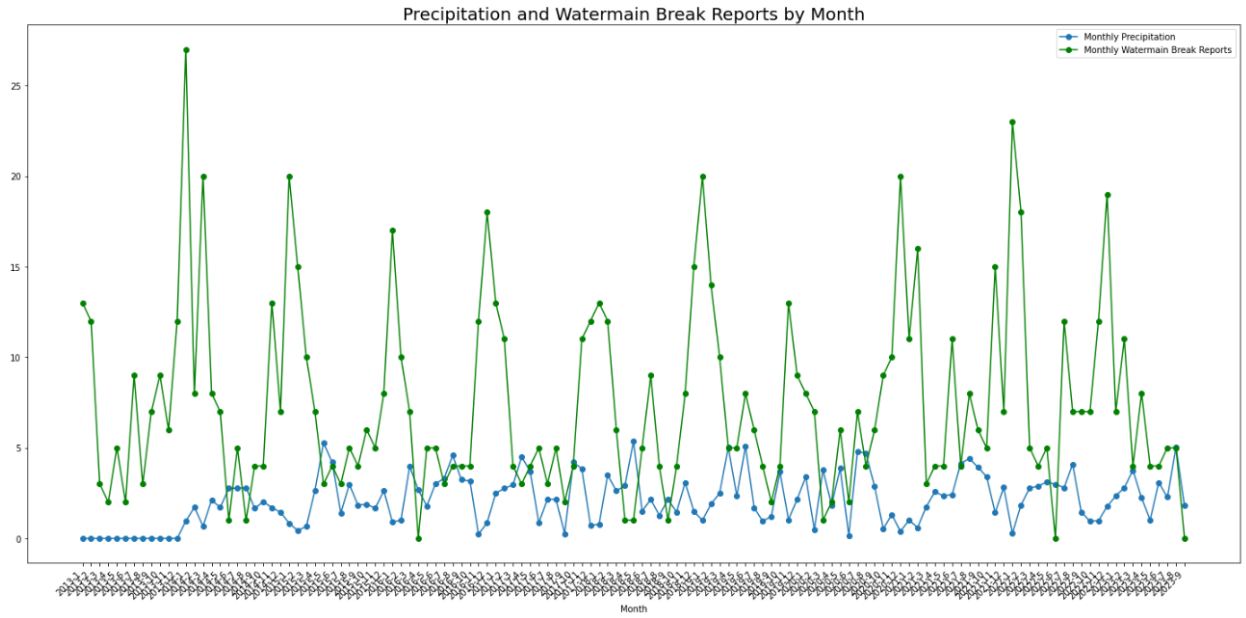

Figure 3: Multiple line plot showing the monthly precipitation and water main break reporting data over the course of 10 years.

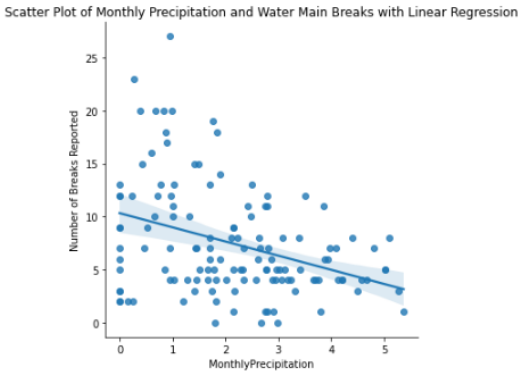

Figure 4: Scatter plot and linear regression model showing relationship between monthly precipitation and number of water main breaks reported.

Interpretation of Findings

Based on the analysis of Research Question 2, it would be difficult and unjustified for the City of Ann Arbor to change their approach regarding water main repairs based on the actual precipitation experienced by the city over the last 10 years. There is no clear correlation between the two variables indicating that preemptive increases or decreases in water main repairs could potentially cost the city lots of taxpayer money. This is because it is challenging to predict when there will be spikes in water main breaks. Therefore, Ann Arbor could leave themselves with insufficient funds or materials to make the necessary repairs to recently-broken water mains. If the Ann Arbor government were to further explore how to most efficiently and effectively use its resources, it should explore the relationship between water main breaks and other variables outside of precipitation accumulation. This is done in Research Question 3, where water main breaks are analyzed by location.

