CLIMATE CHANGE ADAPTATION PLAN FOR THE MONTRÉAL URBAN AGGLOMERATION 2015-2020

REPORT

2017 EDITION

Montréal

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A WORD FROM YOUR REPRESENTATIVES

All over the world, people are recognizing the key role that cities play in both fighting and adapting to climate change. Densely populated urban centres are the first to feel the adverse consequences of climate change. But cities are also places conducive to innovation and action. This is why we are taking up our responsibilities, and planning as of now to ensure better quality of life for Montréalers and secure the future of coming generations.

The Montréal Urban Agglomeration committed to reducing its greenhouse gas (GHG) emissions by adopting, in 2013, the *Plan de réduction des émissions de GES de la collectivité montréalaise 2013-2020*. Despite our mitigation efforts, we are already seeing some of the climate disturbances we feared: heat waves, heavy rainfalls, ice storms and more. A strategy that aims to limit their negative effects is crucial for our administration and for our citizens. This is why I am very proud to present this first *Climate Change Adaptation Plan for the Montréal Urban Agglomeration 2015-2020*.

With this adaptation plan, Central Services, the boroughs and the municipalities have made many ambitious commitments. The measures we are announcing aim, among other things, to reduce heat islands, protect biodiversity, manage runoff water, increase infrastructure resilience, and adopt new practices in regard to the range of recreational activities on offer, to name just a few.

This plan is the first step in a very concrete process that will not only consolidate our accomplishments and strengthen our ability to respond to all these disturbances, but that will also show our desire to help maintain and improve the quality of our citizens' living environment.

Denis Coderre
Mayor of Montréal and President of
the Communauté métropolitaine de Montréal

Heat waves, heavy rains, freezing rain… the extreme events of recent years show that climate change is already having an effect on us. These new conditions pose a challenge, but they also provide opportunities that we can seize to make Montréal a city at the forefront of sustainable development.

This first adaptation plan spotlights our region's vulnerability in regard to climate change. We can't deny the impacts we have seen, and those we anticipate, on the population, the infrastructures, the natural environment and all the activities that happen on the island. The wealth of information brought together in this plan provides solid arguments about the importance of moving from strategy to action, and that's what we commit to doing.

This adaptation plan presents concrete measures for tackling the climate hazards that are already affecting us and whose impacts will most certainly be exacerbated in the coming years. Climate projections confirm that episodes of oppressive heat, intense rain and destructive storms will happen more frequently. This adaptation process is an opportunity for us to change and improve our approaches to mitigate the impacts of climate change.

This plan is the result of a fruitful collaboration among various players in the Montréal Urban Agglomeration. Specialists in the environment, water management, infrastructures, buildings, green spaces and land use planning, along with representatives from every borough and city in the Agglomeration, helped to develop this tool. Thanks to this, our Agglomeration will become more resilient in the coming five years.

Réal Ménard
Member of the executive committee responsible for sustainable
development, the environment, large parks and green spaces

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LIST OF ABBREVIATIONS

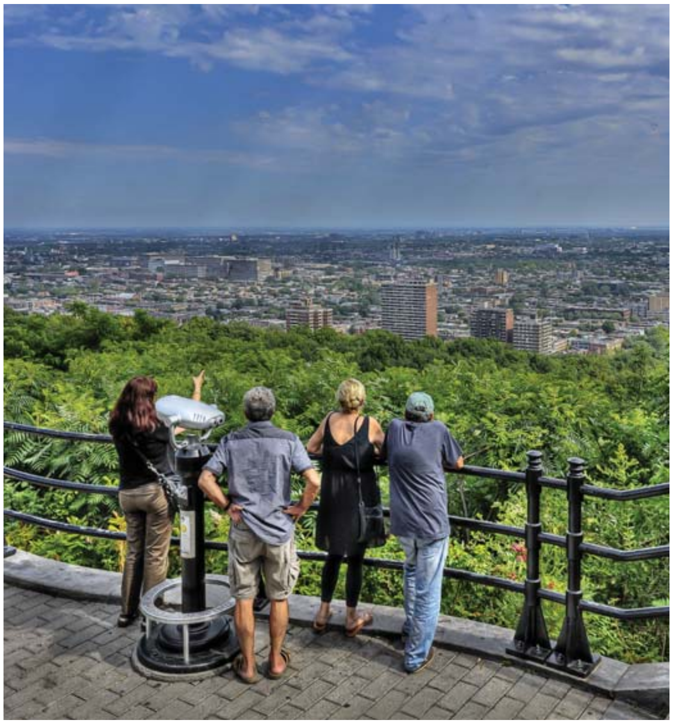
$...M	million dollars
%	percentage
AAFC	Agriculture and Agri-Food Canada
Btk	*Bacillus thuringiensis kurstaki*
°C	degrees Celsius
CEHQ	Centre d'expertise hydrique du Québec
CH_4	methane
cm	centimetre
CMIP	Coupled Model Intercomparison Project
CMM	Communauté métropolitaine de Montréal (Montréal metropolitan community)
CO	carbon monoxide
CO_2	carbone dioxide
CO_2 eq	carbon dioxide equivalent
DSTI	Direction des stratégies et des transactions immobilières (department of strategies and real estate transactions)
EPA	Environmental Protection Agency
g	gram
GHG	greenhouse gas
h	hour
H_2S	hydrogen sulfide
ICI	industrial, commercial and institutional establishments
ICIU	intra-urban heat island
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
km_2	square kilometre
km/h	kilometre per hour
Kt	kilotonne
m	metre
m^2	square metre
m^3	cubic metre
m^3/s	cubic metre per second
MAPAQ	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (Québec department of agriculture, fisheries and food)
MDDELCC	Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (department of sustainable development, environment and the fight against climate change)
MJ	megajoule
mm	millimetre
N_2O	nitrous oxide
NO_x	nitrogen oxides
RCM	regional county municipality
RCP	Representative Concentration Pathways
SRP	special response plan
SIM	Service de sécurité incendie de Montréal (fire safety service)
SMEC	Saint-Michel Environmental Complex
SOPFEU	Société de protection des forêts contre le feu (forest fire protection agency)
SPVM	Service de police de la Ville de Montréal (police service)
t	tonne
UQAM	Université du Québec à Montréal
UV	ultraviolet
VOC	volatile organic compounds
$watt/m^2$	watt per square metre
WNV	West Nile Virus

INTRODUCTION

The scientific community and international political bodies share a broad consensus on the influence that increased concentrations of greenhouse gases (GHG) have on climate. They also agree that this influence is unavoidable.

Beyond expected increases in average temperatures, the heightened concentrations of GHGs will affect many other climate variables, including precipitation and wind. The Montréal Urban Agglomeration must handle changes that will affect the natural environment, the built environment, the population and socioeconomic activities. Many non-climate factors, such as the age of infrastructures, land use planning and sociodemographic characteristics, will either amplify or, in contrast, limit the repercussions that we anticipate.

Adaptation to climate change is a process by which communities and ecosystems adjust in order to limit the negative consequences and profit from the potential benefits of the changing climate. The Ville de Montréal has committed, on behalf of the Agglomeration, to producing a climate change adaptation plan as part of the Québec government's Climat municipalités program.



Credit: © Denis Labine, Ville de Montréal

This first Climate Change Adaptation Plan for the Montréal Agglomeration is the starting point of an iterative process that will expand over the years, as we gather more data on climate change and its risks and as we see the effectiveness of the actions we undertake.

OBJECTIVES

This plan is based on three main objectives:

1. **Consolidate all the adaptation measures already in place which contribute to climate change adaptation, even if they do not refer to it.**
   Many of the climate impacts that relate to health issues and the protection of natural and built environments are already considered in a number of other Montréal Urban Agglomeration plans and strategies. We have catalogued more than 30 strategies, policies, plans and by-laws that, to a greater or lesser extent, relate to climate change adaptation. As such, this adaptation plan rests on initiatives that have already been announced, and provides solid arguments showing that it is important to move from strategy to action.

2. **Provide relevant, tailored information regarding climate change risks to the 34 municipalities and boroughs included in the Agglomeration's territory and to Central Services.**
   While climate projections are the same throughout the Agglomeration, vulnerability factors and risk levels vary depending on the geographic location on the island of Montréal. So it is crucial to know not only the risks, but also the local variations in vulnerability, in order to target actions based on local realities and focus efforts on the places with greater vulnerability.

3. **Plan the Agglomeration's development as well as maintenance and repair operations while taking into account the constraints associated with climate change.**
This objective is at the very core of a climate change adaptation plan. It means we need to find ways to update our ways of thinking and doing things within the Agglomeration in order to reduce the risks that come with climate change.

PLAN CONTENT

The plan consists of two volumes. Volume 1, **Report**, aims to set out a diagnosis of the adaptation challenges that the Montréal Urban Agglomeration is facing. Volume 2, **Adaptation Measures**, in turn, presents the actions that we must consolidate or develop and the commitments made by the Agglomeration's various entities to help meet these challenges.

More precisely, Volume 1 includes three parts:

- background;
- approach;
- analysis per climate hazard.

The background section presents the particularities of the Montréal Urban Agglomeration: its territory, its population, the elements of its landscape and urban fabric. The approach section, in turn, explains the various steps of the climate hazard analysis process used for this plan. Lastly, the analysis proper is subdivided into six chapters, one chapter per climate hazard:

- higher average temperatures;
- heavy rainfalls;
- heat waves;
- destructive storms;
- droughts;
- river floods.

Each climate hazard chapter is organized the same way. First, we analyze the meteorological observations for the Montréal Urban Agglomeration and climate projections provided by Ouranos, which support our lived experience of the extreme climate events we've seen in recent years. This analysis makes it possible to establish whether or not the climate hazard has been amplified by climate change. Next, we discuss the climate hazard's past impacts on Montréal. These may be impacts on the built environment (such as infrastructures or the road network), on health or the economy (such as illnesses or property damage), on municipal operations (such as public works or road maintenance), or on the natural environment (such as water quality or biodiversity). The chapter finishes with a vulnerability analysis of the territory. This means evaluating each sector of the Montréal Urban Agglomeration to see if it is more or less vulnerable to the hazard in question. For example, in the case of heat waves, neighbourhoods located in heat islands are more vulnerable than those located outside heat islands.

After Volume 1 identifies the key impacts and the territory's vulnerabilities for each climate hazard, Volume 2 presents the solutions, or in other words, the action plan that will be put into place to fight the effects of climate change.

While Volume 1 is theoretical, Volume 2 is resolutely practical. It aims to give every player the keys to effectively adapt to climate change. As such, the approach in Volume 2 is completely different. Volume 2 is split into 24 briefs listing practical actions to carry out. Each brief starts with a general introduction to the measure, its justification and its benefits. Then, the commitments made by the various municipal bodies (Central Services, boroughs and reconstituted cities) are listed in the form of summary tables. These tables help paint a picture of all the current and future actions on the Agglomeration's territory that aim to help us adapt to climate change. This database should facilitate discussion between the various players involved in adaptation.

BACKGROUND

TERRITORY

Located where the St. Lawrence River meets the Ottawa River, the island of Montréal is the biggest island in the Archipel d'Hochelaga. It is about 50 km long and 16 km across at its widest point (see map 2.1 on page 14). Surrounded by Rivière des Prairies, the St. Lawrence River and Lac Saint-Louis[38], it has 266.6 km of shoreline and covers an area of 483 km^2 (499 km^2 counting the small nearby islands). The island is located at the centre of a great fertile plain, the former Champlain Sea, with its highest point being Mont Royal at 233 metres. Its subsoil is mostly made up of sedimentary rocks, particularly limestone and clay.

This territory brings together 16 municipalities that form the Montréal Urban Agglomeration, meaning 15 reconstituted cities and the Ville de Montréal. The Ville de Montréal is subdivided in turn into 19 boroughs. The Montréal Urban Agglomeration represents the elements of the administrative mosaic that share their authority on this territory under several laws, including one about land use planning and urban development that aims to ensure the region's harmonious development.

The Agglomeration manages certain key services shared across jurisdictions (such as police services, fire safety, water production and wastewater treatment) while the reconstituted cities and the boroughs manage matters understood as local (such as public works, urban land use planning, sports and recreation, and so forth).

POPULATION

The Montréal Urban Agglomeration is home to nearly two million residents, or 24% of Québec's population.[164] With its neighbouring cities, including Laval and Longueuil, it forms the second most populated metropolitan area in Canada, after Toronto.

In 2011, a population density of 3,779 people per square kilometre was recorded for the Montréal Urban Agglomeration region. Nearly 45% of the population in this area is concentrated in the reconstituted cities and the central boroughs. The boroughs and reconstituted cities at the island's extremities are less dense, with just under 10% of the Agglomeration's population.

© Shutterstock

According to 2011 census data, nearly 16% of the total population is aged 65 and up, which represents 295,295 people.[164] This same data tell us that this age group includes more women than men, to the tune of 9.3% versus 6.4%.[150] By 2026, one out of five people living on the island of Montréal will be aged 65 and up.[159]

The Agglomeration is home to 475,095 families, of which close to 21% (98,050) are single-parent families; 82% of those families are headed by a woman, while 18% are headed by a man. In 2011, households (a person or group of people living together) made up of one individual represented more than 39.2% of the total households in the Montréal Urban Agglomeration. The number of people aged 65 and up living alone grew by 1.1%, from 93,720 people in 2006 to 94,725 people in 2011, representing 36% of this age bracket. This means that more than one-third of senior citizens on the island of Montréal live alone.

The immigrant population, for its part, makes up 33% of the territory's population. Italy, Haiti, France and China are the most common countries of origin for immigrants. French remains the language most often spoken at home, even though a high number of people speak English, Spanish, Arabic or Italian every day.[164] Close to 3% of the population, or 48,540 people, speak neither French nor English.[160]

In 2010, 29% of the Montréal Urban Agglomeration's population lived under the poverty line* (before taxes).[157] If we adjust the scale to consider living environment, the average income is lowest in the north-east of the island of Montréal.[129]

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* The poverty line is defined as the level of income by which it is estimated that families put 20% more of their income than the general average toward food, housing and clothing.

MAP 2.1
MONTRÉAL URBAN AGGLOMERATION

TABLE 2.1
THE MONTRÉAL URBAN AGGLOMERATION IN NUMBERS

1.9 million	people lived on the island of Montréal in 2011 (up by 5.1% from 2006)
3,780	people per square kilometre (2011)[140, 151]
45%	of the population is concentrated in the reconstituted cities and the central boroughs, meaning Ahuntsic-Cartierville, Côte-des-Neiges–Notre-Dame-de-Grâce, the Plateau-Mont-Royal, Mercier–Hochelaga-Maisonneuve, Rosemont–La Petite-Patrie and Villeray–Saint-Michel–Parc-Extension
10%	of the population lives in the boroughs and reconstituted cities at the island's extremities
15%	of the population is between 0 and 14 years old (287,635 people)
11%	of the population is between 65 and 79 years old (203,720 people)
5%	of the population is aged 80 and up, including 51 men for every 100 women in this age bracket (91,575 people)
33%	of the Agglomeration's population is made up of immigrants, or 1 out of 3 residents (610,000 people)[140]
52.4%	of the population of Saint-Laurent is made up of immigrants, followed closely by Côte-des-Neiges–Notre-Dame-de-Grâce, with 47.7%, and Villeray–Saint-Michel–Parc-Extension, with 43.9%[162]
54.3%	of the population speaks French at home (25.3% speak English and 20.4% speak other languages)
2.6%	of the population (48,540 people) speaks neither French nor English
39.2%	of households are made up of one single person (up by 4.9% from 2006 to 2011)[164]
35.8%	of people aged 65 and up live alone
29%	of the island of Montréal's population lives below the poverty line (low income*)
80%	of housing is made up of apartments (plexes and apartment buildings)
11.7%	of housing is made up of single-family homes
42%	of housing was built before 1961 (18% before 1946)
1	international airport with traffic of 13.7 million travellers each year
1	port, the second biggest in Canada, with over 28 million tonnes of merchandise of various kinds passing through
4	universities (two francophone and two anglophone) attended by 170,000 students[108]
42	health establishments, the main ones being the Centre hospitalier de l'Université de Montréal (CHUM) and the McGill University Health Centre (MUHC)[144]

*The poverty line is defined as the level of income by which it is estimated that families put 20% more of their income than the general average toward food, housing and clothing.

LANDSCAPE FEATURES

BODIES OF WATER

The waters surrounding the agglomeration are fed by the Great Lakes and the Ottawa River. The St. Lawrence runs along the southern part of the island and narrows near the boroughs of LaSalle and Verdun to form the Lachine rapids, which are the main source point for potable water. Rivière des Prairies runs along the island's north shore, where it is home to a hydroelectric dam.[166] The great majority of the riverbanks are heavily artificialized, most particularly in the southern sector of the Island of Montréal and the eastern sector of Rivière des Prairies.

Beyond these river areas, let's note the presence of some 70 inland watercourse networks.[165] Most bodies of water (rivers, streams, etc.) have been greatly changed with urban development. They have been channeled, moved and even sometimes backfilled. Some watercourses located in large parks have nevertheless kept their natural character, including some portions of the Rivière à l'Orme, the Ruisseau De Montigny and the Ruisseau Bertrand.[165] Major artificial infrastructures have been added, making a significant mark on the island's urban landscape. Created for commercial navigation and then turned into a major tourist draw, the Lachine Canal, for example, is more than 14.5 km long and 45 m wide. The aqueduct, for its part, stretches over nearly 8 km, beginning upstream from the rapides de Lachine and reaching to the Atwater drinking water treatment plant.[73]

GREEN SPACES

The Montréal Urban Agglomeration features many green spaces classified under various terms, including 19 large parks, 10 ecoterritories, and protected spaces that cover 21.3% of the land.[153, 163, 165]

These green spaces are mostly located at both ends of the agglomeration, except for Mount Royal Park, which acts as a lung at the centre of downtown Montréal, and Parc Jean-Drapeau, also steps away from the business core. Plenty of neighbourhood parks, green alleys and tree-lined streets fill out the urban landscape. There are nearly 1.2 million trees on public land.[155]

Lachine Canal
Credit: © Réseau de suivi du milieu aquatique, Ville de Montréal

To make way for urban development, half of the island's forests disappeared between 1986 and 1994, and 750 additional hectares were removed between 1994 and 2001. The disappearance of the island's forest cover led to the loss of 60% of its biodiversity. Montréal was home to 48 endangered or vulnerable plant species in 2010.[63]

Despite its significant urbanization, the Montréal Urban Agglomeration still has a few croplands in the western part of the island. The permanent agricultural zone (decreed by the Québec government) covers 20 km^2, or 4% of the total land.[166] The island also features many community gardens (104)[165] totalling close to 25 hectares, while urban agriculture is developing in leaps and bounds, with 128 hectares of initiatives to date.[4] For example, the very first commercial farm to be built on a roof, Lufa Farms, grows more than 40 varieties of food year-round on over 2,900 square metres.[94]

URBAN FABRIC

Close to 90% of the Agglomeration's land is urbanized.[166] It has a massive road network made up of highways that cross the territory east-west and north-south (see map 2.2 on page 18). To this we add more than 6,200 km of streets and arterial roads as well as a network of over 600 km of bicycle paths.[152] More than 18 bridges provide access to the island; the biggest ones are the Champlain Bridge and the Jacques-Cartier Bridge, with average daily traffic of 162,740 and 98,082 vehicles per day, respectively (2010 data).[161] In addition to the bridges, the Louis-Hippolyte-La Fontaine Bridge-Tunnel, a huge 1.5-km road structure that dips under the river, links the South Shore and Eastern Montréal. Nearly 119,000 vehicles take the tunnel each day.[161]

Montréal also boasts an underground metro network with 68 stations on four lines across 71 km. As well, five commuter train lines serve the periphery of the island of Montréal. More than 15 million passengers use them each year.[167]

Thanks to its geographic location, the Montréal Urban Agglomeration is a commodity transportation hub. It is home to the country's second biggest port, after Vancouver. Every year, some 28 million tonnes of goods pass through it, with over 1.4 million containers shipped and received. As well, Montréal has the third biggest airport in the country, serving nearly 13.7 million passengers a year. Two railway networks also operate on our territory.

Most of the island's land is devoted to residential zones (29%). The island centre chiefly features multi-apartment buildings (quadruplexes, triplexes, duplexes, condo buildings, etc.) while single-family homes dominate the landscape to the east and west.[74] Along the highways, particularly Highway 40, are vast commercial zones including many shopping malls (8% of the land). Industrial zones, which also occupy 8% of the space, stretch mainly along Highway 40 and Highway 20 in the south-western part of the island. Lastly, we see a diverse range of land usage in the downtown area (offices, shops, factories and more).

Credit: © Ville de Montréal

All these buildings and roads have led to the mineralization of our surfaces, making the Montréal Urban Agglomeration, like that of other major cities, more sensitive to heat waves and floods. These will be discussed in the following chapters. That said, the Agglomeration also has a network of infrastructures, green spaces, places to relax and recreation spaces that greatly contribute to its citizens' quality of life. Among others, we have a network of sports and recreation facilities, including arenas, outdoor skating rinks and over a hundred swimming pools, wading pools and splash pads. The Ville de Montréal alone has 74 public pools (one pool for every 22,540 Montréalers).[91] Among cities with populations of over one million, only Philadelphia surpasses this Québec metropolis in terms of pools per resident.

MAP 2.2
OVERALL VIEW OF THE MONTRÉAL AGGLOMERATION'S URBAN FABRIC

CURRENT CLIMATE AND FUTURE PROJECTIONS

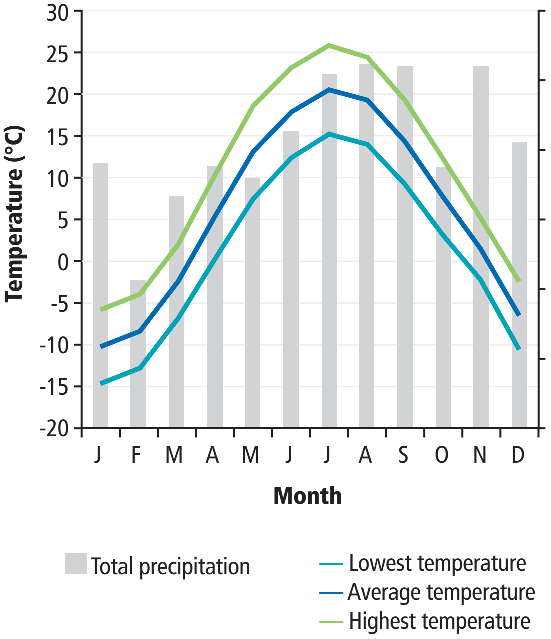
Global warming is no longer a source of debate in the scientific community. The total average temperature increase between the period of 1850-1900 and the period of 2003-2012 was 0.78 °C according to the fifth assessment report[84] by the IPCC (Intergovernmental Panel on Climate Change). 0.78 °C may seem like a relatively minor increase. But bear in mind that 20,000 years ago, the average global temperature was only 5 °C lower than today, there was a 2- to 3-km-thick ice cap covering all of Canada and the sea level was 120 metres below today's.

Because Canada is located in the higher latitudes, the temperature increase is more pronounced here. In Québec, average annual temperatures have increased by about 1 to 3 °C over a period of 62 years (1950-2011) according to a recent study by Ouranos.[122] This more pronounced temperature increase in higher latitudes is related to positive feedback within the climate system. For example, when snow melts, the ground's reflective power (albedo) diminishes, and as a result the ground absorbs more heat, which contributes to further increasing the temperature.

AVERAGE CLIMATE IN MONTRÉAL

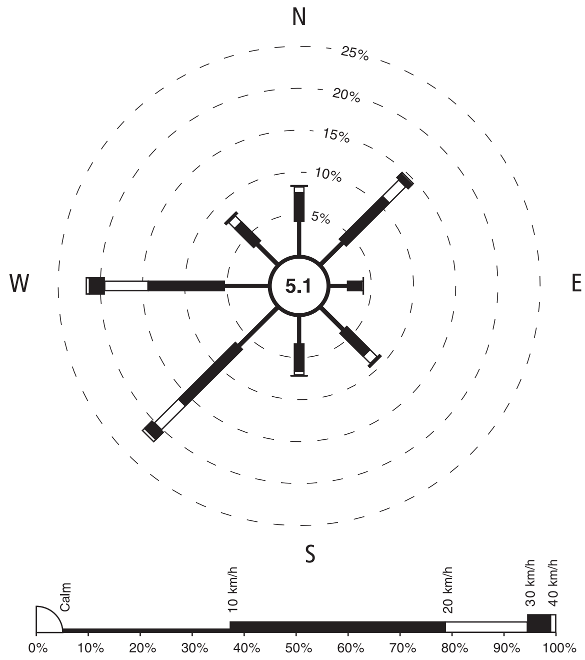
Montréal's climate features strong seasonal temperature variation between winter and summer. Temperatures vary, on average, from -10 °C in January to 20 °C in July (see Figure 2.1). Monthly precipitation varies between 60 mm and 90 mm, which is relatively heavy compared to the rest of Québec (see Figure 2.1). Montréal is part of the wide corridor centred on the Vallée du Saint-Laurent which receives Québec's heaviest precipitation levels.[122] The prevailing winds come mostly from the west and south-west, with some incursions of winds from the north-east (see Figure 2.2).

FIGURE 2.1
CLIMATE AVERAGES FOR MONTRÉAL, 1971-2000



Note: Data from the weather station at the Montréal-Trudeau International Airport.

FIGURE 2.2
ANNUAL WIND ROSE, 1971-2000



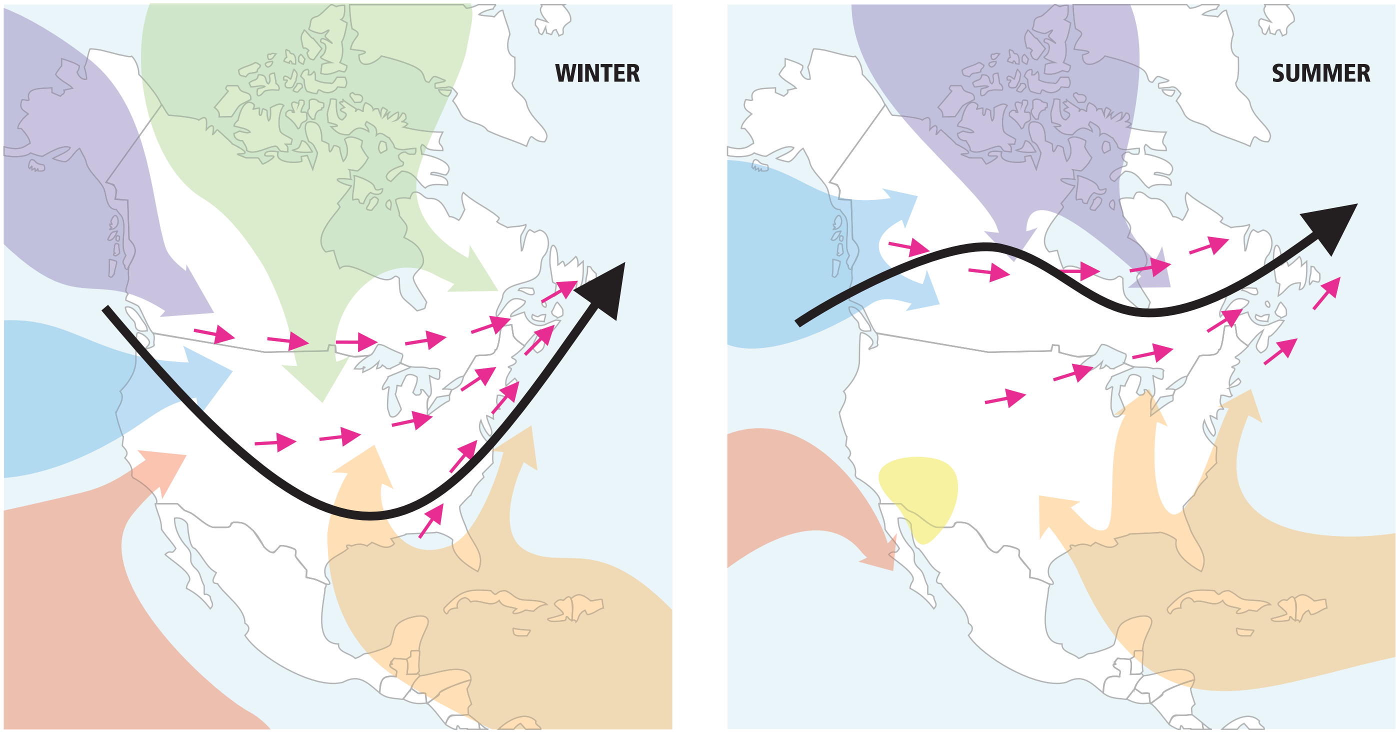
Source: Environment Canada, Québec Région (www.climat-quebec.qc.ca).

Note: Data from the weather station at the Montréal-Trudeau International Airport.

This south-west north-east direction is mainly influenced by the orientation of the Saint-Lawrence corridor and by the polar front jet-stream that runs across the North American continent from west to east (see Figure 2.3).

This seasonally high-contrast climate results from the interaction between various air masses. An air mass is an atmosphere zone with homogenous temperature and humidity characteristics. These characteristics depend on the place where the air mass is created. The air masses that form above the ocean are very humid, because of the strong evaporation from the water's surface, while those that form on the continent are relatively dry. The cold, dry winters that Montréalers know so well are mainly due to the air from the lands in northern Canada ("continental Arctic" air mass, Figure 2.3) while the warm, humid conditions in summer come mostly from the humidified air in the Gulf of Mexico ("Atlantic maritime tropical" air mass, Figure 2.3). The relative influence of the various air masses changes over the seasons, particularly with the north-south movement of the polar front jet-stream. This jet-stream's position in winter brings in a succession of storms from the southern or western United States.

FIGURE 2.3
AIR MASSES THAT INFLUENCE CANADA'S CLIMATE



Adapted from the Canadian Atlas Online[141].

🟩 Continental Arctic
🟪 Maritime Arctic
🟦 Maritime polar
🟥 Pacific maritime tropical
🟧 Atlantic maritime tropical
🟨 Continental tropical
➔ Polar front jet-stream
→ Main storm trajectories

CLIMATE PROJECTIONS

Climate models

Climate models are highly complex software programs that use mathematical equations from the fields of physics and chemistry to describe the atmosphere, oceans and continental surfaces. These equations represent the major exchanges of energy and matter that create meteorological, hydrological and biological phenomena. These models are able, in particular, to simulate the speed and direction of winds and sea currents, as well as the evolution of temperatures and precipitation, and the characteristics of various vegetation covers. For more detail on the content of climate models, watch the explanatory video available online at www.youtube.com/watch?v=bkcrH9tYv8g.

To be able to simulate the climate, the models need to know what the energy exchanges are between Earth and nearby space. These energy exchanges are driven by the solar energy that enters our atmosphere and the quantity of planetary warmth that exits and gets lost in space. The latter quantity is modulated by the greenhouse effect. As the greenhouse effect intensifies, the quantity of warmth trapped on Earth grows too. To obtain climate projections, we must have access to GHG concentrations. These concentrations depend on each country's emissions and use of fossil fuels, which in turn depend on each country's energy policies. This is why climatologists use a range of GHG scenarios.

Emissions scenarios for greenhouse gases

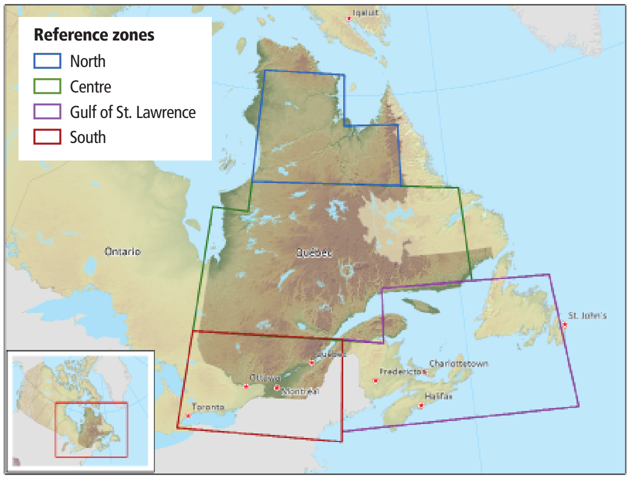
GHG emissions scenarios reflect a range of possibilities in the evolution of GHG concentrations between now and 2100. Each scenario is accompanied by the technical code RCP, for Representative Concentration Pathways. The energy balance between Earth and its surrounding space can be expressed in watt/m^2. The names of the various scenarios reflect this balance. As such, scenario RCP8.5 corresponds to a GHG concentration level equivalent to an energy forcing of 8.5 watt/m^2 in 2100, and RCP4.5 means 4.5 watt/m^2. Scenario RCP8.5 has a stronger energy forcing than scenario RCP4.5, so it corresponds to GHG emissions that continue to increase until the end of the century.

For scenario RCP4.5, however, the emissions stabilize in the second half of the century. As well, scenario RCP4.5 limits the average global temperature rise to about 2 °C by the end of the century.

Climate model projections

The climate projections published over the last number of years are based on the results of various climate models developed across the world, and they leverage the strengths and weaknesses of each model. Climate models are continually updated based on new scientific discoveries. Every six years, when the new IPCC report comes out, international research teams update their climate projections for the most recent version of their model.

No specific climate projections exist for the Montréal Urban Agglomeration. Climate models have not yet reached that degree of precision. In the following sections, we base our work on projections by Ouranos made for the region of southern Québec, including Montréal (see the "South" region, in the red frame on the map below).

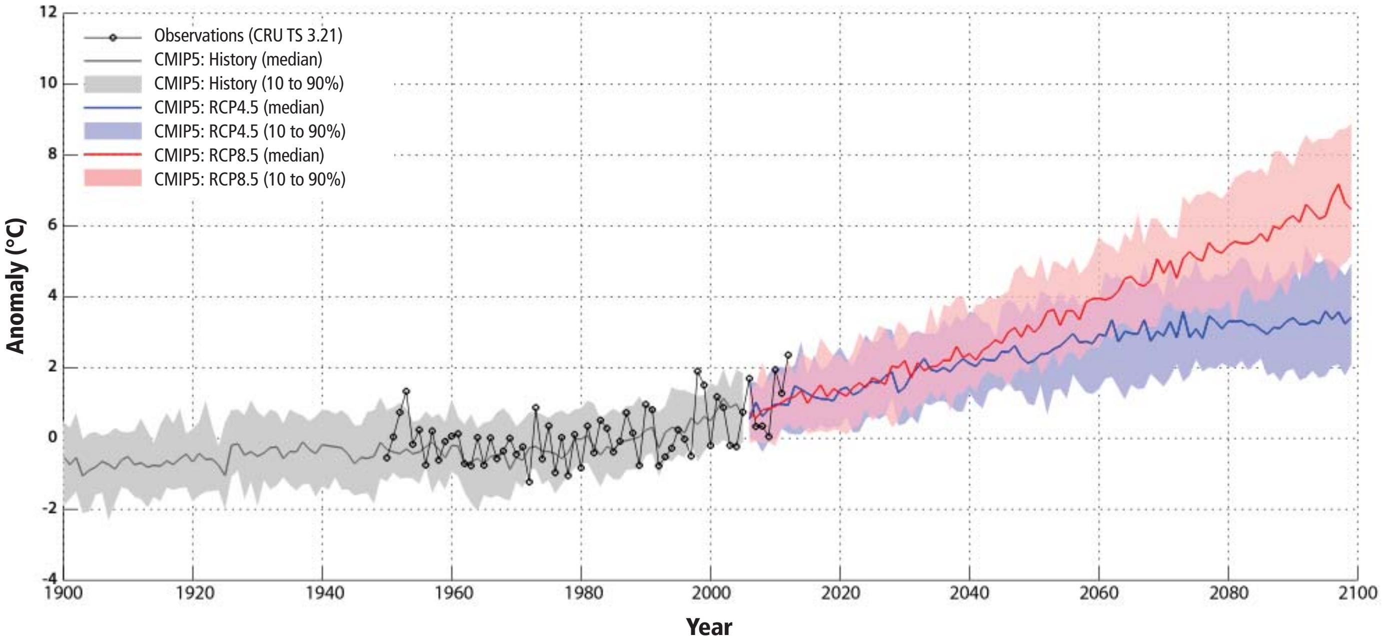


Map excerpted from: Ouranos (2014). *Vers l'adaptation. Synthèse des connaissances sur les changements climatiques au Québec. Partie 1 : Évolution climatique au Québec*, 2014 edition, Montréal, Québec, 79 p.

These projections are based on the results of several climate models from an international project called CMIP (Coupled Model Intercomparison Project). For a scenario with high GHG emissions (scenario RCP8.5), the climate projections indicate an annual temperature increase of about 2 to 4 °C for the 2041-2070 period and of 4 to 7 °C for the 2071-2100 period as compared to the 1971-2000 period (see Figure 2.4).

Note that in the next chapters, we will often refer to the Ouranos document *Vers l'adaptation – Synthèse des connaissances sur les cangements climatiques au Québec. Partie 1 : Évolution climatique au Québec*, particularly in the sections dealing with climate projections.

FIGURE 2.4
EVOLUTION OF AVERAGE ANNUAL TEMPERATURE ANOMALIES RECORDED (1950-2012) AND SIMULATED (1900-2100) FOR THE SOUTHERN QUÉBEC REGION INCLUDING MONTRÉAL



Note: Evolution of average annual temperature anomalies recorded (1950-2012) and simulated (1900-2100) for the southern Québec region, including Montréal, for the historical period (grey) and the greenhouse gas emissions scenarios RCP4.5 (blue) and RCP8.5 (red). The anomalies are calculated in relation to the 1971-2000 average.

Source: Ouranos (2014). *Vers l'adaptation – Synthèse des connaissances sur les changements climatiques au Québec. Partie 1 : Évolution climatique au Québec*, 2014 edition, Montréal, Québec: Ouranos, 79 p.

APPROACH

The adaptation plan was developed and coordinated by a multidisciplinary team within the Ville de Montréal's Service de l'environnement. To achieve its mandate, the team collaborated with many other players: employees from the Ville de Montréal's Central Services and its various boroughs, employees from all the cities in the Agglomeration, and outside experts.

The approach we took for the Montréal Urban Agglomeration's first climate change adaptation plan was developed in respect of the directives set out in the Climat municipalités program by the Ministère du Développement durable, de l'Environnement et la Lutte contre les changements climatiques (MDDELCC). We also took inspiration from the Ouranos scientific consortium's guide intended for Québec municipalities, entitled *Élaborer un plan d'adaptation aux changements climatiques.*[120] The approach is presented in detail in this chapter.

Green roof at the Palais des Congrès
Credit: © Palais des Congrès

Climate projections confirm that extreme events like the ones we have already experienced will continue to occur, quite likely with even greater frequency and scope. As such, while we may see new impacts in the future, the team agreed that current climate impacts would serve as a basis for analyzing vulnerabilities in this first adaptation plan. In that same vein, we agreed that an analysis of current vulnerabilities would be representative of the vulnerabilities to come in the medium term, and could serve to guide our choice of the most promising adaptation measures for the 2015-2020 plan.

HISTORY OF EXTREME CLIMATE EVENTS

To identify the climate hazards to which the Montréal Urban Agglomeration was already vulnerable, the team carried out a non-exhaustive review of extreme climate events of the last 30 years with known impacts, using documents from the Centre de sécurité civile de Montréal, Public Safety Canada and Environment Canada as well as other scientific and university-based reports. Next, we consulted the archives of various media to pin down the impacts of these events.

CHOICE OF CLIMATE HAZARDS

We consulted the climate projections produced by Ouranos for southern Québec. We also analyzed climate data for the last few decades to ascertain trends in climate evolution in Montréal. This analysis was mostly based on meteorological data fom the weather station at the Montréal-Trudeau International Airport[71] and on hydrological data from Rivière des Prairies at the Rapides du Cheval Blanc.[72]

By combining observations from the past with climate projections, we identified six climate hazards whose impacts on the Montréal Urban Agglomeration's land and population are or could be exacerbated by climate change:

- higher average temperatures;
- heavy rainfalls;
- heat waves;
- destructive storms (wind, hail, snow and freezing rain);
- droughts;
- river floods.

The precision of projections relative to these hazards is variable, but since the review of extreme climate events showed that these events do occur occasionally in Montréal and entail major impacts when they do, we agreed that it would be worthwhile to develop the agglomeration's capacity to adapt to these hazards, whether or not their intensity and frequency increase with climate change.

In the same vein, rather than evaluating the risk associated with each hazard by taking into account their respective likelihood of occurrence, we agreed to instead analyze the agglomeration's vulnerability to all six climate hazards.

Risk		**Likelihood**		**Severity**
related to a climate hazard	=	of the hazard's occurrence	x	of the hazard's impacts

In other words, independently of the risk associated with each hazard, if the hazard's potential impacts are severe or if they have already occurred, the hazard is worth analyzing.

EVALUATION OF THE POTENTIAL IMPACTS OF CLIMATE CHANGE

Once we identified the climate hazards, we carried out a review of the literature on the impacts of those hazards. This helped us make a list of the known and potential impacts of climate change in Montréal. To this list, we added the impacts that emerged when we reviewed the extreme climate events that have occurred over the last 30 years, as described in the "History of extreme climate events" section (p. 23).

These impacts are grouped into four categories:

- impacts on the built environment;
- impacts on the natural environment;
- impacts on socioeconomic issues;
- impacts on municipal operations.

To complete the list of impacts and evaluate their significance, we submitted the list to collaborators identified as specialists in their fields. All the central services concerned at the Ville de Montréal received the list of impacts related to their field of expertise. They were asked to select the people best placed to evaluate those impacts and add any they judged were missing. The boroughs and reconstituted cities were also invited to take part, along with a few experts from outside organizations.

Table 3.1 on the next page lists the organizations and administrative units that took part in the impact evaluation process for the various climate hazards.

Let's underscore that, because of the Agglomeration's administrative context, this first climate change impact evaluation process focused on Central Services along with the reconstituted cities and the boroughs, but not the para-municipal bodies. The latter are nevertheless involved in implementing some adaptation measures.

Meetings were held with these specialists. At these meetings, each participant was asked to assign a value to the impacts that fell within their fields of expertise, reflecting each impact's level of severity, for each of the relevant climate hazards. The scale used for this exercise is shown in Table 3.2. The relative severity of the various hazards was not evaluated. As such, the severity of the impacts for one hazard cannot be compared to those of another hazard.

TABLE 3.2
SCALE USED TO EVALUATE THE SEVERITY OF THE VARIOUS IMPACTS OF CLIMATE CHANGE

0	Negligeable impact
1	Minor negative impact
2	Medium negative impact
3	Major negative impact

Respondents were told not to assign a value when their experience and knowledge did not allow them to evaluate an impact. This methodological choice aimed to reduce the bias that could result from a perception-based evaluation.

TABLE 3.1
ORGANIZATIONS AND ADMINISTRATIVE UNITS THAT TOOK PART IN THE CLIMATE CHANGE IMPACT EVALUATIONS

Direction générale (headquarters)	• Division du développement durable (sustainable development division)
Service de la concertation des arrondissements (borough concertation service)	• Division des travaux publics (public works division)
Service de la diversité sociale et des sports (social diversity and sport department)	• Division du développement social (social development division)
Service de la gestion et planification immobilière (property planning and management department)	• Division de la stratégie et du développement durable en immobilier (real estate strategy and sustainable development division)
Service de la mise en valeur du territoire (territory enhancement department)	• Direction de l'urbanisme (urban planning department) • Direction de l'habitation (housing department)
Service de l'eau (water department)	• Direction de l'eau potable (drinking water department) • Direction de l'épuration des eaux usées (wastewater purification department) • Direction de la gestion stratégique des réseaux d'eau (strategic water network management department) • Division de la gestion durable de l'eau (sustainable water management department)
Service de police (SPVM) (police service)	• Direction des opérations - Développement des processus d'innovation et des pratiques opérationnelles (operations department – development of innovative processes and operational practices)
Service de sécurité incendie (SIM) (fire safety service)	• Centre de sécurité civile (civil safety centre) • Direction des opérations (operations department)
Service des affaires juridiques (legal affairs department)	• Direction des affaires civiles (civil affairs department)
Service des grands parcs, du verdissement et du mont Royal (large parks, greening and Mont Royal department)	• Division Stratégies, programmes et politiques (strategy, program and policy division) • Division Bureau de projets Aménagement - Grands Parcs (land development project office division – large parks) • Division de la production horticulture et collections (horticulture production and collections division) • Division gestion de l'entretien des opérations des grands parcs (large parks operational maintenance division)
Service des infrastructures, de la voirie et des transports (infrastructure, roads and transportation department)	• Division de la conception des travaux (construction work design division) • Division de la gestion des actifs (asset management division) • Division du développement des transports (transport development division) • Division expertise et soutien technique (technical support and expertise division)
Service de l'environnement (environment department)	• Division de la planification et du suivi environnemental (environmental planning and monitoring division)

Among these experts, specialists in socioeconomic impacts also evaluated the vulnerability levels of various groups of people to each socioeconomic impact. Table 3.3 shows the scale used for this step.

TABLE 3.3
SCALE USED TO EVALUATE THE VULNERABILITY OF VARIOUS GROUPS OF PEOPLE TO THE IMPACTS OF CLIMATE CHANGE

0	Negligeable vulnerability
1	Minor vulnerability
2	Medium vulnerability
3	Major vulnerability

At the end of the exercise, the averages were calculated for each of the impacts and for each group of vulnerable people. The results so obtained helped us identify the impacts that require special attention from the municipal administration. These results were also used for the vulnerability analysis.

The results of the impact evaluation exercise are shown in Appendix D.

VULNERABILITY ANALYSIS

The impacts evaluated as described in the previous section served as a basis for the vulnerability analysis for the period covered by this first adaptation plan, meaning 2015 to 2020. We carried out a geographic analysis whenever possible, when the impacts affected specific infrastructures or groups of people for whom geographic data were available. In the other cases, we performed a qualitative analysis. Appendix A presents the methodology used to carry out the geographic analysis of vulnerabilities.

CHOOSING CLIMATE CHANGE ADAPTATION MEASURES

As mentioned in the introduction, this approach aims first to consolidate the adaptation measures already in place on the Agglomeration's territory. While this climate change adaptation plan is the first one to be adopted by Montréal's administration, a number of plans, policies, strategies and bylaws already in place in Central Services, the boroughs and the reconstituted cities are helping to reduce the impacts of climate change. These have served as a base for our choices of adaptation measures. The list of documents used for this step is provided in Table 3.4 on the next page.

It is important to note that some of these plans will come to a close during the period covered by the 2015-2020 Adaptation Plan. However, most of them were developed iteratively, and if approved by the agencies in question, will be replaced by other plans. For example, we already know that a new Montréal Community Sustainable Development Plan 2016-2020 will be coming out soon, in continuity with the 2010-2015 plan, which is ending.

The new orientations of forthcoming plans may be added to this adaptation plan when it is updated halfway through the 2015-2020 period.

Secondly, we conducted a literature review in regard to measures implemented elsewhere in the world, and we created a list of potential adaptation measures to implement on the Montréal territory.

To solicit commitments to climate change adaptation from the reconstituted cities and the boroughs, we held a number of meetings in order to present the vulnerability diagnoses. We gave each borough and reconstituted city a set of local diagnostics documents, personalized for each administrative unit. We also gave them the list of potential measures to use as a source of inspiration as they undertook their local processes to select adaptation measures.

Generally speaking, climate change adaptation measures were chosen with respect to the following criteria:

- implementation already underway or planned;
- short-term feasibility for the 2015-2020 period;
- potential for adaptation to more than one climate hazard.

As for adaptation measures for the reconstituted cities and the boroughs to implement locally, we added a final criterion: we asked that measures be properly matched to local vulnerability diagnoses.

