The Urban Heat Island Effect in Windsor, ON: An Assessment of Vulnerability and Mitigation Strategies

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1.0 INTRODUCTION

1.1 THE URBAN HEAT ISLAND EFFECT

The urban heat island effect (UHIE) is the resulting temperature difference between urban and surrounding rural areas. This phenomenon occurs due to the patterns of urban development which result in the conversion of vegetated, permeable land areas into urban landscapes dominated by high albedo (i.e. measure of the amount of solar energy that is reflected by a given surface) and impervious surfaces that absorb a high percentage of solar radiation (Rosenzweig *et al.,* 2006). Other factors that influence the UHIE include: urban form, the thermal properties of buildings, and anthropogenic heat release. The specific causes of the UHIE are discussed in section 2.0 of this report. Typically the temperature difference between urban and rural areas ranges from 3-5°C during the day. However, at night the difference can reach as high as 12°C due to the slow radiation of heat from urban surfaces (Environmental Protection Agency, 2008).

While the UHIE occurs year-round, the magnitude of its effect is variable, in large part due to changes in meteorological conditions (Solecki *et al.,* 2003). The effect is most intense on calm, clear days in the summer and fall. This is because on clear days, short-wave radiation from the sun travels on a direct path to the earth's surface, and is not obstructed by clouds which can reflect a large proportion of incoming solar radiation (Rosenzweig *et al.,* 2006). Furthermore, while the UHIE occurs year-round its occurrence during the summer is of primary concern due to the impacts related to increased electricity and air conditioning use, as well as the increased frequency of heat-related illness and mortality during high summer temperatures (Rosenzweig *et al.,* 2006). The intensity of the UHIE also tends to vary depending on the size of cities. Generally speaking, the intensity of the UHIE increases as the size of a city increases, due to the larger size of the built area (Rinner & Hussain, 2011). The amount of land cover characterized as urban is likely to increase in the future, as the United Nations predict that the amount of people living in urban environments will increase from 48% in 2003 to 61% by 2030 (Yow, 2007).

The UHIE has been associated with a large range of negative impacts (*See Section 3.0)* concerning human health, the environment, and the economy. In order to address and reduce the magnitude of these adverse effects in the City of Windsor, this report aims to:

1) Provide background information on the causes and impacts of the UHIE

2) To develop a heat vulnerability map identifying the geospatial relationship between vulnerable populations and the location of hot spots

3) To outline mitigation measures that the City of Windsor can implement to reduce the intensity of the UHIE

1.2 THE URBAN HEAT ISLAND EFFECT IN WINDSOR, ON

As the southernmost city in Canada, Windsor's humid continental climate results in warm summer temperatures. As a result, Windsor records the greatest number of days annually with the Humidex reaching 35 or higher (Berry *et al.,* 2011). Due to the City of Windsor's climate trends, urban form and the large amount of industrial land use, there is a strong UHIE that combines with extreme heat to present a considerable health risk to residents. The intensity of the UHIE may increase in the future based on climate projections that predict a near tripling of the number of hot days greater than 30°C (86°F) by 2100 (*See figure 1).*

Figure 1: *Temperature variance due to the UHIE in different zones across a municipality*

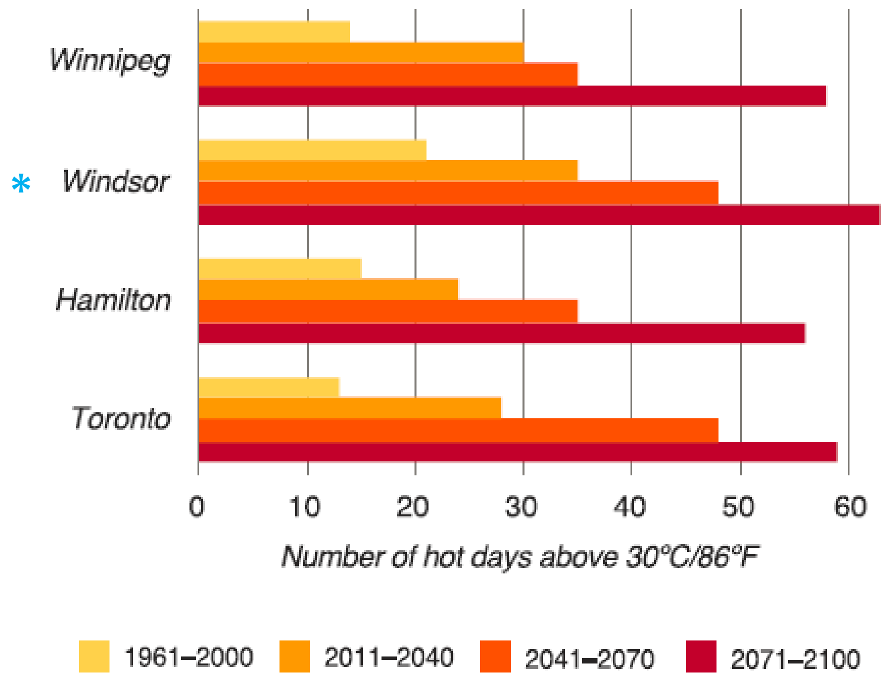


***Figure 2**: Number of hot days above 30°C in Winnipeg, Windsor, Hamilton, and Toronto from 1961-2100 (Health Canada, 2011)*

A study of the UHIE in 275 schoolyards and 529 public spaces (parks, sports fields, squares) across Windsor-Essex, Sarnia-Lambton, and Chatham-Kent was undertaken in 2009. The surface temperatures of these areas were measured using Landsat 7 satellite imagery in order to determine priority areas for shade and cooling efforts. These measurements were taken on August 4, 2009 at 10:20 am when air temperature was recorded at 32°C (Moogk-Soulis, 2010). The study saw clear variation between the surface temperatures of the urban areas such as Windsor to the surrounding rural landscapes in the county. Furthermore, intra-urban variation in surface temperatures was seen, largely attributed to different land uses, construction materials, and density parameters (Moogk-Soulis, 2010).

The results demonstrated significant differences between the top five coolest and hottest public spaces in Windsor, ON. The surface temperatures of the top five coolest public spaces in Windsor included: Brumpton Park, Giradot Street Parkette, South Cameron Woodlots, Mackenzie Hall Park, and Coventry Gardens. The top five hottest public spaces in Windsor included: Captain John Wilson Park, Pearson Park, Gino A. Marcus C.C, McHugh Park, and Firgrove Boulevards. Similar differences were seen when comparing the coolest and hottest schools in the Windsor-Essex District School Board, posing considerable risk to children who are especially vulnerable to heat. These results were attributed to common causes of the UHIE including: a lack of trees and vegetation, large areas covered with asphalt and cement surfaces, and large roof areas (Moogk-Soulis, 2010).

1.3 CLIMATE CHANGE & THE URBAN HEAT ISLAND EFFECT

Climate change is predicted to result in an increased frequency, intensity, and duration of extreme heat events in Windsor. This is significant as prolonged periods of extreme heat have been correlated with the increased prevalence of heat-related illnesses and mortality. This trend may be amplified in the future with an increase in periods of extreme heat along with an increased densification of urban populations. The Global Warming Impacts Assessment Working Group has predicted that increases in temperature as a result of climate change will result in increased risk of heart disease and heat stroke (Shimoda, 2003). An additional study completed by the National Roundtable on the Environment and the Economy (NRTEE) estimated that the increased number of warm days and reduced air quality may lead to additional deaths of 3-6 individuals per 100,000 people by 2020, 5-10 by 2050, and 7-17 by 2080 (NRTEE, 2011). These effects will likely be greatest in urban areas where the UHIE increases the magnitude of temperature increases that result from climate change.

Furthermore, warmer temperatures may amplify the negative interaction between the UHIE and local air pollution. In the future it is likely that warmer temperatures in synergy with the UHIE will result in the amplification of existing public health and air quality problems, and affect a larger proportion of the population (Solecki *et al.*, 2003).

In the future, it remains necessary to incorporate land use patterns and the effects of urban infrastructure into climate models in order to predict how the impacts of climate change will occur in urban versus rural areas. The absence of the UHIE from climate models may lead to underestimation of the current predictions of heat-induced mortality (Oleson *et al.,* 2010). The neglect of this relationship in the most recent climate predictions is recognized as a weakness by the Intergovernmental Panel on Climate Change (IPCC), and it is important that future models incorporate this level of detail. These models will better enable researchers to determine how the UHIE will be modified by climate change (Stone *et al.,* 2010). Obtaining this information will help planners and policy makers to develop the necessary adaptation plans in order to protect the environment and residents from the combined effects of climate change and urban heat islands.

2.0 CAUSES OF THE URBAN HEAT ISLAND EFFECT

The following section outlines the key factors that contribute to the temperature differential seen between rural and urban areas. The UHIE arises from both anthropogenic and natural factors. Humans have the ability to influence the UHIE primarily through design and planning modifications such as the removal of vegetation, construction of urban forms and structures, and through the release of anthropogenic heat *(See Figure 3)*. However, natural factors that humans do not control such as meteorological conditions can also modify the intensity of the UHIE (Rizwan *et al.,* 2008).

