THE IMPLICATIONS OF IMPERVIOUS SURFACES FOR FLOOD MANAGEMENT IN THE GTA

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This paper examines how impervious surfaces increase the amount of runoff from precipitation in the GTA. Impervious surfaces cannot handle heavy precipitation, and the prevalence of such surfaces increases the likelihood of flooding in Toronto and other urban areas. Climate change has heavily influenced the frequency and intensity of storms in the GTA and the rest of Canada, substantially increasing urban runoff in both cases. This paper also examines many well-researched solutions that have the potential to address this issue, although many of them tend to focus on flood mitigation. Future recommendations include implementing reservoir flood storage systems, green roofs, water plazas, and detention reservoirs.

Introduction

Before urbanization, there existed abundant pervious surfaces, including trees and plants. These surfaces were capable of dealing with massive amounts of rainfall by absorbing water through processes such as percolation, infiltration, and interception. Eventually, urbanization largely replaced pervious surfaces with impervious ones. Examples of impervious surfaces include roads and pavement. Unlike pervious surfaces, they cannot absorb water, which leads to greater amounts of runoff developing. Therefore, urbanization, as well as other factors such as climate change, sharply increases the risk of floods (McLeman & Smit, 2006). Because Toronto is a large metropolitan area, it is particularly susceptible to flood risks due to urbanization (Nirupama & Simonovic, 2006).

The frequency of storms in Toronto, as well as the rest of Canada, is increasing due to climate change (Sandink, 2015). As storms become more frequent and intense, greater amounts of urban runoff will develop because there are abundant impervious surfaces. This ultimately leads to flooding. Existing sewers that are used for stormwater collection cannot carry large amounts of water, which also leads to floods. Current flood management solutions focus on mitigation (Muste, 2018), but urban planners and politicians need to consider changes to the capacity of the current sewage system because impervious surfaces are incapable of absorbing water, and existing sewers are not large enough. They should also consider protection of existing permeable surfaces and conversion of impermeable to permeable surfaces in order to help with eliminating runoff, and finally, more proactive measures to address climate change because it increases the frequency and intensity of storms.

This paper has two objectives. First, I will examine the consequences of floods in the GTA because understanding them will help determine to what extent the rise of impervious surfaces, in combination with increasing storms, will risk overflowing Toronto's sewer system. More specifically, I will explore the history of Toronto's floods. Toronto has experienced four major floods to date: 1954, 1976, 2005, and 2013 (Nirupama, Armenakis, & Montpetit, 2014). I will discuss the sources and outcomes of each of these floods. I will look at which of the known flood impacts could have possibly originated from impervious surfaces for each of these floods.

The second objective is to evaluate current solutions and propose future recommendations for flood management to address the dual problem of an increase in both storms and impervious surfaces. Several measures have been taken, notably flood mitigation (Muste, 2018). One example is flood risk mapping in Toronto based on the current population, economic development, and key infrastructure (Armenakis & Nirupama, 2014).

Study Area

Prior to conducting a detailed analysis of the roles that impervious surfaces play on flood management, I will provide some background information on the geography of Toronto. The city is the largest in Canada with approximately 2.5 million residents and a size of 630 km^2 (Nirupama et al., 2014). The Greater Toronto Area (GTA) has a size of 7,100 km^2 and a population of approximately 5.5 million (Nirupama et al., 2014). Toronto is the most populated city in Canada and is close to Lake Ontario, the largest surface water system in the world, which acts as a watershed to where a number of rivers, lakes, and creeks flow (Nirupama et al., 2014). Lake Ontario is also directly impacted by air masses coming from the Gulf of Mexico, the Atlantic Ocean, and the Arctic (Nirupama et al., 2014). As a result, Toronto is vulnerable to floods and other extreme weather events (Nirupama et al., 2014). Toronto and the GTA are located between the Don River and Humber River watersheds, both of which drain into Lake Ontario (Armenakis, Du, Natesan, Persad & Zhang, 2017). Other watersheds of the GTA include the Etobicoke and Mimico Creeks (Figure 1).