TABLE 3.4
PLANS, POLICIES, STRATEGIES AND BY-LAWS ALREADY IN PLACE TOWARD THE MONTRÉAL URBAN AGGLOMERATION'S ADAPTATION TO CLIMATE CHANGE

DEPARTMENT	PLAN OR PROGRAM
Service des infrastructures, de la voirie et des transports (infrastructure, road and transportation department)	Guide d'aménagement durable des rues de Montréal (2013) (in French only) Opération de vérification et de sécurisation préventive des structures routières (in French only) Programme annuel d'inspection des structures (in French only)
Direction générale adjointe - Division du Développement durable (headquarters - sustainable development division)	Montréal Community Sustainable Development Plan 2010-2015
Service de la diversité sociale et des sports (social diversity and sports department)	Plan d'intervention aquatique de Montréal (2013-2025) (in French only) Plan d'intervention des plateaux sportifs extérieurs et du réseau de plein-air (in French only) Programme de revitalisation urbaine intégrée (RUI) (in French only)
Service de la mise en valeur du territoire (territory enhancement department)	Action Plan 2014-2017 to Combat Unsanitary Housing Master Plan (2004) Stabilization of Residential Building Foundations program Schéma d'aménagement et de développement de l'agglomération de Montréal (2015) (in French only)
Service de la gestion et planification immobilière (property planning and management department)	Politique de développement durable pour les édifices de la Ville de Montréal (2009) (in French only)
Service de l'eau (water department)	Stratégie montréalaise de l'eau 2011-2020 (in French only)
Service de l'Espace pour la vie (Space for Life department)	My Space for Life Garden program
Service de sécurité incendie de Montréal - Centre de sécurité civile (Montréal fire safety service – civil safety centre)	Civil Protection Plan for the Montréal Agglomeration (2010) Extreme Heat Special Response Plan Special Response Plan for Floods Extreme Snowstorm Special Response Plan – Snow Section Politique de sécurité civile de l'agglomération de Montréal (2006) (in French only)
Service des grands parcs, du verdissement et du mont Royal (large parks, greening and Mont Royal department)	By-law to stop the spread of the emerald ash borer, and related programs and action plans Plan d'action canopée 2012-2021 (in French only) Programme de contrôle des plantes envahissantes (in French only) Programme de gestion écologique dans les parcs (in French only) Biodiversity Report 2013 Stratégie métropolitaine de lutte contre l'agrile du frêne 2014-2024 (in French only) Tree Policy of Montréal (2005) Policy on the Protection and Enhancement of Natural Habitats (2014)
Service de l'environnement (environment department)	Réseau de surveillance de la qualité de l'air (air quality monitoring network) Réseau de suivi du milieu aquatique (water quality monitoring network) Plan de réduction des émissions de GES corporatives 2013-2020 (in French only)

HIGHER AVERAGE TEMPERATURES

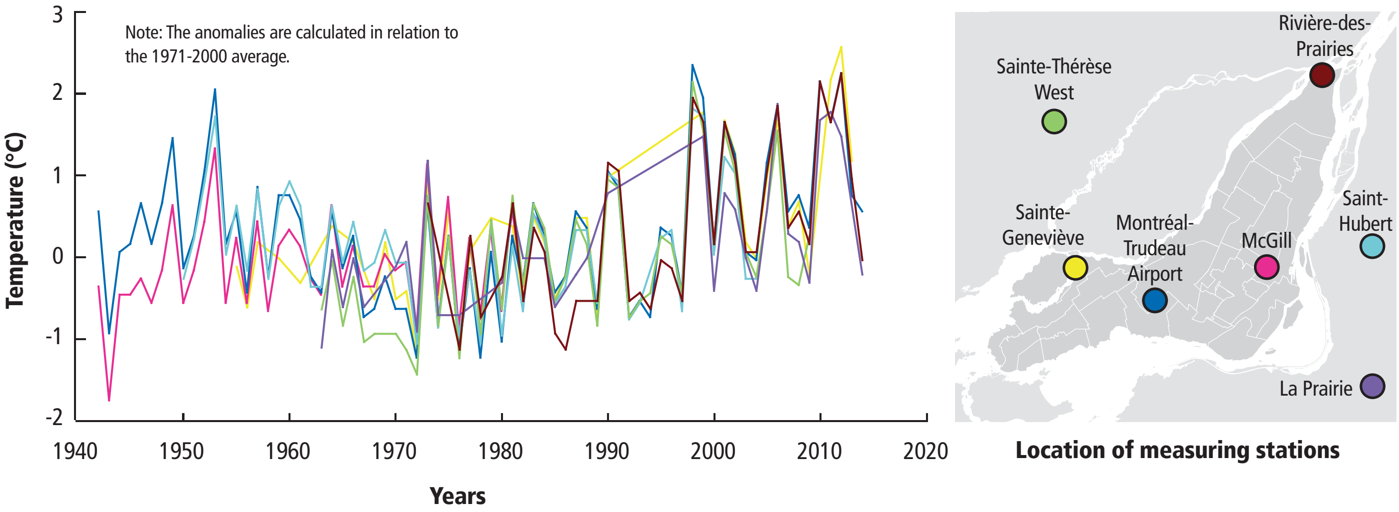
The metropolitan region of Montréal is home to many weather stations, which allow us to evaluate the historical evolution of temperatures. Figure 4.1 shows temperature evolution for seven stations, chosen for the long time period of their recordings. There is a clear trend toward increased temperatures (by about 1 °C) between the decades 1970-1980 and 2000-2010, which is in keeping with Ouranos data for Québec. Temperatures in Montréal also reflect the climate's natural variability. For instance, we can cite the brief temperature drop from 1992 to 1994 following the Pinatubo volcano eruption in 1991, or the temperature spike in 1998 following the very strong El Niño of 1997-1998.

This chapter first looks at the seasonal effects of higher average temperatures on the Montréal Urban Agglomeration, as well as climate projections from now to 2100. Next, we address the impacts this increase generates on the Agglomeration. Events understood as extreme, such as heat waves or heavy rainfalls, are not addressed in this chapter; later chapters are devoted entirely to these subjects.

© Shutterstock

FIGURE 4.1
EVOLUTION OF AVERAGE ANNUAL TEMPERATURE ANOMALIES IN THE MONTRÉAL URBAN AGGLOMERATION

Source: Data from Environment Canada (www.climat.meteo.gc.ca).



CLIMATE EVOLUTION

HISTORICAL PERIOD

Higher average temperatures affect the length of the seasons. Higher temperatures have repercussions on all the seasons, which leads in particular to an extended summer season and a shorter winter season.

The **extended summer season** translates into an extended plant growing season. In Montréal, a nine-day increase in the growing season was recorded between the period of 1955-1984 and that of 1985-2014 (see Figure 4.2). This extension of the growing season is mainly due to an earlier start to growth in the spring. The start of the growing season has moved from April 8 (the average between 1955 and 1984) to April 2 (the average between 1985 and 2014). In this graph, the growing season corresponds to the number of days where the average temperature is above 5 °C for five consecutive days (method from Audet et al., 2012).[13]

The **shorter winter season**, for its part, translates into a reduced frost period and snowy period. In Montréal, we have seen a five-day reduction in the frost period between 1955-1984 and 1985-2014 (see Figure 4.3). For the snowy period, the reduction is even more marked: we have gone from 103 days on average in 1955-1984 to 73 days on average in 1985-2014, or a 29% reduction. In this graph, the snowy period corresponds to the annual number of days with a snow cover of 10 cm or more, and the frost period corresponds to the number of days between the first and last day of freezing temperatures during the winter.

Another consequence of higher temperatures in Montréal is the **increased number of freeze-thaw cycles**. There was a 29% increase in freeze-thaw cycles between the winters of 1942 and 2015 (see Figure 4.4). This graph shows the number of days for which the lowest temperature is below 0 °C and the

FIGURE 4.2
EXTENDED SUMMER SEASON

Source: Data from the weather station at the Montréal-Trudeau International Airport.

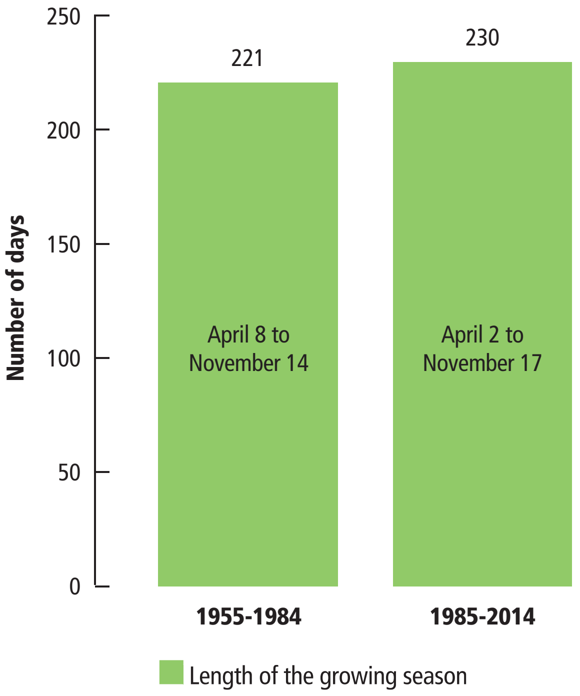
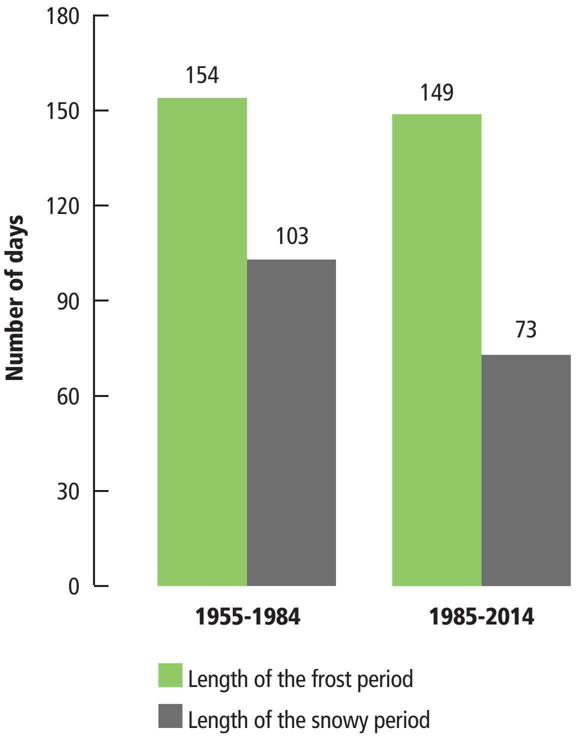


FIGURE 4.3
SHORTER WINTER SEASON

Source: Data from the weather station at the Montréal-Trudeau International Airport.



highest temperature is above 0 °C, which means a shift across 0 °C within a single day, and thus a freeze or thaw. Freeze-thaw cycles have marked impacts on infrastructures, particularly on road networks. These impacts are detailed later in this chapter.

CLIMATE PROJECTIONS

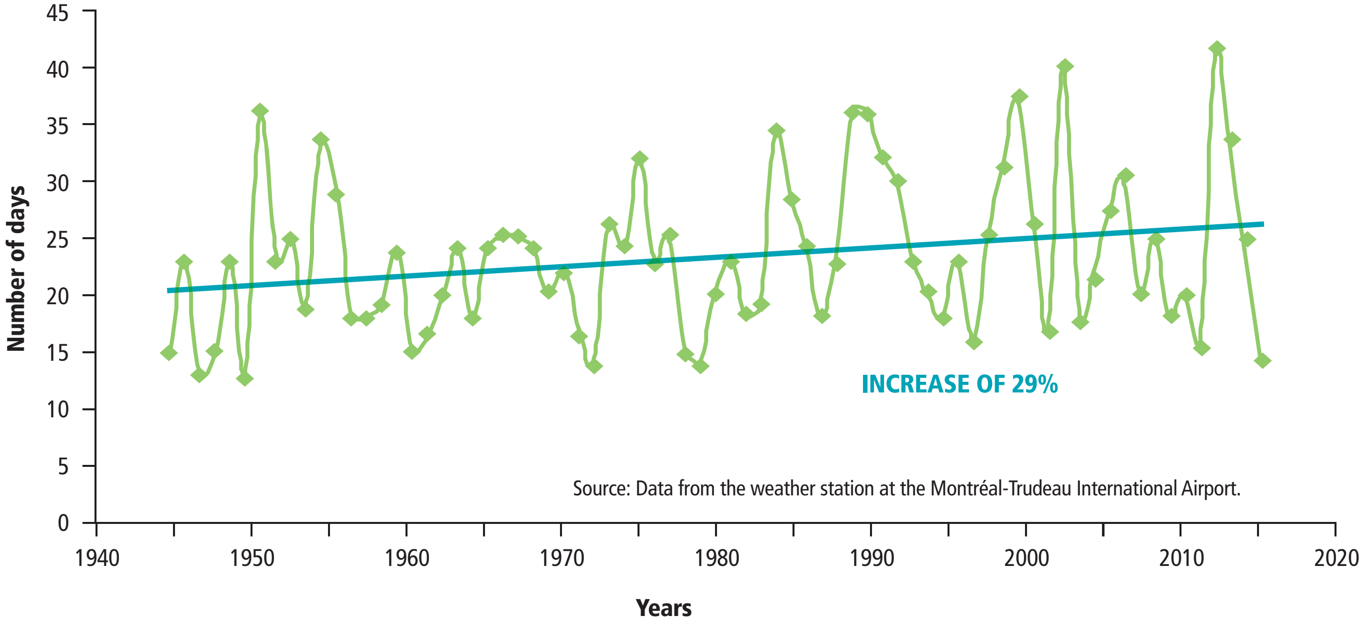
As we noted in the Background chapter, there are no climate projections specific to the Montréal Urban Agglomeration. Climate models have not yet reached that degree of precision. Therefore, the following elements rely on Ouranos projections for the southern region of Québec, which includes Montréal.

For a high-GHG emissions scenario, climate projections indicate an increase in annual temperatures of about 2 to 4 °C for the period of 2041-2070 and of 4 to 7 °C for the period of 2071-2100 (see Figure 2.4 on page 22). In response to these major temperature changes, the trends recorded in recent history should become more acute.

The plant growing season, which has already lengthened in recent years, should become even longer: between 10 and 30 days longer by 2050 depending on the emissions scenario. This significant increase of the impacts on the natural environment is discussed in detail later in this chapter. The frost period should continue to shorten, losing two to four more weeks compared to today. It's estimated that, for 2041-2070, the snowy period should shrink by 65 to 45 days compared to the historical period of 1970-1999. The most extreme projections even envision the possibility that the extreme south of Québec, including Montréal, will see a snow cover lasting fewer than 20 days. Lastly, climate projections indicate that the number of freeze-thaw cycles should increase in winter, but diminish in the fall and spring between now and 2050.

Now that we've set out the climate context for higher average temperatures, let's take a look at the impacts of this increase on the Montréal Urban Agglomeration.

FIGURE 4.4
HIGHER NUMBER OF FREEZE-THAW CYCLES IN WINTER



Source: Data from the weather station at the Montréal-Trudeau International Airport.

IMPACTS

Figure 4.5 illustrates the impacts caused by higher average temperatures on the Montréal Urban Agglomeration. The impacts are divided into four categories: built environment, natural environment, socioeconomic issues and municipal operations. The impacts in each category are explained below.

FIGURE 4.5
EXAMPLES OF POTENTIAL IMPACTS OF HIGHER AVERAGE TEMPERATURES ON THE MONTRÉAL AGGLOMERATION

Built environment

Public infrastructures

- Damages to the road network and adjacent structures
- Accelerated degradation of certain civil engineering works (bridges, tunnels and overpasses) leading to falling fragments
- Breaks to underground drinking water and wastewater networks

Residential infrastructures - ICI

No significant impacts identified

Socioeconomic issues

Health

- Health problems caused by air pollution (pollen)
- Health problems caused by increased exposure to UV rays
- Vector-borne and zoonotic diseases

Expenses for individuals

No significant impacts identified

Inconveniences and accidents

No significant impacts identified

Natural environment

Plants

- Longer pollen season
- Changes to plant phenology (such as earlier plant flowering)
- Faster plant growth
- Change to plant hardiness zones

Insects

- Early arrival of some pests
- Increased number of generations per season
- More frequent infestations
- Risk of desynchronization between pests and their natural enemies

Pathogens

- Larger geographical distribution area
- Higher rate of reproduction

Municipal operations

Infrastructures

- Increased use of abrasives when we are continually nearing the freezing point
- More staff required for inspections during freeze-thaw cycles
- Positive impact on construction work time: more days for public construction work under better conditions

Park and green space management

- Greater demand for resources (seasonal employees)
- Increased costs and labour for green space maintenance

Recreational activities

- Demand to extend the opening season for pools, splash pads and sports fields
- Extended use season for the bicycle path network
- Difficult and costly maintenance for outdoor skating rinks

IMPACTS ON THE BUILT ENVIRONMENT

On the territory of the Montréal Urban Agglomeration, we mostly see the impacts of higher average temperatures on the built environment in winter. Milder winters, alongside a higher number of freeze-thaw cycles, bring about the following impacts:

- damage to urban arteries and local streets in Montréal's road network, particularly caused by the accelerated degradation of the driving surface and a higher number of potholes. These impacts are amplified by the use of road salts;
- accelerated degradation of some civil engineering works (bridges, tunnels and overpasses) leading to falling fragments.

Freeze-thaw cycles subject the Montréal Urban Agglomeration's infrastructures, particularly its road networks, to two main types of deterioration: fissuring and surface flaking (a phenomenon particular to northern regions).

When thaws happen during the winter, the snow and ice melt, which causes water and salt to trickle into the concrete and layers of asphalt mix, down to its foundations. On road surfaces, the process begins with the appearance of surface flaws or fissures. These can be attributed, among other things, to the separation of the asphalt mix, localized weaknesses in the foundation, or too-thin asphalt. When the temperature drops below 0 °C (frost period), the water turns into ice. Because the volume of water increases by 9% when it moves from a liquid to a solid state, the weakened asphalt separates and tears away. This is called fissuring.

Surface flaking is the type of frost-based destruction most frequently seen on structures that are heavily exposed to freeze-thaw cycles (bridge panels, sidewalks, etc.). It manifests in the progressive crumbling away of small particles, often in the form of small flakes. Surface flaking mainly happens when concrete comes into contact with road salts. The possible increased frequency of freeze-thaw cycles for Montréal combined with the resulting increased use of road salts means we can anticipate more surface flaking.

Pothole on boulevard Saint-Laurent, near rue Sherbrooke (25/02/2013)
Credit: © Dario Ayala, *Montreal Gazette*

IMPACTS ON THE NATURAL ENVIRONMENT

Higher average temperatures (summer and winter) have numerous impacts on the natural environment, which are complex to determine. This section paints a non-exhaustive picture of some impacts that affect various components of the natural environment. It focuses on the impacts to insects, plants and pathogens.

INSECTS

Insects are poikilotherms, meaning the regulation of their metabolism depends directly on outdoor climate conditions such as temperature.[11] As such, they are heavily influenced by temperature, and even a minor increase in temperature can have consequences on their development.[26] Studies of the impacts of climate change on insects have been heavily documented in the scientific literature. Below, we present the main impacts of higher average temperatures.

Faster development rate

Higher temperatures generally engender a faster growth rate among pest insects.[64, 65, 124]

Example of impacts in Montréal:

- threshold of tolerance is reached more quickly for insect populations that cause inconveniences.

Higher number of generations per season

When the average temperature climbs, an increase in voltinism (number of generations per year) can be observed in insects.[15, 143]

Examples of impacts in Montréal:

- greater damages to trees, plants and crops;
- higher number of complaints from citizens who are concerned about insects, whether because they are harmful or because of aesthetic considerations;
- extended scouting season for pest insects.


Japanese beetles (*Popillia japonica*) eating plant leaves

© Shutterstock

WHY IS INSECT STUDY CRUCIAL IN URBAN SETTINGS?

- Insects are major pests. Many of them threaten tree survival. Think, for instance, of the emerald ash borer, a boring insect that is currently threatening a large portion of Montréal's urban tree canopy.
- Insects cause many inconveniences in urban settings, and lead to many citizen complaints. In Montréal, for example, insects represent more than two thirds of tree-related problems reported by cities and boroughs, and half the problems associated with green spaces.
- Some insects are vectors for disease, such as the West Nile fever caused by the West Nile Virus (spread by mosquitoes) and Lyme disease (spread by ticks). The risk of contracting some of these diseases is particularly high in urban settings, West Nile fever being a prime example.
- Insects perform ecological services, among others by pollinating plants. A recent study found 164 different species of wild bees in Montréal.[114]
- Beneficial insects (also called auxiliaries) naturally control some harmful weed species and harmful insects, reducing the need to resort to pesticides.
- Lastly, insects are the living organisms that contribute the most to biodiversity. They represent more than 80% of the world's living species.

Better, or possible, winter survival

In temperate regions, insects must face cold winter temperatures. Winter survival is the dominant factor affecting the phenology of many pest insect species, meaning the chronology of plant and animal life stages in relation to weather and climate. It has been shown that an increase of 1 °C in the average temperature can be enough to change the migration time of some harmful insect species.

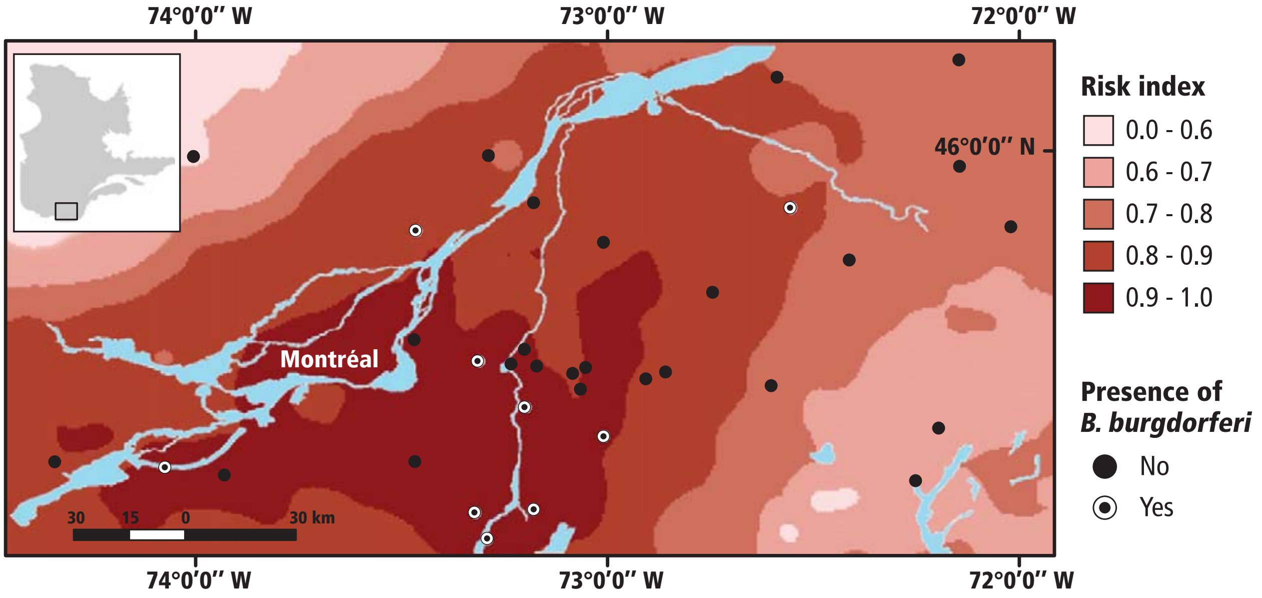
Extended geographical distribution area

Currently, the rigorous winter conditions that prevail on the Montréal Urban Agglomeration's territory prevent certain harmful species of insects from establishing themselves and surviving. But warmer winter temperatures could allow some insect species from the south to make Montréal their home.[172]

DISEASE-VECTOR SPECIES

Disease-vector species are more likely to survive warmer Montréal winters. This is true, for instance, of the deer tick (*Ixodes scapularis*), an insect that carries the *Borrelia burgdorferi* bacteria responsible for Lyme disease.[117] It has been seen to survive in southern Québec, and recent models estimate that there is a high risk that infected ticks will be found in Montréal, particularly in the southern part of the island.[102]

FIGURE 4.6
PRESENCE OF *B. burgdorferi*



Risk was modeled based on climate and habitat variables that predict the presence of white-footed mice and deer ticks. The study sites are shown on the map in black when *B. burgdorferi* was not detected and in black and white when *B. burgdorferi* was detected.

Source: Simon, J. A., Marrotte, R.R., Desrosiers, N., Fiset, J., Gaitan, J., Gonzalez, A., Koffi, J. K., Lapointe, F.-J., Leighton, P. A., Lindsay, L. R., Logan, T., Milord, F., Ogden, N. H., Rogic, A., Roy-Dufresne, E., Suter, D., Tessier, N., & Millien, V. (2014). Climate change and habitat fragmentation drive the occurrence of *B. burgdorferi*, the agent of Lyme disease, at the northern limit of its distribution. *Evolutionary Applications*, 7(7), 750-764.

Higher frequency of infestations

By acting on insects' survival, reproduction and development rates, higher temperatures are likely to increase the frequency of pest infestations.

Pest insects causing more severe damages to plants

Many studies have shown that climate change could increase the damages that insects cause to plants. This is particularly true for herbivore insect species.[15] Defoliating insects (insects that attack leaves), such as the gypsy moth (*Lymantria dispar*), could flourish with a temperature increase.[97] In Canada we have seen herbivore insects infest trees in urban settings.

GYPSY MOTH INFESTATION IN THE TORONTO REGION IN 2013

In May 2013, the Toronto region was battling a serious gypsy moth infestation. Gypsy moth populations had reached levels high enough that traditional control methods (egg cluster removal, sticky bands and ground pesticide application) were ineffective. Toronto authorities had to resort to stronger means; they carried out aerial spraying of biopesticides (Btk) on residential zones. This type of situation is becoming more likely to occur in the Montréal area thanks to higher average temperatures.

Gypsy moth larvae cluster (*Lymantria dispar*)

© Shutterstock

A helicopter sprays a biopesticide on a Toronto-area residential zone to control a gypsy moth infestation. (27/04/2013)
Credit: © CTV Toronto

Early arrival of certain pests

Higher spring temperatures could lead to the early arrival of certain insects on the island of Montréal. For example, ticks, which are vectors for the bacteria that causes Lyme disease, are now present two to three weeks earlier than they were 20 years ago in some areas of the United States.[96] In Europe, the increasingly early arrival of aphids has been widely documented.[75]

Examples of impacts for Montréal:

- early arrival of pests or insects that cause inconveniences for citizens and/or damage to plants, or that are vectors for disease;
- lower intervention threshold*;
- early scouting (starting earlier in the season);
- disease-vector insect surveillance and citizen awareness-raising campaigns must be carried out earlier in the season.

Risk of synchronization loss between pest insects and their natural enemies

Researchers have recently begun to investigate global warming's medium- and long-term impacts on the level of synchronization between pests' biological cycles and those of their natural enemies. In some cases, the natural enemies could remain synchronized with the pests, thereby maintaining a certain control of pest populations despite higher average temperatures. In other cases, higher temperatures could affect pests and their natural enemies differently, resulting in either better pest control or loss of pest control.[25]

Risk of synchronization loss between plants and insects

Higher average temperatures may affect insect and plant phenology differently, and as a result, may affect the synchronization between them. A loss of synchronization could be beneficial if the insect in question is a pest. However, the impact could be negative in the case of beneficial insects such as pollinators.[28]

Parasitoid wasp (natural enemy) attacking an aphid (pest)
Credit: © Bernard Chaubet, Institut national de la recherche agronomique

Pollinating insect

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* Severity of damages based on which it is necessary to take action due to agronomic and economic considerations (Grand dictionnaire terminologique de l'Office québécois de la langue française, English translation)

PLANTS

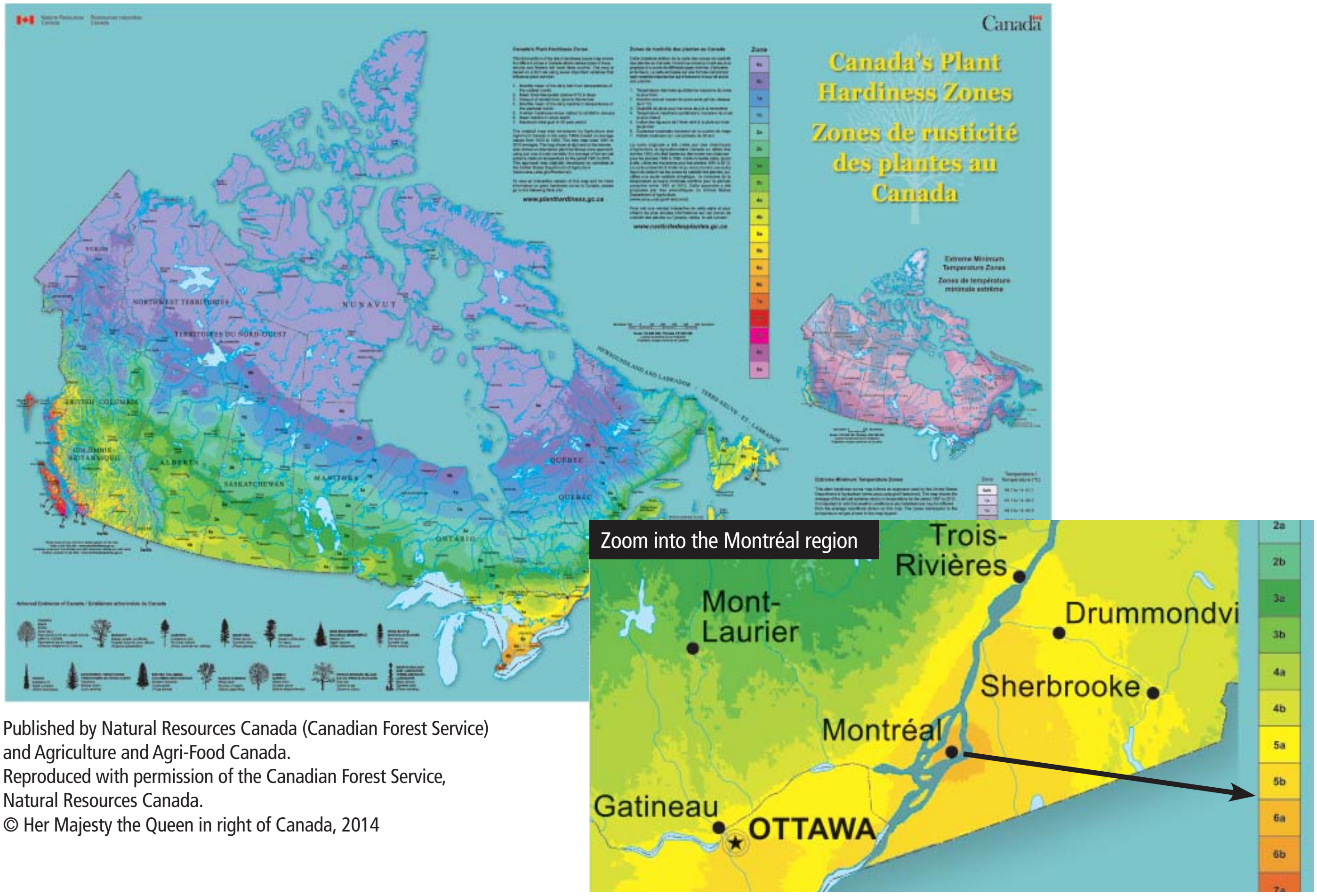
Plants are very sensitive to higher average temperatures. An increase of a few degrees may be enough to cause drastic changes in plant biology. These changes may in turn have major consequences, even for plants in urban settings.[118]

Changes to plant hardiness zones

Scientists and gardeners have long known of the link between plants and climate. One way to see this link is to map hardiness zones. To produce these maps, scientists have used many types of data for each region, such as the survival of various plant species, lowest winter temperatures, the length of the freeze-free period, summer precipitation, highest temperatures, snow, January rains and maximum wind speeds.

Recently, the Canadian Forest Service updated the map of plant hardiness zones for Canadian regions. This exercise showed that many Canadian regions have changed hardiness zones. While Western Canada saw the most significant changes to hardiness zones, eastern regions are also affected. Montréal, for example, has moved from a **zone 5B to a zone 6**. When a region changes hardiness zones, it means that different plant species can grow there.

FIGURE 4.7
MAP OF PLANT HARDINESS ZONES IN CANADA (UPDATED 2015)



Published by Natural Resources Canada (Canadian Forest Service) and Agriculture and Agri-Food Canada.
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Change to species distribution areas

Higher temperatures will allow species that are currently at their distribution limit to appear. This could promote the establishment of some undesirable plant species.[18, 176]

Change to species phenology

Species phenology is the study of the appearance of periodic events (most often annual) in the living world, determined by seasonal climate variations. It is clear that higher average temperatures are already affecting the phenology of plant species. In Montréal, the sap is rising, buds are opening and plants are flowering earlier in the season. Trees are also leafing for longer periods. It was recently shown that many plant species are flowering up to a month earlier than in the past in some American states.[52]

Extension of the pollen season

Higher average temperatures in the summer mean a longer pollen production season. This is particularly worrisome in the case of allergenic plant species. For example, in Montréal, the emission period for ragweed pollen (*Ambrosia artemisiifolia L.*) expanded by three weeks between 1994 and 2002.[24, 67]

Risk of damage following a mild winter and a spring frost

Higher average temperatures in spring and the frequency of freeze-thaw cycles have direct repercussions on risk of cold-related damage to plants.[174] For example, buds may open too soon because of abnormally high spring temperatures, and then be damaged by a spring frost.

Ragweed (*Ambrosia artemisiifolia L.*) with spikes

Loss of cold hardening

Every fall, plants prepare for winter using various mechanisms. This phenomenon is called "cold hardening." Higher temperatures may impede the cold hardening process, and as such, make plants more vulnerable to damage in the winter cold.[90]

Faster plant growth

Plant growth should be encouraged by higher average temperatures in summer. This could be advantageous for people who practice urban agriculture, by fostering higher yields. That said, this faster growth could mean that plants and urban green spaces will need more maintenance work.

PATHOGENS

Fungi, bacteria, viruses and nematodes (small microscopic worms) are pathogenic agents that can cause infections in plants. Most studies on the impacts of climate change on plant pathogens deal with fungi.[33] Temperature and humidity are the key factors that affect the incidence of pathogenic fungi in plants. Temperature can change the growth, rate of reproduction, survival and distribution area of pathogens as well as host plants' sensitivity to them.[66, 68]

Pathogen survival

Higher winter temperatures could allow a larger number of pathogenic agents to survive.[64] For example, we know that milder winters foster the growth of certain pathogens, such as some species of powdery mildew, rusts and circosporiosis.[124] However, other factors also influence pathogen survival, and it is difficult to establish an overall picture of how higher temperatures will affect them.

Tar spots on a maple leaf
Credit: © Équipe de lutte intégrée, Ville de Montréal

Larger geographic distribution area

Higher temperatures could lead to an expanded distribution area for plant pathogens. Pathogen species that cannot survive in current cooler conditions could begin to attack plants in our region.[36]

Higher rate of reproduction

Higher temperatures could encourage some plant pathogens to reproduce. For example, spore germination in several rust species increases when temperatures rise. Other pathogens, including some that attack roots, could reproduce more quickly at higher temperatures. The longer summer season could allow pathogens to reproduce for longer and in higher quantities, leaving larger inoculums* available to create infection the following year.[68]

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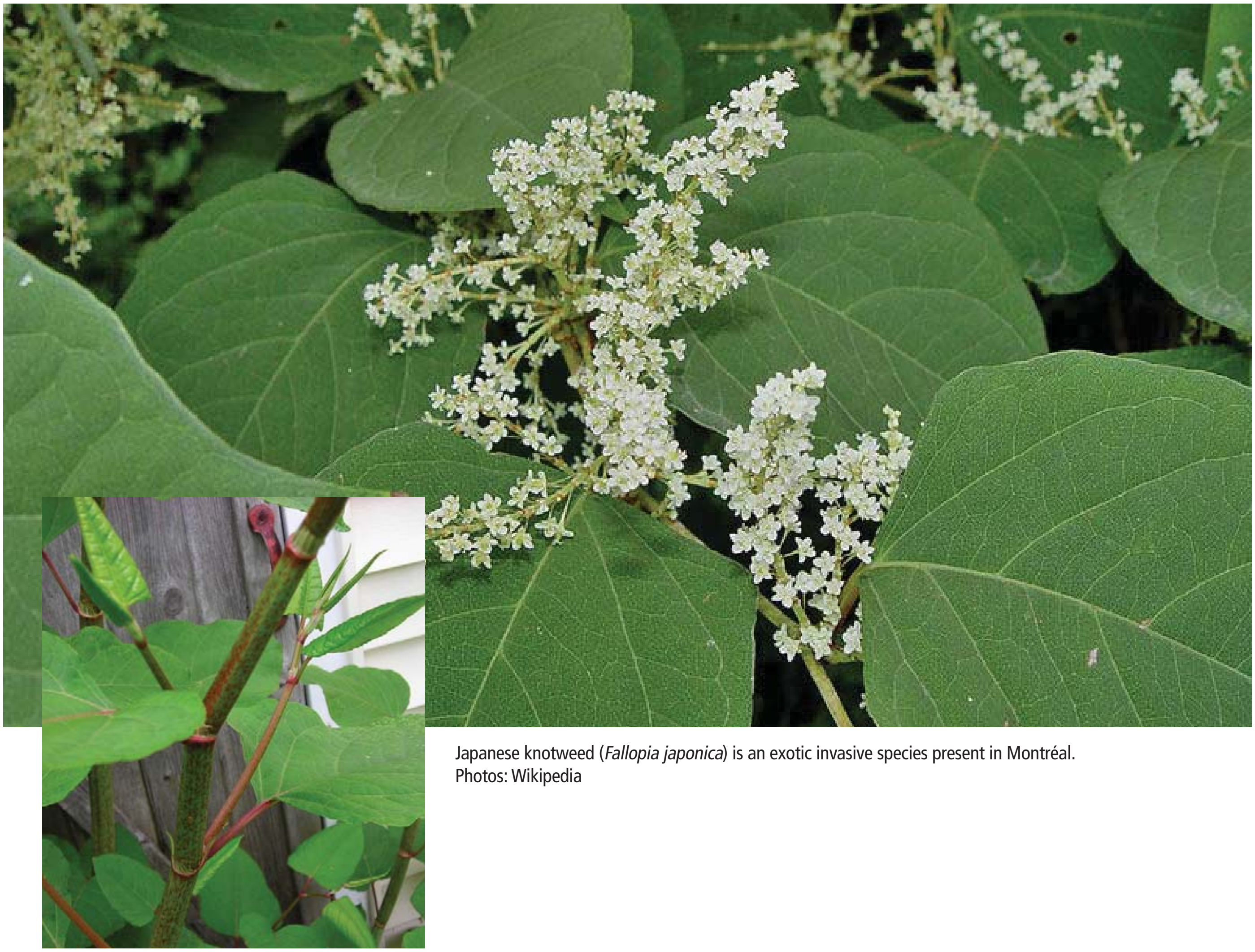
*A pathogen, or part of a pathogen, that can cause an infection in its host when conditions become favourable.

BIODIVERSITY

As we saw previously, higher average temperatures could encourage many invasive species to flourish via various mechanisms. Invasive species threaten biodiversity, so it is important to carefully understand and locate the invasive species already present on Montréal's territory and to determine the ones coming our way that could establish here thanks to the milder climate we expect in years to come.[18]



Japanese knotweed (*Fallopia japonica*) is an exotic invasive species present in Montréal.
Photos: Wikipedia

IMPACTS ON SOCIOECONOMIC ISSUES

The impacts that higher average temperatures have on socioeconomic issues in the Montréal Urban Agglomeration are and will be mainly observed in the summertime. These impacts mostly affect population health (see Table 4.1).

As a result of a longer summer that favours outdoor activities over a longer period of time, the population will be more heavily exposed to ultraviolet rays, which could increase the prevalence of related health problems, such as eye and skin diseases, including cancer.

The longer pollen season brought on by higher average temperatures is leading to growing health problems among people who are sensitive to these allergens. In Montréal, the pollen season in late summer (August and September) has the greatest impacts on health, particularly due to ragweed. Ragweed pollen is responsible for allergies in a significant fraction of the Montréal area's population. Among others, 16.1% of Montréal children aged 6 months to 12 years suffer from ragweed pollen allergies.[3]

TABLE 4.1
NUMBER OF REPORTED CASES OF LYME DISEASE AND WEST NILE FEVER CAUSED BY THE WEST NILE VIRUS (WNV) IN QUÉBEC SINCE 2002

PERIOD	NUMBER OF REPORTED CASES	
	Lyme disease*	West Nile fever**
2002–2003	Info not available	Approx. 20 per year
2004–2010	< 15 per year	< 5 per year
2011	32	42
2012	43	132
2013	141	32

*Ministère de la Santé et des Services sociaux. *Maladie de Lyme - Évolution de la maladie au Québec*, [online]. [www.msss.gouv.qc.ca/professionnels/maladie-lyme.php#evolution-de-la-maladie-au-quebec] (Accessed May 25, 2015.)

** Ministère de la Santé et des Services sociaux. *Virus du Nil occidental (VNO) - Surveillance de cas humains de VNO au Québec*, [online]. [www.msss.gouv.qc.ca/sujets/santepub/environnement/index.php?virus_du_nil#quebec] (Accessed May 25, 2015.)

Lastly, we expect an increased prevalence of vector-borne and zoonotic diseases caused, among other things, by the northward movement of animal populations that are pathogen vectors. Some vector-borne diseases, such as Lyme disease and West Nile fever caused by the West Nile Virus (WNV), have been on the rise in Québec in recent years.

WHAT IS A ZOONOTIC DISEASE?

A zoonotic disease is a disease transmitted directly from a vertebrate animal to a human being, such as hantavirus pulmonary syndrome or rabies (from white-footed mice, raccoons, etc.).

© Shutterstock

WHAT IS A VECTOR-BORNE DISEASE?

A disease is called vector-borne when bacteria, viruses or parasites are transmitted from an animal or from one human being to another through an intermediary, generally a mosquito or a tick. The West Nile Virus is an example of this.

© Shutterstock

IMPACTS ON MUNICIPAL OPERATIONS

A number of impacts on municipal operations were identified in Montréal due to higher average temperature in winter and the frequency of freeze-thaw cycles, as well as to the longer summer season and higher average temperature in summer. As Table 4.2 illustrates, in some cases, these impacts result from previously identified impacts on the built environment and the natural environment.

Generally speaking, impacts on municipal operations result in increased operating costs: higher human resources needs (labour) and increased resource consumption (such as abrasives used during spreading operations), including higher energy bills.

Let's underscore that we can also expect positive impacts in relation to the longer summer season. For example, we will see a higher number of days with weather conditions appropriate for construction work, and a longer season for bicycle path network use. The opening and closing dates for Montréal's bicycle paths have already changed due to climate change, moving from April 15 to April 1 and from November 1 to November 15, respectively.

TABLE 4.2
MAIN IMPACTS ON MUNICIPAL OPERATIONS IDENTIFIED FOR THE MONTRÉAL AGGLOMERATION DUE TO HIGHER AVERAGE SUMMER AND WINTER TEMPERATURES

WINTER
↑ average temperature
↑ frequency of freeze-thaw cycles

Road salt spreading operations aiming to make street surfaces and sidewalks safer will multiply because the temperature will hover around the freezing point more often.

In freeze-thaw cycles, bridges, overpasses, tunnels, retaining walls and other related road structures located on the Montréal territory are inspected in order to prevent falling fragments. The probable increase in the number of freeze-thaw cycles could lead to a rise in the number of these verification and structural safety inspections.

We are already seeing difficulties with maintaining outdoor skating rinks due to fluctuations around the freezing point. In the future, we will see a reduced number of outdoor skating days.

SUMMER
Extended summer season
↑ average summer temperature

The demand for access to splash pads, pools and outdoor sports areas will increase. Citizens will expect an opening or access period starting earlier in the spring and finishing later in the fall. Maintenance and monitoring staff needs for these facilities must be adapted.

The extended summer season will lead to increased demand for resources for park management, green space management and plant maintenance.

VULNERABILITY ANALYSIS

Unlike the other climate hazards, our analysis of the Montréal Urban Agglomeration's vulnerability to higher average temperatures is not based on geography. The entire island of Montréal will be affected by this climate hazard, and its impacts will be felt more or less equally throughout the territory since vulnerable people, infrastructures and ecosystems are located all over the territory.

AREAS AFFECTED BY THE HAZARD (PHYSICAL SUSCEPTIBILITY)

Higher average temperatures will mean an extended summer season, a shortened winter, and an increased frequency of freeze-thaw cycles. These effects will occur more or less equally across the entire island of Montréal.

TERRITORIAL SUSCEPTIBILITY

Generally speaking, concrete infrastructures are sensitive to freeze-thaw cycles. The road network and its related structures, such as roads, bridges, tunnels, overpasses and sidewalks, are identified as vulnerable elements for which we can expect impacts as discussed in the Impacts on the Built Environment section (page 32).

ENVIRONMENTAL SUSCEPTIBILITY

Higher average temperatures cause many impacts on the natural environment (see the Impacts on the Natural Environment section on page 33). These impacts affect many organisms and ecosystems that feature complex interrelations. As a result, it is very hard to precisely describe all the environmental susceptibility factors. This would require an in-depth knowledge of the territory and the living organisms present on it. Currently, much of the data and knowledge that would be necessary for a fine-tuned analysis of the island of Montréal's environmental susceptibility is incomplete, difficult to access or non-existent. As such, this first adaptation plan for the Montréal Urban Agglomeration provides a more basic overview of the environmental issues related to climate change. We hope to provide improved precision in future climate change adaptation plans.

SOCIAL SUSCEPTIBILITY

Various groups of people are particularly vulnerable to health impacts caused by the repercussions of higher average temperatures. The following table shows these vulnerable groups.

TABLE 4.3
GROUPS OF PEOPLE VULNERABLE TO THE IMPACTS OF HIGHER AVERAGE TEMPERATURES

VULNERABLE GROUPS	IMPACTS		
	Pollen	Vector-borne and zoonotic diseases	UV radiation
Children	X	X	X
Young adults	X		
People with asthma	X		
Pale-skinned people			X
People with compromised immune systems		X	
People who regularly practice outdoor activities	X	X	X
People genetically predisposed to allergies	X		

Source: Institut National de Santé Publique du Québec. *Mon climat, ma santé. Pour mieux s'adapter aux changements climatiques*, [online]. [www.monclimatmasante.qc.ca] (Accessed July 7, 2015.)

HEAVY RAINFALLS

Under the effect of climate change, the air trapped in the atmosphere warms up. Warmer air can hold more humidity. As a result, the air carries more water from the tropics toward boreal regions. Subtropical regions, where the biggest desert areas are located, get drier, while sub-polar regions like Québec become wetter. Another consequence is more frequent and more intense heavy rainfalls.[84]

In southern Québec, between 1950 and 2010, an upward trend was recorded for spring and fall rainfalls. For the extreme south of Québec, heavy rainfall episodes and flooding have also been on the rise. As well, precipitation in the form of snow has diminished in this same period, while liquid precipitation has begun to occur more frequently in the winter.[122]

Heavy rainfall events are a real issue for the Montréal Urban Agglomeration. We have already felt many of this climate hazard's impacts. We present a detailed analysis in this chapter, with the ultimate goal being to reduce the impacts of heavy rainfalls on the built environment, the population and the natural environment.

TYPES OF HEAVY RAIN

During the summer, weather systems may cause very intense rainfalls, which we call heavy rainfalls. These rains can cause flooding, sewer backflows and damages. There are two types of heavy rainfalls.[59, 168]

1. **LONG DURATION**. Major low-pressure systems can bring on a large quantity of water over many days. These **heavy rainfalls** can, for instance, cause watercourses to overflow.
2. **SHORT DURATION**. Thunderstorm systems can bring on a large quantity of water over a short period, sometimes in just a few minutes. These **intense rainfalls**, often localized, make heavy demands on the system in a short time, which can cause sewer backflows. Water can then back up into buildings that are not protected by a well-maintained backwater valve or whose plumbing systems are in poor repair.

Flooded street due to violent storms on May 29, 2012.
Credit: © Olivier Pontbriand, *La Presse*

CLIMATE EVOLUTION

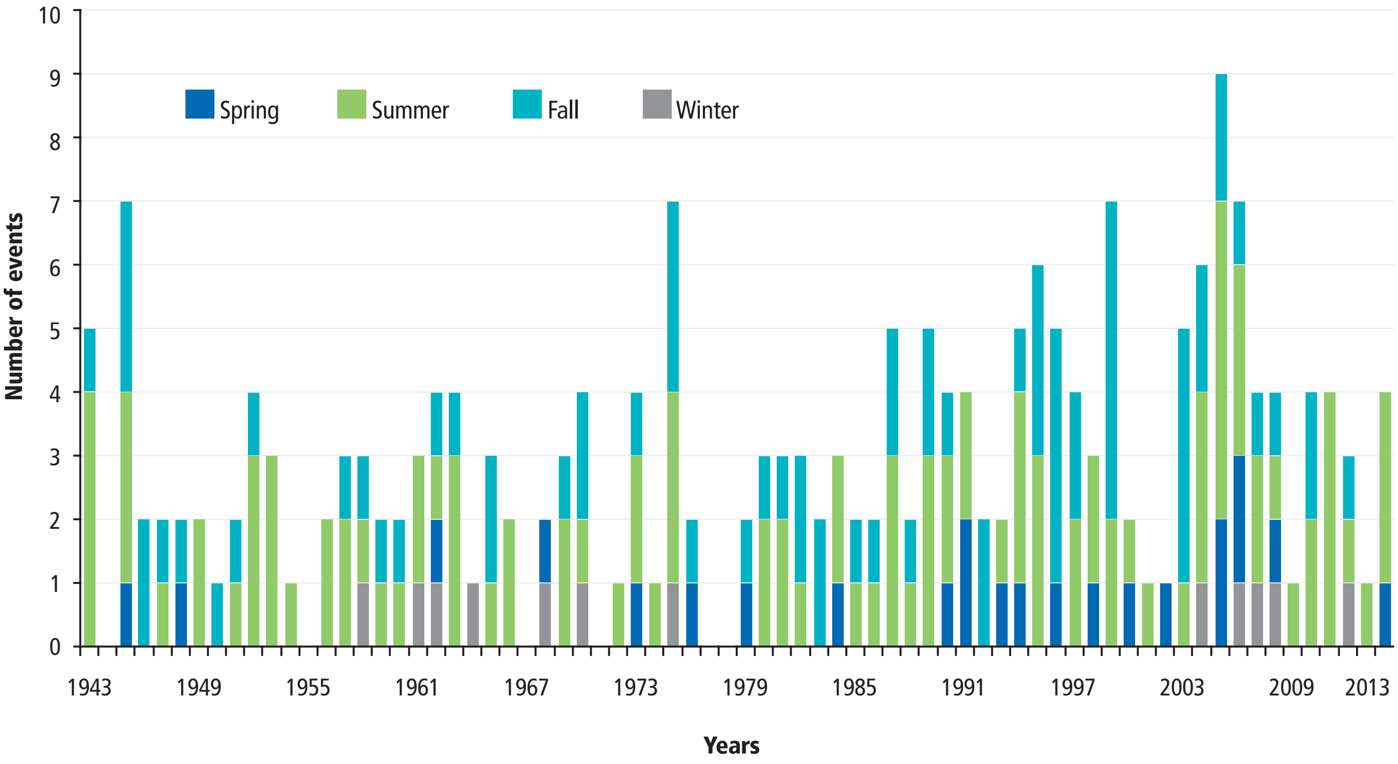
HISTORICAL PERIOD

From 1943 to 2014, we saw an increase in the number of heavy rainfalls on the Montréal Urban Agglomeration's territory (see Figure 5.1). The number of events has gone up in all seasons, with the most marked increases in spring, summer and fall.

FIGURE 5.1

NUMBER OF DAYS DURING WHICH RAINFALL EXCEEDED 30 MM

Source: Data from the weather station at the Montréal-Trudeau International Airport.



The intensity of rains also climbed by about 10% from 1942 to 2014 (see Figure 5.2).

FIGURE 5.2

EVOLUTION OF RAINFALL QUANTITIES ON THE RAINIEST DAY OF THE YEAR

Source: Data from the weather station at the Montréal-Trudeau International Airport.

