

*F*INAL REPORT

URBAN HEAT ISLANDS: A CLIMATE CHANGE ADAPTATION STRATEGY FOR MONTREAL

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The Climate Change Action Partnership
McGill University School of Urban Planning

CCAP

submitted to Services des infrastructures,
transport et environnement
of the City of Montreal

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The authors of the report that follows are four graduate students at the McGill University School of Urban Planning. They are Chee F. Chan, Julia Lebedeva, José Otero and Gregory Richardson. The report was produced for a university course (McGill URBP 624) during the fall of 2007.

All opinions expressed in the report, and any errors contained therein, are solely the responsibility of its four student authors, named above. The report does not present the views or opinions of McGill University or of the City of Montreal or its agencies.

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PREFACE

Who we are

The Climate Change Action Partnership (CCAP) is a consulting group based in Montreal, Canada, that specializes in climate change adaptation policy and planning. CCAP has four founding partners: Chee F. Chan, Julia Lebedeva, José Otero and Gregory Richardson. CCAP is grounded on the complementary areas of expertise of its partners, which include law, physical sciences, geography, political science and planning. Since its establishment, CCAP has gained expertise in transportation and land use, sustainable development, policy analysis, public participation, and ethical planning.

About our client

Our client is the Infrastructure, Transport and Environment Service (SITE) of the City of Montreal. SITE is presently engaged in an effort to study climate change impacts for the island of Montreal and to prepare adaptation strategies across various municipal service sectors. As part of that larger effort, SITE engaged CCAP as a consultant to devise methodologies for identifying geographic areas most vulnerable to urban heat island (UHI) effects due to climate change and for formulating and evaluating possible UHI adaptation measures.

Project sponsors

We would like to thank our sponsors—the Association of Canadian University Planning Programs, in association with the Canadian Institute of Planners, and Natural Resources Canada—for their generous support. This project is one of eight across Canada focusing on aspects of policies, plans, programs, or planning practices that relate to adaptation to climate change.

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EXECUTIVE SUMMARY

Climate change is beginning to have noticeable adverse impacts on cities in Canada and across the world. Attempting to prevent climate change through mitigation efforts has ceased to be the only mission. Cities across the world must start to adapt to the new climates. Consequently, climate change adaptation has become an urgent issue on the policy agenda.

This report focuses on urban heat islands (UHI) as a specific problem expected to be exacerbated by climate change. An urban heat island is the phenomenon that occurs when the air temperature in an urban area is higher than in surrounding areas. Temperatures more than 5°C above the regional average have been deemed indicative of a UHI by Montreal climate scientists (Baudouin 2007). UHIs are a concern for several reasons, including increased human mortality and disease, poor air quality, damage to infrastructure, and increased energy consumption. However, public health concerns are far more serious than the other potential threats. Thus, this study adopts a human health focus in proposing UHI adaptation measures.

The risk of harm from a UHI, as with any event, comprises three main elements: occurrence, exposure and vulnerability. In the preliminary analysis phase of this study (Section 2), the causes for the occurrence of UHIs were studied. They are low vegetation coverage (low biomass), low reflectivity of mineralized surfaces (low albedo), high thermal mass of buildings, and high waste heat production.

The scientific literature reveals that the extent and severity of a particular UHI are highly localized. Thus, the increased heat associated with a large parking lot and the cooling effects of a large park dissipate only a few metres beyond their borders. While wind can displace hot air above a UHI toward adjacent areas, the

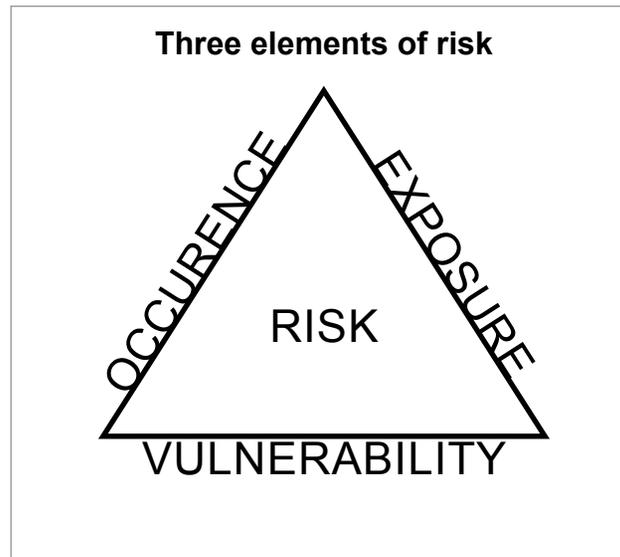
gravest threat to human health from extreme heat arises under calm conditions.

Factors that increase exposure to UHIs include building height, poor building conditions such as lack of ventilation and proper insulation, lack of access to cool places and social marginalization. Vulnerability to UHIs is exacerbated by air pollution and poor health. Accordingly, groups particularly exposed and vulnerable to UHIs include low income earners, the sick, the very young, the elderly, and people living in areas with high air pollution.

The final section of the preliminary analysis describes various adaptation strategies based on research and efforts in other cities. Possible UHI adaptation strategies include increasing biomass through tree planting, green space creation and preservation, green roofs and living walls. To increase albedo, cities have encouraged the use of light paving materials and elastomeric paints for roofs (white roofs). Regarding the thermal performance of buildings, in addition to climate sensitive design and materials,

researchers have studied building bulk and street geometries. Urban design studies have focused on the size of lots in new subdivisions, and the size, location and arrangement of buildings within lots. More research is necessary on the relationship between thermal mass and the density of buildings and UHIs. Finally, waste heat reduction maybe accomplished through more efficient appliances, building energy retrofits and anti-idling bylaws among other measures.

After completing the preliminary analysis, the study team proceeded to develop a UHI Risk Map for the island of Montreal, utilizing a geographic information system (GIS) tool (Section 3). To create this map, an air temperature



map was overlaid with three human vulnerability layers: the density of people living in poverty, children under the age of five and adults over 65, and people over 65 living alone. The values underlying each data layer were combined to produce the final UHI risk index. Based on the mapping of UHI risks for the island of Montreal, a number of key lessons were learned:

1. The most severe UHIs in Montreal occur in areas characterized by large-scale industrial and commercial uses, where dark-surfaced buildings and parking lots predominate;
2. Temperatures in the central areas of Montreal, while not as extreme as in other areas, do constitute one large UHI to which many residents are exposed;
3. Because the most extreme UHIs are located over industrial and commercial developments where fewer people live, vulnerable populations are rarely exposed to the most severe UHIs when at home;
4. Many of the most vulnerable residents of Montreal are exposed to relatively significant UHIs. Areas with high proportions of vulnerable individuals are often located in close proximity to industrial and commercial areas where severe UHIs occur. These heat islands may affect nearby populations in windy conditions or when individuals use or walk through those areas.

Having identified the areas of Montreal facing the greatest UHI threat, the team selected one such high UHI risk neighbourhood for further study. The area selected was a portion of the Saint Michel neighbourhood north of central Montreal (Section 5).

Before proceeding with the Saint Michel case study, a UHI policy framework was developed (Section 4). This framework was grounded in two main concepts: risk-based resource allocations and customized recommendations based on site-specific conditions. As part of that framework, a methodology for evaluating the relative costs and benefits of different strategies for various types of urban contexts was developed. Also, the following multi-step approach was developed to guide policy selection and evaluation:

- Focus UHI adaptation efforts on areas most at risk
- For each area, determine the causes of the local UHI
- Identify site appropriate adaptation measures
- Prioritize measures with greatest heat reduction potential
- Consider the costs and benefits of various alternatives
- Engage residents and other stakeholders
- Include clear and objective performance measures

Causes of UHI

- Low vegetation cover (low biomass)
- Low surface albedo
- High thermal mass of the built form
- High waste heat production

Main exposure and vulnerability factors

- Building typology and condition
- Social marginalization
- Fear of crime
- Lack of access to cool places
- Poor air quality
- Poor health

The site selected, located in the district of Saint Michel, is a densely populated area home to many immigrants. The median income and education level of residents are low on average and the rate of crime is relatively high. Several large and intense UHIs dot the area. An analysis of the built form confirmed the importance of biomass, albedo and thermal mass in the formation of those UHIs (waste heat is not known to be a significant factor in this site). The urban form of five typical block types in Saint Michel was studied in detail. The lack of biomass clearly contributes to UHIs in several residential blocks. In nearby areas with more trees, lower temperatures were found. Areas with higher percentage of low albedo, mineral-

ized surfaces and with larger buildings experience higher temperatures.

Policies, plans and projects in Saint Michel were also studied so as to identify points of tension and areas of alignment with possible UHI adaptation efforts. Of special interest is a large new shopping centre proposed for the site of the former Saint Michel quarry. This project presents a significant potential opportunity or threat to any UHI adaptation plan and merits careful evaluation (Section 5).

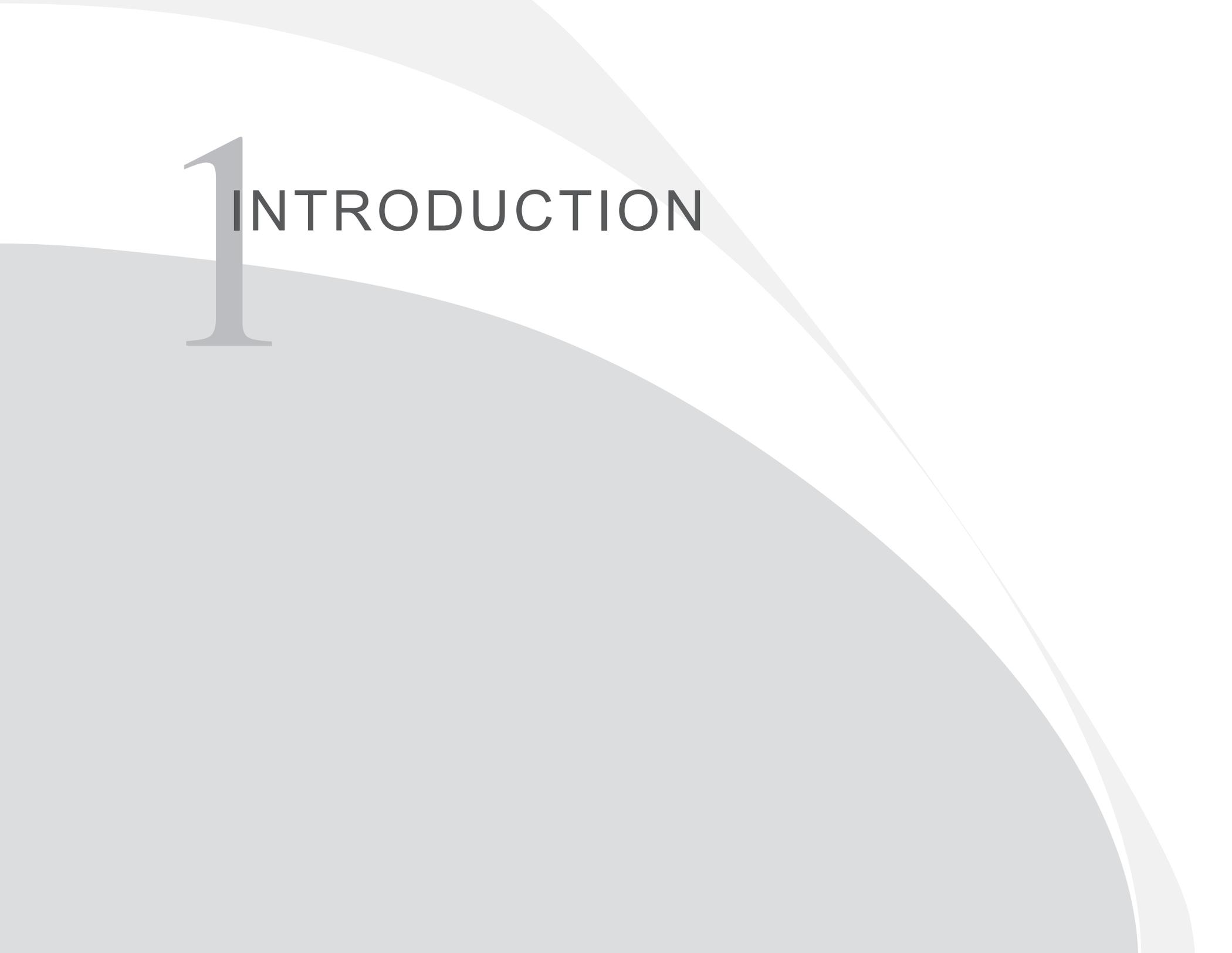
In the final portion of this study, a proposed UHI Adaptation Plan was prepared for the selected site, including a vision and concept for reducing UHI risk. The Plan is grounded on four guiding principles:

1. Give priority to three high risk residential areas
2. Every new construction means a new cool site
3. Engage the private sector in a ‘Cool Saint Michel’ campaign
4. Create cool street corridors

Consistent with the client’s mandate, the measures recommended focus on physical interventions to reduce the occurrence and exposure to UHIs. The interventions also focused on residential areas where the highest risk of death arises. Because the causes and effects of UHIs are highly localized, the Plan contains a separate set of recommendations for each one of five representative block types found in Saint Michel. The planting, preservation and maintenance of trees throughout Saint Michel, in both public and private lands, are key objectives of many of the actions recommended in the Plan. To help policy makers in the implementation of this Plan and in evaluating and selecting from among the various measures being proposed, a matrix of approximate cost and benefits, phasing and responsible parties for each recommended action is provided.

Some adaptation measures

- Increase biomass through tree planting, green space creation and preservation, green roofs, and living walls
- Increase albedo of roof and ground surfaces, including driveways and sidewalks
- Improve thermal performance of buildings and urban form through climate sensitive design and materials
- Reduce waste heat with anti-idling bylaws, building energy retrofits and energy efficient appliances



1 INTRODUCTION

AREA OF STUDY



In this study, UHIs are analyzed at both a municipal and a neighbourhood scale. In the section on assessment of UHI risk, the analysis encompasses the entire island of Montreal, including 16 independent municipalities (Page 19). For the case study section of this report, a small neighbourhood to the north of central Montreal was selected (Page 29). This neighbourhood is located in the borough of Villeray – Saint-Michel – Parc-Extension of the City of Montreal.

Key facts about the island of Montreal

Location:	Saint Lawrence River basin Eastern North America 45°46 N, 73°75 W (at airport)
Altitude:	29 m above sea level (at airport)
Population:	1,812,723 (2001)
Land area:	500 km ²
Population density:	3,625 inhabitants / km ² (2001)
Political divisions:	16 independent municipalities, including City of Montreal
Metropolitan region:	Approximately 3.6 million inhabitants
Current climate:	Humid continental (hot summer, a cold winter and abundant precipitation), average temperatures vary from -13° to -5°C in January to 18° to 27°C in July.
Economy:	Largest sectors by number of employees are trade, manufacturing, healthcare and social assistance and professional services.

Sources: Governments of Canada and Quebec, montreal.com

MANDATE

This report encompasses all remaining deliverables under CCAP's agreement with SITE. In accordance with the terms of CCAP's proposal dated September 27, 2007, this report addresses the following topics:

1. Climate change predicted for Montreal and the impacts of UHIs (task 1.1)
2. Elements of a successful UHI adaptation strategy (task 1.2)
3. Present conditions in Montreal relevant to UHI effects (task 1.3)
4. A methodology for UHI risk assessment and formulation and evaluation of UHI adaptation measures (task 2.0)
5. Map of the island of Montreal showing areas of highest UHI risk (task 3.1)
6. UHI-focused site analysis and adaptation plan for a selected area (Saint Michel) (tasks 3.2 and 3.3)

Each of these six elements of the mandate is addressed beginning with the Preliminary Analysis section of this report. This report also responds to comments and suggestions from SITE regarding CCAP's Preliminary Report delivered November 2, 2007.

CCAP will also deliver an electronic version of the UHI Risk Map. A graphical representation of recommended adaptation plans or strategies, in the form of a concept plan, is also being provided (task 3.2 and 3.3).

CHALLENGES AND OPPORTUNITIES

CLIMATE CHANGE EFFECTS PREDICTED FOR MONTREAL

Climate change will mean higher temperatures in summer and winter; increased and more severe precipitation; increased evaporation; increased tropospheric ozone formation; and greater pollen emissions. These changes have the potential to seriously consequences for the health and well-being of Montreal residents and the local economy.

Water systems

It is predicted that the flow of the Saint Lawrence River will be lower due to increased evaporation. Lower water levels may have serious impacts on shoreline infrastructure, shipping, recreation, hydroelectric generation, and water availability and quality (NRCAN 2004, Ouranos 2004).

Natural environments

Climate change could harm natural environments and lead to animal and plant extinctions. Loss of biodiversity could make Montreal's attempt to protect its few remaining eco-territories more difficult, yet ever more important.

Transportation

The efficiency and longevity of road and rail infrastructure may be reduced by extreme weather events, soil erosion, high tem-

peratures and a drop in water table levels. In addition, shallower navigation channels in the Saint Lawrence River may require under-loading ships. The Port of Montreal is an important point for container shipping and having ships carry fewer containers may reduce its competitiveness and profitability, with serious repercussions for Montreal's economy.

Human health

Rising temperatures, declining air quality, new diseases and extreme weather events will all have direct effects on Montreal residents. Rising temperatures may have a positive effect in the winter, but the negative effects in summer will be of greater magnitude. Moreover, extreme weather events could cause property damage and loss of life.

The economy

Climate change could reduce hydroelectricity production as water levels decrease at a time of increased demand. This may cause a reduction in revenues to Hydro-Quebec on its sale of surplus electricity outside Quebec during the summertime. Increased insurance losses due to more extreme weather events and loss of productivity for health reasons would further burden the local economy.

THE THREAT OF URBAN HEAT ISLANDS

An aggravated UHI phenomenon in Montreal can be expected to have a significant negative impact on public health, energy and water usage, air quality, and the condition of buildings and infrastructure. See Appendix A for a summary of major UHI impacts.

A study by McGill researchers indicates there is a strong correlation between the number of deaths in Montreal and high heat/air pollution events. On average, nearly four excess deaths per day

occur on days of poor air quality and extreme heat (Goldberg 2007). Moreover, Montreal's climate may exacerbate its vulnerability to extreme heat conditions. For instance, the sudden onset of a heat wave early in summer in a city such as Montreal, which rarely experiences extreme weather conditions, can be deadly. Lack of regular exposure to heat is believed to limit the adaptive capacity of residents, leading to higher vulnerability (McGeehin 2001).



DEFINING AN URBAN HEAT ISLAND

An urban heat island is the phenomenon that occurs when air temperatures in cities are much higher relative to their hinterlands. UHI effects are scalar, meaning that the exact definition of what constitutes a heat island is dependent on the scale of analysis. For example, on a regional scale, the urbanized areas of a metropolitan region constitute a UHI in their entirety. At the scale of the city of Montreal, certain areas such as large industrial zones or the airport constitute heat islands when compared with their immediate surroundings. At the level of the city block, a black asphalt road may constitute a heat island in comparison with a vegetated front yard.

There are many intervening scales of analysis, and the choice of such scales is dependent upon the scope of the problem and the goals of the researcher. For example, the diffuse nature of air pollution and its interactions with the urban heat island necessitates a level of analysis at the

island or metropolitan-wide scale. In this report, the UHI phenomenon is examined at the city and block scales of analysis. The former corresponds with the mandate from SITE to identify areas on the island of Montreal that are at particularly high risk to UHI. Having identified these areas, CCAP will examine one of these high-risk areas, Saint Michel, in detail, in order to better understand the causes of UHI and to propose context and site-specific recommendations. Recommending adaptation measures at the island-wide scale is beyond the scope and mandate of this study.

S c a l e s o f A n a l y s i s

Regional



Island



Local area



THE ROLE OF PLANNING

CCAP believes that to be truly effective, the UHI risk assessment and policy making tools described in this report must be part of a much larger and on-going effort to mitigate and adapt to climate change. Planning for climate change differs from other forms of urban planning in a number of important ways. First, the time horizon for desired adaptation and mitigation action can stretch for decades into the future rather than the 20 year, or even shorter, lifespan of a typical master plan. At the same time, the immediate impacts of climate change require quick responses today.

Further, climate change planning requires the integration of complex, rapidly changing, and at times highly uncertain technical and scientific data. The science of UHIs, and urban microclimates more generally, is particularly complex, involving theories and modeling from the fields of physics, meteorology, medicine, mathematics and others. Accordingly, a successful climate change and UHI adaptation plan must allow for frequent and productive interaction between scientists and technical experts, social workers, public health officials, and urban planners (Figure 1). A major challenge in this regard will be the accommodation of public participation and stakeholder engagement within a science and technology dependent policy framework.