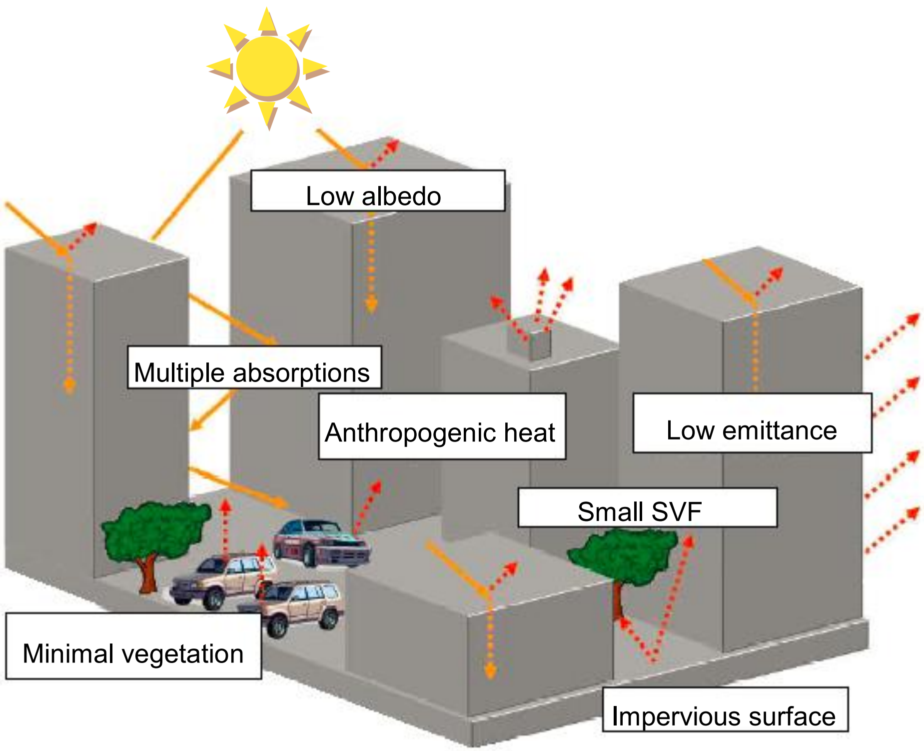


Figure 3*: Causes of the urban heat island effect (Forkes, 2010)*

2.1 VEGETATION REMOVAL

One of the key factors that contributes to the UHIE is the loss of permeable, vegetated landscapes. Vegetation and trees cool landscapes through the shading they provide as well as through evapotranspiration. Shading is primarily provided by larger vegetation such as trees and helps prevent solar radiation from being absorbed by areas and features below the canopy. The solar radiation reaching the canopy may be used for plant processes such as photosynthesis, while some solar radiation is reflected into the atmosphere. As a result, measurable differences can be found in the temperature of surfaces below the tree canopy compared to unshaded surfaces (Environmental Protection Agency, 2008). Therefore, as trees and vegetation are removed, the proportion of solar radiation that is reflected decreases, resulting in warming.

The presence of vegetated landscapes also facilitates cooling through evapotranspiration. Evapotranspiration occurs as plants absorb liquid water and release it into the atmosphere as water vapour. During this process, energy from solar radiation is used and transformed by plants into latent heat rather than sensible heat, which cools the ambient air surrounding vegetation (Bowler *et al.,* 2010). As vegetation is lost, soil moisture content and evapotranspiration rates decrease, resulting in air temperature increases that cause the UHIE. Measurable differences in evapotranspiration rates have been identified in academic studies. For instance, it was determined that evapotranspiration decreased by 38% in Tokyo from 1972 to 1995 due to urbanization (Rizwan *et al.,* 2008).

2.2 PROPERTIES OF URBAN MATERIALS

As vegetation is lost, the conversion of landscapes into areas dominated by urban infrastructure and impermeable surfaces occurs. Urban areas are primarily made up of pavement and roofing surfaces. These surfaces are constructed with materials that cause the UHIE by altering how solar radiation is reflected, emitted, and absorbed.

One of the key properties that impacts the absorption and reflection of solar radiation is albedo. Albedo is a measure of the amount of solar energy that is reflected by a given surface, expressed as a value between 0 (total absorption) and 1 (total reflectance). As a general rule, white and light coloured materials have a high albedo, while darker materials have low albedo (Forkes, 2010). The various albedos of common materials used in the construction of urban landscapes can be seen in *Figure 4.*

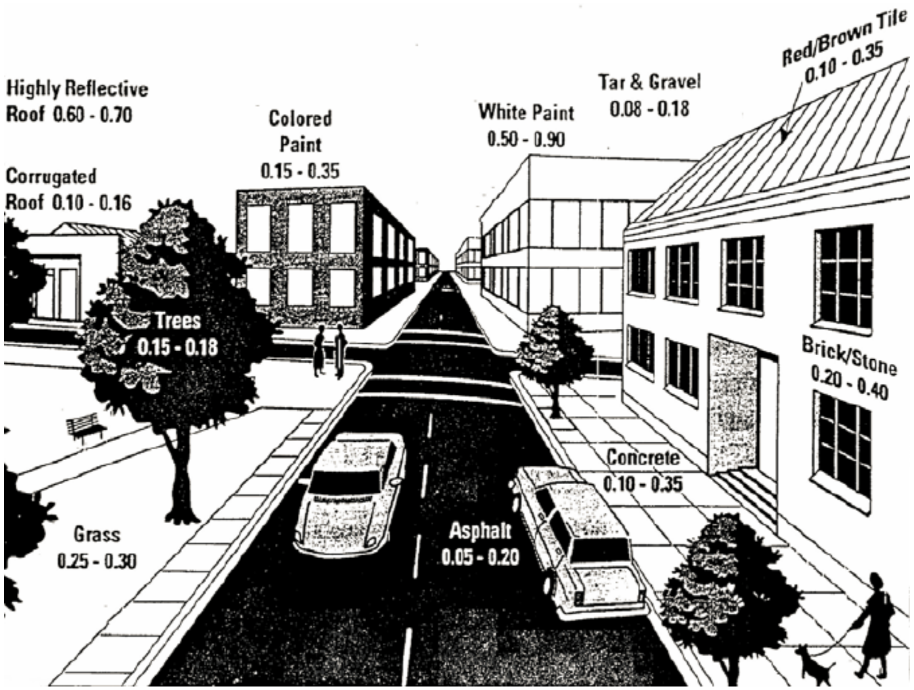


Figure 4*: Differences in albedo amongst urban surfaces (Forkes, 2010)*

In addition to albedo, emissivity, a measure of the amount of heat a surface radiates per unit area at a given temperature, also has an important role in causing the UHIE. Surfaces with low emissivity release heat slowly, causing areas to retain heat and warm air temperatures (Environmental Protection Agency, 2008).

Commonly used paving materials such as asphalt and cement typically have albedos ranging from 0.05-0.4, and high emissivity values of approximately 0.8-0.9. These high emissivity values are similar for roofing materials with the exception of metal roofing, which has very low emissivity at approximately 0.05-0.3 (Houston Advanced Research Center, 2009). Advances in the development of new pavement and roofing materials will help reduce the UHIE by reflecting increasing amounts of solar radiation. As a result, construction methods designed to change the thermal properties of urban surfaces are extremely important for future UHIE mitigation efforts, and are discussed in section 7.0 of this report.

It is also important to note that the thermal properties of urban materials may change over time. With respect to asphalt pavement, its albedo tends to improve over time due to weathering. Conversely, the albedo of cement generally declines with age due to the accumulation of dirt and debris on the originally light surface. A similar process occurs on roofing materials, as the collection of dirt and debris results in their albedo decreasing over time. As a result, it is important for planners to recognize these potential changes when selecting urban materials in order to accurately assess their potential impact on the UHIE.

2.3 URBAN GEOMETRY

In addition to the properties of infrastructure and surfaces in urban areas, the geometry of urban structures can influence the UHIE by changing patterns of absorption and reflectance of solar radiation. The arrangement of buildings can increase the absorption of incoming solar radiation in cities. Without the presence of multiple buildings, solar radiation would typically be absorbed and reflected into the atmosphere by only one surface. However, buildings may interfere with this process by absorbing and reflecting radiation multiple times and by more than one surface. This results in an increase in the total amount of radiation that is absorbed, contributing to the UHIE (Forkes, 2010). Large structures may also reduce wind speeds in built up areas, inhibiting the transfer of warm air by convection (Morris *et al.,* 2001). 2010).

Another important property that has an impact on the intensity of the UHIE is the sky view factor (SVF). Upon absorption of solar radiation, cooling occurs as outgoing long-wave radiation is released back into the atmosphere. The SVF is defined as the amount of visible area of the sky that can be seen from a given point on the ground. It is expressed as a value between 0 (complete obstruction) and 1 (complete visibility). The sky view factor will decrease as building square footage increases, building height increases, street width decreases, and as the space between buildings decreases (Rosenzweig *et al.,* 2006; Unger, 2004). An inverse relationship exists between the sky view factor and the UHIE, which increases as the SVF decreases. This is because large buildings that obstruct the sky view restrict the ability of surfaces to release outgoing long-wave radiation, preventing cooling from occurring (Environmental Protection Agency, 2008).

2.4 ANTHROPOGENIC HEAT

Anthropogenic heat is generated when waste heat is produced and released into the environment as a result of human activity (Rizwan *et al.,* 2008). Sources of anthropogenic heat include: vehicles, heating, ventilation, and air conditioning systems, appliances, industrial processes, and agricultural processes (Environmental Protection Agency, 2008).

Due to variation and changes regarding energy, transportation, and living requirements throughout the year, the quantity of waste heat released may vary diurnally, weekly, and seasonally (Rizwan *et al.,* 2008). Studies regarding the generation of anthropogenic heat across cities have shown considerable variation in their results. For example, studies completed in Basel, Switzerland, Lodz, Poland, six cities across the United States, and Tokyo, Japan determined that annual production of waste heat was approximately 20 W/m^2, 32 W/m^2, 60 W/m^2, and 200 W/m^2, respectively (Rizwan *et al.,* 2008). However, researchers believe that anthropogenic heat release has a small impact overall on the intensity of the UHIE in comparison to the aforementioned causes. As a result, many mitigation strategies and recommendations concerning the UHIE exclude measures to reduce the production of waste heat.

2.5 TEMPORARY METEOROLOGICAL VARIABLES

Natural factors related to meteorological patterns, geographic location, and topography have the ability to exert temporary effects on the formation of urban heat islands (Environmental Protection Agency, 2008). These variables may result in diurnal, weekly, or seasonal variation with respect to the intensity of the UHIE. Research has shown that the UHIE is strongest on clear days with minimal cloud cover as well as on days with low wind speeds. These two conditions generally occur simultaneously during stable anticyclonic periods. Low wind speeds limit the transfer of air that promotes cooling by convection, maintaining warm temperatures in urban environments. Clear, cloudless conditions increase the temperature of the UHIE by enhancing rural cooling at night. This creates a large temperature differential between rural and urban areas, where the thermal properties and structures of buildings result in comparatively slow cooling rates (Morris *et al.,* 2001).

Geographic location and topography may also result in changes to the UHIE in different cities due to their effect on meteorology. Cities located near water bodies may experience wind patterns and convective forces that regulate heat. Additionally, topographic features such as mountain ranges may also alter weather and wind patterns, producing different UHI effects on the windward and leeward sides of mountains (Environmental Protection Agency, 2008).

3.0 IMPACTS OF THE URBAN HEAT ISLAND EFFECT

3.1 HUMAN HEALTH

The human body functions optimally at a core temperature of 37°C (98°F). Above this temperature, individuals become at higher risk for the development of heat-related illnesses, and in the worst case, mortality. The risk of experiencing these health outcomes is greatest when high temperatures occur in unison with high humidity, minimal cloud cover, and low winds. The UHIE can increase the possibility of these adverse health effects occurring by significantly increasing air temperatures above average values, impeding the body's ability to adapt and stay cool (Forkes, 2010). It is important to note that the risk of developing heat induced illnesses and mortality are much greater amongst vulnerable populations, which are identified and discussed in detail within section 4.0 of this report.