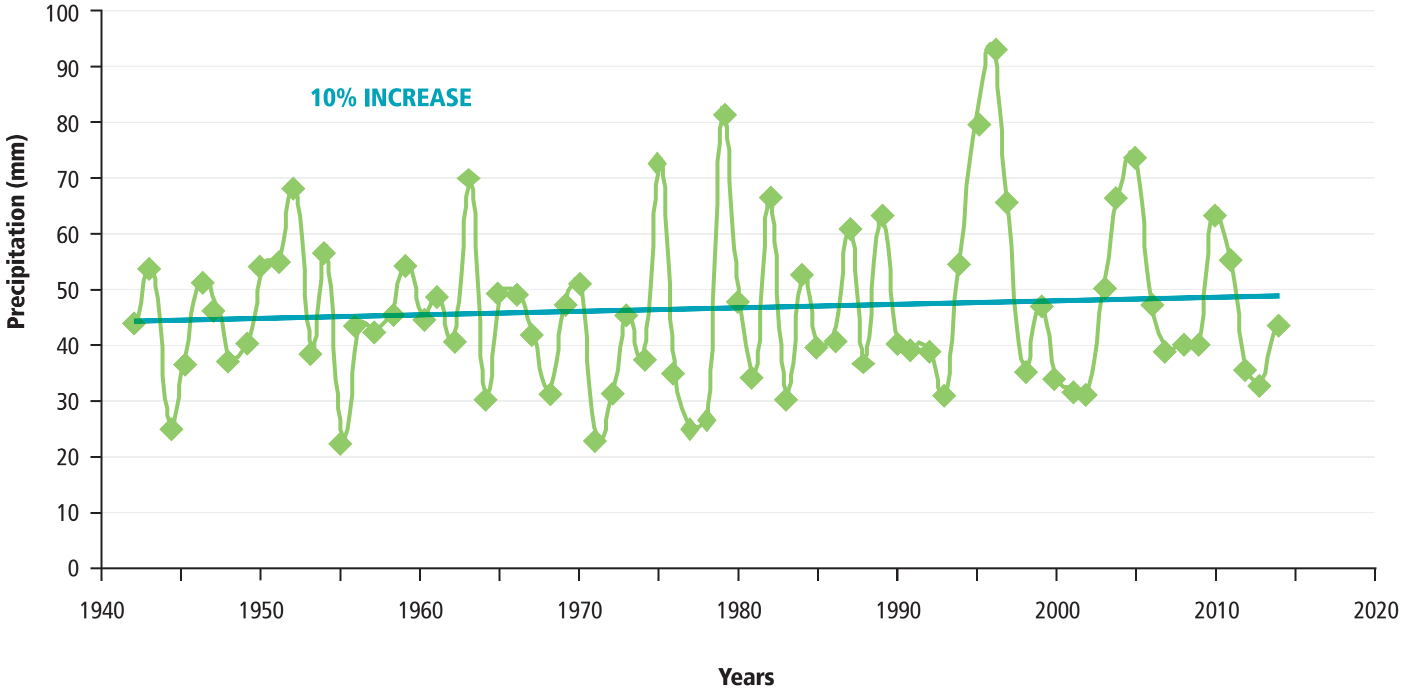
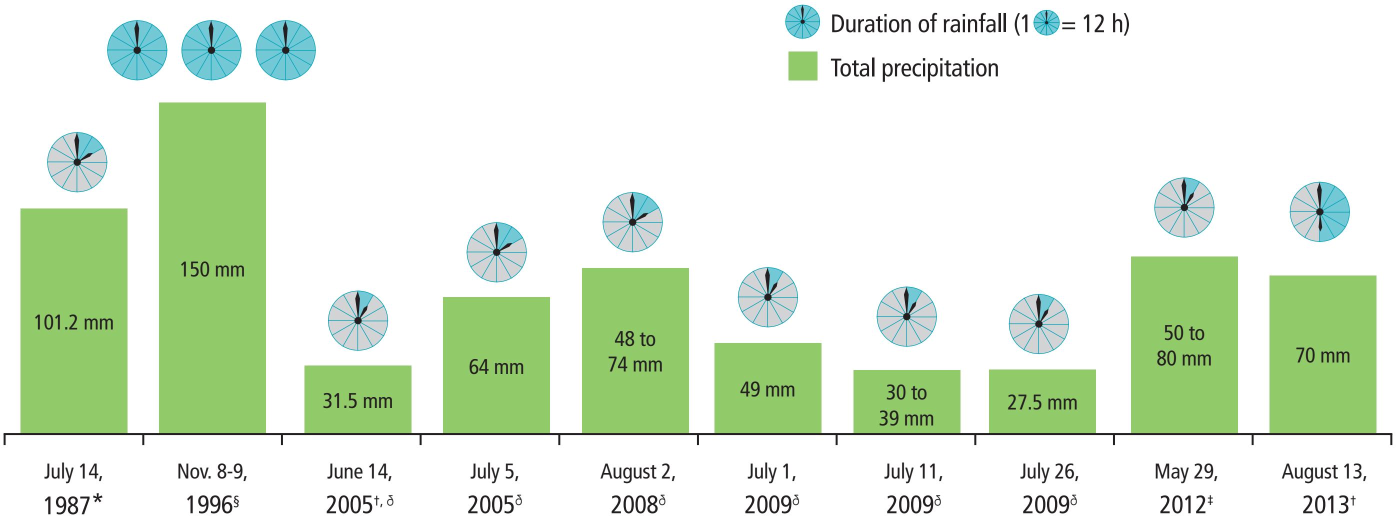


Figure 5.3 presents a few notable heavy rainfall events that occurred between 1983 and 2013. For example, on May 29, 2012, downpours drenched Montréal. The rain that fell in less than an hour caused flooding in various areas of the city, which led to numerous road and tunnel closures. As well, a number of Montréal underground shopping centres had to be quickly evacuated and closed, along with metro stations on the orange line between Berri-UQAM and Lionel-Groulx stations. Nearly 15,300 homes lost power.[92]

Place-D'Armes metro station flooded after the storm of May 29, 2012.
Credit: © André Pichette, *La Presse*

FIGURE 5.3
SOME NOTABLE RAINFALL EVENTS IN THE MONTRÉAL AGGLOMERATION, 1983-2013



* Bergeron, L., Vigeant, G. & Lacroix, J. (1997). *Impacts et adaptation à la variabilité et au changement du climat au Québec. Volume 5 of the Étude pan-canadienne sur les impacts et l'adaptation au climat*, [online], collaboration between Environment Canada and the Association de climatologie du Québec, 270 p. [publications.gc.ca/collections/Collection/En56-119-3-1997F.pdf].

† Climat Québec. *Weather events summaries*, [online]. [www.climat-quebec.qc.ca/home.php?id=summary_weather_events&mpn=climate_mon&lg=en].

‡ Environnement Canada. "The Year of the Urban Flood," *Canada's Top Ten Weather Stories for 2012*, [online], updated on June 21, 2013. [www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=D05E090A-1].

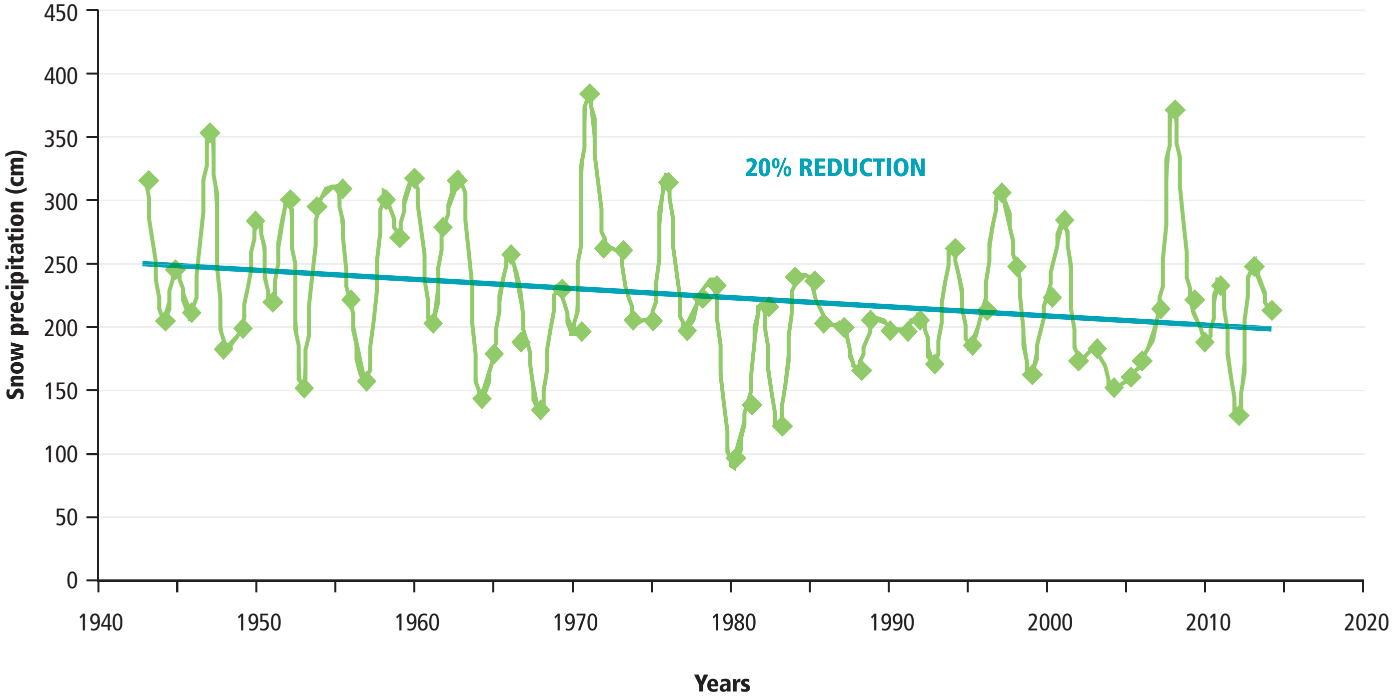
§ Public Safety Canada. *The Canadian Disaster Database*, [online], updated on July 30, 2014. [www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx] (Accessed on June, 19 2015.)

ð Data from the Direction de l'épuration des eaux usées (wastewater purification division) of the Ville de Montréal's Service de l'eau (water department), using the rain gauge network.

In parallel with the increased frequency and intensity of heavy rainfalls, we have also seen a 20% or so drop in the quantity of annual snowfall amounts on the Montréal Urban Agglomeration (see Figure 5.4), a trend also recorded in the southern region of Québec.

FIGURE 5.4
EVOLUTION OF SNOWFALL AMOUNTS, 1942-2014

Source: Data from the weather station at the Montréal-Trudeau International Airport.

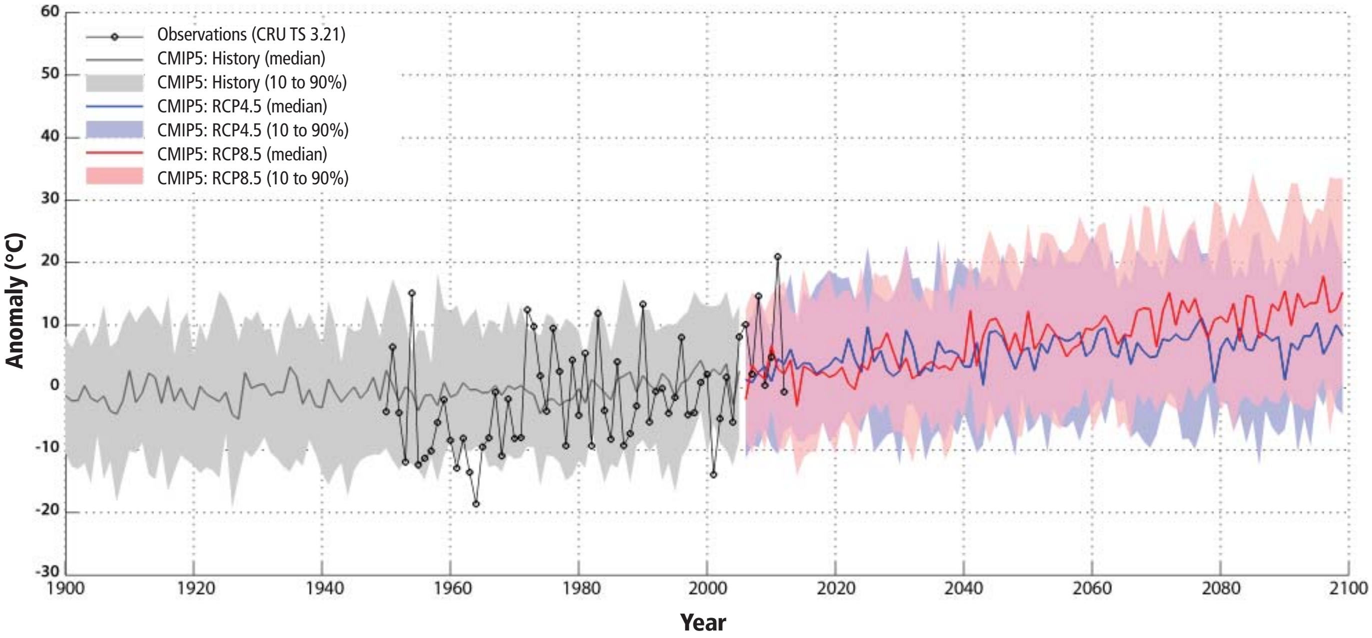


CLIMATE PROJECTIONS

The trend we have observed toward increased precipitation, in particular heavy rainfalls, is confirmed by Ouranos's climate projections for southern Québec. By 2050, annual precipitation should increase by 3 to 14% according to emissions scenarios (see Figure 5.5). The projections also show a stronger emphasis on rainfalls in winter, from 2 to 27%, and in spring, from 3 to 18%.[122]

We also expect a significant increase in the frequency and intensity of heavy rainfall episodes. The intensity of heavy rainfall episodes should increase by 10 to 25% by 2100 according to various scenarios. According to Ouranos, the return period will be significantly shorter for the annual maximum of daily accumulated precipitation. In other words, a rainfall of a given intensity whose return period was 20 years in the 1986-2005 range could recur more frequently in the 2046-2065 range, with a return period of around 7 to 10 years, across all of Québec. For the Montréal Urban Agglomeration, we need to expect more and more frequent heavy rainfall episodes. As for the violent winds that sometimes come along with these heavy rainfall episodes, we discuss them in the chapter on destructive storms.

FIGURE 5.5
EVOLUTION OF ANOMALIES (%) IN TOTAL ANNUAL PRECIPITATION, RECORDED (1950-2012) AND SIMULATED (1900-2100), FOR THE SOUTHERN QUÉBEC REGION INCLUDING MONTRÉAL



Note: Evolution of average total annual precipitation anomalies recorded (1950-2012) and simulated (1900-2100) for the southern Québec region, including Montréal, for the historical period (grey) and the greenhouse gas emissions scenarios RCP4.5 (blue) and RCP8.5 (red).* The anomalies are calculated in relation to the 1971-2000 average.**

*Scenarios RCP8.5 and RCP8.5 correspond to an energy forcing, due to GHG emissions, of 4.5 watt/m² and 8.5 watt/m² in 2100. A more detailed explanation is provided in the Background chapter.
**Figure excerpted from the Ouranos document *Vers l'adaptation – Synthèse des connaissances sur les changements climatiques au Québec*, 2014 edition. [www.ouranos.ca/fr/synthese2014/doc/Partie_1_ANNEXE_B.pdf].

IMPACTS

Figure 5.6 illustrates the impacts of heavy rainfalls on the Montréal Urban Agglomeration. The impacts are split into four categories: built environment, natural environment, socioeconomic issues and municipal operations. The impacts of each category are explained below.

FIGURE 5.6
EXAMPLES OF POTENTIAL IMPACTS OF HEAVY RAINFALLS ON THE MONTRÉAL AGGLOMERATION

Built environment

Public infrastructures

- Damages to the road network and related structures
- Damages to the underground utilities network
- Damages following an incident related to the transportation of hazardous materials
- Increased demand on infrastructures beyond their capacity (pipes, pump stations, etc.)
- Faster deterioration of brick sewer pipes

Residential infrastructures - ICI

- Damages to homes or buildings (landslides, floods, sewer backflow and water infiltrations)

Socioeconomic issues

Health

- Health problems caused by mould growth
- Epidemics of water-borne gastrointestinal illnesses due to sewer backflow and floods
- Disease caused by contaminated swimming water
- Vector-borne diseases
- Psychological distress

Expenses for individuals

- Possible reduction of insurance coverage
- Personal economic losses
- Costs related to destroyed goods (damaged buildings)

Inconveniences and accidents

- Inconveniences related to road mobility (road accidents, slowed or blocked traffic)
- Inconveniences related to service interruptions on underground utilities other than power outages

Natural environment

Plants

- Decrease of certain insect populations

Insects

- Creation of temporary ponds that may foster the growth of mosquito larvae which are vectors for diseases such as the West Nile Virus (WNV)

Bodies of water

- Pollution of watercourses
  - » Leaching of nutrients and pollutants
  - » Sewer overflows
- River bank erosion and slope instability

Municipal operations

Infrastructures

- Delays on construction sites

Cost increases

- To drinking water production, due to a higher number of sewer overflows upstream from water intakes
- To wastewater treatment: higher volume of collected water and more frequent peak flows (increased dosage of chemical products, higher demand placed on equipment)

Health and safety

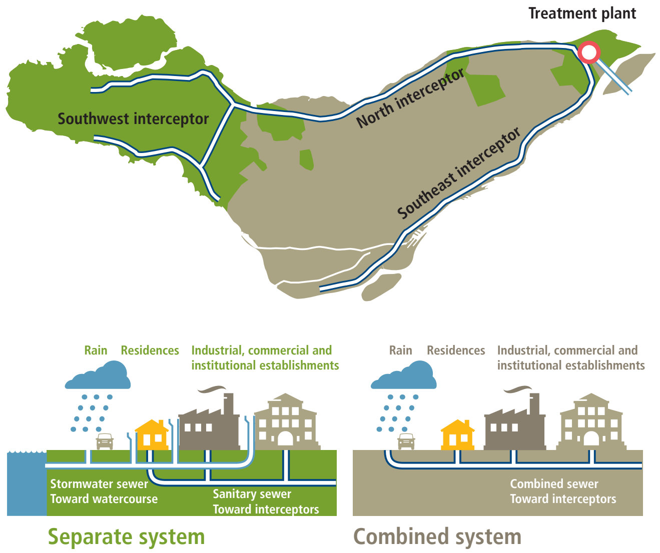
- Increased risk on construction sites due to slope instability

IMPACTS ON THE BUILT ENVIRONMENT

No municipal sewer system is designed to handle the large amounts of water that heavy rainfalls push into the underground pipes and structure. The resulting overflows can have negative impacts on the urban environment. The trouble more specifically concerns combined sewer systems, meaning sewers that handle both stormwater and sanitary wastewater.

Combined sewer systems cover two thirds of the territory. They are mostly present in the central and eastern areas of the island of Montréal. Separate sewers, for their part, are made up of two distinct systems: one that carries sanitary wastewater toward the treatment plant and the other that carries stormwater toward the watercourses on and around the island. These sewers only cover one third of the territory, mostly in the western and far eastern parts of the Agglomeration. Figure 5.7 shows the differences between combined and separate sewer systems, and their distribution on the island of Montréal.

FIGURE 5.7
DIFFERENCE BETWEEN COMBINED AND SEPARATE SEWERS



Source: Service de l'eau, Ville de Montréal.

At times of intense rain, the wastewater flow can rise drastically in combined sewers, and overflow risks may increase quickly in a relatively short time. Unprotected buildings are more vulnerable to sewer backflows. A sewer backflow is when water from the sewers flows back into the plumbing fixtures that are not protected with backwater valves.

As well, once the network is saturated, runoff water can no longer get in, so it accumulates at low points, which can cause flooding. This can lead to road, tunnel and metro station closures.

This phenomenon is worse in areas where the ground has been heavily sealed, since this prevents rainwater from soaking into the ground.

Basements are especially at risk of flooding, whether due to water infiltration, runoff water, or a sewer backflow. Factors such as poor ground levelling and the presence of a downward slope leading to the garage entrance put homes at risk of flooding. These floods cause damages, among others, to finished basements. As well, if no adequate protection and cleaning measures are taken, flooded basements are at higher risk of developing mould problems.

Heavy flows of stormwater runoff and urban flooding also cause damages to road networks, sewer systems and underground utilities.* This climate hazard can affect the transportation of hazardous materials.[158]

---

*According to the *Grand dictionnaire terminologique de l'Office québécois de la langue française* (translated from the definition of "commodité"), utilities are "Equipment that provides comfort to a residence, building or neighbourhood in keeping with our era's ways of life." They can be electricity, natural gas, telephone, Internet and more.

IMPACTS ON THE NATURAL ENVIRONMENT

Overall, heavy rainfalls have relatively few impacts on the environment. Vegetation and ecosystems in temperate zones are fairly resilient to intense precipitation in summertime. However, when precipitation falls in the form of rain in the winter, the impacts on the natural environment are much more significant. This specific case is addressed in the chapter about higher average temperatures.

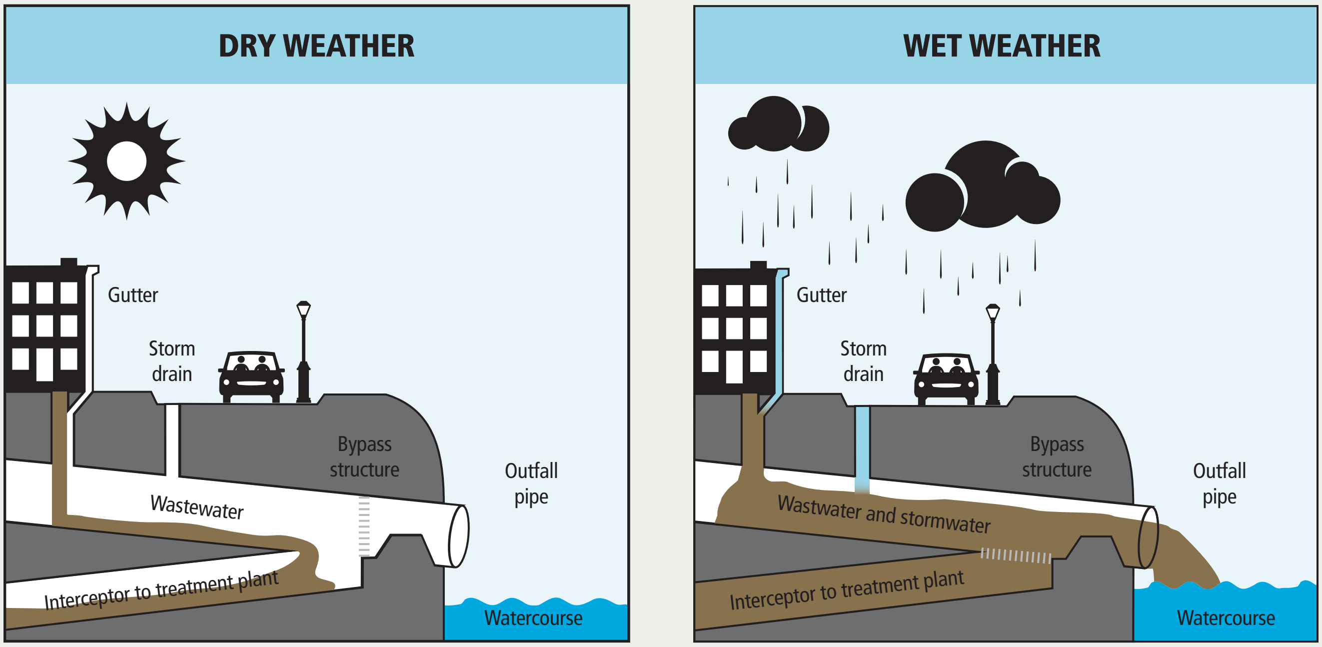
Nevertheless, here are a few environmental impacts of heavy rainfalls:

- increased erosion;
- contamination of watercourses[169] (via leaching of nutrients and pollutants and sewer overflows) – see the box for explanations about overflows;
- slope instability;
- reduced populations of certain insects[46, 115, 142];
- creation of temporary ponds that can foster the growth of mosquito larvae which are vectors for diseases such as West Nile Virus (WNV).[81]

OVERFLOW SYSTEMS

The island of Montréal's sewer systems (both main and secondary) include 162 overflow structures. An overflow structure is made up of an underground chamber that allows wastewater to drain in two directions depending on the operating conditions: the main sewer network and the receptor watercourse. In normal weather, meaning dry weather, and during snow melt and regular rainy periods, wastewater drains entirely toward the main sewer system before reaching the wastewater treatment plant. Sometimes, under the effects of stormwater flow collected during an exceptionally heavy rainfall, the sewer system does not have sufficient capacity to drain all the water toward the plant. Under these conditions, part of the water, a combination of stormwater and wastewater, flows toward the receptor watercourse for a short time. Of course, the receptor watercourse to the south is the St. Lawrence River, and to the north, Rivière des Prairies.

Excerpt translated from the Ville de Montréal's "Eau de Montréal" web page
[ville.montreal.qc.ca/portal/page?_pageid=6497,54389572&_dad=portal&_schema=PORTAL] (Accessed October 14, 2015).



Adapted from the United States Environmental Protection Agency (EPA).

IMPACTS ON SOCIOECONOMIC ISSUES

A number of impacts on socioeconomic issues were identified for the heavy rainfall climate hazard. Most of them ensue from the impacts on the built environment and the natural environment. The impacts on socioeconomic issues were split into three categories: population health, expenses for individuals, and inconveniences and accidents.

HEALTH

Floods may increase[83]:

- the prevalence of health problems caused by an increased presence of mould if adequate measures are not taken quickly after the flood. Mould appears shortly after a flood. When it develops to a significant degree, it can lead to serious health problems such as asthma and allergic reactions, with symptoms including irritation to the eyes, nose, throat and sinuses.
- the prevalence of gastrointestinal disease epidemics, most often related to people's contact with contaminated water and water levels in the flooded area. Water in a flooded area is not made up only of rainwater. It is often contaminated with wastewater. As a result, it may contain bacteria and viruses that are potentially harmful to human health.
- the prevalence of psychological distress. Flooding can cause material losses, which can lead to psychological distress among disaster victims.

The increased number of wastewater overflows into watercourses (see box on page 52) raises the quantity of pathogenic and pollutant organisms, which means that sometimes watercourses may be closed to recreational use.

As well, the increased frequency and intensity of heavy rainfalls may cause disease-vector insect populations to proliferate, which in turn may lead to a higher prevalence of vector-borne diseases.[61]

EXPENSES FOR INDIVIDUALS

Building floods generate major economic losses. First, they occasion costs related to destroyed and damaged goods. Second, they are a source of concern for insurance companies, which may reduce flood risk coverage. In recent years, the Insurance Bureau of Canada noted that about 50% of claims paid out for home insurance were for water-related damages. In addition, the costs related to natural disasters have been climbing exponentially since the 1960s.[32]

Floods may lead to health problems and economic losses.
Credit: © Olivier Pontbriand, *La Presse*

INCONVENIENCES AND ACCIDENTS

Floods are a major cause of inconveniences and accidents. The heavy rainfalls of July 14, 1987, in Montréal showered the city with nearly 100 mm of rain in some places, causing serious floods.[57] Many homes lost power, and the authorities had to evacuate people who were trapped in their vehicles on boulevard Décarie.[128] The high volume of precipitation led municipal authorities on the island of Montréal to create the Bureau des mesures d'urgence (emergency measures bureau) in 1988, which later became the Centre de sécurité civile (civil safety centre).[40]

Urban flooding may hamper transportation, in particular by leading to road closures and traffic slow-downs. As well, submerged tunnels and overpasses, in addition to causing traffic problems, represent a danger to people's lives when they are caught in their vehicles. The risks of electrocution and electrification are also higher.

Lastly, during heavy rainfalls, flooding can also cause damage to the underground utilities network, which can lead to outages of varying degrees of severity, depending on the affected utility (electricity, telephone, Internet, etc.) and the length of the outage.

Boulevard Décarie, July 14, 1987
Credit: © *La Presse*

Boulevard Décarie on July 14, 1987, after 101.2 mm of rain fell in two hours.
Credit: © *La Presse*

IMPACTS ON MUNICIPAL OPERATIONS

In general, the impacts on municipal operations identified in Montréal due to the increased frequency and intensity of heavy rainfalls affect public works, drinking water production activities and wastewater treatment.

Heavy rains may impact some construction sites (ex.: asphalting works). The work can be delayed, which may cause delays for each successive step of the project. If there are slopes on a site, rain can render them unstable, requiring additional inspections to ensure site safety.

stm

To handle the risks that come with climate change, the Société de transport de Montréal (STM) is taking a range of measures to limit the vulnerability of our network, ensure customer safety and maintain service in the case of adverse weather.

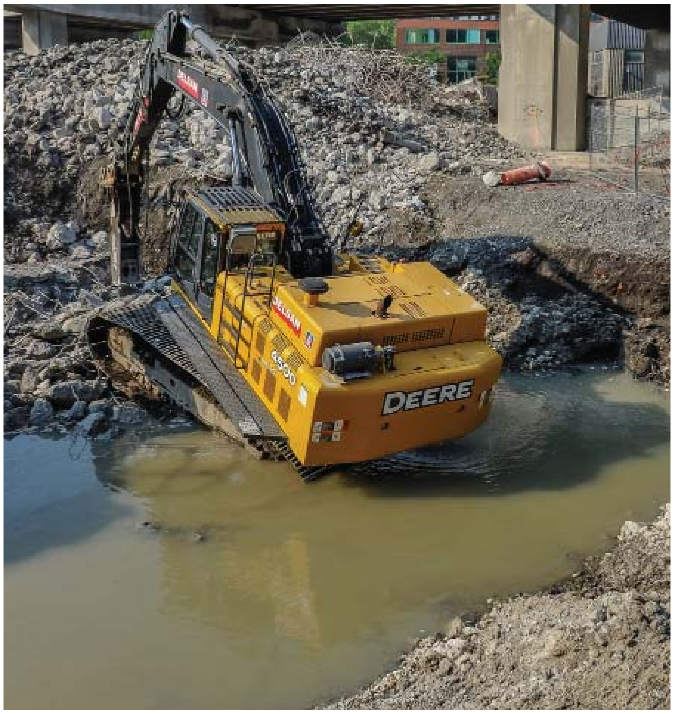
The metro system is equipped with pumping systems to draw off water that may enter the tunnels during heavy rainfalls or river floods. The STM is also carrying out preventative construction work on the system (joint waterproofing, drainage systems, etc.) to limit these risks.

As much as possible, the STM includes greening measures in its construction and renovation projects, to help limit runoff water. We also install retention basins when necessary.

The STM's emergency measures coordination unit (the Unité de Coordination des Mesures d'Urgence, or UCMU) coordinates all of our emergency response actions, in particular those related to extreme climate conditions, in collaboration with the Ville de Montréal and the Agglomeration's operating centres and emergency measures offices.

The STM is also a partner to the Ville de Montréal's emergency measures plans and the Agglomeration's civil safety plans. As such, the STM can be mobilized to move vulnerable people during floods (for instance, senior's home residents).

Contributed by the STM



Water accumulation on a construction site
Credit: © Denis Labine, Ville de Montréal

In another respect, sewer overflows that happen upstream from drinking water intakes, and heavy runoff water in times of heavy rainfalls, can change the quality of the water we source.[48] Water treatment may then require fast adjustment. The drinking water produced under these conditions nevertheless remains of excellent quality, but rapid fluctuations in raw water quality create periods of vulnerability.

The volume of water collected by the sewer network, particularly by combined sewers, is much higher during heavy rainfall periods. This places a heavier demand on equipment associated with the drainage network[153] and leads to the need for higher quantities of chemical products to treat wastewater.

VULNERABILITY ANALYSIS

Once we established about the impacts of heavy rainfalls, we were able to carry out a hazard-specific vulnerability analysis for the Montréal Urban Agglomeration. As some of these impacts affect groups of people who live in particular areas of the Agglomeration, as well as infrastructures whose placement is clearly known, we were able to perform a geographic vulnerability analysis. The methodology we employed is set out in Appendix A.

This section presents the areas of the Agglomeration affected by this hazard, along with environmental, territorial and social susceptibilities, whether they are mapped or not. Lastly, the Vulnerability to Heavy Rainfalls section on page 61 shows and discusses the maps we obtained through geographical analysis.

Urban runoff water
Credit: © Robert Lawton, Wikipedia (CC BY-SA 2.5)

ZONES AFFECTED BY THE HAZARD (PHYSICAL SUSCEPTIBILITY)

The zones of the Agglomeration where runoff water could accumulate and cause surface flooding are shown in dark blue on Map 5.4 on page 61. For a sector to be affected by surface flooding, rainwater must be able to drain toward that sector and accumulate. A number of factors come into play for this.

- **Topography**. Places located in valleys are susceptible to runoff and rainwater accumulation.
- **Vegetation**. Vegetation helps slow down runoff water. As well, the soil under the vegetation can absorb water from precipitation.
- **Soil**. Some types of soil absorb rainwater quickly, while others are almost sealed. The soil's thickness, permeability, texture, porosity, density and initial water content (previous humidity conditions) all influence its capacity to absorb runoff water.
- **Ground occupation**. The presence of buildings deviates the flow of runoff water, while roads and buildings cover the ground, sealing it and preventing it from absorbing water from precipitation.

We used all these factors to design the runoff water model we used to produce Map 5.4. Vegetation and sealed surfaces strongly influence the proportion of rainwater that turns into runoff, as shown in Figure 5.8.

To create the map shown on page 61, we modeled the runoff for a very heavy rainfall affecting the entire island of Montréal for two hours. We also supposed that the entire sewer system was saturated, and that as a result, no more water could drain through it.

The map we obtained overestimates the zones vulnerable to surface flooding because it is basically impossible that such a rainfall could happen over the entire island of Montréal at the same time. Intense rains are a very localized meteorological phenomenon that doesn't affect the entire agglomeration at once. As well, it is highly unlikely that the island of Montréal's entire sewer system would be saturated. We chose a scenario that overestimates vulnerable areas in order to make sure that all these areas would be clearly included on the map.

ENVIRONMENTAL SUSCEPTIBILITY

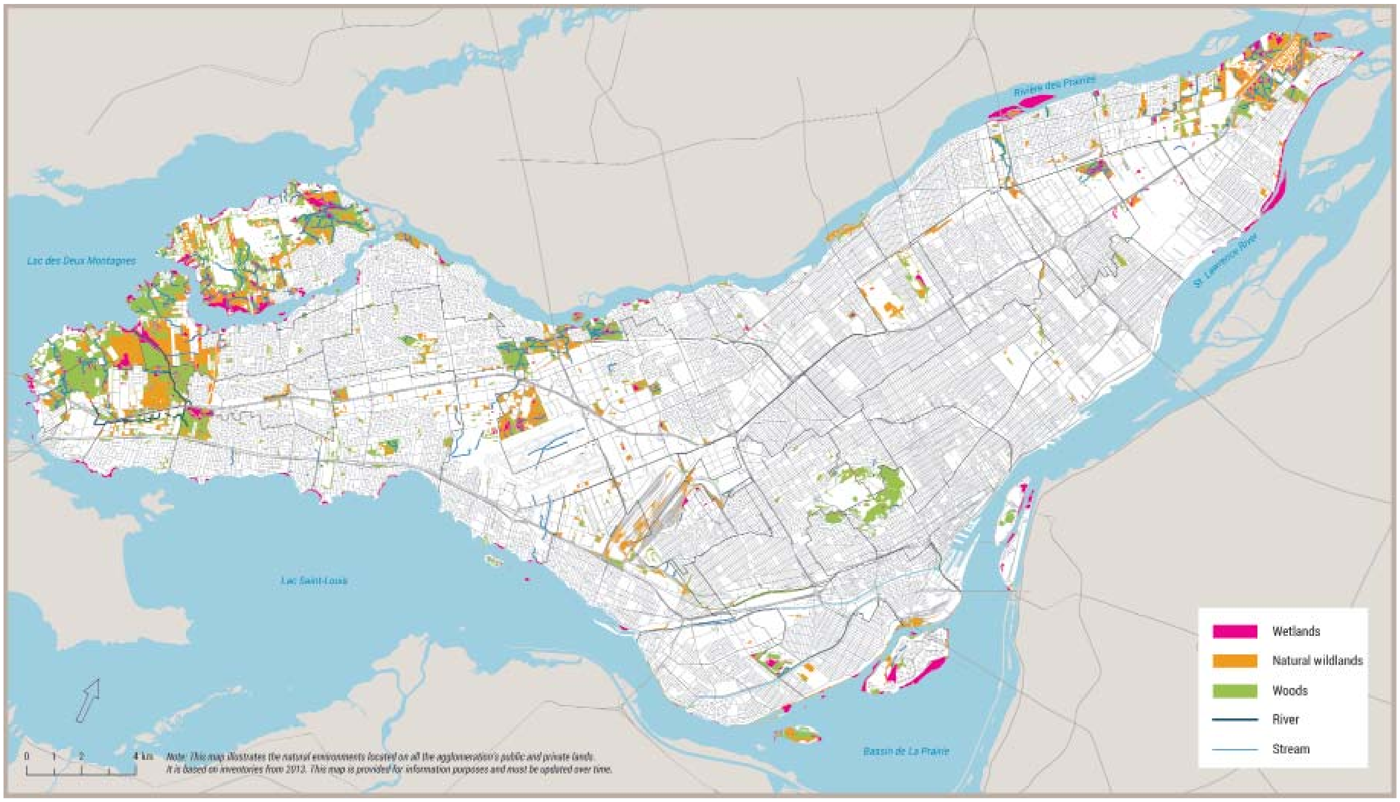
Because of the limited availability of data, environmental susceptibility to heavy rainfalls was not taken into account in the map-based vulnerability analysis for the Montréal Urban Agglomeration.

As we saw in the Impacts on the Natural Environment section (page 52), ecosystems in temperate regions experience relatively few impacts in times of heavy summer rainfalls. Nevertheless, some systems are more vulnerable, particularly watercourses, wetlands and riparian strips (see Map 5.1 on the next page).

FIGURE 5.8
IMPACTS OF URBANIZATION ON HYDROLOGICAL PARAMETERS

Source: British Columbia Ministry of Water, Land and Air Protection. *Stormwater Planning: A Guidebook for British Columbia*, [online], May 2002, 244 p. [www.toolkit.bc.ca/resource/stormwater-planning-guidebook-british-columbia] (Accessed July 15, 2015.)

MAP 5.1
NATURAL ENVIRONMENTS



Note: This map illustrates the natural environments located on all the agglomeration's public and private lands. It is based on inventories from 2013. This map is provided for information purposes and must be updated over time.

Source: *Schéma d'aménagement et de développement de l'agglomération de Montréal*, January 2015.

TERRITORIAL SUSCEPTIBILITY

Map 5.2 on page 61 shows the Montréal agglomeration's territorial susceptibility to heavy rainfalls.

As described in the Impacts on the Built Environment section (page 51), many infrastructures are sensitive to heavy rainfalls. Those that were taken into account in the geographic analysis are described below. The territorial susceptibility analysis takes into account the presence of these infrastructures on the land. Density data was used when geographic data on their more detailed characteristics were not available.

- **Stormwater, sanitary and combined sewer systems**. The volume and flow of water increase in the stormwater and combined sewer systems during heavy rainfalls, which can place heavier demands on some of the equipment associated with the drainage network.[153]
- **Buildings**. Buildings, particularly those with finished basements, may flood during heavy rainfalls. Table 5.1 shows the various factors that play into buildings' vulnerability to heavy rainfalls.
- **Access to critical sites and places of interest**. During heavy rainfalls, areas of prime importance may become inaccessible, which may cause many problems. These places are called critical sites (hospitals, police stations, drinking water plants, etc.) or places of interest (schools, metro stations, bridge entrances and exits, etc.).
- **Underground utilities**. Water infiltration into the underground utilities may lead to failure.
- **The road network**. Runoff water from heavy rainfalls, and infiltration into road foundations, contribute to the wear and breakage of these infrastructures (ex.: roadways and culverts).

TABLE 5.1
BUILDINGS' SUSCEPTIBILITY FACTORS TO HEAVY RAINFALLS

Location-related weakening factors
• Old neighbourhood • Low zone or in a basin (physical susceptibility)
Building-related weakening factors
• Lack of protection for equipment and plumbing devices located in the basement • Finished and lived-in basements • Basement windows located below or near ground level • Insufficient ground levelling, which drains runoff water toward the building • Garage entrance with a downward slope toward the house • Poorly functioning foundation drain • Foundation drain connected directly to the sewer* • Building that has flooded in the past and whose problems were not corrected • Foundations not waterproofed
Building-related protection factors
• Backwater valve properly maintained • Basement windows with curb-stones • Foundation drain** • Presence of a saddle at the top of the driveway if it slopes downward toward the garage • Landscaping that draws water away from the building

*Ville de Montréal. Leaflet: *Sewer backup solutions - Separate system*, [online], Service de l'eau, February 2014. [ville.montreal.qc.ca/pls/portal/docs/PAGE/EAU_FR/MEDIA/DOCUMENTS/MEP_SEPARATIF_ang.pdf] (Accessed July 20, 2015.)

**Institute for Catastrophic Loss Reduction. *Protect Your Home from Basement Flooding*, [online], 2011, 16 p. [www.iclr.org/images/ICLR_-_Basement_Flooding_Brochure_-_English_Final.pdf] (Accessed July 15, 2015.)

SOCIAL SUSCEPTIBILITY

Map 5.3 on page 61 shows social susceptibility to heavy rainfalls in the Montréal Urban Agglomeration.

As described in the Impacts on Socioeconomic Issues section (page 53), many people are vulnerable to the impacts of heavy rainfalls, such as women, children aged 0 to 15, seniors aged 65 and up, people living alone and underprivileged people.

The impacts considered in the geographic analysis are as follows:

- health problems caused by the presence of mould;
- illness caused by the contamination of swimming pool water;
- vector-borne and zoonotic diseases;
- psychological distress;
- gastrointestinal disease caused by sewer backflows and floods;
- accidents other than road accidents;
- inconveniences related to the interruption of utilities other than electricity (telecommunication, gas, etc.);
- economic losses.

Certain impacts that affect some groups of people were not considered in the geographic analysis because the data on the subject were insufficient, such as the location where people suffering from respiratory problems live (they are sensitive to mould problems that may arise after a flood if adequate measures are not taken quickly after the flood), or because the group of people is relatively evenly distributed across the island of Montréal, such as for people who practice aquatic activities (they are more vulnerable to illnesses caused by contaminated swimming pool water).

VULNERABILITY TO HEAVY RAINFALLS

The Montréal Urban Agglomeration's vulnerability to heavy rainfalls (Map 5.5) was calculated by adding together territorial and social susceptibilities, and multiplying that by physical susceptibility, that is, considering territorial and social susceptibilities only in areas that present the potential for water accumulation. This map showing vulnerability to heavy rainfalls is based on the choice of susceptibility factors we determined using the geographic vulnerability analysis methodology described in Appendix A.

Topography is the factor with the greatest influence on physical susceptibility (potential for water accumulation). In looking at Map 5.6, Mount Royal clearly stands out as a zone with very little potential for runoff water accumulation, given its elevation. If we compare maps 5.4 and 5.6, the influence of topography on runoff water is particularly evident in the central portion of the island.

The other parameter that heavily influences physical susceptibility to heavy rainfalls is urbanization. Older neighbourhoods, located in the centre of the island and home to a high density of inhabitants, buildings and streets (Ahuntsic-Cartierville, Côte-des-Neiges–Notre-Dame-de-Grâce, Côte-Saint-Luc, Hampstead, Plateau-Mont-Royal, Rosemont–La Petite-Patrie, Saint-Laurent, Sud-Ouest, Verdun, and Villeray–Saint-Michel–Parc-Extension) feature areas with water accumulation potential on a large portion of their territory. The island's west end and part of its east end are less mineralized areas with more vegetation, which helps the soil absorb some of the rainwater, reducing the accumulation of water in basins.

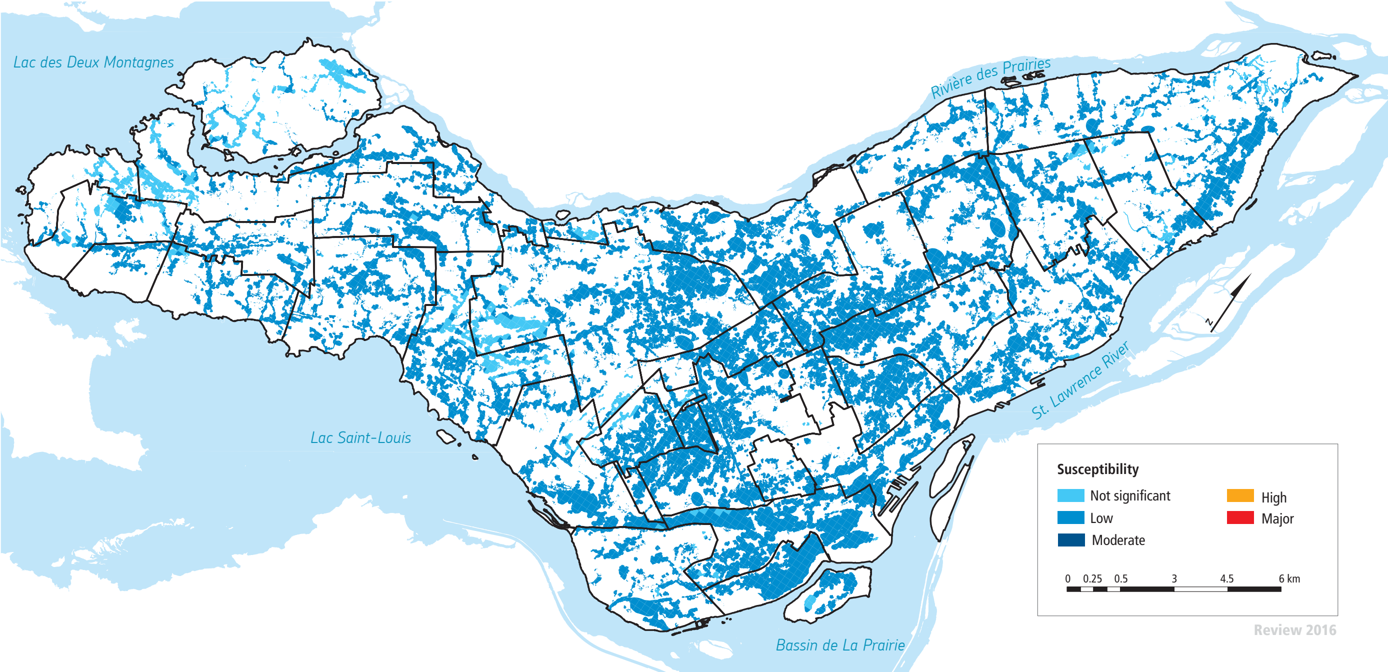
Just like for physical susceptibility, older neighbourhoods that feature high population and infrastructure density are the ones with the highest territorial susceptibility, since they have a higher density of vulnerable infrastructures, as shown on Map 5.2.

It is more difficult to identify a determining factor for social susceptibility (Map 5.3). The presence of underprivileged people increases social susceptibility, since these individuals are more heavily affected by a number of the impacts of heavy rainfalls. Elderly people are also strongly affected. Since a high proportion of elderly people live alone (another social susceptibility factor), and are often underprivileged, they constitute a particularly sensitive group.

Map 5.5 shows that a good part of the agglomeration presents low or moderate vulnerability to heavy rainfalls, and that the most vulnerable areas are in the central and eastern parts of the island. Only a few zones are highly vulnerable, because they are located in areas that risk accumulating runoff water and feature the presence of vulnerable infrastructures and populations.

