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Urban Flooding in Vancouver, Canada

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ABSTRACT

Flooding can have devastating, long-lasting, and costly consequences, including the loss of life and displacement of communities. This review report summarizes the background, causes, and management practices of various urban flooding forms and mitigation efforts in Vancouver, British Columbia (BC) which is located on the Western part on the Pacific coast of Canada. The report makes use of existing literature to understand the flooding phenomena in Vancouver. The city is unique from a flood planning or management perspective because the city is vulnerable to every type of major flooding event, including pluvial, fluvial, and coastal flooding. Nevertheless, Vancouver is considered a globally sustainable city. As such, this report reviews various articles and research to determine the background and causes of various forms of floods experienced in Vancouver and the management practices put in place to mitigate flooding in the city. The study identifies measures in place to address every type of flooding event.

Keywords- urban flooding, flood types, flood causes, flood strategies, Vancouver, British Columbia**.**

I. INTRODUCTION

Vancouver has experienced a series of floods since 1894 that have caused the destruction of properties, loss of life, destruction of infrastructure, and displacement of people, among other impacts (Jakob et al., 2015). The history of flooding in Vancouver includes floods that emanate or are caused by storm rainfall, ice jams during ice formation, freshet flooding or snowmelt runoff, flash flooding, natural dams, spring break-up, coastal flooding on lake or ocean coasts from tsunamis, storm surges, and hurricanes. Urban flooding, especially in Vancouver, has been linked to three main causes: riverine flooding, stormwater runoff, and structural failure, where structures built to manage floods, including levees and dams, are unable to manage the force and quantity of floodwaters.

Floods tend to occur when the groundwater level rises, entering building cracks in floors, foundations, and basements. Flooding in Vancouver, especially along large river systems, is common and most frequent in spring owing to snowmelt and rainfall. In some cases, Vancouver experiences flooding during the summer as a result of short-duration heavy rainfall. Floods in Vancouver are likely to occur five times compared to wildfires, which are the second most frequent natural hazard in the country. Between 1894 and 2019, Vancouver experienced more than 250 floods. The first flooding incident in Vancouver was experienced in May 1894, which was a result of melting snow that flooded the Fraser River, with water levels reaching almost eight meters high (Vitousek et al., 2017).

In 1948, the Fraser River overflowed following an enormous snowpack that was accompanied by an unusually warm late spring that contributed to the melting of snow into the valley (Elliot et al., 1949). This disaster left one-third of Vancouver overwhelmed by dirty water, while more than 16,000 people were displaced from their homes, which were destroyed completely. In addition, more than 22,000 hectares of land have been flooded. During these floods, the Trans-Canada Highway rail lines and Canadian National Railway lines were flooded, while damage exceeded $ 215 million (Sandink, 2016). In addition, this flooding claimed the lives of ten people. On December 11, 2018,

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flash floods hit Vancouver, causing severe transport problems in the city because the highways and roads were submerged. Between 30 mm and 60 mm of rain fell in various parts of Vancouver in a few hours, resulting in flooding. Environmental specialists said that heavy rain was the result of a series of December storms that moved across coastal British Columbia.

II. STUDY AREA

Vancouver is considered to be one of the most vibrant and largest ports in the Pacific Ocean. The city is bounded by the Fraser River and the Strait of Georgia (Figure 1), while it is famous for its strategic position on the Canadian Pacific Coast, with mountain ranges behind. Scientists agree that Vancouver is highly vulnerable to flood risk due to its geographical location and that there is a 30% chance that this area will experience a major flood during the rainy season (Osler, 2020).

"The Flood of 1948" was one of the most destructive floods in the history of Vancouver. However, there was a much larger flood in 1894, which claimed more than 200 lives and caused the destruction of millions of properties. In Vancouver, one of the largest British Columbia cities, the climate is oceanic, humid, and cool, with fairly sunny summers and relatively mild rainy winters. Vancouver City has a moderate oceanic climate that borders a warm-summer Mediterranean climate. It is typically dry during the summer months, which eventually results in moderate drought conditions, especially during July and August. However, the rest of the months were rainy, with heavy rains mostly occurring in March and October. Like the rest of the British Columbia Coast, Vancouver is tempered by the North Pacific Currents and sheltered by the mountains of Vancouver Island to the West. Mountain terrain and sea breezes make Vancouver more vulnerable to microclimates, including flooding, while variations in weather within this city are exaggerated compared to other cities within the coastal region (Sarmiento et al., 2015).