As internal body temperatures rise, the risk of developing a heat-related illness, as well as the potential severity of the illness increases. At the lowest level, extreme heat can lead to general discomfort amongst individuals. However, more severe illnesses may develop as bodies lose water and vital minerals. These illnesses include heat cramps, heat rash, heat edema, fainting, heat exhaustion, and heat stroke (Forkes, 2010). Of these illnesses, heat stroke is the most severe, and the development of organ dysfunction within one year of heat stroke is a common occurrence (Chan *et al.,* 2007). Extreme heat may also exacerbate and increase hospitalization rates for chronic conditions such as cardiovascular disease, respiratory disease, diabetes, renal disease, nervous system disorders, and emphysema (Chan *et al.,* 2007).

In addition to the aforementioned heat-related illnesses, urban heat islands may induce heat-related mortality. Fatality is known to occur as internal body temperatures reach or exceed 105°F (Wilhelmi *et al.,* 2004). The Centers for Disease Control and Prevention determined that from 1979-1999 excessive heat exposure resulted in 8000 premature deaths within the United States. It is interesting to note that the number of annual heat-related deaths in the United States exceeds that of all hurricanes, tornadoes, lightning, floods, and earthquakes (Environmental Protection Agency, 2008). These deaths often occur during prolonged periods of extreme heat. For example, during the 1995 heat wave in Chicago, approximately 500 individuals died, while 70,000 individuals died during the European heat wave in August 2003 (Stone *et al.,* 2010). The European heat wave occurred due to temperatures increasing above average by approximately 3.5°C, indicating that the projected increases in temperature from climate change could significantly raise the incidence of heat-related mortality (Patz *et al.,* 2005). A study of the effects of heat on mortality in Windsor indicated that from 1954-2000 approximately 37 individuals died annually due to heat-related causes. The UHIE may also lead to mortality indirectly. For instance, during a heat wave in Canada in 1936, approximately 400 people died by drowning in an attempt to escape the effects of extreme heat (Health Canada, 2008).

In addition to the previously discussed direct health effects, increased temperatures have also been linked to the spread of infectious diseases. Protozoa, bacteria, and viruses, as well as disease carriers such as mosquitoes and ticks may experience improved reproduction and survival rates as temperature increases (Patz *et al.,* 2005). For example, the transmission of West Nile virus by mosquitoes is known to increase following warm winters and during heat wave periods (Health Canada, 2008). While the relationship between climate change and infectious diseases is evident, the precise relationship between the urban heat island effect and infectious disease is not known. This may be an important area to research in the future as climate change intensifies the strength of the UHIE.

3.2 AIR QUALITY

The impact of the UHIE on air quality arises due to increased temperatures as well as through the indirect effects that greater energy demand has on increasing emissions. Increased temperatures have been correlated with the elevated production of ground level ozone (O_3), also referred to as photochemical smog. Ozone is produced by the photochemical reaction between nitrogen oxides (NO_X) and volatile organic compounds (VOCs) in the presence of sunlight. Nitrogen oxides are common pollutants produced as combustion by-products, and VOCs are reactive hydrocarbon molecules that evaporate from solvents. The production of O_3 initially occurs as NO_2 separates and then combines with O_2 in the atmosphere (*See Figure 5*). Under normal conditions, the reaction would reverse, however, the presence of VOCs blocks the dissociation of O_3 (Bernstein & Whitman, 2005). This reaction sequence results in the frequent issuance of smog alerts on warm summer days. Ozone is a respiratory irritant and is known to exacerbate a number of cardiopulmonary diseases including asthma and chronic bronchitis. Studies have also linked ozone to impaired lung function and development in children (Chan *et al.,* 2007).

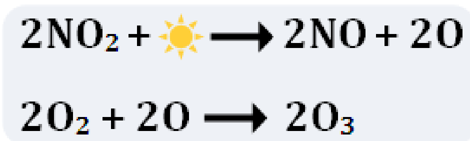


Figure 5: *Chemical reactions that produce ozone*

The UHIE can also indirectly contribute to poor air quality by increasing cooling demand and air-conditioning use. This can lead to increased electricity production, which may correspond to the release of greenhouse gas emissions in communities where fossil fuels are used to produce electricity. Windsor uses electricity produced from nuclear power, hydroelectric projects, renewable energy sources, and natural gas fired combined heat and power plants (Berry *et al.,* 2011). However, in comparison to the combustion of coal, natural gas produces significantly lower emissions of NO_X and CO_2 (Environment Canada, 2010).

3.3 INCREASED ENERGY DEMAND

Warmer surface and air temperatures during both the day and evening create an increased demand for energy. This demand is further increased by construction of urban environments with high albedo surfaces that increase the absorption of solar radiation by buildings (Forkes, 2010). Increased energy demand results from the subsequent increase in air-conditioning use in order to keep buildings at safe and comfortable temperatures. While the warmer temperatures also lower requirements for heating in the winter months, it has been demonstrated that in cities with warm summers, the high energy requirements for cooling outweigh the winter heating savings (Yow, 2007). It has been estimated that 5-10% of community electricity demand results from the need to compensate for the UHIE (Environmental Protection Agency, 2008).

Greater air-conditioning use is especially concerning as it corresponds to increased peak energy demand. Peak energy demand describes the point within a 24-hour period where the demand for electricity is highest. Increases in peak energy demand may compromise the security and stability of power supplies during extreme heat events. This may result in reduced transmission efficiency or compromise the power supply entirely, leading to temporary blackouts. The most recent blackout of significance affected multiple areas in Ontario in July 2003. These events significantly increase the risks of heat-related mortality and morbidity, as the loss of power disrupts cooling. Academic studies have determined that peak energy demand increases by approximately 2-4% for every 1°C increase in maximum temperature (Solecki *et al.,* 2003).

Augmented energy requirements may create a positive feedback loop that amplifies climate change and the UHIE. In this scenario, increased warming may correspond to greater demands for air-conditioning use and therefore electricity generation. Electricity generation using technologies that burn fossil fuels may then lead to increases in the emissions of greenhouse gases, causing further warming in temperate areas through climate change (Solecki *et al.,* 2003). The UHIE may also be amplified due to a greater cooling demand through the subsequent increase in the release of anthropogenic heat (Shimoda, 2003). Due to the potential to increase peak energy demand as well as GHG emissions, the World Health Organization (WHO) has identified the use of air-conditioning as an unsustainable adaptation strategy for extreme heat (Health Canada, 2008).

3.4 AQUATIC ECOSYSTEM HEALTH

Aquatic ecosystem health can be negatively impacted by the discharge of runoff into surface water bodies that causes thermal shock to aquatic organisms as a result of the increase of water temperatures above normal conditions. (Environmental Protection Agency, 2008). The reproduction, development, and survival of aquatic invertebrates and fish occur within an optimal range of minimum and maximum water temperatures. In particular, species within cold-water streams, rivers, and lakes may be the most vulnerable, having ecological requirements for low temperatures between 7-17 °C (Roa-Espinosa *et al.,* 2003). High air temperatures resulting from the UHIE, as well as urban form may lead to increases in water temperatures above these limits. Urban surfaces such as pavement and roofing materials absorb large amounts of solar radiation, leading to significant increases in the temperature of runoff that flows over these areas. Surface water bodies may experience thermal shock that leads to many negative effects such as: declines in fish egg production, decreased reproductive rates, altered metabolic rates, impaired juvenile fish development, and fish lethality due to anoxia (Rossi & Hari, 2007). As a result, water bodies that are subjected to thermal shock may experience declines in species abundance and biodiversity. The precise effects that runoff will have on an aquatic ecosystem depends on the time of exposure, the critical maximum and minimum temperatures specific species can survive within, developmental stage of the species as well as the magnitude of temperature change (Rossi & Hari, 2007).

4.0 VULNERABILITY TO EXTREME HEAT

Within cities, all individuals are not at equal risk to the effects of extreme heat due to differing social and demographic factors between population groups (Reid *et al.,* 2009). It is important to identify and discuss these factors in order to enable decision-makers to prioritize population-specific actions to reduce heat vulnerability, and to selectively implement adaptation measures in areas where there are high concentrations of vulnerable groups. The combination of local vulnerability information with temperature data, outlined in section 6.0, can serve as an important mapping tool in order to visualize and strategically plan urban heat island mitigation efforts. Community and individual factors that may influence the susceptibility of Windsor residents to extreme heat events are illustrated in *Table 1*. Vulnerable groups discussed in this section include: seniors, infants and children, groups with high occupational exposure to heat, people living in poverty, newcomers to Canada, individuals with chronic disease, and individuals with medical prescriptions that increase sensitivity to heat.

Table 1: *Factors that influence community and individual vulnerability to extreme heat (Health Canada, 2011)*

INDIVIDUAL	COMMUNITY
• Health system capacity	• Age
• Urban design	• Income
• Social networks	• Medications
• Income	• Personal behaviour
• Local climate	• Type of housing
• Air pollution	• Fitness level
• Type of housing	• Health status
• Cooling options	• Acclimatization
• Health system preparedness	• Access to cool places
• Public buildings with air conditioning	
• Health warning systems	
• Outdoor festivals and events	

4.1 SENIORS

Seniors are considered to be the most vulnerable group to the effects of heat as a result of multiple physiological and social characteristics. However, while the elderly may be at the greatest risk, it is important to note that no population age group is entirely protected from the risks of extreme heat (Johnson & Wilson, 2009). Physiologically, seniors have inhibited thermoregulation, causing them to have a reduced ability to release heat through sweating (Health Canada, 2011). Seniors are also more likely to be prescribed medications that inhibit thermoregulation. Additionally, they have a diminished ability to perceive the sensation of thirst, increasing their susceptibility to dehydration (Uejio *et al.,* 2011). The elderly also have a higher likelihood of having existing chronic diseases that may be exacerbated during extensive warm periods. Visual, cognitive, and hearing impairments may also impede these individuals from interpreting heat alerts and being able to take the necessary precautions to protect themselves. Finally, reduced mobility and agility, especially amongst those that live in isolation, may prevent them from accessing cooling resources (Basu & Samet, 2002). Currently in Windsor, approximately 15.6% of the population is over age 65, and this percentage is expected to grow by 2021 to 18%. Of this population group, approximately 26% live in isolation, increasing their vulnerability to excessive heat (Barry *et al.,* 2011; Statistics Canada, 2011).