Because the causes of climate change and the factors that contribute to it (including suburban growth patterns, car-based transportation networks, a growth-driven economy) are deeply entrenched in Canadian culture, effective planning for climate change requires the active, fully engaged cooperation of the private, non-governmental, and public sectors, including all levels of government. Measures must be taken to increase public awareness of climate change impacts and, just as importantly, of potential and proposed solutions.

Finally, considering the complexity of the climate change problem, a multi-pronged response strategy that combines the most effective policy tools is required. Persistent, committed and hard working teams of professionals (planners, engineers, scientists, political leaders) and an engaged citizenry will be essential for achieving success.

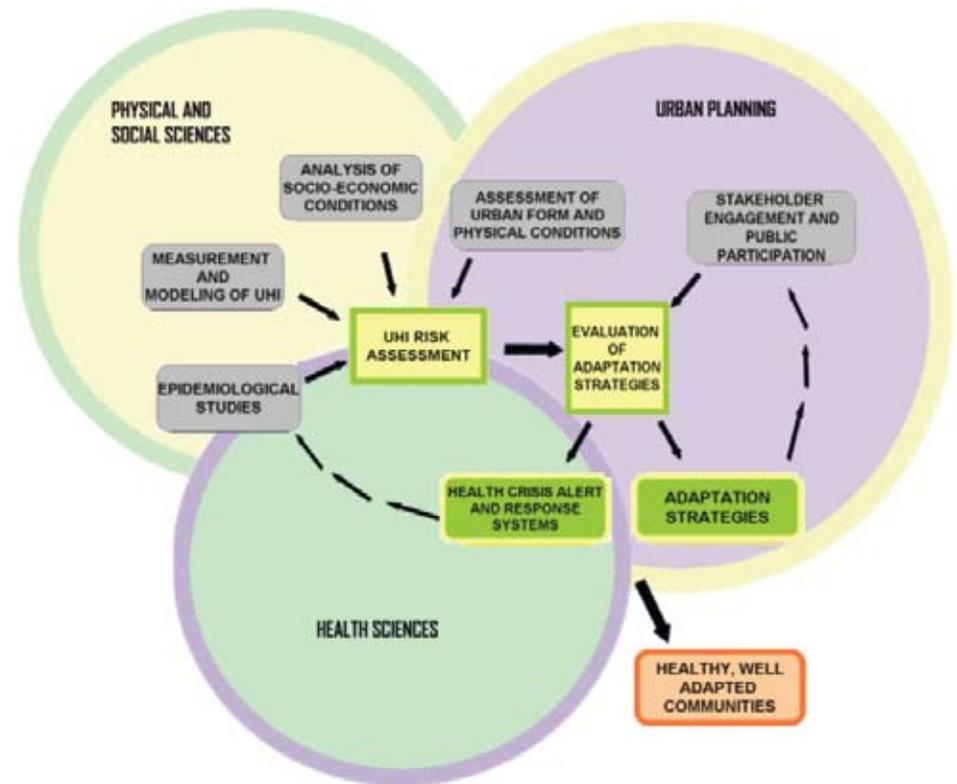


Figure 1. A schematic representation of the many functions and disciplines essential for effective UHI adaptation



PRELIMINARY ANALYSIS

FACTORS AND VULNERABILITIES

CAUSES OF UHI

In order to develop an effective UHI adaptation strategy, it is first necessary to learn what causes UHIs and to understand what factors cause people to be exposed and vulnerable to heat. The first part of this section describes the physical factors that cause UHI, and the second part highlights some characteristics that increase human exposure and vulnerability.

Low albedo of mineralized surfaces

Albedo is a measure of surface reflectivity of solar radiation. The low albedo of roofs and paving materials commonly used in Canada (e.g., tar, gravel, and asphalt) is a major contributor to UHI. These dark materials absorb the sun's energy more readily than lighter coloured surfaces. This in turn increases air temperatures immediately above and downwind from the surface (Taha 1997).

Low biomass coverage

Vegetation creates a localized cooling effect. Trees, for example, provide ground shade, while all vegetation cools the environment through the process of evapotranspiration. Urban districts with low vegetation cover are deprived of this natural cooling effect and are therefore more likely to have high UHI intensity.

Thermal mass of built form

Buildings increase the thermal mass available for heat storage, and interrupt air flows. While buildings can shade the ground, their roofs and walls absorb solar radiation and re-emit it as

heat. Buildings have a greater thermal mass than undeveloped land, absorbing and retaining more heat during the day and releasing it more slowly after sunset. The high thermal mass of urban areas contributes to the nighttime UHI effect (Oke et al. 1991). Street canyons formed by rows of buildings can help cool the urban environment by maintaining prevailing winds through an area. However, when they are not aligned, buildings can interrupt cooling air flows (Ghiaus et al. 2006, Watkins 2007).

High waste heat production

Heat generated from the combustion of fuels, industrial activities and air conditioning is known as waste heat (Oke et al. 1991). It can affect localized air temperatures and exacerbate UHIs (Hart et al. 2007, Taha 1997, Wilhemi 2004). Although primarily studied as a wintertime phenomenon, summertime anthropogenic heat has been observed and measured in Montreal (Taha 1997). Meteorological simulations show that anthropogenic heat in a large city core can raise temperatures by up to 3°C, both during the day and at night. This kind of temperature increase, however, generally only occurs in central city areas where building densities tend to be higher.



EXPOSURE AND VULNERABILITY TO UHI

Microclimate effects

Humidity levels and wind speeds differ within cities, affecting how heat is perceived. Thus, citizens living or working in areas with higher temperatures and humidity, and lower wind speeds will be more exposed and vulnerable to extreme heat events.

Building typology and condition

Building typology and physical conditions of buildings can significantly increase exposure to heat by residents (McGeehin and Mirabelli 2001). For example, people living in high rise apartments, and particularly those living on the top floors, face much greater risks than those living in single storey homes (Wilhemi et al. 2004). Studies of the Chicago heat wave of 1995 showed that residents of multi-unit housing were more than eight times as likely to die as residents of single family homes. People living on the top floors of these buildings, where trapped heat simulates solar ovens, were more than four times as likely to die as those below. Furthermore, flat roofs, a very common feature in Montreal, were determined to exacerbate health risks for occupants by trapping heat (Jusuf 2007).

The age of buildings was also shown to have been a risk factor to people's health during the Chicago heat wave. Simulation models revealed that temperatures on the top floors of buildings constructed during the 1940s had remained higher than outdoor temperatures for four or five days, rarely dropping below human body temperature. Conditions in 1970s

buildings were even worse because of their greater mass and poor insulation (Huang 1996).

Social characteristics

Certain socioeconomic characteristics make people especially vulnerable and increase exposure to severe heat. Young children (under 5 years old) and the elderly (over 65) are less able to cope with severe heat. Socially marginalized people are potentially more exposed to heat. Indicators of social marginalization include living in poverty, living alone, being disconnected from social networks, and suffering from chronic physical and mental illnesses (Buechley 1972, Lindley et al. 2006, Patz 2000). People in poverty are less able to escape the heat due to lack of financial resources to make necessary changes, such as by purchasing air conditioners or making appropriate home renovations (Harlan 2006). For the same reasons, renting, rather than owning a dwelling is an additional source of exposure.

Crime or fear of crime in a community

One major factor that breeds social marginalization and breaks down social networks is crime or the fear of crime (Klinenberg 1999). Residents of high-crime areas have been found to be much more exposed to heat waves because they may be afraid to leave the windows open at night, thus trapping hot air inside dwellings. In sociological studies of the deadly heat wave of 1995 in Chicago, researchers found that a



disproportionately large number of seniors died because they were effectively confined in their apartments due to fear of crime in their communities. These people rarely left their homes, had little contact with family and friends, and – due to cutbacks in public health and transportation programs – were unable to access many of the basic services necessary to cope with extreme heat. The apartment blocks which experienced the highest death toll during that heat wave were those known as havens for crime (Klinenberg 1999).

Lack of access to cool places

UHI exposure is higher for individuals who lack access to cool environments. Access to a cool place, even if just for a few minutes can make the difference between life and death during an extreme heat event. Elevated temperatures during evening hours are the hallmark of lethal heat waves. Thus, access to cool facilities during those hours is particularly important.

Poor air quality

An additional consequence of high air temperatures in urban environments is poor air quality. High temperatures intensify the photochemical reactions that create smog, ground-level ozone, volatile organic compounds, and pollen. Higher temperatures also retain more pollutants in the dust dome, formed by a difference in air temperature between central and suburban areas (Shimoda 2003). These pollutants exacerbate respiratory conditions such as asthma and allergies, making people more vulnerable during high heat events. Children, the elderly, and people who already suffer from respiratory illnesses are especially vulnerable. Like the intensity of UHIs, air quality varies within cities due to a number of factors such as temperature, vegetation cover, wind, and anthropogenic activities. For example, air quality conditions are typically worse along busy transportation routes (Lindley 2006).



STRATEGIES FOR UHI ADAPTATION

This section presents a variety of urban planning strategies for UHI adaptation. These strategies are based on a review of policies and practices in several cities in the US, Canada and the United Kingdom. We present strategies that can be implemented at the city-wide and neighbourhood scales. For a comprehensive description of the various strategies listed below please refer to Appendix B. Where relevant, Montreal specific policies and programs are included in the Saint Michel Case Study starting on page 28.

Increase biomass

Preserving existing trees and planting more trees in the city

- Tree inventory of all trees on public streets and spaces
- Tree planting programs (Municipal, NGO and private sector)
- Landscape ordinances that require certain percentage of tree coverage in new developments/parking lots

Preserving green spaces and creating new ones

- Open space impact fees ordinances requiring developers of new residential properties to pay a fee or contribute a proportionate share of open space
- Restrict expansions of residential buildings into rear courtyards through zoning regulations
- City-financed green roof subsidies
- Green roof demonstration projects on municipal buildings

Increase surface albedo

Installing cool or white roofs

- An education and outreach program to inform developers and the general public about the benefits and costs of installing white roofs
- Technical research of local building standards and monitoring
- Time-dependent valuation of electricity – electricity companies mandated to pass the increased cost of electricity during peak hours on to the consumer, thus creating additional economic incentives for installing cool roofs

- Grant programs that provide homeowners with up to 80% of the costs of roof retrofits

Increasing ground albedo

- Paving guidelines to assist municipalities and developers with appropriate use of materials and design
- Strategy for depaving alleys

Increase thermal performance of built form

- Modification of cool-weather weatherization assistance for all season performance
- Regulate building design and materials
- Climate sensitive urban design and planning

Reduce exposure and vulnerability

- Installation of air conditioning and/or passive cooling techniques
- Access to cool places (schools, libraries and pools)
- Preventative health care

Respond to heat wave emergencies

Comprehensive plan designed to save lives during heat waves

- A heat health alert system to predict days where extreme heat is dangerous
- A response strategy to coordinate the actions of public agencies and non-governmental partners
- Access to medical facilities

Reduce waste heat

- Vehicle anti-idling bylaws and strategies to reduce heat

RISK ASSESSMENT FOR THE ISLAND OF MONTREAL

3

THE RISK MAP

DEVELOPING A METHODOLOGY

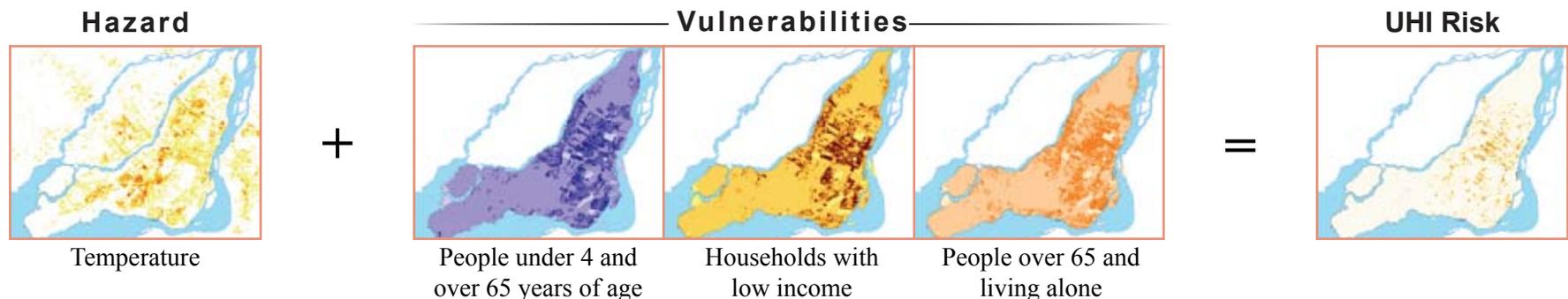
This section describes the methodology employed to create a geographic representation of UHI risk levels on the island of Montreal. Appendix C contains a more detailed discussion of the development and limitations of this approach. This methodology, based upon the GIS work of Lindley et al. (2006), consists of overlaying a hazard layer – a map of near-surface air temperature – with a vulnerability layer to produce a final risk layer. The diagram below is a representation of this methodology.

The hazard layer is a satellite image of the island of Montreal from a day in June 2005, representing near-surface air temperatures. The average temperature for the Montreal metropolitan region for that day was determined from the map. Then, a numerical rating from one to four, representing low to high heat hazard, was assigned to all the areas with temperatures above the average. This data was produced and interpreted by a UQAM research group (Baudouin 2007). It is important to note that this layer represents geographical locations of the areas with the highest heat hazard.

The human vulnerability layer is composed of three characteristics that make people more vulnerable to extreme heat: being under five or over

65 years of age, living on a low income, and being over 65 and living alone. Although not every individual who falls into these categories is necessarily vulnerable to UHI, and while there are many other factors that may make people vulnerable, these three characteristics are the most salient in the current literature. Data for this layer comes from the 2001 Canadian Census at the dissemination area (DA) level of analysis. The density of each vulnerable group is calculated for each DA, and then given a score of one to four, representing low to severe vulnerability. Then, the three scores for each DA are averaged to yield a composite vulnerability index.

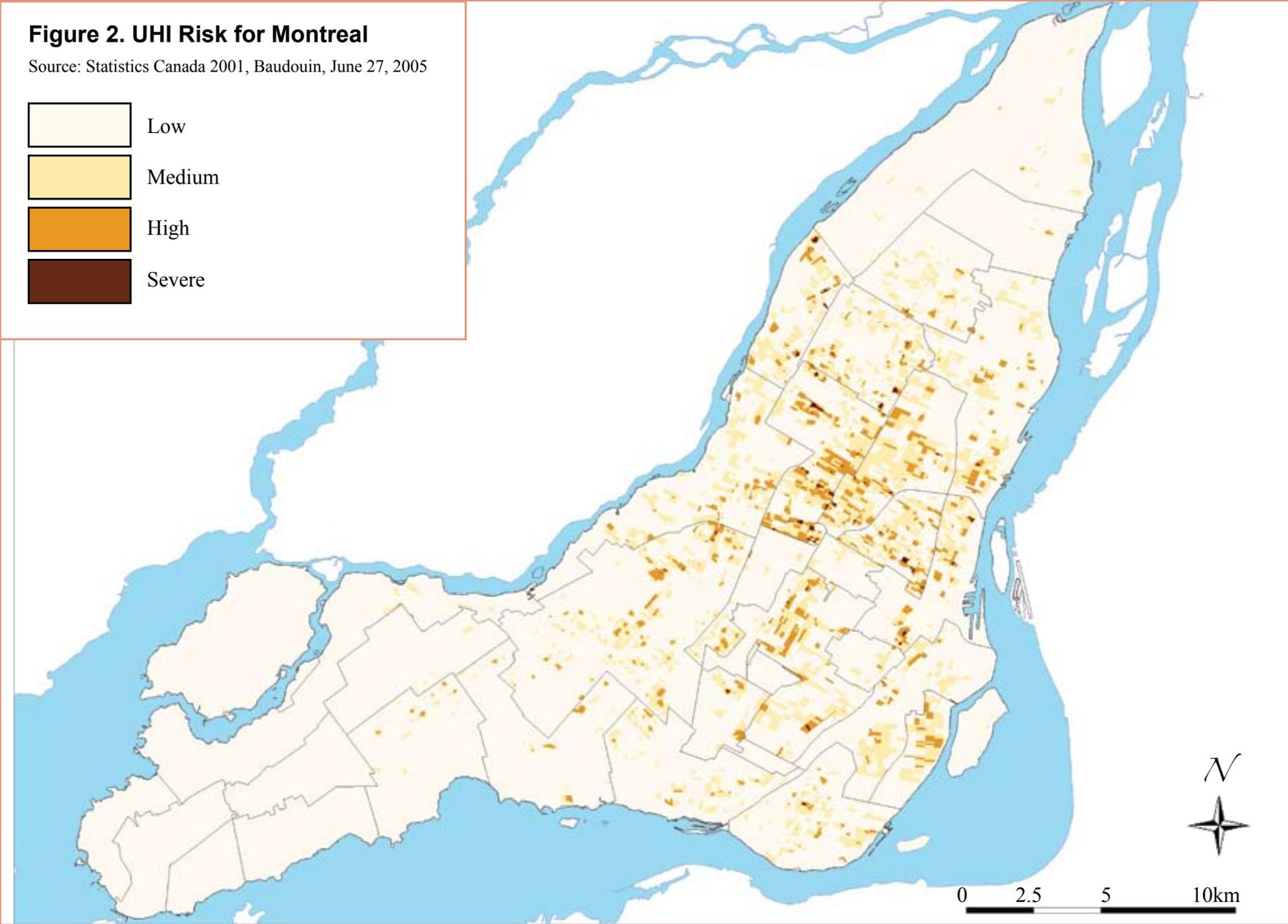
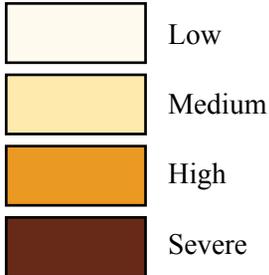
In the final step of this methodology, the hazard and vulnerability layers are averaged to give a final risk index from one to four. Equal weighting was given to the two data layers. The Risk Map on page 21 shows the distribution of areas of highest risk to UHI. This visual tool can be used to easily identify areas of highest risk to UHI and allocate resources accordingly. It is important to keep in mind that this picture is a one-time snapshot of conditions, and should be updated periodically.



THE RISK MAP

Figure 2. UHI Risk for Montreal

Source: Statistics Canada 2001, Baudouin, June 27, 2005



KEY FINDINGS FROM THE RISK MAP

TEMPERATURE AND LAND USE

A review of the Risk Map reveals several key findings. First, a comparison of Figures 3 and 4 below reveals that the hottest areas on the island correspond well to large scale commercial and industrial land uses. This suggests that an urban fabric characterized by large building and parking lots with dark surfaces produces particularly strong UHI effects.

The temperatures in the central areas of Montreal are not as extreme as in the industrial sectors. Nonetheless, the most densely developed areas in the centre of the island – downtown and the neighbourhoods to its north – are sites of elevated temperatures.

