STEM Fellowship Big Data Challenge 2019-2020

Understanding the effect of climate change on river flow in the North Saskatchewan River

Sir Winston Churchill High School
The date you see below will be automatically generated

June 21, 2020

Abstract

Rivers are an integral part of urban civilization, and most of the world lives near one [3], yet the 2013 Floods in Southern Alberta reflect a larger worldwide pattern of unpredictable flows and flooding. By analyzing river flow, the volume of water passing a given point per unit time, and weather data for the North Saskatchewan River at Edmonton using Python, insights into the relationship between climate change and river flow can be revealed. An analysis of the Canadian Disaster Database reveals that while floods are less common in the 2010s, compared to the 1990s and 1970s, they are far more damaging, with higher costs, fatalities and evacuations. Statistical analysis of mean river flow, and its correlation with snowfall, summer precipitation and glacial mass balance reveal a decrease in snowfall over time. This leads to reduced glacial mass balance over time, as less snow accumulates during the winter, thus compounding the effects of glacial retreat. The result is reduced mean river flow, but an increase in the difference between maximum and minimum river flow in a given year, due to earlier and faster snow melt during spring. This suggests that the effects of climate change are reduced flow, but more unpredictable flow, which carries the threat of both flooding during peak flow and water shortage in situations of increased demand.

Keywords
North Saskatchewan River, Peyto, Snowfall, Flooding

1 Introduction

The 2013 Floods in Southern Alberta were among the most destructive in recent history, resulting in the evacuation of 100 000 people and damages upwards of $2.5 million [?]. These floods were a harrowing reminder of the power of rivers, yet they are an irreplaceable part of urban life, with more than 87% of the world's population living near a river[3]. Therefore, any changes in river flow will have a profound impact on human civilization, the most destructive of which is flooding. In the case of rivers in the Canadian province of Alberta, which is located at a mid-high latitude, the majority of their flow is dictated by mountain runoff, the product of glacial melt, and precipitation [1]. Therefore, climate change and particularly global warming would result in quantifiable and noticeable changes in river flow, due to changes in glacial melt, precipitation and temperature. [5]. This paper will focus on the effects of climate change on flooding. A number of papers have analyzed the effects of glacial melt on river flow with the utilization of predictive models which are calibrated using empirical data. However, this paper uses a purely empirical method by analyzing correlations in past precipitation, river flow, and glacial melt to reveal trends since the mid-20th century to present date. In doing so, the current state of the North Saskatchewan River can be assessed, and a greater understanding of the changes in its flow can be achieved, thus explaining observed trends in flooding.

2 Materials & Methods

To understand the effects of climate change on river flow, historic river discharge data was first extracted from the North Saskatchewan River at Edmonton monitoring station from the Environment and Climate Change Canada website[6]. It is important to note that river discharge, or river flow, is a measure of the volume of water passing through a given point per unit time, and measured in m^3/s. Reduced river flow indicates that less water is passing by a given point, and vice versa. The river flow data set contained the mean monthly river flow from 1911 to 2020, however as the glacial melt data was only available between 1966 and 2011, only data from this period was considered. Secondly, only river flow from the spring and summer months was considered, between April and September. For comparison between a rural and urbanized area, the same data was extracted from the Brazeau River below Brazeau plant monitoring station, where the Brazeau River flows into the North Saskatchewan River.

Given river flow, the factors contributing to it must now be assessed. The first contributing factor considered was glacial melt. Since 1966, the Peyto Glacier in the Rocky Mountains has been a site of continual study for glacial mass balance. This data was then downloaded from Statistics Canada[7]. The dataset contained annual mass balance, or how much the mass of the glacier changed in a given year, and cumulative mass balance, how much the mass of the glacier has changed throughout the observed period. For this study, only annual mass balance was considered. The annual mass balance and the mean river flow during the summer months for a given year were then compiled in a separate data set, which was referred to as *Glacier.csv*.

The second assessed factor contributing to river flow precipitation. Given that the North Saskatchewan River at Edmonton was the object of study, precipitation data was extracted from the vicinity. The Edmonton International Airport's weather station, WMO ID 71123, had the most extensive weather data from 1961 to 2012[7]. This data set was then downloaded, and summer precipitation between April and September was separated from winter precipitation between October to March. Summer precipitation during a given year would have an impact on the river flow during that year, but winter precipitation during a given year would have an impact on the river flow during the following summer. Secondly, the snowfall from winter is released during a short time frame, rather than over the whole summer. Therefore, snowfall cannot be considered by month as summer precipitation is. To accurately represent the effect of snowfall, the average monthly snowfall during a given year and the mean summer river flow for the following year were compiled in *Glacier.csv*. The total summer precipitation for a given month and the mean river flow for that month, between 1961 and 2011, was then compiled into a separate data set which was referred to as *PFlow.csv*. From the same data set, the mean monthly temperature was also extracted, to investigate the relationship between temperature, precipitation and river flow.

