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Student Research Report

Managing Shifting Precipitation Regimes

Sustainable Stormwater Management at the University of British Columbia

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Managing Shifting Precipitation Regimes: Sustainable Stormwater Management at University of British Columbia

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Tables of Contents

Abstract

In response to growing concerns about climate change, recent studies have investigated the climate change impact on shifting precipitation and storm events. In this work, we expand on this body of work through various analyses using the data from the Environment and Climate Change Canada (ECCC) and UBC Abacus Data Network to understand the effects of shifting precipitation of climate change on green infrastructure management at the University of British Columbia (UBC) Point Grey campus in Vancouver, Canada. The study has important implications for policymakers, urban planners, and environmental managers, emphasizing the need for proactive planning and management strategies to mitigate potential risks from changing precipitation patterns. Results showed that there are increasing chances of storm events and the existing green infrastructure at UBC is not designed to handle large volumes of precipitation, leading to flooding and erosion issues with a small portion of permeable surfaces and green infrastructure, which highlights the need for sustainable stormwater management practices that take into account the unique characteristics of each location. Based on the findings, several recommendations can be made for UBC's green infrastructure planning and stormwater management, such as balancing permeable and impermeable surfaces, installing and upgrading green roofs and other green infrastructure, and recording and updating related climate data and performance.

Keywords: Climate change, Green infrastructure management, Planning, Precipitation, Stormwater management, University of British Columbia.

Introduction

Climate change is impacting terrestrial ecosystems through changes in temperature and precipitation. It is now one of the most prominent issues all over the world and is not only a natural phenomenon but also a social, economic, and political phenomenon. Many experts have given different explanations and predictions about climate change, for example, the explanations include natural and human impacts. Nevertheless, there has been a scientific consensus that human impact is warming the climate at an unprecedented rate, and only about 25% of the temperature change in the 20th century can be attributed to natural variability (Petrescu-Mag et al., 2022). As climate change is gaining more and more attention, related research is increasing.

One of the impacts of climate change on ecosystems is the shifting of biogeoclimatic zones, known as the Biogeoclimatic Ecosystem Classification (BEC) zones (Wang & Hamann, 2012). BEC zones are a classification system used for ecosystem management in British Columbia (BC), which is using several key variables, for instance, climate, soil content, and associated plant communities to divide BC into different zones (Mahony et al., 2018; Ministry of Forests and Range, 2022). For example, UBC's current BEC zone is CWHxm1, which stands for Coastal Western Hemlock Zone, very dry, maritime, southern, coastal subzone (Ministry of Forests and Range, 2022).

As the effects of climate change continue to be felt, it is becoming increasingly crucial to understand and address the impact on infrastructure management. Green infrastructure is the infrastructure for green spaces or a mixture of buildings, such as forests, parks, permeable pavement, and green roofs, which consists of more natural solutions and approaches with better resilience to flooding and mitigation of climate hazards, such as the urban heat island effect and absorbing carbon dioxide (Demuzere et al., 2014). There is evidence found in the literature that green infrastructure is beneficial to improving water quality, reducing flooding impacts, and human health, and increasing green infrastructure planning and research is conducted to decrease the vulnerability of urban areas to climate change (Demuzere et al., 2014). According to the Climate Action Plan (CAP), UBC is developing adaptation to better understand the climate adaptation benefits by researching climate resilience (UBC, 2021). Moreover, the UBC Green Building Action Plan (2018), aims to make UBC buildings and landscapes have the potential to respond to anticipated and unpredictable climate changes.

Thus, the project Shifting Biogeoclimatic (BEC) Zones is part of a new research area within Campus Planning, and the current knowledge gap is lacking a land classification map and a water flow time and/or velocity map that can be used for green infrastructure planning and stormwater management, specifically in relation to precipitation prediction. The primary objective of this study is to gain a comprehensive understanding of the effects of precipitation changes on the management of green infrastructure at the University of British Columbia (UBC) Point Grey campus, Vancouver, Canada. The research is related to previous studies on climate change and stormwater management in Vancouver, which have emphasized the importance of incorporating climate change factors and green infrastructure and improving drainage systems. The present study contributes to this body of knowledge by focusing specifically on the UBC campus and providing an analysis of precipitation change and stormwater management practices. The findings of this research project will provide valuable insights into the management of green infrastructure in the face of shifting precipitation regimes, particularly in BEC zones such as the CWH.

Data and Site Summary

The study site of the Shifting BEC Zone project is the University of British Columbia Vancouver campus, BC, Canada, shown in Figure 1. The land of the UBC Vancouver campus once belonged to the ancestral and unceded land of Indigenous people (UBC, 2021). UBC Vancouver campus is located in a temperate rainforest of the southwestern coastal areas of BC, and the climate of this study site is mild oceanic climate, with cool summers and mild winters. Moderate climate helps with the growth of various types of vegetation, species, and landscapes. UBC campus land cover could be divided into three general types: 30.4% tree canopy, 25% soft landscape (shrubs and tree understorey included), and 44.6% artificial surfaces that do not have vegetation (UBC, 2021).

