Montreal Up in Smoke:
A Spatial Analysis of Mid-Nineteenth Century Urban Fires

Joint Honours Thesis for the Departments of Geography and Anthropology

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Table of Contents

List of Figures

List of Tables

List of Maps

Abstract

The patterning of Montreal's historic urban fires demonstrates that fire spread is more likely to occur in densely built urban areas. This study aims to demonstrate the relationship between the spread of urban fires and density of buildings. This study uses geographic information systems (GIS) and statistical analysis to shows that a threshold exists at which fires are more likely to spread to nearby buildings. Fire data was collected through archival research in both French and English for the years 1845 to 1855 and layered with physical and political historic maps in order to identify patterns of fire spread. A clear correlation exists between the spread of fires and the proximity of the affected buildings. The case study of Montreal between 1845 and 1855 is particularly interesting because the time period surrounds the 1852 fires that burned a significant portion of the city and led to the adoption of new building and safety codes.

CHAPTER 1: INTRODUCTION

Structure density is a crucial factor in determining whether fire will spread or not. In urban areas such as Montreal, built density and construction materials are considered the most important factors in establishing how a fire will behave (Rehm, Hamins, Baum, McGrattan, & Evans, 2001). By quantifying the concentration of buildings and comparing the values to the prevalence of fire spread, a threshold can be determined for the critical density value, above which all fires will spread from their building of origin. The extent and intensity of fire spread is not possible to quantify through this analysis, but it is clear that hazardous spread through high-density areas continues until acted upon by external forces such as weather events or firefighting.

Urban centers throughout the world have experienced massive conflagrations over the course of history. During enormous summer fires in 1852, over twelve hundred buildings burned in Montreal (Redfern, 1993). This study examines the impact of built density, a quantification of closeness of buildings, on the spread of historic fires in Montreal preceding the 1852 destruction. I conduct this study by analyzing potential causes of urban fires and the extent of their destruction. I use GIS applications and spatial analysis techniques to test the correlation between built density and the spread of fires. I will focus on identifying a threshold at which urban historic fires in Montreal spread to other buildings. This threshold may act as a useful proxy for fire prevention and prediction in developing urban areas with similar environmental and constructed conditions.

The techniques used in this study provide an idea of why fires have spread, but the research is limited by the historic nature of the study and a lack of control over outside factors such as weather conditions, arson, and building material. The news sources used in this study are meant to represent the true occurrences in Montreal's history, but are likely to be incomplete due to their nature. The collection of fire information acquired acts as a large sample rather than the entire population of fires.

GIS techniques are applied here to show the statistical relationship between fire locations and building density. From this type of analysis, statistical methods are employed in order to better understand the relationship between built density and fire spread. The kernel density estimation of the perimeters of buildings enables me to take building size and shape into account as well as structure location, which is essential in determining an accurate density threshold for fire spread.

By combining archival research with GIS analysis, records of the past can be seen in a new light with the use of modern software. While historic newspapers shed light on the past, they sometimes leave out daily occurrences. We must analyze media-worthy reports for evidence that urban density was a major cause of fire spread, a conclusion that could not be identified without the use of GIS. The increasing density of buildings in downtown Montreal was not a major focus of *The Montreal Gazette*, as it was not seen as an immediate issue or hazard. Today we can couple the power of hindsight with current technology to see the patterns that influence the spread of fires and their resulting disasters.

CHAPTER 2: THEORETICAL FRAMEWORK

Research Objectives

The ultimate goal of this project is to determine the relationship between urban density and the potential for fires to spread to multiple buildings in mid-nineteenth century Montreal. This is achieved by mapping the spatial distribution of the outbreak of fires as reported in the *Montreal Gazette*, establishing an appropriate definition and measure of built density, and identifying a level of built density which increases the likelihood that a fire will spread from its building of origin to other structures.

In this research report, I will provide an overview of urban fire prominence and past studies before detailing the methods used in this project. It is important to establish the context in which this study is conducted, including Montreal's specific historic situation, as well as the circumstances of other noteworthy historic fires. I will examine the limitations of historic archive research such as imperfect newspaper reports and poorly rectified maps. I will justify my use of a kernel density and its subjective measurements, as well as covering background information regarding GIS and spatial analysis techniques. After outlining the methodology of the analysis, I will discuss results and conclusions.

Background Information

Montreal in the Mid-Nineteenth Century

Montreal was a fast-growing city by the mid-nineteenth century, with many factories and worker housing near the St. Lawrence River and a commercial center to the northwest of the river (Bradbury, 1979). These peripheral working-class residential areas surrounded a wealthy urban core, which later declined with an exodus of wealthy homeowners away from the financial center of the city (Burgess, 2004). The port area facilities grew rapidly during the nineteenth century, especially during the 1840s (Gilliland, 2004). Separation of classes by neighbourhood was prominent by the 1860s, and working-class living quarters were cramped and often inadequate (Bradbury, 1979). Building types at this time period included residential, storage, workplace, stables, and outbuildings, as well as special institutions such as churches and schools. The city contained a mix of these buildings throughout the landscape, with the population living and working in close proximity.

Separations between French and English, and well as Protestant and Catholic, dominated Montreal's landscape and contributed to political tensions in the region (Sweeny, 2006/2007; Burgess, 2004). Heavy immigration also occurred during this time, especially during the height of the Irish famine, 1847 to 1849 (Olson & Thornton, 2002). This mix of languages, nationalities, and religions led to political dissent among the residents of Montreal. Political tensions often resulted in public displays such as riots and arson, including in the 1849 burning of Montreal's parliament building (Lauzon & Stewart, 2004).

Mid-nineteenth century Montreal was composed of many wooden buildings and narrow streets laid out in the seventeenth and eighteenth centuries (Redfern, 1993). As late as 1881, 52% of buildings were composed of wood, making up 26% of the ground covered by buildings (Goad, 1881). These houses were highly susceptible to fire spread, and the city experienced several large-scale fires during its development, the most extreme in 1852, which displaced over 10,000 people (Redfern, 1993). In response to this tumultuous period, the city government reaffirmed and began to enforce building bylaws banning wooden residential structures, implemented street-widening measures to establish fire-breaks, and established a professional fire department (Redfern, 1993; Gilliland, 2002).

Causes of Urban Fires in Historic Developing Cities

Schmalz (1992) categorizes urban fires as three distinct types. The first category is for accidental, single origin fires. A second type covers fires that are caused by natural events such as earthquakes, often with multiple outbreaks. The third type is for deliberately set fires with multiple origins, such as those caused by acts of warfare. Fires observed in mid-nineteenth century Montreal fall mainly under the first category. Although there are cases of arson, they were confined to single locations. Nevertheless, fires in Montreal at this time period were not caused by major natural events, nor by warfare, and all of the fires observed in this study spread from single origins.

A direct relationship exists between the number of fires and urban population growth in an area. These factors increase together until lot sizes are expanded and large-scale rebuilding of the city takes place using less flammable material (Frost & Jones, 1989). Many cities in North America expanded rapidly during the nineteenth century and were often built using lumber because of its availability and low cost (Shields, 2007). Overcrowding in developing urban areas led to greater hazards as lower construction standards kept costs down (Frost & Jones, 1989).

Montreal's climate furthered the potential for fire outbreaks. A dependency on indoor heating during winter months proved to be a hazard in many northern cities (Schmalz, 1992). Poorly designed chimneys and hearths, as well as the soot they held, led to increased fire outbreaks in Scotland during this time (Ewen, 2006). A general dependency on open fires for everyday activities such as cooking also increased the likelihood of fire outbreaks (Schmalz, 1992).

Industrializing cities in North America were mainly concerned with rapid expansion, and aesthetic values and safety measures were often ignored (Shields, 2007). Firefighting needs were responsible for many water availability initiatives, but water systems in many cities could not produce volumes of water necessary to combat large fires (Shields, 2007; Blake, 1956). Another issue in fire companies was the requirement of horses to pull large equipment, which became problematic when horses were unavailable or ill (Shields, 2007). Like Montreal, most cities grew outward and uphill. Montreal's period of industrialization was marked by typical overcrowding and rapid expansion and suffered from widespread fires as a result.

Prevention of Urban Fires

Infrastructure improvements toward the end of the nineteenth century allowed for a decrease in the prevalence of fires in North American cities. "Fireproofing" was accomplished through larger lot sizes, alarm systems, non-wooden materials, more established fire fighting groups, improved technology for pumping, and fear of discrimination in fire insurance rates based on the quality of building materials (Ewen, 2006). Urban fires led to the straightening and widening of roads, as well as improved building codes and water systems (Shields, 2007). Widened roads, as well as an increase in widespread use of non-wooden building materials, provided fire breaks to contain conflagrations (Frost & Jones, 1989).

The end of the nineteenth century was marked by improved technologies including telegraphic alarm systems, more effective pumps, and the replacement of burning lamps with electric lights (Shields, 2007). The rise of automobiles and decrease in horse-dependent transportation allowed for faster response times from fire fighters and fewer stables with hay in dense urban areas (Shields, 2007).

Social attitudes toward fire prevention also shifted in response to mid-nineteenth century urban fires. Firefighting became a professional occupation with well-established organizations, including Montreal's fire department, established in response to the widespread fires observed in this study (Shields, 2007; Redfern, 1993). Fire insurance became common during the mid-1800s, along with the identification and mapping of fire hazards (Gilliland & Novak, 2006). These insurance plans charged more for wooden buildings due to their flammable nature, which promoted the use of fireproof materials (Frost & Jones, 1989).

Urban Fire Case Studies: London and Istanbul (Constantinople) Compared with Montreal

The Great Fire of London, like Montreal's 1852 fires, led to the adoption of stricter building codes, including new building material requirements and street widening and straightening (Davis, 1923; Hanson, 1989). This fire occurred in 1666 and burned 80% of the mostly wooden city, which was vulnerable after years of plague (Schmalz, 1992). Structures were very densely built, and the city's building codes were outdated by several hundred years (Hanson, 1989). Like in Montreal nearly two centuries later, the conditions were right for fire spread, and there was little in place to stop conflagrations.

Many historic fires occurred in Constantinople (now Istanbul), over the course of hundreds of years, including ninety incidents in the eighteenth century alone (Gürer & Gözek, 2010). During that time, the city had similar conditions to current developing-world slums, with overcrowding and incredible fire risks from make-shift shelters (Frost & Jones, 1989). These fires, along with a desire to westernize the area, led to major re-planning of the city with widened streets and grid and radial patterning, which reduced fire hazards (Gürer & Gözek, 2010).

Of course, London, Instanbul, and Montreal were not the only cities affected by large fires. Major fires raged in cities all over the world, and still do in many areas. A fire in Chicago in 1871 destroyed 17,500 buildings (Shields, 2007). In Tallinn, Estonia, nearly all of the Toompea (Dome Hill) area of the city burned in 1684 and was rebuilt in a new style (Tallinn History, 2011).