Impervious surfaces make up 73% of the GTA, a feature that makes the area vulnerable to floods (Rincón, Khan & Armenakis, 2018). For instance, the Don River is prone to floods due to its

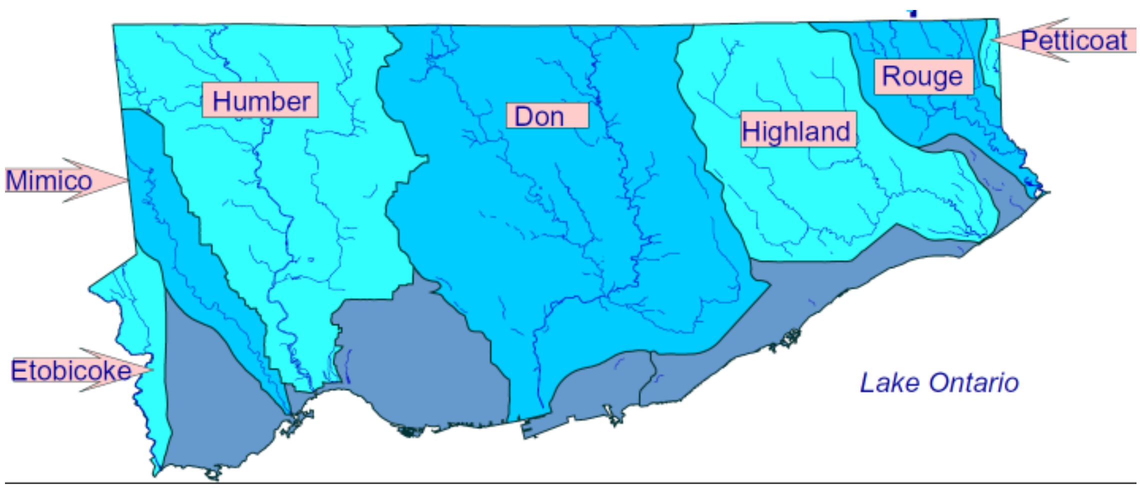


Figure 1 A map of the Greater Toronto Area and its watersheds. From "Toronto Watershed Map" (Evergreen Tour Guide Wiki, 2012).

urbanized nature; small amounts of rainfall can rapidly elevate the water level (Nirupama et al., 2014). This is because the Don River Valley is 400m wide, but the river itself is only 15m wide (Nirupama et al., 2014). To exacerbate issues with impervious surfaces, Toronto's topography is quite smooth, starting at 75m at Lake Ontario above the water and ending at a 209m elevation in the North York area of Toronto (Nirupama et al., 2014). Flat slopes can lower the velocity of surface runoff, ultimately requiring more time for urban runoff to drain (Rincón et al., 2018). Flat slopes therefore constitute a form of impervious surface. Du, Shi, Van Rompaey and Wen (2015) state that replacing vegetation with impervious surfaces results in a decrease in transpiration, soil evaporation, and overall infiltration, and more urban runoff is generated when this happens.

Analysis

In this section, I will provide an analysis of impervious surfaces and flood management based on the objectives I have defined in the introduction. This section will contain three subsections: the history of floods in Toronto and the role that impervious surfaces played in all of them, the types of flood impacts on the city that are directly related to such surfaces, and the evaluation of current and potential solutions that address the rise of impervious surfaces and storms.

History of major floods in Toronto

The first major flood of Toronto occurred in 1954 as a result of Hurricane Hazel (Nirupama et al., 2014). The impacts were profound; 81 people died and 7,472 were left homeless after 210 mm of rain fell over the span of two days (Nirupama et al., 2014). The severity of the flood peaked in low-lying areas of the Don and Humber Rivers as well as the Etobicoke and Mimico Creeks (Nirupama et al., 2014). The Etobicoke Creek itself is urbanized and heavy infrastructural damage occurred, a first for the city at the time (Erechtchoukova, Khaiter & Saffarpour, 2016). Twenty bridges were damaged or knocked down, with many homes completely destroyed (Nirupama et al., 2014). The flood was so severe that it shifted automobiles, trailers, cottages, and homes toward the strong current (Robinson & Cruikshank, 2006).