Study Area Map

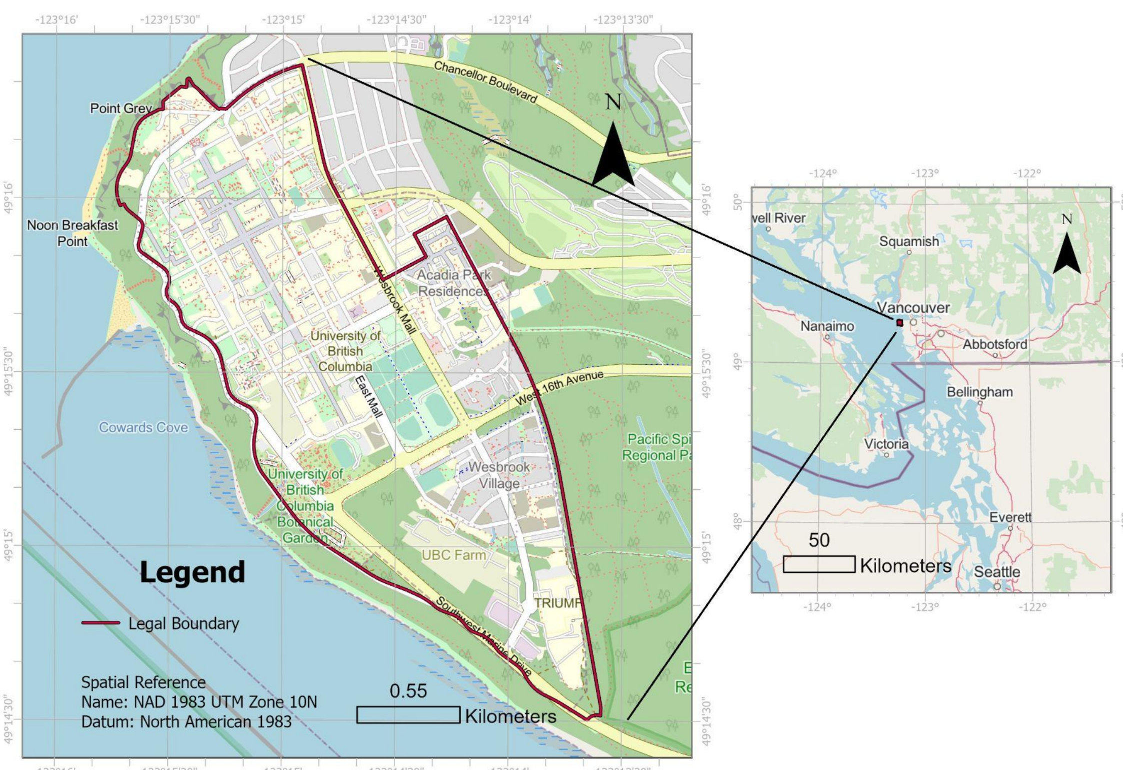

Figure 1. Map of the Study area at the University of British Columbia Vancouver campus.

Data Summary

1. Environment and Climate Change Canada (ECCC). Historical Climate Data website. (2022). https://climate.weather.gc.ca/index_e.html

This government website has been used and cited in many peer-reviewed theses, which is relatively reliable and correct. The historical data is in Environment and Climate Change Canada (ECCC)'s database, and it contains multiple data types, i.e., csv, xml, and txt, for the data that could be downloaded, containing monthly (and daily) data of mean max/min temperature, mean temperature, extreme max/min temperature, total rain, total snow, and total precipitation. Taking Vancouver UBC as an example, after downloading the metadata, it shows Station Name, Province or Territory, Latitude 49.25, Longitude -123.25, Elevation 76.00, Climate Identifier1108487, WMO Identifier, TC Identifier, of Vancouver UBC station, and Legend used. Environment and Climate Change Canada (ECCC) mentioned that "the vast majority of observational data is accurate" (2022), so there might still be some data that need correction. For instance, the Vancouver UBC station climate data only covers from September 1957 to June 1995, which is not considered long enough to meet this project's expectation, as we expect the period of historical data could cover up to 100 years. To overcome this limitation, data from other close climate stations, such as the Vancouver International Airport station within 8 kilometers (from January 1937 till now) and the Vancouver Southlands station within less than 6 kilometers (from January 1960 till 2004) are considered. For stations within 15 km of UBC Point Grey Campus, the Steveston station has the earliest climate data dating back to 1896.

2. ClimateNA. (2023). Retrieved from https://climatena.ca/

The ClimateNA dataset provides climate data for North America, including temperature and precipitation variables, derived from various sources and downscaled to a high-resolution grid, and could be downloaded from https://climatena.ca/ (ClimateNA, 2023). ClimateNA provides high-resolution climate data at a spatial resolution of 1 kilometer (km) for most of North America covering a wide temporal range and can be accessed and processed as a raster format or table format using programming languages, such as R or Python (ClimateNA, 2023). ClimateNA data are derived from multiple sources and undergo a series of processing steps, including downsampling, interpolation, and quality control (ClimateNA, 2023). It provides several climate models that could be chosen in the climate analysis to predict future precipitation.

3. Burton, Jeff; Wiersma, Rachel, 2016, "UBCGeodata, [November 2016]", https://hdl.handle.net/11272.1/AB2/S15BIR, Abacus Data Network, V2

The UBCGeodata could be downloaded from https://hdl.handle.net/11272.1/AB2/S15BIR, which is open data gained from the UBC Campus and Community Planning. Moreover, Jeff Burton has been the systems analyst of UBC since May 2013, and Rachel Wiersma also worked as a manager related to GIS and Data Systems since January 2014 (LinkedIn, 2022). Both authors are educated at UBC and have been working at UBC in the field of GIS and planning for a long time. Therefore, this data could be considered accurate, as it could be regarded as part of UBC's official dataset. Although the data was made in 2016, it is acceptable as the change in the campus is not massive enough. This dataset contains geospatial data of the geodatabase, geojson, and csv data types of the UBC Vancouver Campus of landscapes (such as trees and water), buildings, roads, and locations (Burton & Wiersma, 2016). The attribute table contains the name, global ID, and surface type for landscape features. This dataset is a good source for identifying impermeable surfaces and permeable surfaces.