Analysis for Research Question 3

Findings

4. Are water mains in certain areas breaking more frequently than others and are the upkeep costs in these areas more expensive on a per-replacement basis than the typical water main replacement cost?

There are certain Ann Arbor neighborhoods experiencing more water main breaks than most and they are also responsible for the majority of Ann Arbor's water main repair costs. However, the per-repair cost in these neighborhoods is nothing unordinary compared to all neighborhoods across the city. In Figure 5, there is a very clear positive linear correlation between the number of water main breaks and total cost (in dollars). Intuitively, this makes sense as each repair costs money so the more repairs one neighborhood needs, the more money it will cost the city. It is interesting to note that there are 3 distinct outliers – Mack School Sunset, Bader Ann Arbor Hills, and Dicken – that have many more repairs than the other neighborhoods and have the largest total costs. However, their average repair costs are closely aligned with that of the other

neighborhoods as the city as a whole experiences relatively uniform distribution with most average repair costs being between $2,000 and $4,000. However, there are some high outliers although these may not be as relevant as these neighborhoods experienced very few total water main breaks. Figure 6 shows that the average repair cost is much higher in neighborhoods with little water main repairs and very evenly distributed throughout the rest. However, one limitation is that this data may be affected by the same high outlier neighborhoods found in the second graph in Figure 5.

Interpretation of Findings

One of the most noticeable aspects of the analysis in Research Question 3 is the presence of high outlier neighborhoods that account for the majority of Ann Aror's water main repairs as well as total cost. If the city wants to best use its resources efficiently and effectively, it will need to address these neighborhoods and brainstorm ways to limit the number of repairs and total costs that these neighborhoods are responsible for. Fortunately, the average cost in these neighborhoods is in line with what is expected so it would be interesting if the city were to balance a higher average cost with the expectation that it would reduce the total number of repairs. It is also important to note there are different high outlier neighborhoods in the average cost category as well. While it is likely that these neighborhoods are not at risk of severely hurting the city in the future because they typically have needed only 1 or 2 repairs over the last 10 years, it would also be beneficial for the city of Ann Arbor to further investigate what may have caused these neighborhoods to incur such high costs for their water main repairs to insure this will not happen frequently.

Recommendations

Recommendation #1: Update the Ann Arbor rainfall estimates

Based on the analysis of Research Question 1, there is a very clear need for a more precise re-estimation of rainfall in the City of Ann Arbor. The last estimates, from the Atlas-14, were calculated in 2012, shortly before the Ann Arbor rainfall data began being tracked. This data has clearly shown that the actual instances of certain storms differ greatly from the expected amounts signaling that the current estimates are not reliable and new estimates should be installed. This can be done in one of two ways. The first would be that the NOAA finally updates and publishes new estimates that better take into account recent weather patterns and trends such as global warming. This solution would be preferred as it would help cities across Michigan, the midwest, and the country. In addition to this, a promise to update the estimates on a more frequent basis would also help local governments across the country better plan for their future. Alternatively, Ann Arbor can use their own independent estimates to guide their infrastructure maintenance plans. While this method would likely work, it may not be as effective as an update from the NOAA as Ann Arbor has significantly less funding and resources to make predictions. However, either method would effectively help the city government better plan for the future and avoid the misuse of valuable resources.

Recommendation #2: Dive deeper into the water mains of specific Ann Arbor neighborhoods
Another significant trend derived from the analysis of Research Question 3 is that there are 3 distinct Ann Arbor neighborhoods – Mack School Sunset, Bader Ann Arbor Hills, and Dicken – that are responsible for the majority of the city's water main material and monetary resources. So, it is important that the city of Ann Arbor further investigates this phenomenon to better understand why these neighborhoods are experiencing such a higher frequency of repairs. Possible subjects of research would include whether there are specific water mains within the neighborhoods that are prone to breaking and analyzing their characteristics such as material and length. By doing so, the City of Ann Arbor would gain a better understanding of why these water mains and neighborhoods have been problematic over the past 10 years. The city government would also be able to use this information to make informed decisions regarding how they will treat these neighborhoods in the future. For example, it may be beneficial for Ann Arbor to start spending more money on each repair in these neighborhoods if it ensures that there will be less repairs needed in the future and therefore save the government some money. Without this further analysis, Ann Arbor will likely continue to suffer from higher-than-normal levels of water main breaks and higher costs in these specific neighborhoods.