4.2 INFANTS & CHILDREN

Similarly to seniors, the ability of infants and children to regulate their body temperature does not function at the optimal level due to differences in their physiology. This is concerning because heat illnesses arise when thermoregulation is disrupted, causing the body to retain more heat than it releases through radiation, convection, and evaporation (Grubenhoff *et al.,* 2007). Children have a larger surface area-to-mass ratio than adults which results in the accelerated absorption of heat from the surrounding environment. This results in children who absorb the same amount of heat radiation as adults having increased core body temperatures (Health Canada, 2011). Children and infants also have a greater metabolic rate that results in greater production of body heat per unit mass during physical activity. In addition to the processes that result in children absorbing higher amounts of heat, their ability to release heat through evaporation (sweating) is impaired. Children's sweat glands are less sensitive to heat stress and are small in size compared to adults, resulting in a decreased quantity of sweat production per gland (Grubenhoff *et al.,* 2007).

Greater vulnerability of children and infants to heat is also influenced by social factors. Young children depend on their parents and guardians to take the necessary protective measures to prevent heat related illnesses and mortality. These measures may include: moving children to cool or shaded areas, seeking hydration, or encouraging children to take breaks from physical activity, amongst others. It is therefore important to educate parents and caregivers about the adverse effects of heat and on the measures they can take to limit the exposure of children and infants to excessive heat. At the time of the 2006 census, 5.6% of the Windsor population were less than 4 years old, and 5.7% were between the ages of 5-9 (Statistics Canada, 2011).

However, unlike the seniors population, the population of children and infants is expected to decrease slightly in the future (Berry *et al.,* 2007).

4.3 OCCUPATIONAL EXPOSURE

Many occupational sectors require employees to work in conditions of high heat such as agriculture, landscaping, mining, manufacturing, and construction. Largely due to Windsor's extensive manufacturing industry, the number of people working at jobs that expose them to conditions of extreme heat is significant at 33% (Berry *et al.,* 2011). The risks of occupational exposure to heat may be especially concerning to new residents who are not yet acclimatized to warm job conditions. Due to these risks it is critical that supervisors take the necessary precautions to ensure that health and safety is protected by providing workers with adequate breaks, cool areas, access to drinking water, and by limiting outdoor exposure during the warmest periods of the day (Health Canada, 2011).

4.4 INDIVIDUALS LIVING IN POVERTY

Individuals living in poverty are at a higher risk to the negative health

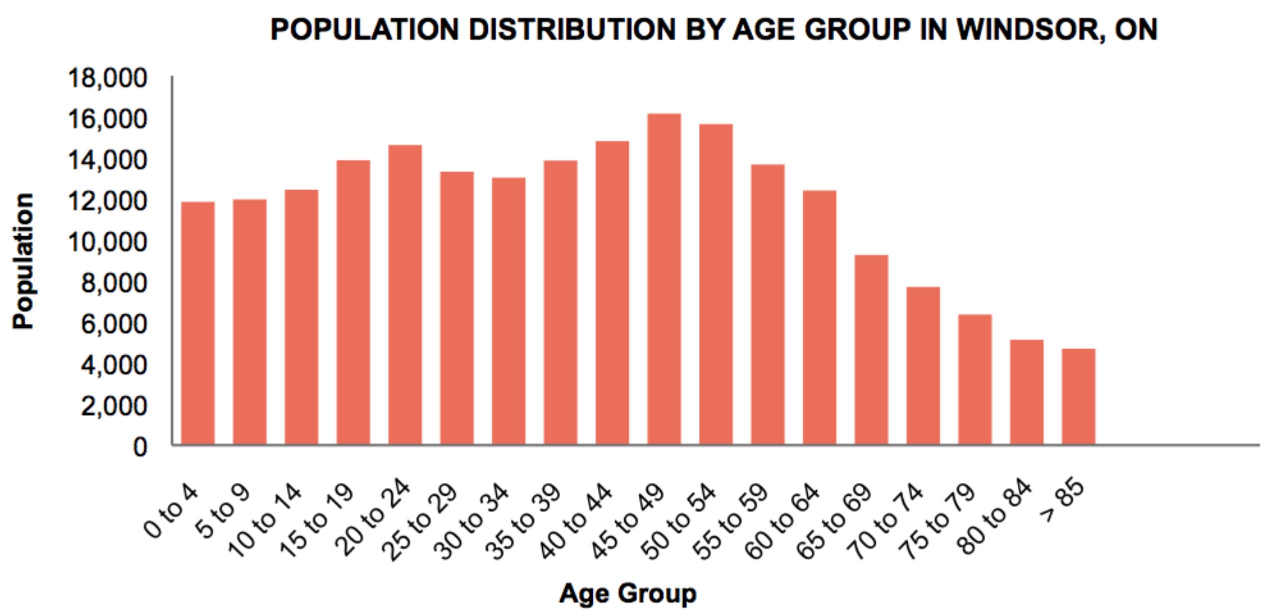


Figure 6: *Population distribution by age group in Windsor, ON (2011)*

effects of heat due to their spatial distribution, living conditions, and limited financial resources. The spatial distribution of populations largely depends on household income. Generally speaking, individuals who live in poverty often live within urban environments rather than the surrounding suburbs and rural areas (Harlan *et al.,* 2006). As a result, these individuals are exposed to higher heat intensities due to the UHIE, which is greatest in dense urban areas. In addition, these individuals may be homeless or be exposed to inferior characteristics such as substandard housing that lack cooling mechanisms such as air-conditioning (Johnson & Wilson, 2009). Individuals living in poverty may also lack transportation and the financial resources necessary to access cooling centres, clean drinking water sources, health care, and social services. Higher rates of drug and alcohol consumption amongst low income populations may also reduce their ability to seek preventative measures or medical attention (Health Canada, 2011). Alcohol and drugs may impair their judgement, result in a loss of self control, and impair the body's thermoregulation abilities (Health Canada, 2008). Within Windsor, approximately 18.2% of the population is low income before taxes (Berry *et al.,* 2011).

4.5 RECENT IMMIGRANTS

The increased risk of new Canadian residents experiencing adverse health outcomes as a result of heat primarily exists due to linguistic and cultural differences. Language and literacy barriers may prevent these individuals from receiving information and warnings about extreme heat. As a result, they may not take the proper precautions to stay cool, and may not be knowledgeable about the community resources available to protect themselves (Health Canada, 2011). Cultural differences such as clothing choices may also make these people increasingly susceptible to higher body temperatures on warm days. New immigrants have also been found to occupy substandard housing lacking preventative amenities such as air conditioning, as well as living in dense urbanized areas which intensify the UHIE (Uejio *et al.,* 2011). Finally, new residents may not be acclimatized to the heat and humidity experienced in Windsor, ON, increasing the intensity of heat exposure for this population group (Health Canada, 2011).

4.6 INDIVIDUALS WITH CHRONIC DISEASES

While not causing heat-related illnesses or mortality directly, extreme heat may exacerbate the effects of chronic diseases and increase hospitalization rates. These illnesses include: cardiovascular disease, cerebrovascular disease, respiratory disease, renal disease, nervous system disorders, diabetes, obesity, and emphysema (Chan et al., 2007). Additionally, individuals suffering from mental illness or with disabilities may be vulnerable due to the difficulties they may experience in interpreting heat alerts and taking protective measures. Overall, a greater number of Windsor residents have been diagnosed with chronic diseases that increase heat vulnerability when compared to the population of both Ontario and Canada (Berry et al., 2011).

4.7 INDIVIDUALS USING MEDICATIONS THAT INCREASE SENSITIVITY TO HEAT

A large number of medications and drugs interfere with the body's ability to thermoregulate, as well as with water and salt retention, making individuals who regularly take these medications increasingly sensitive to the effects of heat (Health Canada, 2011). These drugs may be prescribed, available over-the-counter, taken as supplements, or be purchased for recreational use (Berry *et al.,* 2011). Individuals taking medications in the drug classes listed in *Table 2* should take extra precautions on warm days to seek air-conditioned or shaded areas, to minimize physical activity, to wear cool clothing, and to stay hydrated.

DRUG CLASS
• Anti-drenergics
• Anti-cholinergics
• Anti-depressants
• Anti-epileptics
• Anti-histamines
• Anti-hypertensives
• Anti-Parkinson's
• Anti-psychotics
• Anxiolytics
• Barbiturates
• Bladder antispasmodics
• Carbonic anhydrase inhibitors
• Diuretics
• Recreational drugs
• Neuroleptics
• Sympathomimetics

Table 2: *Drug classes that increase sensitivity to heat (Berry et al., 2011; Hansen et al., 2007)*

5.0 CURRENT ADAPTATION MEASURES IN WINDSOR, ON

The City of Windsor currently has a range of adaptation plans and resources in place to help residents identify heat-health risks, prevention measures, and emergency resources. These resources help community members to reduce the risk of experiencing adverse health outcomes in response to extreme heat which is amplified by the UHIE.

5.1 STAY COOL WINDSOR-ESSEX

As part of Health Canada's Heat Resiliency Project, the City of Windsor was selected to develop a Heat Alert and Response Systems (HARS) Plan. The Stay Cool Windsor-Essex HARS Plan evolved from this initiative as a collaborative effort between the City of Windsor, the County of Essex, and the Windsor Essex County Health Unit. The plan was officially adopted in 2011, and currently remains in place. As per the Plan, the Medical Officer of Health is responsible for issuing heat alerts to the public under a range of three progressively serious levels *(See Figure 7).* These heat alerts are advertised by the media, on the Stay Cool Windsor-Essex website (www.staycoolwindsor-essex.com), and through a publically available e-mail listserv. Concerned citizens can also call the information and referral service, 211, to obtain the latest information on heat alerts (Richters, 2011).

The Plan also involves a media campaign and an educational component in order to inform residents about the risks, adaptation strategies, and pertinent safety information in regards to extreme heat. A series of eight tips to stay cool were outlined and given symbols in order to educate residents about heat safety *(See Figure 8)*. The campaign is promoted through a diverse range of media outlets: radio, print and online newspapers, magazines, and the Stay Cool Windsor-Essex website. Print materials are also produced for distribution to community partners and include: posters, white boards, children's colouring placemats, physically active business cards, pharmacy labels, fridge magnets, information sheets, and water bottles. Train the Trainers Sessions were also developed to educate key community groups about heat related illnesses and prevention methods. Targeted groups include: child care providers, health care providers, long-term care providers, places of worship, government agencies, schools, non-profit organizations, and groups with high occupational exposure to heat (Richters, 2011). Promotion of the campaign also takes place at a variety of community events such as Emergency Preparedness Week and the Community Services Expo, amongst others.