4. MetroVancouver. (2020). Carbon Biomass 2019 - 2m (Raster). http://www.metrovancouver.org/data

The Carbon Biomass dataset has the data of carbon stored in soft landscapes like vegetation and soils for Vancouver, and this raster dataset can be easily downloaded from the website http://www.metrovancouver.org/data (MetroVancouver, 2020). This is open data, but Metro Vancouver is a political body and corporate entity with a Board of Directors of elected officials under provincial legislation to deliver core services of water and waste management, plan for the future related to air quality, regional growth, and parks, and serve as political forum (MetroVancouver, 2022). This data is also widely used and is used to explore the potential relationship and impact between soil and precipitation and help with UBC land classification, and the accuracy of this dataset is acceptable.

5. Simonovic, S.P., A. Schardong, R. Srivastav, and D. Sandink (2015), IDF_CC Web-based Tool for Updating Intensity-Duration-Frequency Curves to Changing Climate – ver 6.5, Western University Facility for Intelligent Decision Support and Institute for Catastrophic Loss Reduction, open access https://www.idf-cc-uwo.ca.

The IDF curve tool generated by Western University is a useful tool when analyzing climate and stormwater and can be found on the website https://www.idf-cc-uwo.ca. It contains the climate data related to rainfall from weather stations across Canada, using the climate data from the ECCC, including historical IDF data and future IDF curves based on different climate data in the format of tables, plots, and csv (Simonovic et al., 2015). Since the data source is basically from ECCC, the tool is rather reliable.

6. University of British Columbia. Campus and Community Planning, (2021) "[University of British Columbia Vancouver Campus Lidar], 2021", https://hdl.handle.net/11272.1/AB2/Y5KQNB, Abacus Data Network, V1

The UBC Lidar data can be downloaded from https://hdl.handle.net/11272.1/AB2/Y5KQNB, which is open data gained from the UBC Campus and Community Planning. The contributor, Paul Lesack, is the data/GIS analyst of the UBC library (UBC Library, 2023). The data is also quite new, as the first version was published in 2021 and updated in 2022, and it has been downloaded over 1000 times (UBC, 2021). Therefore, this data could be considered reliable, as it could be regarded as part of UBC's official dataset. This dataset contains geospatial data of tif, laz, and shapefiles of the Lidar Point Cloud, Canopy Height Models (CHM), Digital Surface Models (DSM), and Digital Elevation Models (DEM) of UBC Vancouver Campus (UBC, 2021). This dataset is a good source when calculating the water flow of the UBC campus.

Methods

Data Pre-Processing:

This study utilizes climate variables like the mean daily, monthly, and yearly total precipitation (rainfall and snow) for winter (Dec-Jan-Feb) and summer (Jun-Jul-Aug), collected from historical climate data in Vancouver. However, some of this data needs to be pre-processed before analysis. For instance, the Vancouver UBC station climate data only covers from September 1957 to June 1995, which is insufficient for this study. Therefore, the historical climate data is pre-processed by using data from close stations within 15 km of UBC and making necessary corrections if overlay data have significant differences, in order to collect the climate data from 1901 to 2021. Since stormwater management is central to this investigation, we are focusing more on the rainfall season.

Climate analysis:

The assumption is that climate change might follow some underlying patterns and models and the dataset of historical climate data from 1901 to 2021 from the Vancouver UBC campus gathered. I will analyze the total monthly precipitation of the UBC Vancouver campus from 1901 to 2022, and the seasonal precipitation for winter and summer rainy seasons from 1901 to 2022 for UBC Vancouver campus to find a historical trend of climate change. We assume stationarity, which means that variations in data are caused by random fluctuations and are independent of any system changes (MacKinnon et al., 2021). ClimateNA v7.30 (ClimateNA v7.30, 2023) will be used to view and evaluate several climate models for predicted climate till 2100. By reviewing the trend of historical data, we select the Coupled Model Intercomparison Project phase 6 (CMIP6) Canadian Earth System Model version 5 (CanESM5) shared socio-economic pathway (SSP) 2.45 model for future climate analysis, which is a climate model simulation to project future climate changes under a moderate mitigation pathway, as this model fits better with the historical trend and is considered a moderate climate change severity compared to SSP1.26, SSP3.70, and SSP5.85 (Simonovic et al., 2015). By comparing the Intensity-Duration-Frequency (IDF) curves provided by Environment and Climate Change Canada (ECCC, 2023), the GHD report (GHD, 2018), the IDF_CC tool (Simonovic et al., 2015), and the BGC report (BGC, 2009), the relationship between the intensity of rainfall and the frequency of rainfall and the predicted possibility of future precipitation in a certain duration can be determined, which will help with stormwater management.

Stormwater analysis:

To analyze the stormwater event, I first calculate the velocity of the water flow at the UBC campus. Soil permeability, slope, and flow accumulation were considered as factors that can influence the velocity. Soil data and UBCGeodata were used to classify permeable and impermeable surfaces, as well as water features. The slope was generated using UBC DEM data in ArcGIS Pro. Based on the hypothesis that the flow velocity is affected by spatial components and surface types, and flow velocity does not change over time at a certain location, we can create a velocity field of UBC water flow. Next, to determine an estimated time for discharge, predicted precipitation from climate analysis was used. The 18 mm value of precipitation is selected, not only indicative of the average and median difference between historical and future precipitation for a 24-hour storm event across all return periods but also represents the predicted precipitation values for many other scenarios, such as a 30-minute storm event in a 50-year return period. Therefore, precipitation duration and discharge time were compared to evaluate the effectiveness of the UBC drainage system. Instantaneous discharge reaching the drain can be calculated since there is only one drain in the northern part of the UBC Vancouver campus.