MAP 5.2

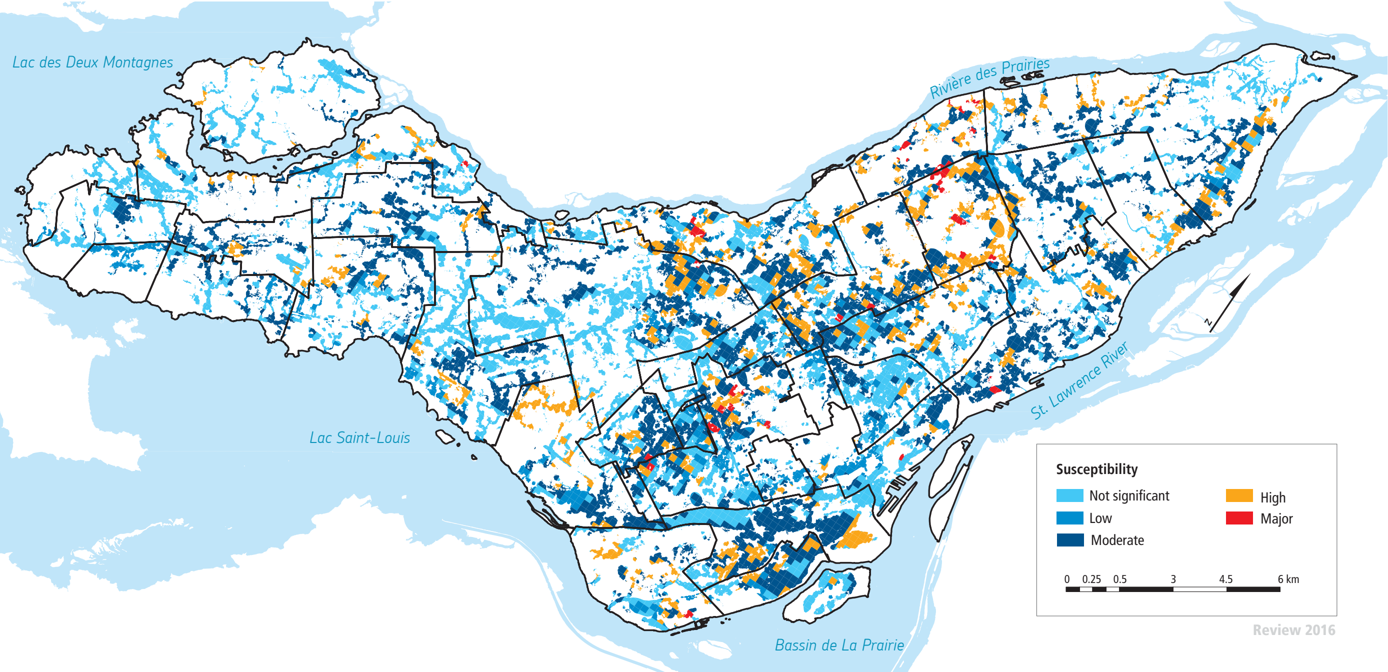
TERRITORIAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO FLOODING CAUSED BY EXCESSIVE RUNOFF WATER



Review 2016

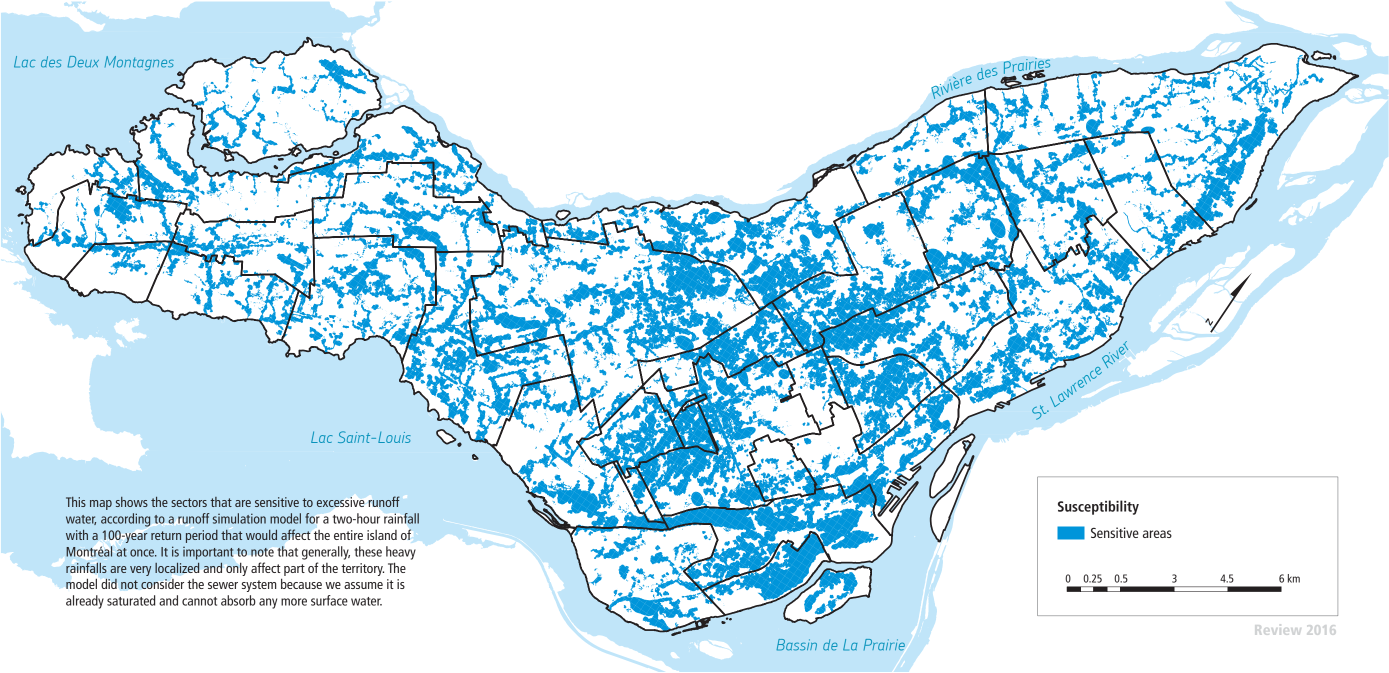
MAP 5.3

SOCIAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO FLOODING CAUSED BY EXCESSIVE RUNOFF WATER



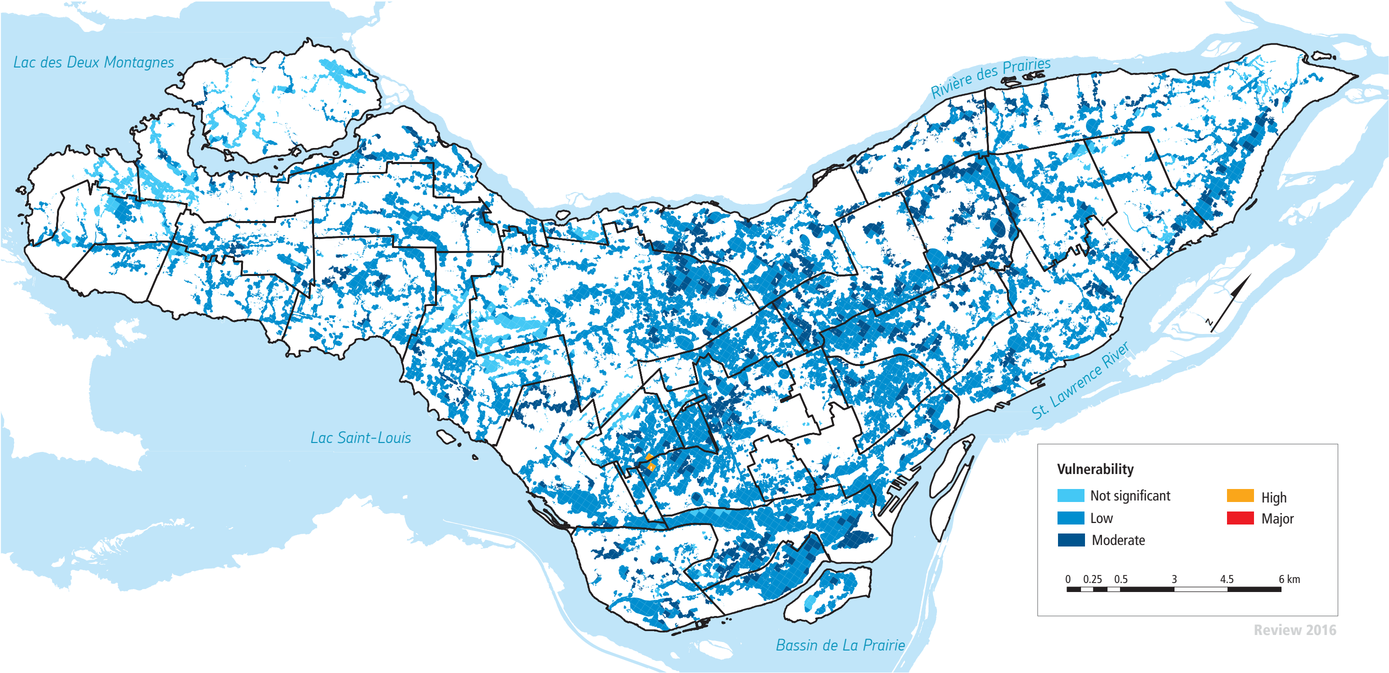
Review 2016

MAP 5.4
AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO FLOODING CAUSED BY EXCESSIVE RUNOFF WATER

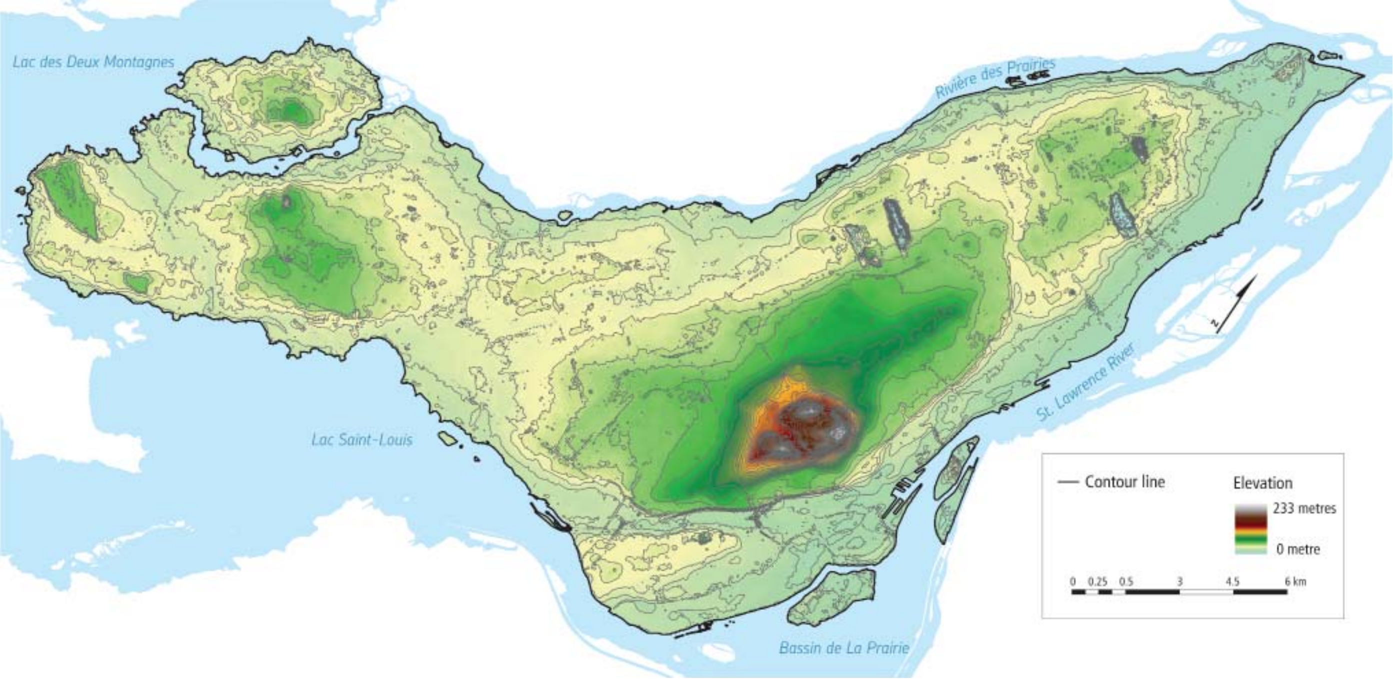


This map shows the sectors that are sensitive to excessive runoff water, according to a runoff simulation model for a two-hour rainfall with a 100-year return period that would affect the entire island of Montréal at once. It is important to note that generally, these heavy rainfalls are very localized and only affect part of the territory. The model did not consider the sewer system because we assume it is already saturated and cannot absorb any more surface water.

MAP 5.5
VULNERABILITY TO HEAVY RAINFALLS IN THE MONTRÉAL AGGLOMERATION



MAP 5.6
TOPOGRAPHY OF THE MONTRÉAL AGGLOMERATION



HEAT WAVES

Heat waves, extreme heat, oppressive heat... there are many ways to talk about an extremely hot temperature event. The terminology varies from one area of the planet to the next based on climate "habits" and each area's tolerance threshold.

One recent study[47] documented the increased number of heat waves across the globe since the 1950s. The number of hot nights and days also increased significantly across most areas, particularly in Québec, along with the duration of heat waves. What does that look like for the Montréal agglomeration?

DEFINITIONS OF HEAT WAVES IN CANADA

Heat wave: Period of at least three consecutive days during which temperatures reach or exceed 30 °C during the day.

Oppressive heat: Environment Canada issues an oppressive heat and humidity warning when they expect the air temperature to reach or exceed 30 °C and the humidex indicator* to reach or exceed 40.

Extreme heat: Public health authorities use this expression to designate a period of three consecutive days when the high reaches or exceeds 33 °C, and the low doesn't dip below 20 °C, or when the temperature doesn't drop below 25 °C for two consecutive nights.**

*The humidex is a Canadian innovation that was first used in 1965. It describes how hot, humid weather feels to the average person. The humidex combines the temperature and humidity into one number to reflect the perceived temperature. (From the Environment Canada website's "Spring and Summer Weather Hazards" section.) [www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=6C5D4990-1#humidex]

**MétéoMédia. *Canicule, vague de chaleur, chaleur accablante... Des termes à démystifier !*, [online], updated June 27, 2014. [www.meteomedia.com/nouvelles/articles/canicule-vague-de-chaleur-chaleur-accablante-des-termes--dmler/3905/] (Accessed July 22, 2015.)

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CLIMATE EVOLUTION

HISTORICAL PERIOD

Montréal has experienced many heat waves in the last 70 years. More specifically, we analyzed the key events of the last 30 years which, among other things, caused numerous deaths (see Table 6.1).

TABLE 6.1
MAJOR HEAT WAVE EVENTS FOR THE MONTRÉAL AGGLOMERATION

DATE	AVERAGE TEMPERATURE	NUMBER OF DEATHS*†
July 9-13, 1987	32.6 °C	169
June 16-18, 1994	33.1 °C	103
July 1-3, 2002	33.2 °C	30
August 14-18, 2009	30.7 °C	Not available
July 5-10, 2010	33 °C	106
July 20-23, 2011	32.9 °C	13
July 14-19, 2013	32 °C	6

* Agence de la santé et des services sociaux de Montréal (2014). *Chaleur accablante ou extrême 2014 - Plan régional de prévention et de protection Guide à l'intention des établissements de santé*, [online], 128 p. [collections.banq.qc.ca/ark:/52327/bs2394682].

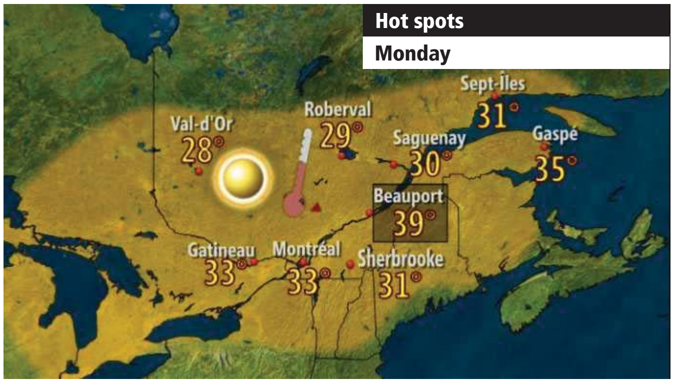
† Climat Québec. *Bilan d'événements météo*, [online]. [www.climat-quebec.qc.ca/home.php?id=summary_weather_events&mpn=climate_mon].

We need to consider a number of aspects when studying heat waves: their duration, the humidity level and the day/night contrast. A heat wave that lasts for a long time or has a high humidity level (high humidex) will be especially uncomfortable for the population. The same is true when nights don't cool down enough (when night temperature stays above 20 °C).

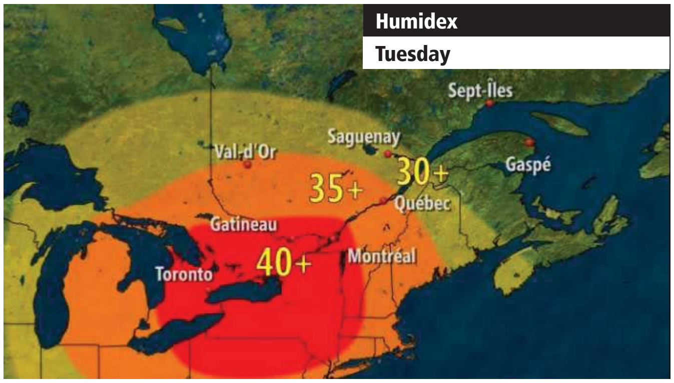
Figure 6.1 gives the example of the heat wave Montréal experienced from July 14 to 19, 2013, with a temperature of 33 °C on July 15 (see Figure 6.1 a) and a particularly high humidex of 40 on July 16 (see Figure 6.1 b). That 33 °C temperature was averaged for the Montréal agglomeration and does not reflect the disparities from one neighbourhood to the next. We must remember that areas prone to becoming intra-urban heat islands (IUHI) (a phenomenon detailed in the Impacts section), for example, may be 7 to 12 °C hotter[60] than elsewhere in the city at night.

FIGURE 6.1
HEAT WAVE MAPS FOR JULY 15 AND 16, 2013

a) Temperature (°C)



b) Humidex (or felt temperature)

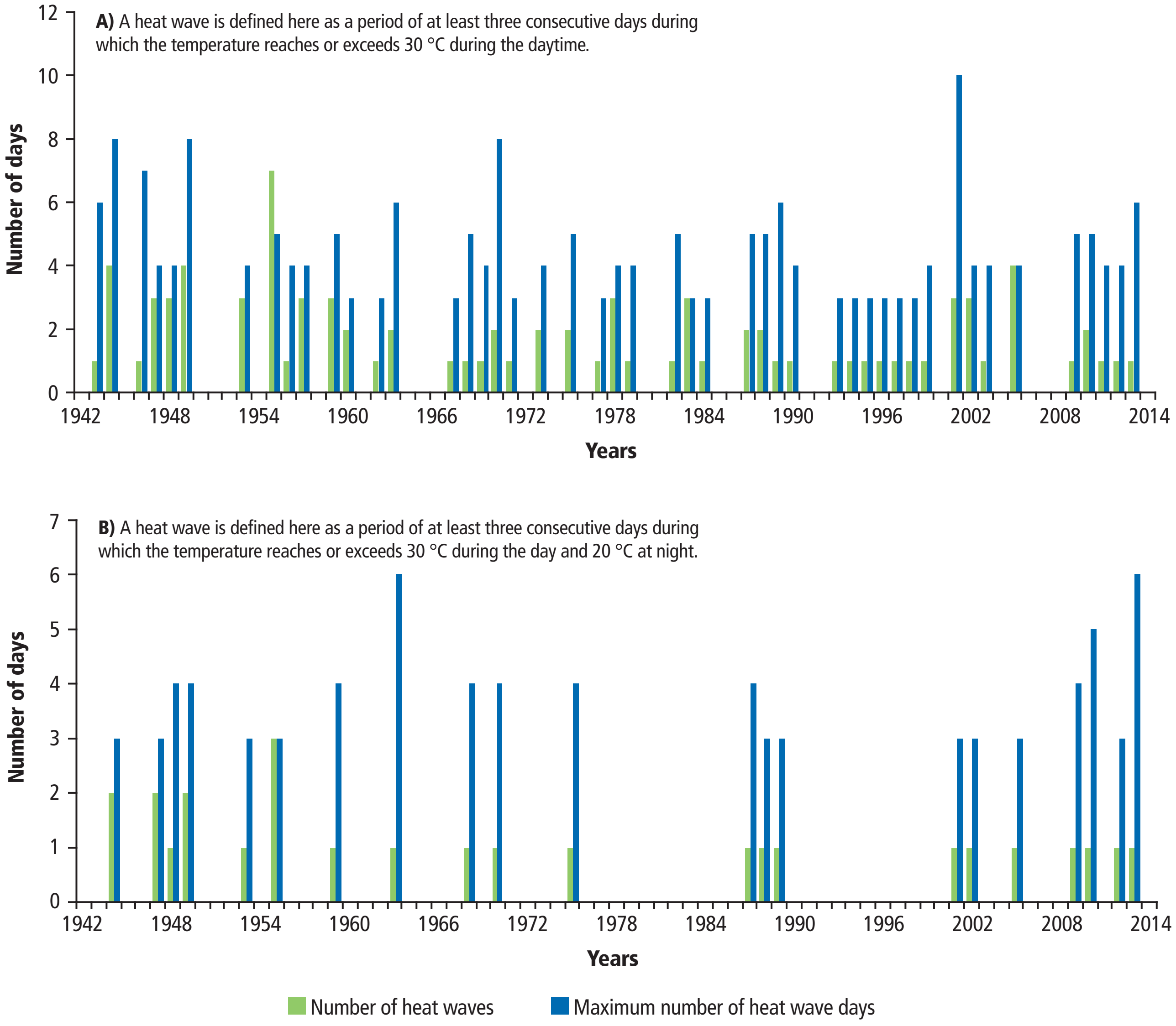


Source: MétéoMédia. *Canicule et vague de chaleur pour l'ensemble de la province*, [online], updated July 16, 2013. [www.meteomedia.com/nouvelles/articles/au-coeur-de-la-canicule/9102/] (Accessed July 22, 2015.)

It is hard to establish a significant trend in the evolution of heat waves in Montréal over the last 70 years, since such a trend greatly depends on the definition we choose for a heat wave. Except for a 10-day, record-length heat wave in 2001, the number of heat waves has been fairly stable on the Montréal agglomeration's territory if we use the definition set out in the introduction (see Figure 6.2 a). If we choose a definition of heat wave that also considers high night-time temperatures, we get a different evolution, and a trend that's even more difficult to discern (see Figure 6.2 b). However, it is clearly apparent that the 2000s were particularly marked by heat waves, especially when compared to the preceding two decades.

FIGURE 6.2
EVOLUTION OF THE NUMBER AND DURATION OF HEAT WAVES IN MONTRÉAL, 1942-2014

Source: Data from the weather station at the Montréal-Trudeau International Airport.



A) A heat wave is defined here as a period of at least three consecutive days during which the temperature reaches or exceeds 30 °C during the daytime.

B) A heat wave is defined here as a period of at least three consecutive days during which the temperature reaches or exceeds 30 °C during the day and 20 °C at night.

The temperature felt by the human body may be higher than the one shown on the thermometer when the air's humidity is high (high humidex). Humidity effectively hinders the sweating process that helps the body cool off. If we consider the evolution of the humidex indicator from 1953 to 2012 in Montréal, more specifically for nights (see Figure 6.3), we can see that the frequency of nights with a humidex above 30 has clearly increased. It is important to note that we analyzed the data collected at the Montréal-Trudeau International Airport station, which is minimally affected by the intra-urban heat island effect. So there could be a higher frequency of nights with a humidex above 30 in areas of the Montréal agglomeration that are more prone to becoming heat islands. Nights with oppressive heat and humidity are particularly hard on people, because they alter sleep quality.

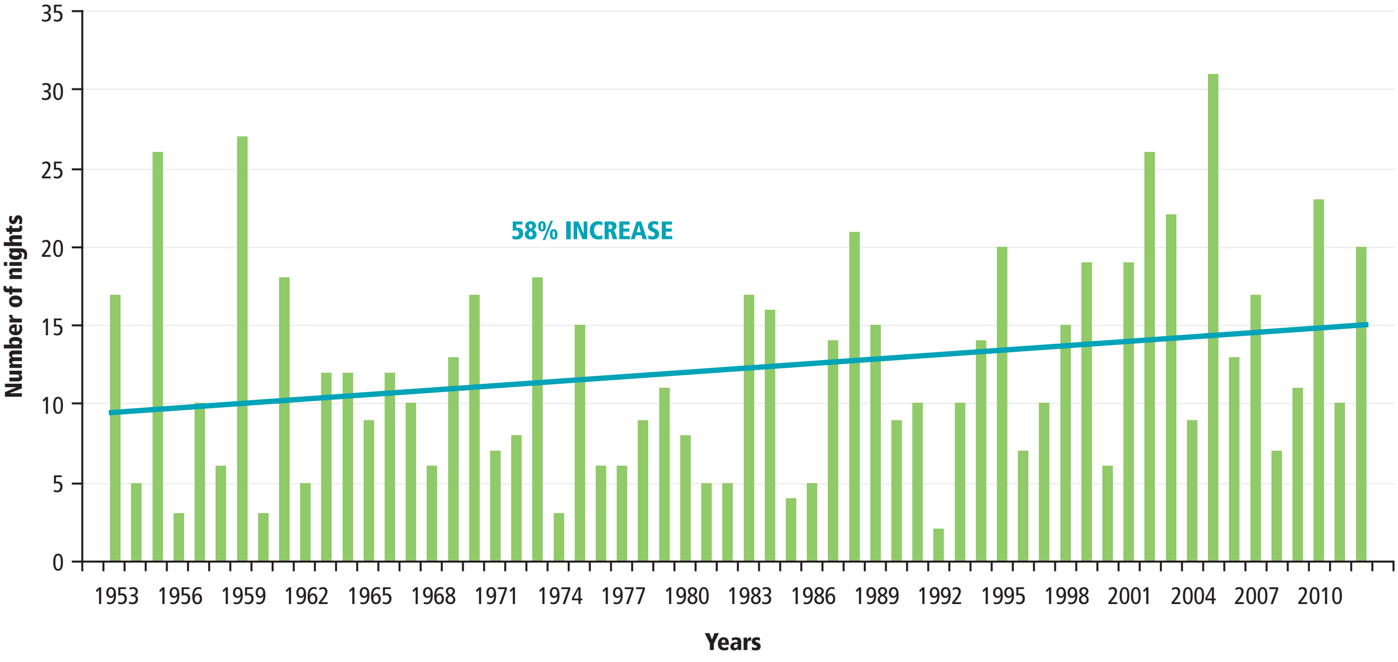
To sum up, whether or not we consider the humidex factor, and regardless of what definition we choose for a heat wave, we can see a rising trend for such events in Montréal. That trend was especially visible over the decade following the year 2000.

CLIMATE PROJECTIONS

Like for the rest of the world, climate models predict major increases in the duration of heat waves and the frequency of hot nights (minimum temperature > 20 °C) for southern Québec, including Montréal. According to these same projections, extremely high summer temperatures will rise more than average summer temperatures. This means we can expect longer and more intense heat waves in the coming decades. Climate projections are unanimous on the subject. The impacts are already tangible, and could become even more significant, so it's important for the Montréal agglomeration to adapt to this climate hazard.

FIGURE 6.3
EVOLUTION OF THE NUMBER OF NIGHTS WITH A HUMIDEX OF 30 OR HIGHER, 1953-2012

Source: Data from the weather station at the Montréal-Trudeau International Airport.



IMPACTS

The impacts of heat waves on the Montréal agglomeration are illustrated in Figure 6.4. We divided the impacts into four categories: built environment, natural environmental, socioeconomic issues and municipal operations. The impacts of each category are explained below.

FIGURE 6.4
EXAMPLES OF POTENTIAL IMPACTS OF HEAT WAVES ON THE MONTRÉAL AGGLOMERATION

Built environment

Public infrastructures

- Damage to the road network
  - Premature damage to the expansion joints on civil engineering works
  - Loss of adhesion between asphalt and bridge decks – "slippage cracks" in the asphalt when pulled by vehicles
  - Ruts formed on driving surfaces
- Damage to the sewer system caused by the increased generation of H_2S, harmful to concrete infrastructures
- Thermal expansion of rails

Residential and ICI infrastructures

No significant impacts identified

Socioeconomic issues

Health

- Health problems caused by air pollution (smog, fine particles, pollen)
- Illnesses caused by contaminated swimming water
- Health problems linked to body temperature imbalances (hyperthermia)
- Health problems caused by limitations to mobility
- Increased premature death rate

Expenses for individuals

- Economic losses caused by absenteeism and temporary job cessation

Inconveniences and accidents

- Inconveniences related to road mobility (discomfort in metros and buses)
- Food poisoning

Natural environment

Plants

- Increased water stress
- Management of undesirable plant species: loss of effectiveness of some herbicides

Insects

- Reduced insect populations (pests and auxiliaries) as they reach their thermal development limit
- Management of pest insects: loss of effectiveness of many pesticides

Fauna

- Changes to bird communities

Water bodies

- Proliferation of cyanobacteria
- Change to the structure of communities of aquatic organisms

Municipal operations

Increased demand for cooling-off areas

- Demand to extend the opening hours of air-conditioned public spaces (libraries, community centres, etc.)
- Increased demand for pools, wading pools and splash pads
- Curtailed outdoor works

Increased demand for drinking water

- Shorter system idle time will weaken the system in case of problems
- Higher costs for chemical products and electricity
- Increased presence of cyanobacteria in the water requiring ozone treatment (not available in all plants)
- Faster degradation of chlorine in the system, which will increase rechlorination needs and associated operating costs

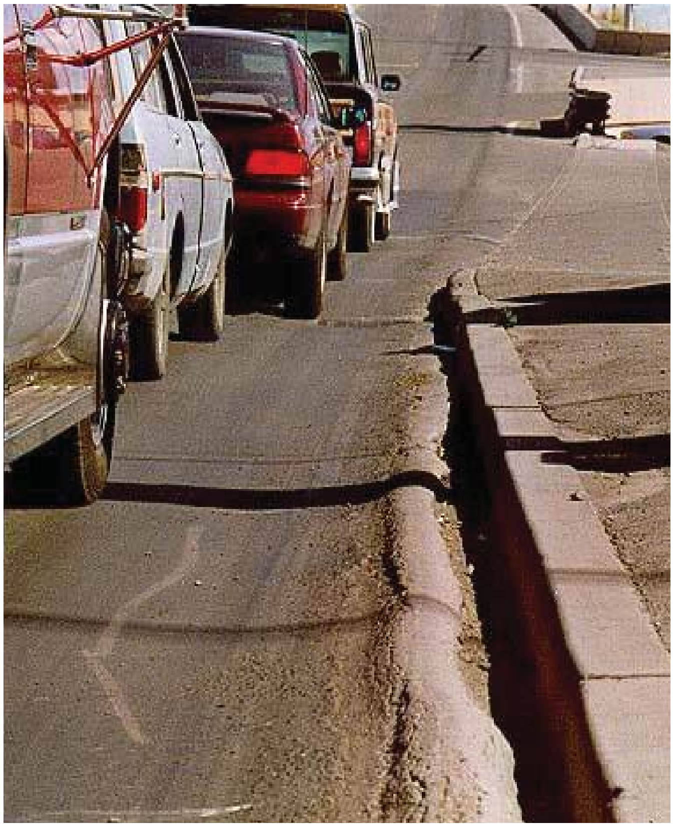
Increased complaints

- Problems with bad smells from manholes during heat waves and drought periods
- Problems with residual material management (bad smells, proliferation of flies, etc.)

IMPACTS ON THE BUILT ENVIRONMENT

High heat does not really affect the integrity of structures, but it can affect their technical performance. Rising temperatures during heat waves particularly affect the Montréal agglomeration's roads and arteries. Driving surfaces with high traffic and many heavy vehicles may soften and deform under the vehicles' weight, forming ruts. The heat may also cause a loss of adhesion between the asphalt and bridge decks, causing premature damage to these structures' expansion joints.

Heat waves have made few other impacts on the island of Montréal's infrastructures to date. However, some impacts observed elsewhere may eventually become concerns for the agglomeration in the coming years. For instance, the increased temperature of wastewater in the sewer system during hot weather generates an increased amount of hydrogen sulfide (H_2S), which is harmful to the concrete used in these infrastructures and can cause damage. As well, when it comes to buildings, excessive heat can cause façades and roofs to overheat and weaken some materials. In some cases, it can cause joints to dilate excessively, which can cause glass panes to shatter. A poorly insulated roof can cause increased temperatures inside buildings, which can drive up air conditioning costs. Lastly, intense heat can also represent a risk to the integrity of train tracks. By causing the metal to dilate, high temperatures can cause the rails to twist, which affects both the effectiveness and the safety of transportation services.[29]



Credit: © Pavement Interactive courtesy of Pavia Systems

IMPACTS ON THE NATURAL ENVIRONMENT

PLANTS

Plants are especially vulnerable to fast climate change that does not allow adaptive mechanisms to activate or evolve.

Increased water stress

Water stress, meaning the stress a plant experiences due to lack of water, is certainly one of the most dangerous stresses for plants, as it directly affects the plant's metabolism (photosynthesis, respiration), but also because of the negative indirect effects. Summer heat waves lead to increased evapotranspiration. If sufficient water resources from the soil don't compensate, the plant will experience water stress.[7, 130]

Plants can mitigate the negative effects of extreme temperatures using several mechanisms. One of the most significant is the closing of their stomata (microscopic pores on their leaves and stems that permit gaseous exchanges with the atmosphere) in order to limit water loss. Some may shed their leaves in order to limit the surface that sweats. These defense mechanisms can be insufficient to handle extreme temperatures. If the temperature stays high for a long time, it can kill some plants, particularly those that are already stressed and not doing well, whether due to pests or other non-optimal growing conditions.

Intra-urban heat islands generally have little vegetation. However, when these areas do have vegetation, they exacerbate the negative effects of climate change on plants.[100] As such, any vegetation present in an intra-urban heat island is much more vulnerable to water stress. The ecological services provided by trees in heat islands are less significant than if those same trees had been located in a cooler part of town.[87]

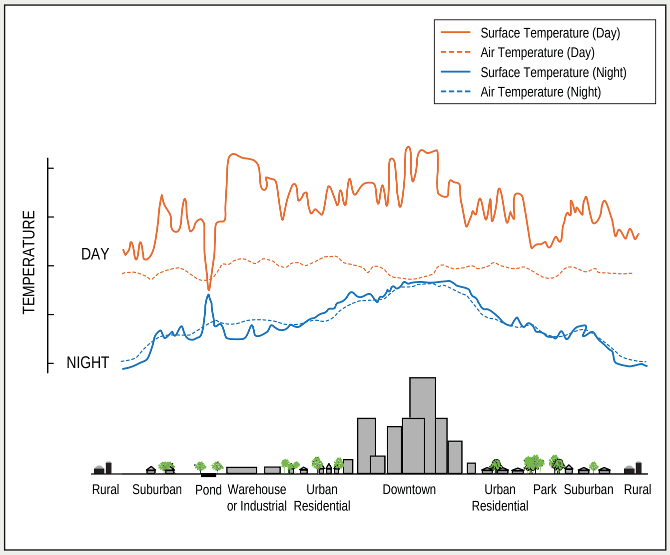
INTRA-URBAN HEAT ISLANDS

An intra-urban heat island (IUHI) happens when there is a temperature difference between an urban area and its surrounding rural areas. The temperature may be up to 12 °C higher in urban concentrations compared to rural areas. There are two types of urban heat islands:

- heat islands on the ground's surface;
- heat islands in the urban canopy, meaning the layer of air between the ground and the treetops or building roofs, where most human activity takes place.

Figure 6.5 illustrates the surface and air temperature variations for day and night based on how the ground is occupied. We can clearly see how the temperature is higher in the areas with high building density, and how it gradually goes down as building density diminishes. We can also see how surface temperatures are more variable than air temperatures. Lastly, we can see that the heat islands' impact on air temperature shows mostly at night. While the temperature goes down at night in natural environments or areas with low mineralization, it remains just as high at night as during the day in heavily urbanized places.

FIGURE 6.5
AIR AND SURFACE TEMPERATURE VARIATION



Source: U.S. Environmental Protection Agency. *Reducing Urban Heat Islands: Compendium of Strategies*, [online]. [www.epa.gov/heatisland/resources/compendium.htm]. Adapted from Voogt, J. 2002. Urban Heat Island. In Munn, T. (ed.) *Encyclopedia of Global Environmental Change*, Vol. 3. Chichester: John Wiley and Sons. (Accessed July 22, 2015.)

Vegetation and trees located within intra-urban heat islands are also much more vulnerable to insects and diseases.[42] In these places, pests are likely to do greater damage or survive more easily due to more favourable climate conditions. For example, some pests, such as scale insects, may have populations 200 times bigger on red maples located within intra-urban heat islands than on red maples located in cooler areas.[42, 43] In fact, intra-urban heat islands give us a preview of the climate change impacts that may occur in the future in a more generalized way in areas not subject to intra-urban heat islands.[178]

Management of undesirable plant species: loss of effectiveness for some herbicides

After insects, undesirable plant species are next on the list of phytosanitary problems in green spaces as reported by the agglomeration's reconstituted cities and boroughs. To control them, those responsible for maintaining these spaces sometimes rely on herbicides. But the closing of stomata during extreme heat periods may prevent the herbicides from penetrating or spreading, which will make this type of control method ineffective.[65] Climate change is one more reason to develop alternative methods for controlling undesirable plant species. For instance, we could opt for physical methods (such as weeding and thermal shock) or biological control methods (use of natural enemies).

Scale insects (small sap-sucking insects) on a maple branch located within an intra-urban heat island.
Credit: © Adam G. Dale

INSECTS

Insects' body temperature depends directly on the surrounding temperature.[11] This internal temperature in turn influences several aspects, such as the insect's physiological functions and behaviour. Insects' physiological functions work properly within an optimal temperature range.[12, 34] Extreme temperatures, such as the ones we experience during heat waves, may negatively affect insects.

Decreased insect populations

Extreme heat episodes, even short ones, can reduce the populations of a number of insects that may reach their thermal threshold for development. This reduction could happen, for instance, when heat-exposed insects die directly, or after the survivors lose their vigour. For example, a thermal shock with temperatures above 36 °C even for just an hour can be enough to kill some insects.

Both harmful and beneficial insects (pollinators, insects that control harmful organisms) could be affected by high temperatures. High temperatures could be beneficial by increasing the vulnerability of some pests to their natural enemies and boosting those enemies' effectiveness.[15, 68] However, some natural enemies may be negatively affected by these same climate conditions.[45]

Harmful insect management: loss of effectiveness among many pesticides

As mentioned earlier, high temperatures have a direct effect on plants, causing them to close their stomata. This impact has repercussions on many pesticide-based pest control operations. Many systemic pesticides use the upward sap flow, initiated by plant sweating, to reach and spread throughout the various parts of the plant. When stomata close during extreme heat periods, this prevents the systemic pesticide from spreading throughout the plant.[66]

Many insecticides that target tree pests are systemic and must be injected into the tree's trunk in order to spread within it. Treatments targeting the pest insects that threaten urban forests, such as the emerald ash borer, will be less effective or ineffective if the treatments are applied during high temperatures. This factor should be taken into account for operations that aim to control this type of pest. The people managing green spaces should avoid treating trees with systemic pesticides during heat waves.

Treatment with insecticidal soap
Credit: © Équipe de lutte intégrée, Ville de Montréal

AQUATIC ENVIRONMENTS

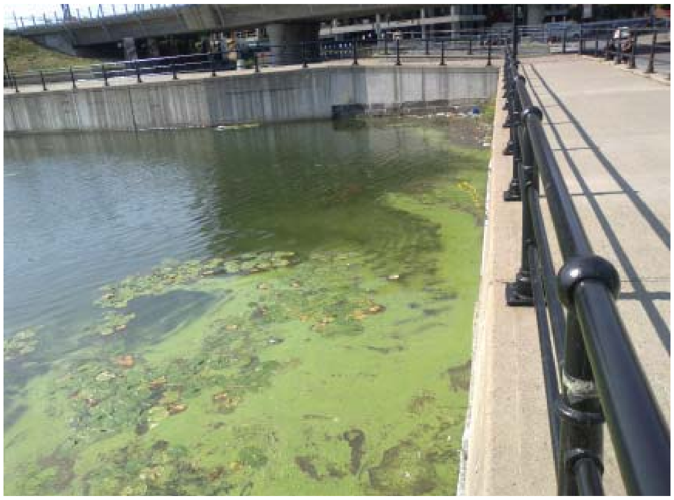
Proliferation of cyanobacteria → Reduction of water quality

One major impact of heat waves on aquatic environments is the increase of cyanobacteria blooms.[88] The proliferation of cyanobacteria can have numerous repercussions, such as:

- the eutrophication of water bodies, which disturbs the growth of aquatic species and reduces biodiversity;
- obstructed filtration systems;
- coloured water;
- bad water taste;
- the production of toxins (some species produce toxins that can be fatal to animals and humans);
- reduced water accessible for swimming;
- drinking water supply problems.

Structural changes to communities of aquatic organisms

Heat waves may affect the structure of benthic* communities by changing the composition relative to the various species. Monitoring of aquatic microorganisms in water bodies could be an effective tool for documenting the effects of climate change. Some species may effectively serve as bio-indicators, meaning species whose presence or state provides information that can help determine certain features of a natural environment.[109, 125]



Cyanobacteria bloom in summer 2012 at the last lock of the Lachine canal, with its mouth in the Vieux-Port de Montréal
Credit: © Réseau de suivi du milieu aquatique, Ville de Montréal

Spotted sandpiper with breeding plumage
Credit: © Réseau de suivi du milieu aquatique, Ville de Montréal

FAUNA

Changes to bird communities

Heat waves have major effects on bird communities in North America's temperate zones.[6] Birds that nest on the ground are especially vulnerable to heat waves.

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* Termium Plus, Government of Canada, Translation Bureau. "Benthic: Of, relating to, or occurring on the bottom underlying a body of water." [online]. [www.btb.termiumplus.gc.ca] (Accessed July 22, 2015.)

IMPACTS ON SOCIOECONOMIC ISSUES

In a densely populated urban area like the agglomeration's, heat waves are a serious issue for public health. They drive up the prevalence of health problems as well as affecting quality of life, causing forced work stoppages, and leading to many other inconveniences.

HEALTH IMPACTS

Oppressive heat provokes heat stress in people, causing cramps, fainting, heat stroke and more. Extreme heat causes a range of discomforts, leading to many hospitalizations, and can also aggravate the fragile health of people suffering from certain diseases and cause premature deaths. On the territory of the Montréal agglomeration, more than 400 deaths have been attributed to heat waves over the last 30 years.[2]

Combined with high humidity, extreme heat weakens the human body's temperature regulation process. The human body cools off when sweat evaporates, and a high humidity level makes this mechanism difficult. The body can no longer control its temperature, which rises quickly. Heat waves that involve a high humidex will have even more significant impacts on Montréal's population health.

Heat waves can also lead to and accentuate the effects of air pollution. They boost the number and scope of smog episodes. Reduced air quality aggravates the symptoms of many of the health problems set out above, and can limit people's ability to practice outdoor activities and sports.

The discomfort resulting from heat waves is felt not only outdoors, but also on public transit, such as the metro and bus. Some at-risk or isolated people may find their mobility restricted, which can help exacerbate the problem of isolation as well as some health problems.

SMOG

In summer, smog forms especially on very hot, sunny days. It is mostly made up of fine particles and ozone. The ozone forms at ground level when its precursor pollutants, nitrogen oxides and volatile organic compounds (VOCs), react in the presence of the sun's rays. These precursors are mostly emitted by car engines and industrial processes.

FIGURE 6.6
IMPACTS OF HEAT ON HEALTH

Chronic illnesses whose effects are exacerbated by heat

- Diabetes
- Respiratory failure
- Cardiovascular illness
- Neurological diseases
- Cerebrovascular diseases
- Kidney diseases

Source: Giguère, M. (2009). *Mesures de lutte aux îlots de chaleur urbains*, Institut national de santé publique du Québec, Direction des risques biologiques, environnementaux et occupationnels, 95 p.

IMPACTS ON MUNICIPAL OPERATIONS

Heat waves also affect municipal operations and services. The increased demand for some services requires municipal administrations to adjust their activities to meet their citizens' needs, so we may need to hire more staff, review some practices or adjust budgets.

For example, very hot periods lead to an increased demand for pools, wading pools and splash pads. This demand influences the way services are organized and affects equipment maintenance. High traffic at pools has occasionally pushed water quality systems to the limit of their capacities, and in some cases, has led to temporary facility closures. Air-conditioned public spaces such as libraries and community centres are also very popular, so the population demands extended opening hours so they can keep cool. In the same vein, because they have an effect comparable to cooling islands, parks get more traffic in the evenings and even at night during heat waves. Because of this, we are seeing an increased number of interventions and a higher need for staff to provide services such as safety rule enforcement, infrastructure maintenance and, as needed, emergency measure enactment.

In terms of heat's direct impacts on operations, clearly, heat can slow or restrict the many outdoor construction works scheduled during the hot season, which derails work timetables.

In terms of population services, while the capacity to meet the demand does not seem to be under threat, there is an increased need for water during heat waves. The system's idle time is shorter at these more critical times, which weakens the system in case of problems. The increased presence of cyanobacteria in the water (which requires ozone treatment that is not available in all plants) and the faster degradation of chlorine in the system increase the need for chlorine and the associated operating costs.

Lastly, major heat waves, when combined with drought periods, lead to stronger smells in manholes and public garbage cans, which boosts the number of citizen complaints.

High traffic in the Parc Laurier pool, Plateau-Mont-Royal
Credit: © Marco Campanozzi, *La Presse*

To handle the risks related to climate change, the Société de transport de Montréal (STM) takes various measures to limit its system's vulnerability, ensure customer safety and maintain service in case of bad weather.

Heat waves affect the temperature felt in the metro. Some 80 mechanical ventilation stations as well as natural ventilation shafts help us refresh the air in the metro system. They modulate the ambient temperature and bring fresh air to our clientele by performing air exchange between the metro system and the outdoors. During the summer, ventilation helps draw off some of the heat generated by the metro trains when they brake and accelerate.

Alongside this, the STM works to reduce sources of heat within the metro system. Since the heat mostly comes from the operation of metro trains, the new Azur trains were designed to reduce the amount of heat given off into the system. Ventilation onboard the new Azur trains will be optimized to improve customer comfort.

To help reduce heat islands, the STM includes greening measures as much as possible in construction and renovation projects. As such, 25% of the Stinson bus garage's roof is carpeted in plants. That's 8,000 m^2 or the equivalent of one and a half football fields, making it one of Québec's biggest green roofs, possibly the biggest. The rest of the roof is covered with white reflective surfacing. Greened parking lots, more than 500 trees, shrubs and various other plants, and some 22,000 m^2 of lawns complete the landscaping. The roof of Champ-de-Mars metro station was also greened as part of recent renovations.

The STM's emergency measures coordination unit (UCMU, or Unité de Coordination des Mesures d'Urgence) coordinates all of our emergency response actions, in particular those related to extreme climate conditions, in collaboration with the Ville's and the agglomeration's operating centres and emergency measures offices.

Credit: © Société de transport de Montréal

The STM is also a resource for vulnerable populations during heat waves. As a partner to the Ville de Montréal's emergency measures plan and the agglomeration's civil safety, the special needs transportation service and bus services can be mobilized to move vulnerable people to air-conditioned sites.

Contributed by the STM

VULNERABILITY ANALYSIS

Once we established how heat waves impact us, we were able to analyze the Montréal agglomeration's vulnerability to this hazard. Since many of these impacts affect groups of people who live in specific places in the agglomeration and infrastructures in known locations, we were able to carry out a geographic vulnerability analysis. The methodology we employed is detailed in Appendix A.

This section presents the areas of the agglomeration that are affected by this hazard, along with environmental, territorial and social susceptibilities, whether they can be mapped or not. To finish, the maps obtained through geographic analysis are presented and discussed in the Vulnerability to Heat Waves section on page 81.

AREAS AFFECTED BY THE HAZARD (PHYSICAL SUSCEPTIBILITY)

The areas of the agglomeration where heat is felt the strongest are intra-urban heat islands (IUHI; see the box for more information on page 71). Map 6.4 on page 83 shows where they are. A number of factors contribute to forming IUHIs[22, 27, 37, 79]:

- **Materials**. Reflectivity of the sun's rays varies from one material to another. Rays that are not reflected are absorbed and stored in the form of heat. Urbanized areas contain many materials that absorb a lot of heat during the day (bricks, stone, asphalt, tar, etc.). When night falls, these materials emit some of their accumulated heat in the form of infrared rays. This is why the temperature stays high at night in intra-urban heat islands during heat waves.
- **Vegetation**. The presence of trees, if they are well positioned, helps block some of the sun's rays and prevent them from reaching surfaces where they would be absorbed. As well, plants, like humans, sweat. During this process, part of the liquid water they contain changes into a gaseous state. For water to change phase this way, it needs to absorb energy from the surrounding air, which cools it down along the way.
- **Soil sealing**. In a heat wave, part of the water contained in the soil evaporates. Like with plant transpiration, this evaporation works by absorbing the energy from the surrounding air, which cools it down.
- **Human activities**. Many human activities give off heat, including air conditioning, transportation and some industrial activities.
- **Urban morphology**. Materials that have gathered heat during the day let it out in the form of infrared rays when night falls. If these rays hit an obstacle (another building, a tree, etc.), they bounce back and hit the surface of origin, which reabsorbs part of it. Some aspects of urban morphology, such as the presence of tall buildings or narrow streets, contribute to forming IUHIs.

Credit: © Ville de Montréal

KNOWLEDGE OF OUR ARBOREAL HERITAGE

Our knowledge of our arboreal heritage has greatly improved in recent years when it comes to trees located in public spaces. Because the emerald ash borer was found in 2011 on the island of Montréal, and because it has caused so much damage since then, we became aware of how important it is to have an inventory of urban trees that's complete and up to date. Today, most of the street trees on Montréal's territory have been georeferenced.

A map showing the Ville de Montréal's 254,444 public trees is available online at www.quebio.ca/fr/arbresmtl.

ENVIRONMENTAL SUSCEPTIBILITY

Map 6.1 (see page 82) shows the Montréal agglomeration's environmental susceptibility to heat waves.

As mentioned in the Impacts on the Natural Environment section (page 71), heat waves have major effects on living organisms, particularly plants. Trees and vegetation located within IUHIs are especially vulnerable to the impacts of climate change. The cartographic analysis took into account trees located in IUHIs.

Aquatic environments are also sensitive to heat. The cartographic analysis also took into account the presence of watercourses located within IUHIs.

Due to the limited data available, it was not possible to account for other environmental susceptibility factors.

TERRITORIAL SUSCEPTIBILITY

Map 6.2 (see page 82) shows the Montréal agglomeration's territorial susceptibility to heat waves.

As described in the Impacts on the Built Environment section (page 70), few infrastructures are vulnerable to heat waves. The ones that were included in the geographical analysis are described below. The territorial susceptibility analysis considers the presence of these infrastructures on the territory, and sometimes their density, because more detailed geographic data on their features were not available.

- **The road network**. The pavement of road surfaces can soften in the heat and form ruts.
- **Railroad tracks**. Very hot temperatures can dilate the metal of the rails and cause them to twist.

SOCIAL SUSCEPTIBILITY

Map 6.3 (see page 83) shows social susceptibility to heat waves in the Montréal agglomeration.

Generally speaking, anyone can have health problems when there's a heat wave, especially if it happens in the early summer when the body is not yet accustomed to heat.[80] However, as described in the Impacts on Socioeconomic Issues section (page 75), many groups of people are particularly vulnerable to the impacts of heat waves, such as children aged 0 to 15, seniors aged 65 and up, people living alone, underprivileged people and recent immigrants or people who speak neither French nor English.

The impacts considered in the geographic analysis are as follows:

- health problems caused by air pollution;
- health problems caused by pollen;
- illnesses caused by contaminated swimming water;
- health problems caused by poor thermoregulation;
- increased mortality rate;
- economic losses.

Some impacts affecting certain groups of people were not taken into account in the geographic analysis because the data about them are insufficient, such as the location where people with respiratory problems live (they are sensitive to the degraded air quality that can come about during a heat wave), or because the group's distribution across the island of Montréal is relatively constant, such as for people who practice aquatic activities (they are more vulnerable to illnesses caused by contaminated swimming water).

Alleyway in the Villeray–Saint-Michel–Parc-Extension borough
Credit: © Vincenzo D'Alto

VULNERABILITY TO HEAT WAVES

The Montréal agglomeration's vulnerability to heat waves was obtained (see Map 6.5) by adding together environmental, territorial and social susceptibilities and multiplying that by physical susceptibility, meaning by applying territorial and social susceptibilities only to the IUHIs. This map showing vulnerability to heat waves is based on the choice of susceptibility factors we determined using the geographic vulnerability analysis methodology described in Appendix A.