5.2 PLACES TO STAY COOL

Access to air-conditioned facilities as well as pools and splash pads provide opportunities for Windsor residents to stay cool. Areas where

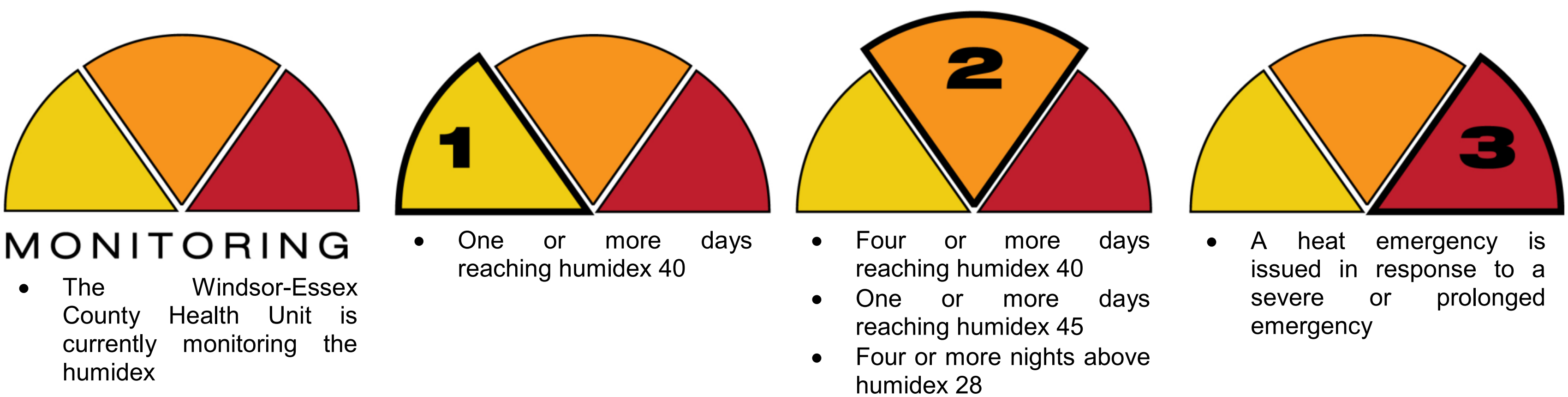


Figure 7: *Stay Cool Windsor-Essex heat alert levels (Stay Cool Windsor-Essex, 2012)*

Drink plenty of water.

Go to an air conditioned place.

Wear a hat and lightweight loose-fitting clothing.

Take a cool bath or shower.

Limit outdoor activities to the coolest parts of the day.

Check on your neighbours and family.

Never leave children or pets alone in closed vehicles.

If you feel ill, faint, have difficulty breathing, or feel disoriented, visit your doctor or nearest hospital right away. In an emergency, call 911.

Figure 8: *Tips to stay cool (Stay Cool Windsor-Essex, 2012)*

residents can seek relief from the heat include: community centres, libraries, recreation centres, waterplay areas, malls, movie theatres, senior centres, shelters, special needs centres, and emergency housing. Through the provision of these publicly accessible areas, the likelihood of individuals developing adverse health conditions related to heat is minimized. However, some barriers to adaptation do exist regarding the accessibility of these areas. For instance, the usage of indoor (~$2-4) and outdoor (~$2) pools in Windsor is subjected to fees, while splash pads remain free. Entrance fees may deter vulnerable populations from using cool centres and therefore increase health risks. A recent City of Windsor initiative aims to address this issue by offering a reduced fee swim pass for low-income residents during extreme heat alerts. It is also important to ensure that the places to stay cool are relatively evenly distributed throughout the city to ensure that transportation issues do not arise. A full listing of places to stay cool throughout Essex County is available at: www.staycoolwindsor-essex.com/files/PlacestoStayCool.pdf.

5.3 HEALTH SERVICES

The aforementioned public areas may offer relief from the heat through the provision of air conditioning and access to water. However, if medical attention or advice is needed, it becomes necessary to visit health services facilities. These facilities have the information, tools, and practitioners available to minimize exposure to heat, to reduce health risks, and to offer medical care. One key organization is the Windsor-Essex County Health Unit. They are responsible for issuing heat alerts and also provide a wide array of resources related to the health effects of extreme heat. However, if medical attention is needed individuals must visit a doctor at a health clinic or hospital. Windsor currently has two hospitals to serve the public, which include Hôtel Dieu Grace Hospital and Windsor Regional Hospital. In the event of an emergency where the capacity of Windsor hospitals to provide care is exceeded, agreements have been made with Detroit area hospitals to provide care.

In addition to facilities that provide medical care, a number of health focused community organizations help to provide assistance during periods of extreme heat. These organizations may help to offer air conditioned spaces, water, and first aid to individuals in need of relief from the heat. These organizations help to reduce the demand on health clinics and hospitals for relatively minor health issues. Examples of these community organizations include the Ontario Lung Association, Salvation Army, St. John Ambulance, the United Way of Windsor Essex, and the Canadian Red Cross.

6.0 MITIGATING THE URBAN HEAT ISLAND EFFECT

In addition to the adaptation measures that help individuals cope with the UHIE, it is necessary to implement mitigation measures in order to diminish the overall intensity of the UHIE. Implementing the following measures will help to reduce the occurrence of the associated negative effects on health, air quality, water quality, and energy demand. Mitigation techniques are designed to reverse the root causes of the urban heat island effect by implementing strategies to increase albedo and emissivity, to increase cooling by evapotranspiration, and to reduce the amount of impermeable surfaces. In order to achieve these objectives, potential actions within the following categories are addressed:

- Cool Roofs (6.1)
- Green Roofs (6.2)
- Cool Pavement (6.3)
- Urban Greening (6.4)

6.1 COOL ROOFS

Roofing materials comprise a significant proportion of the exposed surfaces in urban environments, at approximately 20-25%. They also absorb large amounts of solar radiation, reaching surface temperatures as high as 65.6 – 82.2°C (150-180°F) on clear summer days (Houston Advanced Research Center, 2009). In general, commercial and industrial roofs are made from: modified bitumen, built-up roofing, or single-ply roofing materials. Residential roofs are primarily constructed using asphalt shingles.

With respect to the traditional thermal properties of roofs, they tend to have low albedo, but high emissivity, with the exception of metal roofs which also exhibit low emissivity (Environmental Protection Agency, 2008). Due to these properties, traditional roofing materials readily absorb solar radiation, heating both the surface and internal areas of buildings. This has been related to many negative implications including: elevated cooling costs, higher energy use, poor thermal comfort, and early roof deterioration (van Tijen & Cohen, 2008). The impact of roof type on the reflectance and emittance of solar radiation is depicted in *Figure 9.*

Unlike traditional roofs, cool roofs are built with materials that give them high albedo and high emissivity in order to minimize the absorption of solar radiation, and to maximize the release of outgoing long wave radiation (van Tijen & Cohen, 2008). By reducing the amount of solar radiation absorbed by roofs and decreasing the surface temperature of roofing materials, cool roof applications help to minimize the UHIE. Cool roof technologies have been credited with reducing roof temperatures by approximately 28-33°C during peak summer weather (Environmental Protection Agency, 2008). While cool roofing products initially consisted of white-based materials, these technologies have expanded greatly to include a wide variety of colours and roof types. These options are further discussed in section 6.1.2.

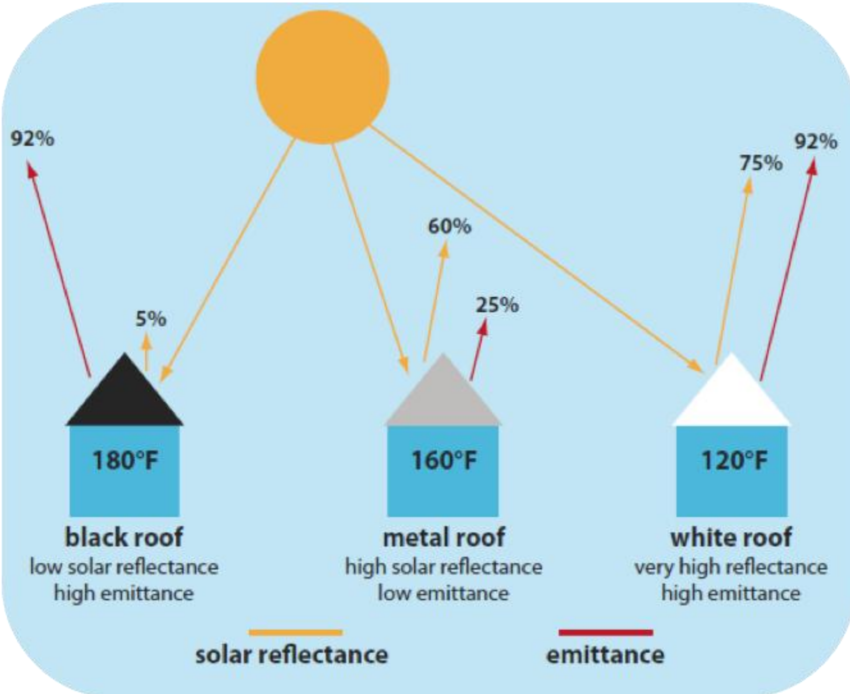


Figure 9: *The impacts of roof type on the reflectance and emittance of solar radiation (Environmental Protection Agency, 2008)*

6.1.1 BENEFITS

Energy Conservation

One of the primary benefits of installing cool roof applications is energy conservation in buildings. This is significant, as commercial energy consumption in buildings has been estimated to account for approximately 30% of the total energy consumption within many developed countries (Synnefa *et al.,* 2007). This benefit has been widely recognized, and resulted in the development of energy policies mandating the use of cool roofing materials in areas such as California (Graveline, 2009). Through decreasing the surface temperature of roofs, the indoor thermal environment also experiences cooling. This subsequently reduces the cooling demand and associated energy required to operate HVAC systems. A systematic review of 25 studies addressing the energy conservation benefits of cool roofs determined that energy demand was reduced by approximately 20% (Environmental Protection Agency, 2008).