The next flood occurred in 1976. Two massive storms over the course of two days resulted in 75 mm of rainfall (Nirupama et al., 2014). Important infrastructure, such as bridges, was directly impacted as in the 1954 flood (Nirupama et al., 2014). The flood cost $1.3 million in damages (Nirupama et al., 2014).

On August 19, 2005, 153 mm of rain fell over the span of three hours (Nirupama et al., 2014). The storm was so strong that flooding occurred in the Don Valley for a short period of time (Nirupama et al., 2014). Power outages affected about 10,000 residents, and there were over 1,200 cases of flooded basements (Nirupama et al., 2014). The flood became Ontario's most expensive natural disaster, resulting in $500 million in damages (Nirupama et al., 2014). Creeks, rivers, and ravines were flooded, leading to bank erosion as well as damage to sewer backups and key infrastructure (Nirupama et al., 2014).

The most recent major flood happened on July 8, 2013. It was caused by a heavy storm yielding extreme rainfall that had major impacts on the city. Thousands of homes in the GTA were flooded (Sandink, 2015). The intensity of the storm varied by area; parts of the GTA received around 90mm of rain (Nirupama et al., 2014), while other areas received over 100 mm of rain (Nirupama et al., 2014). At Pearson International Airport, over 126 mm of rainfall was reported, well above the monthly average of 74.4 mm (Nirupama et al., 2014). 300,000 people in the GTA were left without power on that day (Nirupama et al., 2014). Flight cancellations and subway closures were among the serious disruptions that occurred as a result of the flood (Nirupama et al., 2014). Property damage from this flood exceeded $850 million, surpassing that of the 2005 flood (Nirupama et al., 2014).

How did impervious surfaces contribute to each of these floods? The GTA's population has grown 700% since 1931, and more than 75% of the GTA has undergone urban development (Rincón et al., 2018). More urbanization implies more impervious surfaces and greater runoff rates (Rincón et al., 2018). For example, Etobicoke Creek was one of the major watersheds that flooded in 1954 (Nirupama et al., 2014). According to Erechtchoukova et al. (2016), the Spring Creek, a tributary of Etobicoke Creek, is heavily impervious, leading to rapid runoff responses to extreme rainfall.

Impervious surfaces and their impacts on floods

When urbanization increases, so does the number of impervious surfaces. Runoff rates therefore increase substantially, especially during periods of extreme rainfall (Rincón et al., 2018). Nirupama and Simonovic (2006) state that urbanization reduces infiltration in addition to increasing the number of impervious surfaces. Moreover, according to the Intergovernmental Panel on Climate Change (IPCC), heavy precipitation due to climate change increases the likelihood of flood events (McLeman & Smit, 2006). Excess water that rivers are unable to carry overflows river banks and fills nearby, low-lying lands (Rincón et al., 2018). This is known as river flooding, one of the costliest and most frequently occurring natural disasters (Rincón et al., 2018). The limited storage capacity of rivers makes extreme rainfall a primary driver of such flooding (Rincón et al., 2018). Erechtchoukova et al. (2016) state that in urbanized watersheds with impervious surfaces, stormwater runoff causes stream water levels to rise, also contributing to river floods. The 1954 Toronto flood reflects this phenomenon, with the Don and Humber Rivers being filled beyond capacity. Since the Don River watershed is heavily urbanized (Nirupama et al., 2014), it is prone to increasing stream water levels from heavy precipitation as Erechtchoukova et al. (2016) state. Similarly, transforming watersheds from rural to urban watersheds generates consequences such as flooding and erosion (Bocking, 2006).