Current Urban Fire Issues

Developing-world barrios and slums are susceptible to large, spreading fires due to poor living conditions, high population density, and lack of capital to improve infrastructure (Frost & Jones, 1989). Many urban fires occur in the developing world, but are not reported by many western news sources (Frost & Jones, 1989). The United Nations cites building density as a major cause of urban slum fires, showing that this issue is still quite prevalent in current society (United Nations Human Settlements Programme, 2003).

Industrialized and developed cities also suffer from urban fire issues, although for different reasons than in developing regions. In urban areas of the United States, 30% of structure fires in non-residential buildings and 14% of residential building fires are due to arson (TriData Corporation, 1999). Cooking, heating, and other activities are still responsible for urban fires (TriData Corporation, 1999). Urban fires in North America are generally not as devastating as those in the nineteenth century due to strict building codes and availability of fire prevention equipment. However, the issue of large-scale urban fire risk still exists for many developing cities that lack fire prevention measures and infrastructure.

Previous Fire Studies using Spatial Analysis

Urban geographers work with historical GIS and statistical analyses to identify the scale of patterning (Gilliland & Olson, 2010). The applications of GIS and statistical techniques used in this study are based in GIS theory, as well as previous studies of fire spread and urban density. This research is unique in its attempt to measure the relationship between these two elements and the conclusions therein. Historical GIS is able to employ fire insurance maps in order to gather details about patterns of urbanization (Gilliland & Novak, 2006). Fire insurance maps were not available for this time period, but could be a useful tool for similar studies in other areas or time periods.

Previous studies of fire spread have often addressed the dangers of brushfire and forest fire. Ecologists and foresters have involved inventive GIS techniques in their work for decades, apparent from ArcGIS software additions. Such analyses must be undertaken with different methods than urban fire occurrences because of the nature of the fires in urban and wilderness conditions. An example of a typical study of wildfire spread in Tasmania implements GIS analysis using both raster and vector analysis, but focuses on wild overland spread rather than extending beyond the urban interface (Atkinson, Chladil, Janssen, & Lucieer, 2010). Other wilderness fire studies have used Monte Carlo simulations to predict fire spread, but have also excluded urban areas from study (Carmel, Paz, Jahashan, & Shoshany, 2009). Monte Carlo simulations were not appropriate for this study because the of the historical nature of the work.

CHAPTER 3: METHODOLOGY

In this study, five methods are used that require further explanation: (1) collection of fire-related data from historic archival sources, (2) use of historic maps and images as a framework for kernel data analysis, (3) preparing and executing a kernel estimator for density of structures, (4) determining a threshold at which fires are guaranteed to spread to other buildings, and (5) organizing graphics and statistical tests for the relationship I hypothesize between spread of fire and density of structures.

Archival Research

Newspaper-based research provides a primary context for fire events that cannot be achieved by reading historic narratives of the times. By viewing daily and bi-weekly newspapers, the depth of detail is enhanced, though it is not perfectly accurate. This method provides a large sample of relevant information about the occurrences of fires in Montreal in the mid-nineteenth century. The two newspapers, *La Minerve* and the *Montreal Gazette*, represent different spheres of Montreal's population and interests, and are compared with each other to draw attention to the biases of these news sources. These two newspapers were compared by linking similar fires together based on the dates they were reported, any owner names mentioned, and the location of the fires. By comparing the reports in this matter, it was obvious which fires were reported in both newspapers and which were only documented in one of the sources.

La Minerve was a bi-weekly newspaper based in Montreal from 1826 to 1899, with two multi-year gaps (Bibliothèque et Archives nationales du Québec, 2011). This newspaper was chosen because it reported local news stories as well as national and foreign, and it was circulated extensively in Montreal and surrounding areas. As a French newspaper, it was politically aligned with French and Quebecois culture and values (Dzanic, 2009).

In contrast to *La Minerve*, the *Montreal Gazette* represents more conservative English values and business practices (Dzanic, 2009). The *Gazette* was published six days per week (with a weekly Sunday hiatus) from May through October, and three times per week during the winter months. This newspaper reported for the Montreal and Quebec City areas, including trade transactions at ports along the St. Lawrence River. This newspaper's main news section contain relevant fire information and usually appeared on the second page of each issue. Information about Montreal fires was gathered from this section and compiled in a spreadsheet containing owner names, fire location, number of buildings affected, and other useful details (Table 1). The newspapers are available on microfilm reels through McGill University. The results of the spatial analysis of these fires were compiled in a separate spreadsheet for statistical analysis (Table 2).

The main archival research for this project involved an in-depth survey of *The Montreal Gazette* from 1845 to 1850. A five-year analysis of fire data allows us to observe small-scale fires that may not have been headline news. It is likely that small fires were not always reported in the newspaper because they may not be considered as newsworthy as large-scale fires. Because the fire sample compiled from newspaper articles is already biased based on the degree to which the fires were newsworthy, it is important to not further this bias by looking only at headline news stories.

The 1845 to 1850 sample was chosen because this time period closely precedes the Great Fire of 1852, which burned 1200 buildings in Montreal and led to the adoption of stricter building codes (Redfern, 1993). Data was collected for 117 fires that occurred during this time period, but only ninety-seven of these could be mapped (Table 1). Events that could not be mapped lacked crucial information regarding location and/or magnitude and extent of the fire, and therefore could not be used for this study.

A one-year sample of *La Minerve* was also surveyed for fire information in order to highlight dissimilarities and biases between news sources. The year 1846 was chosen for survey because that time period also corresponds to the available housing data from the 1846 Cane map, and offers the most accurate fit to the contemporaneous landscape. I read each issue of *La Minerve* systematically from January 1846 through December 1846 through the online archives from Bibliothèque et Archives nationales du Québec (2011). Instances of Montreal fire reports were each noted and the account was saved in PDF format. A list was made with the details of the fire reports, including location, ownership, and the number of buildings burned.

The fire sample collected from the *Montreal Gazette* is assumed to be less accurate than *La Minerve* because this newspaper was focused on trade rather than local news, and only the major news stories (located on the second page of each issue) were surveyed. Due to the nature of the microfilm archive, not all of the *Gazette* issues were available for the time period, and some were damaged beyond functionality. However, the vast majority of newspapers was available and legible, ensuring a large and well-represented sample.

Fire reports in the *Montreal Gazette* most often reported the names of property owners and the nearest cross-streets of the damaged buildings. In order to verify the locations reported, the names of homeowners were compared to the 1848 tax roll, which listed address information and is available in digital form thanks to the MAP database (Sweeny & Olson, 2003). House numbers were rarely reported by the *Gazette* during this time, so mapped addresses are approximate. In cases where fire locations were identified only by one street, the fires were mapped at the approximate center of the street's length. Instances which only listed a neighbourhood, region, or owner were excluded from the study, as their locations could not be accurately mapped.

Fires from *La Minerve* were mapped using the same technique as those from the *Montreal Gazette*, but because they were not used for the same purpose as the *Gazette* fires, they were not given separate identification numbers or spread coding values. These fires were added to the map as a unique shapefile which was used to compare the 1846 fires from both newspapers. These fires were not used in the kernel density analysis because some of the data overlapped with fires reported in the *Montreal Gazette*. Including this data set would have counted several fires twice, and therefore could have skewed the results of the study.

Use of Historic Maps

The historic map used in this study was surveyed and drawn by James Cane in 1846 from public space, with an urban-commercial focus on land commodities under contract from the Municipal Corporation (Sweeny, 2006/2007). The Cane map was digitized with individual polygons for each building as part of the MAP historical geodatabase project for Montreal (Sweeny & Olson, 2003). This map displays individual buildings, but no corresponding addresses. A previously rectified digital image was used in this project, as well as a vector layer with individual polygons for each building. This map is not a perfect representation of the city, and although its building footprints are relied upon for accurate details in this study, I acknowledge that the map is not a direct proxy for Montreal's historic built environment. It is uncertain whether the lots and buildings were accurately subdivided on Cane's map. There is no indication of the types of construction materials used, but in the downtown (now thought of as "Old Montreal"), bounded by Craig, McGill, Lacroix and the St. Lawrence River, reasonably well-enforced bylaws required stone or brick construction with tin roofing. Various later sources suggest that many buildings represented on Cane's map had multiple owners with double walls and parapets to reduce spread of fire (Goad, 1881; Burgess, 2004).

Historic maps are notoriously difficult to work with due to a number of factors. Even with careful digitization and rectification, original maps from this time period are subject to poor surveying techniques during their creation (Sweeny & Olson, 2003). Despite the careful digitization of the Cane map, the building polygon layer cannot be viewed as an exact replica of the city at the time. Some areas of the Cane map are distorted, and we cannot rely on the accuracy of the map's projected street widths. Maps that were used for commercial purposes, such as the Cane map, also tend to be biased toward their intent, which could potentially decrease the accuracy of this study (Bromberg & Bertness, 2005).

Despite the shortcomings of historic map analysis, these resources can be an invaluable insight to the past. For more information and access to the MAP databases employed in this study, interested parties can consult the McGill University Libraries; the Walter Hitschfeld Geographic Information Centre; Robert Sweeny, History Department, Memorial University of Newfoundland; or Sherry Olson, Geography Department, McGill University.

Calculating Built Density Values

Kernel density estimation can be applied to datasets of point or line values, and produces a raster of the predicted sums of weighted bumps placed at each observation (Silverman, 1986; Gibin, Longley, & Atkinson, 2007). This type of analysis can be used to create a continuous raster surface of density values for a set of points or lines (Borruso, 2003). In this study, kernel density estimation is used to create a raster with continuous values of "urban density" in Montreal from the outlines of building footprints for 1846 (Map 1). This type of estimation can also be employed in hot-spot analysis, which is a similar application to that undertaken in this study (Maciejewski, et al., 2010).

The only subjective aspect of kernel density estimation is the bandwidth, or search radius, that the researcher chooses (Borruso, 2003). In this study, I applied several measures of bandwidth and cell size and chose the most precise one to be sampled (Map 1a). As the chosen cell size increases, the accuracy and detail of the raster output becomes less precise. For this study, I chose a five-meter cell size because it gives a precise measure of the kernel density for building centroids and follows the fire stop model created by Ren and Xie, described below (2004). A smaller cell size was deemed unnecessary because the project focuses at the scale of the whole city, and will not necessarily become more accurate with increased precision because the raster produces estimates of urban density rather than concrete known values.

The five-meter cell size was chosen because previous fire studies have shown that the minimum distance required between wooden buildings of any size to prevent spread is six meters (Ren & Xie, 2004). The kernel size of ten meters was determined by Ren and Xie's study as well, which shows that two-floor large wooden buildings must have at least ten meters of space between them in order to stop fire spread when no wind is present (Ren & Xie, 2004). This minimum value was used as the kernel radius because many buildings in the city were wooden, and this larger fire stop distance allows for the incorporation of buildings of all sizes rather than just small buildings, which have smaller fire stop radii. Because this study gives a general survey of the city, a single approximate fire stop distance is adequate for determining urban density.