The Lawrence Berkeley National Laboratory (LBNL) completed a study using the DOE-2.1E building energy model to quantify the energy benefits of cool roofs versus traditional roofs. The study compared the heating and cooling energy uses of retail and office buildings with cool white roofs (solar reflectance – 0.55) versus traditional gray roofs (solar reflectance – 0.20) across multiple states in the USA. Energy savings in Arizona, New Mexico, and Nevada were determined to be 7.69, 6.92, and 6.86 kWh/m^2, respectively. The energy savings in northern states such as Minnesota and Illinois were lower at 4.17 and 4.22 kWh/m^2. Overall, in the United States the cooling energy savings were determined to be 5.02 kWh/m^2 on average. When factoring in the winter heating energy penalty (the increased cost to heat the building as a result of a cool roof), the average energy cost savings were \$0.356/m^2. In all states examined, including Alaska, the cooling energy savings exceeded the winter heating penalty, resulting in a net financial benefit with respect to energy consumption and costs. However, the greatest energy savings were found in areas with warmer climates. It is expected that the benefits from cool roofs in terms of energy cost savings will improve over time as energy prices increase (Graveline, 2009).

Air Quality

The installation of cool roof technologies has also been associated with improved air quality by minimizing emissions resulting from energy production. Using a similar methodology to the one utilized in the energy conservation study, an examination of the effects of cool roofs on air pollutant emissions was also conducted by LBNL within the United States. The study calculated the emissions reductions of two greenhouse gases, CO_2 and NO_X, as well as SO_2, which contributes to acid rain formation through conversion into sulphuric acid (H_2SO_4). In addition to their negative environmental effects, these pollutants have been linked to human health issues. Nitrous oxides are respiratory irritants and may impair lung function, contribute to breathing issues, and aggravate existing conditions such as asthma and bronchitis. Sulphur dioxide has also been associated with respiratory problems such as breathing issues (Health Canada, 2006).

The emission reductions were calculated by quantifying the emissions from the dominant types of energy production in each region. Average reductions in the United States of CO_2, NO_X, and SO_2, were determined to be 3.02 kg/m^2, 4.81 g/m^2, and 12.40 g/m^2. It is likely that the reductions in the Windsor area would be less significant as energy production relies on cleaner sources than those used in many U.S. states, such as the combustion of coal. Instead, Windsor's energy is largely derived from nuclear power, hydroelectric projects, renewable energy sources, and natural gas fired combined heat and power plants (Berry *et al.,* 2011). However, the emissions decrease of these pollutants will still have important benefits regarding the mitigation of the greenhouse effect, acid rain, and human health issues in the Windsor area.

Increased Roof Lifetime

The installation of cool roofing materials has also been associated with increasing the lifetime of roofs. This occurs due to the decrease in roof temperatures which corresponds with the reduced weathering of roofs. Extreme changes in temperature cause damage to roofs, but cool options help to minimize the large temperature fluctuations that cause damage (Global Cool Cities Alliance, 2012). This may result in financial savings by minimizing maintenance needs as well as by reducing the necessary frequency of roof replacement. The increase in roof lifetime may also yield indirect benefits such as the minimization of waste production and use of resources (Houston Advanced Research Center, 2009).

Improved Thermal Comfort

Cool roofs help to improve thermal comfort by reducing the amount of heat absorbed within the internal environment of buildings. This benefit is particularly important in buildings that lack air conditioning where the occupants lack the ability to control indoor temperatures (Environmental Protection Agency, 2008). In one study, researchers estimated improvements in thermal comfort by measuring the number of hours where the optimal indoor summer temperature range of 23.3-27°C was exceeded. It was found that increasing the solar reflectance of a roof by 0.4 resulted in a 75% decrease in the number of hours in which this range was exceeded (Synnefa *et al.,* 2007).

6.1.2 COOL ROOF OPTIONS

The following options are the most popular applications used to achieve cool roof benefits. Cool roof products may be manufactured directly, or traditional materials may be modified in order to improve albedo. These options include modifications of traditional materials through the use of coatings, pigments, and paint that change the solar reflectance of these materials. A summary of the full range of cool roof options, their lifetime, and their albedo in comparison to traditional roofing materials is provided in *Table 3.*

Cool Pigments

When choosing cool roof options in the past, builders were often limited to white coloured materials in order to achieve the desired increases in albedo. However, cool roof materials are now available in a range of colours that offer significant improvements in solar reflectance over traditional products *(See Figure 10).* These products are treated with cool pigments in order to increase their reflectivity, allowing dark colours to be used. The availability of these products helps to reduce concerns regarding aesthetics and limited selection that may have deterred individuals from building cool roofs in the past. Available materials that utilize cool pigment technology include: asphalt shingles, clay tiles, concrete tiles, and metal roofing (Global Cool Cities Alliance, 2012).

Figure 10: *The albedo differences between standard (above) and cool coating (below) concrete tiles (Global Cool Cities Alliance, 2012)*

Built-up Roofing and Modified Bitumen

The basis for the structure and design of cool built-up and modified bitumen roofs remains the same as their traditional counterparts. However, these roof types are modified through changes in gravel and coating colours to increase albedo. Built-up roofs are constructed by layering roofing felts bound with bitumen to form a solid, watertight roof surface. A layer of gravel is commonly applied on top of the felts, becoming the exterior surface exposed to the sun (National Research Council Canada, 2005). By utilizing white gravel instead of dark gravel, the albedo of built-up roofs increases to about 0.30-0.50. In cases where coatings are applied to the top roof layer in lieu of gravel, white coatings may be selected to maximize solar reflectance.

Modified bitumen roofs consist of two layers of polymer modified bitumen sheets that are applied with heat torches, asphalt, or cold adhesives. White coatings can also be applied to these roofing systems in order to increase albedo.

Liquid Applied Coatings

Liquid applied coatings are polyurethane based and applied on top of roof structures in order to serve as a waterproof sealant. Once applied, the coating forms an elastic sealant similar to rubber that returns to its original shape upon expansion. Liquid applied coatings can be used on many of the traditional roof types including built-up roofs, modified bitumen roofing, asphalt, and concrete. While these coatings have traditionally been manufactured to have a smooth black finish, they can be formulated to have a smooth white finish instead. Liquid applied coatings are an attractive option for cool roof upgrading as they are inexpensive, durable, and can be applied in a timely manner when roofs are required to undergo maintenance (Global Cool Cities Alliance, 2012).

Single-ply Membranes

Single-ply membranes are prefabricated roofing materials that are applied in uniform sheets. These membranes contain various combinations of polymers, bitumen, fillers, stabilizers, plasticizers, and other additives. Single-ply membranes are known to be durable, flexible, adaptable, resistant to damage, and cost-effective.

One of the most versatile classes in this roofing category are polyvinyl chloride (PVC) membranes. Their versatility allows them to be applied to a wide range of industrial and commercial roof surfaces, including application onto surfaces such as sheet metal. These membranes are modified with colour pigments in order to increase solar reflectance. Another common class are prefabricated elastomeric membranes which are formulated by vulcanizing different types of polymers. These membranes are produced in 1-2mm sheets, and a popular elastomer that is modified to produce cool roofs is ethylene propylene diene monomer (EPDM). EPDM membranes are generally modified by applying coatings of paint in order to increase their solar reflectance (National Research Council Canada, 2012). Both PVC and EPDM membranes are available in multiple colours, but the greatest benefits in terms of cooling result from utilizing white membranes.

Table 3: *A comparison of albedo (solar reflectance) between traditional and cool roof options (Global Cool Cities Alliance, 2012)*

ROOF TYPE	ROOF LIFE (years)	TRADITIONAL ROOF OPTION	ALBEDO	COOL ROOF OPTION	ALBEDO
Asphalt shingle	15-30	• Black/brown with conventional pigments	0.05-0.15	• White or cool colour pigments	0.25
Built-up roof	10-30	• Dark gravel • Aluminum coating	0.10-0.15 0.25-0.60	• White gravel • White smooth coat	0.30-0.50 0.75-0.85
Clay tile	50+	• Dark colour with conventional pigments	0.20	• Terra cotta • Colour with cool pigments • White	0.40 0.40-0.60 0.70
Concrete tile	30-50	• Dark colour with conventional pigments	0.05-0.35	• Colour with cool pigments • White	0.30-0.50 0.70
Liquid applied coating	5-20	• Smooth black	0.05	• Smooth white	0.70-0.85
Metal roof	20-50	• Unpainted, corrugated • Dark paint, corrugated	0.30-0.50 0.05-0.10	• Colour with cool pigments • White painted	0.40-0.70 0.55-0.70
Modified bitumen	10-30	• Mineral surface capsheet	0.10-0.20	• White coating	0.60-0.75
Single-ply membrane	10-20	• Black PVC or EPDM rubber	0.05	• Colour with cool pigments (PVC/EPDM) • White (PVC/EPDM)	0.40-0.60 0.70-0.80
Wood shake	15-30	• Dark colour	0.35-0.50	• Natural wood	0.40-0.55

6.2 GREEN ROOFS

In addition to changing the thermal properties of roofs by utilizing cool roof technologies, mitigation of the UHIE and other concerns such as stormwater management can be addressed through the construction of green roofs. Green roofs are contained vegetation areas situated on built structures. They consist of many components including: vegetation, a growing medium, filter, drainage system, insulation, root barrier, waterproof membrane, and structural support (*See Figure 11*). The precise design specifications of green roofs vary greatly between projects. As a result, the design, construction, function, and costs associated with green roofs are also variable.

The incorporation of green roofs into building design helps to reduce the UHIE by increasing albedo and evapotranspiration rates. Vegetation has a higher albedo than traditional roofing materials such as asphalt shingles, tiling, concrete, gravel, and corrugated roofing, at approximately 0.70-0.85. As a result, vegetation helps to reflect a larger proportion of solar radiation, minimizing air temperatures. Additionally, plants initiate cooling by releasing water vapour into the atmosphere through evapotranspiration. During this process sensible heat is transformed into latent heat, resulting in cooling.