Figure 3. Commercial and industrial land uses

Source: City of Montreal 2001

-  Light industry
-  Heavy Industry
-  Commercial centres

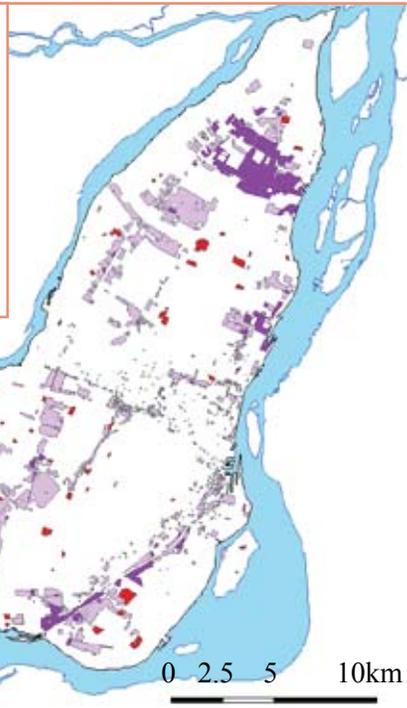
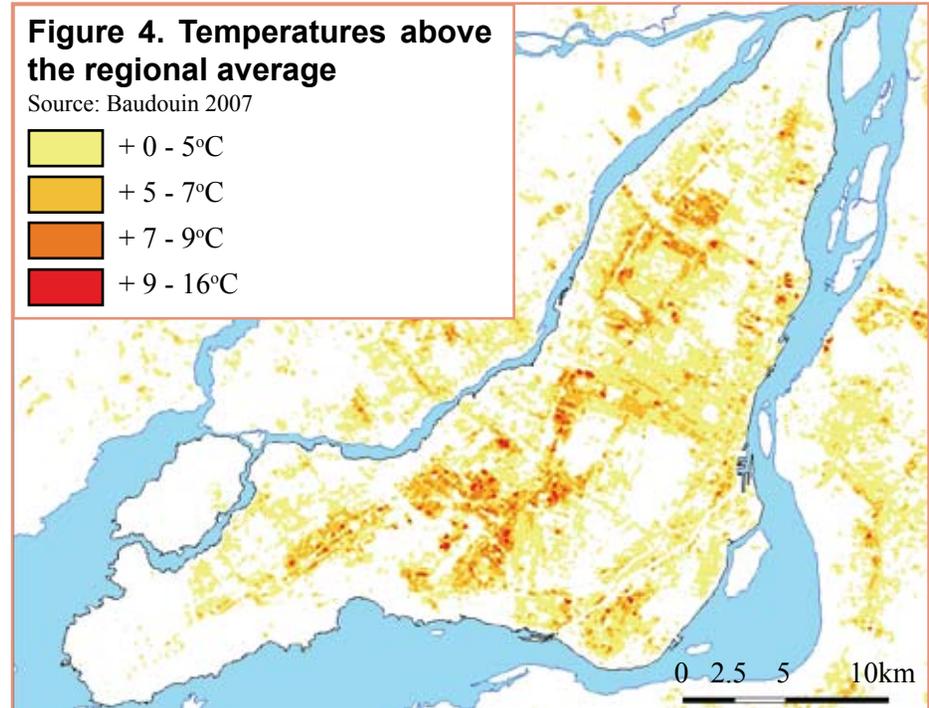


Figure 4. Temperatures above the regional average

Source: Baudouin 2007

-  + 0 - 5°C
-  + 5 - 7°C
-  + 7 - 9°C
-  + 9 - 16°C

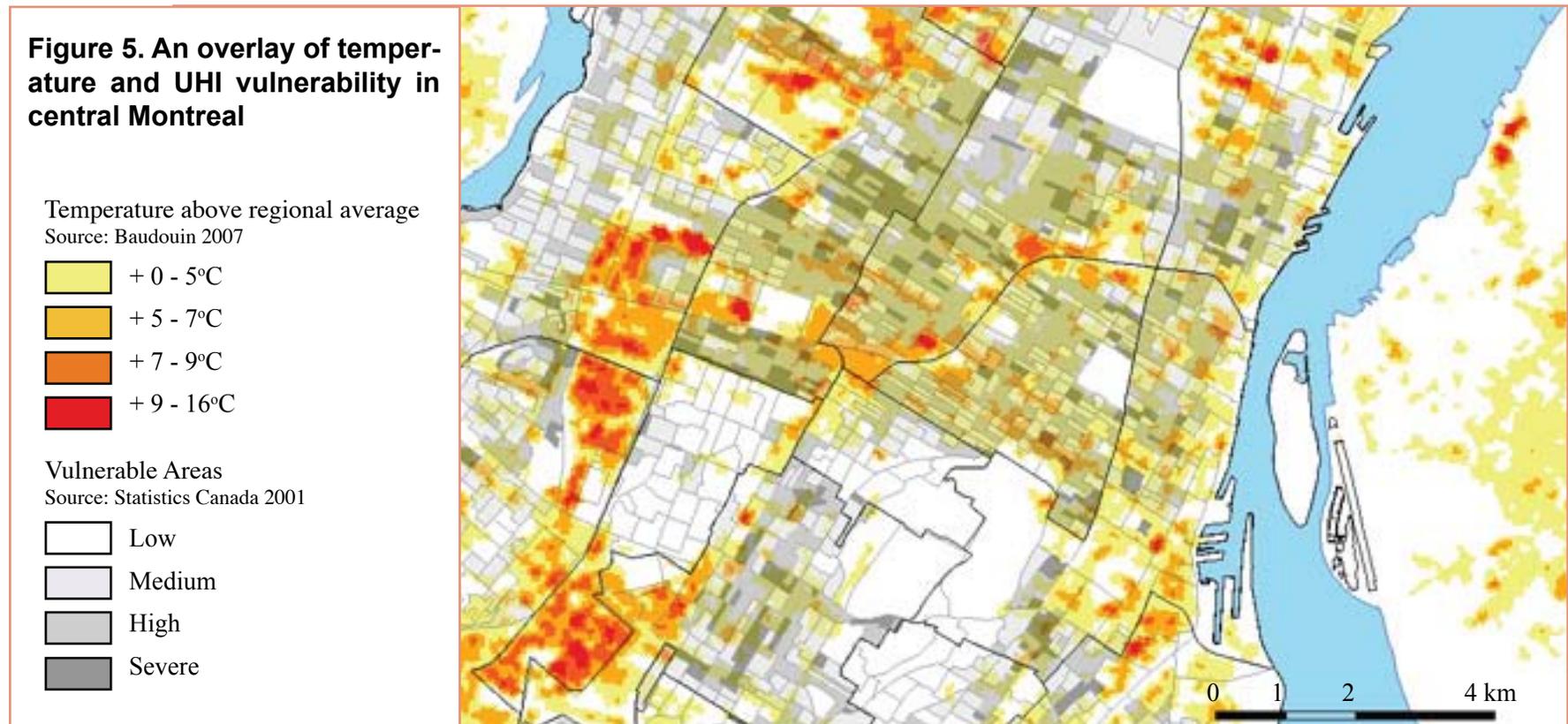


TEMPERATURE AND VULNERABLE POPULATIONS

Since the most severe UHIs are located over industrial and commercial developments where few people live, we find that vulnerable populations almost never reside in the most severe UHIs. The overlay of the temperature and vulnerability layers (Figure 5) demonstrates this point: the darkest red zones generally do not overlap with the darkest grey areas.

However, because the central areas of Montreal have higher proportions of vulnerable populations, as well as higher temperatures, we find that many vulnerable groups are still exposed to significant UHIs. In addition, areas with a high proportion of vulnerable groups are often located in

close proximity to the industrial and commercial areas that are the most severe UHIs. These heat islands may affect nearby populations when they travel through, work or shop in these areas. In addition, wind may blow warm air into adjacent neighbourhoods.





DEVELOPMENT OF A POLICY FRAMEWORK

A MULTI-STEP APPROACH

The need for quick and effective responses to the UHI threat is great and increasing. As described in the preliminary analysis, many policies and programmes for UHI adaptation have been adopted by cities around the world or have been recommended by experts. These include tree planting programs, cool roof subsidies, and revised zoning, land use and building codes. However, each of them involves different requirements, and have varying costs and benefits. It is therefore essential that policy makers be able to evaluate the feasibility and effectiveness of various UHI adaptation alternatives to achieve maximum benefits under budget constraints.

In this Section, we set forth and recommend a methodology for evaluating alternative strategies for UHI adaptation and offer guidelines for choosing among them. We seek to answer the question: how should city leaders determine which UHI adaptation strategies make sense for different parts of Montreal? In a later phase of the project, we will use the methodology developed in this section to recommend a specific UHI adaptation program for a selected high-risk area in Montreal.

It is important to note at the outset that flexibility is critical when developing a UHI adaptation policy. Knowledge about the UHI phenomenon is developing rapidly. Physical, climatic, budgetary, political, and social conditions will evolve. Along with these changes, the incidence of UHI, and the exposure and vulnerability of residents will change. Accordingly, these guidelines and any policies and programs implemented using these guidelines will need to be reviewed and adjusted periodically. No methodology should be used as a one-size-fits-all, now-and-forever formula.

Close cooperation between central and borough authorities will be essential for successful UHI adaptation because interventions will come from both levels of local government. Borough officials may be best positioned to know local conditions and to assess and engage public opinion and participation. However, some UHI adaptation functions will be more appropriately carried out by central authorities. For example, these may include cost allocations, the development and oversight of a comprehensive urban forest management program, building code and master plan revisions, on-going UHI risk assessments and overall program

monitoring and evaluation. Central authorities would also play a key role in ensuring that resources are spent in accordance with mandates and that borough activities are well targeted to assist the populations and areas most at risk.

While the ultimate success of a UHI adaptation strategy will depend on the engagement of private individuals, land owners, and business leaders, cities and other public sector agencies can play a key role in stimulating change by using their own buildings, public spaces and motor vehicle fleets as models for ‘cool city’ programs. For instance, cities throughout the continent have been leaders in the installation of green roofs. Expanding adaptation activities beyond the public sector will require a ‘virtuous cycle’ of regulatory mandates and market-based incentives, many of which are identified in this report.

To develop UHI adaptation strategies, we recommend a multi-step policy making approach, presented in the following pages (see Appendix D for a more detailed discussion).

Two guiding principles for policy making:

1. Risk-based resource allocations: UHI adaptation efforts and resources should be targeted primarily to those areas that are most at risk to UHI impacts, as determined using the risk assessment methodology.
2. Customized implementation based on site-specific conditions: Each area at risk to UHI presents its own set of relevant physical and socio-economic conditions.

Seven steps for effective UHI policy making:

- A. Focus UHI adaptation efforts on the geographic areas most at risk;
- B. For each area, assess local conditions to determine the principal likely causes of the UHI;
- C. Based on local social and physical conditions, identify possible adaptation measures suitable to each area;
- D. Prioritize those measures with greatest temperature reduction potential;
- E. Consider the full implications of alternatives and evaluate costs/benefits across multiple time scales;
- F. Engage residents and other stakeholders, especially regarding program implementation;
- G. Include clear and objective performance measures, monitor results, and reward success.

A. Focus UHI adaptation efforts on geographic areas most at risk

UHI adaptation efforts and resources should be targeted primarily to those areas in Montreal where the most exposed and most vulnerable populations reside. The UHI risk assessment methodology in this report has been designed to identify these areas and it is there that efforts and resources should be spent first. Certainly, some city-wide UHI adaptation measures may be deemed appropriate and budget resources allocated to them. However, since UHI events and impacts are highly localized, most

of the resources and efforts should be devoted to developing and implementing site-specific policies and programs.

B. Assess local conditions to determine principal likely causes of the UHI in each area

It is imperative to study the interplay of existing land uses, vegetation and open areas, built form and other physical characteristics at the local scale to identify the principal contributing factors to the UHI. An examination of the changes of land use over time, correlated with temperature studies can illustrate the impact of those land use changes. This analysis is useful because it provides clues to what may be the most practical and effective solutions to a particular UHI scenario.

C. Identify the range of possible UHI adaptation strategies suitable to each area

Not all UHI adaptation measures are equally suitable for all areas. For instance, in a low-income area, the relatively high costs of green roofs will likely keep them out of the reach of most home owners (even if subsidized). Thus, a first and critical step for considering UHI adaptation strategies is to determine which measures make sense in the given area. A short list of potential strategies should be developed, including only those that are deemed most feasible considering the area's physical and socio-economic conditions and trends.

D. Identify measures with the greatest temperature reduction potential

Once a shortlist of possible UHI adaptation strategies for an area has been identified, evaluate the temperature reduction potential of each alternative. There is a great wealth of literature available on this subject. For instance, a study of UHI mitigation strategies for New York City found street tree planting to be a more effective cooling strategy per-unit area than open space tree planting or reduction in albedo through living roofs, light-coloured roofs, and light-coloured surfaces (Rosenzweig et

al. 2006). However, while tree planting is more effective per unit area, available space for tree planting is limited in some dense urban areas. Thus, other mitigation strategies may be equally effective because they can be applied to larger surface areas.

E. Consider the full implications of alternatives and evaluate costs and benefits across multiple time scales

When evaluating and selecting from the various alternatives, it is important to consider all costs and benefits, including those that are ancillary to the UHI phenomenon. Perhaps the most obvious example is tree planting. Planting a tree requires not only a young tree and a shovel, but a decades' long commitment to the maintenance and care of the new tree. On the other hand, a tree performs a great number of ecological services beyond cooling, like the absorption and filtering out of nitrogen dioxide (NO₂), sulfur dioxide (SO₂), ozone (O₃), carbon monoxide (CO), and particulate matter from the air, significantly improving air quality. Trees also retain storm water runoff, prevent erosion, and add aesthetic, recreational and economic value to neighbourhoods.

F. Engage residents and other stakeholders, especially regarding program implementation

In the effort to alleviate UHI, the involvement of multiple stakeholders will be crucial for successful policies and programs. In the early stages of studying a UHI it is critical to engage the scientific community. When the results of the scientific research has been obtained and a list of possible strategies, with their costs and benefits, have been identified, the general public should be invited to give its input.

G. Develop clear and objective targets, monitoring results and rewarding success

After identifying a range of strategies most suitable for local areas, clear and objective targets should be set with corresponding monitoring regimes. Doing so ensures that allocated resources are appropriately

spent and targets in heat reduction and other spin-off benefits are indeed achieved. If targets are not achieved, the reasons for these failures should be investigated in order to reevaluate the efficacy and benefits of policy directions. Monitoring results is critical, not only to assess the improvements to the UHI, but also to identify areas experiencing less than expected heat reductions. This will help identify knowledge gaps such as inadequacies in scientific understanding or barriers to program implementation. Monitoring results provides critical information to be fed back into the policy and decision making cycles, and help policy makers better discern between competing alternatives. Efforts must also be made to identify successful strategies that other jurisdictions can share. This contributes to the wealth of the knowledge base, tracking of the UHI effects, and refinement of further policy measures. Policy makers should be weary of using monetary means to address non-compliance with targets because withholding funding punitively may adversely affect the health and well-being of vulnerable populations.

An equitable allocation of resources

The UHI risk scores assigned to various areas in Montreal could be the basis for an allocation formula of UHI-adaptation resources. Multiplying the risk score by the total population within a UHI and the geographic area of the UHI would allow policy makers to determine the percentage of resources that should be allocated to each area.



SAINT MICHEL CASE
STUDY

SELECTING A SITE

An examination of the Risk Map shown on page 21 showed several sites were good candidates for detailed study. These areas constitute significant heat islands and have relatively high concentration of vulnerable populations. Among these areas, we have selected Saint Michel (Figure 6 outlined in red). Saint Michel's built form resembles the typical Montreal urban fabric with long blocks of row housing and a mix of land uses. Thus, the adaptation measures developed for this site can serve as a demonstration for other similar morphologies in Montreal.

Figure 7 shows the boundaries of the study area and the levels of risk to UHI. The study area is bounded by Boulevard Industriel to the north, Jarry Street east to the south, and by the Francon and Miron quarries to the east and west, respectively.

Figure 6. UHI risk in central Montreal

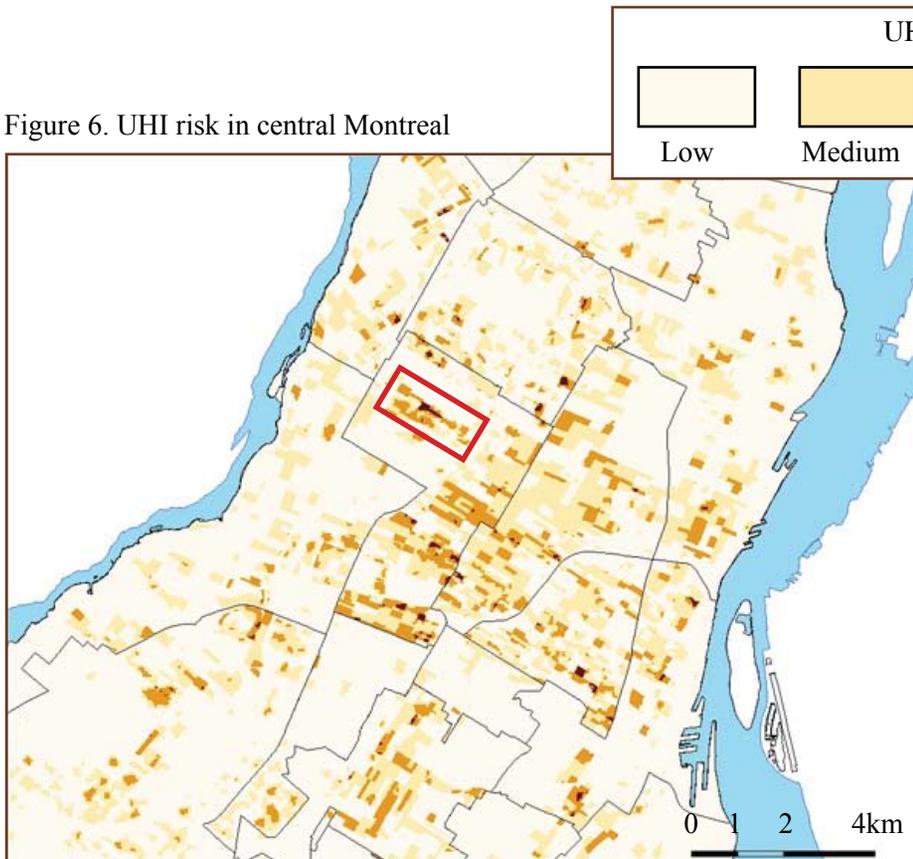


Figure 7. UHI risk for Saint Michel



SITE ANALYSIS: AREA PROFILE

ABOUT THE SITE

To become familiar with Saint Michel, we first looked at the general site characteristics, including demographics, socioeconomic indicators, housing, environmental quality, safety, and areas of activity (Figure 8).

Demographics

The total population of the study area is 19,350 people. It is a relatively young population composed of many families with children. There are also a high proportion of immigrants in the area: 42% of the residents were born outside of Canada, compared to 28% in Montreal. Of the UHI vulnerable populations, there are 7,960 (41%) people living under low incomes; 3,900 (20%) below age 5 or over 65; and 600 (3%) who are over 65 and living alone. The number of people over 65 living alone rose by 10% between 1996 and 2001.

Socioeconomic characteristics

The average income in Saint Michel is \$34,927, which is 71% of the Montreal average. 41% of the population lives under the Low income cut-off, compared to 29% in Montreal. By another measure of poverty, 39% of the population spends 30% or more of household income on housing, even though the housing in Saint Michel is relatively inexpensive compared to other areas in Montreal.

Housing

Two thirds of the population lives in rental housing. 83% of residents live in apartment buildings of less than 5 storeys. Although the housing stock is relatively new, built largely between 1946 and 1970, it is in mediocre condition: 8% and 29% of it needs major repairs and minor repairs, respectively.

Environmental quality

The environment of Saint Michel has been significantly affected by the Miron and Francon quarries that border the neighbourhood on the west and east, respectively. Environmental quality in the neighbourhood was further deteriorated by the use of the Miron quarry as a landfill for sev-

eral decades in the late 20th century. However, these sites are currently being redeveloped and bring new opportunities to Saint Michel. Another important factor that has impacted the quality of life is the historic lack of land use planning. The close proximity of industrial and residential uses that was permitted continues to be a source of nuisances for local residents.