Combining the impervious classification, water flow velocity, and rain flow time, potential areas of concern or risk for stormwater management were identified. Areas with low flow velocity may be more susceptible to flooding, while areas with high impervious surface coverage can increase the volume of runoff during storms, potentially overwhelming the capacity of the drainage system and leading to flooding. Areas near sensitive environments can also be more prone to environmental damage if stormwater is not properly managed. By using various data sources and tools, this analysis will help to identify areas of concern and inform the development of effective stormwater management strategies.

Workflow diagram figure:

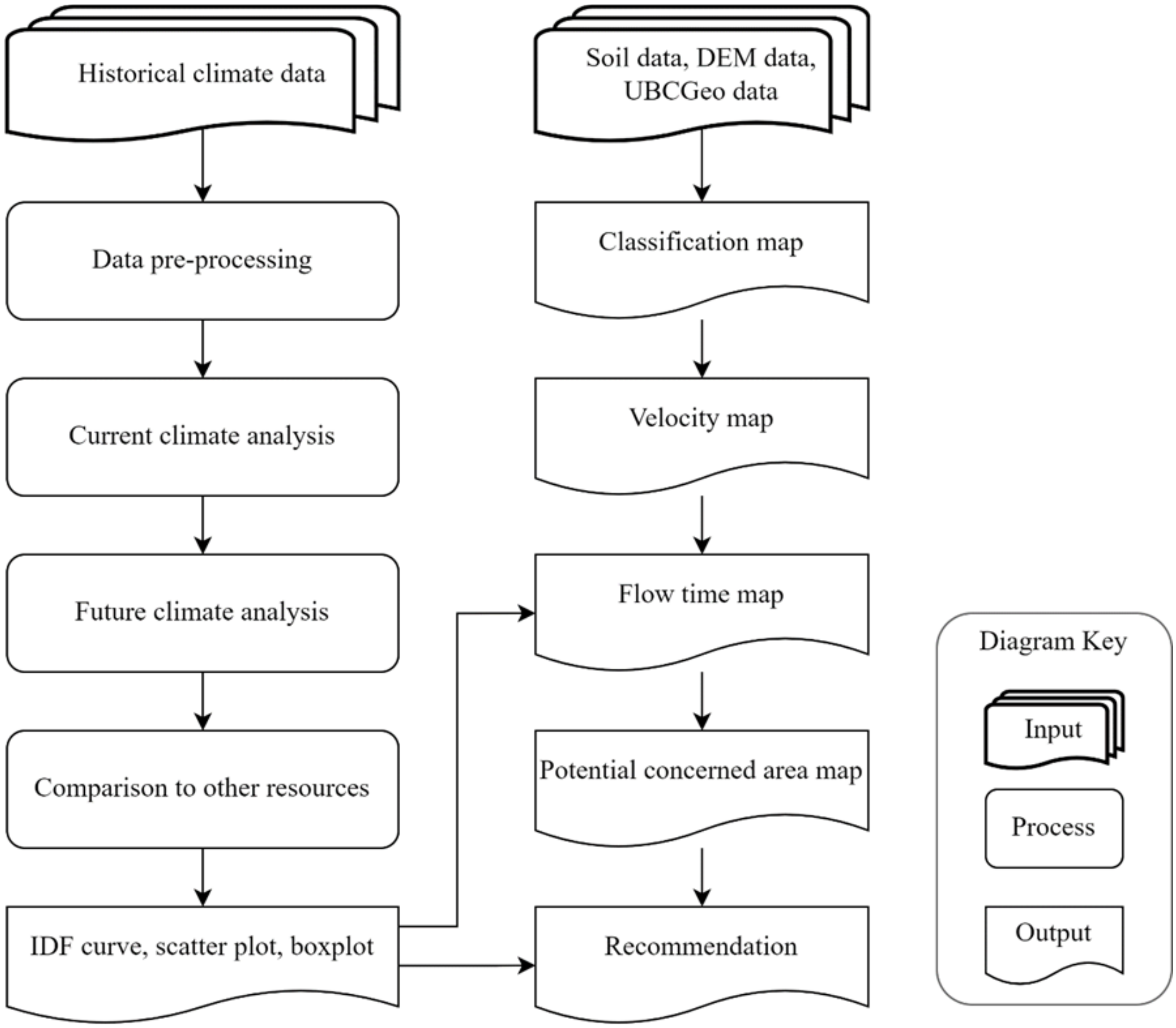

Figure 2. A general workflow chart of researching climate change on shifting BEC zone at the UBC Vancouver campus

Results

The analysis of precipitation data suggests that both the intensity and amount of rainfall for different durations are increasing, indicating a higher probability of extreme rainfall events in the future. However, the current stormwater management system at UBC may not be equipped to handle such severe weather events. The historical climate data and Climate BC v7.30 show that the precipitation for winter and summer seasons exhibits an oscillating trend with a slight overall increase, as depicted in Figure 1 and Figure 2. The IDF curve in Figure 3 indicates that more than 25% of the actual rainfall intensity occurs within 5 minutes for a 50- and 100-year return period. However, the precipitation intensity for other durations is lower than 25%. Moreover, the intensity of each duration has increased compared to the historical IDF curve. According to Figure 4, the prediction of the total rainfall for the UBC Vancouver campus from 2023 to 2100, indicates a relatively large range of predicted precipitation with less rain in summer compared to winter.