River floods in particular cause damage to agriculture and infrastructure, death, the spread of diseases, and water supply contamination (Rincón et al., 2018). In the 2005 flood, flooded rivers notably caused bank erosion and infrastructure damage (Nirupama et al., 2014). Negative impacts of floods increase with soil saturation, high suspended matter, and landslides (Rincón et al., 2018). Basement flooding, among other flood types, results from negative flood impacts (Sandink, 2015).

Soil saturation, which occurs when soils cannot absorb any more water, can be linked with impervious surfaces. For example, the Thames River watershed in London, Ontario consists of impervious clay soils that increase runoff rates, thereby making it susceptible to floods (Nirupama & Simonovic, 2006). The Soil Conservation Services (SCS) developed a parameter known as the Curve Number (CN) to estimate the level of runoff or infiltration from excess rainfall (Rincón et al., 2018). The CN takes into consideration soil type and land use (Rincón et al., 2018). A high CN is associated with impervious surfaces, meaning high runoff and low infiltration (Rincón et al., 2018). In contrast, a low CN is assigned to soils that produce very little runoff and therefore indicates low runoff and high infiltration (Rincón et al., 2018). Because of urbanization (i.e. adding impervious surfaces), there are no soils to infiltrate precipitation.

Different flood types are worsened by impervious surfaces. Sandink (2015) lists three types of floods that can occur in ground-related homes as a result of extreme rainfall: infiltration, stormwater, and sewer backup. Infiltration flooding is a well-known cause of basement flooding (Sandink, 2015). This occurs when groundwater levels surpass the lowest level of basement floors (Sandink, 2015); water then seeps through cracks found in the foundation wall and eventually enters the home (Figure 2). Stormwater flooding is the result of stormwater flows exceeding the capacity of stormwater management systems and moving towards the home (Figure 3). Finally, sewer backup flooding happens when underground public storm and/or wastewater systems surcharge, ultimately leading to sewage flowing towards the home via a private sewer connection (Figure 4). Sewer backup flooding can occur in either combined or separated sewers (Sandink, 2015). In particular, they are related to increased urbanization (Sandink, 2015). For instance, one of the impacts of urbanization on urban hydrology is that there are more peak stormwater flows during periods of rainfall (Sandink, 2015).

Combined sewer overflows are another major contributor to floods. Combined sewer overflows result in wet weather flow discharges, ultimately leading to floods (D'Andrea, Snodgrass & Chessie, 2004). By impervious paving as well as installing sewers and storm drains, runoff routing becomes smoother and there becomes very little lag between precipitation and peak discharge (Du et al., 2015).

Solutions and future recommendations

After the Hurricane Hazel flood in 1954, conservation authorities began to develop more flood control and flood management options (Bocking, 2006). Various solutions have been developed to manage floods, although many of them focus on flood mitigation, such as flood risk mapping. The motivation behind creating flood risk maps comes from risk assessment, defined as: how methodologies can be applied to determine the risks from hazards and exposures to an event as well as impacts of that event (Armenakis & Nirupama, 2014). It can map areas based on impervious surfaces and other factors. Armenakis and Nirupama (2014) use GIS (Geographical Information System) technology to develop flood risk maps, evaluating the following factors: terrain slope, drainage networks, land depression, and demographics. Putting all these factors together, a flood risk map for the entire GTA can be developed (Figure 5). Using GIS technology for spatial modelling and visualization allows for the prioritization of flood risk areas (Armenakis & Nirupama, 2014). This helps create specific strategies that reduce flood impacts and increase the effectiveness of flood management, as the maps can help decision makers visualize flood-prone areas (Armenakis & Nirupama, 2014).