Safety

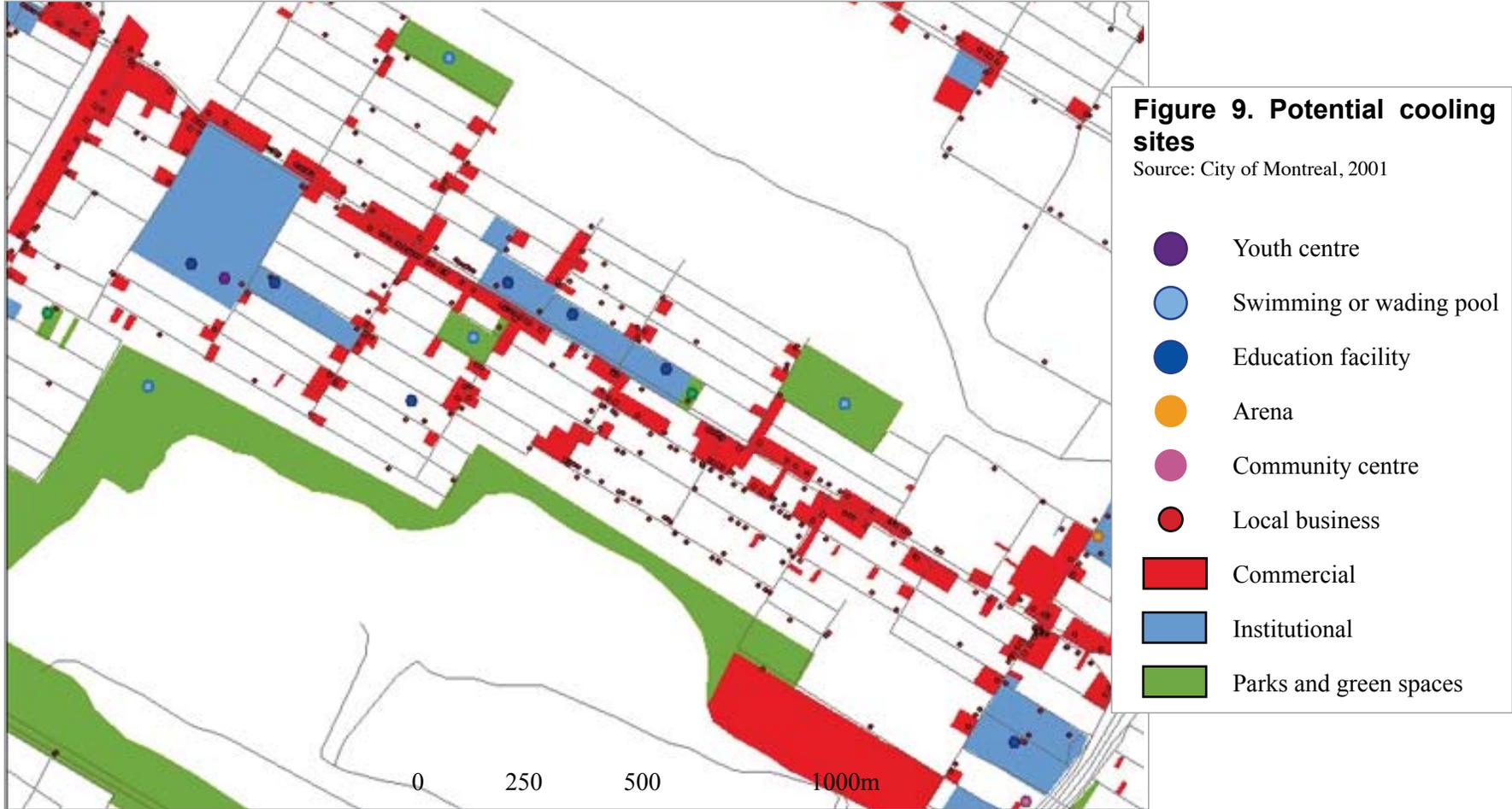
Crime is a significant concern in Saint Michel, especially with increasing street gang and prostitution activities in this area in recent years. Vehicle theft, aggression, vandalism, sexual abuse, and robberies are also more prevalent in Saint-Michel than in surrounding neighbourhoods. In a survey done by the CDEC, one out of two people reported fearing to go out at night because of youth street gangs and prostitution.

Figure 8. Summary statistics of the study area

Total population	19,350
Immigrant population	42%
Low-income residents	7,960 (41%)
People below age 5 or over 65	3,900 (20%)
People over 65 living alone	600 (3%)
Average income	\$34,927
Households spending more than 30% of income on housing	39%
Renters	67%
People living in apartment buildings of less than 5 storeys	83%
Housing needing minor repairs	29%
Housing needing major repairs	8%

AREAS OF ACTIVITY

Saint Michel is relatively well served by community facilities and neighbourhood services. There are many parks, two community gardens, three pools, and several education facilities, one of which offers a youth program (Figure 9). Also, just south of the site, there is a community centre. Private businesses along Saint Michel Boulevard offer many services and serve as cooling places for the local population in times of severe heat.

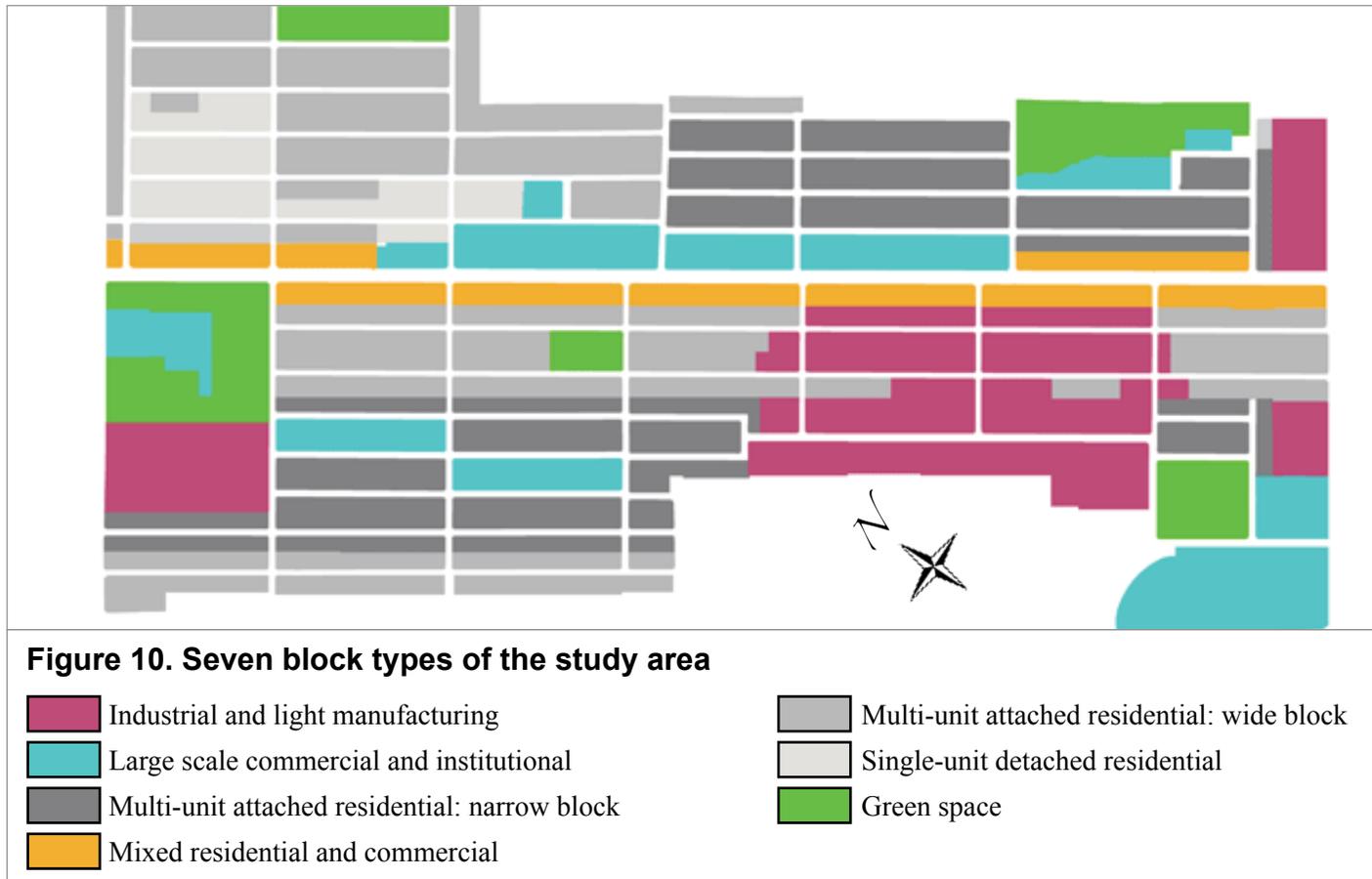


SITE ANALYSIS: UHI INTENSITY BY BLOCK TYPE

This section looks at the factors contributing to UHI in Saint Michel. As discussed in the preliminary analysis, built form, vegetation cover, proportion of surfaces that are mineralized, and land use are important factors that cause UHIs.

In order to take a more in-depth look at the causal factors of UHI in Saint Michel, the study area is categorized into seven typologies based on UHI intensity and built form (Figure. 10). UHI intensity is measured on a five-point scale from very low to very high.

The next page presents some findings from this block level analysis. Pages 35 to 40 take an in-depth look at the areas identified in the UHI intensity map. For each area, there is a diagram showing the surface type of a typical block, a description of the physical characteristics of the built form, and photographs depicting the predominant built form in the area.



KEY FINDINGS FROM THE BLOCK TYPE ANALYSIS

It is evident that the built form on this site has a significant effect on UHI intensity. This is consistent with the findings in the scientific literature regarding UHI formation. A comparison of the map of the seven block types (Figure 10) and the UHI temperature map (Figure 11) reveals significant overlap. As discussed in the paragraphs that follow, block types with more mineralized surfaces (low albedo), less vegetation (biomass) and larger buildings (thermal mass) generally experience more intense UHIs.

The effect of biomass

Compare the zones marked A and B in Figure 11. The block type found in zone A (multi-unit attached residential-wide block) has medium UHI intensity while the block type found in zone B (multi-unit attached residential-narrow block) has high UHI intensity. What makes these areas different? Zone B contains two and a half to four storey attached apartment buildings or row houses, very small front yards, very few trees and small grass covered back yards (Page 37). By contrast, zone A, although also having two and a half story attached buildings, contains larger front and back yards, with more grass covered areas and more trees shading the roads and buildings (Page 36). The greater amount of vegetation (biomass) appears to make the difference in the ambient temperatures of these two zones. Note also that it is the greater width of the blocks in zone A that provides space for more biomass.

identical-narrow block) has high UHI intensity. What makes these areas different? Zone B contains two and a half to four storey attached apartment buildings or row houses, very small front yards, very few trees and small grass covered back yards (Page 37). By contrast, zone A, although also having two and a half story attached buildings, contains larger front and back yards, with more grass covered areas and more trees shading the roads and buildings (Page 36). The greater amount of vegetation (biomass) appears to make the difference in the ambient temperatures of these two zones. Note also that it is the greater width of the blocks in zone A that provides space for more biomass.

The effect of thermal mass

Consider the zone marked C in Figure 11. The block type found there



(industrial and light manufacturing) is characterized by large two storey industrial buildings and warehouses, with no back yards and the highest building coverage of any of the seven block types (44% of the block) (Page 40). It is a very high UHI risk area. Compared with the built form in zone B, the key difference appears to be the higher thermal mass of the buildings and also the geometries created by the built form. The bulkier buildings and dense arrangement are exacerbating the UHI.

The effect of albedo

Another block type in the site which experiences relatively high UHIs is characterized by large scale commercial and institutional buildings (Page 39). In fact, the buildings, although large, cover a relatively small percentage of the block (20%), suggesting thermal mass is not the main factor. Rather, it is that the rest of the block is mostly filled with asphalt parking lots, wide driveways and large areas of mineralized surfaces. High albedo explains the relatively high UHIs there.

Low UHI in single unit detached residential blocks

The single unit detached residential block has the lowest UHI intensity on the site. It has a smaller area of dark paved surfaces and a much higher proportion of vegetation cover, including many mature trees. However, it is important to note that low density car-oriented development can be even hotter than denser central neighbourhoods (see box “Is urban sprawl the solution to UHI?”).

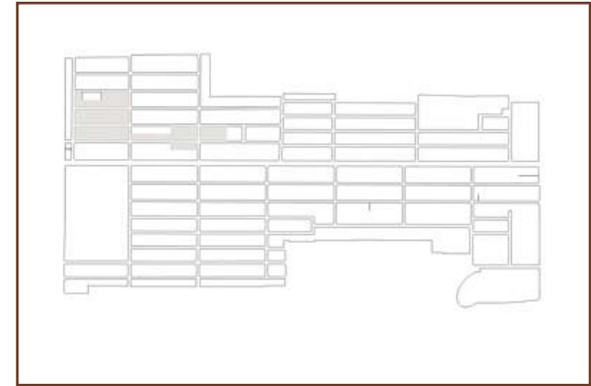
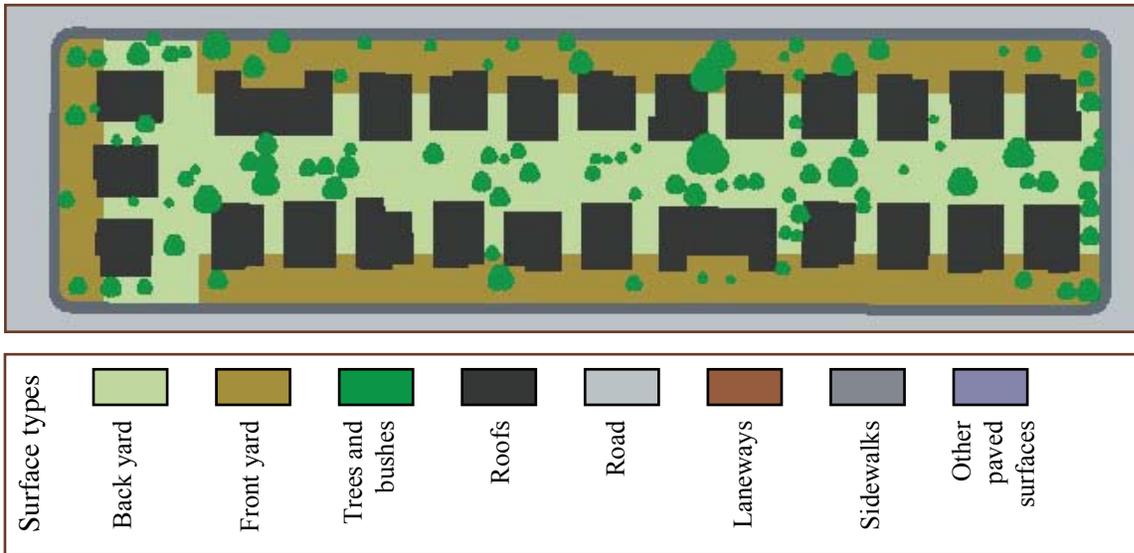
Is urban sprawl a solution to UHI?

No! While it is true that indiscriminate densification of the built form can aggravate UHIs, low density, car-oriented development makes matters worse. Studies have shown that low density areas can get even hotter than central, dense neighbourhoods. (Stone et al 2001). One reason is loss of biomass. While open spaces may remain between buildings, large lawns tend to predominate. Lawns, especially in mid summer when grasses are dormant, may be

only marginally better than light paved surfaces in their heat reduction capacity. Further, low density development requires extensive paved surfaces to support car traffic and parking, and those areas give rise to significant UHIs. Finally, car-oriented development is a key contributor to green house gas emissions, air pollution and climate change, which further increases temperatures across the globe and human vulnerability to UHIs.



SINGLE UNIT DETACHED RESIDENTIAL



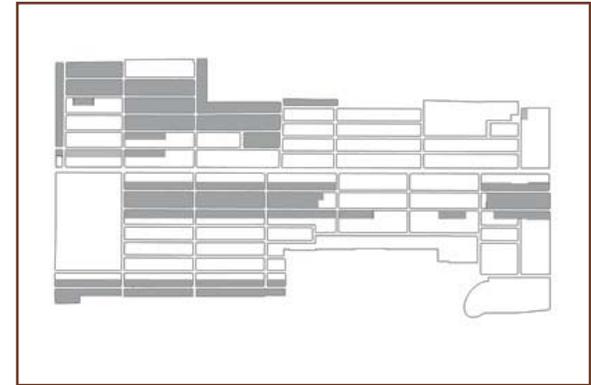
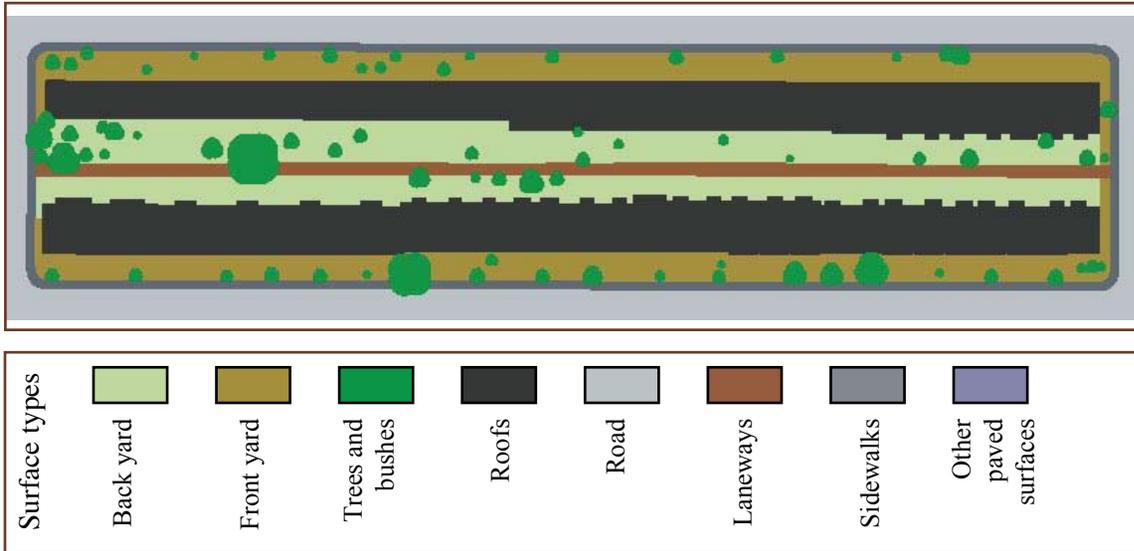
Physical characteristics

- Predominantly single storey detached homes
- Large front yards with many driveways and garages; houses setback approximately 10 metres from the road
- Large mainly grass covered back yards
- Buildings occupy about 22% of the block
- Many mature trees
- No alleys
- Wide roads with on-street parking
- Shingled roofs

These characteristics make this block type:

LOW UHI

MULTI-UNIT ATTACHED RESIDENTIAL: WIDE BLOCK



Physical characteristics

- Two and a half to four storey apartment buildings and row houses
- A small front yard that is approximately 50% paved (paths and driveways), 50% vegetated (grass and trees); buildings are setback approximately seven metres from the street
- Small backyards that are mainly grass covered
- Buildings occupy about 29% of the block
- A moderate number of trees
- Paved alleys
- Wide roads with on street parking
- Tar and gravel roofs

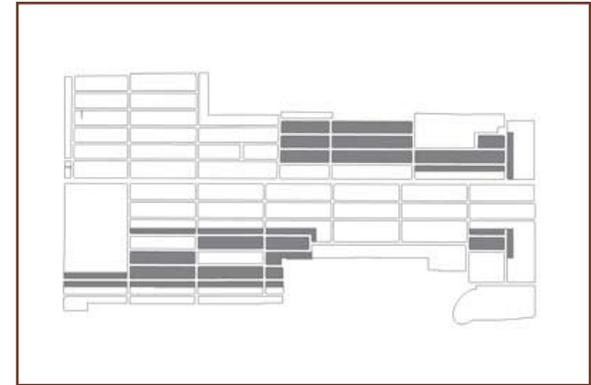
These characteristics make this block type:

MEDIUM UHI

MULTI-UNIT ATTACHED RESIDENTIAL: NARROW BLOCK



Surface types	Back yard	Front yard	Trees and bushes	Roofs	Road	Laneways	Sidewalks	Other paved surfaces



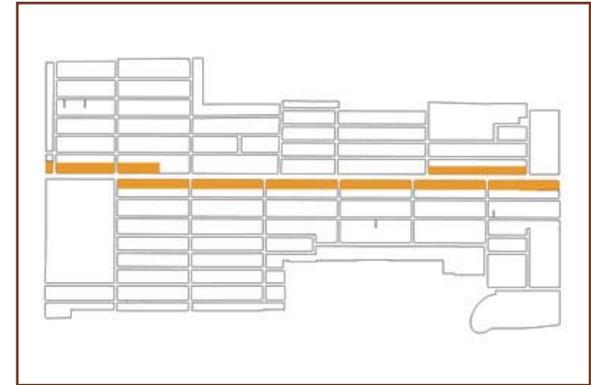
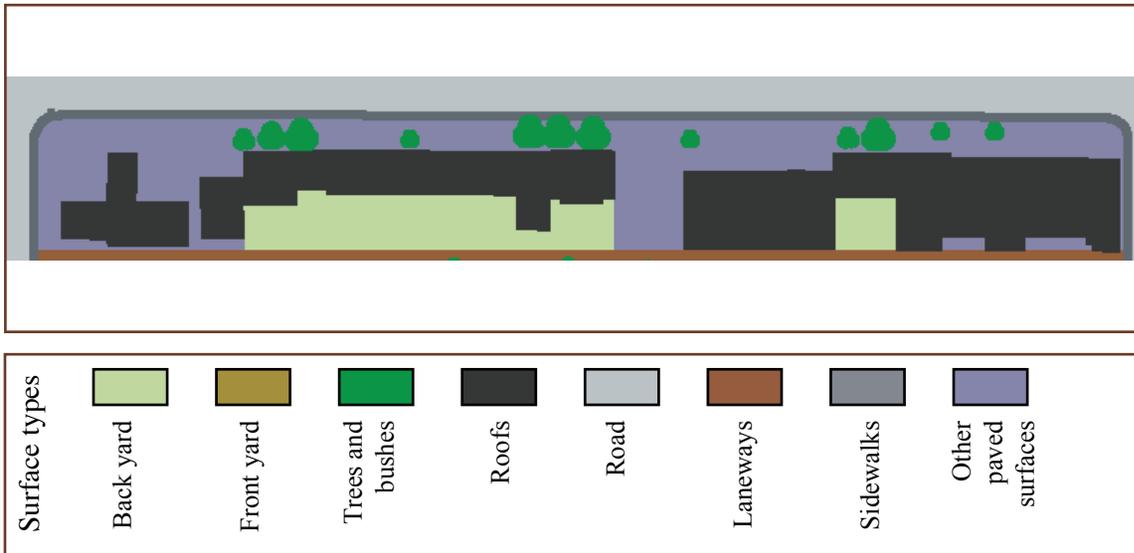
Physical characteristics