Lastly, data from the Canadian Disaster Database [8] for all floods within Alberta since 1915 was downloaded. No cleaning was done with this data, and data on flood damages, occurrences and evacuations were used as is.

Data was analyzed through Python, utilizing the PANDAS, NUMPY and SCIPY packages. PANDAS was primarily used for organizing data and visualization, whereas SCIPY was primarily used for correlation analysis. Microsoft Excel was also used to remove selected variables and clean data files before they were analyzed with Python.

All data sets were first analyzed using Pearson's and D'Agostino's normality test to see if any data came from a normal distribution, the results of which suggested that nonparametric tests were required. Therefore all correlation tests used Spearman correlation. Date was represented in the serial representation used by Microsoft Excel, where January 1st 1900 was 1, January 2nd 1900 was 2, and so on and so forth. From the Canadian Disaster Database, a simple counting and summing algorithm was used to extract information on flood occurrences and impacts.

3 Results

To understand the trend of river flow over time, we first plot the mean monthly flow during the summer months, from April to September, against a serial representation of the date (Fig.1). Performing a Spearman correlation test on this data gives $r = -0.191$ and $p = 0.000806$. To further understand how the river's flow has changed over time, we investigated how the river's flow range, the difference between it's maximum and minimum flow in a given year, has changed with time. The correlation between these two variables (Fig. 7) is $r = 0.688$ and $p = 6.63e-7$.

To investigate whether or not similar effects were seen in a non-urbanized environment, where changes in river flow were not caused by humans, a correlation test was performed between mean monthly flow and date for the Brazeau River monitoring station (Fig.10). The resulting correlation was $r = 0.0766$ and $p = 0.182$.

Given that river flow has decreased over time, we now seek to understand the role glacial retreat has played in this by plotting mass balance against river flow (Fig. 2). We find $r = 0.187$ and $p = 0.241$. The change in mass balance

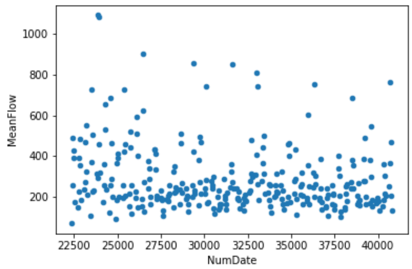

Figure 1: Mean River Flow for a given month plotted against a serial representation of date.

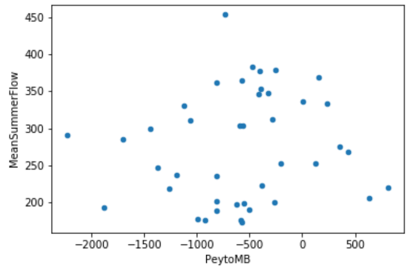

Figure 2: Mass balance for a given year plotted against mean river flow for the summer months in that year.

over time was investigated by plotting mass balance against the year it was recorded (Fig. 8), which resulted in a correlation of $r = -0.390$ and $p = 0.0117$.

Therefore, we look at another possible contributor to river flow, summer precipitation. Plotting the total precipitation for a given month against the mean river flow for that month (Fig. 3) gives $r = 0.394$ and $p = 7.80e-13$.

Given that river flow has decreased over time, and summer precipitation shows relation with river flow, we look at how precipitation has changed with time. By plotting the total precipitation for a given month against a serial representation of date, which is always the first of the given month (Fig. 4), we find that $r = -0.0245$ and $p = 0.670$.

Given the lack of correlation between temperature and time, we chose to investigate the last possible natural cause of changes in river flow, snowfall. First, we must investigate the relationship between snowfall in a given year and the river flow in the following summer due to melting. A correlation test between mean monthly snowfall in a given year and mean monthly flow in the following year (Fig. 5) returns $r = 0.258$ and $p = 0.103$. Therefore, we then plotted total monthly snowfall against date (Fig. 6) to see how snowfall has changed over time. The correlation between snowfall and date was $r = -0.134$ and $p = 0.0194$.

Lastly, a simple algorithm was used to divide flood data from the Canada Disaster Database into decades, from the 1960s to the 2010s. Then, the average total damage costs due to floods (Fig. 9), total fatalities due to floods (Fig. 10) and total number of people evacuated due to floods (Fig. 11) were calculated for each decade.