However, flood maps alone are insufficient in determining the risks to people, property, infrastructure, and services (Armenakis et al., 2017). To expand on the development of flood maps as a solution, Armenakis et al. (2017) suggest creating enhanced flood maps by using high spatial resolution earth observation (EO) data. This generates and updates existing flood maps based on population, economic development, and critical infrastructure, ultimately improving a city's flood mitigation and preparedness strategy. A suggested approach was to combine flood maps, socio-economic factors, and impacts on infrastructure and services (Armenakis et al., 2017). The GTA was used as a case study to test the proposed methodology by developing an enhanced flood map (Figure 6). Impervious surfaces were incorporated into these maps through the flood hazard spatial layer (Armenakis et al., 2017). Armenakis et al. (2017) take into account impervious surfaces among other areas that are prone to flooding. Spatial impact weights, such as areas of water concentration, are

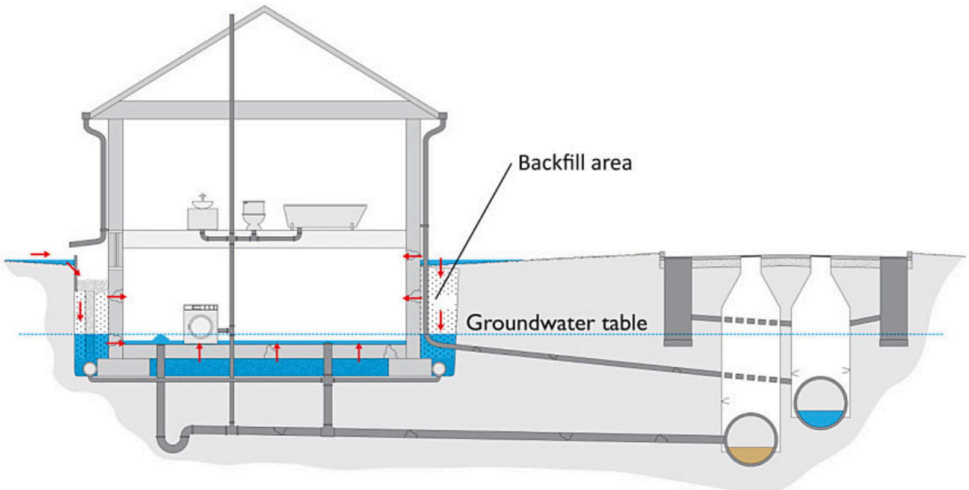


Figure 2 Infiltration flooding in homes (Sandink, 2015, p. 210).

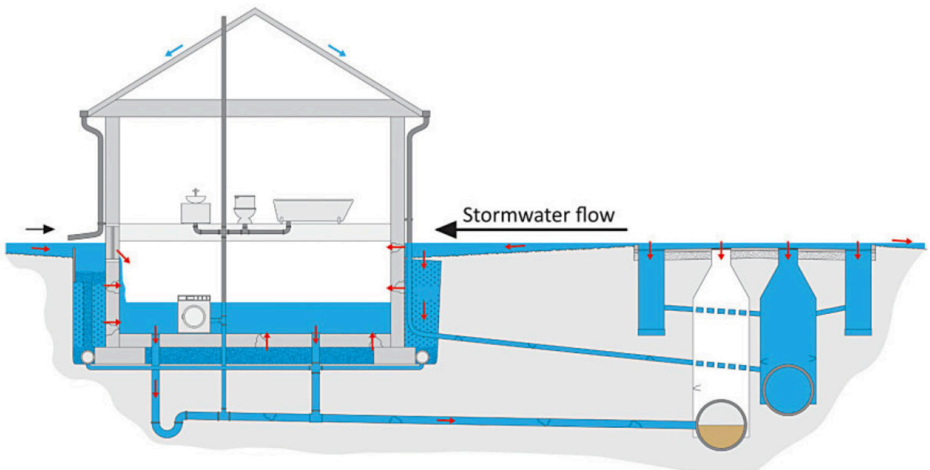


Figure 3 Stormwater flooding in homes (Sandink, 2015, p. 210).