- Two and a half to four storey apartment buildings and row houses
- A small front yard that is approximately 50% paved (paths and driveways), 50% grass; buildings are setback approximately five metres from the street
- Very small, mainly grass covered back yards
- Buildings occupy about 34% of a typical block
- Very few trees
- Paved alleys
- Wide roads with on street parking
- Tar and gravel roofs

These characteristics make this block type:

HIGH UHI

MIXED RESIDENTIAL AND COMMERCIAL



Physical characteristics

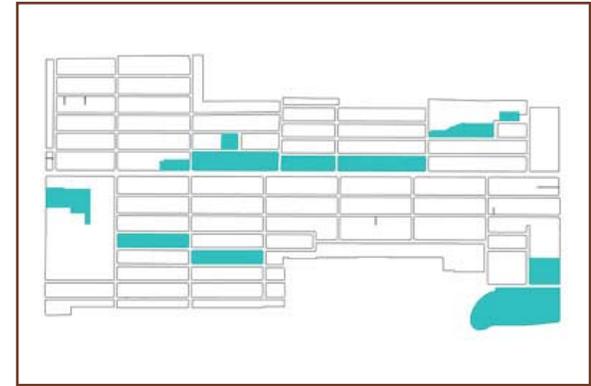
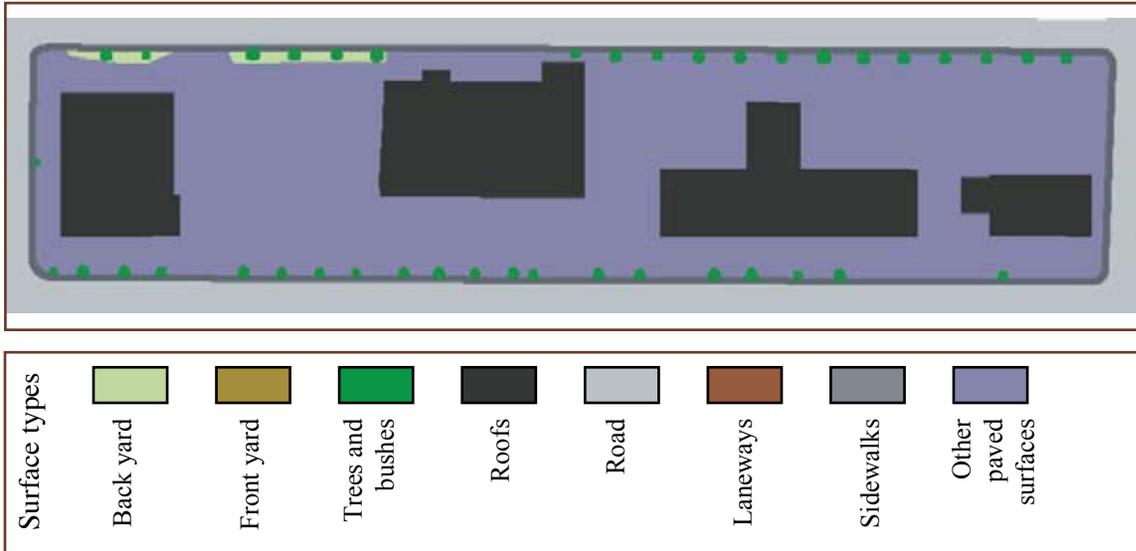
- Predominantly two to three storey apartment buildings and row houses with ground floor commercial. The area is characterised by a mix of residential and commercial uses.
- Area in front of stores mainly paved with a row of trees; variable setbacks from Saint Michel Boulevard
- Some buildings have grass covered back yards
- Buildings occupy about 29% of a typical block
- Moderate number of trees
- Paved alleys
- Wide roads with on street parking
- Tar and gravel roofs

These characteristics make this block type:

MEDIUM UHI



VERY HIGH: LARGE SCALE COMMERCIAL AND INSTITUTIONAL



Physical characteristics

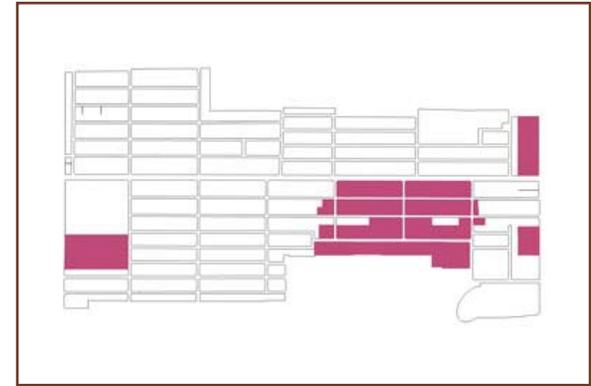
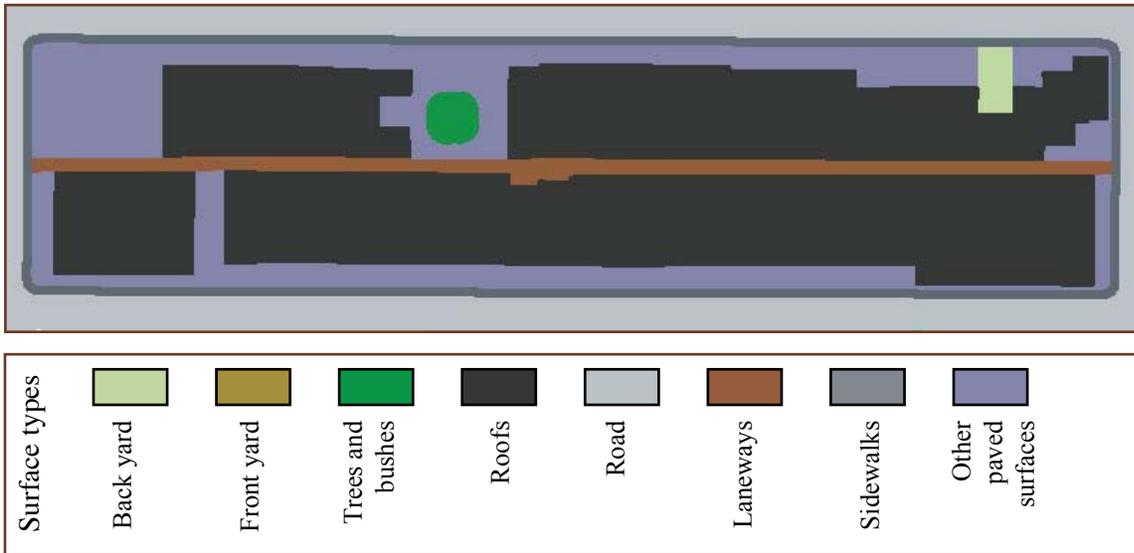
- Large big-box stores, schools, offices and municipal buildings, and large surface parking lots
- Variable setbacks
- No backyards
- Buildings occupy about 20% of the typical block
- Less than 5% greenspace. Row of trees bordering roads
- No alleys
- Wide roads and large areas of impermeable surface parking
- Large tar and gravel roofs

These characteristics make this block type:

VERY HIGH UHI



INDUSTRIAL AND LIGHT MANUFACTURING



Physical characteristics

- Predominantly two storey industrial or warehouse storage buildings
- Parking on dark asphalt surfaces in front of the manufacturing and light industrial buildings with variable setbacks
- No back yards
- Buildings occupy about 44% of the block
- Very little vegetation (less than 5% of the block)
- Paved alleys
- Very wide roads to accommodate truck traffic
- Large tar and gravel roofs

These characteristics make this block type:

VERY HIGH UHI



SITE ANALYSIS: POLICY

CHAPTER 26 OF THE MONTREAL MASTER PLAN

Current development orientations

Planning documents currently in effect prescribe several development objectives for Saint Michel. Some of those objectives could help reduce UHI risks while others, if not carefully implemented, could aggravate the risks. Below, we examine various planning policies applicable to Saint Michel and identify their relevance to UHI adaptation.

This part of the Montreal Master Plan contains the current development orientations for several areas of the site (Figure 12). A number of those orientations are of particular importance to UHI adaptation, as discussed in the surrounding text.

Improve housing stock and the quality of the living environment

Improvement of housing stock could include better ventilation and insulation of living spaces in order to lower UHI exposure. Renovations to buildings and public areas also can provide opportunities for increasing biomass and surface albedo.

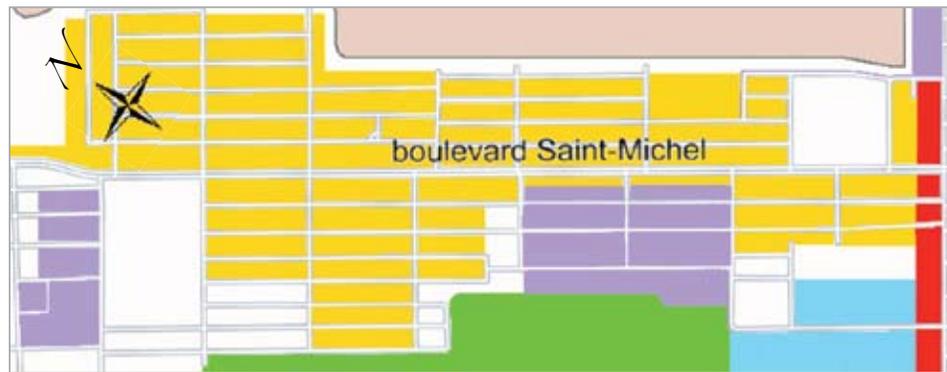


Figure 12. Development orientations for Saint Michel
Source: Montreal Master Plan, 2004

Reduce intensity of industrial activities and mitigate impacts to nearby residences

Measures to mitigate pollution and nuisance from industrial areas are also excellent ways to reduce UHIs (for example planting trees and establishing landscaped buffer zones). Also, a decrease in industrial uses in Saint Michel could alleviate the UHIs. However, as industrial areas are transformed to residential uses, a greater number of residents near or within such zones will be exposed to high UHI effects.

Improve the public domain and enhance commercial activities

Improvement to the public domain could include tree planting and new landscaped areas and gardens as well as a quality built environment (well insulated and ventilated buildings, more shade and shelter), all of which could reduce UHI occurrence and exposure. However, increased commercial activity, if not properly managed, may lead to more air pollution, aggravating vulnerability to UHIs.

Land use designations

With regard to land use designations, the Master Plan calls for creating two mixed-use areas in what today are primarily light industrial and/or commercial areas. These two areas are marked as 'A' and 'B' (Figure 13). Significant UHIs occur in both these areas today. By introducing more residential development, there is the potential for increased exposures to UHIs.

Built Density

The Master Plan also identifies some sectors for build-up and transformation around Jarry Street East. Today, these areas contain mostly one or two storey, detached buildings, with occasional large commercial or industrial buildings and several large parking lots. This area also sees significant car and pedestrian traffic, including many public transit users.

According to the Master Plan, the built density (Figure 14) is to be increased significantly, both in terms of the number of storeys and lot coverage of buildings. Specifically, buildings are set to go to up to ten storeys, with lot coverage in most of these areas in the medium to high range.

If not properly planned and designed, the erection of large, multi-storey structures occupying a high portion of their lots could significantly increase the occurrence of UHIs. Because the new structures could be residential (the area is also marked for mixed use designation), UHI exposures could increase significantly as well.

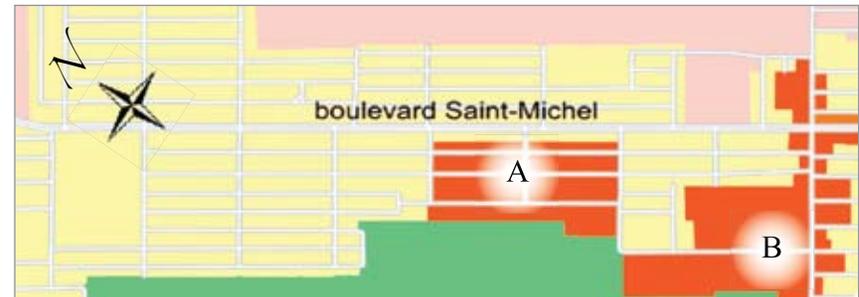
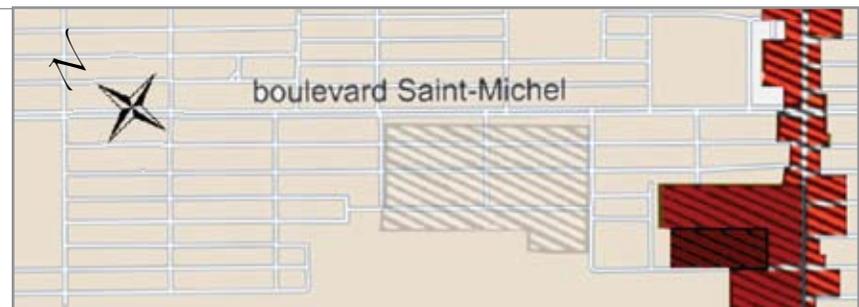


Figure 13. Land use designation, Source: Montreal Master Plan, 2004

-  Residential sectors
-  Mixed-use sectors
-  Employment sectors
-  Green spaces or parks

Figure 14. Areas for new construction and development
Source: Montreal Master Plan, 2004

-  1 to 4 storeys, medium/high lot coverage, FAR 0.5 to 2
-  1 to 6 storeys, medium/high lot coverage, FAR 0.2 to 3
-  1 to 10 storeys, low/medium lot coverage, FAR 0.2 to 3



Managing density to reduce UHI occurrence and exposure

Increasing the density of the built form can aggravate UHIs. Taller buildings covering more of their lots generally possess greater thermal mass, create street geometries that trap heat, and leave little surface suitable for planting. Thus, understanding built density and how to mitigate its UHI aggravating effect is important.

The Montreal Master Plan measures built density across four scales: lot coverage, building type (detached, semi-detached or attached), number of storeys and floor area ratio. As each of these measures increase, there is a greater potential for more serious UHI effects. Thus, when planning increased density of an area, UHI counter measures

should be taken to improve the thermal performance of buildings year round, increase biomass and increase albedo. In this regard, climate sensitive building design and materials, as well as urban design (size, spacing and arrangement of buildings on their lots) matter. Similarly, when lots are to be subdivided, the size and arrangement of the resulting lots should also be selected so as to minimize UHI occurrence and exposure.



STRATEGIC PLAN FOR SUSTAINABLE DEVELOPMENT

Montreal's strategic plan for sustainable development likely represents the most prominent and potentially effective course of action in fighting climate change. The four major orientations laid out in the 2007 to 2009 phase of this plan - reducing green house gase emissions, ensuring high quality living environments, managing resources responsibly, and adopting better sustainable practices in industrial, commercial and institutional sectors - will have ramifications not only for UHI, but many other climate change issues facing Montreal. However, the sustainable development

strategy is still in its infancy, and many of its actions call for more study and the implementation of only a handful of demonstration projects. As such, while there are many synergies between the sustainable development plan and this work to address UHI, there are, at this time, no specific or concrete actions identified for Saint Michel.

SAINT MICHEL'S POLICY ON TREES

As increasing biomass is one of the most effective ways to reduce UHI risks, Saint Michel's policy and practice regarding tree planting and maintenance are of particular interest.

Saint Michel's bylaws currently require the planting of trees on all private property for which a construction permit is issued. Such plantings must cover all un-built areas at a rate of at least one tree per 200 square metres. This applies also to parking areas. Only private properties occupied exclusively by residential buildings of three units or less are exempt (Saint Michel Bylaw section 384). Further, pursuant to a Montreal bylaw, in case of private developments requiring subdivision, Saint Michel can require that a specified portion of the site be reserved as park land or playground, or demand payment of an amount equivalent to a portion of

the value of the land (Montreal Bylaw 02-065). It is believed that Saint Michel's council has established 10% as the specified figure.

The felling of existing mature trees on private property requires a permit in Saint Michel. Only those trees which are dead or dying which may cause harm or nuisance to persons or property, or which are located in an area to be built upon may be felled (Saint Michel Bylaw sections 379 to 383).

A NEW TREE POLICY FOR MONTREAL

In 2005, Montreal promulgated a new, city-wide tree policy. It identifies a number of serious problems, including a considerable decrease in the number of new tree plantings due to budget constraints, deaths of trees from disease, weather, construction work and motor vehicle accidents, unnecessary and improper felling, and an incomplete urban forest inventory.

The intent of this new tree policy is in part to develop new tools which boroughs like Saint Michel may use in conjunction with the city's park and recreation department to better manage the urban forest. The policy strives to accomplish its goals by outlining four main objectives:

1. Develop and provide the tools necessary for defining a long term vision;

2. Establish rules and practices for the protection, management and maintenance of trees;
3. Increase the number of trees planted; and
4. Step up information, publication and awareness initiatives.

These four objectives are complemented by eleven specific actions (see Appendix E). Currently, the city is still developing a work plan for the implementation of the new tree policy. It is believed that at the borough of St Michel, no Tree Plan has been promulgated yet and no tangible implementations of the tree policy have been realised.

SITE ANALYSIS: UPCOMING PROJECTS

While policy is important, it is also essential to identify the new developments actually planned or being built in Saint Michel. Every such new development presents an opportunity for reducing UHIs or, conversely, a potentially new location for UHI occurrence and exposure. There are three major developments of note in Saint Michel.

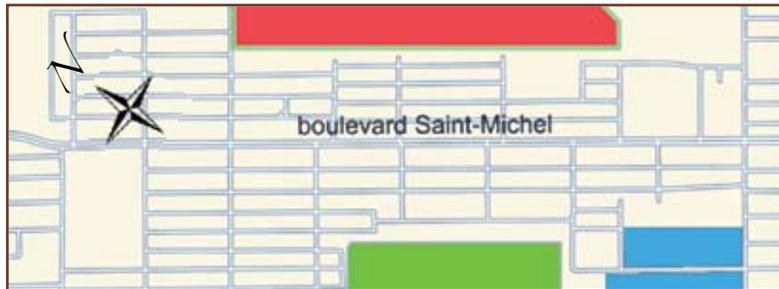


Figure 15. Sites of future development. Source: Montreal Master Plan 2004

Jarry Street and 2nd Avenue

The Cirque du Soleil has constructed two large buildings on the corner of Jarry Street and 2nd Avenue. One is a residential building and the other a circus school. Both buildings are much taller and bulkier than their neighbours. Additional similar buildings are expected. This area already suffers from significant UHI occurrence. The construction of more buildings may aggravate the problem and bring more people to the area, increasing exposures. It should be noted that Cirque du Soleil has in the past partnered with community groups to improve the urban environment in parts of Saint Michel.

Environmental Centre Saint Michel

This former large landfill site is located to the west and south of the study area. The plan, already partly completed, is to create a multi-functional centre including a linear park, cultural and sports facilities, education and environmental remediation activities, playgrounds and leisure areas. Today, this site presents the most significant single UHI in Saint Michel, possibly caused by materials remaining from the former landfill activities. By creating a large green space with trees and greenery, this project has the potential to reduce UHI occurrence significantly in the immediate areas. Moreover, this could become a new and major cooling site easily accessible to most residents of the area. Already, a linear park extends the length of several blocks and may be accessible at several entry points from the neighbourhood. However, the cooling effect of the park will be limited, extending only to the immediately adjacent blocks, at most.