4 Discussion

The correlation between mean monthly flow and date provides our first insight, showing a weak

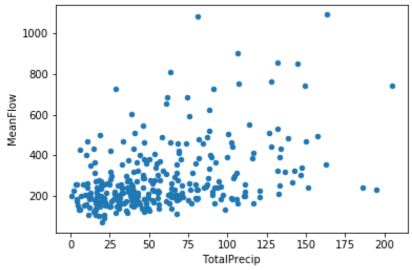

Figure 3: Mean River Flow for a given month plotted against total precipitation during that month.

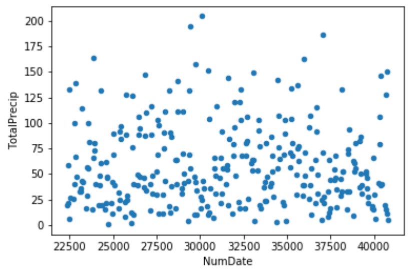

Figure 4: Total Precipitation on a given day plotted against a serial representation of that date.

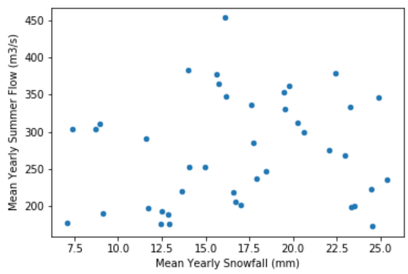

Figure 5: Mean monthly snowfall for a given year plotted against mean monthly river flow for the summer months in the following year.

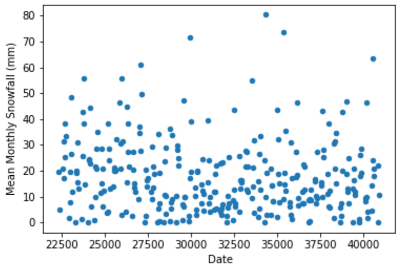

Figure 6: Total monthly snowfall plotted against a serial representation of date.

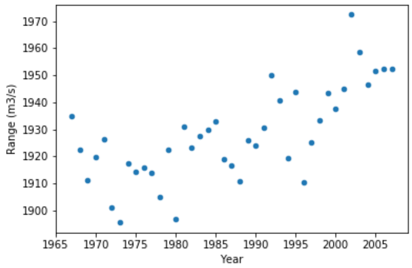

Figure 7: Difference between maximum and minimum river flow (Range) for a given year plotted against year.

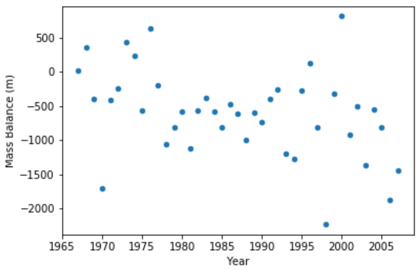

Figure 8: Mass balance of the Peyto Glacier plotted against year

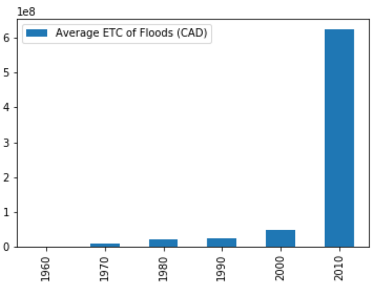

Figure 9: Average "Estimated Total Cost" of floods during each decade

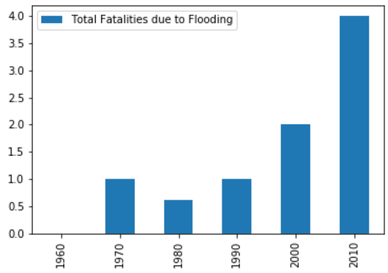

Figure 10: Total fatalities due to flooding during each decade

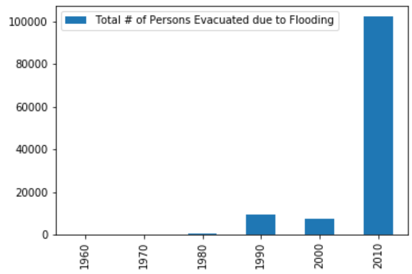

Figure 11: Total number of people evacuated due to flooding during each decade

negative correlation that suggests river flow has been decreasing over time. However, there is a moderately strong correlation between river flow range and date, suggesting that the North Saskatchewan River's flow varies more in recent years. This can be attributed to increased seasonality of flow, where warming results in an earlier peak flow during initial snow melt but decreased flow afterwards due to reduced snow pack [2]. Increased seasonality of flow results in decreased overall flow but an increased flow during a specific time frame, resulting in higher flood risk.