A classification map of impermeable and permeable surfaces in the UBC Vancouver campus (Figure 5) clearly classifies different types of surfaces, providing a basis for green infrastructure and stormwater management. Based on this map, DEM data, and soil data, Figure 6 illustrates the water flow during storm events at the UBC campus. According to Figure 6, the red regions show that it takes longer travel time for water to pass through the UBC campus, and they are further from the northern spiral drain and three other catchments with impervious surfaces and soil. The velocity calculation considering soil and slope shows that the quickest places are basically roads of the UBC campus, which is correlated to our assumption (Figure 6b). The dark green areas of Figure 6c highlight areas that are more sensitive to storm events and indicate that the current stormwater management system may not be able to handle a 30-minute storm event with a return period of 25 years, 50 years, and 100 years. However, the UBC campus stormwater system seems to work effectively for storm events with a return period below 10 years. Figure 7 suggests areas where stormwater infrastructure improvements may be needed.

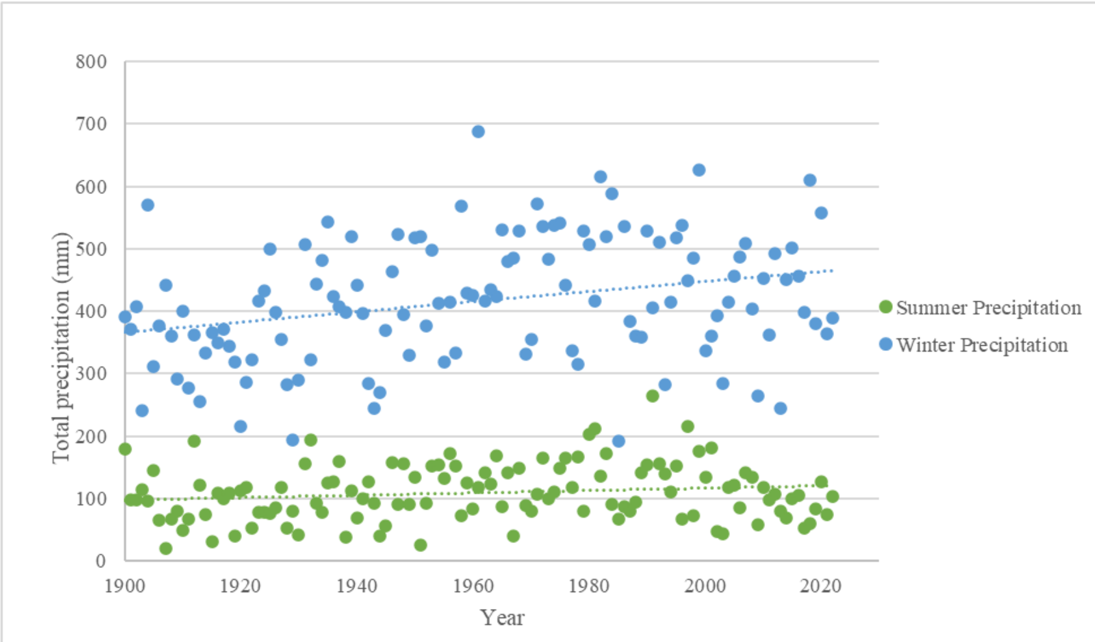

Figure 3. Total precipitation (mm) for summer (Jun-Jul-Aug) and winter (Dec-Jan-Feb) of the University of British Columbia from 1900 to 2022, according to the ECCC dataset.