Smart!centre

This project is proposed for the western section of the former Saint Michel quarry. It is expected to cover up to 370,000 square metres in a below grade, multi-level complex. At present, the developer is performing technical, economic and environmental feasibility studies. Construction is planned to start in 2009.

There are good reasons to be very concerned about the impact of this development on UHIs. The area slated for construction is today one of the cooler areas in the entire neighbourhood. There are several pool, recreation centres, amenities and several housing complexes very near this large site. The planned construction could turn this area into a new and potentially large source of

UHI exposures. Also, the additional traffic that this large shopping complex would generate may increase air pollution and human vulnerability to UHI.

It is important to note that many people in the area believe this project could bring more employment for Saint Michel residents, and therefore support it. Several borough leaders and organizations have created an oversight group working with the developer to maximize benefits to the community from this planned major development. Clearly, a major challenge will be to reap the benefits of economic development while reigning in increased pollution, UHI risk and other potential nuisances.

PROPOSED UHI ADAPTATION PLAN

INTRODUCTION

In this Section of the report, a UHI Adaptation Plan is proposed for the selected site in Saint Michel. The aim of this Plan is to reduce significantly the threat posed by UHIs in this area. The main concepts and guiding principles on which this Plan is based are depicted graphically and described on page 48. A post-implementation vision of Saint Michel 25 years from now, in 2032, is found on page 49.

Because the causes and effects of UHIs are highly localized, this Plan contains a separate set of recommendations for each one of five representative block types found in Saint Michel. Each block type is defined by its most prevalent built form and use, as listed below:

1. Multi-unit attached residential
2. Single-unit detached residential
3. Mixed residential and commercial
4. Large scale commercial and institutional
5. Industrial and light manufacturing

These five block types are similar to those used in the site analysis above to identify the causes of UHIs in Saint Michel¹ (See pages 35 to 40). The specific recommendations for each block type start at page 50. To help policy makers in the implementation of this Plan and in evaluating and selecting from among the various measures being proposed, a matrix of approximate cost and benefits, phasing, and responsible parties for each recommended action is provided. It begins on page 57.

¹The two multi-unit attached residential areas with differing block widths identified in the site analysis have here been merged into one category to avoid duplication of implementation measures; the implementation measures proposed for both block types are similar.

SCOPE OF THE PLAN

This Plan focuses only on physical interventions to reduce UHI occurrence and exposure. Many non-physical interventions to reduce vulnerability to UHI exist (e.g., heat emergency crisis response programs and preventive health campaigns). Although important and worthy of additional study, such interventions are beyond the scope of the mandate and are not directly addressed here. Note that some interventions proposed in this Plan could indirectly alleviate UHI vulnerability. For instance, a new community garden project could increase physical activity levels of senior citizens in Saint Michel as well as improve the diet of area residents, helping to improve general health.

When reading this Plan, bear in mind the four principal factors that cause UHIs (low biomass, low albedo, high thermal mass and waste heat). Every one of the interventions prescribed here aims to accomplish one or more of the following:

1. Increase the number of trees and plantings (biomass)
2. Lighten all surfaces, including roofs (albedo)
3. Improve building performance (thermal mass)

As waste heat is not known to be a significant factor in the creation of the UHIs in the study area, no recommendations are being proposed in that regard.

One physical intervention commonly used to reduce exposure to extreme heat, air conditioning, is NOT recommended in this Plan. Widespread use of air conditioning has serious negative effects on the environment. In fact, its use is a direct cause of climate change and aggravated UHIs, through greenhouse gas emissions and waste heat. Moreover, the expense of obtaining and operating air conditioning raises social equity concerns. The measures that are recommended in this Plan, especially climate-appropriate designs and plentiful trees for shading buildings, are believed to be sufficient to reduce UHI exposure without having to resort to unsustainable practices that helped cause the problem in the first place.

RECOMMENDATIONS REGARDING TREES

The planting, preservation and maintenance of trees throughout Saint Michel, in both public and private lands, are key objectives of many of the actions and programs recommended in this Plan. In fact, a major preoccupation during this study was how to create space for new trees and greenery within existing public rights of way. Fortunately, many of the streets in the site where the highest UHI risk exists are much wider than necessary for traffic and parking needs and could relatively easily be narrowed to create small front yards. This, of course, would require the close cooperation of transportation and planning officials in Saint Michel.

It is recommended that roadway narrowing and street tree planting measures be incorporated in all existing plans for street repaving and infrastructure work. Every year, more than four million dollars are spent on road resurfacing projects in the borough (*Programme triennal d'immobilisations 2008 - 2010 pour Villeray - Saint Michel - Parc Extension*, City of Montreal 2007). Of course, the borough would need to account in its budget allocations for the added costs of planting new trees, as well as the ongoing maintenance that new trees entail. It is estimated that planting new trees and maintaining them the first four years of their lives costs the City of Montreal \$1000 per tree (Montreal Tree Policy 2005).

Bylaws in Saint Michel for the protection and planting of trees must be strictly enforced and strengthened. For existing trees, the current bylaw requiring permits for felling, and allowing it only in limited circumstances, must be strictly enforced. The bylaw requiring tree planting in newly built sites must be strengthened. Currently, only one tree every 200 square metres is required. This bylaw should be revised to require, in addition, rows of deciduous trees in numbers sufficient to shade a substantial portion of the warmest facades of every building as well as all abutting pedestrian corridors. In parking lots, the revised bylaw should require rows of trees placed so as to shade a substantial portion of the lot.

The goals outlined in this Plan regarding trees are consistent with the goals and 11 actions set out in Montreal's tree policy. The first priority for the borough is to ensure that Montreal's tree policy is translated into

bylaws, and enforced throughout all departments of the borough carrying out public work projects. However, given the three to five year time horizon in which boroughs have to complete an inventory and develop a plan of action, many public works projects set out by the annual triennial budget plans represent valuable opportunities for action. For instance, the most recent triennial plan allocates more than one million dollars for the renovation of the roof in the Saint Michel garage (*Programme triennal d'immobilisations 2008 - 2010 for Saint Michel, City of Montreal 2007*). The installation of a green roof should be considered in that project. It is recommended that the borough move forward with projects for increasing tree coverage in order to coincide with street works, even if an overall tree plan has not been finalized within borough bylaws and planning codes.



MAIN CONCEPT AND GUIDING PRINCIPLES

Give priority to three high risk residential areas

The heat and the most vulnerable residential populations are concentrated in three areas identified in the concept plan as blue zones. While other parts of the site deserve attention, these three areas are priorities for intervention.

Create cool street corridors

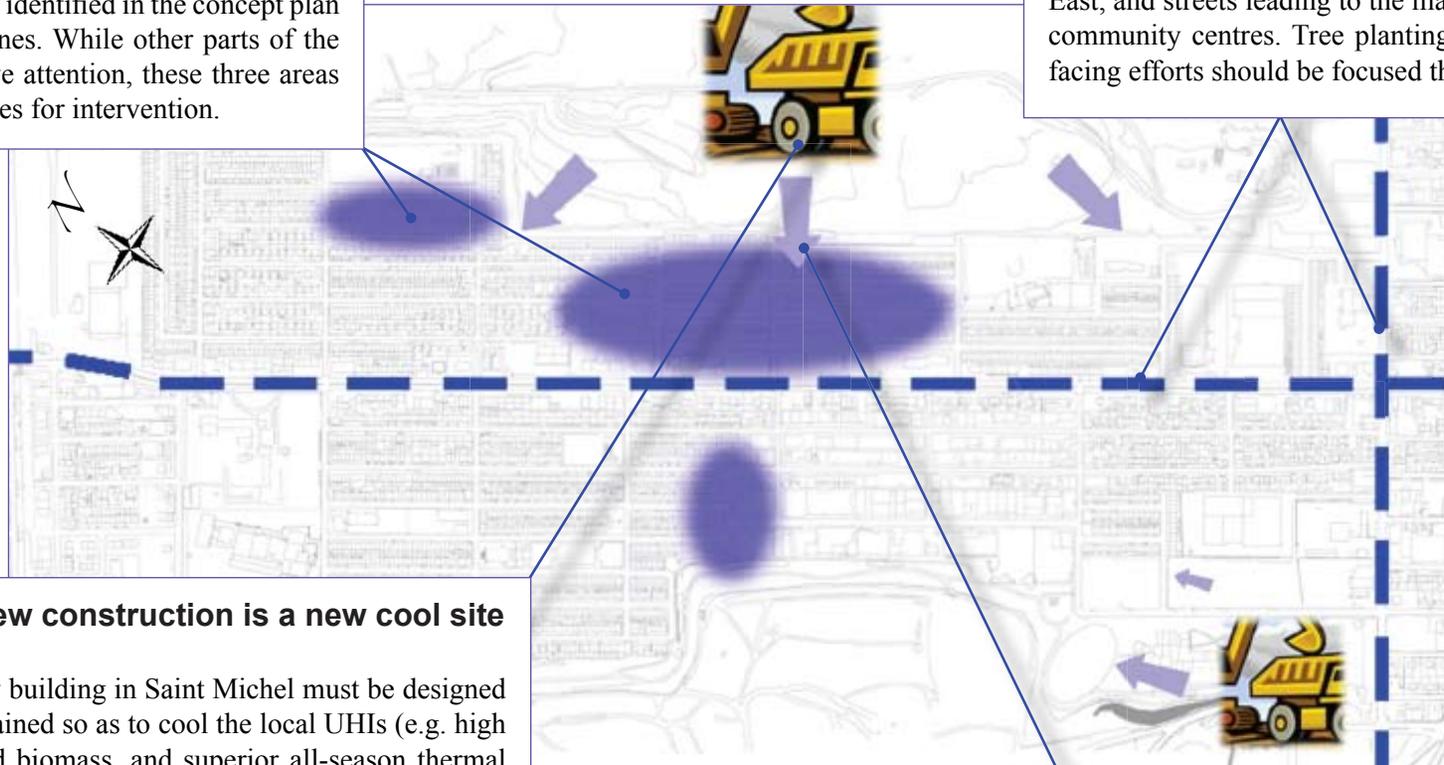
The comfort and safety of pedestrians and transit users requires cool corridors, especially along Saint Michel Boulevard, Jarry Street East, and streets leading to the main parks and community centres. Tree planting and re-surfacing efforts should be focused there.

Every new construction is a new cool site

Every new building in Saint Michel must be designed and maintained so as to cool the local UHIs (e.g. high albedo and biomass, and superior all-season thermal efficiency). This is especially true for the proposed Smart!Centre development. Public expenditure, especially that involving sub-surface work, should also implement UHI-reduction measures. Showcase UHI adaptation projects in and around civic buildings (e.g., living walls, white roofs) should be completed.

Engage private sector in 'Cool Saint Michel' campaign

All private sector developers and business owners should be engaged in a community-led, all stakeholder campaign to reduce the UHI in the public realm beyond the boundaries of any particular development site. A combination of incentives and assessments may be used for funding.



A VISION FOR 2032

Imagine visiting this site after the implementation of this Plan on a very hot mid-summer day in 2032. Perhaps the most striking physical changes one notices immediately are the rows of mature trees, lush front gardens and plant covered facades that line nearly all residential streets. Those trees and plantings help to cool homes in areas of Saint Michel where once UHI risk was highest. A streetscape that used to be characterized by few if any trees and densely packed housing is now almost entirely covered with a dense canopy of green foliage. The new vegetation creates cool pedestrian corridors and public spaces where residents of Saint Michel walk in comfort. White roofs, permeable and light coloured paving, and colourful awnings are everywhere.

In this future Saint Michel of 2032, building renovations have improved ventilation and insulation in many older buildings, increasing residents' safety and comfort. Several of the larger industrial and institutional buildings along Saint Michel Boulevard and near the Environmental Centre site support rooftop gardens. In fact, many new buildings have been designed specifically to be cool spots, dissipating further the high heat that was once prevalent in the area.

New shops and offices near Jarry Street East and possibly in the site of the former Saint Michel quarry now employ many residents and are also models of UHI-sensitive design. They have lush green roofs, use minimal paved ground surfaces and offer plentiful green space. Further, area businesses and developers contribute resources and funds to several community-led climate change adaptation programs, including tree planting and maintenance and UHI awareness and education campaigns. The participation of many area residents in such programs has strengthened social bonds and increased public safety.

Most cherished of all are the new gardens and greenways located where there were once hard paved alleys. The new alley gardens of Saint Michel are a great source of pride for residents and indeed have become a symbol of the entire neighbourhood. On this hot summer day of 2032, many residents, young and old, can be seen comfortably tending these gardens, making plans for the coming harvest.

Setting temperature reduction targets

This report does not stipulate long-term targets for temperature reductions in any of the areas under study. This is done deliberately for several reasons. First, an understanding of what constitutes an adequate temperature reduction for Montreal is insufficient. Second, it is beyond the expertise of CCAP and the mandate of this project to set these targets. As such, we recommend that as scientists continue to develop temperature reduction targets, planners should continually adjust and incorporate these targets into planning practice. Furthermore, these temperature reduction targets should be set relative to the metropolitan average, rather than in absolute terms, since the impact of climate change on future temperatures is highly uncertain.

This report also does not provide specific temperature reduction potentials of different strategies. While this data is available from other cities (Appendix B), it is not directly translatable to the Montreal context. A tree in New York or Manchester is not a tree in Montreal; particular conditions related to the geographies, climates, and urban forms of these cities make it difficult to report specific temperature reduction potentials of such measures for Montreal. Thus, this report recommends that a study be conducted to determine the temperature reduction potentials of various adaptation strategies for Montreal. A better understanding of these potentials would allow local decision makers to choose the best context relevant strategies among the range of options.

MULTI-UNIT ATTACHED RESIDENTIAL



Plant street trees by:

1. Inserting trees between the sidewalk and private property line where possible
2. Narrowing the roadway to create available space



Encourage vegetation in available spaces on private property, including trees, living walls, shrubs, and grass

1. Establish free public distribution program for plants and shrubs
2. Create awareness through education of the benefits of more vegetation
3. Ensure enforcement of tree preservation bylaws to prohibit the unnecessary felling of trees



Narrowing the roadway

Where there is insufficient space for street tree planting, roadways should be narrowed to accommodate street trees. Many residential streets, particularly those with few trees, are wider than necessary for their current use, with two parking lanes and a driving lane that could easily fit two cars side-by-side, even though it is only meant for one. Without loss of road capacity, roadways could be narrowed in order to make space for trees. Several options are available. One is to nar-

row the street along its whole length; another is to create tree wells at regular intervals, which may be a less expensive alternative, but would complicate snow clearing. The relative costs and benefits of various street tree planting strategies need to be explored, and public agencies need to coordinate with each other to undertake road narrowing and tree planting during regular road maintenance work in order to maximize efficiency and minimize costs.



Build green alleys

1. Depave alleys to allow for more green plantings
2. Encourage neighbourhood organisations to plant and maintain green alleys



Install white roofs

1. Educate residents about the benefits of white roofs
2. Mandate through a bylaw that all renovations beyond a certain threshold and all new developments must install a white roof
3. Create a subsidy program to assist homeowners in the cost of constructing white roofs



Green versus white roofs

Green and white roofs are both excellent strategies for UHI reduction. Although green roofs are more effective in terms of UHI and more desirable in other ways, they are often prohibitively expensive, especially for older residential buildings. However, green roofs are still appropriate for industrial buildings in Saint Michel because their structures can support the weight of a green roof. It is recommended that green roofs

be required or strongly encouraged for all new industrial buildings and old ones that require roof resurfacing. White roofs are more appropriate for residential areas because they are cheaper to install and do not require a strong building structure.

SINGLE-UNIT DETACHED RESIDENTIAL



Increase and protect trees in the area

1. On private property, encourage owners to plant trees where space is available
2. Ensure enforcement of tree preservation bylaws to prohibit the unnecessary felling of trees



Depave driveways

1. Mandate through a bylaw that all new driveways and renovations of existing driveways must be done so as to decrease the paved surface area
2. Create a subsidy program to assist homeowners in the cost of constructing better green or porous driveways



MIXED RESIDENTIAL AND COMMERCIAL



Increase and protect trees in the area

1. On private property, encourage owners to plant trees where space is available
2. Increase vegetation cover along large paved setbacks



Install white or green roofs

1. Educate landlords about the benefits of white roofs
2. Mandate through a bylaw that all renovations beyond a certain threshold and all new developments must install a white or green roof
3. Create a subsidy program to assist landlords in the cost of constructing new white or green roofs



LARGE SCALE COMMERCIAL AND INSTITUTIONAL



Increase vegetation cover in parking lots and school yards of public buildings

1. Depave space as necessary to create wells for trees and other vegetation on public property
2. Use public buildings as demonstration projects for cooling



Greening parking lots and school yards

Saint-Michel Bylaw Section 384, Chapter V, Section II stipulates minimum tree planting requirements of one tree per 200 square metres for all new constructions; parking lots should respect this requirement in all cases. Moreover, public institutions can take the lead in redesigning parking lots to add green space. For example, shrubbery and trees can be planted around the perimeter, and tree wells can be built at regular intervals to create shading and a more pleasant environment. School yards could be greened to an even greater extent. Although some hard surfaces are necessary to preserve for playing games

like basketball, school yards could accommodate much more green space than they currently do. Trees should be planted around the perimeter, in tree wells, and around sitting areas and playgrounds. Pavement in sitting areas and playgrounds should be replaced with grass or light-coloured paving stones. The large number of institutional buildings in Saint-Michel offers many opportunities for public intervention. These projects would not only have a notable impact on reducing UHI, but also serve as models for private property owners.





Increase tree coverage in parking lots and other paved areas

1. Provide incentives to encourage private property owners to plant trees in existing parking lots
2. Ensure that minimum vegetation coverage is met in all new developments



Install white or green roofs

1. Educate landlords about the benefits of white roofs
2. Mandate through bylaw that all renovations beyond a certain threshold and all new developments must install a white or green roof
3. Create a subsidy program to assist landlords in the cost of constructing new white or green roofs



INDUSTRIAL AND LIGHT MANUFACTURING



Increase tree coverage in area

1. Where possible, plant street trees in the public domain while taking into account the needs of industry to accommodate large trucks for the movement of goods



Install green roofs

1. Educate business owners about the benefits of green roofs
2. Mandate through bylaw that all renovations beyond a certain threshold and all new developments must install a green roof
3. Create a subsidy program to assist business owners in the cost of constructing green roofs



Regulatory mandates versus incentive based programs

Due to the severity of the threat and the level of effort required, a UHI adaptation policy merits the use of regulatory mandates in addition to incentive based programs. Optimally, the policy framework would prescribe incentives to reward superior performance as well as required minimum standards for all. Both incentives and requirements would be revised periodically as UHI adaptation efforts proceed, creating a virtuous cycle of improvement.

Because regulatory mandates can be politically difficult and burdensome for residents and businesses (especially in a lower income neigh-

bourhood like Saint Michel), it is recommended that regulatory mandates be accompanied with assistance and support programs to relieve extreme hardship, reduce inequity and other undesired results.

For residential areas of Saint Michel, this Plan recommends mandatory regulations for installing white roofs and for greening and de-paving front parking lots and driveways. For all new institutional and commercial buildings over a certain size, and for existing ones that require roof renovation, green roofs should be mandatory, at least for a portion of the roof area.