The measurements chosen for cell size and search radius produce density values in units of meters of wall per five square meters of land. These units are rather arbitrary, as this study focuses on a comparison of these values in relation to each other. For the purposes of this study, the units will be implicit in the term 'density value'.

The fire data used in this study totalled ninety-seven separate fires encompassing 376 burned buildings, compiled from the Montreal Gazette from 1845 to 1850. Fifty-four fires did not spread, while forty-three spread from the building of origin to at least one other structure as described in the news account. Each fire-affected building polygon was identified in a new layer and over laid on the historic Cane 1846 map in order to identify patterns of fire spread in relation to the urban density of the city (Map 2).

The digitized Cane map does not contain street addresses or owner names in the attribute table, and it is rarely possible to determine precisely which buildings which were affected. When cross-streets were available, building footprints that best fit the newspaper description were identified as burned. In cases where only one road was reported, buildings were chosen from the middle block as a effort of standardization. The number of buildings that burned was always matched to that listed in the newspaper reports. If the report described “at least” a minimum number of buildings burned, this minimum value was mapped. By remaining conservative with the number and location of buildings, the study preserves accuracy as much as possible.

The GIS mapping components of this project were created with ArcGIS 9.3 software. The fires compiled through newspaper archive research were mapped as a layer and overlaid on a digitized layer of building footprints from the 1846 city map by James Cane (Cane, 1846). This building footprint layer was the basis for all subsequent shapefiles of buildings, such as fire locations.

Mid-nineteenth century Montreal was a mosaic of industrial and residential buildings; therefore it was crucial to account for variation in building size and shape as a factor in fire spread. To conduct this analysis, I used three types of functions in examining the density of building polygons. The feature-to-line function in ArcGIS 9.3 was used to first identify the outer walls of all buildings. The second fuction I used was kernel density estimation, which was calculated based on the outer walls of 6,437 buildings present on the 1846 Cane map using a kernel with a 5-meter cell size and 10-meter search radius. This was calculated based on the perimeters of each building in order to account for building size and shape in the predicted values of urban density. In other words, in each five-meter by five-meter cell, we ask how many other walls could spread fire to the cell from a ten-meter radius. The third step performed was the sampling of building centroids. These centroids were used to sample the kernel density raster as a standard representation for each building's density value.

In this study, I assume that all buildings were capable of spreading fires, but larger buildings were presumed to have a higher potential to spread. Therefore, urban density was calculated using the perimeter of each building, rather than the centroid, to account for structure size. This measure of urban density is quantified by overlapping the search radii of kernels established at the perimeters of buildings and assigning values to this overlap. Each five-meter by five-meter raster cell is assigned a value of overlap, thus quantifying the density of all parts of the city. The kernels can be pictured as three-dimensional fields in a city-wide Venn diagram.

This density is a visual demonstration of the clustering of buildings in Montreal's urban environment. The search radius, also known as bandwidth, was set at ten meters, which is approximately half of the average street width during the studied time period according to measurements taken from the Cane map. The kernel diameter was chosen because streets are frequently used as fire breaks (either intentionally and incidentally), and typical fires would be less likely to cross major roadways. This choice was reaffirmed by Ren and Xie's study of fire stop distances (2004). Of course, there are exceptions to this rule, and large fires can often spread over roadways. St. Lawrence Street (Boulevard St-Laurent) and many other streets were widened after the 1870s, in part as a response to the Great Fire of 1852 and the role of the roadways as barriers to fire spread (Gilliland, 2002). Each building was coded as a spreading (1) or non-spreading (0) fire.

Determining a Threshold of Urban Density that Causes Fire Spread

A threshold for guaranteed fire spread was hypothesized to exist due to the nature of fires as contagious entities. I thought that it was likely that a specific density existed at which fires were not only able to catch from one building to another, but did so in a high proportion. It was likely that fire spread increased along with built density, but at a certain level of built density, fires couldn't avoid spreading due to the proximity of other flammable structures. This study shows that while fire spread and built density increased together, they also experienced a threshold, after which all observed fires spread.

In order to determine the plausibility of a threshold of built density that creates a hazard for fire spread, I examined the two sets of fires separately; the mapped fires were split into separate layers determined by whether they spread or not. For this study, spreading is defined as the occupation of two or more adjacent buildings by fire. Non-spreading fires are defined as fires that are confined to a single building, regardless of size. Fires were determined to have spread or not based on the description given in *The Montreal Gazette* and *La Minerve*. Spreading fires were reported as affecting multiple buildings, multiple owners, and insurance policies, as well as described explicitly in the details of each event. Both spreading and non-spreading fires were selected from the 1846 building footprint polygons of fire-affected buildings.

Fires from the *Montreal Gazette* were mapped by selecting the buildings from the Cane 1846 maps that best fit the description of fire locations given by the surveyed newspapers. Each building in the Cane 1846 shapefile was coded with a value of 0, 1, or 2 that signified a lack of fire, a non-spreading fire, and a spreading fire, respectively. This attribute was later used to create a binary variable for fire-affected buildings, which had 0 as a non-spreading fire and 1 as a spreading fire. This binary can be seen in a color-coded choropleth map of fire-affected buildings (Map 3 and 3a). An identification number for each separate fire was added to all city buildings during the fire mapping process, which matched the identification number given to the fires when they were compiled from the *Montreal Gazette*. The *Montreal Gazette* fires were exported as a separate shapefile that was added to map and layered on top of the 1846 buildings.

Statistical Methods

STATA statistical software was used to look for a correlation between built density and spreading and non-spreading fires. A logistic regression was performed using kernel density estimation values as the independent variable and spread of fires as the binary dependant variable (Table 3). A simple correlation was also performed on these two variables (Table 3a). Ultimately, these statistical methods did not prove to show significant relationships between the variables. This is likely to be attributed to the fact that the data set of kernel values for spreading fires is very wide; it encompasses nearly all kernel values for non-spreading fires. STATA was also used to summarize the data sets for spreading and non-spreading fires (Table 4).

Urban density values were graphed against both building perimeter and area variables separately in order to show the distribution of density values for both fire-affected buildings and the built landscape as a whole (Figures 1 and 2). By using area and perimeter as dependent variables, the spread of data can be better analyzed than it could by only graphing the binary values. A cumulative graph was created with the number of all buildings and their urban density values in order to show the distribution of spreading and non-spreading fires in fire-affected buildings (both spreading and non-spreading) in comparison to all city buildings (Figure 3).

CHAPTER 4: RESULTS

In buildings with urban densities above .22 meters of wall per five square meters, outbreaks of fire all spread to nearby buildings (Figure 1). While spreading fires occur in nearly the entire range of densities, non-spreading fires occur only at low densities of zero to .22. This finding demonstrates that unless a building is very isolated (below a density value of .04), fires are likely to spread. However, if a fire occurs in an area with a density of less than .22, it also is likely to remain in the building of origin without spreading.

The mean values of kernel density estimations for spreading and non-spreading fires were calculated in order to observe a difference in the average values of spreading and non-spreading fires. The minimum and maximum values for the two types show the ranges of kernel density estimation values for the two fire types. We can observe that there is a difference in the distribution of the two types, with spreading fires occurring at a higher average urban density than non-spreading fires (Table 4a). The mean value of spreading fires is .20 while the mean value of non-spreading fires is .14, which shows that non-spreading fires occur in a generally lower pattern of kernel densities than spreading fires.

A threshold occurs around urban densities of .2, where non-spreading fires cluster. This threshold indicates an upper limit for non-spreading fires and shows that above this level of urban density, fire occurrence will result in spread. The threshold is specific to Montreal during this time period, as it could shift based on other factors such as different climates, weather conditions, and building materials.

Fires that occurred in areas with a built density lower than 0.04 do not spread, but the sample size for buildings of this density was relatively low. However, densities this low indicate that buildings are quite isolated and would not have any neighbouring structures to spread to.

Buildings with such low densities do not occur frequently in this study because the observed area is metropolitan and lower-density buildings in the observed region often neighboured outbuildings such as stables, sheds, and barns.

While the mean built densities of spreading and non-spreading fires were different, a correlation between the two fire types was not observable because the range of spreading fires encompasses the set of non-spreading fires (Table 4). The correlation yielded a value of .26, which does not indicate a strong relationship between the data sets (Table 3a). A similar issue occurred with the logistical regression, which resulted in a pseudo-R^2 of .11, which is quite low (Table 3). These calculations seem to indicate that the spread of fires is not highly affected by levels of urban density, but this suggestion is nullified in the graphing of the data against variables of area and perimeter (Figures 1 and 2), as well as when observing the range of each binary value for kernel density estimation.

The distribution of the kernel density values for both spreading and non-spreading fires followed the same trend as the values for all city buildings (Figure 3). They all follow an approximate sigmoid curve, with all buildings having the most smooth curve due to its larger dataset. This shows that the most frequent urban density values for spreading fires correspond to the most frequent values for the city as a whole. The flatter curve of the non-spreading fires and steeper curve of spreading fires show that urban density positively affects the frequency of spreading fires more drastically than fires that do not spread. The outbreak of fire could occur anywhere in the city, but its likelihood of spreading is dependent on its built surroundings, as evaluated by urban density.

CHAPTER 5: DISCUSSION OF FINDINGS

Trends in Urban Density Values

Urban density is a frequently changing aspect of cities, which is affected by continuous development, destruction and sprawl of the urban landscape. On the whole, urban density is greatest near the center (docks) and has increased over time. This model of Montreal's fire spread risks shows that above the risk threshold of .2, fires will spread. However, fires below this threshold are also susceptible to spread unless they fall below a very small density. Above the density of .22, this model demonstrates a 100% probability that fires will spread to nearby buildings. Although it is impossible to completely guarantee fire spread, we can conclude that fires occurring in buildings above this density will spread if not acted upon by external forces such as firefighting measures or natural extinguishment.

A correlation between the trends of spreading and non-spreading fires is not observable through the statistical analysis performed in STATA because spreading fires occur in both low- and high-density areas, encompassing most of the instances of non-spreading fires. This may indicate that once fires spread, they can affect areas of lower density than are necessary for the spread to begin. This conclusion is likely because fires can increase in heat and magnitude as they spread (Himoto & Tanaka, 2008).

Other factors affecting fire spread, such as weather, building material, and prevalence of arson, are not treated in this study, due to both the extent of research and historical limitations. While rough weather data could be gathered from newspapers, the accuracy of this data would not be guaranteed. Many fires were reported as arson or suspected arson, which is a potential topic for further study. In some instances, the *Montreal Gazette* reported the building material of affected structures, but this data was not complete enough to take into account. If this study had been conducted using later maps that included building type, this variable could have been included.