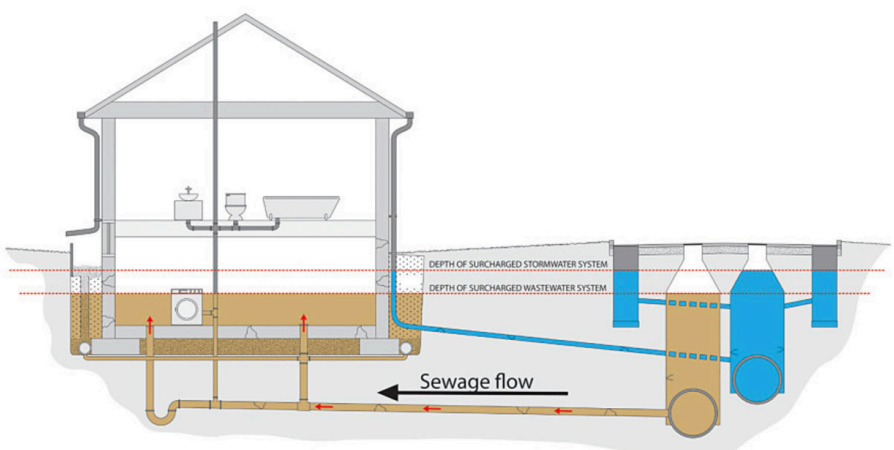


Figure 4 Sewer backup flooding in homes (Sandink, 2015, p. 211).

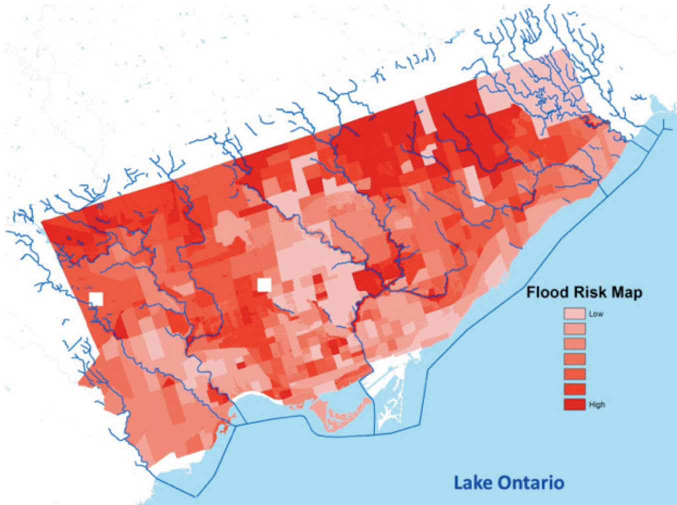


Figure 5 Flood risk map for the GTA to map the risk of floods based on population data and topography (Armenakis & Nirupama, 2014, p. 325).

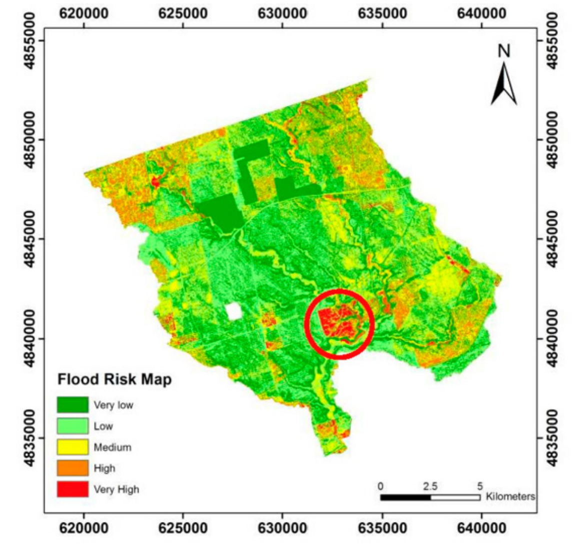
assigned to the layer (Armenakis et al., 2017). Figure 7 shows a flood hazard area map that was developed based on impervious surfaces, vegetation, water, bare soil, and grasslands.