PHASING AND RESPONSIBILITY MATRIX

<i>Areas and Actions</i>	<i>Timeframe for action (short, medium, long term)</i>	<i>AGENCIES RESPONSIBLE FOR ACTION</i>						
		<i>Borough</i>	<i>City of Montreal</i>	<i>Provincial government</i>	<i>Federal government</i>	<i>Non-governmental organisations</i>	<i>Private residential owners</i>	<i>Small business establishments</i>
Residential areas								
Plant street trees	S-L	•						
Encourage vegetation on private property	S	•					•	
Build green alleys	S-L	•				•	•	
Protect existing trees	S-L	•					•	
Install white roofs	M-L		•				•	
Depave driveways	M-L		•	•			•	
Mixed residential and commercial								
Increase trees and greenspace	M-L	•	•					
Protect existing trees	S-L	•					•	•
Install white or green roofs	M-L		•	•	•		•	•
Large scale commercial and institutional								
Increase vegetation in parking lots and school yards (public)	S-L	•	•	•	•	•		•
Increase tree coverage in parking lots (private)	S-L	•	•					•
Install white or green roofs	M-L		•	•	•			•
Industrial and light manufacturing								
Increase tree coverage in area	S-L	•	•					•
Install green roofs	L		•	•	•			•

COSTS AND CONSTRAINTS MATRIX

<i>Areas and actions</i>	<i>Relative cost \$ = low \$\$ = medium \$\$\$ = high</i>	<i>upfront capital spending by public sector</i>	<i>maintenance costs by public sector</i>	<i>capital and maintenance costs borne by private sector</i>	<i>physical space require- ments</i>	<i>stakeholder opposition</i>	<i>conflict with other policy objectives?</i>
Residential areas							
Plant street trees	\$\$\$	•	•		•		
Encourage vegetation on private property	\$			•	•	•	
Build green alleys	\$\$	•		•		•	
Protect existing trees	\$		•	•		•	
Install white roofs	\$\$	•		•		•	
Depave driveways	\$\$	•		•		•	
Mixed residential and commercial							
Increase trees and greenspace	\$\$	•	•		•		
Protect existing trees	\$		•	•		•	
Install white or green roofs	\$\$\$	•		•		•	
Large scale commercial and institutional							
Increase vegetation in parking lots and school yards (public)	\$\$	•	•		•		
Increase tree coverage in parking lots (private)	\$\$			•	•	•	
Install white or green roofs	\$\$\$	•	•	•		•	
Industrial and light manufacturing							
Increase tree coverage in area	\$\$	•	•		•	•	
Install green roofs	\$\$\$	•		•		•	

The background features a large, light grey number '6' on the left side. A curved, grey shape sweeps across the bottom and right side of the frame. The word 'CONCLUSION' is written in a bold, black, sans-serif font, positioned to the right of the number '6' and partially overlapping the curved grey shape.

6 CONCLUSION

CONCLUSION

The severity of the UHI threat to human health is considerable, and is likely to intensify as the climate continues to change. This issue deserves serious attention. While international cooperation on climate change is stagnating, local levels of government should take the lead in reducing anthropogenic contributions to climate change and take steps to adapt to new climatic conditions. In addition to global warming, physical factors of urban settlements, such as the mineralization of surfaces, low vegetation cover, and the production of waste heat contribute to UHI. It is imperative to address these issues to prepare cities for a warmer climate.

Human health has been the primary concern of this study, as it is the most urgent issue related to UHI. Some characteristics, such as young and old age, low income, and living alone, make people especially vulnerable to UHI, and we have focused on these vulnerable groups to target UHI adaptation interventions. Although not discussed at length in this report, addressing human vulnerabilities directly – through improved health and social services, education and awareness about climate change, and enhanced social networks – presents another major avenue for UHI adaptation.

No simple answers are provided in this report. The way forward will involve further study of UHI and human vulnerabilities, coordination among committed individuals, and sometimes difficult decisions. We do not recommend any particular set of strategies for every case, but rather recommend a methodology for formulating a strategic adaptation plan. The actual policy development will have to happen at neighbourhood scales, in accordance with local physical, demographic, and socioeconomic characteristics. The Saint Michel case study can serve as one example of a strategic adaptation policy framework.

A number of lessons should be taken away from this study. While the work here is specifically focused on Montreal, the following points are applicable to many other cities facing similar challenges. First, it is important to recognize that UHI is a micro-scale phenomenon, and should be addressed accordingly. This means that the set of possible adaptation strategies will be different from one area to another, and thus UHI ad-

aptation strategies should be developed at the local government level. Moreover, the strategies themselves have to be micro-scale: UHI can not be alleviated by a series of neighbourhood parks; rather, interventions at the level of streets and buildings are necessary.

Second, UHI needs to be put on the agendas of various government agencies. Giving the responsibility for UHI to a single department without proper interagency coordination may be ineffective and inefficient: without the understanding and support of other agencies, a single department would have difficulty promoting its agenda. Municipal governments have many goals, which compete for limited budget resources, and may conflict with one another. Allowing government agencies to work without coordination on these diverging goals creates unnecessary conflict and wastes scarce resources. Preferably, several groups, including municipal departments, scientists, university researchers, business communities, developers, NGOs, and the general public should work together on a concerted effort to develop UHI adaptation strategies. A municipal directive should institutionalise UHI as the responsibility of all relevant agencies, and encourage them to work with external actors. This point is especially pertinent given that many of the UHI adaptation strategies are costly. Thus, available resources should be used all the more efficiently to achieve the greatest results.

Third, a number of lessons were learned from the Saint Michel case study. It is evident that the risk to UHI is highly localized, and its effects are felt unequally across the metropolitan area. It is significant that the areas of highest UHI risk are often burdened with other urban problems, including low socioeconomic standing, unemployment, high levels of crime, and low levels of education. The needs of Saint Michel are acute in many respects other than UHI. Solutions that address numerous issues should be adopted to achieve the most impacts given limited resources. Saint Michel is also the site of major new development in the near future; the land use at this site will have UHI implications for the neighbourhood. Currently, a large-scale car-oriented commercial development is proposed. This type of urban form promotes car dependency, wastes resources, contributes to climate change at the local and global scales,

and would exacerbate the UHI in Saint Michel. For many reasons, it is inferior to human-scale pedestrian environments; UHI is another reason why large-scale car-oriented developments should be reconsidered. It is imperative that the building approval process includes UHI as a criterion for evaluating future development proposals.

In conclusion, the limitations of this study should be explained with the purpose of setting the future research agenda. The data on temperature used in this study is a rough approximation of the air temperature as it is perceived by people on the ground. A better measure of air temperature that accounts for humidity, wind speed, shading, and the effects of built form would paint a more precise picture of the location of heat islands. In addition, more information about the factors that make people vulnerable to UHI, their relative importance, and data for those vulnerability factors are needed to make the research more complete. To help policy makers discern between competing alternatives, the knowledge base about the effectiveness, costs and benefits of various adaptation strategies for different types of neighbourhoods needs to be strengthened. Given the aforementioned limitations of the study, we stress that the answers to the questions posed here should not be prerequisites for action. Although they would give more detail and insight, enough is known already to formulate a UHI adaptation strategy, and the gravity of UHI effects demands prompt action.

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APPENDICES

APPENDIX A

SUMMARY OF MAJOR IMPACTS FROM UHIs

<i>Health Impacts</i>	Heat-wave related deaths and health events	Heat cramps, heat syncope (fainting), heat exhaustion, heatstroke leading to death. Increased incidence of death from ischemic heart disease, diabetes, stroke, respiratory diseases, accidents, violence, suicide and homicide. Survivors of heatstroke often experience persisting organ dysfunction that is predictive of death within one year of an event. Heat stroke mortality and heat-related mortality from all causes peak with a 1 to 2-day lag following high temperatures. Increase in hospital admissions and emergency rooms specifically for fainting, nausea, dizziness, and heat cramps.
	Chronic diseases	Increased risk for hospitalization during heat waves for underlying medical conditions, including cardiovascular and respiratory diseases, diabetes, renal diseases, nervous system disorders, emphysema, and epilepsy. Indirect impacts, such as pre-existing health conditions exacerbated by extreme heat, cover a wide range of circulatory, respiratory and nervous system problems.
	Air quality-related deaths and disease	Higher levels of ozone and other smog-causing gases aggravate respiratory diseases and greater pollen concentration in urban areas increase incidence and severity of asthmatic and allergic events.
	Prevalence of diseases	Higher temperatures leading to greater numbers of mosquito and other infectious agents.
<i>Other Impacts</i>	Increased energy demand	Energy demands tend to increase during heat events as air conditioning use increases, potentially causing rolling black-outs. Heat events are particularly problematic because power demand increases at a time when transmission efficiency is reduced.
	Harm to urban plant life.	Decrease in crops from urban gardens
	Damages to roads, railroads and airports	Prolonged periods of summer heat may adversely affect construction as well as damage road, rail, and air transportation infrastructure. Engine and tire performance, air conditioning use, and road surface conditions may also be affected. Summer heat can be problematic in construction and for road and rail infrastructure. High ambient temperatures, particularly when coupled with low relative humidity, increased wind velocity, and high solar radiation, can lead to moisture loss in concrete during mixing and pouring, and thus result in cracking from thermal shrinkage. Changes in temperature affect bridges as well, leading to expansion and contraction. Heat can increase rutting of paved highways, resulting in higher maintenance costs and shorter life span. It may also cause flushing or “bleeding” of the asphalt surface, which can increase skidding, a safety concern. Heat effects on rail infrastructure include track expansion or buckling. High ambient temperatures also affect power infrastructure. Warmer air temperatures reduce the transducers’ ability to dissipate heat to the environment, reducing efficiency. Metal power lines expand under extreme heat and may sag.
	Increased water usage	Water use is also affected by temperature, with demand typically increasing in summer. Studies of U.S. cities demonstrated that water use first increases above 21°C, with substantial increases in demand above approximately 30°C. In addition, a study of New York City showed that precipitation was highly important in summer for reducing water demand, while in winter precipitation had little effect on daily water use. Under hot and dry conditions, municipal water demand is at its highest, at a time when water availability may be limited.

APPENDIX B

POSSIBLE STRATEGIES FOR UHI ADAPTATION

This section presents a variety of urban planning strategies that could be implemented to adapt to UHI in Montreal. These strategies are based on our review of policies and activities in other cities, particularly several cities in the US, Canada and the United Kingdom. As the number of days of extreme heat increases in Montreal due to global climate change, urban planners will be called upon to modify the way we build and use urban environments to improve the thermal comfort level and reduce serious health risks for residents. This action will have positive effects for the health of residents and decrease summer energy use, among other benefits.

We present strategies that can be implemented at the city-wide or neighbourhood scale. It is important to note that for the Montreal context there are other scales – regional, provincial and federal – at which UHI adaptation policies and programs could be implemented. However, in this report we focus primarily on those strategies that could be implemented by planners within the City of Montreal and local boroughs.

Increase biomass by preserving existing trees and planting more trees in the city

Vegetated surfaces maintain cooler ambient temperatures within the urban environment (Soleckia 2005, Gill 2007, Watkins 2007). Two processes by which vegetation cools air temperature are evapotranspiration and shading. All vegetation affords some degree of cooling through transpiration, but larger vegetation such as mature trees provide more evaporative cooling than young trees, bushes or grass. Providing shade for the ground and buildings is another role of vegetation, with large mature trees having the greatest cooling impact. As higher air temperatures enhance the formation of smog, vegetation also indirectly maintains better air quality by keeping temperatures lower (Chameides 1990). For temperate climates, deciduous trees are the best choice for improving thermal comfort. They provide shading in the summertime while maximizing sunlight in the wintertime. It is also important to note that the location of trees and

other vegetation in relation to nearby buildings affects the extent of their cooling impact. Appropriate location of trees is also important for their survival. Thus, new plantings need to be located strategically to maximize desired effects.

A common first step taken by many cities to preserve and increase their urban canopy is to create and update an inventory of all trees in public streets and spaces. Proper tree maintenance is critical to preserving the existing urban canopy. Many cities have engaged private sector and non-governmental agencies to spearhead tree planting programs. Another approach that municipalities have taken to increase tree planting is by enacting landscape ordinances that require a certain percentage of tree coverage in all new development and major renovations of existing buildings. They also can include requirements for planting trees in all parking lots.

Preserving green spaces and creating new ones

In a study modelling green cover and its impact on UHI in Manchester, UK, Gill et al. (2007) found that a ten percent addition in green space in downtown and high density residential areas would keep temperatures at or below 1961 to 1991 baseline levels. The authors also found that reducing green cover in the city would result in sharp increases in local temperature. Therefore, they recommended an adaptation strategy that both preserves and enhances green space wherever possible. The authors note that within the built-out urban context adding green space may be unfeasible. “Thus green space will have to be added creatively by making the most of all opportunities” (Gill et al. 2007, p.127). The authors state that this should include private gardens, public spaces and streets, roofs, building facades and along railway lines.

While the protection and creation of parks is important for urban areas, the cooling effect of open-space trees tends to be localized. A study of mitigation scenarios for New York City found that surface cooling around

the 850 acre Central Park tends to be limited to about 60 metres from the Park's borders; outside the 5 acre Bryant Park, cooling is limited to just 15 metres (Rosenzweig et al. 2006). Nonetheless, tree planting is being promoted as a UHI adaptation strategy because the cooling effect of trees is significantly greater than that of grass and low shrubbery.

One way that cities have attempted to preserve and create open spaces in private lands is through open space impact fee ordinances. These ordinances require developers of new residential properties either to pay a fee or contribute a proportionate share of open space and recreational 'cooling' facilities. Another approach may be to restrict the approval of expansions of residential buildings into rear courtyards. Not only does this reduce green space of the rear yard, but it also obstructs the views of neighbours (Deny et al. 2007).

Building green roofs

A New York City study of mitigation scenarios found that living roofs have significant potential for reducing UHIs. Although curb side tree planting was found to have the greatest per-unit area cooling effect, living roofs may have a greater impact in dense urban areas such as Midtown Manhattan because available rooftop space greatly exceeds the potential for street tree planting (Rosenzweig et al. 2006). Although the benefit of living roofs is slightly larger than that of light-coloured roofs, they cost more than ten times as much to install. Thus, in terms of a cost-benefit analysis, living roofs may not be the optimal solution. Nonetheless, it is an effective strategy when combined with other mitigation strategies.

The City of Toronto, for example, has implemented an innovative green roof program in order to reduce storm water runoff, lower energy consumption and mitigate the effects of UHIs. The City has funded demonstration projects on city buildings and is using the development approval process to encourage green roofs. It has also recognized that increased cost of green roofs is a barrier to implementation by private individuals and businesses. To encourage construction of green roofs, the city provides \$50 per square metre for a certified green roof, to a maximum

of \$10,000 for single-family homes and a maximum of \$100,000 for all other property owners.

Many cities, a particularly good example being Chicago, have created green roof demonstration projects on municipal buildings. In addition to enjoying savings from lower energy usage in summertime, these projects also serve as excellent conduits for increasing public awareness and promoting market demand for green roofs.

Increase surface albedo

Installing cool or white roofs

The use of high albedo materials reduces surface temperatures significantly. Light-coloured roofs have higher albedo and reflect solar radiation more than dark-coloured roofs, thereby altering the surface energy balance. Researchers have found, for example, that white elastomeric coatings (with an albedo of 0.72) were 45°C cooler than black roof coatings (with an albedo of 0.08) in the early afternoon of a clear summer day. A white surface with an albedo of 0.61 was only 5°C warmer than ambient air whereas conventional gravel with an albedo of 0.09 was 30°C warmer than air. Simulations of the effects of large scale albedo increases in urban areas have shown the magnitude of impacts on air temperature in summer: increasing albedo by only 0.13 decreases ambient air temperatures by 2°C on average, and reductions of up to 4°C are possible (Taha 1997).

Los Angeles is one of many cities that have adopted a cool roof strategy to reduce air conditioning use and lower ambient temperatures (Rosenfeld 2002). To promote the strategy, the Cool Roof Rating Council (CRRC) was created in 1997, with a mission to develop methods for evaluating and labelling reflective roofing products. The CRRC's activity includes education and outreach; technical research; systematizing rating, codes, and standards; and monitoring membership. An innovative strategy that has been used in conjunction with tax credits and building requirements is time-dependent valuation (TDV) of electricity. TDV increases the cost of electricity during peak hours, thus creating additional economic incen-

tives for installing cool roofs. In addition to focusing on buildings, the colour of bus roofs and public service vehicles has also been changed to white. The study has found that the cool roof program has amounted to energy savings of US\$171 million per year in Los Angeles.

The City of Chicago has for several years operated a grant program that provides homeowners with up to 80% of the costs of roof retrofits that meet or exceed the US Environmental Protection Agency's (EPA) Energy Star cool roof standards, up to US\$6,000 per roof. The grants are provided before construction. Under the most recent cycle of this grant program, approximately 55 grants are expected to be awarded, with a total value of US\$185,000. Eligible building owners include residences, small businesses and the industrial sector. The program is specifically intended to reduce the UHI effect. Eligible properties must also meet albedo and slope requirements, thereby targeting those roofs most susceptible to UHI effects. Information on roof cooling materials is readily available online with one particularly well known database produced by the Lawrence Berkeley National Laboratory in California.

Other governments have mandated high albedo surfaces by revising their energy codes. For example, California's 2005 Energy Efficiency Act requires that all new roofs and renovations of a certain size meet energy efficiency standards. This requirement applies only to non-residential properties.

Increasing ground albedo

Replacing hard urban surfaces with permeable pavement has been shown to reduce UHI effects. Through the extensive testing of various paving materials Asaeda and Ca (2000) found that the surface temperature of permeable paving types is considerably lower than traditional paving types. This is because permeable paving allows water to move freely between the atmosphere and the soil, allowing evaporation to occur. The authors state that permeable paving is "one of the most effective methods to moderate the thermal conditions of the pavement surface."

North Shore City, New Zealand has produced guidelines which outline the various permeable paving solutions available in the Auckland region context, which also meet government regulations. Such guidelines are used by designers and assist cities in the design of developments and in the review of application permits.

Other interesting approaches include asphalt alley removal and school-yard de-paving. Asphalt paving entered into widespread use around 100 years ago. Its hard smooth surface proved excellent for pedestrians, cars and bicycles. However, because of its dark surface it absorbs direct solar radiation and heats up extensively, especially in summer. The percent cover of asphalt and other dark surfaces in a city is a key factor contributing to UHIs. Lighter paving materials reflect the incoming radiation back out to space. Akbar et al. (2001) found that a 0.25 increase in albedo of paving materials reduced the surface temperature by 10 degrees in a computer model performed on Los Angeles. The lower temperature has other cascading benefits for cities including reduced smog and reduced energy consumption. Studies have also shown that lighter paving surfaces reflect street lighting better, which creates a higher night time visibility and better night time safety for pedestrians.

Increase thermal performance of built form

Weatherization of buildings and providing access to cool places
Weatherization assistance programs have operated in Canada and in northern regions of the United States for many years primarily to ensure proper insulation of older buildings to reduce exposure to cold weather in winter and to reduce wintertime heating bills. Such programs can be modified to include upgrades that will improve summertime building performance as well. Measures would include upgrading windows for better summertime ventilation and adding ceiling insulation. Ventilation will not keep the buildings comfortable, but it will prevent them from acting like solar ovens and keep temperatures indoors close to or below those outdoors (Huang 1996). Simulations of building thermal performance do indicate that substandard buildings can be made safer and more habitable.

Another step would be to provide air conditioning. By one estimate, air conditioning prevented about 3,500 deaths in New York City between 1964 and 1988 (Kalkstein 1993). More recently, in response to increased cooling demands and concern about greenhouse gas emissions, technologies for passive cooling systems are being used in place of conventional air conditioners. Such systems include discharging building heat into the ground or the installation of passive ventilation systems, as well as measures to reduce the cooling loads, such as by increasing the reflectivity of windows and installing awnings for shade (Shimoda 2003).

Clearly, access to cool places can be crucial to populations at risk. Spending a few hours in a cool place allows people to take a break from the extreme heat. This in turn, can prevent heat strokes and save lives. Public places where residents can go to cool off include pools, churches, libraries, schools, shopping centres, and other community facilities. Access to medical services is equally important as access to cool public places. Ensuring that people at risk are able to reach public health services is a key aspect of planning for adaptation to extreme heat in urban areas. However adequate access requires more than physical proximity of community facilities to residents; people's lack of mobility due to poor transit service or physical disabilities, fear of crime, and cultural considerations are some factors that can affect access to cool places.

Promoting 'smart' density, mixed use and brownfield development

The effect of density on UHI has already been discussed in so far as it relates to building height and creating street canyons and heat trapping street geometries. However, growth through densification can decrease the effect of UHI at the conurbation scale, where such growth helps to prevent sprawl and the urbanization of rural areas at the city's fringe or other green spaces within the city limits (Stone 2006). However, it is important to plan for 'smart' density as otherwise densification may lead to a decrease in available space for tree planting and vegetation coverage in an area. Without adequate design measures at the macro and micro scales, UHI effects could intensify in the areas being densified.

Another way to limit urban expansion at the fringe is to promote the development of brownfields. In fact many brownfields such as former rail yards are characterized by high levels of mineralized surfaces and few trees. By promoting well designed, dense and mixed use development of such areas can help alleviate the UHI phenomenon.