Figure 1: Vancouver location

Vancouver is one of Canada's warmest cities, with average annual temperatures exceeding 11.0 °C (51.8 °F). Vancouver is ranked the third rainiest city in Canada, with more than 161 rainy days per year. The city receives an average of 1,189 mm (46.8 in) of rain annually (Raikes & McBean, 2017). Vancouver is vulnerable to every major type of flooding event, fluvial, coastal, and pluvial, yet it is the highest-ranking North American city according to the 2016 Arcadis Sustainable Cities Index, where the city leads the continent in social, environmental, and economic sustainability efforts.

III. TYPES OF FLOODING EVENTS IN VANCOUVER AND THEIR CAUSES

Vancouver is vulnerable to three forms of flooding: coastal, pluvial, and fluvial. Chang et al. (2020) argue that each of these floods has a different impact in terms of the damage it causes, how it occurs, its causes, how it is forecasted, and the type of protection needed to curb it. A fluvial, also known as a riverine flood, is a type of flooding that occurs when water levels in a stream, lake, or river rise and overflow onto the neighboring land, shores, and surrounding banks (Macdonald et al., 2012). The rise in the water level could be attributed to excessive snowmelt or excessive rain. Damage from lakes, rivers, or streams can have catastrophic effects and can be widespread, such that overflow affects smaller lakes and rivers downstream, which can eventually cause dikes and dams to break and swamp in nearby areas. The probability of a river flooding can be determined by embracing various models, such as considering past precipitation, current river levels, forecasted precipitation, and terrain and soil conditions.

The severity of a river flood can be determined by the intensity, volume, and duration of rainfall, especially in river catchment areas. Other factors that can determine the severity of a river flood include the terrain surrounding the river system and soil water saturation resulting from previous rainfall. In flatter urban areas, floodwater rises more slowly and tends to be shallower, and in most cases can remain for days. In mountainous or hilly areas, floods tend to occur within a few minutes after a heavy downpour, cause damage due to debris, and drain very quickly (Oliver-Smith, 2009). River flooding is one of the most common types of Vancouver flooding. This type of flood poses a significant safety threat and can cause considerable damage to surrounding properties. This type of flood can be prevented by establishing or constructing good defenses along rivers or lakes, particularly in populous or flat areas.

The Fraser River is the longest river that borders Vancouver and is a major cause of flooding in this city. The river flows from the mountains through the city to the Lower Mainland and out to the Strait of Georgia. Flooding of the Fraser River is a natural

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process that has shaped various regions in the Lower Mainland over time. Flooding mostly occurs during spring snowmelt (spring freshet) when there is an increase in water volume and the river runs fast and high. Fresher flow in the Fraser River is influenced by a combination of three conditions: precipitation, temperature, and snow volume. In essence, a large snowpack on the river contributes to a larger river flow; rain falling on snow further adds to the flow as it makes the snow melt faster, while warmer weather increases the rate at which the snow melts, thereby increasing the flow of the river, which eventually leads to flooding (Oliver-Smith, 2009). Although the land along the Fraser River is lined with dikes or protective earthen barriers that prevent water overflow, the dikes are overtopped by large-scale floods. In some cases, these dikes tend to extend the flooding duration, and it may take weeks for water to drain.

A pluvial flood occurs when an extreme rainfall event creates a flood independent of an overflowing water body (Pallathadka et al., 2021; Pallathadka et al., 2022). According to Raikes and McBean (2017), there is a misconception about flooding because most people believe that for a place to flood, it must be located near a river, lake, stream, or simply near a body of water. Pluvial flooding can occur at any location, whether rural or urban, even in areas that have no water bodies, such as rivers or lakes. Basically, there are two common types of pluvial flooding that are experienced, especially in Vancouver: flash floods and surface water floods. Surface water floods are a type of flooding that occurs when an urban drainage system fails; hence water flows out of the drainage system into the nearby structures and into the street (Falconer et al, 2009). Surface water floods are gradual; hence, people have ample time to relocate to safer grounds. In addition, the level of water in surface water floods is usually shallow, in the sense that it barely exceeds 1 m deep (Falconer et al., 2009). Furthermore, this type of flood poses no immediate threat to life. However, this tends to result in significant economic damage. Sewer flooding also falls under this category, because it is not always attributed to weather. They occur as a result of failure within the drainage system, which eventually results in flooding in the city.