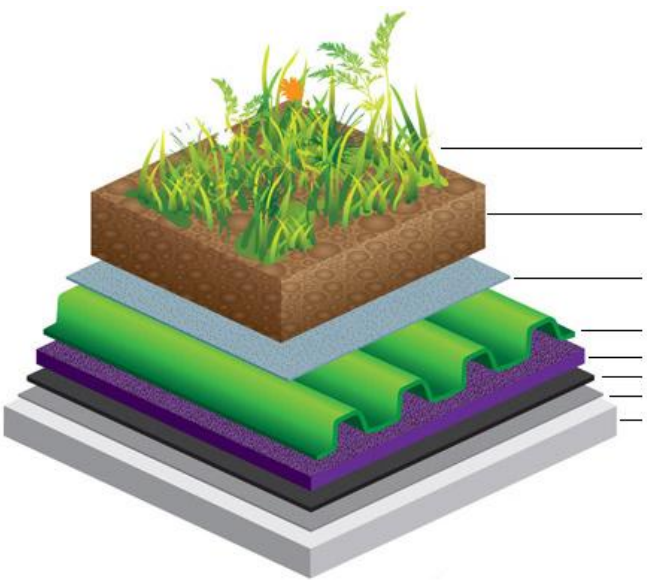


Figure 11: *Green roof structure (Green Roof Guide, 2012)*

6.2.1 BENEFITS

Stormwater Management

Urban areas consist predominantly of hard nonporous surfaces which leads to significant runoff that periodically overburdens municipal stormwater management operations. Within urban environments, approximately 50% of impervious surfaces are roofs (Oberndorfer *et al.,* 2007). Issues associated with urban runoff include: combined sewer overflows (CSOs) into surface water bodies, the transport of pollutants, erosion, sedimentation, and flooding. The development of green roofs can also help to mitigate these issues.

Precipitation is held within plant foliage, absorbed by roots, and stored in the drainage layer. This helps to reduce the rate of runoff, which minimizes the amount of water entering the sewer system during intense rainfall, decreasing the risk of CSO events. It is estimated that green roofs can delay stormwater runoff by 1.5-4 hours (Getter & Rowe, 2006). Water is also used by plants and returned to the atmosphere via evapotranspiration, helping to reduce the volume of overall runoff. Studies have shown that green roofs can reduce building runoff by 60-79% depending on the intensiveness of the green roof. The reduction will vary depending on the plant species, root depth, membrane selection, roof slope, and rainfall intensity. In addition to decreasing the quantity of stormwater runoff, research has also demonstrated that green roofs have the ability to improve the quality of stormwater by selecting species that remove contaminants such as heavy metals and nutrients (Oberndorfer *et al.,* 2007).

Energy Conservation

Green roofs help to improve the energy efficiency of buildings by dissipating solar radiation and by providing shading therefore decreasing indoor air temperatures. By resulting in interior cooling, the demand for air conditioning decreases, minimizing energy demands. Furthermore, vegetation helps to reduce heat transfer by improving insulation, further minimizing the need for energy production (Oberndorfer *et al.,* 2007).

Emission Reductions

Vegetation removes atmospheric CO_2, a greenhouse gas (GHG), through sequestration and storage. Improving and enhancing the amount of vegetation in urban areas by constructing green roofs will therefore increase the mass of CO_2 that is stored, as sequestration is proportional to plant biomass.

Green roofs may also help to improve air quality through the absorption of gaseous pollutants in stomata, and the interception of particulates by vegetation. Through these processes pollutants such as NO_x, SO_2, O_3, CO, and particulates can be removed from the atmosphere, resulting in improvements to regional air quality (Getter & Rowe, 2006).

6.2.2 GREEN ROOF OPTIONS

Multiple options exist that should be taken into consideration and evaluated when designing green roofs. These alternatives are associated with various degrees of intensiveness, construction methods, planting configurations, maintenance, and accessibility. Such options may result in the achievement of different cost, thermal, social, hydrologic, and atmospheric benefits. As a result, planners and developers should carefully consider the range of alternatives available to them in order to best satisfy the objectives of green roof projects.

New Construction or Retrofit

When considering options to increase the number of green roofs in municipalities one of the key decisions to be made is whether developers should incorporate green roofs into new construction plans or by conducting retrofits of existing buildings. It is necessary to verify that buildings are structurally sound in order to bear the added weight of green roofs and to prevent moisture penetration (Banting *et al.*, 2005). As a result, if building retrofits are being completed the roofs of existing buildings may need to be reinforced, and additional membranes may need to be added to prevent damage. In cases where the costs of making these upgrades are significant, incorporating green roofs into the design of new buildings may be a better alternative. In most cases, building retrofits are limited to the development of extensive roofs, described below, as roof strength may limit the plant variation and substrate depth that can be used. Public accessibility may also be limited when retrofits are being completed, as initial building designs likely did not consider opportunities for providing viewing areas.

Complete or Modular

The assessment of whether a green roof system is complete or modular depends on how the living green roof components are integrated with the roof structure as a whole. In complete systems, all components in the roof system are designed to support the vegetation which is grown on site. Complete systems offer the greatest flexibility regarding the diversity of protective layers, drainage layers, growing medium, and vegetation that can be successfully used. These systems also allow for the greatest maximum thickness and weight of green roof structures, allowing intensive green roofs to be built (Banting *et al.,* 2005).

Conversely, modular green roofs lack the same integrative structure seen in complete green roofs, and are positioned above existing roof systems. Oftentimes, trays containing the growing medium and vegetation are precultivated off site and then overlaid on existing roofs in a grid format (*See Figure 12)*. The diversity of modular systems in terms of potential vegetation type, depth, and weight is limited.

Figure 12: *Modular green roof (Banting et al., 2005)*

Extensive, Semi-Intensive, or Intensive

Green roofs can be developed using increasingly complex designs plans ranging across extensive, semi-intensive, and intensive roof types. The decision to select one of these green roof types may depend on a range of factors including: budget constraints, time constraints, local climate conditions, aesthetic values, maintenance options, and installation options.

Extensive green roofs have the lowest plant diversity, growing medium depth, and weight. They support shallow depth plant species such as herbs, grasses, and mosses. As a result, they can be built on sloped roofs and require minimal structural support. Extensive roofs are low maintenance, have minimal irrigation needs, and have low costs associated with them. As green roofs become increasingly intensive their resemblance to ground level parks and gardens increases. While semi-intensive green roofs can support larger plants such as shrubs, intensive green roofs can support the highest variety of plants, including trees. As green roofs become more intensive their needs in terms of maintenance, cost, and irrigation also rise (Getter & Rowe, 2006). Furthermore, intensive and semi-intensive green roofs generally provide more opportunities for public viewing, as well as valuable amenity space. Differences between extensive and intensive green roofs are illustrated in *Figure 13,* and a summary of the key properties of these three green roof types is provided in *Table 4.*

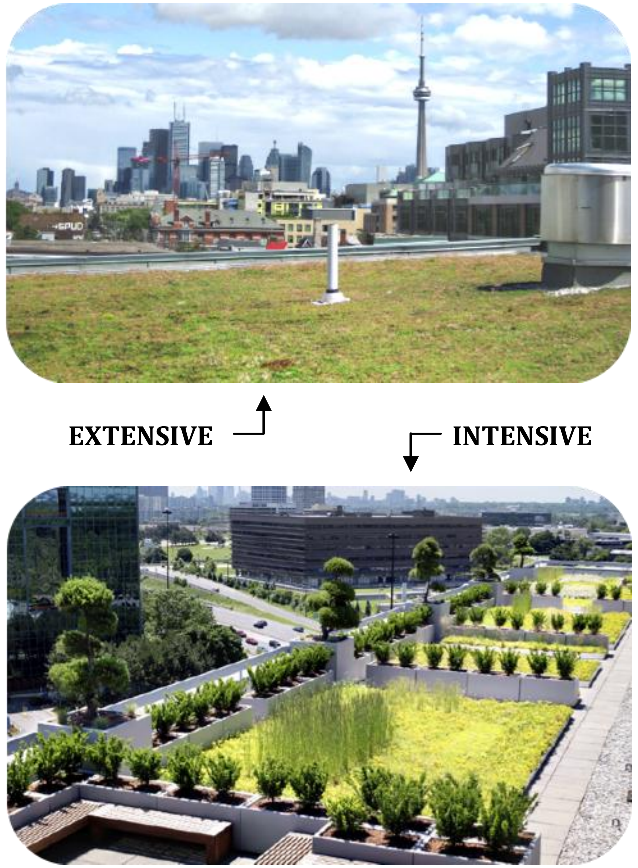


Figure 13: *Extensive and intensive green roofs in Toronto, ON*

Table 4: *Properties of extensive, semi-intensive, and intensive green roofs (Green Infrastructure Foundation, 2009)*

	EXTENSIVE	**SEMI-INTENSIVE**	**INTENSIVE**
GROWING MEDIUM DEPTH	≤ 15 cm	15-30 cm	≥ 15 cm
WEIGHT	10-35 lb/ft^2	35-50 lb/ft^2	50-300 lb/ft^2
MAINTENANCE	Low	Medium	High
IRRIGATION	None	As needed	Consistent
PLANT DIVERSITY	Grasses, mosses, herbs	Shrubs, grasses, mosses, herbs	Trees, shrubs, grasses, mosses, herbs
ACCESSIBILITY	Often inaccessible	Partially accessible	Often accessible
COST	Low	Medium	High

6.3 COOL PAVEMENT

Within urban environments, paved areas account for approximately 30-45% of exposed surfaces, which causes them to have a significant impact on UHI intensity (Environmental Protection Agency, 2008). Traditional pavement typically consists of a binder, such as asphalt or cement, as well as an aggregate, such as crushed rock. The binder serves as an adhesive, while the aggregate provides strength, resistance, and creates friction. The two most popular pavement types used currently are asphalt and impervious concrete, which can each reach high surface temperatures of 48-67°C (120-150°F). With respect to the thermal properties of asphalt and concrete, they generally have low albedo (~0.05-0.40) and high emissivity (~0.90). Due to its darker pigmentation, asphalt typically has a lower albedo, also measured as solar reflectance, than concrete *(See Figure 14)*. However, over time the solar reflectance of asphalt increases due to weathering, while concrete's solar reflectivity often decreases as it accumulates dirt and debris (Environmental Protection Agency, 2008).