Smaller buildings are likely to be made of wood, such as sheds, stables, and outbuildings. It is clear from the distribution of building areas that most fire-affected buildings had areas below 500 square meters (Figure 1). A closer look at small buildings shows that spreading fires become even more prevalent as urban density increases (Figure 1a, 3a). Small buildings are defined as structures with areas below 148.453 square meters, as determined by the first division of the Jenk's Break (Figure 1b). These buildings made up nearly 80% of the city's built environment. By looking at the sample of small buildings, I eliminate the issue of large outliers that make data trends more difficult to identify. It is clear that small buildings were more likely to suffer from spreading fires when they were in higher densities, as indicated by the distribution of urban densities of spreading versus non-spreading fires (Figure 1a). The sharp increase in spreading fires at an urban density of about .10, coupled with the slowly rising slope of the non-spreading fire frequency, shows that spreading fires became much more prevalent along with increasing urban density (Figure 3a).

A one-year sample of 1846 fires was taken from *La Minerve* newspaper in order to identify publishing biases and the subjectivity of historic archive studies. Twenty fires were reported in *La Minerve* in 1846, while eighteen fires were reported for this year in *The Montreal Gazette*. Seven of the fires were reported in both newspapers, and five of these were spreading fires. It is clear that the two newspapers did not report the same sample of fires, but it is unclear as to whether this was due to political differences, language or ethnic discrimination, or simply by mistake. Publishing days may have affected this discrepancy as the two newspapers had different weekly schedules, but determining the extent of this factor would require study beyond the scope of this project.

Applying the Urban Density Model to the Great Fire of 1852

In order to test the functionality of the urban density threshold, I looked at the case of Montreal's Great Fire of 1852. A shapefile of this fire's approximate extent was available through the MAP database (Sweeny & Olson, 2003). The urban density values of buildings within the extent of the fire were identified and summarized to assess whether the 1845 to 1850 fire spread threshold was relevant to the Great Fire. The average density value for fire-affected buildings in this fire was .21, which falls just above the threshold density of .2. In addition, a statistical summary shows that 40% of buildings burned in the 1852 fire had urban densities greater than .22, the highest non-spreading fire density from the 1845 to 1850 fires (Map 5). This suggests that buildings with lower densities are more likely to contribute to the expansion of a fire that has spread from a more dense area than if the fire had originated in the lower-density building. The size of this fire is also important to consider, as it is far larger than the fires observed in the previous decade. Overall, the threshold remains a viable measure for the likelihood of fire spread when used in this case study.

Project Limitations

Any historic study is subject to the whim of preserved memory and the fickle reconstruction of a past that the researchers did not experience. It is necessary to identify the limits of historical studies in order to interpret the gathered data. My use of newspapers to gather information about historic fires is limited by the fact that newspaper writers and editors do not write with the purpose of providing complete and accurate details about all historic events. Like historic maps, the memories of others are subject to their intentions and biases, many of which we cannot easily identify today. It is likely that not all fires were considered newsworthy, especially if they did not require assistance from firefighters or other civic organizations. Large fires are likely to be sensationalized, especially when involving arson, loss of property or life, and fire-fighting heroics.

A serious limitation in this exercise comes from the lack of numbered street addresses in Montreal at the studied time, which reduces the accuracy of fire locations to the block in which they occurred (determined by information provided in individual news stories such as nearest cross-streets). This area is larger than the kernel bandwidth. In some cases, such as if a block contains the same number of buildings that burned, the accuracy is as precise as it would be if cadastral data was available. In other instances, it is impossible to tell whether the correct building has been identified within the block. However, the spatial distribution of buildings in Montreal is such that many areas have similar building distributions within individual blocks. Although numbered buildings would certainly improve the accuracy of the study, their absence is not greatly detrimental to the study as a whole.

CHAPTER 6: CONCLUSIONS

The Fires of Mid-Nineteenth Century Montreal

This study enables the characterization of the pattern of built density of Montreal in the 1840s. By identifying a threshold for inevitable fire spread, I predict and identify areas at risk of developing major conflagrations by highlighting all areas with urban density values above the specified threshold (Map 4).

The spread of fires in Montreal from 1845 to 1850 was affected by the spatial density of buildings. This trend can be observed from the presence of only spreading fires above the density value of .22. Areas with buildings that are close together are more susceptible to widespread fire damage, especially when the urban density value exceeds .2 meters of outer wall per 5 square meters.

Fire spread is more likely to occur in dense urban areas, but it is not the only factor involved. This research focuses on one major factor in the spread of fires, but does not cover important variables such as weather and building material. Further studies on this topic could employ multivariate logistic regression with spread as the binary dependent variable. This type of study would be better suited for more recent datasets, as Montreal's weather conditions and building material are not well-documented. Other potential factors in fire spread danger include the spread of embers (branding), topography, and types and quantities of fuel (Rehm, Hamins, Baum, McGrattan, & Evans, 2001).

Once fires spread, they can affect buildings with densities well below the threshold for guaranteed spread. This is apparent because spreading fires are present even in buildings that have relatively low densities (Table 2). The threshold of urban density identified by this study suggests that fires are more likely to spread when occurring in neighbourhoods that approach and surpass this value. The density indicates that areas with close buildings are more susceptible to widespread fire damage. It is important to note that the city as a whole has an incredibly variable density, and that various areas of the city had not approached this threshold.

The threshold density is also subjective to temporal and spatial constraints, as continuous changes to the urban landscape shift the extent of building proximity and the viability of fire spread. The methods used to identify a fire spread threshold can be used in other contexts, but will likely yield different results for each separate location and time period observed.

Broader Projections

Developing cities in many countries can benefit from this study by using it as a precautionary tool. Cities with similar developmental conditions can view this study as a proxy for their own expansion. As with Montreal's building code reforms, other cities with many wooden buildings may benefit from stone or brick façade requirements as they approach a similar built density.

Further studies would be required to detail the wealth distribution in Montreal at this time, and compare fire-affected areas with poverty. By identifying the value of fire-affected buildings in comparison with Montreal's average building values, the socio-economic status of the city could be identified. The 1848 tax roll lists property values, number of families, and rent level, as well as occupant households and lot owners. If the owners and lots could be properly georeferenced, this database could be used to conduct socioeconomic analyses. This type of research could further recent research in slum studies, which identifies building density as a major cause in widespread fires in impoverished areas (United Nations Human Settlements Programme, 2003). It would also be interesting to further this study by comparing the urban density threshold identified here to that of other historic fires such those in Istanbul and London.

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APPENDIX

Table 1: Fires in the Montreal Gazette, 1845-1850

Year	Fire Location	#Buildings	Owner	Spread
	13 Hospital St	2	Dubois	Yes
1845	St. Francois Xavier St	2	Mills	Yes
1845	St. Lawrence St	1	Bernard D?	No
1845	St. Dominique St. behind Steller's Hotel	3	Siebold	Yes
1845	St. Maurice St. Church	1		No
1845	Longueuil	2		Yes
1845	village of the Tanneries	3		Yes
1845	Griffintown	1	Ward	No
1845	Notre Dame St. near St. Helen St.	1	Ferrier	No
1845	Griffintown		Gibbon	
1845	Vine St. between Sanguinet and St. Denis	1	Teit	No
1845	St. Denis	1	Jackson	No
1845	corner of Lagauchetiere and Bleury	1	McDonald	No
1845	Griffintown near Willington St	4	Taily	Yes
1845		2	Neil Campbell	Yes
1845	sheds near St. Lawrence Market	2		Yes
1845	Griffintown-Queen, Gabriel, Prince, Naz, Well	60	Swale	Yes
1845	Griffintown (King Street)	7	H. Allan	Yes
1845	Griffintown- George St.	4	Thompson	Yes
1845	Shed behind Mack's Hotel	1		No
1845	226 St. Paul St. (Near McGill St.)	9	Thomas Ruston	Yes
1845	Quebec Suburbs			
1845	NW corner of Queen Square, St. Mary's Sub.	3		Yes
1845	Griffintown- Queen St; St. Paul St.		Thompson	No
1845	St. John St. (Prince of Wales' Hotel)			No
1845	Head of Queen St.	1	Andrews	No
1846	30 St. Nicolas Tolentin	1	Dumas	No
1846	Quebec Suburbs	1	Molson	No
1846			British-Am Land	No
1846	College St.		Redhead	No
1846	Aylmer St. near Beaver Hall	5	Strathearn	Yes
1846	between Notre Dame and Little St. James St.		McCauley	Yes
1846	Head of Sanguinet St.	5		Yes
1846	Dalhousie St.	8	Dorwin	Yes
1846	Lagauchetiere near the Methodist Church	4	Lamb	Yes
1846	St. Paul St (south side)	3	Gordon	Yes
1846	Current St. Mary	7	Thompson	Yes
1846	St. Joseph St.		Pidgeon	
1846	Notre-Dame St.	1	Perry	No
1846	Dunder	4	Marsh	Yes
1846	Main St of St. Antoine suburb	3	T. McCreedy	Yes
1846	St. Antoine St.	1	Djarmy	No
1846	McGill St.	1	Kershaw	No
1846	Syke's Tennery, Griffintown		Cutter	Yes
1847	Notre-Dame St.	1	J. R. Frazer	No
1847	St. Joseph St. and Guy	1	Thomas Forsyth	No
1847	St. Maurice St.	2		Yes
1847	Mountain St.	2	Rodier	Yes
1847		4	John Mathewson	Yes
1847	St. Dominique St.	1		No
1847	St. Elizabeth St.	1		No
1847	Great St. James St.	1	Mrs. Tate	No
1847	Mountain St.	1	G.W. Wicksteed	No
1847	Rear of Transcript office on Hospital St.	1		No
1847	Craig St. near Bleury	1		No
1847	Mountain St.		Asselin	??
1848	Griffintown (Gabriel St.)	1	Noah Shaw	No
1848	St. Maurice St.	1	Montmarquet	No
1848	Main St. in St Lawrence Suburbs	1		No
1848	Hermine St. (stopped intersection with Craig)	20		Yes