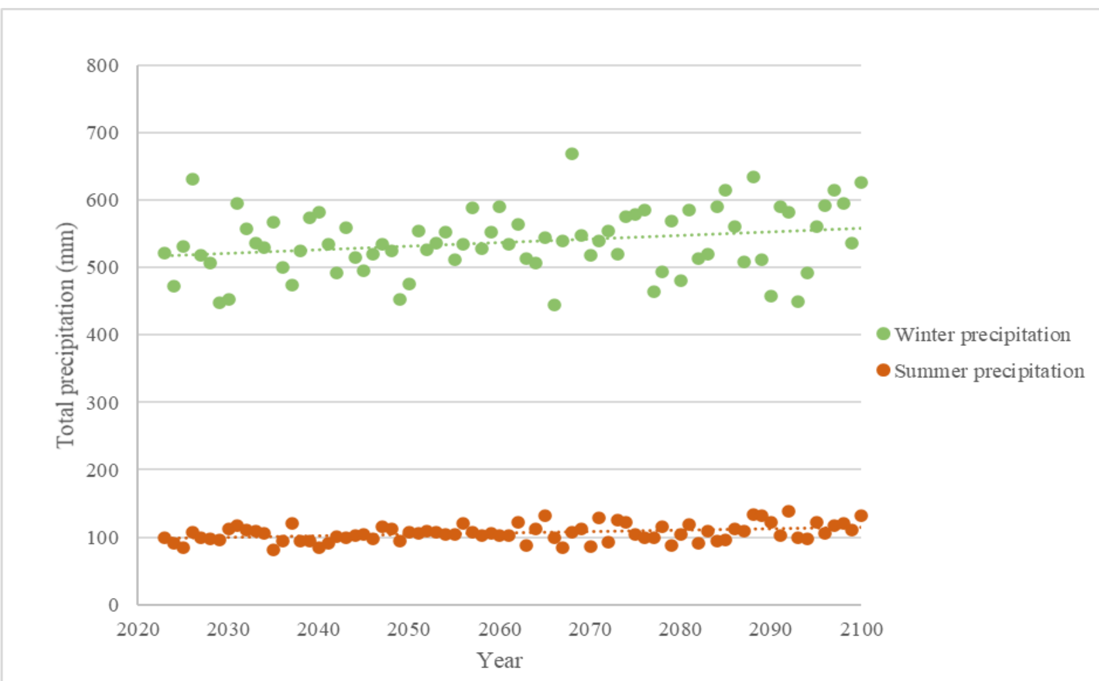

Figure 4. Total precipitation (mm) for summer (Jun-Jul-Aug) and winter (Dec-Jan-Feb) of the University of British Columbia from 2023 to 2100, according to the ECCC dataset.

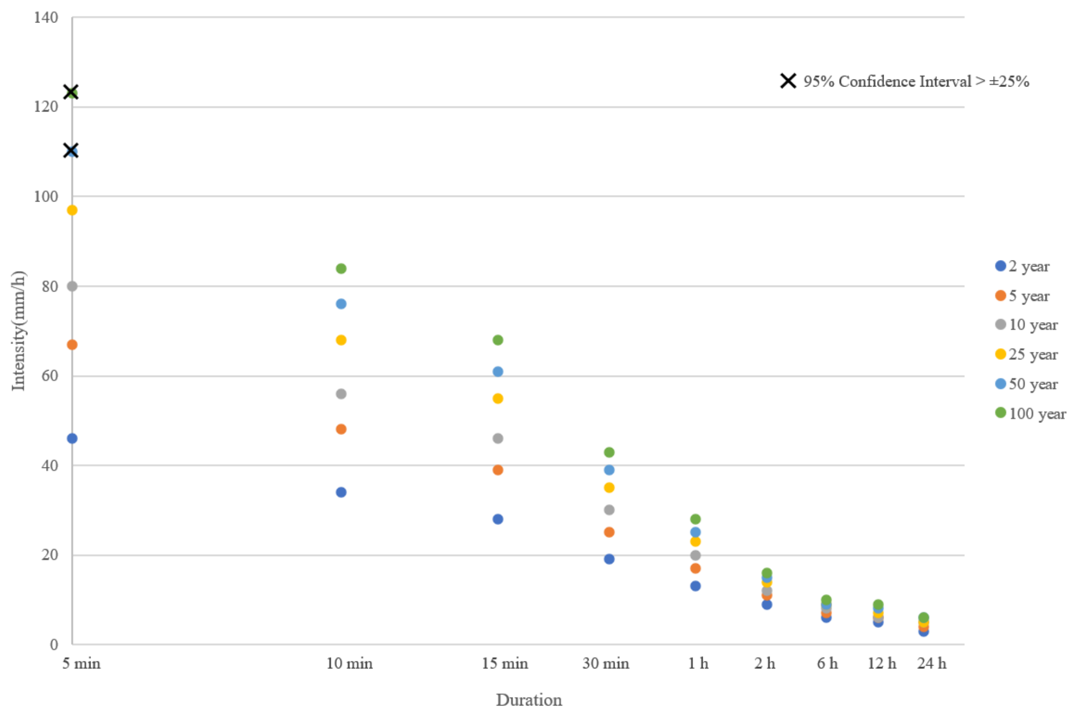

Figure 5. Short Duration Rainfall Intensity-Duration-Frequency (IDF) curve of Vancouver UBC

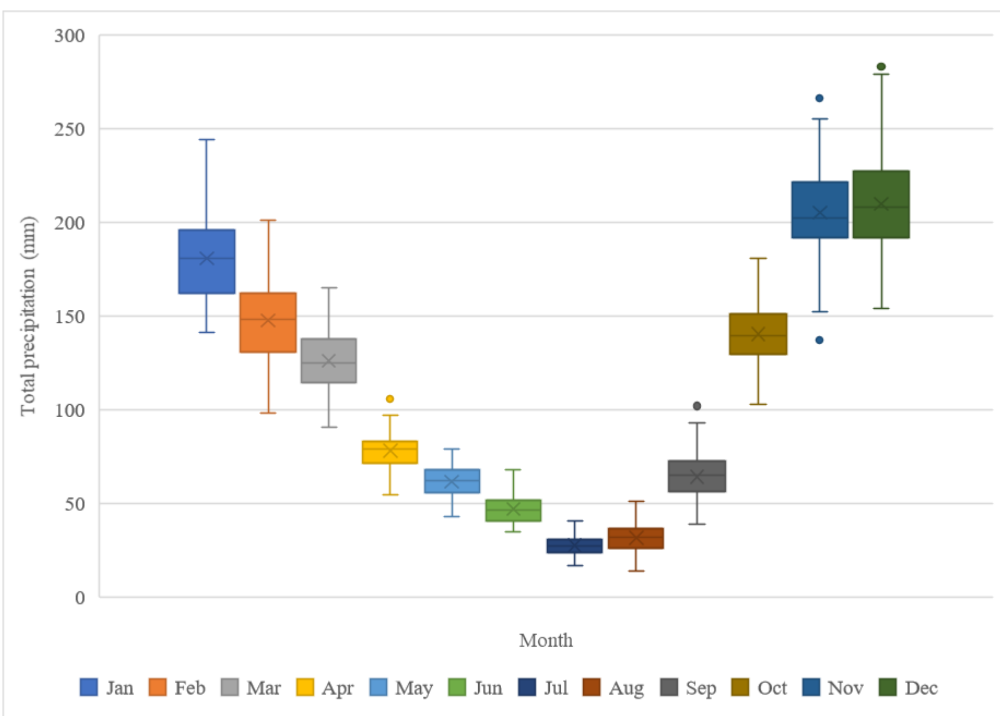

Figure 6. Boxplot of Monthly Total Precipitation(mm) at the University of British Columbia Vancouver Campus from 2023 to 2100