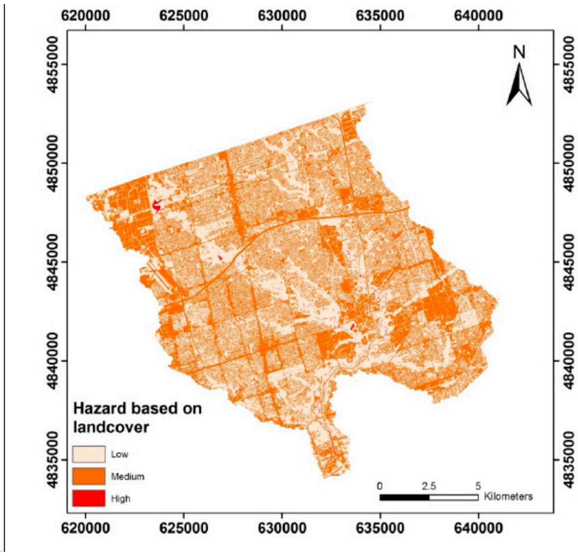
Mann and Wolfe (2016) propose that flood mitigation on a smaller scale could be beneficial to reduce flood risks and impacts. Some examples of strategies include having homeowners take careful measures at the lot level and making use of effective risk communication tools (Mann & Wolfe, 2016). These types of strategies can be associated with impervious surfaces. One such example is the implementation of user charges being allocated to the amount of imperviousness of an individual lot (D'Andrea et al., 2004). To support the City of Toronto's Wet Weather Flow and Management Plan, a stormwater public education and community outreach program has also been developed to promote the reduction of impervious surfaces (D'Andrea et al., 2004).

But how effective are these flood mitigation strategies? According to Mann and Wolfe (2016), effectiveness depends on personal beliefs that individuals hold about floods.

Infrastructure solutions with respect to impervious surfaces have also been on the agenda for flood management in Toronto. In 2007, construction in the West Don Lands in downtown Toronto started, with civil engineering projects for flood protection and other purposes in mind (Bellas & Oliver, 2016). Parks and open green spaces that were developed in the area had great potential to control floods and ultimately benefit the Don River Park (Nichols, 2009). The addition of these green areas also addressed the problem of impervious surfaces, which are unable to control floods. The Don River Park was proposed to bring environmental benefits through flood control, since pervious surfaces are capable of absorbing water (Nichols, 2009). Additionally, one member of the Waterfront Toronto project has stated that flood protection infrastructure is under development in the Port Lands, one of Toronto's remaining slices of publicly-owned waterfront real estate (Bellas & Oliver, 2016).

There are several possible directions that Toronto can take with respect to flood management. The state of California, USA, is well known for its flood management and has implemented a reservoir flood storage system (Lund, 2012). Nearly all of California's major reservoirs have a seasonal flood





Figures 6 & 7 GTA flood risk map based on total flood hazard and vulnerability (Armenakis et al., 2017, p. 11); GTA flood hazard area map that is based on impervious surfaces and other land cover areas (Armenakis et al., 2017, p. 9).

management pool to decrease the amount of peak flows from storms (Lund, 2012). I suggest that Toronto follow in the footsteps of California and implement a reservoir flood storage system that would be capable of carrying large amounts of water from storms.

To a certain extent, the motivation behind California implementing reservoirs as a flood management solution comes from impervious surfaces. Moura, Pellegrino, & Martins (2015) state that impervious surfaces increase the amount of runoff, resulting in negative impacts on drainage systems with a greater risk of flooding. Impervious surfaces are incapable of handling large volumes of water; this ties in drainage systems, but such systems often have a limited carrying capacity. Infrastructure, such as separate sewers, is also prohibitively expensive. Detention reservoirs therefore constitute sustainable investments that have been proven to be effective in eliminating floods in urban watersheds found in Greater Sao Paulo (Figure 8; Moura et al., 2015). I recommend that Toronto build a detention reservoir near its urbanized watersheds, such as the Don River. I believe that this should be a priority because of the area's urbanized nature and demonstrated vulnerability to floods.