1848	Sherbrooke St. (Devonshire Place)	4	D. L. McPherson	Yes
1848	corner Lagauchetiere and St.Charles Barromee	1	Thompson	No
1848	Craig St. in the rear of Banque de Peuple	2	Hutchinson	Yes
1848	Bonaventure St.	8	John Jones	Yes
1848	Griffintown- Murray St.	1	Thomas McGrath	No
1848	College St. in front of the Catholic College	5	T. Laflamme	Yes
1848	Cote St. Paul	3	Evans	Yes
1848	St. Lawrence Toll Gate Hotel	1		No
1848	Hospital St.	1	Maitland and	No
1848	Griffintown- Gabriel St.	1		No
1848	corner of St. Peter and St. Paul St.	1	Asselin	No
1848	172 Notre-Dame St.	1	Arthur	No
1848	off Bonaventure St.	1	Jeremie	No
1848	St. Joseph St.	1	Bridge	No
1848	corner William & Colbourn, St. Ann Suburbs	1	Drumgoold	No
1848	St. Catherine St.	1	Hugh Allen	No
1848	Bonsecours Hotel	1	McAulay	No
1848	Craig St.- Haymarket and St. Antoine St.	6	McKee	Yes
1848	St. Lawrence between Main and St. Dominick	8	Jobin	Yes
1848	between St. Philip and St. Urbain St.	1		No
1848	Aqueduct St.	2	L. Blache	Yes
1848	Rear of St. Patrick's Church	1	the Fabrique	No
1848	Notre-Dame St.	1	Sadlier	No
1849	Griffintown- Colborne St.	1	Magrath	No
1849	123 Craig St.	7	Kelly	Yes
1849	St. Henry St. and St. Maurice St.	2	Jean Bruneau	Yes
1849	St. Paul St., 2nd house from McGill St.	1	D. P. Ross	No
1849	Lagauchetiere near church, Quebec Suburbs	4	Neilson	Yes
1849	corner St. Gabriel and Notre-Dame	1	John Tiffin	No
1849	corner of William and Colbourn St., Griffintown	2	Adams	Yes
1849	Government Emigrant Sheds	1		No
1849	foot of Alexander St.	5	Ostell & Co.	Yes
1849	corner of Notre-Dame and William St.	1	Arthur Samuels	No
1849	Griffintown- Ann St.	1	Irwin	No
1849	rear of houses at Beaverhall Place			Yes
1849	St. Elizabeth St. near Champ-de-Mars	40	Lamothe	Yes
1849	George St, crossed the st to corner of Vitre St.	6	Goodwillie	Yes
1849	Notre-Dame St.	2		Yes
1849	corner Notre-Dame and St. Gabriel	1	William Skakel	No
1849	St. Lawrence and St. Charles Borrommee	7	Bowie	Yes
1849	St. Hubert and Mignonne St.	1	Peter Devins	No
1849	corner St. Dominique and Vitre St.	5	Racioot	Yes
1849	near St. Joseph and Mountain St.	1		No
1849	St. Paul St. under Mack's Hotel	1	Thomas Wilson	No
1849	St. Urbain St.	4	Phillips	Yes
1849	10 DeBleury St.	1	John Ryan	No
1849	Bellevue Terrace (between Guy and Mountain)	1	Charles Phillips	No
1849	159 Notre Dame	1	Macrow	No
1849	corner of St. Joseph and Acqueduct St.	3	Asselin	Yes
1849	corner Dorchester and St. Constant	1	J. B. Hooper	No
1849	St. Lawrence Market	1		No

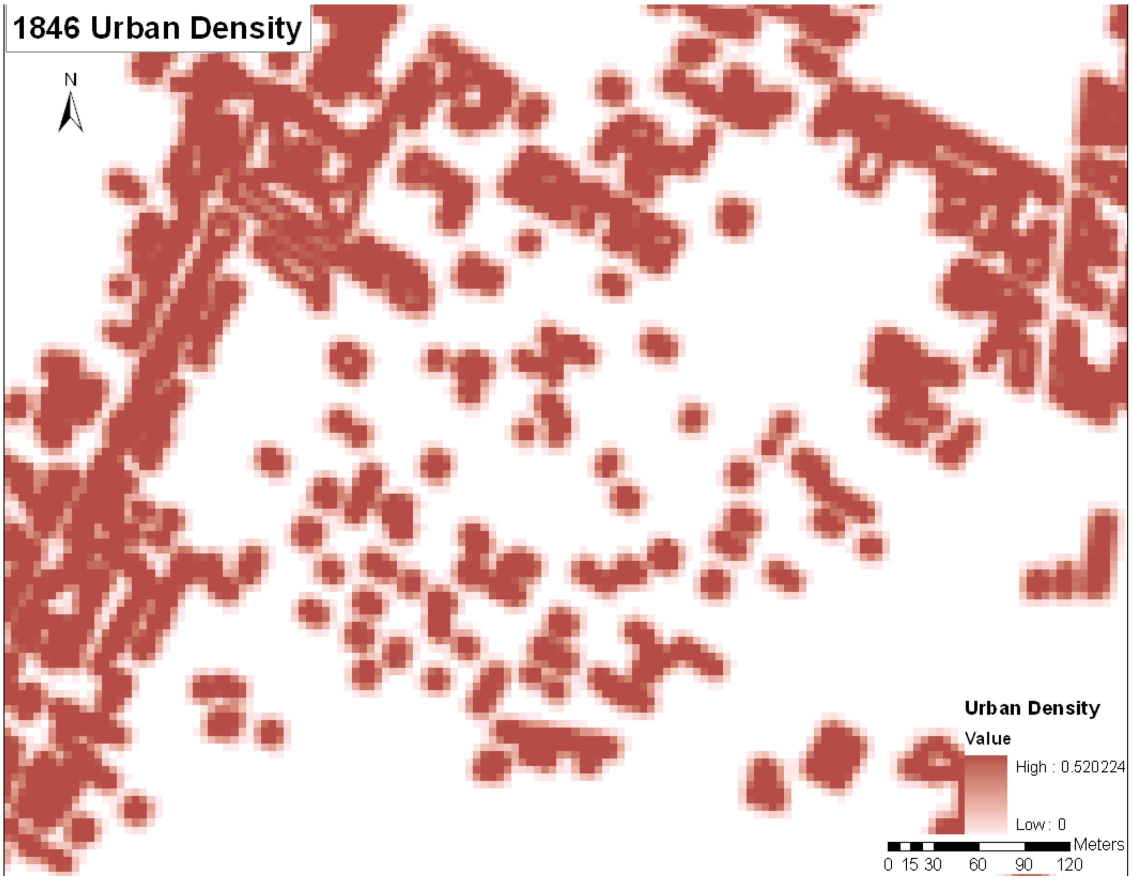
This table shows the database for fire data collected from the Montreal Gazette. Fires highlighted in yellow did not yield enough information to be mapped.

Fire	Kernel Density	Spread Binary
111	0.00000000000	0
106	0.01811870000	0
99	0.04223409000	1
40	0.04612028000	1
85	0.04912491000	1
61	0.05113641000	0
44	0.05635698000	1
44	0.05898045000	1
44	0.05968283000	1
72	0.06343208000	1
82	0.06418014000	0
40	0.06423612000	1
44	0.06471178000	1
41	0.06557372000	1
73	0.06733282000	1
73	0.07515633000	1
40	0.07628025000	1
12	0.07828478000	1
40	0.08329726000	1
24	0.08616219000	0
40	0.08792488000	1
42	0.09051598000	1
16	0.09594072000	1
44	0.09609362000	1
105	0.09645906000	1
107	0.09886411000	1
40	0.09905740000	1
40	0.10006730000	1
114	0.10113760000	0
19	0.10251150000	0
103	0.10292830000	1
37	0.10325440000	1
49	0.10404510000	0
12	0.10432680000	1
40	0.10710010000	1
63	0.10786730000	0
59	0.10968550000	0
40	0.11145570000	1
51	0.11369860000	0
12	0.11386570000	1
85	0.11494100000	1
16	0.11510320000	1
41	0.11516630000	1
65	0.11518700000	0
16	0.11519090000	1
40	0.11612900000	1
40	0.11626760000	1
40	0.11709370000	1
41	0.11855000000	1

Table 2:

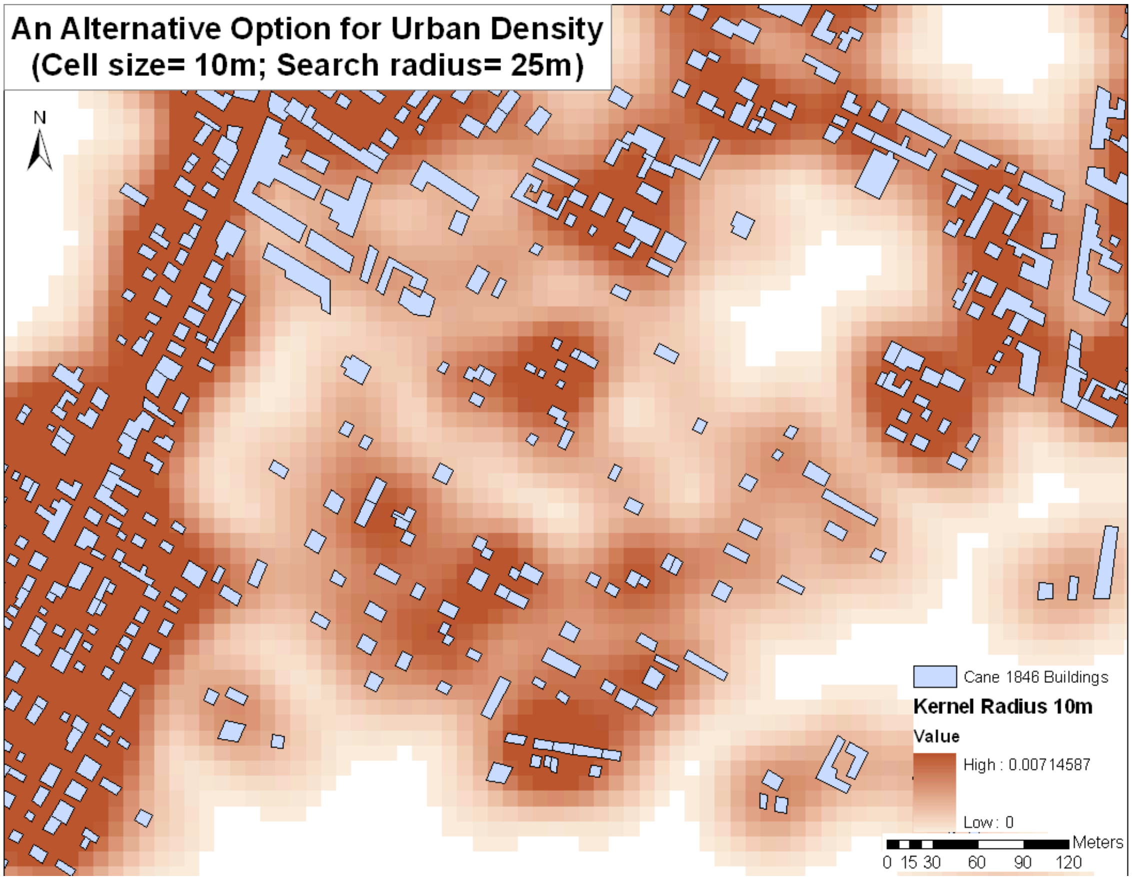
This chart shows the fifty lowest kernel values for fire-affected building observations. It is obvious that both spreading and non-spreading fires occur in low-density areas. From this observation we can also conclude that as fires grow larger, they can spread to buildings that may have been otherwise unaffected in smaller spreading fires.