Reduce and regulate waste heat

Limiting heat radiation emitted from industrial processes and transportation uses can help limit UHI effects. One way many cities have attempted to accomplish this is through vehicle anti-idling. The Citizens' Advisory Committee on Air Quality (CACAQ) is a community coalition in Waterloo Region. The coalition's Idling Reduction Education Campaign is a major region-wide education and awareness initiative, which targets idling reductions in municipal operations, at schools and workplaces, and in the community at large. One of the coalition's most impressive achievements is the development – and widespread adoption – of the Waterloo Region Idling Control Protocol. The centrepiece of the protocol is that municipal vehicles must be turned off after 10 seconds of being parked. "There are a few exemptions in the policy, including some for transit and emergency vehicles" (NRCAN 2004, p.3).

Responding to heat wave emergencies

In addition to plans to mitigate the effects of UHIs, it's important to have plan in place to respond to extreme heat waves in order to reduce the number of premature deaths. The City of Toronto, for example, has implemented a comprehensive Hot Weather Response Plan designed to save lives during heat waves. The plan, administered by the Toronto Public Health Department, has two major components 1) a Heat Health Alert System to predict days where extreme heat is dangerous and 2) a response strategy which coordinates the actions of over 800 public agencies and non-governmental partners.

The system calculates heat alert days by analyzing current and historical data for temperature, cloud cover, wind direction and speed, and the dura-

tion of the heat waves. If the number of predicted premature deaths reach predetermined critical thresholds a “heat alert” or more extreme “heat emergency” is announced by the City’s Chief Medical Officer. Once a heat alert has been announced a plethora of steps are taken to educate the population and assist vulnerable populations. Information is provided to the local media to circulate to the public at large; public health officers and nurses contact vulnerable clients and provide them with information; the Red Cross operates an information hotline that provides information to Toronto residents on how to handle the heat. In addition, Red Cross volunteers and staff distribute information and water to homeless people; The City’s housing administration provides outreach to homeless people; Air-conditioned community centres and libraries extend hours and are made available to the public to go and cool off. The City of Toronto also prepares 4 cooling centres that provide water, cots and snacks for anybody who requires the service. One cooling centre is provided for overnight visits.

APPENDIX C

DESCRIBING THE RISK ASSESSMENT METHODOLOGY

Risk assessment methodologies have been developed to help policy makers and the public manage risks to natural and human derived hazards (Slovic et al. 1979). A risk-based approach to decision making “has the advantage of explicitly handling the hazard itself, exposure to the hazard and the vulnerability of the elements at risk” (Lindley et al. 2006, p.526). Risk assessments have often been used in addressing public health concerns due to potential exposure to dangerous chemicals, industrial processes, or dangers of energy generation facilities.

Any risk assessment methodology must have sufficient complexity to adequately represent the nature of the problem. At the same time, such a methodology must be practical in terms of data needs and level of skill required to use it, flexible enough to accommodate different kinds of analyses, and useful in the planning context. A GIS-based tool engenders these qualities; its capacity for layer-based analysis and spatial representation allows it to easily incorporate changing data sets and new scientific knowledge. By choosing appropriate data sets and layer interaction procedures, a GIS based tool can produce many different types of physical, socio-economic, and temporal assessments. It can be used to identify measures ranging from short-term emergency responses to long-term physical adaptation and mitigation solutions (Lindley 2007).

Lindley et al. (2006) successfully employed a conurbation-scale risk assessment method to identify areas vulnerable to UHI in Greater Manchester, UK. This GIS approach translates levels of hazard, exposure, and vulnerability to heat into discrete layers, which can be superimposed upon one another and weighted based on the relative importance of each layer. These weights can be easily modified according to stakeholder input or expert advice based on the current scientific knowledge of acceptable risk levels. The overlay of all relevant layers produces a risk assessment map that visually represents the spatial dimension of risk and the spatial aspects of potential adaptation responses (Lindley et al. 2006).

The hazard layer

The hazard layer presents a current picture of UHI on the island of Montreal as a starting point for identifying the priority areas for near future adaptation interventions. Currently, the best data available for determining temperature is through the interpretation of satellite imagery. A discussion of the current best practice of carrying out the transformations of satellite imagery to produce the temperature map is beyond the scope of this text; we understand that it is the subject of a project by a UQAM research group (Baudouin 2007). However, a brief interpretation of the temperature map is necessary to understand subsequent steps of this methodology. This temperature map has a resolution of 30m x 30m, and was taken at 10:30 am on a June day when cloud cover and wind speed were not significant. While it could have been more instructive to use maps from the mid afternoon or early evening, the data is limited to 10:30 am because this is the time when the satellite passes over Montreal. The temperatures shown on the map are the interpretation of the absorbance, storage, and reflectance of solar radiation of the surface materials. These temperatures represent air temperatures just above the ground. However, we use this air temperature as a good first approximation of the actual air temperature as perceived by people.

The next step involves categorizing temperatures into three ranges. To establish these ranges, the average temperature, or threshold value, was determined for the Montreal metropolitan area for that day. Temperatures below the threshold value, 27°C, form the lower range; temperatures up to five degrees above this threshold value form a middle range. Finally, temperatures above 5°C of the average temperature comprise the upper range of temperatures. This temperature categorization scheme was developed by a UQAM research group (Baudouin 2007).

To construct the final heat hazard layer, numerical values are assigned according to the three temperature categories identified above. Areas with temperatures below the threshold value are not considered a hazard and are given a heat hazard rating of zero; areas with temperature values in

the middle range are given a hazard rating of one; and areas with temperatures in the upper range are assigned increasing heat hazard scores of two, three, and four according to two-degree increments in temperature. This method assigns numerical hazard scores across the island. This heat hazard layer can now be superimposed on subsequent layers to produce the final risk assessment layer.

Limitations of the hazard layer

First, one must keep in mind that the temperature layer is a one-time snapshot of current conditions, and is not meant to be a predictive model. Thus, to use this methodology in the future, the temperature layer would need to be updated every several years to account for changing land uses, vegetation cover, and other factors that contribute to UHI. It is possible that the locations of most intense heat islands may change, and thus the focus of interventions should shift accordingly.

The temperature hazard rating index presented in the UHI map geographically locates heat islands based on a comparison of localized temperatures to the regional average. Clearly, if temperatures were considerably higher, as might occur in an intense heat event, this methodology would create a threshold that is considerably higher, whereby areas below the threshold may not necessarily be hazard-free zones with a rating of zero. However, this methodology is designed to identify areas of priority for long-term adaptation during a typical summer season and not during a heat wave crisis situation. Furthermore, while management of a crisis situation will differ markedly from the implementation of longer-term adaptation measures, this hazard rating system still produces a spatial representation of areas in most critical need of first response.

The methodology approximates ambient, or perceived, air temperature from data of air temperature close to the ground. The lack of any other data set about air temperature necessitates this estimate. While air temperatures close to the ground have a direct effect on the air temperature that people feel, actual perceived air temperature would also be influenced by a host of other factors such as building and street wall geometries, humid-

ity, wind, and shading. Since the temperature map was obtained on a day when cloud cover and wind speeds were not a factor, the use of this data set serves as a good first approximation to exterior air temperature.

The methodology attempts to assign heat hazard scores based on an approximation of air temperature. However, employing air temperature to identify heat hazards is overly simplistic in terms of the UHI effect on human thermal comfort and safety (Watkins 2007). Other factors on human thermal comfort such as humidity, wind, and direct sunlight may not be adequately accounted for in air temperature alone. Another problem arises out of the fact that the measure of air temperature is for the exterior. While this provides a potential indicator for interior air temperature, it does not capture the host of other factors, such as the availability of air conditioning or the quality of housing, which influence actual indoor temperatures. These caveats highlight the need for more research to obtain data on actual air temperatures as perceived by people.

Human vulnerability layer

In this part of the methodology, we introduce the human element into the identification of risks to UHI. Based on a review of literature we have chosen three proxies to assess vulnerabilities to UHI: age, low income, and elderly people living alone. Data about these characteristics is taken from the 2001 Canadian Census at the dissemination area level of analysis (DA) – small areas composed of one or more neighbouring street blocks with a population of 400 to 700 persons (Statistics Canada 2001). Analysis at the DA-level data offers an adequate level of spatial precision. While access to individual records and addresses would provide the most precise identification of vulnerabilities to UHI and enable more targeted planning, access to such data is restricted for confidentiality reasons and the resources needed for processing such micro-scale data is beyond the scope of this study.

A simplified methodology was devised to evaluate the level of vulnerability to UHI based on the three demographic and socioeconomic factors. First, the number of vulnerable people per km² is mapped for each

factor over the island of Montreal by DA. Then, distribution curves of vulnerable population densities across the island are constructed. The distribution curve is divided into quartiles and DAs in each of the four quartiles are assigned a score from one to four. The DAs in the lowest quartile receive a score of one while the DAs in the highest quartile are scored as four. A score of one indicates an area of low vulnerability, two - medium-low, three – medium-high, and four – high vulnerability. Finally, the three scores are added up for each dissemination area, and divided by three, to produce a vulnerability index score. Note that this methodology gives equal weight to all three factors. The result of these steps generates a human vulnerability map for the island showing the density of vulnerable populations by dissemination area.

Age

Multiple studies have shown that the very young and the elderly tend to be particularly vulnerable to extreme heat. In our analysis, we define the vulnerable age groups as children under 5 and adults over 65. The age at which the line is drawn is rather arbitrary, but commonly accepted in literature. For the elderly, some studies use the age of 75, but we have chosen 65 because it is the age of retirement, which is a point in people's lives at which they may become less active physically, mentally, and socially.

Income

Living under a low income is an important measure of vulnerability because it affects people's financial ability to adapt to extreme heat. Also, poverty is identified in the literature as an important factor that exacerbates people's vulnerability to UHI (Buechley 1972, Harlan 2006, Patz 2000). We estimate the incidence of poverty according to the low income cut-off (LICO) threshold used by Statistics Canada, which is defined as the income level at which households or individuals spend 20% more than average on food, shelter and clothing combined (Statistics Canada 2001). LICOs vary by household size and the size of agglomeration (i.e. city). While this poverty index is one of many that can be used to measure poverty, the principal reason for its inclusion in this study is its ready availability through the census.

Over 65 and living alone

Being over the age of 65 and living alone is another significant measure for vulnerability to UHI. We use cross-referenced data (people that are both over 65 and live alone) because studies have shown that this is a particularly vulnerable sector of the population. By using this factor, we count people over 65 for a second time. This is consistent with numerous studies that have shown that being elderly makes people more vulnerable than other socioeconomic or demographic characteristics.

Limitations of human vulnerability layer

This methodology takes into account three of the most important demographic and socioeconomic factors that make people vulnerable to extreme heat. However, there are numerous other factors, for which data is less readily available, that are also proxies for vulnerability to UHI. These include being dependent; suffering from mental, respiratory, and chronic illnesses; bed-ridden; taking certain prescribed medications or illicit drugs; homeless; living on the top floor of buildings, in old housing with poor insulation, or without air conditioners; and being a renter rather than a homeowner. Localized differences in air quality also place certain populations at greater risk to UHI effects. The inclusion of these data layers would allow for a more accurate identification of vulnerable groups. However, most of this data is either unavailable or very hard to access at the scale of dissemination areas for confidentiality reasons.

Another important consideration for developing a methodology to evaluate vulnerabilities is the relative weights assigned to the factors. In our methodology, all of the factors are weighted equally, except that people over 65 were counted twice, once in the age category, and again in the category of elderly people living alone. The vulnerability index developed in this report is a very gross estimate of actual vulnerabilities to UHI, partly due to a lack of available data as discussed in the preceding paragraph, and partly to the fact that the relative importance of demographic and socioeconomic factors is not well understood. One avenue for developing a better measure of vulnerability to UHI is discussed by Pampalon and Raymond (2000). They create a deprivation index for

health and welfare planning based upon six factors which are related to a large number of health and welfare issues, material and social forms of deprivation, and data availability considerations. Then they use principal component analysis, a form of factor analysis, to assign weights to each indicator based on statistical relationships that exist among the indicators within the geographic area in question. Pampalon and Raymond's methodology can be equally applied to develop a UHI vulnerability index for Montreal: the importance of the various factors discussed above would need to be evaluated using statistical analysis for their influence of adverse heat-related health effects.

The risk layer

The final step in this risk assessment methodology is to overlay the UHI map with the human vulnerability. Adding the two layers and their respective indices together results in a scale that ranges from two to eight. These values are then divided by two to come up with the final risk assessment index, which will give each DA a UHI risk rating from one (low), two (medium), three (high), and four (severe) risk.

It should be noted that the temperature hazard layer and the human vulnerability layer do not possess the same spatial resolution; the temperature layer has a resolution of 30 by 30 metres and the vulnerability layer is divided by DA. However, GIS still allows the superposition of one layer over the other. The intersections of the highest temperature and the highest levels of vulnerability identify the geographic areas where the population is most at risk to UHI. As will be discussed in section 2.2, this risk index can be used to allocate resources for alleviating UHIs.

Limitations of the risk assessment methodology

The one significant benefit of the methodology just described is the spatial representation of UHI risk, which allows an easy visual reference. However, it does not provide answers to the most important questions about policy directions, but is only a tool for making such decisions. Interpretation of the scores and critical analysis are important for targeting

action. For example, a hotter, but less vulnerable area may have the same risk assessment score as a cooler, but more vulnerable area. Although these areas may receive the same final score, they should not necessarily be treated equally in the policy-formulation stage.

Moreover, the limitations of the methodology must be kept in mind when analysing situations and making decisions on resource allocation. Some shortcomings of the methodology are related to data limitations. These include less-than-ideal data about temperature, demographics, and socio-economic characteristics. The system of allocating weights to the data layers presents additional difficulties. Much more scientific understanding and analysis about the effects of high temperatures on health and the relative importance of demographic and socioeconomic factors are needed to develop a better weight-allocation system. In addition, this methodology is not designed to capture behavioural practices that may make people more or less vulnerable to UHI. Variables such as living and work environments, daytime activities, cultural influences, and opportunities to escape the heat, which are not addressed here, may also be important in developing policies for adaptation.

The methodology presented above is based upon recent data sets. No time lapse data was collected to carry out projection or trend analyses. Data layers are based on data sets from 2001 and 2005. Thus, while it is likely that the Risk Map would be typical of the risk pattern for the last several years, major changes to the urban fabric and shifts in population characteristics will change the spatial locations and magnitude of risks to UHI. Our analysis provides a snapshot of the risks associated with UHI on the island of Montreal, but does not make any predictive assessments about how this risk has changed, or is likely to change over time. As such, new data and research on the relative importance of the data layers need to constantly inform this methodology.

APPENDIX D

DEVELOPMENT OF A POLICY FRAMEWORK

Several points from the section of the development of a policy framework of a UHI adaptation strategy are elaborated here.

A. Focus UHI adaptation efforts on geographic areas most at risk

It is true that the UHI risk assessment tool focuses on the threat to human life and health, even though it is only one of several negative impacts associated with UHIs. For instance, energy and water demand tends to spike in UHIs in the summertime. Also, exposed buildings and infrastructure can deteriorate more quickly due to higher levels of ground-level ozone. Nevertheless, we believe that a focus on human health and welfare is appropriate when crafting UHI adaptation policies. The potential harm to human life and welfare is by far our greatest concern, especially considering that it is the poor, the young, the aged, and the sick and dependent who are most vulnerable. We believe a moral imperative exists to target UHI efforts accordingly. Thus, while an industrial or commercial area may be exposed to UHI effects as much as a residential area densely populated with poor senior citizens, our UHI risk index would assign a higher UHI risk score to the latter, and we would recommend that priority in terms of developing and implementing an adaptation strategy be given to that area.

C. Identify the range of possible UHI adaptation strategies suitable to area

Some policies and programs will be administered by central authorities and thus all high risk areas of Montreal would benefit. For instance, a borough may determine to focus on a street tree planting program rather than resurfacing a local community centre with a green roof. However, a citywide green roof grant program aimed at private home owners would be accessible to homeowners in various boroughs.

D. Identify measures with the greatest temperature reduction potential

The following is a set of software packages to help in the evaluation of between various potential adaptation strategies:

MIST: MIST is a software tool that estimates the impacts of UHI mitigation strategies on urban air temperatures, ozone, and energy consumption. The cooling strategies assessed include increasing urban albedo (reflectance), increasing urban vegetative cover, or a combination of both. Alternatively, users can evaluate how a particular temperature change will impact ozone concentrations and energy use. The basic steps involved in running MIST are: (1) select the city to model, (2) define the mitigation strategy to test, and (3) estimate impacts on meteorology, air quality, and energy. All the data necessary to run MIST exists for over 240 cities.

CityGreen: This GIS tool identifies the benefits, expressed in dollar values, of urban trees for a particular municipality. It was developed by the American Forestry Association.

TR-55: The US Natural Resource Conservation Service's TR-55 model evaluates the effects of land cover/land use changes and conservation practices on storm water runoff.

Gill: Gill et al. (2007) employed a GIS approach to explore the potential of green strategies in mitigating the effect of UHI in Greater Manchester. Using various climate change scenarios for 2080, the authors calculated the exact land area required for various greening strategies - such as tree planting and green roofs - to reduce local temperatures to the 1961 to 1990 baseline. Although the authors didn't include cost considerations in the GIS model, the pricing for various strategies could be added to the GIS model in order to compare and contrast cost effectiveness.

F. Engage residents and other stakeholders, especially regarding program implementation

From the start of UHI adaptation policy making, a group of people composed of scientists, policy makers, local NGOs and community organizations, and a small committee of neighbourhood residents and business owners should be deeply involved in the background work of the policy formulation process. It is important to involve some community members from the start because they add particular socio-cultural elements to the discussion, of which scientists and local policy makers may be unaware. In addition, early participation will enhance community buy-in and the level of legitimacy of the adopted course of action. However, in creating citizen committees, it is imperative to ensure that they are representative of the neighbourhood population and that they are guided by the public interest of their neighbourhoods. It may be appropriate to limit the engagement of the public before adequate information is available. However, at the final decision-making stages, public participation is important for the reasons discussed above and also for the purpose of education and building awareness about UHI and climate change issues in general. The precise process of public consultations should be determined and guided by the Office de consultation publique de Montréal (OCPM).

G. Develop clear and objective targets, monitoring results and rewarding success

The choice of targets and monitoring regime will depend highly upon the kinds of strategic interventions being chosen. Once appropriate strategies are chosen, policy makers need to determine the best set of measures, whether prescriptive or performance-based, to allow for progress to be tracked. Such targets could include the number of new trees planted, reduction of the number of hospital visits due to heat stress, and changes in temperature. Targets should also include timelines at which physical measures are evaluated. Different agencies in the city may be involved in setting up these targets and monitoring regimes. For instance, a local borough will be better suited to develop targets for and monitor the progress of a tree planting program or the number of new green roofs

installed. On the other hand, a central agency may be better suited to monitoring changes in temperature over a larger area and time period, or ensure that all local boroughs contribute appropriately to island-wide UHI adaptation.

APPENDIX E

RELEVANT OBJECTIVES AND ACTIONS OF THE TREE POLICY

In 2005, Montreal promulgated a new, city-wide tree policy. That policy identifies a number of serious problems, as follows:

- Tree planting has decreased considerably in recent years due to budget constraints;
- Diseases and a recent ice storm killed or mutilated thousands of trees in recent decades;
- Trees are often injured during construction, development or maintenance work;
- Infrastructure and equipment are often installed without allowance for the needs of trees;
- Bylaws requiring compensation for harming public trees are rarely enforced;
- Trees are often felled without proper permits or without proper justification;
- The inventory of Montréal's urban forest remains incomplete.

The intent of this new tree policy is in part to develop new tools which the boroughs like St Michel may use in conjunction with the city's park and recreation department to better manage the urban forest. The policy outlines the following four main objectives:

1. Develop and provide the tools necessary for defining a long term vision;
2. Establish rules and practices for the protection, management and maintenance of trees;

3. Increase the number of trees planted; and
4. Step up information, publication and awareness initiatives.

Eleven specific actions are set forth in the policy, including:

Action 1: Each Montréal borough shall draw up a Tree Plan;

Action 2: Each Montréal borough shall complete a detailed inventory of its public trees;

Action 3: The City and the boroughs shall conduct new planting operations;

Action 4: The City of Montréal and the boroughs shall seek above all to preserve and protect trees;

Action 5: The City of Montréal and the boroughs shall draw up maintenance programs for public trees;

Action 7: The boroughs shall institute measures to protect trees during construction or require new plantings for new buildings;

Action 8: The boroughs shall stipulate that a construction or expansion project must maximize the conservation of trees.