Changes in summer precipitation are not considered to be significant factors contributing to the decrease in river flow, for the purposes of this paper, as it shows little change over time. Further, the p-value for the correlation between precipitation and time is well in excess of the critical value, thus the data is considered too unreliable to be used for a conclusion.

Snowfall shows a moderate correlation with river flow, as the snow that accumulates during winter forms snow pack. This snow pack then melts during the summer, and the resulting water enters nearby rivers as run-off. [10] However, the p-value of this correlation does exceed the critical value, but by a small margin. Further, the moderately weak, negative correlation between total snowfall and date suggests that reduced snowfall is a factor leading to reduced river flow. As less precipitation during the winter falls as snow at higher latitudes[2] , due to climate change, less snow is accumulated. Lower snow accumulation will lead to reduced overall flow, but the rapid melting due to warmer temperatures will result in an increased, earlier peak flow [9]. Therefore, reduced snow fall during winter due to warming is suggested to be the strongest contributing factor to increased seasonality and decreased flow.

The results of our data also suggests that glacial mass balance has played a role in the changes in flow regime seen in the North Saskatchewan River. It is important to note that the mass balance of a glacier is affected by both the amount of snow it accumulates during the winter, and the amount of snow that melts during the summer due to glacial retreat. Given the moderate correlation between snowfall and river flow, it is suggested that a combination of glacial retreat and reduced snowfall have led to changes in flow regime. The moderate positive relationship between mass balance, which reflects how much of a glacier is lost, and river flow suggests that as glacier size decreases, river flow also decreases. This is because if a glacier fails to accumulate mass due to reduced snowfall, it loses mass in the summer due to melting, resulting in a low mass balance. However, if the glacier failed to accumulate mass during the winter, less snow is available to melt during the summer, therefore run-off is reduced. This results in reduced river flow, despite an increased peak flow during the initial melt [2].

Another possible factor leading to decreased river flow at the observed station, which is located in Edmonton, an urban centre, is the effect of urbanization. While the mean monthly flow shows a downwards trend over time in Edmonton, mean monthly flow shows little change at Brazeau River. Urbanization tends to decrease river flow, while increasing its variability due to changes in a river from damming, diversions, channelling and exploitation for water supply [11]. Considering the North Saskatchewan River passes through Edmonton, it is regulated and used for the city's water supply [11], therefore the effects of urbanization are very much seen when flow is measured at Edmonton.

The analysis of Canadian Disaster Database flood data for Alberta shows that while fewer floods have occurred in the present decade than in the 1990s and 1970s, they have caused far more damage, resulted in more evacuations and far more fatalities. Our study suggests that this is, in part, caused by environmental changes in the flow regime of Albertan rivers. The North Saskatchewan River is a model of a glacially fed river, originating in the Rocky Mountains, and there are many similar rivers to it within Alberta. The environmental cause is suggested to be glacial, caused by reduced snowfall in the winter and rapid warming in the spring resulting in a violent peak flow followed by reduced flow throughout the rest of the summer.

Beyond the metrics analyzed in this paper, there are a number of latent variables, factors that increase or decrease river flow which were not considered. These include the effect of urbanization on flooding, as modification of the land through grading, removal of vegetation and construction of impermeable concrete structures increases flood risk. Specifically, concrete's impermeable nature results in flood water being redirected to the surrounding environment, rather than being absorbed. Further, as there is little soil present in urban areas, little to no water is absorbed and the majority enters a nearby river or lake as run-off, possibly causing flooding during periods of high precipitation [12]. This paper is limited by its focus on empirical data analysis, rather than a complete model of river flow, as certain variables have simply not been recorded and therefore cannot be considered quantitatively. It is also important to note that this paper relies on correlation to lead to conclusions, however correlation is not always indicative of causation without appropriate justification. The high p-values seen in many data sets, a product of the Python package used to calculate correlation, results in uncertainty on the validity of certain data sets. There is a reduced probability that the correlations observed are due to pure chance if there is theoretical reasoning behind them. Therefore, all correlations are justified using previous scientific research which validates our empirical analysis with theory, allowing us to come to conclusions despite p-values which exceed 0.05.