Industrial, commercial and highly populated areas are prone to forming IUHIs, because a good part of their surface is made up of materials that absorb the sun's rays, the soil is often sealed, and there is little vegetation. Residential buildings in densely populated areas (triplexes, multiplexes and multi-apartment buildings) are often adjoining, are not set back very far from the street, and have little or no backyard space. This maximizes sealed surfaces and limits planted spaces, as well as being the kind of morphology that hinders the dissipation of the heat gathered by materials. The boroughs and municipalities in the western part of the island are less prone to forming IUHIs (Map 6.4), because they have lower density and the most common type of dwelling is a single-family home surrounded by a yard. Some areas in the central and eastern parts of the island which share these characteristics are also located outside IUHIs, such as certain sections of Rivière-des-Prairies–Pointe-aux-Trembles and Rosemont–La Petite-Patrie.

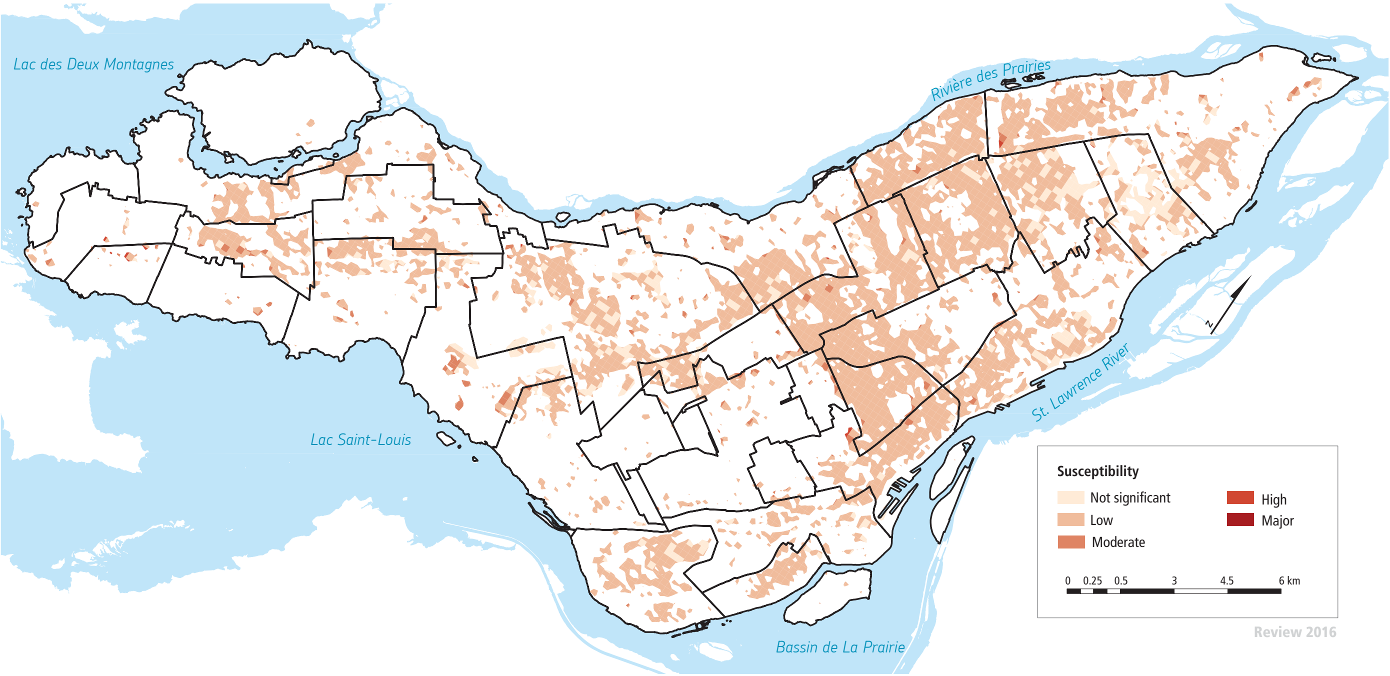
As shown on Map 6.1, the environmental susceptibility of most areas located in IUHIs is minor. The other areas have a susceptibility level that's not significant.

The vast majority of the agglomeration's territory presents only a low or insignificant territorial susceptibility (Map 6.2). The rare sectors that have a high or severe susceptibility are places with lots of train tracks (such as marshalling yards), the infrastructure that's the most vulnerable to heat according to the experts consulted by the Service de l'environnement.

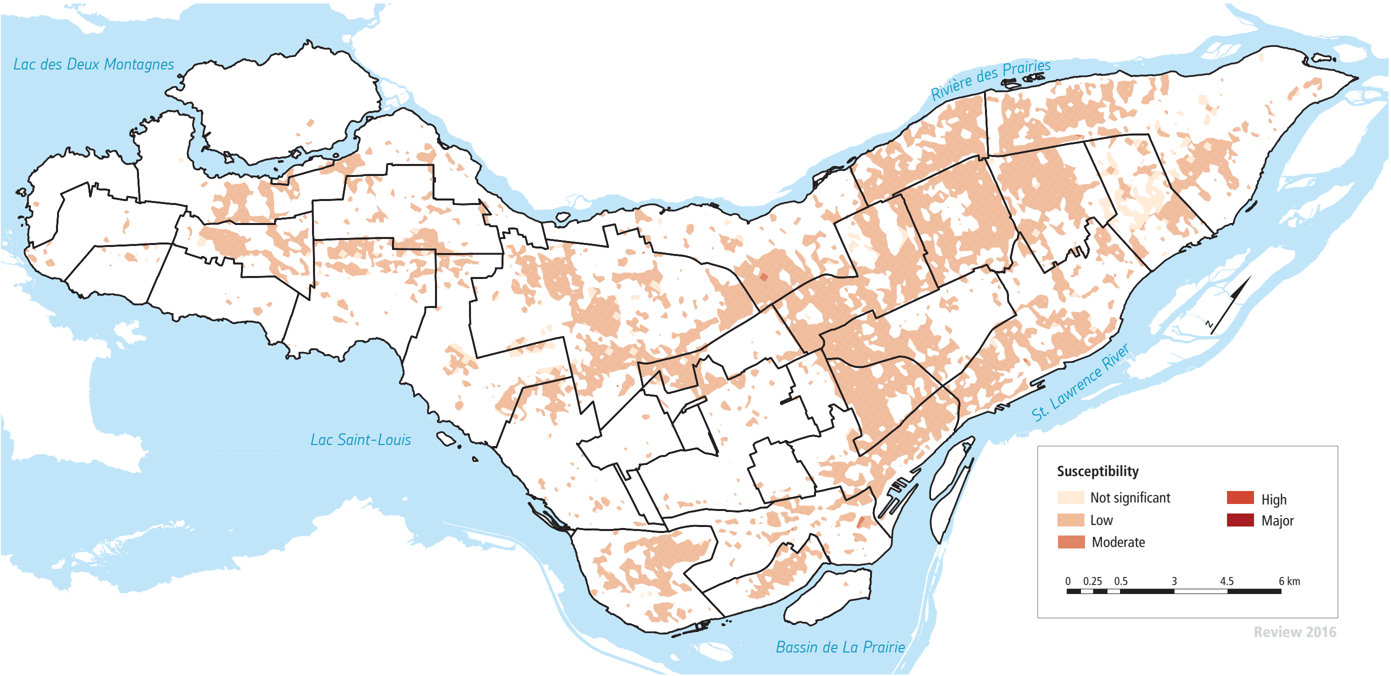
Unlike environmental and territorial susceptibilities, the agglomeration's social susceptibility is more significant, as shown on Map 6.3. A number of areas on the island feature moderate or high social susceptibility, and a few areas show major social susceptibility. The boroughs of Ville-Marie, Mercier–Hochelaga-Maisonneuve, Villeray–Saint-Michel–Parc-Extension and Montréal-Nord have especially vulnerable populations: underprivileged people, people living alone, seniors and people who speak neither French nor English.

Map 6.5 shows that most of the agglomeration presents no vulnerability at all (because the areas are outside IUHIs), or vulnerability that's minor or insignificant. No area of the island features major vulnerability, and only a few places have a high vulnerability. Areas with moderate vulnerability are the ones whose social susceptibility is more significant.

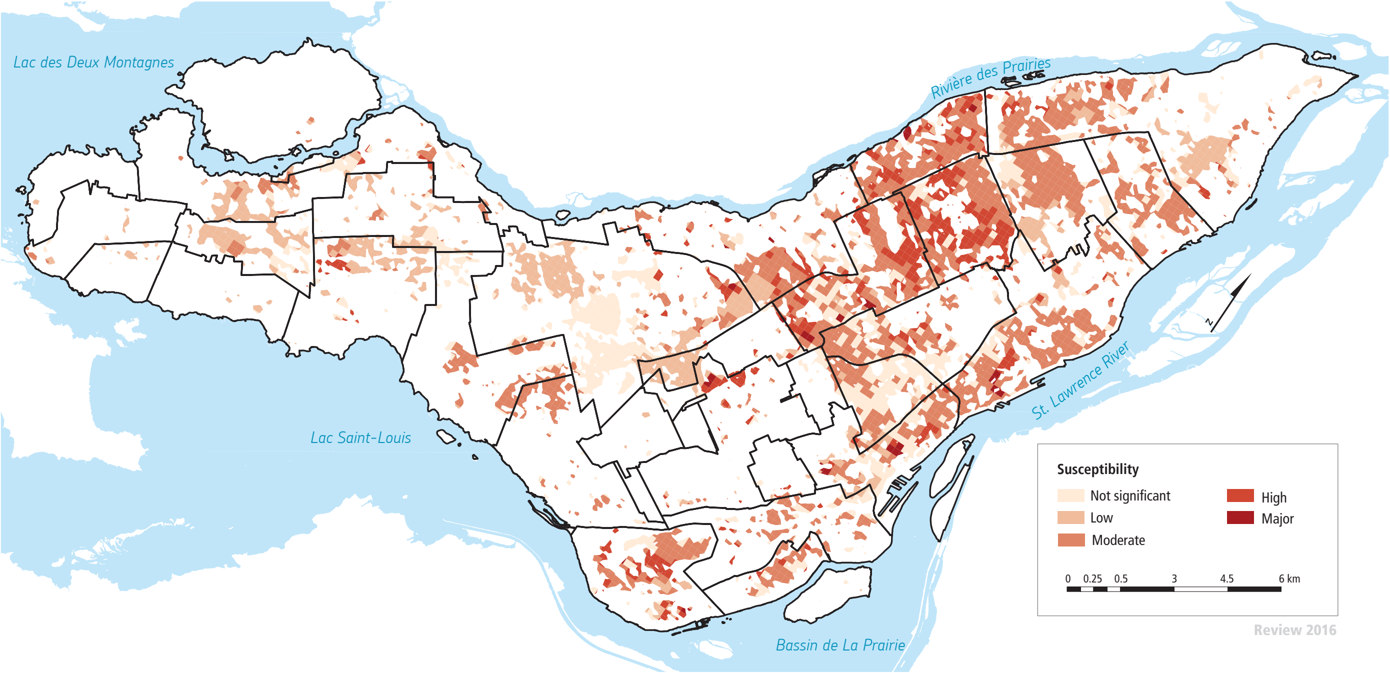
MAP 6.1
ENVIRONMENTAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO INTRA-URBAN HEAT ISLANDS



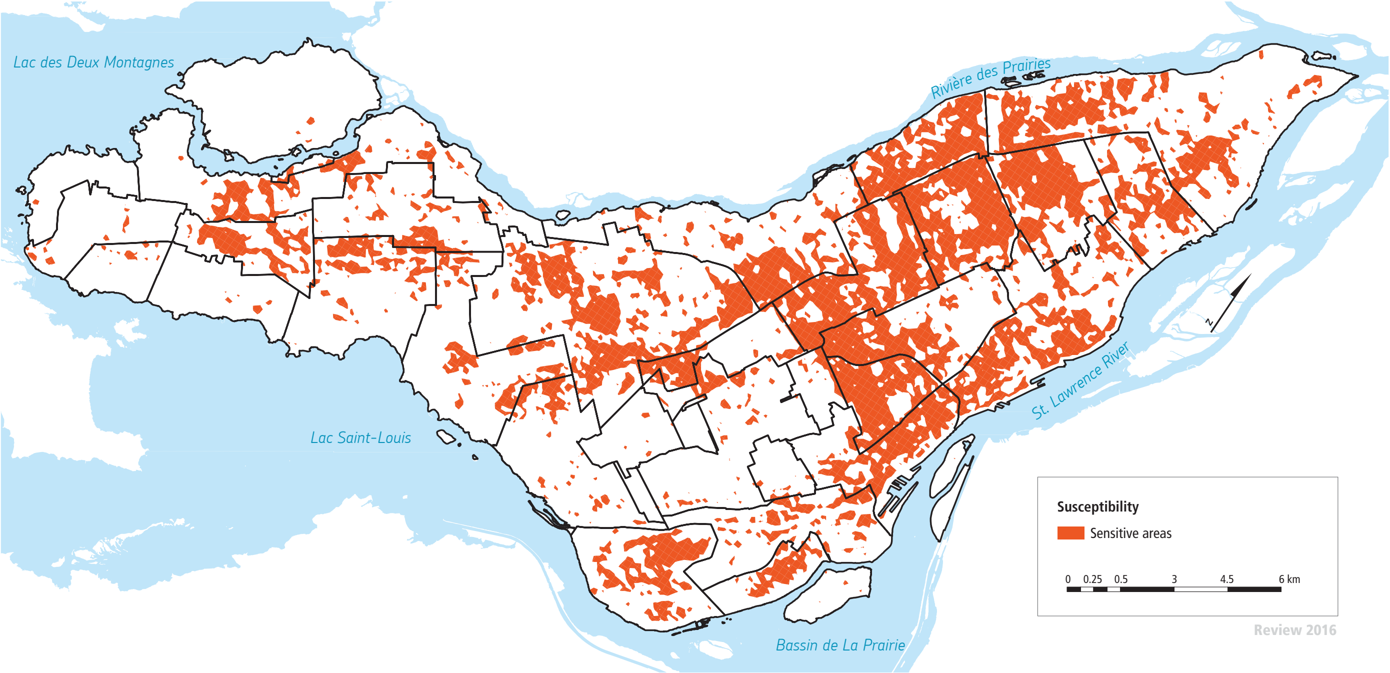
MAP 6.2
TERRITORIAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO INTRA-URBAN HEAT ISLANDS



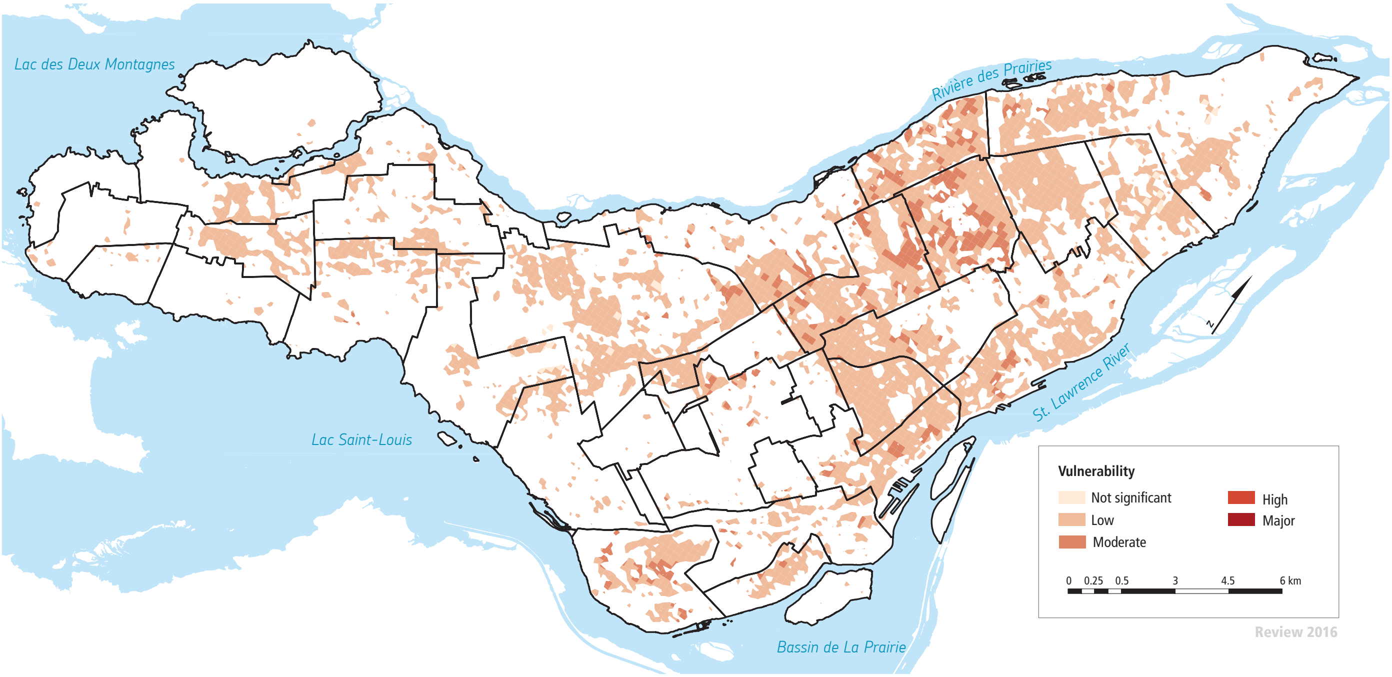
MAP 6.3
SOCIAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO INTRA-URBAN HEAT ISLANDS



MAP 6.4
INTRA-URBAN HEAT ISLANDS IN THE MONTRÉAL AGGLOMERATION



MAP 6.5
VULNERABILITY TO HEAT WAVES IN THE MONTRÉAL AGGLOMERATION



DESTRUCTIVE STORMS

The destructive storms hazard includes several types of storms: windstorms, hailstorms, heavy snowfalls and freezing rain. We grouped these together by taking into account, above all, the devastating impacts that such events can bring about.

From 1901 to 2000, 351 destructive storms hit Canada, including 31 that affected Québec.[83] Still, scientific studies of this type of extreme climate event are quite limited, essentially due to lack of high-quality data. In Québec, from 1953 to 2006, it seems there was a downward trend in the annual average wind speed. Cyclonic activity, which generates storms, rose from 1985 to 1995 and has been dropping ever since.[122]

© Shutterstock

DEFINITIONS

Freezing rain: Liquid precipitation with a temperature lower than 0 °C that freezes when it comes into contact with the ground or other objects (trees, electrical wires, etc.). Freezing rain can make surfaces very slippery for pedestrians and drivers, and can lead to accidents and downed electrical wires.[105]

Heavy snowfall: Snow is mist in the air that freezes into ice crystals, which fall in light flakes onto the ground.[56] We call it a storm when a very cold air mass leaves the polar regions and causes heavy snowfalls, especially if those snowfalls are accompanied by violent winds.[83] In this chapter, we consider a heavy snowfall to be any snowfall that dumps more than 30 cm in a day, which corresponds to a Level 1 in the mobilization levels of the Organisation de sécurité civile de l'agglomération de Montréal, which handles snow removal, among other things.

Hail: Precipitation in the form of ice granules with a diameter of at least 5 mm. Hail forms in the centre of a storm, and hailstones can gather water as they fall, becoming bigger, heavier and more dangerous. The size of hailstones can vary from that of a small pea to that of a cherry. We have even seen them as big as grapefruits. In Canada, hailstorms happen mostly in summer, when storm activity hits its peak. Hailstorm damages can be severe, particularly to cars and houses.[170]

Wind: Wind is the movement of air caused, among others, by Earth's rotation and differences in atmospheric pressure. These differences in pressure happen because temperature is not horizontally uniform.[122]

CLIMATE EVOLUTION

HISTORICAL PERIOD

Meteorological data currently available for Montréal do not allow us to evaluate the evolution of wind speeds or hail episodes over the last few decades. Nevertheless, we can note a few particularly violent events, most of which qualify as destructive storms, in the last 30 years: an episode of wind with a speed of over 100 km/h on July 19, 2013, and four hailstorms over 1986 and 1987, featuring hailstones up to 8 cm in diameter (see Table 7.1).

As for freezing rain, a team of researchers from McGill University recently gathered data from 1979 to 2008[131] showing an increase of about 26% in the number of events across the Montréal agglomeration (see Figure 7.1). Among the significant events in Montréal (see Table 7.1), let's recall the extremely intense ice storm of January 5, 1998, which saw 5 to 80 mm of freezing rain. This particular event spread far beyond Montréal, extending from the Maritimes to the Outaouais and Saint-Laurent valleys. It was the second most expensive disaster in the entire history of Canada, with 28 deaths, 945 injuries, 600,000 people evacuated[54, 83] and 5.4 billion dollars in damages.[112]

FIGURE 7.1
EVOLUTION OF FREEZING RAIN EPISODES IN THE MONTRÉAL AGGLOMERATION

Data from Ressler et al. (2012)[131].

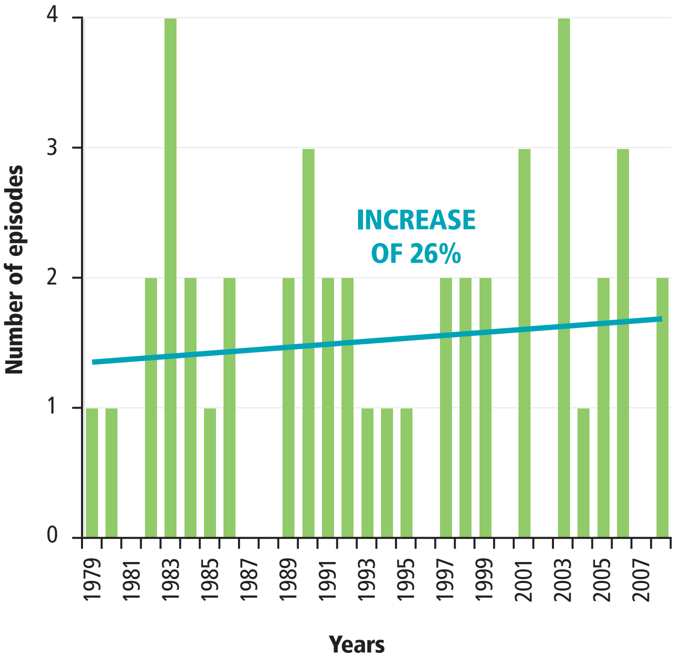


TABLE 7.1
SOME NOTABLE DESTRUCTIVE STORM EVENTS IN THE MONTRÉAL AGGLOMERATION

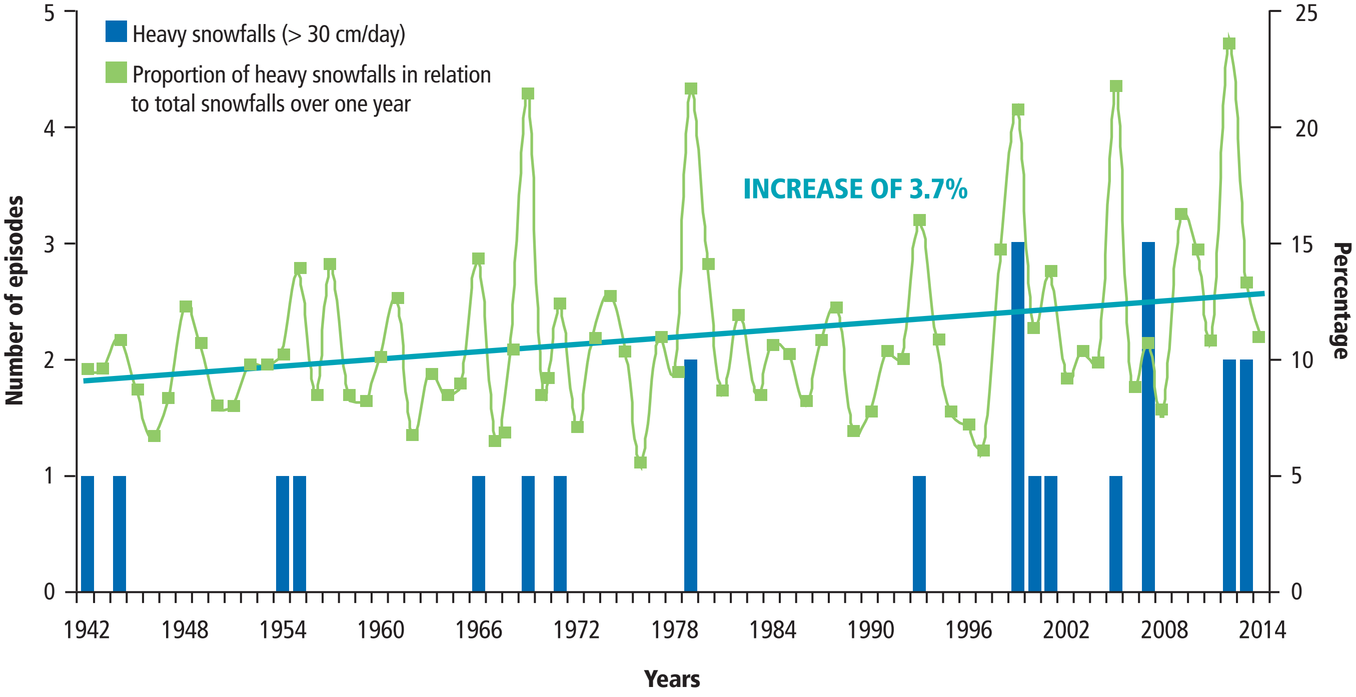
DATE	TYPE OF STORM	DETAILS
November 16, 1983	Snow and freezing rain	20 cm of snow
December 13, 1983	Freezing rain	Not available
December 3, 1984	Snow	21 cm of snow
May 29, 1986	Hail	Hailstones up to 8 cm in diameter
June 29, 1986	Hail	Hailstones from 0.5 to 1.5 cm in diameter
November 20-22, 1986	Snow	30 cm of snow
January 22-23, 1987	Snow	30 cm of snow
May 29, 1987	Hail	Hailstones from 1 to 1.2 cm in diameter
July 18, 1987	Hail	Not available
February 12-13, 1988	Snow	20 cm of snow
January 5, 1994	Snow	25 cm of snow
January 5, 1998	Freezing rain	Depending on the source, 5 to 80 mm of freezing rain
January 18, 2012	Wind	Not available
December 27, 2012	Snow	45 cm of snow in less than 24 hours
July 19, 2013	Wind	Winds above 100 km/h

The number of heavy snowfalls has increased over the last 70 years (see Figure 7.2). Among others, let's recall the snowstorm of December 27, 2012 during which 45 cm of snow fell in less than 24 hours (see Table 7.1). The proportion of heavy snowfalls to annual snowfall amounts has also increased (see Figure 7.2, green line). This may seem paradoxical because we know that, alongside this, the quantity of snow has gone down over the last few years in Montréal (see the chapter on heavy rainfalls). In fact, in recent years, we have seen snowfalls become more concentrated into a few extreme events.

Whether for freezing rain or heavy snowfalls in Montréal, no scientific link has yet been established with our current reality of climate change. We will have to wait for a longer-term and more homogenous historical database to be set up for the territory in order to establish or refute a link to climate change.

FIGURE 7.2
EVOLUTION OF HEAVY SNOWFALLS (> 30 CM/DAY) ON THE MONTRÉAL AGGLOMERATION

Source: Data from the weather station at the Montréal-Trudeau International Airport.



CLIMATE PROJECTIONS

As for historical data, climate projections are very uncertain about the future evolution of destructive storms in the context of global warming. However, we do note a reduction of summer winds for the 2079-2099 period as compared to 1979-1999 and a minor increase in winter winds.[122] Climate projections that follow the scenario with the highest greenhouse gas emissions suggest a reduction in cyclone activity, which generates storms, across all the depression tracks that will affect Québec in the 2081-2100 range compared to 1980-1999.[122] However, there is still much uncertainty about the evolution of cyclones known as "post-tropical." These cyclones are in fact the leftovers of tropical storms that can make their way all the way to Québec. The frequency of the most intense tropical storms should increase in the future, but it is not yet possible to establish whether the frequency and intensity of post-tropical cyclones that cause destructive storms in Québec will change in the coming decades. Lastly, projections are not yet able to say whether the number, length and intensity of freezing rain episodes will change in Québec in the coming decades.[122]

Despite the uncertainties surrounding the future of destructive storms in Montréal, their serious impacts require us to consider them and tailor adaptation measures so that the agglomeration can better prepare to face them in the future.

Credit: © Yves Provencher, *Journal Métro*

IMPACTS

The following pages review the main impacts of high winds, hail, heavy snowfalls and freezing rain, which present risks to infrastructures, buildings, plants and people across the entire territory of the Montréal agglomeration.

FIGURE 7.3
EXAMPLES OF POTENTIAL IMPACTS OF MORE FREQUENT HIGH WINDS, HAIL, HEAVY SNOWFALLS AND FREEZING RAIN ON THE MONTRÉAL AGGLOMERATION

Built environment

Public infrastructures

- Damages to the road network and related structures
  - Electrical and telephone poles
  - Traffic lights
- Damages to above-ground utility systems

Residential and ICI infrastructures

- Damage to the envelope and roofing of homes and buildings in the form of components breaking, lifting or tearing off
- Damages to homes and buildings (frozen and burst pipes during winter power outages)
- Damages to infrastructures other than homes and buildings (sheds, reservoirs, culverts, etc.)
- Damages to infrastructures via hazardous materials spills

Socioeconomic issues

Health

- Psychological distress
- Health problems caused by travel limitations

Expenses for individuals

- Possible reduction of insurance coverage
- Personal economic losses due to travel limitations
- Costs related to destroyed goods (damaged buildings, loss of vegetation, etc.)

Inconveniences and accidents

- Higher number of road accidents
- Inconveniences related to road traffic (difficult for emergency services to reach people)
- Injuries related to falls or structural collapses, falling trees and debris
- Higher mortality rate
- Electrical outages
  - Food poisoning
  - In-home medical equipment shorts
  - Carbon monoxide poisoning
- Service interruptions for above-ground utilities other than electricity

Natural environment

Plants

- Change in the composition of plant species in wooded areas (long-term impact)
- Loss of canopy
  - Thin and already-weakened branches may break
  - Trees that are already doing poorly or dead (due to illness, insects, injuries, etc.) may break
  - Some trees may die following damages caused by freezing rain
- Plants more vulnerable to insects and illnesses after sustaining injuries caused by hail or freezing rain

Municipal operations

Recreational activities

- Ice melts in arenas due to power outages
- Reduced services offered in arenas

Increased costs

- Snow removal operations
- Use of generators during power outages in water production plants and drinking water pump stations
- Loss or damage to materials or street furniture
- Increased pruning

Health and safety

- Increased deployment of first responders
- Increased deployment of snow removal staff: possible burnout, increased accident risk

HEALTH AND SAFETY

High winds, freezing rain accumulations, hail and heavy snowfalls all cause deformation, accelerated wear and breakage to infrastructures and vegetation. The scope of damages depends on how powerful the storm is (wind speeds, ice or snow accumulation thickness, size of hailstones). For wind speed and ice accumulation, we have evaluated the gradation of the impacts (in tables 7.2 and 7.3 respectively).

TABLE 7.2
TYPICAL IMPACTS BASED ON WIND SPEED

WIND SPEED	TYPICAL IMPACTS
70-90 km/h	Small branches break, loose objects blown about, possible power outages
90-100 km/h	Some tree limbs break, occasional trees topple, some poorly constructed signage damaged, power outages
100-120 km/h	Prevalent tree branches breakage, some trees topple, some shingle and siding damage to homes, power outages
120-140 km/h	Many trees toppled or uprooted, many signs are damaged or destroyed, glass in high-rise buildings can break, widespread power outages possible
140 km/h +	Widespread forest blowdowns, prevalent cladding and roofing damage, some roofs blown off or heavily damaged, widespread power outages possible

Source: Environment Canada. "Wind." *Hazards and Impacts*, [online], updated July 18, 2013. [www.ec.gc.ca/ouragans-hurricanes/default.asp?lang=En&n=502E94BA-1] (Accessed June 10, 2015.)

TABLE 7.3
INDEX OF DAMAGES TO TREES AND STRUCTURES FOLLOWING FREEZING RAIN EPISODES

Adapted from Hauer, Dawson and Werner (2006)[76].

FREEZING RAIN ACCUMULATION	TYPE OF DAMAGES
↓	Slippery roads
	Minor ice accumulation on trees
	Power outages caused by broken trees (distribution network and telecommunications systems)
	Bending of some trees (ex.: birch)
	Broken branches – vulnerable trees (ex.: poplar)
	Power outages caused by galloping* of high-voltage lines
	Broken branches – resistant trees (ex.: oak)
	Power outages not caused by broken trees (distribution network and telecommunications systems)
	Broken branches – resistant coniferous trees (ex.: fir trees)
	Power outages on the high-voltage line network not caused by broken trees
	Collapsed pylons and communication towers

Note: Damages to trees and structures will increase if the freezing rain is accompanied by violent winds.

*According to Termium, galloping is "a strong, primarily vertical oscillation of overhead conductors when loaded with freezing rain, snow or rime ice and exposed to particular wind conditions... Galloping conductors may move too close to one another, causing a short circuit and tripping the line."

IMPACTS ON THE BUILT ENVIRONMENT

In the Montréal agglomeration, destructive storm damages mainly include fallen trees or tree branches, broken roofs and other broken building envelope components. Major gusts can not only compromise a building's integrity, but can also cause serious damages around the building, considering that debris can fly around and pierce windows, glass storefronts and façades, as well as being a danger to pedestrians. These impacts are often exacerbated in densely built areas. Infrastructures beyond houses and buildings can also be damaged, such as sheds, reservoirs and culverts. Winds can tear off or lift some pieces of a home, such as the roof. Heavy snowfalls and freezing rains can load down a roof structure and cause breakage.

When power outages happen in winter, building pipes can freeze and even burst. When a building isn't heated, the water freezes and increases in volume, which can burst pipes and cause water damage to the building.

Electrical and telephone poles (and above-ground utilities more generally) can also be damaged, whether by ice accumulation, like in 1998, or by falling trees or other heavy debris. Damages caused to traffic lights and traffic signs can severely hinder traffic.

Lastly, when industrial sites are affected by violent storms, the infrastructures may be further damaged by hazardous materials spills.

SNOWSTORM ON DECEMBER 27, 2012

The snowstorm that hammered Montréal and its surrounding area on December 27, 2012 buried the city under nearly 45 cm of snow, setting a new record for the biggest snowfall in Montréal. The storm created extremely difficult road conditions, leading to blockages on several sections of the city's highways, severe public transit slowdowns, and a few power outages.

Translated from the Ville de Montréal's website, La Sécurité civile à Montréal (civil safety in Montréal). [ville.montreal.qc.ca/portal/page?_pageid=7637,81923612&_dad=portal&_schema=PORTAL#hi_temp_neige_2012] (Accessed June 15, 2015.)

Credit: © Claude Robillard, Flickr (CC BY-NC 2.0)

Credit: © Matias Garabedian, Flickr (CC BY-SA 2.0)

IMPACTS ON THE NATURAL ENVIRONMENT

The impacts of destructive storms on the natural environment in urban settings mostly affect vegetation, particularly trees. Storms damage vegetation, sometimes with serious repercussions, and can even kill trees.

Freezing rain can cause tree branches to crack and fall by drastically weighing them down.
Photo: Wikipedia

PLANTS

Tree injuries and deaths

When snow or ice accumulates and is accompanied by violent winds, trees may be uprooted or their trunks may be split. This directly causes the loss of part of the urban forest. Sometimes, the damages are less serious, and only branches or the upper part of the treetop are damaged. Some trees may survive this type of damage, but their structure is often weakened and deformed as a result.

Plants' increased vulnerability to insects and illnesses after injuries caused by hail or freezing rain

In addition to affecting trees' normal growth and shape, the injuries that freezing rain inflicts on trees may make them more vulnerable to insect-related damages and illnesses.[139] For example, these injuries can serve as an entry point for fungi that cause tree rot, meaning wood decomposition.

Violent winds made a huge tree branch fall onto a vehicle in the Hochelaga-Maisonneuve neighbourhood. (01/11/2013)
Credit: © Patrick Sansfaçon, *La Presse*

Change to the composition of plant species in wooded areas

By causing the death of many trees in wooded areas, destructive storms often change the composition of plant species found in these areas, as we observed in some places following the ice storm of 1998.[44, 132] As such, freezing rain can influence forest populations by encouraging tree species that are more resistant to this hazard.[86]

IMPACTS ON SOCIOECONOMIC ISSUES

High winds, hail, heavy snowfalls and freezing rain do not only cause material damages to the built environment, infrastructures and vegetation. They also directly affect the population because of the consequences they have on people's lives and health and on the smooth operation of various activities that take place in the city.

HEALTH

The damages caused by destructive storms can psychologically traumatize disaster victims. As well, existing health problems may be exacerbated when people are limited in their ability to get around the city.

EXPENSES FOR INDIVIDUALS

The damages caused to residences may lead to costs related to destroyed and damaged goods (damaged buildings or cars, loss of vegetation, etc.). This may be a source of concern for insurance companies, which may reduce risk coverage for individuals.

Ice storm crisis of 1998
Credit: © Denis Labine, Ville de Montréal

INCONVENIENCES AND ACCIDENTS

Destructive storms often lead to electricity outages. Strong winds can make cables sway violently ("galloping") to the point of breaking, which sets off network outages. Freezing rains can also take down electrical cables under the weight of accumulated ice. When power outages happen in winter and last several hours, they may force people to leave their homes in search of warmth and light. The ice storm of January 1998 is a good example of this, as it led to electricity outages for more than three million homes (meaning 4.7 million people, or 16% of Canada's population) from the Maritimes to the Outaouais and Saint-Laurent valleys.[83]

Electricity shutdowns not only affect heating and lighting; they can also have indirect effects on health, such as:

- shutdown of in-home medical equipment;
- food poisoning: power outages prevent people from using fridges and freezers, which can alter how food is stored;
- carbon monoxide poisoning: the indoor use of heating or cooking equipment designed for outdoor use (camping stoves, gas or combustion barbecues) creates carbon monoxide emissions which, in poorly ventilated settings, can cause poisoning and even death.

As well, power outages can lead to building damages due to frozen and burst pipes, as we saw in the section about impacts on the built environment (page 91).

Lastly, more generally speaking, the interruption of utility services (gas, communications, etc.), which can affect emergency responders' ability to take action, is also part of the indirect impacts of power outages.

Destructive storms also disturb transportation. Traffic may be hindered by vehicles veering off the road, heavy congestion and accidents if trees or debris end up in traffic lanes. This also hampers movement in emergency situations.

In the Montréal agglomeration, destructive storms are also associated with a higher number of injuries related to accidental falls, building collapses, falling trees and debris; such incidents can even cause premature death. This cocktail of impacts puts added pressure on health and emergency services, which must meet the increased need.

IMPACTS ON MUNICIPAL OPERATIONS

The various experts the Service de l'environnement met with detected a number of impacts that destructive storms have on municipal operations.

REDUCTION IN RECREATIONAL ACTIVITIES

Power outages in arenas lead to melting ice, because the facilities can no longer guarantee the appropriate temperature to keep it stable. Since the affected skating rinks are no longer usable, arenas are unable to offer their usual services to citizens. As well, the damages caused by bad weather lead to increased costs and labour for maintenance operations.

INCREASED COSTS

In Montréal, storms can bring about various types of operating costs. Heavy snowfalls require bigger snow removal operations, while violent winds that damage trees lead to increased pruning operations. Drinking water pumping and production activities are also impacted. More specifically, power outages on the network require the heavier use of generators, which boosts production costs by that same measure. Generator capacity may be limited in some cases. Lastly, storms may damage urban street furniture or material, which entails repair costs.

Credit: © Martin Chamberland, *La Presse*

The Société de transport de Montréal (STM) takes a range of measures to limit its system’s vulnerability to the risks that come with climate change, and to ensure customer safety and maintain service in case of bad weather.

The metro’s electrical power comes through several Hydro-Québec transport lines, which makes it possible to reduce the risks of major electrical outages. The metro system is also equipped with generators to power essential systems and equipment in case of a power outage. During the ice storm of 1998, the STM was able to maintain reduced service by relieving some electrical loads (we turned off escalators and reduced the number of trains), while a large portion of the Ville de Montréal was undergoing major electrical outages.

As for the bus system, we adapt service delivery depending on the problems at hand, and customers are informed via various communication tools. In 2016, the iBus information and passenger system will allow the STM to react even more quickly when this type of event occurs, both to adjust services and to inform our clientele. As well, to minimize the impacts on our bus service, the STM works closely with the Ville de Montréal to signal places where buses are having difficulty getting through so that the city can react quickly. In case of a snowstorm, the Ville de Montréal’s snow removal plan prioritizes the routes used by the STM’s surface network.

The STM’s emergency measures coordination unit (the Unité de Coordination des Mesures d’Urgence, or UCMU) coordinates all of our emergency response actions, in particular those related to extreme climate conditions, in collaboration with the Ville de Montréal and the Agglomeration’s operating centres and emergency measures offices.

The STM is also a partner to the Ville de Montréal’s emergency measures plans and the Agglomeration’s civil safety plans. As such, the STM can be mobilized to move vulnerable people (for instance, senior’s home residents) who fall victim to the consequences of destructive storms (prolonged power outages, risky local travel due to snow and freezing rain, etc.).

Contributed by the STM

HEALTH AND SAFETY

When storms have affected Montréal in past years, experts noted the increased deployment of first responders, snow removal staff, and employees who spread road salts and abrasives to make driving surfaces and sidewalks safer. This sudden and sustained need can lead to fatigue among employees in times of serious bad weather. For example, employees working in snow removal are tired when snow removal lasts for many days in a row, and this in turn leads to increased health and accident risks.

VULNERABILITY ANALYSIS

Once we established the impacts of destructive storms, we were able to carry out a hazard-specific vulnerability analysis for the Montréal Urban Agglomeration. As some of these impacts affect groups of people who live in particular areas of the Agglomeration, as well as infrastructures whose placement is clearly known, we were able to carry out a geographic vulnerability analysis. The methodology we employed is set out in Appendix A.

This section presents the areas of the agglomeration affected by this hazard, as well as the social and territorial susceptibilities, whether they are mapped or not. Lastly, the Vulnerability to Destructive Storms section on page 102 shows and discusses the maps we obtained through geographic analysis.

AREAS AFFECTED BY THE HAZARD (PHYSICAL SUSCEPTIBILITY)

We set out the hypothesis that physical susceptibility to destructive storms is the same throughout the Montréal agglomeration, meaning that all areas are likely to be affected by a storm. This is why Map 7.3 on page 104, which shows physical susceptibility, is all one colour.

That said, we know that the wind's strength and direction can be changed by local factors (funnel effect and slot effect). Nevertheless, at this time there are no studies that quantify these effects on the Montréal agglomeration, so we chose to attribute identical physical susceptibility to the whole territory.

ENVIRONMENTAL SUSCEPTIBILITY

Due to the limited availability of data, and because many environmental parameters cannot be mapped, environmental susceptibility was not taken into account in the cartographic analysis of the Montréal agglomeration's vulnerability to destructive storms. Nevertheless, the natural environment is sensitive to the impacts of storms, as discussed below.

Line of ash trees in an industrial area
Credit: © Équipe de lutte intégrée, Ville de Montréal

Lack of local species diversity

The urban forest generally lacks species diversity.[116] In Canada, a few dominant species make up approximately 50 to 70% of the forest in some cities.[89] In Montréal, about 74% of street trees are made up of three different types (maple, ash and linden). A homogenous urban forest is more vulnerable to climate change because of the higher risk of tree loss if a pest attacks one particular species. The example of the emerald ash borer is an eloquent one.[78] In Montréal, this insect currently threatens nearly 20% of public trees. In some parts of the territory, this percentage climbs to over 40%. Trees that are not doing well (sick, broken, infested by a pest such as the emerald ash borer) are particularly vulnerable to being damaged during destructive storms.

Structural features and placement of trees

Some structural and physical features make trees more vulnerable to being damaged by destructive storms. Here are a few[76]:

- tall trees;
- thin branches;
- spread-out crowns;
- imbalanced crowns;
- poorly pruned trees;
- injured trees;
- trees attacked by certain pest insects (such as emerald ash borer) or diseases;
- dead or broken branches;
- dead standing trees;
- trees located at the edge of a wooded area;
- compacted roots;
- superficial or imbalanced root systems.

Figures 7.4 and 7.5 illustrate some structural features that make a tree either vulnerable or resistant to freezing rain damage.

FIGURE 7.4
FEATURES THAT MAKE TREES VULNERABLE TO FREEZING RAIN DAMAGE

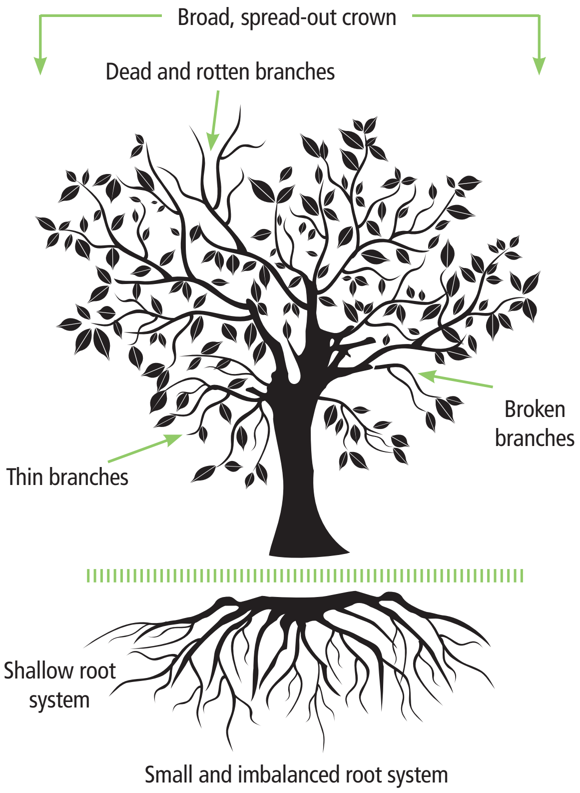
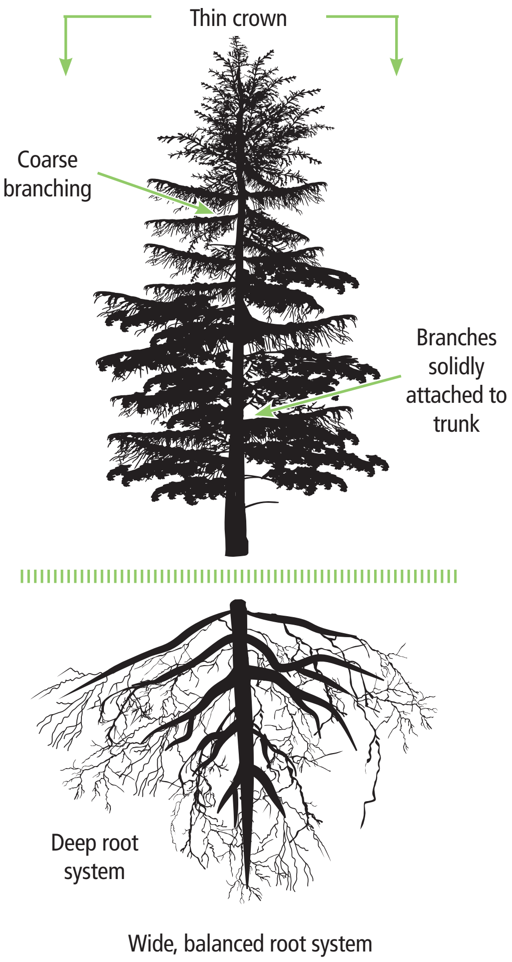


FIGURE 7.5
FEATURES THAT MAKE TREES RESISTANT TO FREEZING RAIN DAMAGE



Weeping willow along promenade Bellerive
Credit: © Jean Gagné, Flickr

Because of their structural and physiological features, some tree species are more vulnerable than others to the damages caused by destructive storms. The following table presents some of the species used in urban settings based on their level of resistance to freezing rain damage.

TABLE 7.4
ICE STORM VULNERABILITY IN VARIOUS TREE SPECIES USED IN URBAN SETTINGS

Adapted from Hauer, Dawson et Werner (2006)[76].

SENSITIVE	INTERMEDIATE	RESISTANT
Acer saccharinum	*Acer negundo*	*Abies balsamea*
Betula nigra	*Acer rubrum*	*Acer platanoides*
Celtis occidentalis	*Acer saccharum*	*Acer tataricum*
Fraxinus nigra	*Betula lutea*	*Aesculus flava*
Gleditsia triacanthos	*Betula papyrifera*	*Aesculus glabra*
Juglans cinerea	*Betula populifolia*	*Aesculus hippocastanum*
Pinus banksiana	*Fagus grandifolia*	*Carpinus caroliniana*
Populus deltoides	*Fraxinus americana*	*Carya cordiformis*
Populus grandidentata	*Fraxinus pennsylvanica*	*Carya glabra*
Populus tremuloides	*Larix kaempferi*	*Carya ovata*
Prunus serotina	*Larix laricina*	*Catalpa sp.*
Pyrus calleryana	*Liriodendron tulipifera*	*Ginkgo biloba*
Quercus nigra	*Pinus resinosa*	*Gymnocladus dioica*
Robinia sp.	*Pinus strobus*	*Hamamelis*
Salix sp.	*Pinus sylvestris*	*Juglans nigra*
Tilia americana	*Prunus virginiana*	*Juniperus virginiana*
Ulmus americana	*Pseudotsuga menziesii*	*Larix decidua*
Ulmus pumila	*Quercus coccinea*	*Malus*
Ulmus rubra	*Quercus montana*	*Ostrya carpinifolia*
	Quercus palustris	*Picea abies*
	Quercus rubra	*Picea glauca*
		Picea pungens
		Quercus alba
		Quercus bicolor
		Quercus macrocarpa
		Thuja occidentalis
		Tilia cordata
		Tsuga canadensis
		Tupelo

Recently, the composition of Montréal's urban forest has been relatively well documented. Most boroughs have taken an inventory of public street trees. This inventory includes a range of information, including the species, the georeferenced location, and the trees' condition. A map cataloguing the Ville de Montréal's 254,444 public trees is available on the website www.quebio.ca/en/arbresmtl.

By knowing the location of more fragile tree species, trees in areas heavily affected by a pest such as the emerald ash borer, and streets where tree species are not very diversified, we can get a sense of the most environmentally vulnerable locations. It will be very useful to include this data in future updates of the vulnerability analysis when the inventory is completed.