Vancouver is growing, and the city is working to improve its sewer and drainage infrastructure. Nevertheless, the city has experienced a series of flooding incidents as a result of drainage failure. For example, on October 29, 2018, heavy rainfall overnight led to localized flooding on Metro Vancouver Road. On this day, up to 25 mm of rain fell in Vancouver and Richmond within a duration of two hours, resulting in stranded cars, while city officials received more than 120 calls. After trying to drive through a large volume of water, drivers were forced to abandon their cars on Vancouver's streets. Several intersections within the city were left covered with water as deep as 30 cm on the sidewalks and roads (Helaire ET AL, 2020). The flooding water went so deep that it started to rise over the floorboards of some vehicles. Three days after the flooding incident in Vancouver, city officials confirmed that the flooding in the city was a result of blockage of the drainage system, which had not been maintained for over three months.

On the other hand, flash flooding occurs when the ground is unable to absorb rainwater as quickly as it hits the ground. In most cases, flash flooding is caused by sudden heavy rainfalls. In addition, flash floods are characterized by high velocity and intense torrent of water that is triggered by torrential rain falling within a short amount of time in the nearby elevated terrain or within the vicinity. Also, flash floods can occur as a result of the sudden release of water from dams or upstream levees. Flash floods tend to gather steam within a duration of six hours following the event that spawned the floods. Hallegatte et al. (2013) argued that water moving at 10 mph exerts the same pressure as wind gusts of 434 kph (270 mph). Besides, water that exceeds a speed of 2.7 meters per second tends to move rocks that weigh about a hundred pounds. As such, flash floods carry debris and rocks that elevate their potential to injure people and damage structures.

Flash floods are destructive and very dangerous not only because of the hurtling debris that accompanies the water flow but also because of the water force, which could be very strong. Flash flooding can be prevented by avoiding the overdevelopment of floodplains and maintaining a good drainage system. On September 9, 2019, a sudden downpour caused a flash flooding in Vancouver. Between 30 and 60 mm of rain fell within a few hours in the city, resulting in flooding, which submerged highways and roads within the city. Some streets in the city turned into rivers and ponds within a few minutes. Within a few hours, social media platforms were lit up with videos and photos of water overflowing onto sidewalks and pooling on the streets. In addition, drainage systems were overwhelmed quickly at different locations, including the intersection of Nelson Street and Homer Street (Yumagulova, 2019). The heavy downpour also caused major issues for transit services on the Expo Line after flooded tunnels. In addition, three streets within the city were temporarily closed until flooding was addressed. While heavy rainfall was received in Vancouver within a short period, other parts of the Lower Mainland were bright and sunny. However, flooding did not last for a long time, but had adverse economic effects.

Coastal flooding is a type of flooding that is usually linked with tropical storms or tsunamis and hurricanes. Coastal flooding occurs along the edges of the ocean, predominantly driven by storm surges and wave damage. In other words, coastal flooding is the overflow of water on land, especially in coastal areas. Intense windstorms, high tides, and tsunamis are the

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common causes of coastal flooding (Jongman et al. 2012). In essence, storm surges form when high winds emanate from a windstorm forcing water onshore. Windstorms are the major causes of coastal flooding and are often the greatest threat. The impact of coastal flooding tends to increase, depending on the magnitude of the tide. This means that windstorms that occur during high tides contribute to devastating and destructive storm-surge floods. In coastal flooding, water tends to overwhelm low-lying areas and cause property destruction and devastating loss of life. Various factors determine the severity of coastal floods, including the direction, size, strength, and windstorm speed (Lyle & Mills, 2014).

The offshore topography and onshore topography also play a crucial part in enhancing coastal flooding. Furthermore, to determine the magnitude and the probability of a storm surge, coastal flood experts consider this information as well as the history of storms that have affected the area over the period of time. Also, high tides and extreme weather can lead to rising sea levels, which eventually results in coastal flooding (Jongman et al, 2012). In most cases, low-lying seaside areas have defenses against the coastal water, whether natural or man-made barriers, including sand dunes. When a tsunami arrives, it occurs as a forceful increase in water levels that eventually results in violent flooding, causing massive loss of life and devastating property damage (Lyle & Mills, 2014). In 1946 a tsunami struck Vancouver with two waves, the first one being two meters high, and the second one was one meter high. An earthquake of magnitude 7.0M accompanied this tsunami. This was one of the most damaging earthquakes in Vancouver's history, through its damage was restricted since the City of Vancouver was not densely populated during this period. The tsunami led to the death of ten people, while properties worth millions were destroyed.