Jonkman and Dawson (2012) mention water plazas and green roofs that are implemented at the local level to decrease surface water runoff. Urban areas are one of the most compelling cases when it comes to implementing flood risk management technologies because of the abundance of impervious surfaces (Jonkman & Dawson, 2012). Once again, this solution can be linked to these surfaces. The purpose of these solutions is to decrease runoff, but impervious surfaces and urbanization only increase runoff, especially during times of heavy rainfall (Moura et al., 2015). I believe that implementing green roofs in the West Don Lands area of Toronto would be an ideal option because of its proximity to the Don River, a flood-prone watershed. Since flood infrastructure development is underway in the Port Lands (Bellas & Oliver, 2009), it would also be a good idea to implement these features there.

Figure 8 A detention reservoir in Sao Paulo that is used for flood control (Moura et al., 2015, p. 247)

Toronto must protect existing green spaces from being converted to impervious surfaces, as this only increases the likelihood of flood events occurring. Protecting the transformation of certain areas to other uses (ex: transforming open land to urban areas) is important, as emphasized in a survey conducted by the Don Valley Conservation Authority (Bocking, 2006). This protection can be emphasized through the development of local or governmental policies. Through transforming pervious to impervious surfaces, watersheds such as the Don River could experience more flooding and erosion (Bocking, 2006).

Du et al. (2015) propose an index called the Impervious Surface Impact Index (ISII) to assist in finding appropriate locations for urban development while reducing the impact of urban development on flood risks. The index quantifies the impact of impervious surfaces on floods (Du et al., 2015), and a greater ISII corresponds with greater urban runoff and vice versa (Du et al., 2015). Areas with low ISII values are more suitable for urban development, while areas with high ISII should not go through development at all (Du et al., 2015). I strongly believe that Toronto should take this into consideration and use the index to determine appropriate urban development areas at the local level.

Conclusions

Flood risk is rapidly increasing due to climate change. Existing sewers have a limited carrying capacity, and excess water from extreme rainfall cannot be absorbed by impervious surfaces, thereby increasing the rate of stormwater runoff (Rincón et al., 2018). Most of the GTA consists of impervious surfaces, and the four major floods experienced by Toronto provide evidence of its vulnerability. However, it is not only existing sewers that are incapable of handling large amounts of water; urbanized watersheds such as the Don River watershed are prone to flooding. River floods also occur frequently and have devastating impacts, such as death, damage to infrastructure, disease outbreaks, and flooding in ground-related homes.

Currently, there are several flood management solutions, though many focus on flood mitigation. A notable example of a flood mitigation solution is flood risk mapping; GIS technology is used to map out specific areas of the GTA that are especially vulnerable to flooding. Vulnerability is decided based off factors like demographics and topography (e.g. land depression, terrain slope, and drainage networks), as well as impervious surfaces. In flood maps, Armenakis et al. (2017) create a flood hazard spatial layer that maps out impervious surfaces in Toronto, analyzing the impacts that floods have on these surfaces. Infrastructure projects, such as the West Don Lands project, also focus on flood protection through the creation of parks and green spaces. These initiatives attempt to address the issue of impervious surfaces generating greater amounts of runoff. The Don River Park was a proposal that was developed to better control floods in Toronto through adding green spaces (Nichols, 2009).

In the future, urban planners and politicians could look into implementing reservoir flood storage systems similar to those in California or Sao Paulo. In both cases, water plazas and green roofs reduce impervious surface area and aid flood management by reducing surface water runoff. Government policies that restrict the urban transformation of green spaces to impervious surfaces could prove useful. Finally, it is recommended that urban planners and politicians develop an index that calculates the impacts that impervious surfaces have on floods. With this in mind, future developments can be planned appropriately.

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