The lack of local diversity makes the urban forest more vulnerable to the harmful impacts of climate change. We must avoid planting a single species on a section of the territory, such as part of a street, like the line of linden trees along place Arthur-Buies in Mercier–Hochelaga-Maisonneuve.
Credit: © Équipe de lutte intégrée, Ville de Montréal

TERRITORIAL SUSCEPTIBILITY

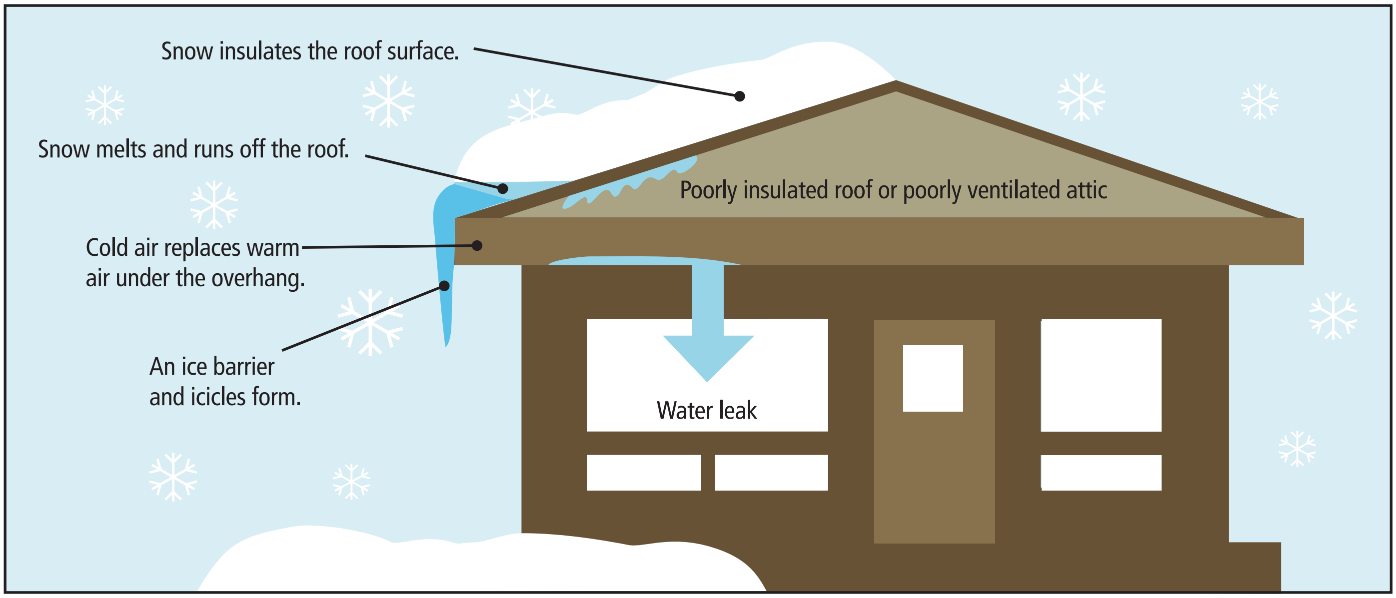
Map 7.1 (page 103) shows the territorial susceptibility to destructive storms in the Montréal agglomeration.

As described in the Impacts on the Built Environment section (page 91), many infrastructures are vulnerable to destructive storms. The ones considered in our geographic analysis are described below. The territorial susceptibility analysis considers the presence of these infrastructures on the territory, and sometimes their density; geographic data on their more detailed characteristics were not always available.

- **Buildings**. Buildings can be damaged by violent winds (particularly gabled roofs) and the weight of ice or snow. In addition to threatening the roof's structural integrity, snow and ice accumulations can also lead to water damage when the accumulated snow or ice melts and leaks into the basement. This can happen when an ice barrier forms at the edges of sloped roofs on homes whose roofs are poorly insulated or whose attics are poorly ventilated. As well, when a winter power outage occurs, building pipes can freeze and even burst.
- **Access to critical sites and places of interest**. During heavy rainfalls, areas of prime importance may become inaccessible, which may cause a range of problems. These places are called critical sites (hospitals, police stations, drinking water plants, etc.) or places of interest (schools, metro stations, bridge entrances and exits, etc.).

Other infrastructures are also heavily affected by storms. For example, bridges, traffic lights and road signs are vulnerable to strong winds, while pylons are vulnerable to ice accumulations. Above-ground utilities*, for their part, are vulnerable to both winds and ice accumulations. These infrastructures were not considered in our geographical analysis due to the lack of precise data on their locations.

FIGURE 7.6
FORMATION OF AN ICE BARRIER WHEN HEAT ESCAPES FROM A HOME'S INTERIOR OR ATTIC AND MELTS THE SNOW ACCUMULATED ON THE ROOF



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*According to the Grand dictionnaire terminologique de l'Office québécois de la langue française (translated from the definition of "commodité"), utilities are defined as "Equipment that provides comfort to a residence, building or neighbourhood in keeping with our era's ways of life." This can include electricity, natural gas, telephone, Internet and more.

SOCIAL SUSCEPTIBILITY

Map 7.2 (page 103) shows the Montréal agglomeration's social susceptibility to destructive storms.

As described in the Impacts on Socioeconomic Issues section (page 93), many people are vulnerable to the impacts of destructive storms. Table 7.5 lists the impacts and groups of people that were taken into account in our geographic analysis, such as children aged 0 to 15, seniors aged 65 and up, people living alone and underprivileged people. The impacts considered in the geographic analysis are as follows:

- inconveniences and accidents related to power outages;
- inconveniences related to service interruptions on above-ground utilities other than electricity (telecommunications);
- economic losses;
- accidents other than road (falls, falling debris, electrification and electrocution);
- psychological distress.

Some impacts affecting certain groups of people were not considered in our geographic analysis because the data about them were insufficient; this is the case for the question of aggravated health problems due to difficulty getting around town to access care. Other impacts were not considered because the distribution of the affected group across the island of Montréal is relatively constant, such as for road accidents.

WINDS AND COLD

In winter, the strong winds that can arise during a storm cause wind chill, which can increase the chances of hypothermia. Young children and seniors are more vulnerable to the cold, even if they are in good health, because low muscle mass, the inability to express that one feels cold, and poor temperature perception contribute to the risk of hypothermia, particularly during a long power outage. Winds also encourage serious frostbite as well as hypothermia among people exposed to bad weather for long periods, such as people who work outdoors or homeless people.

VULNERABILITY TO DESTRUCTIVE STORMS

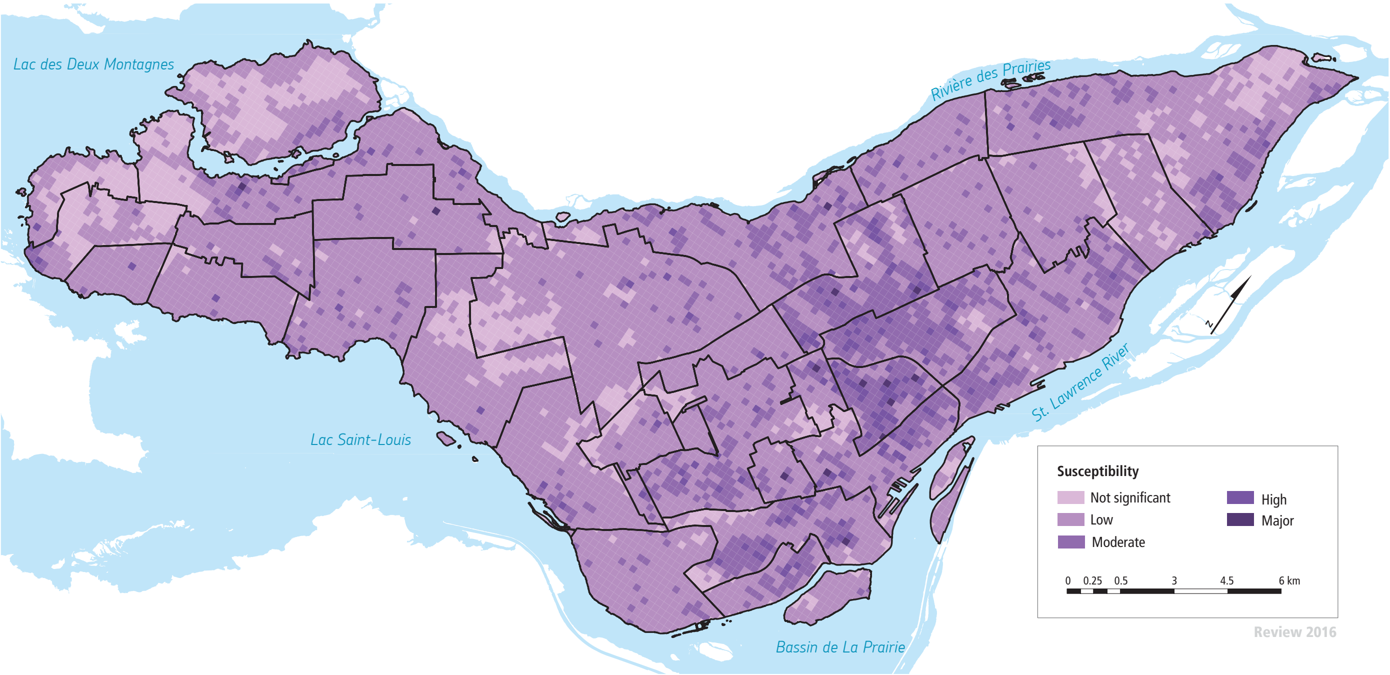
The Montréal agglomeration's vulnerability to destructive storms was established (Map 7.4) by adding together territorial and social susceptibilities, and multiplying that by physical susceptibility, meaning by applying the territorial and social susceptibilities to the entire territory, since storms can happen everywhere (Map 7.3). This map showing vulnerability to destructive storms is based on the choice of susceptibility factors we determined using the geographic vulnerability analysis methodology described in Appendix A.

Given that the territorial susceptibility used in the geographic analysis considers building density and the presence of critical sites and places of interest, the most densely populated neighbourhoods stand out as being areas whose territorial susceptibility is the highest in the agglomeration, as shown on Map 7.1. Note that most of the agglomeration's territory has minor or insignificant susceptibility levels.

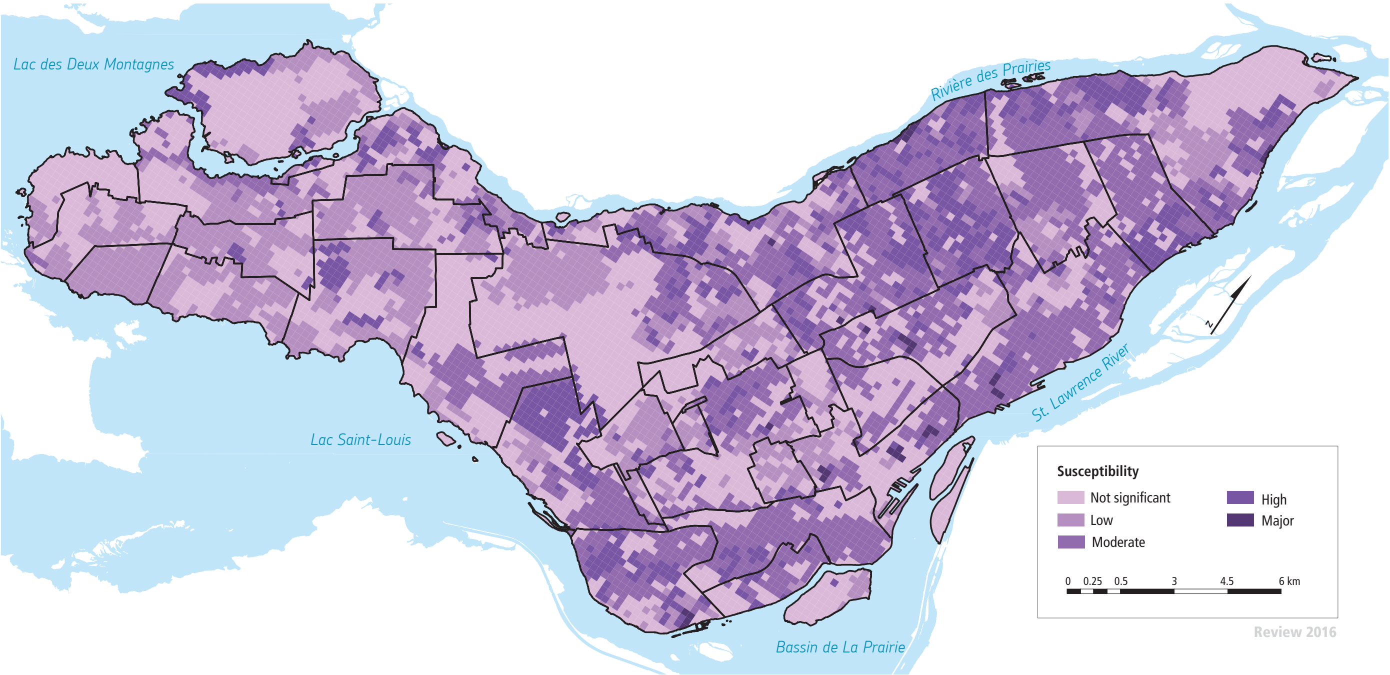
As for social susceptibility, the three most vulnerable groups are underprivileged people, people living alone, and seniors. These three factors are often combined (ex.: underprivileged people living alone, seniors living alone, underprivileged seniors, and even underprivileged seniors living alone). As a result, the areas where people with several of these characteristics live present particularly high social susceptibility. These areas are shown on Map 7.2.

Map 7.4 shows that a good part of the agglomeration presents minor or insignificant vulnerability to destructive storms.
More vulnerable areas are scattered throughout the island of Montréal, with a light concentration in more densely populated neighbourhoods, because territorial susceptibility is also focused in these neighbourhoods.

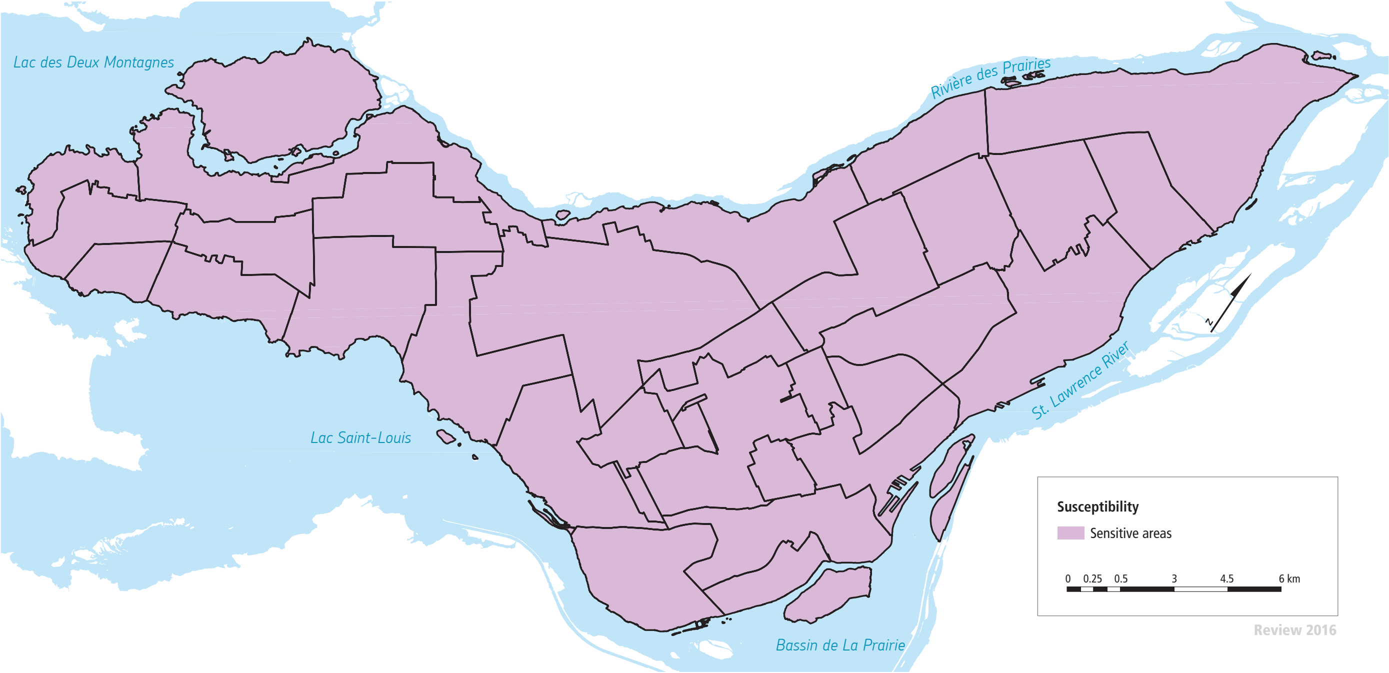
MAP 7.1
TERRITORIAL SUSCEPTIBILITY TO DESTRUCTIVE STORMS IN AREAS OF THE MONTRÉAL AGGLOMERATION



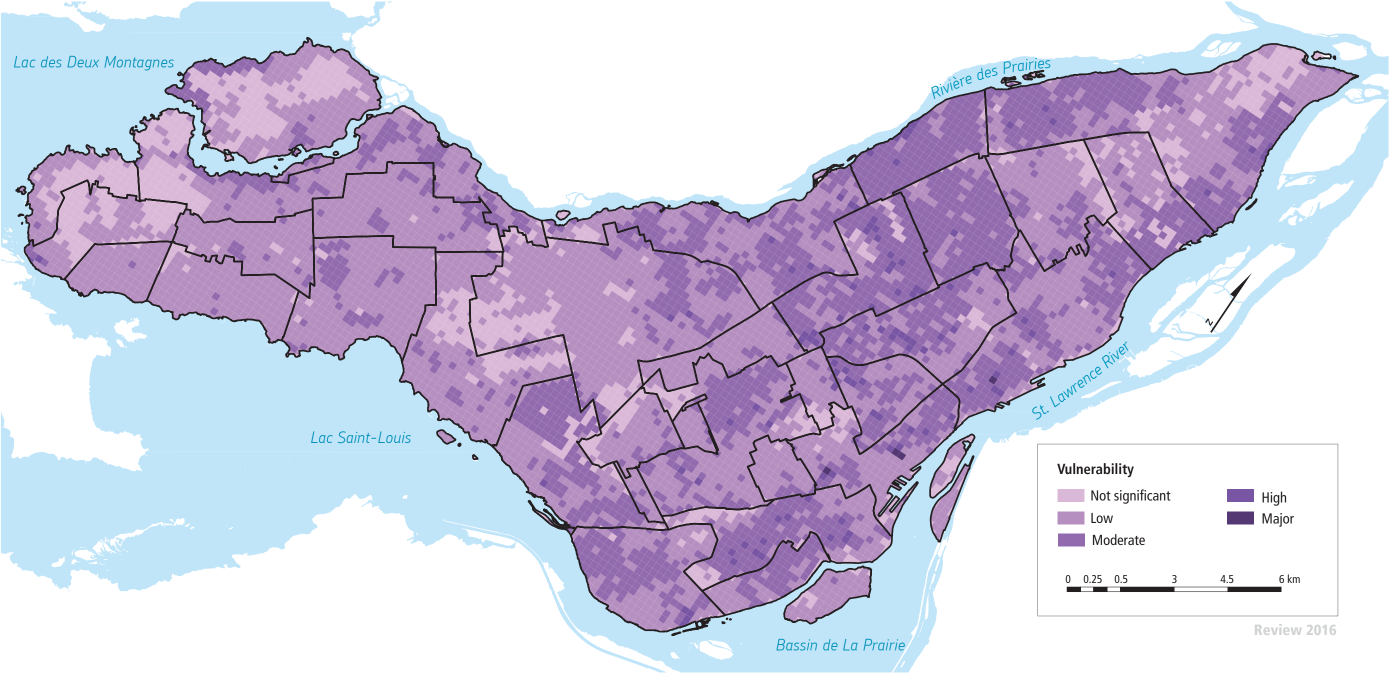
MAP 7.2
SOCIAL SUSCEPTIBILITY TO DESTRUCTIVE STORMS IN AREAS OF THE MONTRÉAL AGGLOMERATION



MAP 7.3
AREAS OF THE MONTRÉAL AGGLOMERATION SENSITIVE TO DESTRUCTIVE STORMS



MAP 7.4
VULNERABILITY TO DESTRUCTIVE STORMS IN THE MONTRÉAL AGGLOMERATION



DROUGHTS

The literature contains various definitions of drought. Each definition describes a distinct reality, and their usage depends on the set of issues being considered. If we look at the number of consecutive days without rain, we're talking about **meteorological drought**. If we focus on a water deficit in the soil, then we're talking about **soil moisture drought** (also called agricultural drought). **Hydrological drought** concerns an especially low watercourse and water table level. Lastly, **socioeconomic drought** includes humankind's pumping of water resources. All these types of drought are of course interrelated, but it is important to specify which one we're talking about when dealing with a given problem in order to avoid confusion.

For the most part, in this adaptation plan, we discuss soil moisture drought, because of the more marked impacts it can have on the agglomeration's territory.

Credit: © Ville de Montréal

CLIMATE EVOLUTION

HISTORICAL PERIOD

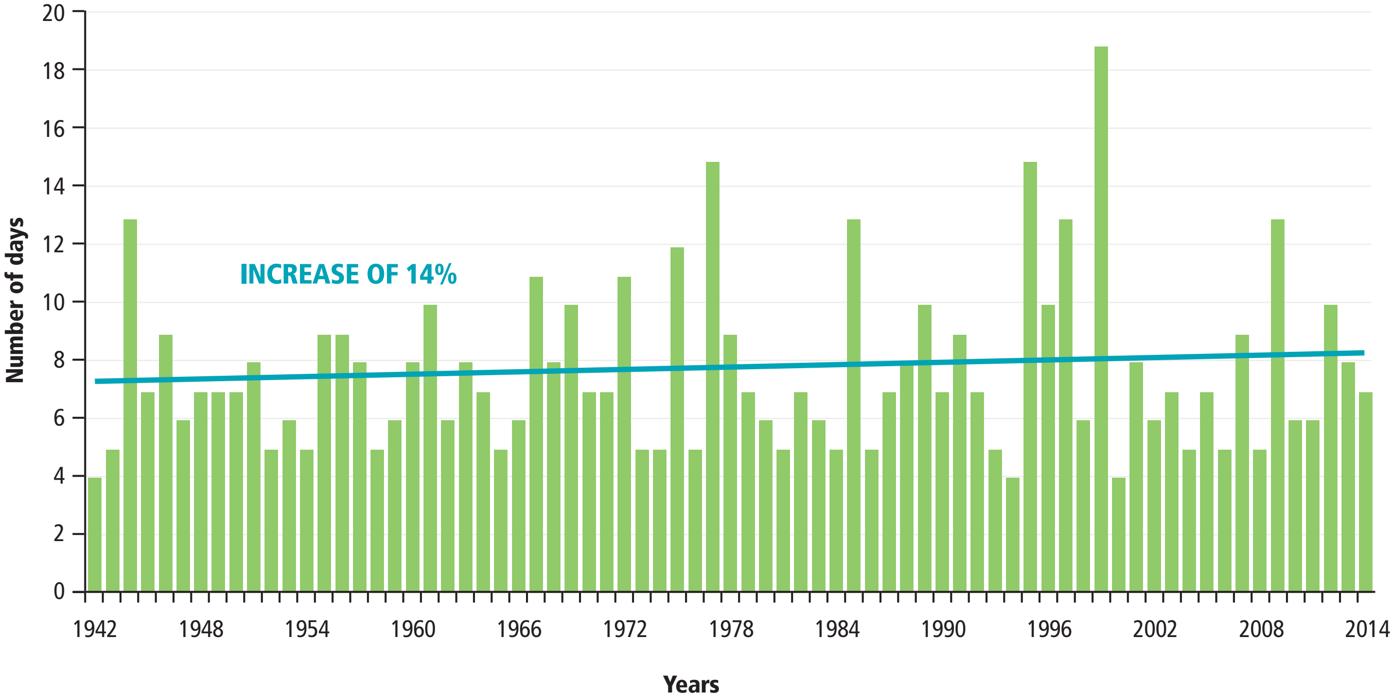
Over the last 30 years, no major droughts have been noted in the Montréal agglomeration. The last major drought dates back to 1957, when, in the month of August, only 2.1 millimetres of rain were recorded for Dorval and 0.6 millimetres at the McGill University station. August 1957 is considered to have been the driest month in the history of the greater Montréal area.[145] For comparison, from 1900 to 2014, 46 droughts were reported Canada-wide, including five in the province of Québec[127]

Nonetheless, we can evaluate whether **meteorological droughts** have increased in Montréal by calculating the number of consecutive days without rain over time (see Figure 8.1). We can observe a very minor trend toward more drought episodes during the summer months, in particular with a drought lasting 19 consecutive days in 1999. This upward trend is not significant, though, and it is still too early to attribute it to climate change. As well, on average for southern Québec overall, observations show a slight downward trend when it comes to meteorological drought indicators.[122]

It is more difficult to evaluate soil **moisture drought**, because precipitation alone does not determine it. Soil moisture drought depends on precipitation, but also on evapotranspiration. Evapotranspiration combines evaporation from the soil and water transpiration from the plants that cover that soil. When evapotranspiration increases, soil moisture drought increases. Evapotranspiration is difficult to estimate for a territory, because it depends on the type of soil and the vegetation growing there, among other things. In Québec, scientific studies disagree on the historical trends observed in regard to soil moisture drought, particularly due to different methods of calculating evapotranspiration. This disagreement makes it impossible to conclude as to whether soil moisture drought has increased or decreased in recent years.

FIGURE 8.1
EVOLUTION OF THE MAXIMUM NUMBER OF CONSECUTIVE DAYS WITHOUT PRECIPITATION FROM MAY TO SEPTEMBER, 1942-2014

Source: Data from the weather station at the Montréal-Trudeau International Airport.



When it comes to **hydrological droughts**, field observations from 56 hydrometric stations located in southern Québec allowed us to detect a slight upward trend over the last 15 years. More specifically, we identified:

- more severe (11%) and longer low flows (+ three days);
- less intense spring droughts (-8%);
- greater variability in watercourse flow rates (+22%).[121]

Variations in the precipitation pattern can induce a rise or drop in hydrological droughts. In the last chapter, we saw that the quantity of winter precipitation in the form of snow had decreased over the last 70 years. This in part explains why springtime river floods, as snow is melting, are less intense. The distribution of annual precipitation has evolved in recent years in southern Québec, to become more concentrated into heavy precipitation falls (snow and rain). As a consequence, watercourse flow rates are more variable.

Lastly, no in-depth studies have been conducted on **socioeconomic drought**. It seems that such events are rare in the Montréal agglomeration. However, we can cite for example the recent episode of yellowish water in Châteauguay (May 2-3, 2015)[149] linked to heavy water use by local residents, due to a particularly hot and sunny weekend.

To sum up, current historical observations do not permit us to conclude that there is any significant drought increase in Montréal in response to climate change. Despite these uncertainties, the prognosis for change in the long term seems a bit clearer.

CLIMATE PROJECTIONS

In Québec, for 2081-2100, most climate projections agree that we can expect shorter meteorological drought periods both year-round and in the winter (December to February), but longer ones in the summer season (June to August).[122] As for soil moisture drought, projections for soil moisture anomalies indicate that we can expect drier conditions year-round and even drier ones in the summer season for 2081-2100.[122]

The climate system's components provide various kinds of feedback to each other. In the case of drought, we can name a few. Heat waves can accentuate soil moisture drought. Basically, when the temperature climbs, evapotranspiration increases, because the air's potential humidity level increases; and so the soil moisture decreases. Heat waves are expected to increase in Montréal in response to climate change. This could lead to an intensification of soil moisture drought.

Paradoxically, the projected increase in heavy rainfalls could also intensify soil moisture drought. Intense rain does not have time to soak into the ground, and a good part is "lost" and carried away in runoff water. This means that for the same amount of water, it's better to have regular light rains than occasional heavy ones in order to guarantee good soil moisture.

Higher average temperatures lead to earlier and weaker spring river floods, under the combined effects of spring's early arrival and lighter precipitation in the form of snow. The earlier arrival of the spring snowmelt, along with the lighter influx of meltwater, could lead to lower water reserves by the end of the summer.

Increased drought is a process we must keep a close eye on so that we can adjust our water consumption accordingly and avoid socioeconomic droughts. However, there should not be any alarming situations between now and 2020. Projections of increased drought are only really reliable starting in 2081-2100.

IMPACTS

The impacts of drought on the Montréal agglomeration's territory are above all related to soil moisture drought. The drying of certain types of soils causes damage to the built environment, particularly to home and building foundations, road surfaces and sidewalks. The impacts on the built environment in turn cause economic impacts due to the costs associated with reconstruction work on damaged infrastructures. Other impacts have also been noted, including degraded air and watercourse quality. They are all illustrated in Figure 8.2 and described in the following pages.

FIGURE 8.2
EXAMPLES OF POTENTIAL IMPACTS OF THE INCREASED FREQUENCY AND DURATION OF DROUGHTS ON THE MONTRÉAL AGGLOMERATION

Built environment

Public infrastructures

- Damages to pavement and sidewalks
- Damages to sewer systems

Residential and ICI infrastructures

- Damages to homes and buildings
- Damages to infrastructures other than homes and buildings (sheds, reservoirs, culverts, etc.)

Socioeconomic issues

Health

- Health problems caused by air pollution (smog, fine particles, pollen)
- Illnesses caused by contaminated swimming water

Expenses for individuals

- Costs related to destroyed goods (damaged buildings, homes with meandering cracks, loss of vegetation, etc.)

Inconveniences and accidents

No significant impact identified

Natural environment

Plants

- Water stress on plants (flowers, plants and trees) that can lead to death if the drought is prolonged
- Increased plant vulnerability to insects and pathogens
- Lawns go dormant, which makes them more vulnerable to being overtaken by weeds
- Reduced incidence of fungal diseases for plants
- Reduced ecosystem services provided by trees (temperature regulation, air and water quality improvement, etc.)
- Increased risk of forest fires (in wooded areas)
- Reduced agricultural production (such as community gardens)

Water bodies

- Drying of some wetlands
- Altered water quality

Municipal operations

Maintenance

- More frequent street cleaning operations required
- Increased labour required to maintain green spaces (more frequent maintenance and watering)

Water

- Increased demand for water: shorter network reserve time, which weakens the system in case of a problem
- More complex water treatment due to the alteration of raw water
- Reduced system water carriage capacity in case of lower levels that limit plant capacity
- Increased demand for water: higher cost for chemical products and electricity

Additional complaints

- Increased problems with bad smells in manholes
- Intensified problems with drinking water taste and smell during severe low flows

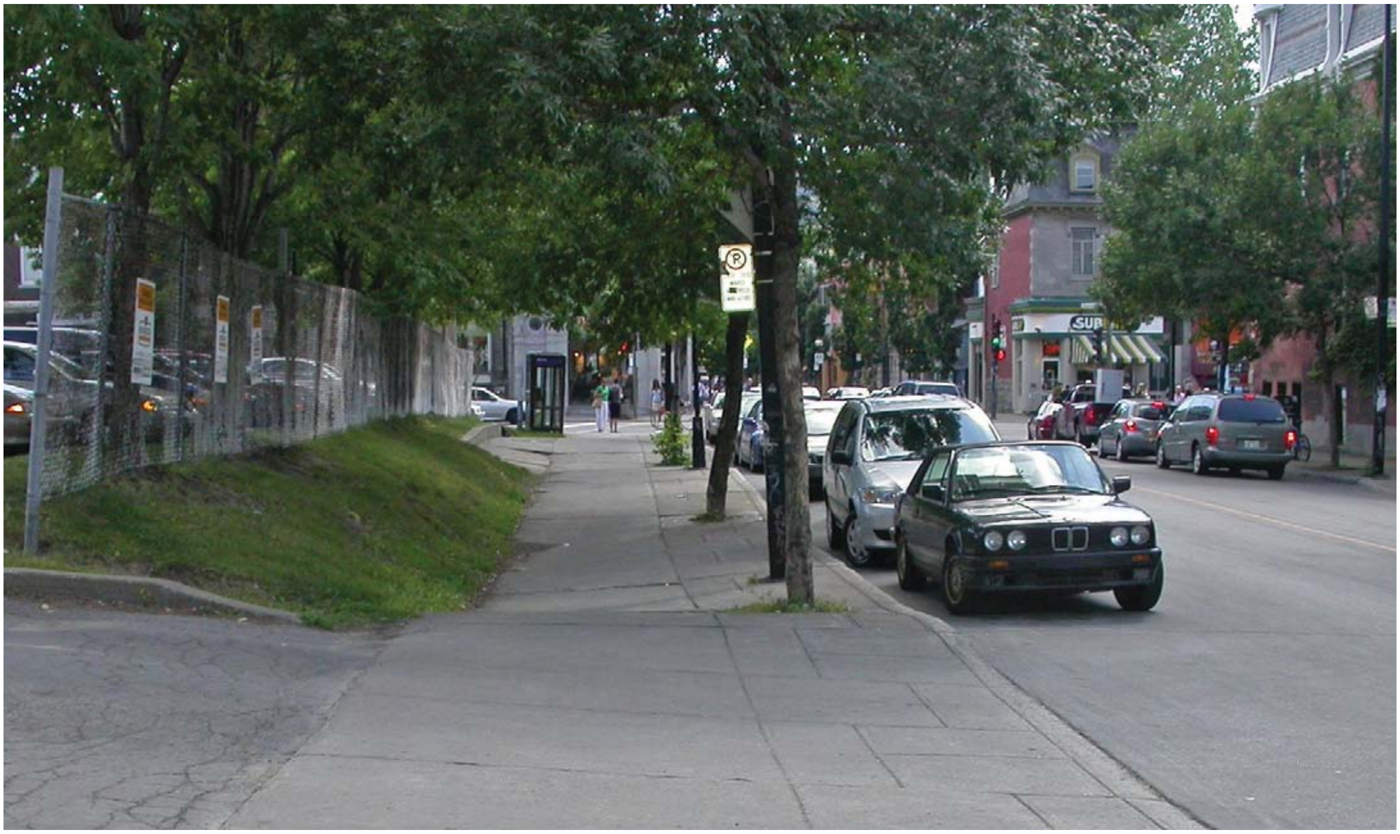
IMPACTS ON THE BUILT ENVIRONMENT

Soil moisture drought causes damage to buildings and infrastructures built on clay soils. Clay soils cover a good portion of the Montréal agglomeration's territory, so it's common practice here for buildings and infrastructures to be built on such soils.

When the necessary remedial measures are not applied to constructions, foundations can collapse when clay soils dry out. Basically, a change to the water composition of a clay soil affects its volume and causes it to shrink. This soil shrinkage can cause serious damage to buildings and infrastructures. Cracks appear in the foundations (these are known as meandering cracks) and can progress toward the walls. These cracks are the main consequences of soil collapse.

Soil moisture drought can also damage sidewalks, pavement and sewer pipes that are built on clay soil. Soil collapse can also cause waves and deformations in the pavement and sidewalks.

Lastly, aging and already-weakened infrastructures are more sensitive to soil collapse, which can lead to breakages and major construction works for the boroughs and municipalities.



Deformations observed at the south sidewalk level of rue Roy Est, westward view (30/07/2007)
Credit: © Division de l'expertise et du soutien technique, Ville de Montréal

IMPACTS ON THE NATURAL ENVIRONMENT

Drought can have major repercussions on the natural environment. In this section, we'll see how drought affects various components of the environment, particularly plants and water bodies.

PLANTS

Water stress

Drought is a source of water stress for plants. The harmful repercussions of water stress are detailed in the chapter on heat waves. A prolonged drought can ultimately kill plants.[7, 173]

TABLE 8.1
EXAMPLES OF PEST INSECTS WHOSE POPULATIONS REACHED HISTORIC LEVELS OF INFESTATION FOLLOWING DROUGHTS, AND THEIR HOST TREES

Adapted from Mattson and Haack, 1987

PEST INSECTS			HOST TREES
ORDER	FAMILY	TYPE	TYPE
Coleoptera	*Buprestidae*	*Agrilus*	*Betula, Populus, Quercus*
	Cerambycidae	*Tetropium*	*Abies*
	Scolytidae	*Corthylus* *Dendroctonus* *Ips* *Scolytus*	*Acer* *Picea, Pinus* *Picea, Pinus* *Abies, Carya*
Hemiptera	*Aphididae*	*Aphis*	*Crataegus*
	Psyllidae	*Cardiaspina*	*Eucalyptus*
Hymenoptera	*Diprionidae*	*Neodiprion*	*Pinus*
Lepidoptera	*Geometridae*	*Bupalus* *Lambdina* *Selidosema*	*Pinus* *Abies, Picea* *Pinus*
	Lymantriidae	*Lymantria*	*Picea,* many leafy trees
	Tortricidae	*Choristoneura*	*Abies, Picea, Pinus*
Orthoptera	*Acrididae*	Several types	Many grasses

Dormant grass due to drought
Credit: © Équipe de lutte intégrée, Ville de Montréal

Increased plant vulnerability to insects and pathogens

The stress that plants experience during drought can reduce tree vigour and increase their vulnerability to pest insects and pathogens.[7, 98, 134] As well, physiological changes in plants (nutrient levels, reduced defense mechanisms, etc.) brought on by drought can make them more attractive to pest insects.[98] Table 8.1 presents examples of pests across the world whose populations reached historic levels of infestation following drought.

Grass dormancy

In an urban setting, many green spaces are covered in grass (private yards, sports fields, parks, medians, etc.). In drought, the grass may turn brown. This browning, due to lack of rain, doesn't mean the grass is dead, but rather that it has gone dormant. Dormancy is an adaptive strategy that allows a species to survive when environmental conditions are difficult.[147] Despite appearances, each dormant blade of grass is still alive, and will turn green again in the weeks after it is watered. Grass dormancy can last up to six weeks before the plant becomes damaged. It's recommended not to cut or walk on dormant grass.

Reduced incidence of fungal diseases

Most fungi that cause fungal diseases in plants need a certain level of humidity to be able to grow and survive. Drought caused by climate change would be unfavourable to the development of fungal diseases.[66, 124,]

Reduced ecosystem goods and services provided by trees

Human societies benefit from nature. These benefits are called ecosystem goods and services.[51] Trees, and vegetation in general, provide ecological services (food, wood resources, temperature regulation, improved air quality, structural support for the soil, aesthetics and more).[101] By affecting plants, drought may reduce the ecological services they provide.[9]

Increased risk of forest fires

The prolonged absence of rain during the summer greatly increases the risk of forest fires. The Montréal agglomeration has many natural wooded areas on its territory. Various users regularly visit these areas. While open fires are always prohibited, some people who use the woods ignore the rules, and occasionally build small fires. In drought periods, the risk of forest fires is higher, and we should make efforts to boost our awareness-raising work with the people who use parks and wooded areas.

The Montréal agglomeration can also be indirectly affected by the impact of forest fires that may occur elsewhere in Québec. For example, in 2013, an intense drought that had plagued the James Bay region (in the northern part of the province) for several weeks contributed to the occurrence of several forest fires. While they were hundreds of kilometres away from the Montréal agglomeration, these fires still had major repercussions for us.

Credit: © SOPFEU, Stéphane Chalifour (23/06/2013)

On July 3, 2013, a major power outage during afternoon rush hour completely interrupted the metro service and affected a number of commercial buildings. The intense heat caused by the forest fires led to voltage fluctuations on the electrical lines located in the James Bay region. Emergency mechanisms were set off to protect the equipment, which in turn caused the outages we experienced in Montréal.

Reduced agricultural production

Drought has a direct impact, generally a negative one, on agricultural production. Montréal has few agricultural areas. In 2013, cropland represented 21% of the permanent agricultural zone, or nearly 410 hectares.[166] The majority of agricultural land is located in Montréal's West Island. However, other agricultural activities take place all over Montréal, particularly in community gardens, of which there are about a hundred on the Montréal territory.[50] The practice of urban agriculture could be affected by drought.

WATER BODIES

Alteration of water quality

Climate change can have major effects on water quality in watercourses.[110] Generally speaking, water quality tends to go down during a drought.[146] This decline can be attributed to various factors: warmer water temperature, reduced concentration of dissolved oxygen, conditions that favour the development of cyanobacteria blooms, eutrophication and a higher concentration of some pollutants and metals.[146] The increased frequency and intensity of drought due to climate change could lead to reduced ecological and recreational potential for watercourses.[146]

Drying of certain wetlands

During a drought, the water level in water bodies goes down, and some may even dry up completely. In these cases, it is likely that we would see increased mortality among some organisms whose survival depends on these small watering places (frogs, dragonflies, etc.).[136, 171]

Wetland in the Bois-de-Saraguay nature park suffering from a chronic deficiency in its water source
Credit: © Réseau de suivi du milieu aquatique, Ville de Montréal

IMPACTS ON SOCIOECONOMIC ISSUES

In the case of drought, the impacts on socioeconomic issues amount to health impacts and impacts on individuals' expenses. Health impacts are related to meteorological drought. Individuals' expenses, for their part, result from the impacts caused to the built environment.

Drought periods are often combined with high heat, which affects the levels of air pollutants. In dry weather, dust and particles, such as pollen, are more easily carried and contribute to poor air quality. The presence of pollutants and pollen in the surrounding air exacerbates the symptoms of respiratory and cardiovascular illnesses, and contributes to degrading health in people who are already weakened.[41]

As we underscored in the Impacts on the Natural Environment section (page 110), water quality can also be affected in times of serious drought. In very hot weather and drought, pollutants in watercourses are more difficult to dilute due to lower water flow rates. Swimmers who want to take a dip are more likely to be contaminated and get sick. Water-borne diseases generally manifest in the form of short-term gastrointestinal trouble (nausea, vomiting and diarrhea). Skin contact with or ingestion of poor-quality water can also cause dermatitis, as well as infections to the eyes, ears and throat.[104]

From an economic standpoint, drought can also have serious consequences. Since home insurance generally does not cover damage caused to houses by the collapse of clay soil, owners must handle the entire expense of foundation work—often very costly.

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IMPACTS ON MUNICIPAL OPERATIONS

The impacts on municipal operations identified for the territory, as related to the increased frequency and duration of periods without rain, particularly affect drinking water production activities and the maintenance of green spaces and roads.

Summer droughts, which may become longer, may increase the demand for water. The quantities of water consumed for watering lawns or green spaces place pressure on treatment and purification equipment. The increased demand for water could lead to shorter reserve time in the network, which would weaken the system in case of problems. This same increase would necessarily lead to additional production costs. Drought could also limit the system's water carriage capacity when water levels are very low, because low water limits the plants' capacity. As well, this could cause more severe low flows, which in turn cause drinking water taste and smell problems.

In addition, droughts have major impacts on all vegetation, as we saw in the Impacts on the Natural Environmental section. As a result, we need stronger coordination and more resources to ensure the longevity of landscaping, green spaces and street trees.

Lastly, when it doesn't rain for a long period, street cleanliness tends to degrade, which requires an increase in road cleaning operations.


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VULNERABILITY ANALYSIS

Once we established the impacts of drought, we were able to carry out a hazard-specific vulnerability analysis for the Montréal Urban Agglomeration. As some of these impacts affect groups of people who live in particular areas of the agglomeration, as well as infrastructures whose placement is clearly known, we were able to carry out a geographic vulnerability analysis. The methodology we employed is set out in Appendix A.

This section presents the areas of the agglomeration affected by this hazard, as well as the social and territorial susceptibilities, whether they can be mapped or not. Lastly, the Vulnerability to Drought section on page 117 shows and discusses the maps we obtained through geographic analysis.

AREAS AFFECTED BY THE HAZARD (PHYSICAL SUSCEPTIBILITY)

In case of drought, physical susceptibility is different depending on territorial susceptibility and social susceptibility.

For territorial suscept#ibility, only the buildings located in areas where the soil contracts when it dries are at risk. These areas represent physical susceptibility. They are illustrated on page 118. For an area to be prone to soil contraction, a few factors come into play:

- **Soil type**. Clay soils contract when they dry. In Eastern Canada, clay soils have a strong water retention capacity, so they lose considerable volume when they dry.
- **Soil water retention potential**. Some types of soil absorb water more easily than others.
- **Soil occupation**. Roads, parking lots and buildings are sealed infrastructures that prevent the soil from absorbing rainwater. This water is directed toward the sewer system instead. As a result, the soil in a heavily urbanized area is more difficult to re-moisturize because not much water can penetrate. As well, surface heat storage (such as asphalt) concentrates heat and encourages the soil to dry out.

For our geographic analysis, we used only soil type to determine the physical susceptibility related to territorial susceptibility.

As for social susceptibility, it is related to the areas affected by drought. In times of drought, the entire agglomeration is equally affected (constant physical susceptibility). This is illustrated on Map 8.4 (page 119).

ENVIRONMENTAL SUSCEPTIBILITY

Because of the limited availability of data, and because a number of environmental parameters cannot be mapped, environmental susceptibility was not taken into account in the cartographic vulnerability analysis of drought for the Montréal agglomeration. However, as we saw in the Impacts on the Natural Environment section (page 110), drought can have major impacts on the natural environment, particularly on plants and aquatic environments.

Current forestry models have difficulty predicting which trees would die prematurely due to drought, and when that would happen. Still, recent advances make it possible to create models that aim to predict tree mortality in forests due to drought. Such models are currently being tested in the United States. They bring together field data and data from aerial and satellite readings.[9] It would be worthwhile to adapt these models for urban forests.

Some tree and plant species are known for their resistance to drought[9, 23], while others, in contrast, are vulnerable to it. A future adaptation plan could attempt to map the areas where plants are more vulnerable to drought by using, for instance, data from the boroughs' tree inventories.

TERRITORIAL SUSCEPTIBILITY

Map 8.1 (page 117) shows the Montréal agglomeration's territorial susceptibility to drought.

As described in the Impacts on the Built Environment section (page 109), infrastructures are not directly exposed to drought. However, buildings and sidewalks are vulnerable to soil contraction when the soil dries out. Montréal is particularly vulnerable to this phenomenon because a good part of our soils are clay (see Map 8.2 on page 118). However, the only factor we took into account in the geographic analysis of territorial susceptibility is building density.

SOCIAL SUSCEPTIBILITY

Map 8.3 (page 118) shows social susceptibility to drought in the Montréal agglomeration.

As described in the Impacts on Socioeconomic Issues (page 113), many people are vulnerable to the impacts of drought, such as children aged 0 to 15, seniors aged 65 and up, people living alone and underprivileged people. The impacts considered in the geographic analysis are as follows:

- health problems caused by smog and fine particles;
- health problems caused by pollen;
- illnesses caused by contaminated swimming water;
- economic losses.

The most significant impact is degraded air quality. During a drought, concentrations of smog, fine particles and pollen tend to go up, since the rain is not leaching contaminants from the air as it usually would. The problems that soil movement causes to buildings can lead to major reconstruction work costs or loss of building value. Lastly, water quality in watercourses can be lightly degraded during drought, which can cause illnesses among people who practice aquatic activities.

VULNERABILITY TO DROUGHT

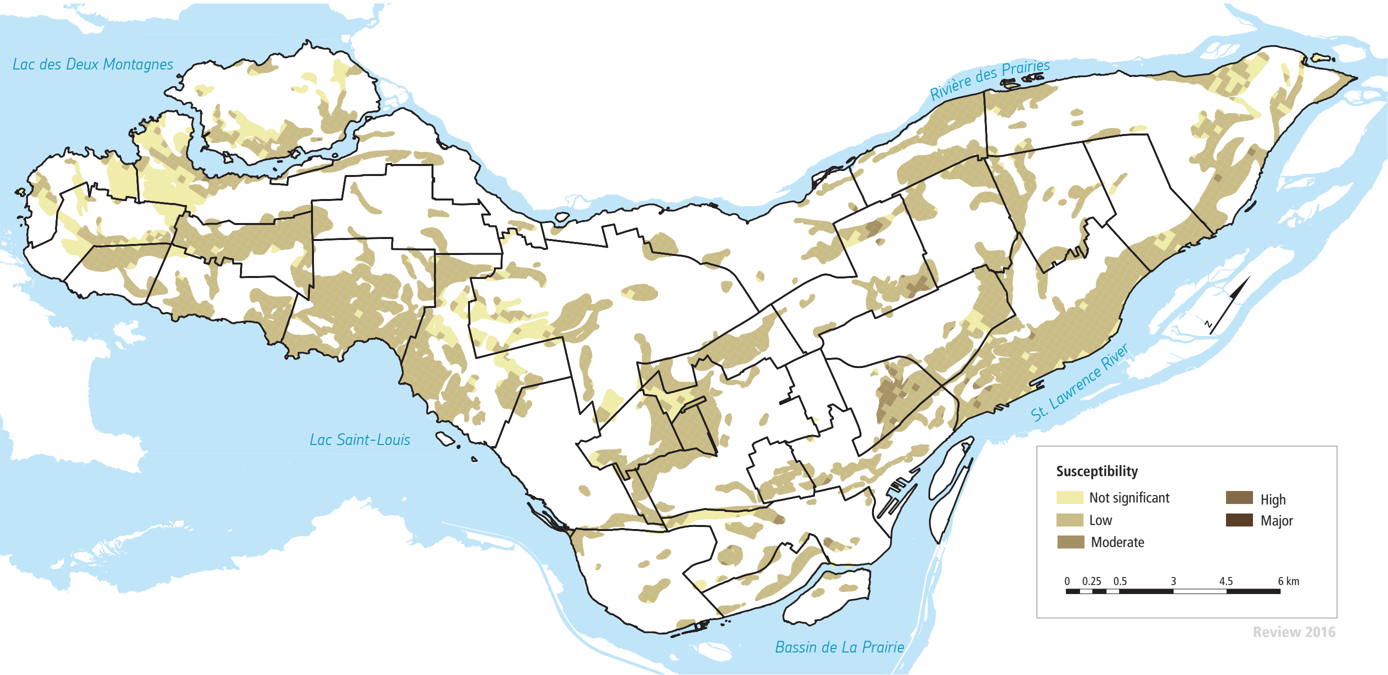
The Montréal Urban Agglomeration's vulnerability to drought (see Map 8.5) was obtained by multiplying territorial susceptibility by associated physical susceptibility (soil contraction areas); multiplying social susceptibility by associated physical susceptibility (areas of the agglomeration affected by drought, meaning the entire agglomeration); and adding the two values together. This map showing vulnerability to drought is based on the choice of susceptibility factors we determined using the geographic vulnerability analysis methodology described in Appendix A.