According to Lyle and Mills (2016), Vancouver is located in an active earthquake region that is skeptical of an earthquake at any moment that could be accompanied by a tsunami. Furthermore, Vancouver is susceptible to floods, whereas rainstorms cause localized flooding (Lyle & Mills, 2016). During flooding, essential infrastructure, including homes, is damaged, public transport is disrupted, and sewers overflow. With climate change that has been experienced over the decades, Vancouver expects more flooding in the coming years, especially along street storm drains and waterfronts, due to a rise in sea levels, more frequent heavy rain, and more intense windstorms (Macdonald et al., 2012). The mountainous terrain of Vancouver has a strong influence on the flood and climate characteristics. In essence, the moist air of the Pacific Ocean is forced by the existing westerly winds over coastal mountain ranges, where it drops its moisture load as snow or rain, which contributes to flooding.

IV. FLOOD MANAGEMENT PRACTICES IN PLACE

In collaboration with the Lower Mainland Management Strategy (LMFMS), the government has embraced various flood management strategies aimed at improving flood resilience and reducing flood risks in Vancouver. Vancouver has established coastal defenses including barrier islands, beach nourishment and sea walls. A seawall is a form of coastal defense structure that is constructed where the sea directly impacts the city or landforms of the coast. A sea wall protects an area's leisure activities and human habitation from the impacts of tsunamis, waves, and tides. Beach nourishment entails a process by which sand that is lost through erosion or longshore drift is replaced with other materials or sources that reduce the damage from floods, thereby protecting urban structures and infrastructure. Barrier islands entail coastal landforms and are a type of dune system that absorbs energy and protects coastlines from flooding. In essence, island barriers create areas of protected water where wetlands may flourish. The width and length of island barriers are related to several parameters, including wave energy, sediment supply, tidal range, and sea-level trends (O'Donnell et al., 2018). A breakwater is also an important aspect of coastal engineering; it is an offshore structure that is constructed parallel to the shore and acts in a similar way to an island barrier. A breakwater reduces the energy of the currents and waves striking the coast, thereby mitigating the impact of flooding in the city.

Tide gates have also been established in conjunction with culverts and dikes. Tide gates or tidal barrages are dam-like structures used to reduce and capture energy from large volumes of water moving out of a river as a result of tidal forces. As such, tide gates are located at the mouths of rivers and streams. Tide gates have been established in various streams and large rivers such as the Fraser River in Vancouver to prevent flash floods. During incoming tides, tide gates are closed to prevent excess water from moving upland, while the gates are opened during the outgoing tides, allowing water to drain into the estuary side of the dike via the culvert (O'Donnell et al., 2018). The water levels on either side determine when tide gates are open or closed. In addition, various river defense systems have been established across various rivers, including the Fraser River. These defenses include reservoirs, bunds, levees, and weirs that prevent a river from bursting its banks, thereby reducing the possibility of flooding during heavy downpours. Besides, weirs were also identified as low-head dams designed to reduce flood levels by one meter. On the other hand, levees increase the height of riverbanks; hence, the river can contain more water, which could otherwise cause flooding.

The use of diversion canals is also a flood mitigation strategy that Vancouver embraced to curb flooding in urban areas. Flooding in Vancouver is

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controlled by redirecting excess water into floodways and purpose-built canals that divert water to other water bodies and temporarily hold ponds, which lowers the impact or risk of flooding. For instance, various diversion channels have been established along the Frasier River to minimize the chances of flooding, even after a heavy downpour. These canals have also been used to divert water to land that absorbs excess water. This strategy is very effective, as it entails using the ground as a natural reservoir while simultaneously reducing the impact of drought in some areas outside the urban center. Storm water management ponds (SWMP), commonly known as retention basins, have also been established to minimize the risk of flooding. The retention basis is simply an artificial pond that has a permanent pool of water in its design with vegetation around the perimeter of the basin. The retention basis is used to prevent flooding by managing storm water runoff, improving water quality for an adjacent lake, stream, or river, and simultaneously preventing downstream erosion (Thistlethwaite, 2017).

Dams such as the Cleveland Dam have been established to aid in flood control and protection. Many of these dams have flood-control reservations, whereby the water level in the reservoir must be kept below a certain level during the summer or just before the rainy season, which leaves a certain amount of space in the reservoir to accommodate floodwater. Dam-created reservoirs have other beneficial uses, including hydroelectric power generation, recreational purposes, and water conservation. Dry dams have also been used to curb flooding in various cities across Canada including Vancouver. A dry dam is simply a dam that is specifically constructed for one purpose: to control floods. A dry dam contains no turbines or gates and is intended to allow water to flow freely under normal conditions. Water from the dam is released downstream at a controlled rate, particularly during periods of intense ice and rainfall, which can cause floods. Dry dams therefore hold excess water that could otherwise result in flooding, thereby mitigating the impact of this menace. Self-closing flood barriers have also been established in Vancouver to control floods in the city (Thistlethwaite, 2017). This flood system is designed to protect property and people from inland waterway floods that emanate from rapid melting snow, gales, or heavy rainfall. In addition, self-controlling flood barriers have been established to protect entire urban areas, including residential, industrial, and other strategic areas within the city.