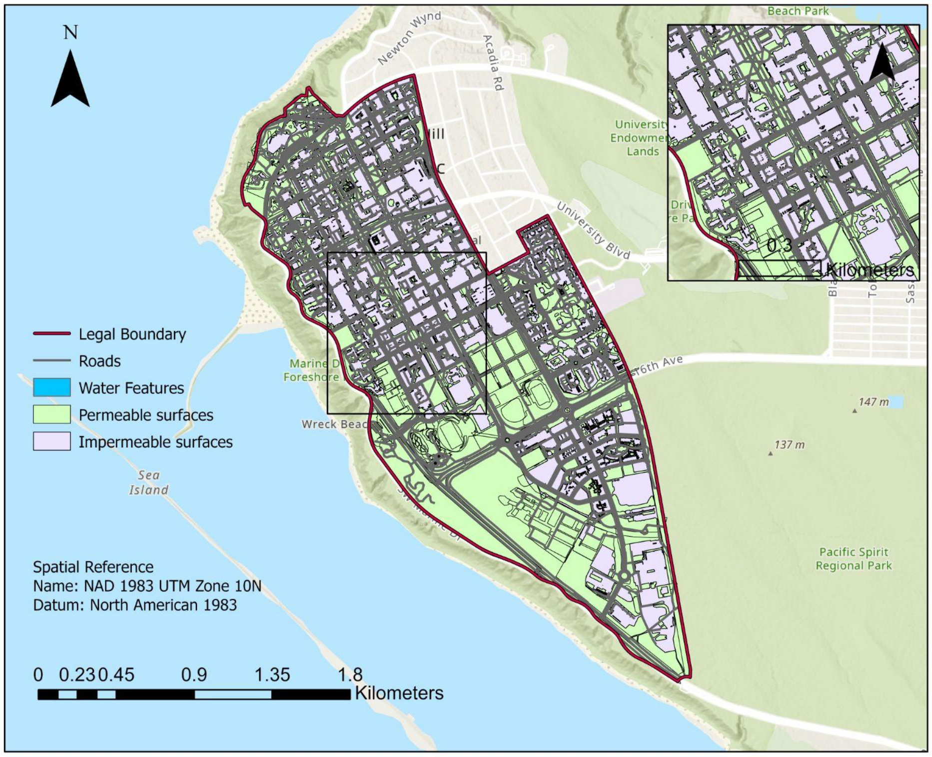

Figure 7. Classification map of the University of British Columbia Vancouver Campus. Landcover is categorized into impermeable surfaces, water features, and permeable surfaces.