Map 1:



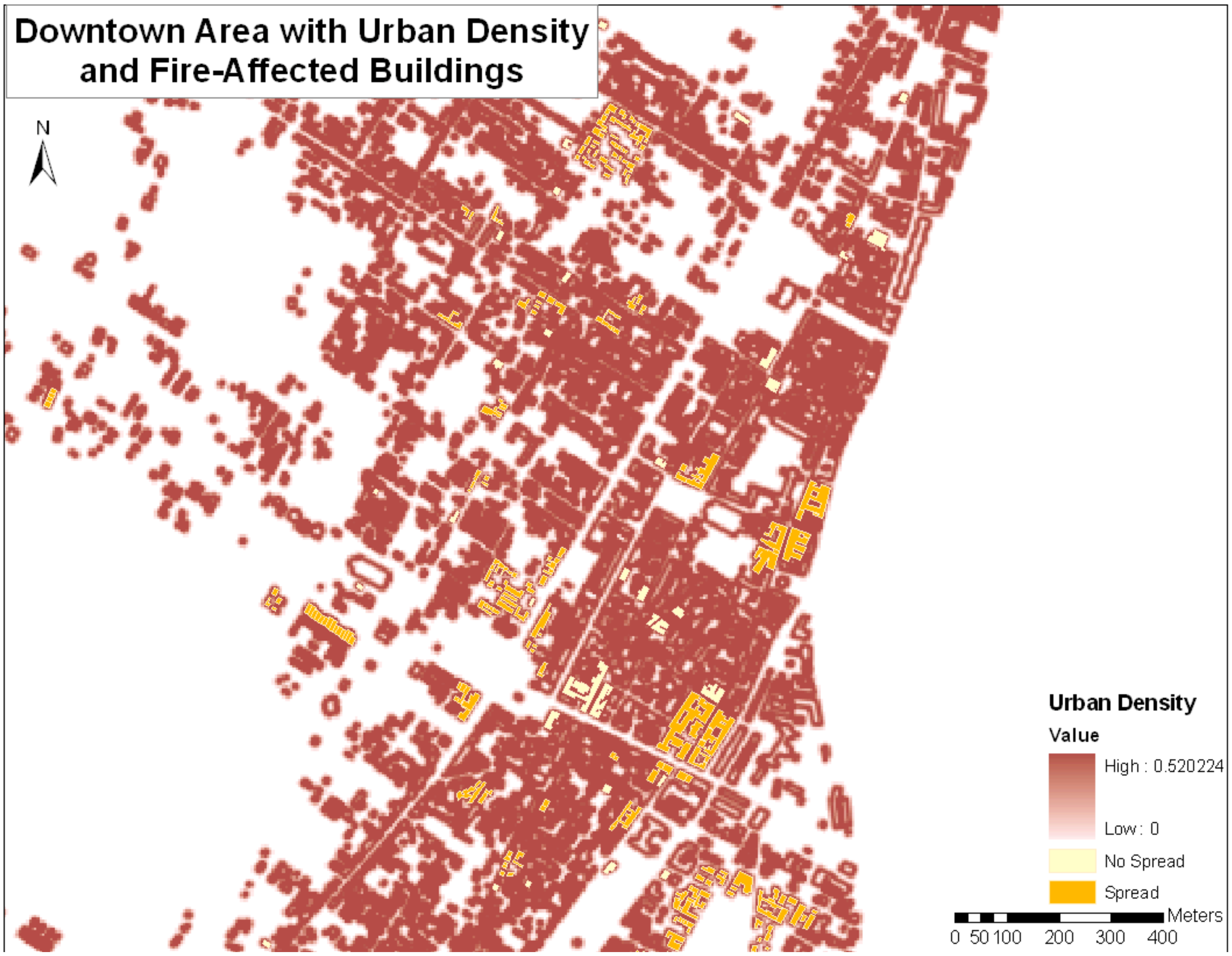
The chosen urban density is shown above, with a 5m cell size and 10m search radius, determined by the work of Ren and Xie (2004).

Map 1a:



An alternative urban density (with the buildings in the area) is shown above, with both a larger cell size and search radius. It is clear that the smaller values used in the chosen density layer give more precise values to the urban landscape.

Map 2:



This map shows the prevalence and distribution of spreading and non-spreading fires in the central business district of Montreal in the 1840s. It is clear that spreading fires are clustered in higher-density areas of the city.

Table 3:

```
. logit  spreadbinary kernelvalue

Iteration 0:   log likelihood = -154.71478
Iteration 1:   log likelihood =  -137.7605
Iteration 2:   log likelihood = -136.15213
Iteration 3:   log likelihood = -136.14833
Iteration 4:   log likelihood = -136.14833

Logistic regression                               Number of obs   =        376
                                                  LR chi2(1)      =      37.13
                                                  Prob > chi2     =     0.0000
Log likelihood = -136.14833                       Pseudo R2       =     0.1200
```

spreadbinary	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
kernelvalue	14.95562	2.715821	5.51	0.000	9.632705	20.27853
_cons	-.7825735	.4474743	-1.75	0.080	-1.659607	.0944601

A logistic regression was performed using STATA with binary (0 or 1) spread values as the dependent variable and kernel density estimation value as the independent variable. The pseudo-R2 value was .12, which indicates that the fire spread is not dependent on urban density. The relationship between the variables is masked by the overlapping ranges of built density values for spreading and non-spreading fires.

Table 3a:

```
. corr  spreadbinary kernelvalue
(obs=376)
```

	spread~y	kernel~e
spreadbinary	1.0000	
kernelvalue	0.3026	1.0000

The correlation between the binary spread value and kernel density estimation value have a correlation value of .30.

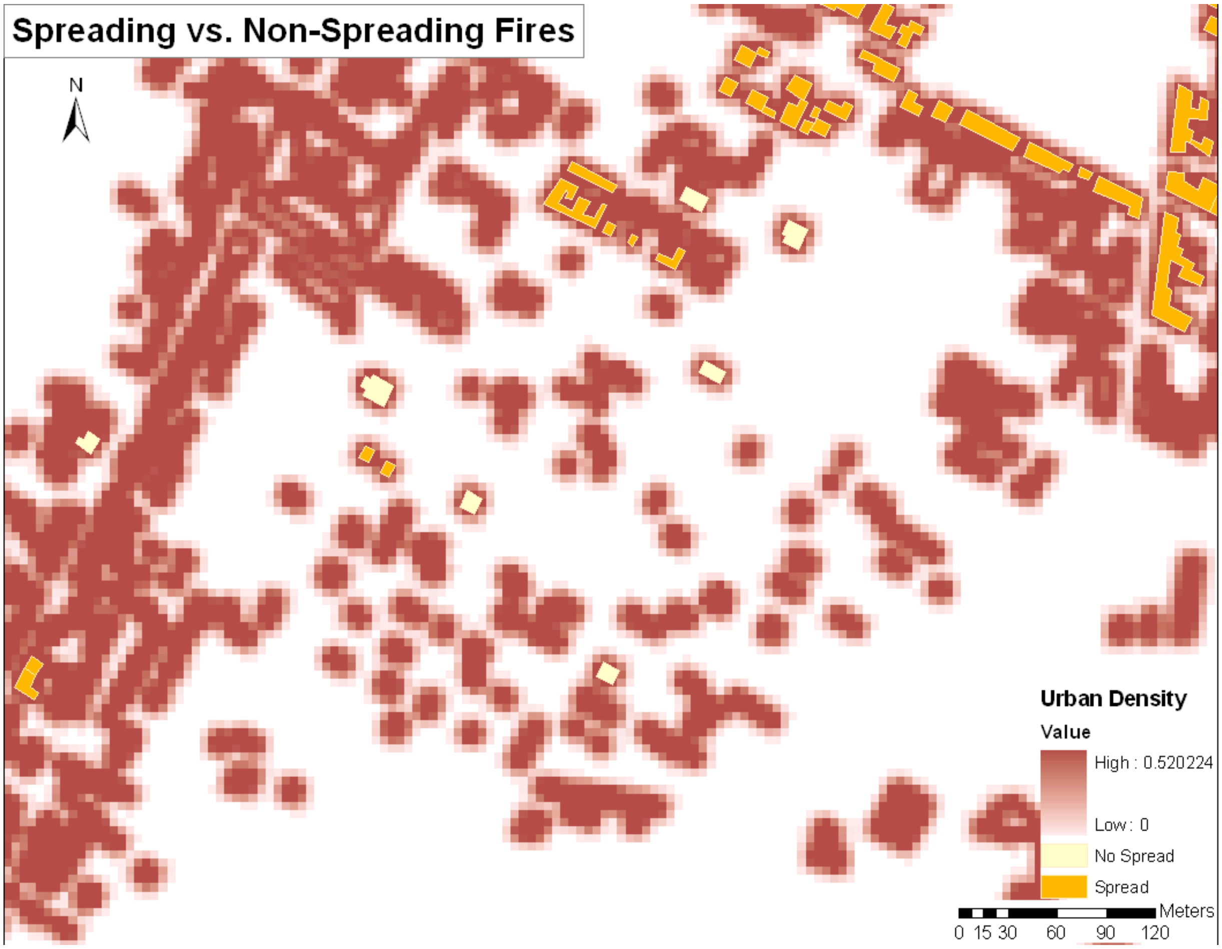
Table 4:

```
. summarize  SpreadKernel NoSpreadKernel

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
SpreadKernel |        322     .201312    .0667792   .0422341   .3834571
NoSpreadKe~l |         54    .1435905    .0426992          0   .2207015
```

The range of values for urban density for spreading fires is from .04 to .38. The range urban density values for non-spreading fires is from 0 to .22. The mean urban density value for spreading fires is .20 and the mean urban density value for non-spreading fires is .14. These values indicate that a threshold exists, above which can only spread.