Drought vulnerability varies greatly from one place to another within the agglomeration, which can be explained by territorial and social factors.

As mentioned in the subsection on areas affected (page 115) by the hazard (physical susceptibility), territorial susceptibility only affects buildings located in areas where the soil is clay (maps 8.1 and 8.2). Most of these areas present minor or insignificant susceptibility. Only a few places, with higher building density, present moderate territorial susceptibility. The Plateau-Mont-Royal and Villeray–Saint-Michel–Parc-Extension boroughs feature a stronger concentration of areas with high building density.

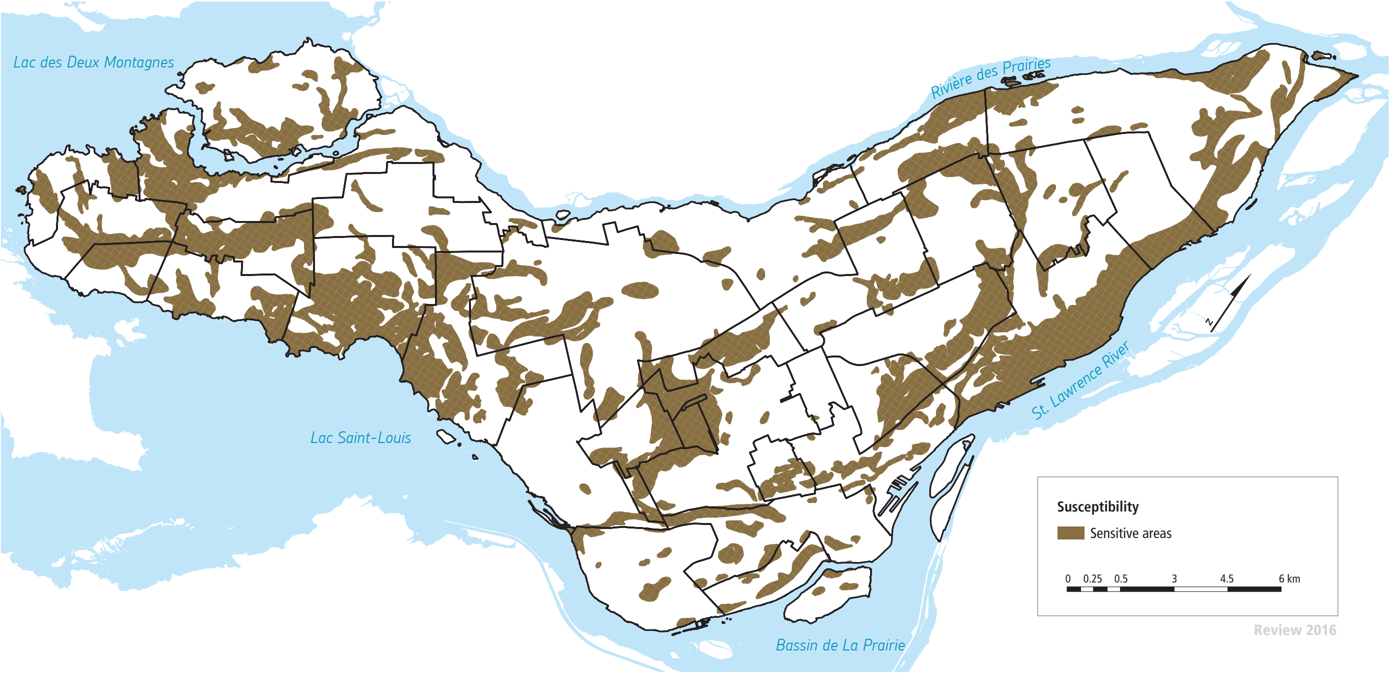
Sensitive areas to drought, for their part, concern the entire Montréal territory (Map 8.4). Underprivileged people are the most vulnerable to the various impacts of drought. As a result, the social susceptibility map (Map 8.3) mostly represents underprivileged areas, although some areas present higher susceptibility for other reasons, such as the presence of senior citizens living alone.

MAP 8.1
TERRITORIAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO SOIL CONTRACTION



Review 2016

MAP 8.2
AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO SOIL CONTRACTION



Review 2016

MAP 8.3
SOCIAL SUSCEPTIBILITY TO DROUGHT IN THE MONTRÉAL AGGLOMERATION

Review 2016

MAP 8.4
AREAS OF THE MONTRÉAL AGGLOMERATION SENSITIVE TO DROUGHT

MAP 8.5
VULNERABILITY TO DROUGHT IN THE MONTRÉAL AGGLOMERATION

RIVER FLOODS

In the preceding chapters, we demonstrated that climate change modifies the water cycle in the Montréal region (in particular, more episodes of heavy rain and meteorological drought). This change to the water cycle also has an impact on river floods. We call it a river flood when the flow or level of a river rises above a critical threshold.

The risk of river floods in the Montréal agglomeration mainly concerns the boroughs and municipalities that border Rivière des Prairies. The flow of the St. Lawrence River is regulated upstream by a number of hydroelectric dams, which considerably reduce the risk of river floods. Rivière des Prairies, for its part, is mainly fed by Lac des Deux Montagnes and the Ottawa River, the longest river in Québec, which drains water from the Outaouais drainage basin (a surface of 146,000 km^2). The Ottawa River is also regulated by dams, but only at its northern part (about 33% of the drainage basin). The rest of the water in the Outaouais basin flows directly into Rivière des Prairies, with major seasonal variations (flows ranging from 1,000 m^3/s to 8,000 m^3/s).[121]

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CLIMATE EVOLUTION

HISTORICAL PERIOD

The last notable river floods for the Montréal agglomeration took place in 2004 and 2008 (see Table 9.1). Rivière des Prairies flooding can be generated by various processes: the snow cover and ice melt in springtime, the forming of frazil ice mainly in winter or the forming of ice jams in spring and winter. A river flood in a given territory is basically brought on by either an increased flow upstream (for Rivière des Prairies, this would be an increased flow of the Ottawa River) or by the forming of an obstacle that prevents the water from draining downstream (such as ice jams or frazil ice accumulation).

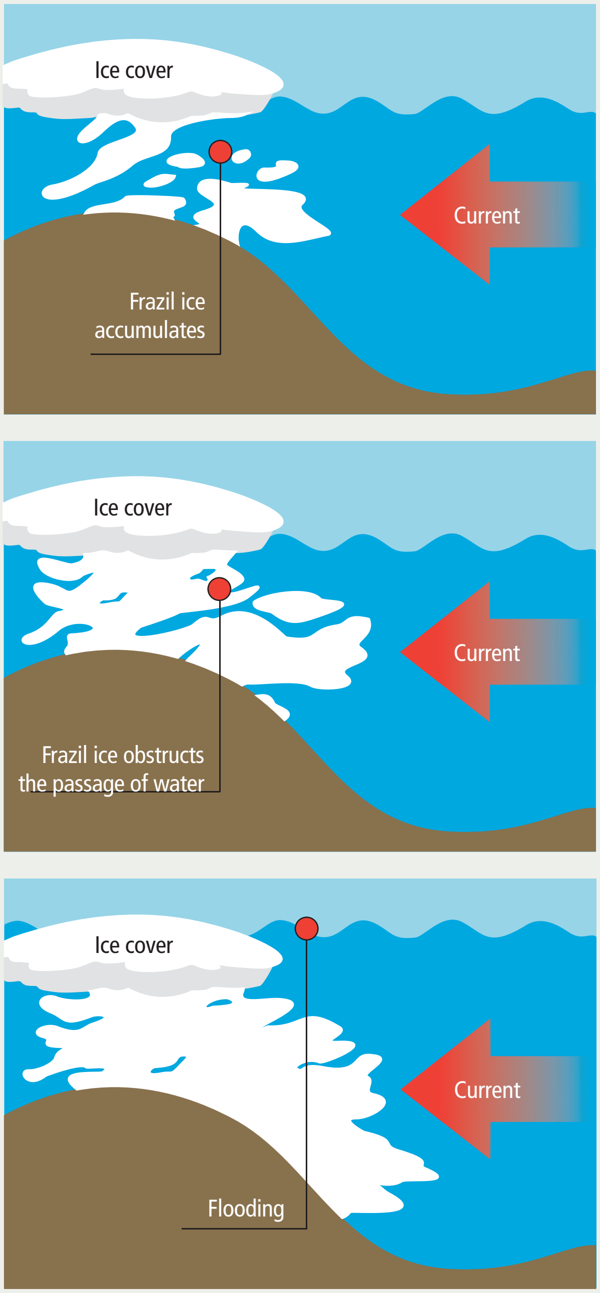
TABLE 9.1
KEY FACTS ABOUT THE NOTABLE RIVER FLOODS OF 2004 AND 2008

DATE	DETAILS
April 2004	A frazil ice accumulation in Rivière des Prairies in the Pierrefonds area led to rising water levels. An ice jam* downstream also worsened the river flood. A few homes were flooded.
April 2008	Heavy snowfalls in the winter of 2007-2008 and the regular melting of the snow cover in the entire Outaouais drainage basin led to a major flow of water into Rivière des Prairies in spring 2008. Many areas were affected, including Ahuntsic-Cartierville, Pierrefonds, L'Île-Bizard, Sainte-Anne-de-Bellevue and Senneville.

*According to the Environment Canada definition, an ice jam is "an accumulation of broken river ice or sea ice which is not moving, due to a physical restriction and its resistance to pressure."

FLOODING CAUSED BY AN ACCUMULATION OF FRAZIL ICE

Frazil ice is formed of fine needles or plaques of ice held in suspension in the water.[58] When these ice needles accumulate in a watercourse, they can impede its drainage, to the point of causing a flood.

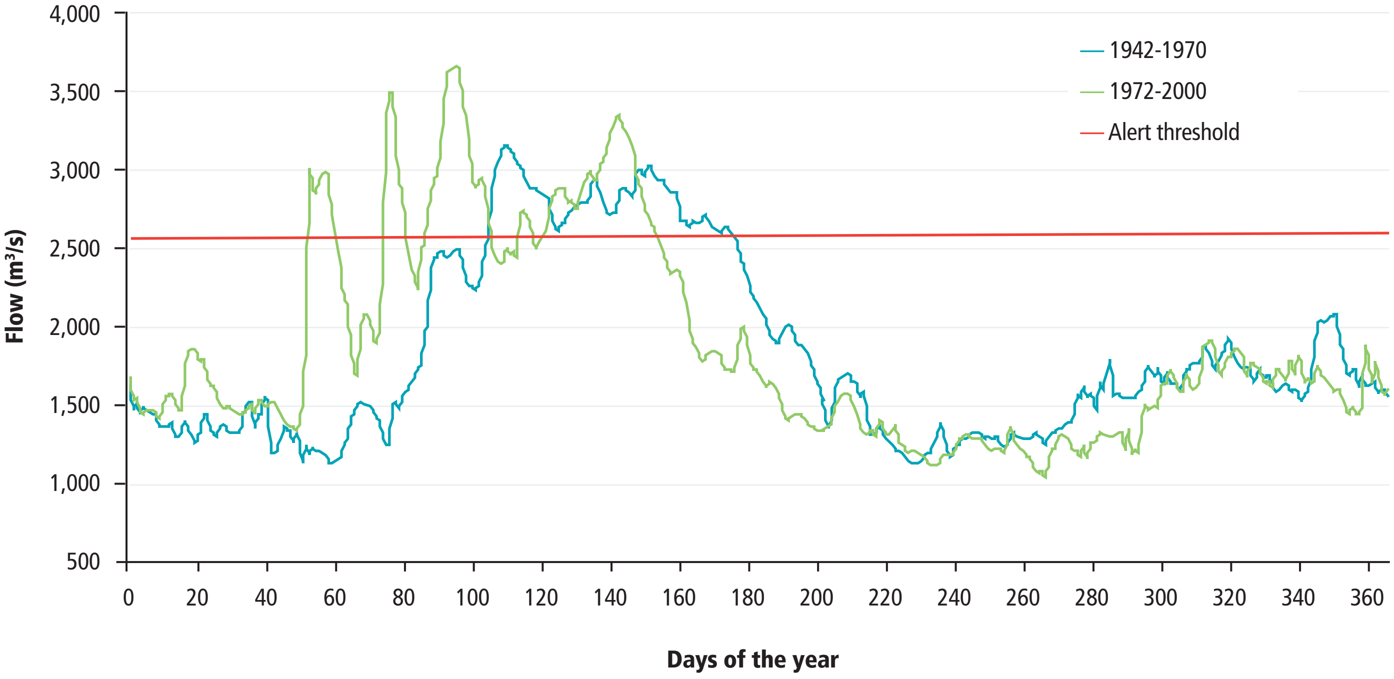


When we consider the maximum flows of Rivière des Prairies in the 1942-1970 and 1972-2000 periods, we see that spring river flooding episodes are happening earlier in the year (see Figure 9.1). In particular, in the 1942-1970 period, there were no spring river floods that rose above the threshold of 2,550 m³/s (alert threshold set by the Centre de sécurité civile) before April 14, whereas in the 1972-2000 period, that threshold was surpassed by February 22. As well, the maximum flows for 1972-2000 reached levels (over 3,550 m³/s) that were never reached in 1942-1970.

The shortened winter season leads to an earlier spring thaw, which explains the earlier timing of spring river floods. The higher number of freeze-thaw cycles in winter indicates milder periods in winter that encourage ice jams to form. Ice jams form when blocks of ice detach during milder weather and accumulate in an area of the river, creating an obstacle to drainage. The Montréal agglomeration was accustomed to having ice jams from early April to late May, but for a number of years now, ice jams have been observed in January and February.[154] The higher frequency of mild winter weather could also lead to an increase in river floods due to frazil ice.[21]

FIGURE 9.1
MAXIMUM DAILY FLOW FOR RIVIÈRE DES PRAIRIES

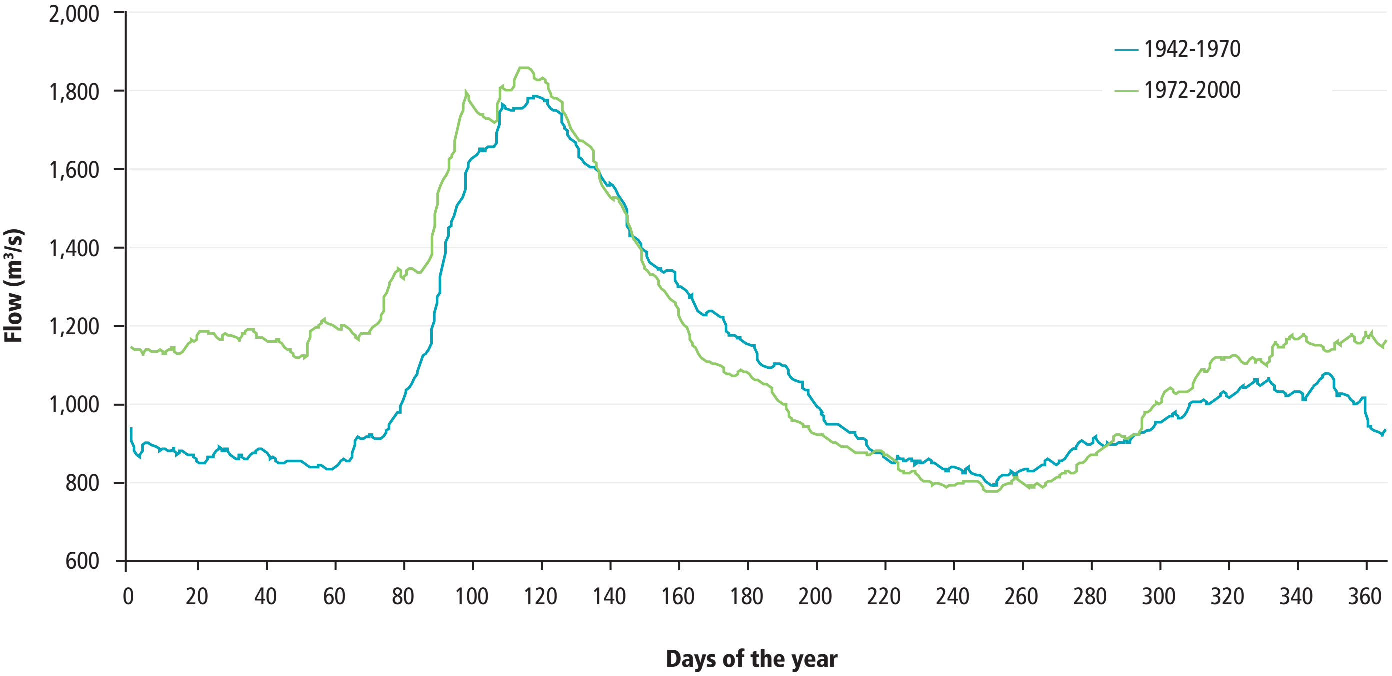
Note: Data from station no. 02OA004, Rapides du Cheval Blanc on Rivière des Prairies (45°31′6″ N, 73°50′33″ W).



The increased probability of river floods in winter is also clear when we consider the average flows for Rivière des Prairies (see Figure 9.2). We can observe that for 1972-2000, the average winter flows were about 300 m³/s higher compared to 1942-1970. This can be explained in part by the increase in winter rain due to higher temperatures.

FIGURE 9.2
AVERAGE DAILY FLOW FOR RIVIÈRE DES PRAIRIES

Note: Data from station no. 02OA004, Rapides du Cheval Blanc on Rivière des Prairies (45°31′6″ N, 73°50′33″ W).



CLIMATE PROJECTIONS

Climate projections for Québec indicate an increase in average river flows in winter for 2041-2070.[122] According to a study from the Centre d'expertise hydrique du Québec (CEHQ)[30], for 2050:

- spring river floods will be of a much lower volume in southern areas;
- spring river floods will quite likely happen earlier throughout southern Québec;
- average monthly flows will increase by 50% for the months of December to March;
- average monthly flows will decrease by 25% for May to October.

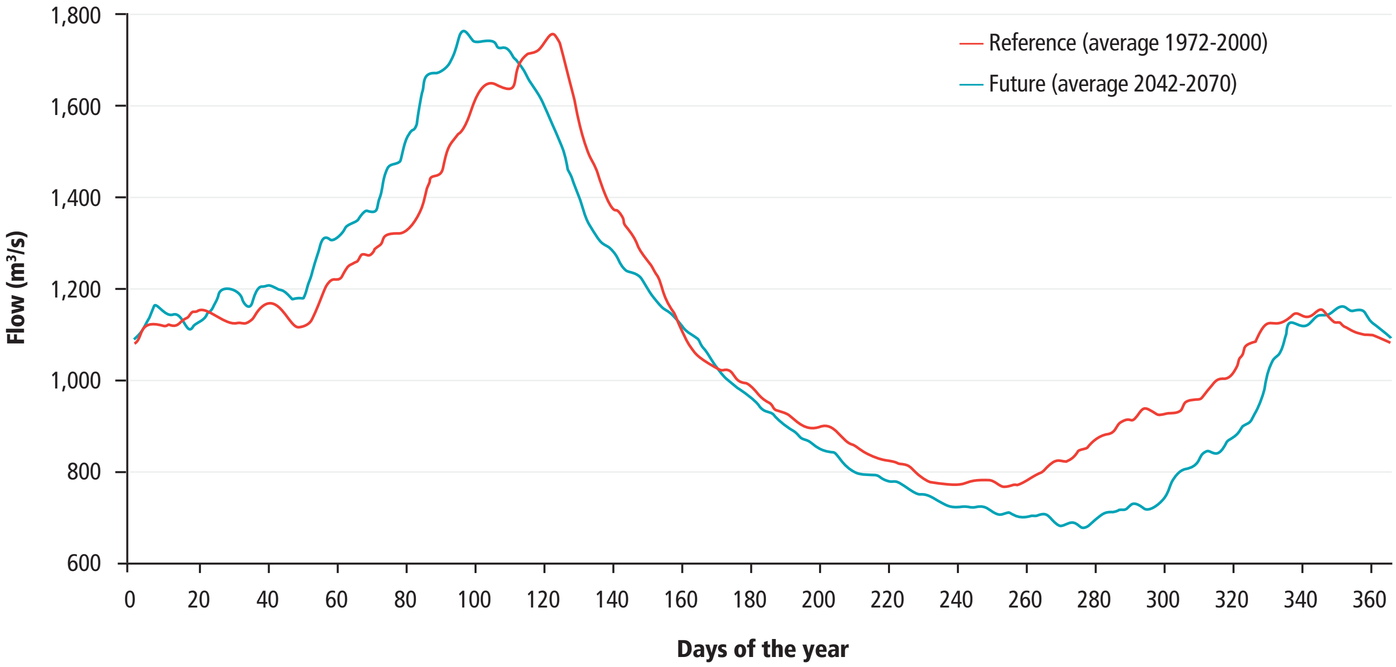
As concerns Rivière des Prairies, a recent study[48] simulated the average daily flow for 2042-2070 (see Figure 9.3). We noted that spring river floods should begin even earlier in the year than they have in the past (1972-2000, and by extension 1942-1970; see Figure 9.3).

Lastly, according to an Ouranos study[121], the St. Lawrence's levels should drop in the Montréal area by a maximum of 20 cm to 120 cm (depending on the climate scenario used) for 2050.

To sum up, we can clearly expect spring river floods from Rivière des Prairies to begin increasingly earlier in the year. However, it's not clear whether flooding in the future will be more intense than in the past. Hydrological models do not yet have the capacity to take into account frazil ice, which limits their predictive power for this type of river flood for the moment.

FIGURE 9.3
AVERAGE DAILY FLOW FOR RIVIÈRE DES PRAIRIES – REFERENCE AND FUTURE

Note: Simulated data from a hydrological model.



Source: Report by Sarah Dorner, *Impacts et adaptations aux changements climatiques des infrastructures municipales en eau de la rivière des Prairies*, Ouranos, March 2013.

IMPACTS

The impacts caused by river floods on the Montréal agglomeration are illustrated in Figure 9.4. As we mentioned earlier, these impacts mainly affect the boroughs and municipalities that border Rivière des Prairies. The impacts were divided into four categories: built environment, natural environment, socioeconomic issues and municipal operations. The impacts in each category are explained below.

FIGURE 9.4
EXAMPLES OF POTENTIAL RIVER FLOOD IMPACTS ON THE MONTRÉAL AGGLOMERATION

Built environment

Public infrastructures

- Damages to the road network and related structures
    - Roads and arteries
    - Local urban roads
- Damages to the sewer system
- Damages to underground utility networks

Residential and ICI infrastructures

- Damages to homes or buildings
- Damages to infrastructures by hazardous substance spills

Socioeconomic issues

Health

- Health problems caused by the growth of moulds
- Epidemics of waterborne gastrointestinal diseases due to sewer backups and floods
- Psychological distress

Expenses for individuals

- Possible reduction of insurance coverage
- Costs related to destroyed goods (damaged buildings, loss of vegetation, etc.)

Inconveniences and accidents

- Inconveniences related to road mobility (slowed or blocked traffic)
- Accidents other than road accidents (drowning, electrocution)
- Inconveniences related to underground utility service interruptions other than electricity

Municipal operations

Health and safety

- Increased demand for resources to implement emergency measures
- Delays in asphalting construction sites, renovating or replacing pipes

Natural environment

Water bodies

- Erosion of river banks

IMPACTS ON THE BUILT ENVIRONMENT

On the island of Montréal, river floods especially affect the boroughs and municipalities located on the banks of Rivière des Prairies. When a river's flow or water level rises above a critical threshold, its water overflows the riverbed and causes flooding. In an urban setting, flooding causes damage to the built environment, particularly to sewer system infrastructures, underground utility networks, and buildings located in flood-prone areas. A flood-prone area is the space occupied by a watercourse in times of river flooding. It corresponds with the geographic borders of the flooded areas.[107]

During a river flood, the sewer system may saturate very quickly, because the volume of overflow water is immense. This saturation places heavy demands on components of the sewer system (especially retention basins, rainwater and combined sewers, and pump stations), which can lead to more breakages. It also causes sewer backups in unprotected buildings.

Basements are especially at risk of flooding, whether due to overflows or to sewer backups. Factors such as inadequate ground levelling and the presence of a downward slope leading to the garage door entrance make it easier for homes to flood. Flooding causes damage, particularly to finished basements. As well, flooded buildings are at higher risk of developing mould problems.

While river floods can wash away culverts and even bridges, these impacts have not been observed in the recent past in Montréal. However, this does help us see the scope of the impacts this hazard can cause.

Lastly, flooding due to river floods can also damage the underground utility network (electricity, telephone, Internet, etc.), which can cause outages. These floods can even cause hazardous materials spills by damaging such materials' storage locations or transportation tanks.

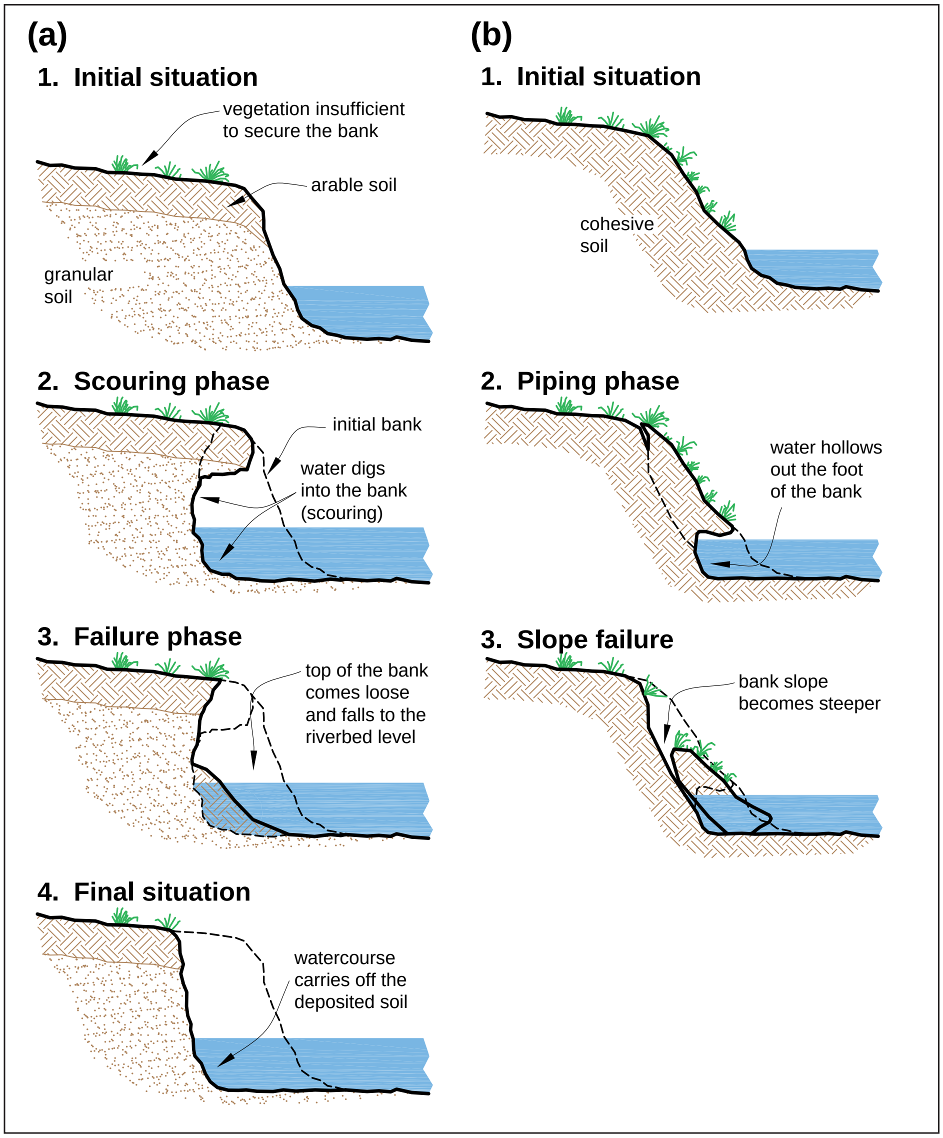
As mentioned earlier, river floods generate impacts that are similar to those of heavy rainfalls. However, the impacts of river flooding are felt in specific areas of the boroughs and municipalities located near Rivière des Prairies.

Ice from Rivière des Prairies broke down the rear fence of Résidence Berthiaume-du-Tremblay in the Ahuntsic-Cartierville borough. (18/04/2014)
Credit: © Philippe Rachiele – journaldesvoisins.com

IMPACTS ON THE NATURAL ENVIRONMENT

The main impacts of river floods on the natural environment are bank erosion and destabilization. Riverbanks that have little vegetation and that experience river flooding are at risk of eroding. The erosion process washes away the soil and reduces the water quality. The type of soil will influence the erosion process. Figure 9.5 shows how a river bank without much vegetation can erode based on the type of soil it's made up of.

FIGURE 9.5
RIVER BANK EROSION PROCESS ENCOUNTERED (A) IN COHESIONLESS SOIL (B) IN COHESIVE SOIL WHEN WATER SPEED IS HIGH



Source: Luc Lemieux, MAPAQ, adapted from G. Bentrup and J. C. Hoag (1998)[103]

IMPACTS ON SOCIOECONOMIC ISSUES

The impacts on socioeconomic issues identified for this hazard are split into three categories: **population health**, **expenses for individuals** and **inconveniences and accidents**. Most of them result from impacts felt on the built environment.

HEALTH

Floods increase:

- the prevalence of health problems caused by the increased presence of mould. Mould appears shortly after a flood. When it grows significantly, it can lead to serious health problems including asthma and allergic reactions that in turn can cause irritation to the eyes, nose, throat and sinuses;
- the prevalence of gastrointestinal disease epidemics, linked mostly to people's contact with the water in the flooded area. Water in a flooded area is not made up only of river water. It is often contaminated with wastewater when sewers have backed up. As such, it can contain bacteria and viruses that may be harmful to health;
- the prevalence of psychological distress. Flooding can cause major emotional and material losses, which can lead to psychological problems among disaster victims.

EXPENSES FOR INDIVIDUALS

Building floods generate major economic losses, such as the costs associated with destroyed and damaged goods. A flood can damage buildings and cause major material losses. As well, they are a source of concern for insurance companies, which may reduce flood risk coverage. In recent years, the Insurance Bureau of Canada noted that about 50% of claims paid out for home insurance were for water-related damages. In addition, the costs related to natural disasters have been climbing exponentially since the 1960s.[32]

INCONVENIENCES AND ACCIDENTS

Floods are a major cause of accidents, injuries and deaths. Urban floods hamper transportation, in particular by leading to the closure of some road sections and to traffic slow-downs. As well, submerged tunnels and overpasses, in addition to causing traffic problems, can endanger people's lives; if they are caught in their vehicles, they may risk drowning. The risks of electrocution and electrification are also higher. During river floods, flooding can also cause damage to the underground utilities network, which can lead to outages of varying degrees of severity, depending on the affected utility (electricity, telephone, Internet, etc.) and the length of the outage.

IMPACTS ON MUNICIPAL OPERATIONS

In general, the impacts on municipal operations identified in Montréal due to river floods are related to the implementation of emergency measures. The planning of such measures requires the input of many players from various entities, which can make the task complex.

On another note, flooding can impact some construction sites, including asphalting works and pipe rehabilitation and replacement. The work can be delayed, which causes delays for each successive step of the project.

The Amphibex machine breaks up ice in Rivière des Prairies. (27/01/2009)
Credit: © Ivanoh Demers, *La Presse*

VULNERABILITY ANALYSIS

Once we established the impacts of river floods, we were able to carry out a hazard-specific vulnerability analysis for the Montréal agglomeration. As some of these impacts affect groups of people who live in particular areas of the agglomeration, as well as infrastructures whose placement is clearly known, we were able to carry out a geographic susceptibility analysis. The methodology we employed is set out in Appendix A.

This section presents the areas of the agglomeration affected by this hazard, along with environmental, territorial and social susceptibilities, whether they can be mapped or not. Lastly, the Vulnerability to River Floods section on page 132 shows and discusses the maps we obtained through geographical analysis.

AREAS AFFECTED BY THE HAZARD (PHYSICAL SUSCEPTIBILITY)

The areas of the agglomeration that risk being flooded when Rivière des Prairies overflows its riverbanks are shown in dark blue on Map 9.3 (page 134). For an area to be affected by a riverbank flood, it must be located within the flood-prone area. A number of factors enter into play for this. However, simply being outside the flood-prone area does not guarantee that flooding will never occur.[31]

Flood-prone areas can be determined by regional county municipalities (RCM) or local municipalities. In this analysis, the cartography we used was based on 100-year flood return levels relative to Rivière des Prairies as set out in 2006 by the Centre d'expertise hydrique du Québec.

ENVIRONMENTAL SUSCEPTIBILITY

Due to the limited availability of data, and because a number of environmental parameters cannot be mapped, we did not consider environmental susceptibility in our cartographic analysis of the Montréal agglomeration's vulnerability to river floods.

As we saw in the Impacts on the Natural Environment section (page 127), river banks with little or no vegetation, located within flood-prone areas, may erode and become destabilized during river floods.

TERRITORIAL SUSCEPTIBILITY

Map 9.1 (page 133) shows the Montréal agglomeration's territorial susceptibility to river floods.

As described in the Impacts on the Built Environment section (page 126), many infrastructures are exposed to river floods. The ones we considered in our geographical analysis are described here.

The territorial susceptibility analysis considers the presence of these infrastructures on the territory, and sometimes their density, because geographic data on their more detailed characteristics were not available.

- **Buildings**. Buildings, particularly finished basements, can be flooded when rivers overflow their banks.
- **Access to critical sites and places of interest**. During a river flood, areas of prime importance may become inaccessible, which may cause many problems. These places are called critical sites (hospitals, police stations, drinking water plants, etc.) or places of interest (schools, metro stations, bridge entrances and exits, etc.).
- **The road network**. Riverbank floods and their leakage into road foundations contribute to the wear and breakage of these infrastructures. Culverts and bridges are particularly sensitive to this hazard. They may even be torn away if the water flow across them becomes very heavy.
- **The stormwater and combined sewer systems.** (Low susceptibility.) The quantity and flow of wastewater increase radically in the stormwater and combined sewer systems during river floods, which contributes to wear and breakage on pipes, retention basins and pumping stations.

SOCIAL SUSCEPTIBILITY

Map 9.2 (page 133) shows the Montréal agglomeration's social susceptibility to river floods.

As described in the Impacts on Socioeconomic Issues section (page 128), many people are vulnerable to the impacts of river floods, such as women, children aged 0 to 15, seniors aged 65 and up, people living alone and underprivileged people. The impacts considered in the geographic analysis are as follows:

- health problems caused by the presence of mould;
- psychological distress;
- gastrointestinal diseases caused by sewer backups and floods;
- accidents other than road accidents;
- inconveniences related to the interruption of underground utilities other than electricity (telecommunications, gas, etc.);
- economic losses.

Some impacts affecting certain groups of people were not considered in our geographic analysis because the data about them are insufficient. This is the case when it comes to the places where people who suffer from respiratory problems live (they are sensitive to mould problems that may follow a flood).

VULNERABILITY TO RIVER FLOODS

The Montréal agglomeration's vulnerability to river floods (see Map 9.4 on page 134) was obtained by adding together territorial and social susceptibilities, and multiplying them by physical susceptibility, meaning by applying territorial and social susceptibilities to flood-prone areas.

This map showing vulnerability to river floods is based on the choice of susceptibility factors we determined using the geographic vulnerability analysis methodology described in Appendix A.

As explained at the beginning of this chapter, the impacts of river floods on the Montréal agglomeration mainly affect the boroughs and municipalities located near the shores of Rivière des Prairies (Pierrefonds-Roxboro, Ahuntsic-Cartierville, Montréal-Nord, Rivière-des-Prairies–Pointe-aux-Trembles and Senneville). However, the borough of Saint-Laurent (which is not on the shores of Rivière des Prairies) also presents both insignificant and minor risk in regard to river flooding on a small part of its territory (see Map 9.1).

Any infrastructure or population located within a flood-prone area represents vulnerability for the territory. The breadth of this vulnerability depends, on the one hand, on territorial susceptibility factors, such as building density, the presence of critical sites and places of interest, and roads; and on the other hand, social susceptibility factors, meaning areas with high population density, particularly with the presence of groups that are vulnerable to the impacts of river floods.

The presence of underprivileged people considerably boosts social susceptibility, because they are the most heavily affected by a large number of river flood impacts. Children aged 0 to 15, as well as seniors, are also heavily impacted. Since a high proportion of seniors live alone (another social susceptibility factor) and are underprivileged, they constitute a particularly vulnerable group.

Map 9.3 shows that only a small part of flood-prone areas present high or severe vulnerability, and most flood-prone areas present low or moderate vulnerability.

MAP 9.1
TERRITORIAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO RIVER FLOODS

MAP 9.2
SOCIAL SUSCEPTIBILITY IN THE AREAS OF THE MONTRÉAL AGGLOMERATION EXPOSED TO RIVER FLOODS

MAP 9.3
AREAS OF THE MONTRÉAL AGGLOMERATION SENSITIVE TO RIVER FLOODS (FLOOD-PRONE AREAS)

- 100-year return levels (sources: Révision des cotes de crues, Rivière des Prairies, CEHQ, 2006; Lac des Deux Montagnes, cartography by Ville de Montréal).
- The 100-year return levels increased by 30 cm to compensate for topographical data errors (they are at ± 30 cm).
- The areas' border is rounded up; it is adjusted to the higher-altitude isoline (0.5 m).

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MAP 9.4
VULNERABILITY TO RIVER FLOODS IN THE MONTRÉAL AGGLOMERATION

Review 2016

APPENDICES

APPENDIX A: METHODOLOGY FOR THE GEOGRAPHIC VULNERABILITY ANALYSES

We carried out a geographic vulnerability analysis of Montréal relative to climate change for each of the following climate hazards:

- heavy rainfalls;
- heat waves;
- destructive storms;
- droughts;
- river floods.

The methodology we used was adapted from that presented in the report entitled Analyser la vulnérabilité sociétale et territoriale aux inondations en milieu urbain dans le contexte des changements climatiques, produced for Ouranos, which takes the Ville de Montréal as a case study.

The vulnerability equation is:

Equation 1

$$V = S_{phys.} \text{ x } (S_{soc.} + S_{terr.} + S_{env.}) - CA$$

The value of our capacity to adapt was not evaluated, due to the methodological difficulties of such an operation. As such, we considered that capacity to adapt has a nil value in Equation 1, which gives the following equation:

Equation 2

$$V = S_{phys.} \text{ x } (S_{soc.} + S_{terr.} + S_{env.})$$

We hope to be able to deepen our work on this subject and find a way to quantify adaptation capacity so that we can include this parameter in the vulnerability analysis in future adaptation plans.

DEFINITIONS

CA	**capacity to adapt** – the capacity of communities and ecosystems to adjust when faced with climate change in order to minimize its negative effects and enjoy its benefits (adapted from Ouranos[120])
$S_{env.}$	**environmental susceptibility** – proportion in which the natural environment is likely to be affected (positively or negatively) by the manifestation of a climate hazard (adapted from Ouranos[120])
$S_{phys.}$	**physical susceptibility**, meaning the degree to which a territory is affected by climate hazards (adapted from ADEME[1])
$S_{soc.}$	**social susceptibility** – proportion in which a community is likely to be affected by the manifestation of a climate hazard (adapted from Ouranos[120])
$S_{terr.}$	**territorial susceptibility** – proportion in which infrastructures are likely to be affected (positively or negatively) by the manifestation of a climate hazard (adapted from Ouranos[120])
V	**vulnerability**, meaning the propensity or predisposition to suffer damages (adapted from IPCC[85])

The impacts on the natural environment, for their part, were not evaluated except for heat waves due to the limited availability of data and because many environmental parameters cannot be mapped ($S_{env.} = 0$). Despite this, it is important to mention that municipalities are beginning to be interested in the effects of climate change on urban plant life.

Climate change vulnerability analyses have been carried out for some urban forests.[177] However, this type of process remains marginal, as a vulnerability analysis for the urban forest can be complex. Still, experts recommend conducting them.[118] Ideally, this analysis should be done locally and can serve as a basis for putting into place local adaptation measures.[118]

Vulnerability to all climate hazards was evaluated using Equation 2, except for drought. The social impact of drought can extend across the entire territory of the agglomeration (such as increased prevalence of health problems caused by a higher quantity of fine particles in the air), while the impacts on infrastructures are only felt in areas where the potential for soil contraction is high (such as building foundation problems). As a result, two physical susceptibilities were used. The first, in relation to social susceptibility, is constant across the entire territory ($S_{phys.(soc.)} = 1$).

The second, in relation to territorial susceptibility, has a value of 1 in the areas where the potential for soil contraction is high, and a value of 0 elsewhere ($S_{phys.(terr.)} = [0.1]$). As a result, the equation used to evaluate vulnerability in the case of drought is:

Equation 3

$$V = S_{phys.(soc.)} \text{ x } S_{soc.} + S_{phys.(terr.)} \text{ x } S_{terr.}$$

Since $S_{phys.(soc.)} = 1$, Equation 3 can be simplified as follows:

Equation 4

$$V = S_{soc.} + S_{phys.} \text{ x } S_{terr.}$$

where $S_{phys.}$ corresponds to $S_{phys.(terr.)}$. This latter equation was used to evaluate vulnerability to drought.

PHYSICAL SUSCEPTIBILITY

Physical susceptibility represents the places affected by the climate hazard, as described in Table A.1 on page 138. The table also briefly presents the methodology followed to obtain physical susceptibility. It has a value of 1 (exposed areas) or of 0 (non-exposed areas).

TABLE A.1
DESCRIPTION OF PHYSICAL SUSCEPTIBILITY AND THE METHODOLOGY FOLLOWED TO OBTAIN IT PER HAZARD

HAZARD	DESCRIPTION OF PHYSICAL SUSCEPTIBILITY	METHODOLOGY
Heavy rainfalls	Areas where runoff water could accumulate in the absence of a sewer system	We developed a runoff water model that takes into consideration topography, the presence of vegetation, soil type and soil sealing attributable, for instance, to paving or to the presence of buildings. The model factors out the sewer system because we presume it is already saturated and cannot absorb more water. Next, we modeled the runoff water for a rainfall lasting two hours and with a return period of 100 years falling simultaneously on the entire Montréal territory. The areas where runoff water accumulated, according to the model, were considered to be exposed areas. A safety factor of 10 m (in both the X and Y axes) was added.
Heat waves	Intra-urban heat islands (IUHI)	Based on a photo taken by satellite Landsat 5 on July 14, 2011, the Groupe de recherche sur les îlots de chaleur (heat island research group) from UQAM's geography department produced a map of surface temperatures. This map was used to calculate the average surface temperature for the Montréal agglomeration, once cooling islands were removed and using standardized temperatures (using the temperature logarithm in Kelvin degrees). Areas identified as IUHIs are those whose standardized temperature was above the average of a number equivalent to half the standard deviation.
Destructive storms	Areas affected by a storm	We assumed that the entire island of Montréal was equally affected by a storm ($S_{phys.}$ = 1 for the entire island of Montréal).
Drought	Areas where the potential for soil contraction is high (in relation to territorial susceptibility)	The areas that may contain clay were identified on the Surficial Geology map by the Geological Survey of Canada (1975).
	Areas exposed to drought (in relation to social susceptibility)	We assumed constant susceptibility for the entire island of Montréal ($S_{phys.(soc.)}$ = 1).
River floods	Flood-prone areas in case of river floods	Flood-prone areas were determined using 100-year return levels for Rivière des Prairies produced in 2006 by the Centre d'expertise hydrique du Québec. These marks, from the Ville de Montréal, were drawn onto a topographical map for the Montréal agglomeration. Since the altitude data for this map had a margin of error of 30 cm, a safety factor of +30 cm was added to the 100-year return levels. To finish off, the result we obtained was rounded up to the higher-altitude isoline. The topographical map's isolines were placed every 0.5 m. As a result, the safety factor added to the high water marks varies from +30 cm to +80 cm.

SOCIAL SUSCEPTIBILITY

As mentioned in the Evaluation of the Potential Impacts of Climate Change section of the Approach chapter (see page 24), experts evaluated the relative severity of impacts for each hazard by assigning them one of the following numbers: 0 (negligible), 1 (minor), 2 (moderate) or 3 (major). It is important to recall that the relative severity of the various hazards' impacts was not evaluated, and for this reason, the susceptibility levels for two hazards cannot be compared to one another.

In the same way, we consulted experts from the field of public health and social impacts to determine the susceptibility of various groups of people to each climate hazard under study by assigning them one of the following numbers: 0 (negligible), 1 (minor), 2 (moderate) or 3 (major). These values were then assigned to groups of people for whom mapped data were available (data drawn from the 2006 census).*

For example, an impact that heat waves can cause is to favour smog episodes and increase the concentration of fine particles in the air. People with cardiopulmonary diseases are sensitive to these conditions. Since the data about where people with these conditions live is not available, we used data about the location of seniors' residences for people 65 and up, since the prevalence of cardiopulmonary disease is higher for seniors than it is for people aged under 65. Table A.2 details the groups for which these geographic distribution data exist and were considered to be good indicators for groups exposed to various climate hazards. As for tables A.3 to A.7, they detail the impacts of each climate hazard and the groups of people that were taken into account in the geographical analysis.

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*In 2010, the Government of Canada abolished the obligation to fill out the long-form census. As a result, the data gathered in the 2011 census cannot be used, because they are not sufficiently reliable.

TABLE A.2
GROUPS OF PEOPLE CONSIDERED IN THE GEOGRAPHIC ANALYSIS OF SOCIAL SUSCEPTIBILITY PER HAZARD[A]

GROUPS OF PEOPLE	CLIMATE HAZARDS					
	Higher average temperatures	Heavy rainfalls	Heat waves	Destructive storms	Droughts	River floods
Women	Yes	Yes	No	No	No	Yes
Children aged 0 to 15	Yes	Yes	Yes	Yes	Yes	Yes
Infants and young children (0 to 6)	Yes	Yes	Yes	Yes	Yes	Yes
Seniors aged 65 and up	Yes	Yes	Yes	Yes	Yes	Yes
People living alone	Yes	Yes	Yes	No	Yes	Yes
Underprivileged people[B]	Yes	Yes	Yes	Yes	Yes	Yes
Recent immigrants or people who speak neither French nor English	No	No	Yes	No	No	No

[A] A group's susceptibility to a hazard varies depending on the various impacts that hazard may have.

[B] The Pampalon and Raymond indicator adapted for Montréal ranks material deprivation from 1 (low) to 7 (high). We considered areas where the indicator was 5 or higher as being areas where the population is underprivileged.

TABLE A.3
IMPACTS OF HEAVY RAINFALLS AND VULNERABLE GROUPS OF PEOPLE CONSIDERED IN THE GEOGRAPHICAL ANALYSIS OF SOCIAL SUSCEPTIBILITY

IMPACTS	VULNERABLE GROUPS OF PEOPLE					
	Women	Children aged 0 to 15	Infants and young children (0 to 6)	Seniors aged 65 and up	People living alone	Underprivileged people
Health problems caused by the presence of mould	X	X	X	X		X
Illness caused by the contamination of swimming pool water		X				
Vector-borne and zoonotic diseases		X				
Psychological distress						X
Gastrointestinal disease caused by sewer backflows and floods	X	X		X		
Accidents other than road accidents		X	X	X	X	
Inconveniences related to the interruption of utilities other than electricity (telecommunication, gas, etc.)					X	X
Economic losses						X

TABLE A.4
IMPACTS OF HEAT WAVES AND VULNERABLE GROUPS OF PEOPLE CONSIDERED IN THE GEOGRAPHICAL ANALYSIS OF SOCIAL SUSCEPTIBILITY

IMPACTS	VULNERABLE GROUPS OF PEOPLE					
	Children aged 0 to 15	Infants and small children (0 to 6)	Seniors aged 65 and up	People living alone	Underprivileged people	Recent immigrants or people who speak neither French nor English
Health problems caused by air pollution		X	X	X	X	
Health problems caused by pollen					X	
Illnesses caused by contaminated swimming water	X					
Health problems caused by poor thermoregulation		X	X	X	X	X
Increased mortality rate		X	X	X	X	
Economic losses					X	

TABLE A.5
IMPACTS OF DESTRUCTIVE STORMS AND VULNERABLE GROUPS OF PEOPLE CONSIDERED IN THE GEOGRAPHICAL ANALYSIS OF SOCIAL SUSCEPTIBILITY

IMPACTS	VULNERABLE GROUPS OF PEOPLE				
	Children aged 0 to 15	Infants and small children (0 to 6)	Seniors aged 65 and up	People living alone	Underprivileged people
Inconveniences and accidents related to power outages			X		X
Inconveniences related to service interruptions on above-ground utilities other than electricity (telecommunications)				X	X
Economic losses					X
Accidents other than road accidents (falls, falling debris, electrification and electrocution)	X	X	X	X	
Psychological distress					X

TABLE A.6
IMPACTS OF DROUGHT AND VULNERABLE GROUPS OF PEOPLE CONSIDERED IN THE GEOGRAPHICAL ANALYSIS OF SOCIAL SUSCEPTIBILITY

IMPACTS	VULNERABLE GROUPS OF PEOPLE				
	Children aged 0 to 15	Infants and small children (0 to 6)	Seniors aged 65 and up	People living alone	Underprivileged people
Health problems caused by smog and fine particles		X	X	X	X
Health problems caused by pollen					X
Illnesses caused by contaminated swimming water	X				
Economic losses					X

TABLE A.7
IMPACTS OF RIVER FLOODS AND VULNERABLE GROUPS OF PEOPLE CONSIDERED IN THE GEOGRAPHICAL ANALYSIS OF SOCIAL SUSCEPTIBILITY

IMPACTS	VULNERABLE GROUPS OF PEOPLE					
	Women	Children aged 0 to 15	Infants and young children (0 to 6)	Seniors aged 65 and up	People living alone	Underprivileged people
Health problems caused by the presence of mould	X	X	X	X		X
Psychological distress						X
Gastrointestinal diseases caused by sewer backups and floods	X	X		X		
Accidents other than road accidents		X	X	X	X	
Inconveniences related to the interruption of underground utilities other than electricity (telecommunications, gas, etc.)					X	X
Economic losses						X

For each group of people, the distribution of their proportion in the population for each dissemination area* on the island of Montréal was divided into quintiles (five groups made up of an equal number of people). We judged that the presence of a group was sufficiently large to influence the social susceptibility of a dissemination area when its proportion of the dissemination area's population was located in the first or second quintile. If its proportion was located in the third, fourth or fifth quintile, we considered the group's influence on social susceptibility in that dissemination area to be negligible. The following example illustrates this concept.