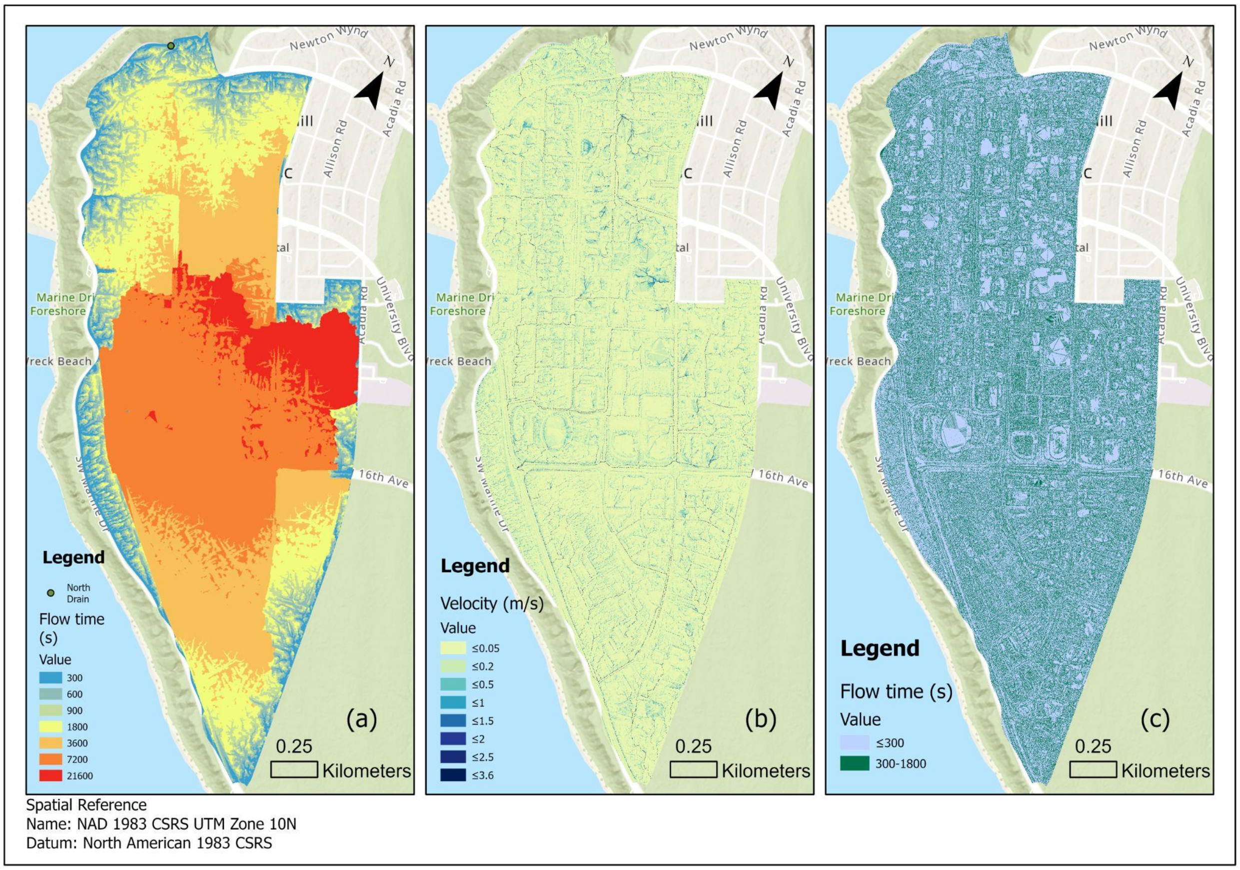

Figure 8. (a). The flow runoff time at the University of British Columbia Vancouver Campus. (b). The velocity field of flow at the University of British Columbia Vancouver Campus, where darker colors represent a slower velocity and lighter colors represent a faster velocity.
(c). The rainwater flow time of 18mm precipitation at the University of British Columbia Vancouver Campus.

Figure 9. Potential areas of concern for stormwater management of the University of British Columbia Vancouver Campus.

<u>Discussion</u>

Objectives: Understanding and analyzing the effects of precipitation changes on the green infrastructure at UBC

The aim of this project was to understand how shifting precipitation regimes would impact green infrastructure management at the University of British Columbia (UBC) Point Grey campus, Vancouver, Canada. Through various analyses, the study aimed to gain a comprehensive understanding of the effects of these precipitation changes on the management of the green infrastructure at UBC. This discussion highlights the major findings of this research, the recommendations for future green infrastructure planning, the limitations of the study, and potential aspects for future improvement.

The research is related to previous studies on climate change and stormwater management in Vancouver in large zones, such as GHD and BGC report, and UBC planning plans that do not include detailed precipitation change and water flow analysis. The present study contributes to this body of knowledge by focusing specifically on the UBC campus and providing an analysis of precipitation change and stormwater management practices. First, this could provide insights into the effectiveness of the UBC drainage system in managing stormwater during heavy rainfall events and identify areas with potential for flooding, overloading of the drainage system, or the potential to improve stormwater management through the enhancement of green infrastructure. Second, the study considers spatial components and surface types in stormwater management planning. Third, the study underscores the need for sustainable stormwater management practices that take into account the unique characteristics of each location, and integrated stormwater management plans that incorporate a range of strategies, such as green roofs, rain gardens, and permeable pavement. In summary, the results of this research can be valuable in informing future management strategies for green infrastructure, not only at UBC but also for other similar locations facing precipitation changes.

Major Findings: Increasing chances of stormwater, limited permeable surfaces and green infrastructure, recommendations for future planning

The results of this research showed that there are increasing chances of storm events, and the green infrastructure at UBC is not designed to handle large volumes of precipitation, leading to flooding and erosion issues. Additionally, there is only a small portion of permeable surfaces and green infrastructure. Based on the results, several recommendations can be made for UBC's green infrastructure planning and stormwater management. These include balancing permeable and impermeable surfaces, installing and upgrading green roofs, and other green infrastructure. Moreover, keep monitoring and evaluating climate change factors and the performance of the current stormwater system, ensure these data and recorded, used, and updated, and hire professional people for elevating and planning.

Limitations and future research opportunities of data and methods:

There are some limitations that could influence the accuracy and outcome of the project. First is the availability and quality of data. Since the predicted future short-duration precipitation and intensity data are based on the Vancouver International Airport’s 65-year data, and this weather station is in another zone in GHD and BGC reports, the accuracy of the predicted value can be slightly impacted. Furthermore, there are many assumptions when calculating the velocity field and instantaneous discharge of the UBC campus. For example, the velocity is affected by spatial components such as slope and flow accumulation and surface types (ESRI, 2023), but the coefficient weight when calculating the velocity may be improved. The flow time assumes that all flow at any particular location flows with the same speed and does not take into account the storage effects of the watershed (ESRI, 2023). It does not take into account runoff interception nor spatial variation in precipitation as well. Therefore, there is still room for future research to expand on these findings, such as improving the quality and availability of data, improving velocity and flow time calculation, and exploring alternative methods. Additionally, it is recommended to incorporate additional factors like soil types and validate the analysis by comparing existing stormwater management studies and using multiple scenarios.

Implications and recommendations:

Overall, this study provides valuable insights into future green infrastructure planning and stormwater management strategies, not only at UBC but also for other similar locations facing precipitation changes. The findings of this research demonstrate the importance of understanding the impacts of changing precipitation patterns on stormwater management and the need for proactive planning and management strategies to mitigate potential risks. Incorporating climate change as a crucial element while considering other design factors is essential in the planning and construction of resilient infrastructure, as discussed. As cities continue to grow and expand, it is essential that policymakers and urban planners prioritize effective stormwater management practices that not only reduce the risk of flooding but also protect the environment and promote sustainable development. Moreover, the policymakers can balance the risks to decide whether infrastructure be designed for a moderate or high increase in rainfall, and consider using more sustainable and integrated approaches to urban stormwater management.

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