5 Conclusions

The goal of this study was to analyze the impacts of climate change through its effects on precipitation and glacial melt. By analyzing river flow over time, it was determined that there was a gradual decrease in river flow at the Edmonton measuring station, but no such decrease at the Brazeau river measuring station. The results demonstrated that summer precipitation had an uncertain impact on river flow, snowfall showed some correlation with river flow. Due to the impact of snowfall on glacial mass balance, a weak correlation was also seen between mass balance and river flow. Therefore, the decrease in snowfall caused by warming results in reduced snow accumulation in snow pack[9] and glaciers [2]. Warmer temperatures result in an earlier spring melt with a higher peak flow, explaining the increase in flow range seen over time. This increase in variability results in flooding, which is exaggerated by urbanization, and occurs at unpredictable times due to earlier melting. However, due to reduced run-off from snow melt, the mean flow of the North Saskatchewan River decreases. While not a concern currently, as a city grows its water needs grow as well, and it begins to put more pressure on its water resources. In the case that water demand increases while water supply decreases, a water crisis can occur[2]. The data analyzed in this paper shows that this process has already begun occurring, causing concern for the future of Alberta's rivers.

Acknowledgements

We would like to thank Rylan Marianchuk for his assistance as our team mentor, and the staff of STEM Fellowship for providing this invaluable opportunity for us.

References

[1] Bash, E. A., Marshall, S. J. (2014). *Estimation of glacial melt contributions to the Bow River, Alberta, Canada, using a radiation-temperature melt model.* Annals of Glaciology, 55(66), 138–152. https://doi.org/10.3189/2014aog66a226

[2] Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., & Wiltshire, A. (2010). *Implications of climate change for agricultural productivity in the early twenty-first century.* Philosopgical Transactions of the Royal Society Section B, 365, 2973–2989. doi: doi:10.1098/rstb.2010.0158

[3] Kummu, M., de Moel, H., Ward, P. J., Varis, O. (2011). *How close do we live to water? A global analysis of population distance to freshwater bodies.* PloS one, 6(6), e20578. doi:10.1371/journal.pone.0020578

[4] Nilsson, C., and B. Malm Renöfält. 2008. *Linking flow regime and water quality in rivers: a challenge to adaptive catchment management.* Ecology and Society 13(2): 18. [online] URL: http://www.ecologyandsociety.org/vol13/iss2/art18/

[5] Xu, H., Luo, Y. (2015). *Climate change and its impacts on river discharge in two climate regions in China.* Hydrology and Earth System Sciences, 19(11), 4609–4618. https://doi.org/10.5194/hess-19-4609-2015

[6] Extracted from the Environment and Climate Change Canada Historical Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/historical$_{data_index_e}$.ht $//open.canada.ca/data/en/dataset/57ba3e50-2024-4570-8acf-4b99544fb689$

[7] $EnvironmentCanada.(2019, October22).MonthlyDataReportfor20$ $//climate.weather.gc.ca/climate_data/monthly_data_e.html?hlyRang$ $1961-01-01|2012-04-12dlyRange = 1959-05-01|2012-04-11mlyRange = 1959-01-01|2012-04-01StationID = 1865Prov = ABurlExtension =_e .htmlsearchType = stnNameoptLimit = yearRangeStartYear = 1840EndYear = 2020selRowPerPage = 25Line = 10searchMethod = containsMonth = 4Day = 12txtStationName = Edmontontimeframe = 3Year = 2012$

[8] Government Of Canda. (2013, December 9). Canadian Disaster Database. Retrieved from https://cdd.publicsafety.gc.ca/rslts-eng.aspx?cultureCode=en-CaboundingBox=provinces=1eventTypes='FL'eventStartDate=inj

[9] Xu, Chong-Yu Halldin, Sven. (1997). The Effect of Climate Change on River Flow and Snow Cover in the NOPEX Area Simulated by a Simple Water Balance Model. Hydrology Research. 28. 273-282. 10.2166/nh.1997.017.

[10] USGS. (2019). Snowmelt Runoff and the Water Cycle. Retrieved from https://www.usgs.gov/special-topic/water-science-school/science/snowmelt-runoff-and-water-cycle?qt-science$_center_objects = 0qt - science_center_objectsZaharia, L., G.Ioana - Toroimac, O.Coco, F.A.Ghi, andE.Mailat.2016.Urbanizationeffe$ $e01247.10.1002/ehs2.1247$

[11] City of Edmonton. (n.d.). North Saskatchewan River - Water Quality. Retrieved from https://www.edmonton.ca/city$_government/environmental_steward$ $saskatchewan - river - water - quality.aspxUSGS.(2019, October29).EffectsofUrbanDevelopmen$ $//pubs.usgs.gov/fs/fs07603/$