Vancouver has also established hazard-reduction strategies, including resilience strategies and strategic retreats. To reduce the damage caused by flooding, buildings and homes have been removed from the flood-prone areas. Additionally, the government has integrated modern technology identified as flood insurance rate maps that enable local governments to identify areas of future risk; hence, necessary measures have been implemented to minimize and prevent property damage. In addition, buildings, structures, and other urban infrastructure are being designed in such a way that even if flooding occurs, the cost of damage is minimized and the city recovers quickly. For instance, homes are being placed on stilts, while HVAC and electrical equipment are placed on the roof rather than on the basement, while tunnels and subway entrances have moveable water barriers.

Other flood control methods that Vancouver has embraced include the construction of floodways, terracing hillsides to slow the flow of water downhill, and planting vegetation to retain extra water. Additionally, the city uses a combination of various drainage strategies to reduce or mitigate the risk of flooding in public areas, properties, businesses, and homes. Through the use of modern technology, the government has established various flood warning systems that predict floods, giving people more time to take necessary action to mitigate the effects of flash flooding. In essence, pre-planning and advance warnings have significantly reduced property destruction and loss of lives in Vancouver over the last few years.

Moreover, homes and businesses have been modified to withstand floods. For instance, people in Vancouver are advised to replace the plasterboard and MDF with concrete floors and materials that can withstand floods (BC Housing, 2019). The Environmental Agency of British Columbia is also at the forefront of protecting wetlands that soak moisture and act as sponges. In addition, the agency has advocated for strategic plantation of trees as a way of slowing down water, especially when rivers overflow (Raikes & McBean, 2017). The agency also offered several tips on how people can protect themselves and prepare for the flood season. For example, people living in low-lying areas have been advised to prepare for possible flooding by moving their assets and equipment to higher ground and simultaneously clear perimeter drains, gutters, and eaves troughs. Recognizing danger signs is important. According to Thistlethwaite (2017), those living near rivers and waterways need to recognize danger signs such as rapid changes in water levels or changes in water color, which could be an indication of a problem upstream.

V. CONCLUSION

In conclusion, flooding has numerous impacts, including damaging property and endangering the lives of people. Studies agree that the city's geographical location, together with rising sea temperatures, is to blame for a series of floods experienced in Vancouver over the decades, as the city is located on the Pacific coast, bounded by the Fraser River and the Strait of Georgia, making the city vulnerable to every type of flooding event, including pluvial, fluvial, and coastal flooding. Over the decades, the city has experienced

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numerous flooding incidents, resulting in the loss of lives, displacement of people, and destruction of property. However, various management strategies have been put in place to mitigate flooding in Vancouver and its impact (Table 1). These techniques include the construction of floodways, terracing hillsides to slow downhill flow, planting vegetation to retain extra water, and construction of dams, lakes, levees, retention ponds, and reservoirs that hold water to prevent flooding.

Table 1: Summary of type of flood event, identified causes, and mitigation practices in place.

Type of Flood Event	Identified Causes	Practices in Place	Reference
Pluvial	Rise of water level in a stream, lake or a river.	Construction of levees, dams and reservoirs.	Falconer, R. H., Cobby, D., Smyth, P., Astle, G., Dent, J., & Golding, B. (2009). Pluvial flooding: new approaches in flood warning, mapping and risk management. *Journal of Flood Risk Management*, *2*(3), 198-208.
Fluvial	Urban drainage system fails; hence water flows out of the drainage system into the nearby structures and into the streets	Regular maintenance of urban drainage systems. Use of technology to control the drainage system.	Macdonald, D., Dixon, A., Newell, A., & Hallaways, A. (2012). Groundwater flooding within an urbanised flood plain. *Journal of Flood Risk Management*, *5*(1), 68-80.
Coastal	Tropical storms or tsunamis and hurricanes.	Construction of overflow tunnels, levees, dams and reservoirs.	Jongman, B., Ward, P. J., & Aerts, J. C. (2012). Global exposure to river and coastal flooding: Long term trends and changes. *Global Environmental Change*, *22*(4), 823-835.

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