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* A dissemination area is the smallest standardized geographic area for which all census data are distributed. Dissemination areas cover the entire territory of Canada. They contain 400 to 700 people. The dissemination areas we used are those from the 2006 census (see note on page 139 for explanations on our choice to use data from the 2006 census instead of the 2011 one).

Example: distribution of a group of people into a quintile

Figure A.1 represents a fictional rectangular territory divided into 10 dissemination areas identified by letters A to J. The percentage indicated within each of these dissemination areas corresponds to the proportion of people who live in this dissemination area and whose favourite colour is blue. The dissemination areas are divided into quintiles (two dissemination areas per quintile) and are ranked based on the proportion of their population whose favourite colour is blue (see Table A.8). As a result, in this example, the dissemination areas for which the proportion of the population that likes blue best is sufficiently high to eventually be taken into account in calculating social susceptibility are those for which the proportion is 13% or more.

Social susceptibility per hazard is evaluated for each dissemination area in the agglomeration using the following formula:

Equation 5

$$S_{soc.DA} = \sum_{i=1}^{I} \sum_{j=1}^{J} SI_i \times SG_{ij}$$

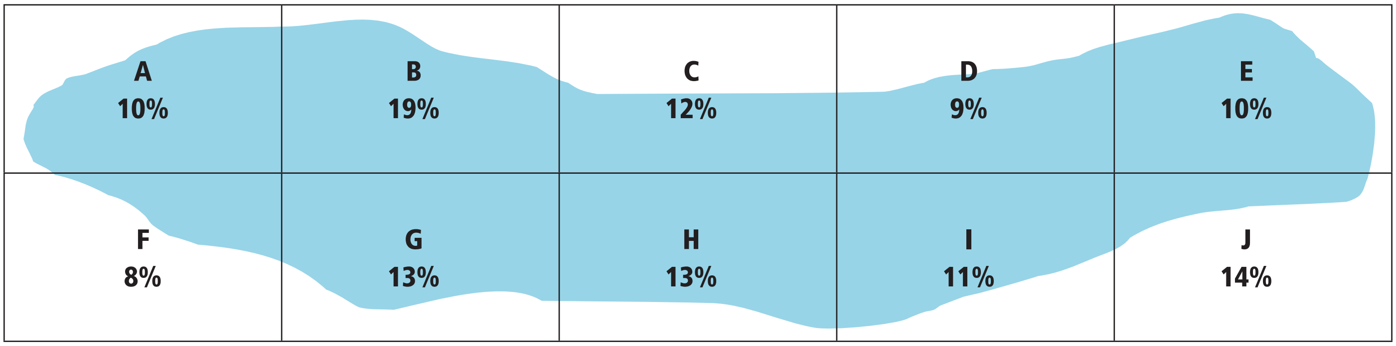
where

- **$S_{soc.DA}$**: social susceptibility of a dissemination area;
- **SI_i**: severity of impact i;
- **SG_{ij}**: susceptibility of group of people j to impact i.

TABLE A.8
DISTRIBUTION OF THE FICTIONAL TERRITORY'S DISSEMINATION AREAS INTO QUINTILES

Quintile	Dissemination area	Proportion of the population whose favourite colour is blue	Dissemination area considered in the calculation of social susceptibility
1st	B	19%	Yes
1st	J	14%	Yes
2nd	G	13%	Yes
2nd	H	13%	Yes
3rd	C	12%	No
3rd	I	11%	No
4th	A	10%	No
4th	E	10%	No
5th	D	9%	No
5th	F	8%	No

FIGURE A.1
FICTIONAL TERRITORY DIVIDED INTO 10 DISSEMINATION AREAS AND PROPORTION OF THEIR POPULATION WITH BLUE AS A FAVOURITE COLOUR (EXAMPLE)



Example: calculation of social susceptibility for a fictional hazard on the territory of a dissemination area

Two impacts of the fictional hazard were identified (in this case, the i of Equation 5 varies from 1 to 2). Table A.9 shows the severity assigned to them by the experts we consulted.

As shown in Table A.10, five groups of people are exposed to the impacts of the fictional hazard. However, only three groups are present in a sufficient proportion in the dissemination area under study (their proportion is in the first or second quintile). As a result, the j of Equation 5 varies from 1 to 3 in this case. The calculation of social susceptibility for the fictional hazard is detailed in Table A.11.

For all hazards except for drought, social, territorial and environmental susceptibility must be added together to calculate vulnerability (see equations 1 and 2). To get there, the territory grid unit used for the three susceptibilities must be the same. The grid unit used for social susceptibility is the dissemination area, while the one used for the territorial and environmental susceptibilities is that of a square cell measuring 250 m by 250 m (a grid unit generally bigger than a dissemination area). So the following step in calculating social susceptibility consists of taking the value of the highest score among the various dissemination areas ($S_{soc.DA}$) present on each of the 250-m-by-250-m cells used for territorial and environmental susceptibilities.

TABLE A.9
SEVERITY OF THE FICTIONAL HAZARD'S IMPACTS

IMPACT 1	IMPACT 2
3	1

TABLE A.10
SUSCEPTIBILITY OF VARIOUS GROUPS OF PEOPLE TO THE IMPACTS OF THE FICTIONAL HAZARD AND QUINTILE OF THEIR PROPORTION IN THE POPULATION WITHIN THE DISSEMINATION AREA UNDER STUDY (FICTIONAL DATA)

	QUINTILE	IMPACT 1	IMPACT 2
Group A	1st	0	3
Group B	1st	1	1
Group C	3rd	2	0
Group D	5th	3	0
Group E	2nd	3	2

TABLE A.11
CALCULATION OF SOCIAL SUSCEPTIBILITY FOR THE FICTIONAL HAZARD

	SEVERITY OF IMPACT 1	SUSCEPTIBILITY TO IMPACT 1	SOCIAL SUSCEPTIBILITY TO IMPACT 1	SOCIAL SUSCEPTIBILITY TO IMPACT 1
Group 1 (A)	$SI_1 = 3$	$SG_{11} = 0$	$SI_1 \text{ x } SG_{11} = 3 \text{ x } 0 = 0$	$\sum_{j=1}^{3} SI_1 \text{ x } SG_{1j} = 0 + 3 + 9 = 12$
Group 2 (B)	$SI_1 = 3$	$SG_{12} = 1$	$SI_1 \text{ x } SG_{12} = 3 \text{ x } 1 = 3$	
Group 3 (E)	$SI_1 = 3$	$SG_{13} = 3$	$SI_1 \text{ x } SG_{13} = 3 \text{ x } 3 = 9$	
	SEVERITY OF IMPACT 2	**SUSCEPTIBILITY TO IMPACT 2**	**SOCIAL SUSCEPTIBILITY TO IMPACT 2**	**SOCIAL SUSCEPTIBILITY TO IMPACT 2**
Group 1 (A)	$SI_2 = 1$	$SG_{21} = 3$	$SI_2 \text{ x } SG_{21} = 1 \text{ x } 3 = 3$	$\sum_{j=1}^{3} SI_2 \text{ x } SG_{2j} = 3 + 1 + 2 = 6$
Group 2 (B)	$SI_2 = 1$	$SG_{22} = 1$	$SI_2 \text{ x } SG_{22} = 1 \text{ x } 1 = 1$	
Group 3 (E)	$SI_2 = 1$	$SG_{23} = 2$	$SI_2 \text{ x } SG_{23} = 1 \text{ x } 2 = 2$	
	SOCIAL SUSCEPTIBILITY OF A DISSEMINATION AREA FOR THE FICTIONAL HAZARD			
	$S_{soc.DA} = \sum_{i=1}^{2} \sum_{j=1}^{3} SI_i \text{ x } SG_{ij} = 12 + 6 = 18$			

Lastly, after assigning the same weight to the various susceptibilities (as they have been considered to be of equal severity), the social susceptibility score for the 250-m-by-250-m cell is divided by the social susceptibility score for the cell with the highest social susceptibility score in the Montréal agglomeration (see Equation 6). In this way, the cell with the highest social susceptibility score in the agglomeration will have a standardized social susceptibility score (final social susceptibility or $S_{soc.}$) of 1, while the final social susceptibility score of other cells will vary from 0 to 1.

Equation 6

$$S_{soc.} = \frac{S_{soc.cell.}}{S_{soc.cell.max}}$$

TERRITORIAL SUSCEPTIBILITY

Like for social susceptibility, the severity of the territorial impacts of the various climate hazards was evaluated by experts on a scale of 0 (negligible) to 3 (major). Then, an average of the severity of all the impacts of a hazard was calculated for each type of infrastructures. The seven types of infrastructures that we considered in our analysis are:

1. roads (networks);
2. railways (networks);
3. underground* utilities** (networks);
4. stormwater sewer pipes;
5. sanitary sewer pipes;
6. combined sewer pipes***;
7. buildings;
8. critical sites;
9. places of interest.

Table A.12 describes what was considered to be a critical site or a place of interest.

Note that other types of infrastructures may be exposed to climate hazards, but they were not considered due to the lack of data about their locations.

TABLE A.12
LIST OF CRITICAL SITES AND PLACES OF INTEREST

CRITICAL SITES

- Municipal workshops
- Fire stations
- Emergency communications centres
- Emergency measures coordination centres
- Blood product distribution and processing centres
- Centre de sécurité civile de Montréal (agglomeration) (Montréal civil safety centre)
- Emergency operations centres (for boroughs and municipalities)
- Hospitals
- Centre intégré du Ministère des Transports du Québec (integrated traffic management centre)
- Centres locaux de santé et de services sociaux (local health and social service centres, or CLSCs)
- Service de police de la Ville de Montréal operations centres
- Urgences-Santé operations centres (paramedics)
- Road maintenance equipment storage sites
- Société de transport de Montréal (public transit) garages
- Sûreté du Québec (provincial police) highway stations
- Service de police de la Ville de Montréal neighbourhood stations
- Montréal police headquarters
- Service de sécurité incendie de Montréal (fire safety) headquarters
- Sûreté du Québec (provincial police) headquarters
- Sécurité publique (public safety), Gouvernement du Québec
- Drinking water production plants

PLACES OF INTEREST

- Schools
- Bridge entrances and exits
- Daycares
- Metro stations

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*Above-ground utilities can also be affected by the various climate hazards. However, they were not considered in our geographic analysis due to the lack of data about their locations.

**According to the Grand dictionnaire terminologique de l'Office québécois de la langue française (translated from the definition of "commodité"), utilities are defined as "Equipment that provides comfort to a residence, building or neighbourhood in keeping with our era's ways of life." This can include electricity, natural gas, telephone, Internet and more.

***A combined sewer is a sewer that contains both sanitary wastewater and stormwater or runoff water.

To evaluate territorial and environmental susceptibilities, the territory of the Montréal agglomeration was divided into cells measuring 250 m by 250 m. The territorial susceptibility per hazard was evaluated for each of the cells using the following formula:

Equation 7

$$S_{ter.cell.} = N + B + CS + PI$$

where:

- $\mathbf{S_{terr.cell.}}$: territorial susceptibility of a cell;
- **N**: network indicator;
- **B**: building indicator;
- **CS**: critical sites indicator;
- **PI**: places of interest indicator.

The network indicator was calculated as follows:

Equation 8

$$N = \sum_{i=1}^{6} \frac{\rho R_i}{\rho R_{i-\max}} \text{ x } SIN_i$$

where:

- $\boldsymbol{\rho}\mathbf{R_i}$: density of network i in the cell;
- $\boldsymbol{\rho}\mathbf{R_{i\text{-}max}}$: highest ρR_i for all the cells;
- $\mathbf{SIN_i}$: severity of this hazard's impacts on the network (Table A.7 presents the various values of SIN_i).

The i varies from 1 to 6 because there are six types of susceptibility levels for networks. We used the networks' density (length ratio on its surface) rather than their length to avoid having the network indicator for truncated cells (because part of a cell covers a watercourse or falls in an area not affected by the hazard, meaning where $S_{phys.} = 0$) be systematically lower than that of complete cells. As well, the density of the network was divided by the highest density of all the cells so that the size order of Equation 7's four indicators would be the same.

TABLE A.13
SEVERITY OF THE IMPACTS OF CLIMATE HAZARDS ON NETWORKED INFRASTRUCTURES (SINI)*

	ROADS	RAILWAYS	UNDERGROUND UTILITIES	STORMWATER SEWER PIPES	SANITARY SEWER PIPES	COMBINED SEWER PIPES
Higher average temperatures	0	0	0	0	0	0
Heavy rainfalls	1.29	0	1.50	2.44	1.13	2.38
Heat waves	0.99	2.00	0	0	0	0
Destructive storms	0	0	0	0	0	0
Drought	0	0	0	0	0	0
River floods	1.97	0	0	1.50	0	1.38

*The severity of the impacts cannot be compared from one hazard to the next, only from one infrastructure to the next for the same hazard.

The building indicator is calculated as follows:

Equation 9

$$B = \frac{\rho B}{\rho B_{max}} \times SIB$$

where:

- **ρB**: density of buildings in the cell;
- **ρB_{max}**: highest ρB of all the cells;
- **SIB**: severity of this hazard's impacts on buildings (Table A.14 presents the various values of SIB).

TABLE A.14
SEVERITY OF THE IMPACTS OF CLIMATE HAZARDS ON BUILDINGS (SIB)*

Higher average temperatures	0
Heavy rainfalls	1.82
Heat waves	0
Destructive storms	2.00
Drought	1.07
River floods	1.26

*The severity of the impacts cannot be compared from one hazard to the next, only from one infrastructure to the next for the same hazard.

As in the case of networks, we used building density (number of buildings on the surface) rather than the number of buildings to avoid having the network indicator for truncated cells be systematically lower than that of complete cells. As well, building density was divided by the highest density of all the cells so that the size order of Equation 7's four indicators would be the same.

During heavy rainfalls, destructive storms and river floods, places of key importance can become inaccessible, which can cause many problems. This is what the critical site (CS) and place of interest (PI) indicators mean. For the other climate hazards, CS = 0 and PI = 0.

The critical site indicator is calculated as follows:

Equation 10

$$CS = \frac{n_{CS}}{n_{CS\text{-}max}}$$

where:

- **n_{CS}**: number of critical sites present in the cell;
- **$n_{CS\text{-}max}$**: n_{CS} present in the cell with the highest number of critical sites.

Once again, the number of critical sites is divided by the number of critical sites present in the cell with the highest number of critical sites so that the size order of Equation 7's four indicators is the same.

Access to places of interest is also important, although of lesser importance than access to critical sites. The indicator for places of interest is calculated as follows:

Equation 11

$$PI = \frac{n_{PI}}{(n_{PI\text{-}max})} \times 0.5$$

where:

- **n_{PI}**: number of places of interest present in the cell;
- **$n_{PI\text{-}max}$**: number of places of interest present in the cell with the highest number of places of interest.

In this case, the number of places of interest is divided by the number of places of interest present in the cell with the highest number of places of interest, and then the result is multiplied by a factor of 0.5. This is so that the size order of Equation 7's four indicators is the same, but also to represent the fact that access to places of interest is somewhat less important than access to critical sites.

To finish, in order to assign the same weight to the various susceptibilities (because they are considered of equal severity), the cell's territorial susceptibility score is divided by the territorial susceptibility score of the cell with the highest territorial susceptibility score in the Montréal agglomeration (see Equation 12). This way, the cell with the highest territorial susceptibility score in the agglomeration would have a standardized territorial susceptibility score of 1, while the final susceptibility of the other cells would vary between 0 and 1.

Equation 12

$$S_{\text{terr.}} = \frac{S_{\text{terr.cell.}}}{S_{\text{terr.cell.max}}}$$

ENVIRONMENTAL SUSCEPTIBILITY

Due to the limited availability of data and because a number of environmental parameters cannot be mapped, environmental susceptibility was evaluated only for heat waves. For other climate hazards, it was considered to be equal to zero. It was evaluated using the following formula:

Equation 13

$$S_{\text{env.cell.}} = W + T$$

where:

- **$S_{\text{env.cell.}}$**: environmental susceptibility of a cell;
- **W**: wetland indicator;
- **T**: tree indicator.

Wetlands and inland watercourses (streams) contain species that are sensitive to heat. To represent this, a value of 1 was assigned to W when at least one wetland or watercourse was present in the cell and was located in an intra-urban heat island.

The tree indicator, for its part, was calculated as follows:

Equation 14

$$T = \frac{\rho T}{\rho T_{\text{max}}}$$

where:

- ρ**T**: density of trees located within an intra-urban heat island inside the cell;
- ρ**T**$_{\text{max}}$: highest ρT of all the cells.

Tree density (the number of trees on the surface) was used instead of the number of trees to prevent the size of the intra-urban heat island from having an impact on the indicator (since the bigger the heat island, the higher the chance that it will contain a larger number of trees).

Lastly, the cell's environmental susceptibility score was divided by the environmental susceptibility score of the cell with the highest environmental susceptibility score in the Montréal agglomeration, and then the result was multiplied by a factor of 0.5 (see Equation 15). This way, the cell with the highest environmental susceptibility score in the agglomeration would have a standardized environmental susceptibility score of 0.5, while the other cells' final environmental susceptibility scores would vary between 0 and 0.5.

Equation 15

$$S_{\text{env.}} = \frac{S_{\text{env.cell.}}}{S_{\text{env.cell.max}}} \quad x\ 0.5$$

VULNERABILITY GRADATION

Once the vulnerability to a hazard was calculated using Equation 2, each cell in the agglomeration was ranked based on its vulnerability score using the following scale: not significant, low, moderate, high or severe. Cells whose V = 0 were assigned a vulnerability range of not significant. The other cells were distributed among the four more significant vulnerability ranges based on their scores.

The vulnerability ranges are of a size equal to δV:

Equation 16

$$\delta_{V.} = \frac{V_{max} - V_{min}}{4}$$

where:

- **δV**: gap between the vulnerability scores that serves to rank the cells' vulnerability;
- **V_{max}**: maximum potential vulnerability score (worth 2 for all hazards except heat waves where it is 2.5);
- **V_{min}**: vulnerability score obtained by the cell with the lowest vulnerability.

The cells were ranked based on their vulnerability as described in Table A.15.

TABLE A.15
VULNERABILITY RANGE SCORES FOR RANKING PURPOSES

RANKING OF VULNERABILITY	VULNERABILITY RANGE
Not significant	$V = 0$
Low	$V = [V_{MIN}, V_{MIN} + \delta_V]$
Moderate	$V = [V_{MIN} + \delta_V, V_{MIN} + 2\delta_V]$
High	$V = [V_{MIN} + 2\delta_V, V_{MIN} + 3\delta_V]$
Severe	$V = [V_{MIN} + 3\delta_V, V_{MAX}]$

APPENDIX B: GLOSSARY

NOTE: DEFINITIONS TAKEN OR TRANSLATED INTO ENGLISH FROM THE FOLLOWING DOCUMENTS UNLESS OTHERWISE INDICATED.

Office québécois de la langue française. *Le grand dictionnaire terminologique (GDT)*, [online]. [gdt.oqlf.gouv.qc.ca] (Accessed in September 2015.)

Intergovernmental Panel on Climate Change (2007). *Climate Change 2007: Synthesis Report*, [online], Contribution from Working Groups I, II and III to the Fourth Assessment Report of the IPCC [Core Writing Team, Pachauri, R. K. and Reisinger, A. (Eds.)], Geneva, Switzerland, 104 p. [www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_appendix.pdf] (Accessed in September 2015.)

Ouranos. *Vers l'adaptation - Synthèse des connaissances sur les changements climatiques au Québec*, Montréal, Québec, [online], 2014 edition. [www.ouranos.ca/fr/synthese2014/doc/Glossaire.pdf] (Accessed in September 2015.)

Ville de Montréal (2015). P*lan d'adaptation aux changements climatiques de l'agglomération de Montréal 2015-2020 : Les constats*, Service de l'environnement, Division de la planification et du suivi environnemental, 174 p.

A

ADAPTATION TO CLIMATE CHANGE: Process by which communities and ecosystems adjust to climate change and its associated effects, in order to limit their negative consequences and enjoy their potential benefits. For human environments, adaptation makes it possible to prepare for new climate conditions. In natural environments, plant and animal populations also adapt, but in a reactive way, and will suffer more negative short-term impacts. Adaptation concerns every level of decision-making (individual, local, regional, national, international) and demands a worldwide and highly integrated approach, as issues affect many sectors and often stretch beyond administrative limits. (Translated from: Élaborer un plan d'adaptation aux changements climatiques. *Guide destiné au milieu municipal québécois*, Montréal (Québec), 2010, 48 p. [www.mddelcc.gouv.qc.ca/programmes/climat-municipalites/Plan-adaptation.pdf].)

ALBEDO: The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo, the surface albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo. Earth's planetary albedo varies mainly through varying cloudiness, snow, ice, leaf area and land cover changes.

ANTHROPOGENIC: Resulting from or produced by human beings.

AVERAGE (MEAN) TEMPERATURE: The mean temperature in degrees Celsius (°C) is defined as the average of the maximum and minimum temperature at a location for a specified time interval. (Source: Environment Canada. *Climate - Glossary*, [online], updated February 11, 2015. [climate.weather.gc.ca/glossary_e.html].)

B

BENTHIC (COMMUNITY): Group of aquatic organisms living close to the bottom of a sea, lake or watercourse.

BIODIVERSITY: The total diversity of all organisms and ecosystems at various spatial scales, including that of a city.

BIOPESTICIDE: Pesticide made from living organisms.

BUILT ENVIRONMENT: Includes all buildings (all sectors) and the systems that make them up (mechanical, electrical, etc.); transportation networks (ground, water, air) and peripheral infrastructures (signage, etc.); telecommunications and power networks (production, transportation, distribution); water-related infrastructures (access, treatment, distribution, collection); and infrastructures specific to certain industrial sectors (agricultural, mining, etc.).

C

CAPACITY TO ADAPT: Capacity of communities and ecosystems to adjust in order to handle climate change, to minimize its negative effects and enjoy its benefits.

CLIMATE: The historical record and description of average daily and seasonal weather events that help describe a region. Statistics are generally drawn over several decades. Climatology, or the study of climate, includes climatic data, the analysis of the causes of the differences in climate, and the application of climatic data to the solution of specific design or operational problems. It differs from weather, which is concerned with short-term or instantaneous variations in the state of the atmosphere at a specific time. (Source: Environment Canada. *Climate - Glossary*, [online]. [climate.weather.gc.ca/glossary_e.html].)

CLIMATE CHANGE: Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

CLIMATE CHANGE ADAPTATION PLAN: Planning tool used to examine the issue of climate change as a whole and in all of a municipal administration's areas of activity, to pinpoint and prioritize the main risks, adopt a vision and set out implementation steps for climate change adaptation measures in the short, medium and long term.

CLIMATE HAZARD: Phenomenon, physical manifestation or human activity that could lead to injury or loss of human life, damages to goods, social and economic disturbances, or environmental degradation. Each hazard is characterized, among other things, at a given point on a map, a probability of occurrence, and a given intensity. (Translated from: Ministère de la Sécurité publique. "Annexe 1 - Glossaire," *Concepts de base en sécurité civile*, 2008, 60 p. [www.securitepublique.gouv.qc.ca/fileadmin/Documents/ securite_civile/publications/concepts_base/concepts_base_partie_5.pdf].)

CLIMATE MODEL: Highly complex computer software that uses mathematical equations in the fields of physics and chemistry to describe the atmosphere, ocean and continental surfaces. These equations represent the main energy and matter exchanges that govern weather and hydrological and biological phenomena. These models in particular are able to simulate the speed and direction of wind and ocean currents, as well as the evolution of temperatures and precipitation and the features of various plant covers.

CLIMATE PROJECTION: A projection of the climate system's response to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission, concentration or radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

CLIMATE RISK: Combination of the likelihood that a climate event will occur and the consequences that can result from it for exposed elements of a given environment. (Translated from: Ministère de la Sécurité publique. "Annexe 1 - Glossaire," *Concepts de base en sécurité civile*, 2008, 60 p. [www.securitepublique.gouv.qc.ca/fileadmin/Documents/securite_civile/publications/concepts_base/concepts_base_partie_5.pdf].)

CLIMATE SCENARIO: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information, for instance, about the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.

CLIMATE VARIABILITY: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

CO-BENEFITS: In the context of adapting to climate change, the positive effects of certain measures that give rise to indirect positive impacts on other climate hazards.

COOLING ISLAND: Place or space that helps cool the surrounding air or that provides protection against the sun's rays. These places may take a range of forms, such as parks, gardens, shelters and green structures (green roofs and walls), or they may be lines of trees along the street that provide shaded areas. They can also be spaces with water basins, fountains, pools, misters and so forth. The elements that make up such spaces provide better quality of life for citizens who are exposed to oppressive heat. (Source: Service de l'environnement, Ville de Montréal.)

CRITICAL SITES: As part of this Plan, a list of the critical sites specific to Montréal is provided in Table A.12.

CYANOBACTERIA BLOOM: Proliferation of algae in a lake, watercourse or ocean.

D

DISSEMINATION AREA: A dissemination area (DA) is a small, relatively stable geographic unit composed of one or more adjacent dissemination blocks, with a population of 400 to 700 persons. It is the smallest standard geographic area for which all census data are disseminated. All of Canada is divided into dissemination areas. Dissemination areas used in the present document are those from the 2006 census. (Source: Statistics Canada, Census Dictionary [www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo021-eng.cfm] Accessed May 3, 2016.)

DROUGHT: The literature contains various definitions of drought. Each definition describes a distinct reality, and their usage depends on the set of issues being considered. If we look at the number of consecutive days without rain, we're talking about meteorological drought. If we focus on a water deficit in the soil, then we're talking about soil moisture drought (also called agricultural drought). Hydrological drought concerns an especially low watercourse and water table level. Lastly, socioeconomic drought includes humankind's pumping of water resources.

E

ECOLOGICAL SERVICES: Correspond to the benefits nature provides us in terms of ecosystems and species "that make possible and facilitate human existence." As such, biodiversity is at the root of providing ecological services to citizens. There are several categories of ecological services: regulation services (climate regulation, air and water purification, pollination, soil fertilization, etc.), supply services (food, fibres, medicinal plants, etc.) and sociocultural services (recreation and tourism, education, inspiration, heritage, spirituality, etc.). (Translated from: Boucher, I. and N. Fontaine (2010). La biodiversité et l'urbanisation, *Guide de bonnes pratiques sur la planification territoriale et le développement durable*, ministère des Affaires municipales, des Régions et de l'Occupation du territoire, coll. Planification territoriale et développement durable, 178 p. [www.mamrot.gouv.qc.ca/pub/grands_dossiers/developpement_durable/biodiversite_urbanisation_complet.pdf].)

ECOSYSTEM: A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.

EMERGENCY MEASURES: Set of methods and procedures that allow operational intervention teams to respond quickly in case of emergency (fire, armed attacker, medical emergency, etc.). These measures also include safety-oriented user behaviours. (Translated from: Université de Montréal, "Plan de mesures d'urgence," Direction de la prévention et de la sécurité, [online]. [www.dps.umontreal.ca/gestion-urgences/mesures-urgences].)

EMISSION SCENARIO: A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development and technological change) and their key relationships. Concentration scenarios, derived from emission scenarios, are used as input to a climate model to compute climate projections.

ENVIRONMENTAL SUSCEPTIBILITY: Proportion in which the natural environment is likely to be affected (positively or negatively) by the manifestation of a climate hazard.

EROSION: The process of soil and rock removal and transport by weathering, mass wasting, and the action of streams, glaciers, waves, winds and underground water.

EUTROPHICATION (OF WATER BODIES): Enrichment of water by nutrients, which results in a proliferation of aquatic plants or cyanobacteria and a reduced oxygen content in deep water. Eutrophication happens most often in aquatic environments where water circulation is reduced, such as lakes and estuaries. Phosphorus and nitrogen are the main nutrients responsible for eutrophication.

EVAPOTRANSPIRATION: The combined process of water evaporation from Earth's surface and transpiration from vegetation.

EXTREME HEAT: Expression used by public health authorities to designate a period of three consecutive days where the high temperature reaches or rises above 33°C and the low temperature does not drop below 20°C, or when the temperature does not dip below 25°C for two consecutive nights.

EXTREME WEATHER EVENT: An event that is rare at a particular place and time of year. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

F

FLOOD: Water overflow that submerges ground that is usually dry for the majority of the year. There are two types of floods: those from open water without the presence of a jam, and those caused by jams. An open-water flood is caused exclusively by the significant increase in the quantity of water in a river and not by a backflow in a given area. If a backflow does happen, it can be due to a build-up of ice in a section of the river that prevents the free flow of water; in that case, the resulting flood would be due to the jam.

FLOW: Volume of liquid passing through a transverse section of a watercourse per unit of time. Flow can be expressed, for instance, in l/s or in m³/s. (Translated from: Centre d'expertise hydrique du Québec, *Glossaire*, [online], updated July 3, 2013. [www.cehq.gouv.qc.ca/glossaire.htm])

FRAZIL ICE: Fine spicules or plates of ice suspended in water. When these needles of ice accumulate in a watercourse, they can disturb its flow to the point of causing a flood. (Adapted from: Environment Canada. *Ice Glossary*, [online], updated March 28, 2013. [http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=501D72C1-1].)

FREEZE-THAW CYCLES: Days of the year for which the lowest temperature is below 0 °C and the highest temperature is above 0 °C, which means a shift across 0 °C within a single day, and thus a freeze or thaw (a criterion used for the calculations provided in this Adaptation Plan).

G

GREEN INFRASTRUCTURES: Alternative drainage methods that make it possible to slow down and store water. Set-ups of this kind, also known as best management practices, can take a range of forms, including bioretention basins, landscaping with absorbent soil, detention basins (dry ponds), rooftop water collection structures, pits (valleys) or green roofs. (Translated from: Ville de Montréal. *Quelles infrastructures vertes pour la gestion des eaux de ruissellement*?, Service de l'eau, Division de la gestion durable de l'eau, January 2015, 45 p.)

GREENHOUSE GAS (GHG): Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by Earth's surface, the atmosphere itself, and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

H

HARDINESS ZONE: In 1967, Agriculture Canada scientists created a plant hardiness map using Canadian plant survival data and a wide range of climatic variables, including minimum winter temperatures, length of the frost-free period, summer rainfall, maximum temperatures, snow cover, January rainfall and maximum wind speed. (Source: Agriculture and Agri-Food Canada. *Plant Hardiness Zones in Canada*, [online]. [sis.agr.gc.ca/cansis/nsdb/climate/hardiness/index.html].)

HEAT STRESS: (in plants) Set of changes to plant physiology when the temperature rises or drops outside usual conditions. It differs depending on the species and the form and scope of the temperature change. (Translated from: Wikipedia. *Stress thermique chez les végétaux*, [online]. [fr.wikipedia.org/wiki/Stress_thermique_chez_les_v%C3%A9g%C3%A9taux].)

HEAT WAVE: Period of at least three consecutive days during which the temperature reaches or rises above 30°C during the daytime, or in other words, period of abnormally warm and unpleasant atmospheric conditions.

HUMIDEX: Humidex is an index to indicate how hot or humid the weather feels to the average person. It is derived by combining temperature and humidity values into one number to reflect the perceived temperature. For example, a humidex of 40 means that the sensation of heat when the temperature is 30 degrees and the air is humid feels more or less the same as when the temperature is 40 degrees and the air is dry. (Source: Environment Canada. *Climate - Glossary*, [online], [climate.weather.gc.ca/glossary_e.html].)

HYPOTHERMIA: Cooling of the human body below its normal temperature.

HYPERTHERMIA: Elevation of the body's core temperature above its normal value.

I

ICE JAM: Accumulation of floating ice against an obstacle on a watercourse (such as a narrowing or curve in the river, or still-frozen ice). The ice that is held back creates a sort of temporary dam, which can cause water to overflow upstream. (Translated from: Centre d'expertise hydrique du Québec, *Glossaire*, [online], updated July 3, 2013. [www.cehq.gouv.qc.ca/glossaire.htm].)

IMPACTS (OF CLIMATE CHANGE): The effects of climate change on natural and human systems. In this Plan, the term is mainly used to designate the effects, on natural and human systems, of extreme weather and climate phenomena and climate change. In general, this means effects on people's lives, modes of subsistence, health, ecosystems, our economic, social and cultural heritage, services and infrastructures, resulting from their interactions with climate change or with dangerous climate phenomena that occur over a given period of time, and the vulnerability of the exposed society or system. In this sense, we also use the term consequences. Here, we more specifically address impacts on the built environment, the natural environment, populations, operations and municipal services.

INTRA-URBAN HEAT ISLAND (IUHI): Place in an urban environment where the air temperature is higher than elsewhere, with the effect of increasing the heat felt locally. (Translated from: Bureau de normalisation du Québec. *Norme BNQ 3019-190/2013, Lutte aux îlots de chaleur urbains - Aménagement des aires de stationnement - Guide à l'intention des concepteurs*, 204 p.)

INVASIVE SPECIES: Exotic (alien or non-native) species whose introduction or propagation threatens the environment, economy, society and public health. (Source: Granby Zoo. *To the Rescue of Endangered Species – Invasive species*, [online]. [especesmenacees.ca/en/invasive-species.php].)

J K L

LOW FLOW: Minimum water level reached by a watercourse or lake during a dry period. (Translated from: Centre d'expertise hydrique du Québec, *Glossaire*, [online], updated July 3, 2013. [www.cehq.gouv.qc.ca/glossaire.htm].)

M

MALADAPTATION: Actions that can lead to an increased risk of negative climate-related consequences, increased vulnerability to climate change, or reduced current or future well-being.

MEASURES: In this Plan, technologies, processes or practices aiming to reduce the impacts of climate change.

MITIGATION: Change and substitution of techniques employed in order to reduce the resources used and the emissions per unit of production. While some social, economic and technological policies can help reduce emissions, from a climate change perspective, mitigation means putting policies into action with the intent to reduce greenhouse gas emissions and strengthen sinks.

N O P

OPPRESSIVE HEAT: According to Environment Canada, oppressive heat is when the air temperature reaches or rises above 30°C and the humidex reaches or rises above 40.

PATHOGEN: That which causes illness, in particular a germ capable of determining an infection. (Translated from: Dictionnaire de français Larousse, [www.larousse.fr/dictionnaires/francais/pathog%C3%A8ne/58638].)

PEST INSECT: (zoology) Harmful insect that severely damages or destroys a crop, a harvest or a landscape.

PESTICIDE: Any substance, material or micro-organism that aims to control, destroy, mitigate, attract or repel, directly or indirectly, an organism that is harmful, toxic or irritating to human beings, fauna, vegetation, crops or other goods, or that aims to serve as a regulator for vegetation growth, excluding medications and vaccines, as per the *Loi sur les pesticides*. (Translated from: Recueil des lois et règlements du Québec, chapter P-9.3; Règlement sur l'utilisation des pesticides, RVM 04-041.)

PHENOLOGY: Chronology of the stages of plant and animal life in relation to weather and climate.

PHOTOSYNTHESIS: The process by which green plants, algae and some bacteria take carbon dioxide from the air (or bicarbonate in water) to build carbohydrates. There are several pathways of photosynthesis with different responses to atmospheric carbon dioxide concentrations.

PHYSICAL SUSCEPTIBILITY: Degree to which a territory is affected by climate hazards.

PLACE OF INTEREST: In this Plan, a place of interest means a school, a bridge entrance or exit, a daycare or a metro station (see Table A.12).

POLLEN: Fertilizing dust produced by flowers, made up of tiny spores and often possessing allergenic properties, especially when airborne. It produces antigens that can irritate predisposed subjects and cause allergic symptoms to manifest.

PREVALENCE: (of an illness) Number of cases related to a specific illness or health event, tallied for a given population, at a given time, and expressed as a percentage, without distinguishing between new and old cases.

PROBABILITY: The likelihood of a risk will occur at a specific intensity (probability of occurrence can be expressed qualitatively or quantitatively). (Source: Ville de Montréal, "Glossary," *La sécurité civile à Montréal*, [ville.montreal.qc.ca/portal/page?_pageid=9657,125131596&_dad=portal&_schema=PORTAL#p].)

Q R

RESILIENCE: The capacity of a population, a society, its economic and political system or the infrastructures that make it up to resist and surmount major disturbances and stresses to regain normal function. (Adapted from: Craig Applegath, www.resilientcity.org)

RIVER FLOOD: Rise in the water level of a river or increase in its flow well beyond the usual levels.

RUNOFF WATER: Flow of water on the soil's surface before it reaches a watercourse.

S

SOCIAL SUSCEPTIBILITY: Proportion in which a community is likely to be affected by the manifestation of a climate hazard.

SOIL SEALING: Soil sealing is the permanent covering of an area of land and its soil by impermeable artificial material, such as asphalt and concrete. (Source: European Commission. *Guidelines on best practice to limit, mitigate or compensate soil sealing*, 2012, 61 p. [ec.europa.eu/environment/soil/pdf/guidelines/EN%20-%20Sealing%20Guidelines.pdf].)

STOMA: Pore-like structures on a leaf's surface surrounded by two guard cells that can open and close to allow for gas exchange. The plural of stoma is stomata. (Source: Canadian Wildlife Federation. *Glossary*, [online]. cwf-fcf.org/en/discover-wildlife/resources/glossary].)

T

TERRITORIAL SUSCEPTIBILITY: Proportion in which infrastructures are likely to be affected (positively or negatively) by the manifestation of a climate hazard.

U V

UNCERTAINTY: An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgement of a team of experts.

URBAN MORPHOLOGY: Study of the city's forms and features (road network, density, usages) and the phenomena behind them: topography, history, cultural influence, economy, urban planning rules, technological or energetic context. (Translated from: Wikipedia. *Morphologie urbaine*, [online]. [fr.wikipedia.org/wiki/Morphologie_urbaine#cite_note-Kenworthy_1989-2].)

UTILITY: Equipment that provides comfort to a residence, building or neighbourhood in keeping with our era's ways of life. This can include electricity, natural gas, telephone, Internet and more.

VECTOR-BORNE DISEASE: A disease is called vector-borne when bacteria, viruses or parasites are transmitted by an intermediary from one human to another. This intermediary, called a vector, is generally an animal, a mosquito or a tick. The West Nile Virus is an example of a vector-borne disease. (Translated from: Institut national de santé publique du Québec, "Maladies à transmission vectorielle et zoonoses," *Mon climat, Ma santé*, [online]. [www.monclimatmasante.qc.ca/public/maladies-vectorielles-et-zoonoses.aspx].)

VULNERABILITY: Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, as well as its sensitivity and its adaptive capacity.

W X Y Z

WATER CYCLE (OR HYDROLOGICAL CYCLE): The cycle in which water evaporates from the oceans and the land surface, is carried over the Earth in atmospheric circulation as water vapour, condenses to form clouds, precipitates again as rain or snow, is intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, refills groundwater, discharges into streams, and ultimately, flows out into the oceans, from which it will eventually evaporate again. The various systems involved in the hydrological cycle are usually referred to as hydrological systems.

WATER STRESS: (in plants) A plant is water stressed if soil-available water, and thus actual evapotranspiration, is less than potential evapotranspiration demands.

ZOONOTIC: An illness is called zoonotic when it is transmitted directly from vertebrate animals to human beings. This is the case with hantavirus pulmonary syndrome and rabies. (Translated from: Institut national de santé publique du Québec, "Maladies à transmission vectorielle et zoonoses," *Mon climat, Ma santé*, [online]. [www.monclimatmasante.qc.ca/public/maladies-vectorielles-et-zoonoses.aspx].)

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APPENDIX D: IMPACT EVALUATION MATRIX

	IMPACTS ON SOCIOECONOMIC ISSUES 🟨 Negligible 🟧 Minor 🟥 Moderate ■ Major ▨ Sum of the subsections	HIGHER AVERAGE TEMPERATURES		HEAVY RAINFALLS	HEAT WAVES	DESTRUCTIVE STORMS	DROUGHTS	RIVER FLOODS
		EXTENDED SUMMER SEASON	SHORTER WINTER SEASON AND INCREASED NUMBER OF FREEZE-THAW CYCLES					
1. HEALTH	**1.1 Increased prevalence of health problems caused by air pollution**	2.50			1.75		3.00	
	1.1.1 Smog and fine particles	2.00	-	-	2.50	-	3.00	-
	1.1.2 Pollen	3.00	-	-	1.00	-	3.00	-
	1.2 Increased prevalence of health problems caused by mould growth	-	2.00	2.00	-	-	-	2.50
	1.3 Increased prevalence of waterborne illness epidemics due to contaminated swimming water	-	-	1.00	1.00	-	1.00	-
	1.4 Increased prevalence of waterborne gastrointestinal diseases due to sewer backflows and floods	-	-	1.00	-	-	-	1.00
	1.5 Increased prevalence of health problems caused by higher exposure to UV rays	1.00	-	-	-	-	-	-
	1.6 Increased prevalence of vector-borne and zoonotic diseases	1.00	1.00	1.00	-	-	-	-
	1.7 Increased prevalence of health problems related to imbalanced body temperature (hyperthermia and hypothermia)	-	-	-	3.00	0.00	-	-
	1.8 Increased prevalence of psychological distress	-	-	2.00	-	1.50	-	1.50
	1.9 Increase in health problems caused by mobility limitations	-	-	0.00	3.00	3.00	-	0.50
	SUB-TOTAL	**1.50**	**1.50**	**1.17**	**2.19**	**1.50**	**2.00**	**1.38**
2. EXPENSES FOR INDIVIDUALS	**2.1 Increased insurance premiums and reduced coverage**	-	-	3.00	-	1.00	-	1.00
	2.2 Personal economic losses			1.08	1.50	1.83		0.78
	2.2.1 Absenteeism	-	-	0.50	1.50	1.25	-	0.50
	2.2.2 Temporary job cessation	-	-	0.75	1.50	1.25	-	0.50
	2.2.3 Mobility limitations	-	-	2.00	-	3.00	-	1.33
	2.3 Costs related to destroyed goods	-	-	1.75	-	3.00	2.00	1.67
	SUB-TOTAL			**1.94**	**1.50**	**1.94**	**2.00**	**1.15**

IMPACTS ON SOCIOECONOMIC ISSUES

🟨 Negligible 🟧 Minor 🟥 Moderate
🟫 Major ▨ Sum of the subsections

		HIGHER AVERAGE TEMPERATURES		HEAVY RAINFALLS	HEAT WAVES	DESTRUCTIVE STORMS	DROUGHTS	RIVER FLOODS
		EXTENDED SUMMER SEASON	SHORTER WINTER SEASON AND INCREASED NUMBER OF FREEZE-THAW CYCLES					
3. INCONVENIENCES AND ACCIDENTS	**3.1 Increase in road accidents**	▨	0.38	0.60	▨	1.45	▨	0.50
	3.1.1 Light bodily injury and material damages only	-	0.50	0.80	-	1.40	-	0.50
	3.1.2 Serious bodily injury and fatalities	-	0.25	0.40	-	1.50	-	0.50
	3.2 Inconveniences related to road mobility	-	-	1.60	1.00	2.50	-	0.80
	3.3 Accidents other than road accidents	▨	▨	1.00	▨	1.58	▨	0.80
	3.3.1 Drowning, electrocution	-	-	1.00	-	-	-	0.80
	3.3.2 Injuries due to falls	-	-	-	-	1.60	-	-
	3.3.3 Cardiac problems related to snow shoveling	-	-	-	-	1.00	-	-
	3.3.4 Injuries due to structural collapses and falling trees or debris	-	-	-	-	2.13	-	-
	3.4 Increased mortality rate	▨	▨	0.33	1.50	1.50	▨	1.50
	3.4.1 Premature	-	-	-	3.00	3.00	-	-
	3.4.2 Non-premature	-	-	0.33	0.00	0.00	-	1.50
	3.5 Inconveniences and accidents due to power outages	▨	▨	▨	2.00	1.89	▨	▨
	3.5.1 Food poisoning	-	-	-	2.00	2.00	-	-
	3.5.2 Home medical equipment shorts	-	-	-	-	1.67	-	-
	3.5.3 Carbon monoxide poisoning	-	-	-	-	2.00	-	-
	3.6 Inconveniences related to the interruption of utility services other than electricity	▨	▨	3.00	▨	2.50	▨	3.00
	3.6.1 Underground utilities	-	-	3.00	-	-	-	3.00
	3.6.2 Above-ground utilities	-	-	-	-	2.50	-	-
	SUB-TOTAL		**0.38**	**1.31**	**1.50**	**1.90**		**1.32**

IMPACTS ON THE BUILT ENVIRONMENT

🟨 Negligible 🟧 Minor 🟥 Moderate
🟫 Major ▨ Sum of the subsections

		HIGHER AVERAGE TEMPERATURES						
		EXTENDED SUMMER SEASON	SHORTER WINTER SEASON AND INCREASED NUMBER OF FREEZE-THAW CYCLES	HEAVY RAINFALLS	HEAT WAVES	DESTRUCTIVE STORMS	DROUGHTS	RIVER FLOODS
4. PUBLIC INFRASTRUCTURES	**4.1 Damages to the road network and related structures**	▨	1.48	1.04	0.99	1.25	1.25	1.24
	4.1.1 Roads	▨	▨ 1.98	1.29	0.99	0.64	0.49	1.97
	4.1.1.1 Arteries	-	2.29	1.43	1.17	0.71	0.57	2.30
	4.1.1.2 Local urban roads	-	2.14	1.29	1.00	0.71	0.57	2.10
	4.1.1.3 Highways	-	1.50	1.17	0.80	0.50	0.33	1.50
	4.1.2 Bridges	-	1.50	0.60	-	1.00		1.33
	4.1.3 Culverts	-	1.00	2.00	-	0.20		1.00
	4.1.4 Electrical and telephone poles	-	-	-	-	2.67		-
	4.1.5 Traffic lights	-	-	-	-	2.43		-
	4.1.6 Sidewalks	-	1.43	0.29	-	0.57	2.00	0.67
	4.2 Thermal expansion/contraction of rails	-	1.50	-	2.00	-		-
	4.3 Damages to utility networks	▨	▨	1.50	▨	2.67	▨	0.67
	4.3.1 Underground utilities	-	-	1.50	-	-	-	0.67
	4.3.2 Above-ground utilities	-	-	-	-	2.67	-	-
	4.4 Damages to the water infrastructure network	▨	0.58	2.05	▨	1.00	0.33	1.07
	4.4.1 Water supply network – Drinking water distribution	▨	0.51	▨	▨		0.35	
	4.4.1.1 Reservoirs	-	0.50	-	-	-	0.67	-
	4.4.1.2 Pipes and sluice gates	-	0.71	-	-	-	0.14	-
	4.4.1.3 Pump stations	-	0.50	-	-	-	0.33	-
	4.4.1.4 Chlorination systems	-	0.33	-	-	-	0.25	-
	4.4.2 Sewer system – Wastewater collection	▨	0.65	2.05	▨	1.00	0.32	1.07
	4.4.2.1 Retention basins	-	0.57	2.00	-	-	0.29	0.88
	4.4.2.2 Stormwater sewers	-	0.86	2.44	-	-	0.36	1.50
	4.4.2.3 Sanitary sewers	-	0.57	1.13	-	-	0.21	0.29
	4.4.2.4 Combined sewers	-	0.86	2.38	-	-	0.58	1.38
	4.4.2.5 Pump stations	-	0.40	2.29	-	1.00	0.17	1.33
	SUB-TOTAL		**1.19**	**1.53**	**1.49**	**1.64**	**0.79**	**0.99**

IMPACTS ON THE BUILT ENVIRONMENT

🟨 Negligible 🟧 Minor 🟥 Moderate
🟫 Major ▨ Sum of the subsections

	IMPACTS ON THE BUILT ENVIRONMENT	HIGHER AVERAGE TEMPERATURES		HEAVY RAINFALLS	HEAT WAVES	DESTRUCTIVE STORMS	DROUGHTS	RIVER FLOODS
		EXTENDED SUMMER SEASON	SHORTER WINTER SEASON AND INCREASED NUMBER OF FREEZE-THAW CYCLES					
5. RESIDENTIAL AND ICI INFRASTRUCTURES	**5.1 Damages to homes and buildings**	▨	1.17	1.84	▨	2.00	1.31	1.26
	5.1.1 to infrastructures by:	▨	1.00	2.17	▨	▨	1.31	1.43
	5.1.1.1 drying out of clay soils	-	-	-	-	-	1.31	-
	5.1.1.2 landslides	-	1.00	2.17	-	-	-	1.43
	5.1.2 to foundations and finished basements by:	▨	0.83	2.34	▨	▨	▨	1.08
	5.1.2.1 flooding	-	1.13	2.29	-	-	-	1.50
	5.1.2.2 sewer backflow	-	0.38	2.57	-	-	-	0.88
	5.1.2.3 water infiltration	-	1.00	2.17	-	-	-	0.88
	5.1.3 to the envelope by fissuring and degradation	-	1.33	-	-	-	-	-
	5.1.4 to the envelope or roof in the form of components lifting, tearing away or breaking off	-	-	-	-	2.00	-	-
	5.1.5 to parking lots and alleyways (asphalt, concrete, paving stones) in the form of corrosion (particularly the use of de-icing salts)	-	1.50	1.00	-	-	-	-
	5.1.6 to the roof due to fatigue, abrasion or breakage of the membrane and sealing material	-	1.33	-	-	-	-	-
	5.1.7 to the roof structure due to heavier loads	-	1.00	-	-	2.00	-	-
	5.2 Damage to infrastructures other than homes and buildings (sheds, reservoirs, culverts, etc.)	-	0.33	0.33	-	0.50	0.25	0.67
	5.3 Damages to infrastructures due to hazardous materials spills	-		2.00	-	2.00	-	2.00
	SUB-TOTAL		**0.75**	**1.39**		**1.50**	**0.78**	**1.31**

This document is a production of the Service de l'environnement under the supervision of Roger Lachance, director of the Service de l'environnement. This document is a translation of the *Plan d'adaptation aux changements climatiques de l'agglomération de Montréal 2015-2020, Les constats*.

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