Map 3:

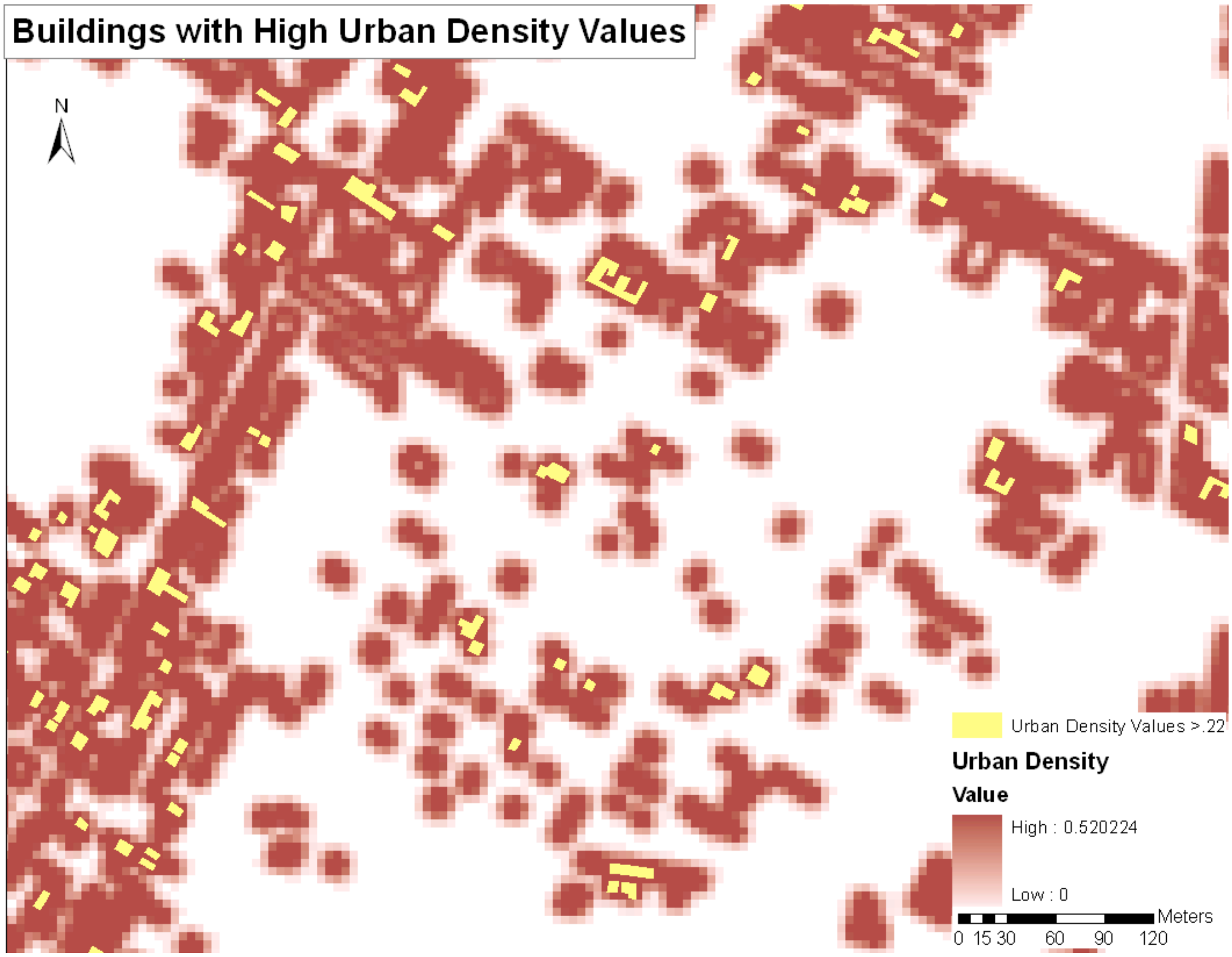


Fire-affected buildings in Montreal from 1845-1850 are shown on this map of the Griffintown area. The kernel density estimation raster used in this map has a 5m cell size and 10m search radius.

Map 3a:

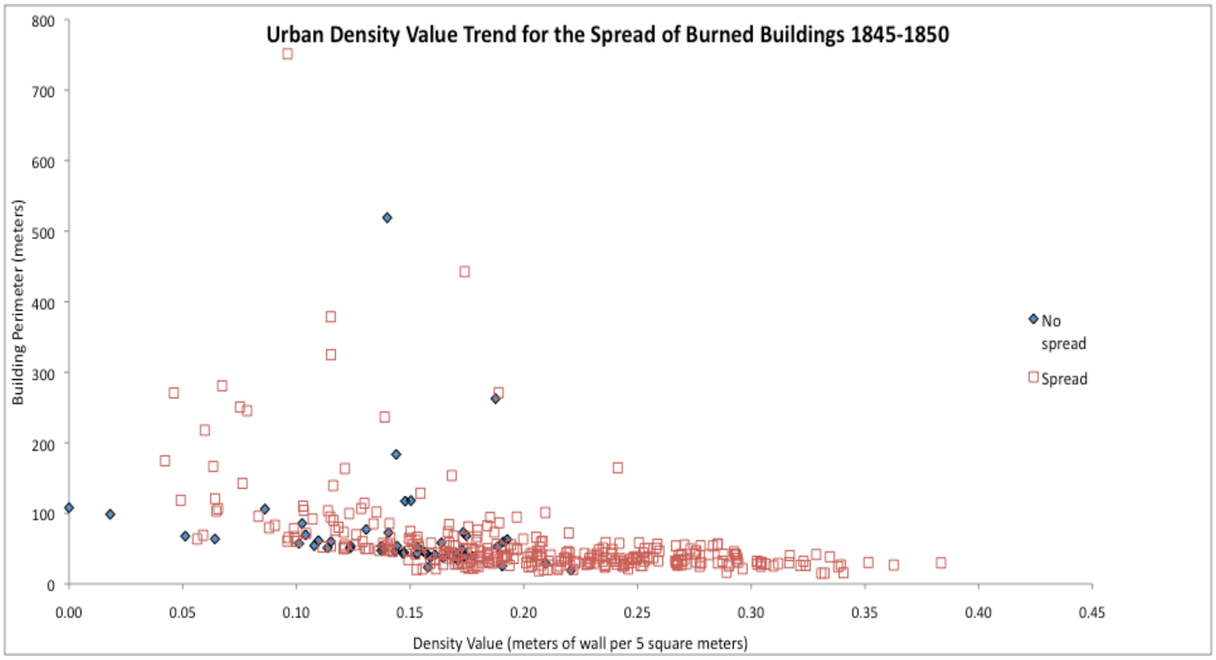
Spreading fires in Griffintown are shown on this map, providing a visual demonstration of the clustering of spreading fires in very dense areas, as well as their presence in less dense places.

Map 4:



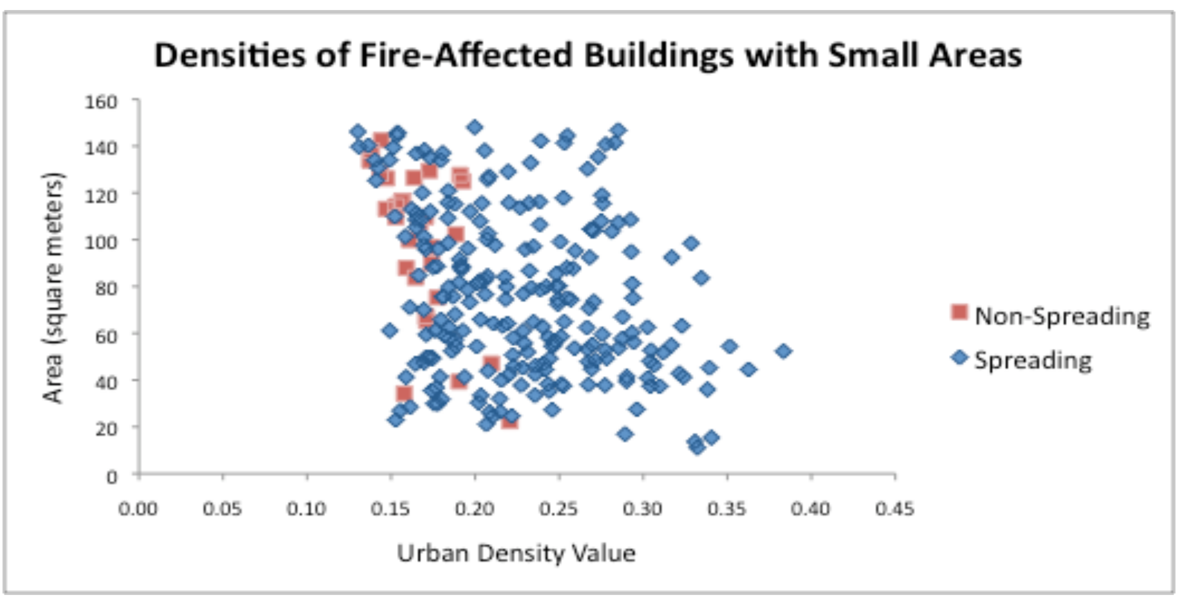
This map shows all buildings in the Griffintown area of Montreal that occur in areas of urban density greater than .22. These buildings are deemed "at risk" of fire spread. It is clear from this map that buildings with high densities are common in the city at this time.

Figure 1:



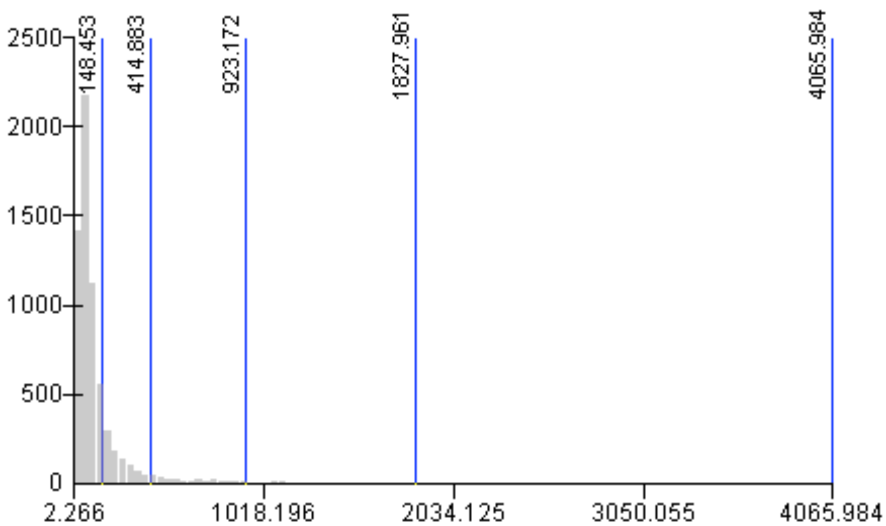
Non-spreading fires do not extend beyond a density value of .22, while spreading fires appear over a wider range of values.

Figure 1a:



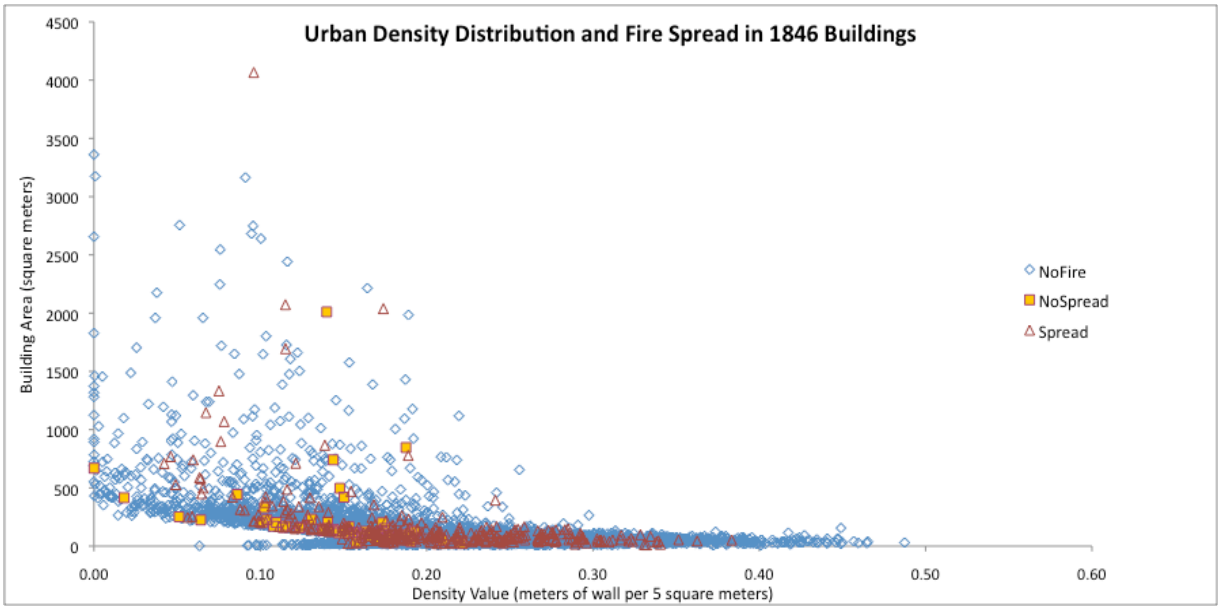
The urban densities of small fire affected buildings demonstrate significant prominence of spreading fires throughout the range of densities, and non-spreading fires only in lower densities.

Figure 1b:



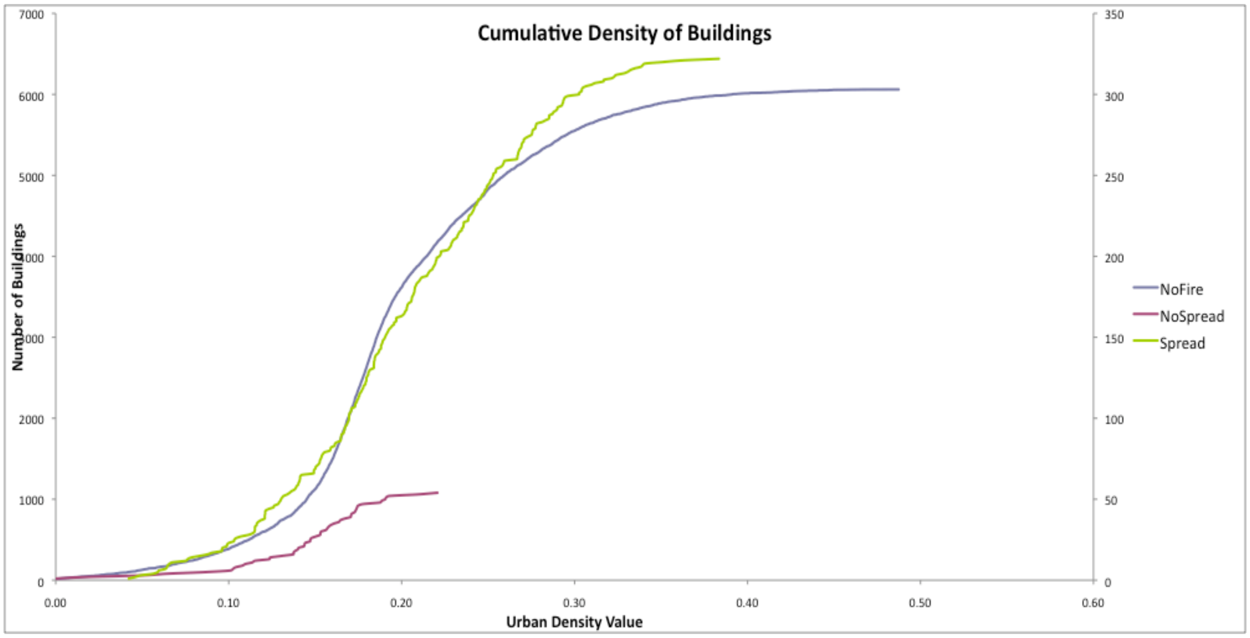
The Jenks breaks shown here demonstrate that a natural break in building areas occurs at 148.453 square meters. This value was used as the determinant for whether buildings were classified as “small” or “large”.

Figure 2:



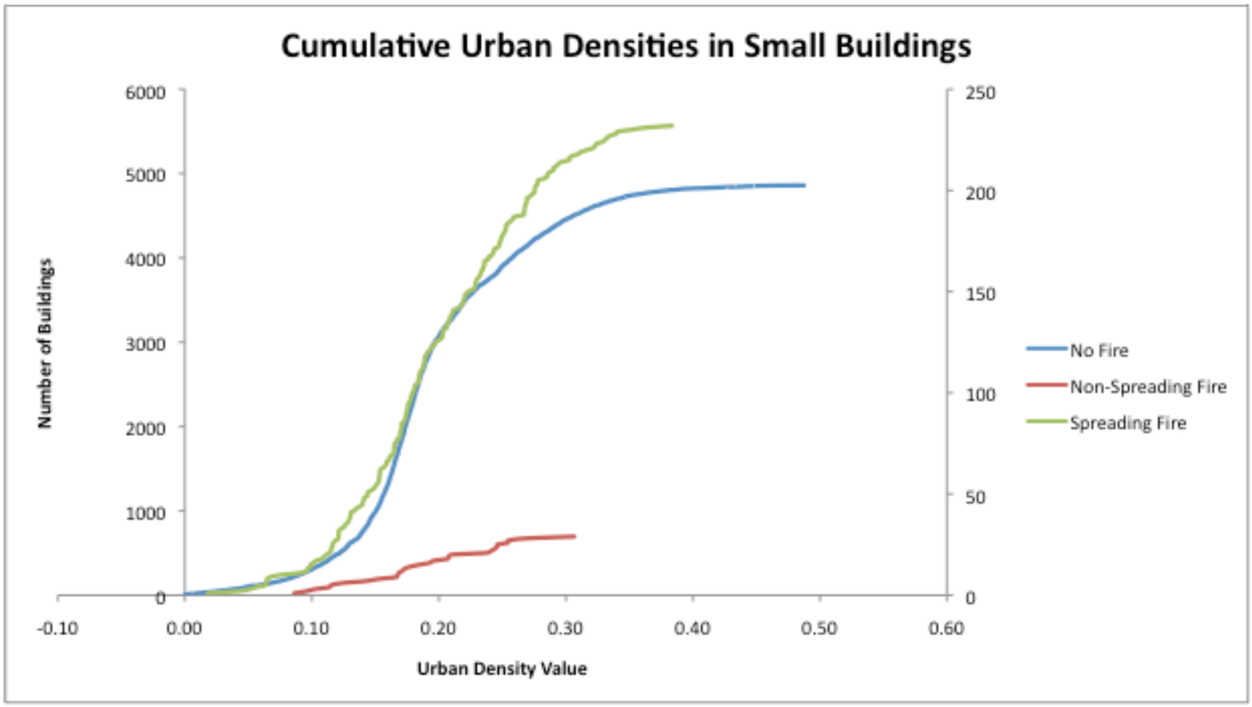
When viewing all buildings in Montreal, it is clear that most buildings were not fire affected. The same trend in values of spreading and non-spreading fires from Figure 1 is seen here.

Figure 3:



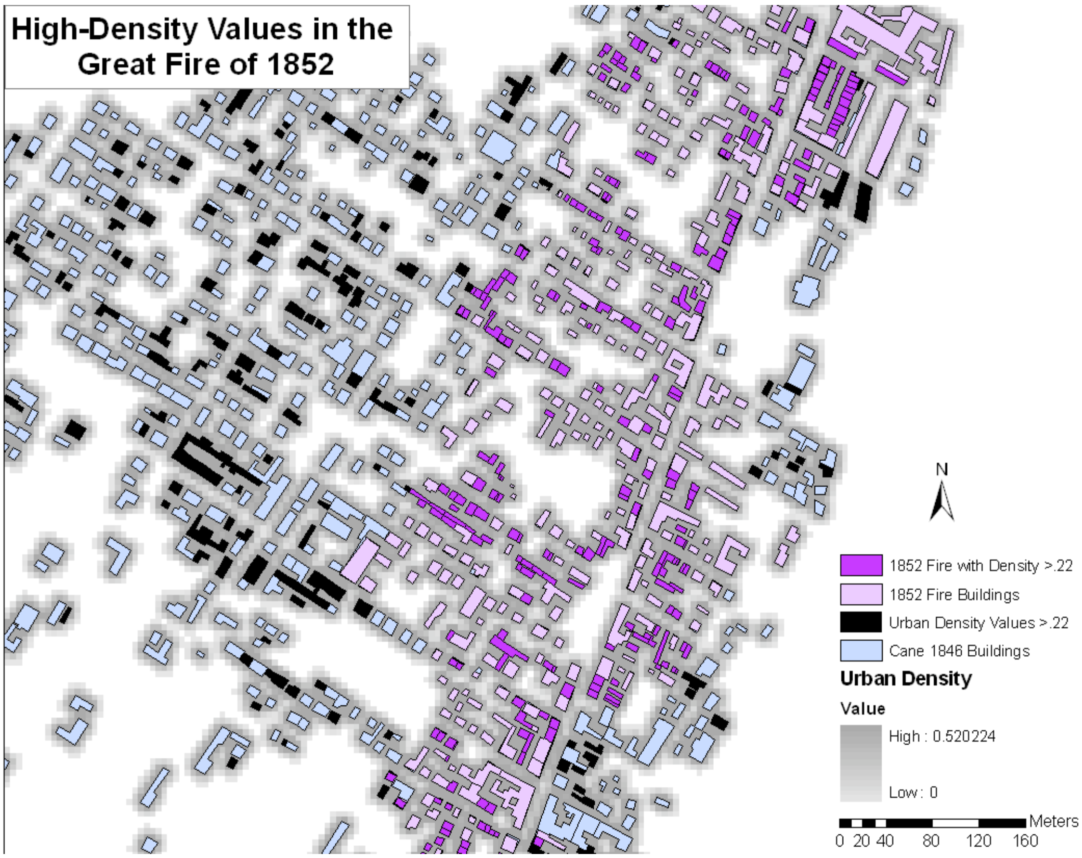
The distribution of the kernel density estimation values for all of the buildings of Montreal follows a sigmoid curve. The values for both spreading and non-spreading fires follow similar curves. The fire-affected building curves are not as smooth as the curve for all buildings because they use much smaller datasets.

Figure 3a:



In small buildings, spreading fires occur in more densely clustered buildings at a much higher rate than non-spreading fires. This is shown by the slope of the two types of fires, with the spreading fires rising steeply around a density value of .10.

Map 5:



The buildings affected by the Great Fire of 1852, shown in part above, had an average urban density of .21. The map above shows buildings that were identified as "high density," with density values greater than .22.