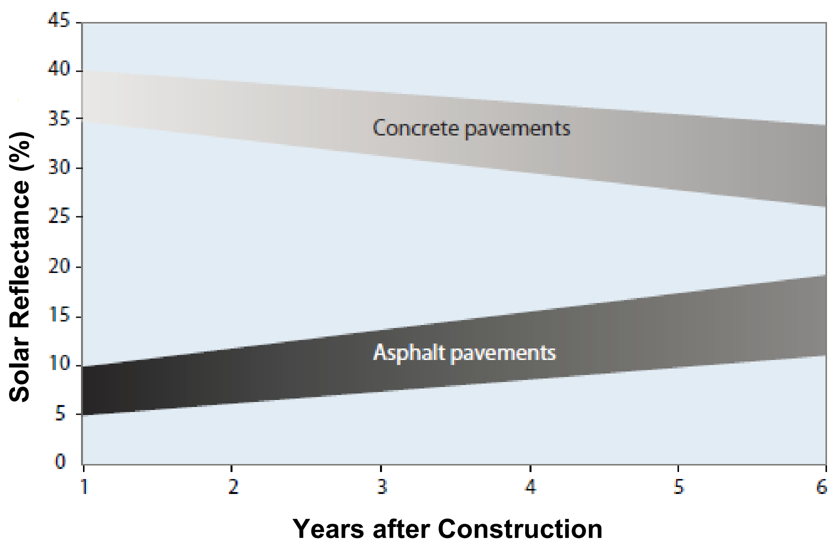


Figure 14: *Changes in solar reflectance in concrete and asphalt pavement over time (Environmental Protection Agency, 2008)*

Pavement temperatures are affected by: solar radiation, solar reflectance, emittance, heat capacity, surface roughness, heat transfer rates, and permeability. Due to the low solar reflectance of both asphalt and concrete, alteration of the thermal properties of paving materials presents a strong opportunity to reduce the intensity of the UHIE. To mitigate the UHIE, cool pavements can be used in order to alter the thermal and permeability properties of conventional pavement. Much of the research and development of cool pavement technologies has focused on methods that alter its solar reflectance, as this property has been determined to be the primary factor affecting the influence of pavement on UHIE intensity. By increasing albedo, a greater proportion of solar radiation is reflected by pavement surfaces, resulting in cooling.

The term cool pavement has also been broadened to include permeable pavement applications. The properties and structure of permeable pavement differ from other types of cool pavement which are impermeable. Permeable (porous, pervious) pavement contains void spaces that allow precipitation and stormwater runoff to infiltrate, become stored within subsurface layers, and exfiltrated beneath the earth's surface (Scholz & Grabowiecki, 2007). The presence of void spaces allows water that is stored in the pavement to evaporate, producing an effect similar to evapotranspiration that results in cooling (Global Cool Cities Alliance, 2012). Convective airflow through the pavement voids may also help to induce cooling (Environmental Protection Agency, 2008).

6.3.1 BENEFITS

Stormwater Quantity

The use of permeable pavement will improve stormwater management by reducing the quantity of runoff entering wastewater treatment plants and storm sewers. The use of porous pavement helps to reduce runoff rates by facilitating infiltration of stormwater below the pavement surface, and temporarily storing it in the subsurface layers. This decreases both the total volume and rate of runoff flow to wastewater treatment plants. Therefore, the risk of flooding, CSOs, and pollutant washout into nearby sewers and water bodies becomes decreased. This also helps to lessen the demand on Pollution Control facilities by reducing peak flow and the costs of treating stormwater (Ordonez & Duinker, 2012).

Stormwater Quality

Similarly to the benefits regarding stormwater quantity, improved stormwater quality may result from the use of permeable pavement. Improved stormwater quality occurs through the removal of pollutants such as suspended solids, dissolved solids, nutrients, hydrocarbons, and heavy metals (Frazer, 2005).

A study completed by the City of Calgary found that the concentration of suspended solids in runoff from impervious pavement ranged between 30-300 mg/L, while their concentration in runoff from pervious surfaces ranged from 0-50 mg/L. Reductions in runoff pollutant concentrations result due to the presence of lower runoff volumes, as well as from the physical removal of contaminants within the structure of permeable pavement. Processes that result in pollutant removal include: runoff filtration, entrapment, sedimentation, and biodegradation as stormwater travels between the subsurface layers (City of Calgary, 2007).

Aquatic Ecosystem Health

Through facilitating infiltration and removing pollutants, the use of permeable pavements may help to protect aquatic ecosystem health. Increasing infiltration helps to minimize stormwater runoff across impermeable surfaces into nearby waterways. This can improve aquatic ecosystem health through decreasing rates of sedimentation that may destroy aquatic habitats. Furthermore, the abundance, reproductive success, and diversity of aquatic species may be threatened by high contaminant and nutrient levels in stormwater runoff. However, these concentrations are likely to be reduced due to the removal of pollutants through the soil and/or plants used with permeable pavements, and due to reductions in the quantity of stormwater runoff entering aquatic environments (Environmental Protection Agency, 2003).

Pavement applications that increase solar reflectance as well as permeable pavement may also help protect the health of aquatic environments. By decreasing the surface temperature of pavement, the temperature of stormwater runoff that passes across these surfaces will also be reduced, decreasing the likelihood of thermal shock in water bodies. The reproduction, development, and survival of aquatic organisms occur within an optimal temperature range. By decreasing surface and water temperatures, cool pavement technologies will help to ensure that their maximum temperature thresholds are not exceeded, ensuring that species abundance and diversity is maintained (Roa-Espinosa *et al.,* 2003).

Road Safety

Research on the benefits of cool pavements has indicated that their properties may also help to enhance road safety. Permeable pavements may improve vehicle traction by reducing the amount of water covering roadways as water infiltration occurs. Additionally, by increasing the reflectivity of pavement, drivers are better able to see street and car lights along paved surfaces. This may help improve driver safety by increasing visibility and decreasing reaction times (Environmental Protection Agency, 2008).

6.3.2 COOL PAVEMENT OPTIONS

Cool pavement options fall into two categories, those that increase solar reflectance, and those that increase permeability. Examples of pavement types from each of these classes can be seen in *Figure 15.* Potential options in these categories may involve modifying existing pavement surfaces, altering the formulas of traditional paving materials, or by constructing entirely new pavement systems. Final selection of a specific pavement type for a project may depend on: cost restrictions, desired pavement function, anticipated use intensity, time constraints, environmental objectives, and if the project is for a new development or maintenance of an existing development.

Figure 15: *Cool pavement options that increase solar reflectance [left, centre] and permeability [right] (Lawrence Berkeley National Laboratory, 2012)*

INCREASING SOLAR REFLECTANCE

Reflective Aggregates

As mentioned previously, pavement aggregate helps to provide strength, resistance, and to create friction along paved surfaces. Potential aggregate materials include crushed rock, sand or gravel. These materials can be selectively chosen in order to increase solar reflectivity. For instance, builders can choose materials such as limestone, as they are lighter in colour and therefore have a greater albedo.

Resin Binders

Another component of pavement that can be altered in order to reduce the absorption of solar radiation is the binder. As mentioned previously, binders serve as adhesives and commonly consist of either asphalt or cement. The chemical composition of such binders can be altered in order to increase albedo. For instance, microsurfacing is a process in which a thin asphalt overlay is applied that contains advanced polymers in the binder to increase reflectivity. The colours of binders can also be altered to increase reflectivity. For instance, in the first photo of *Figure 15*, a clear resin binder was used to maximize the path's solar reflectance (Environmental Protection Agency, 2005).

Cool Coatings

Application of cool pavement coatings is more limited than the use of cool roof coatings, due to requirements for safety and visibility. However, depending on the use of a surface, seals and coatings may be applied to achieve a higher albedo. One option in this category is to apply whitetopping. Whitetopping involves applying a layer of concrete pavement over an existing asphalt surface for maintenance and resurfacing purposes. Through this process, the albedo of the surface is improved over traditional concrete, as the whitetopping layer is lighter in colour. Whitetopping is commonly completed to resurface road segments, intersections, and parking lots.

Another common coating is a Chip Seal which is used for maintenance on asphalt pavements. These seals contain aggregates that increase the albedo of asphalt surfaces. This technique is best suited to low traffic roadways as the chips (stones) in the coating may loosen due to vehicle movement (Environmental Protection Agency, 2005).

Conventional Portland Cement Concrete Pavement

Conventional Portland Cement Concrete (PCC) has been suggested as a suitable cool pavement option due to its light colour and enhanced reflectivity. Different additives can be added to PCC in order to lighten it. One of these potential additives is slag cement, a by-product of iron and copper processing that is ground into a cement product. It has a lighter colour that increases the reflectivity of the surfaces it is used in. Furthermore, it provides additional benefits such as increased strength, and resistance to chemicals and warm temperatures. Another potential option is fly ash, a by-product of coal burning. Fly ash varies in colour and additional research is necessary to determine source specific reflectivity benefits (Environmental Protection Agency, 2005).

INCREASING PERMEABILITY

Permeable Asphalt

Permeable asphalt *(See Figure 16)* differs from conventional asphalt due to differences in the amount of filler, which is minimal at <0.075 mm in diameter. Larger particle sizes are used to ensure that migration of water can take place. Stormwater is able to infiltrate this pavement as it has 15-25% pore space. Finally, extra polymers are added to the asphalt to prevent migration of particles, increasing the concentration of binder relative to conventional asphalt mixes (City of Calgary, 2007).

Figure 16: *Porous asphalt in Calgary, AB (City of Calgary, 2007)*

Permeable Concrete

Similarly to permeable asphalt, the appearance of permeable concrete is coarser than traditional concrete. To synthesize permeable concrete, water is combined with cement-like materials to form a coating around the aggregate particles. The permeable concrete mixture contains minimal sand particles, and has a void ratio of 15-25%, allowing water to infiltrate at rates of over 12,000 mm/hr (City of Calgary, 2007).

Concrete Interlocking Pavers

While concrete interlocking paving blocks themselves are impermeable, they are laid in a manner that renders the overall surface as permeable (*See Figure 17)*. These blocks are laid on gravel sublayers, and porosity can be controlled by adjusting the amount of space between the edges of each block. Sublayers are chosen carefully to ensure that the materials used are conductive to allowing water infiltration (City of Calgary, 2007).

Figure 17: *Concrete interlocking pavers in Olympia, WA (City of Calgary, 2007)*

Turf Pavers

Turf pavers *(See Figure 18)* are more limited in their use than the aforementioned permeable pavement types, as they can only be subjected to low traffic volumes and light vehicles loads, and they cannot be snow-plowed. To build turf paving systems, concrete or plastic grid units must be laid to provide structure, stability, and to resist compaction from vehicle weight. Within these grid units, a series of open gaps are then filled with soil and planted with turf grass, which allows water to infiltrate. In order to reinforce their strength and structure, these systems are often reinforced with wire mesh.

Figure 18: *Turf pavers (Unilock, 2012)*

6.3.3 CHALLENGES

Durability

In comparison to impermeable pavement, porous pavements lacks durability as the void spaces may deteriorate due to air infiltration, oxidation, stripping, and shear stress. Concerns about the durability and longevity of porous pavement have rendered it suitable for only surfaces that receive light and infrequent usage. As a result, the use of porous pavement is commonly reserved for the following areas: driveways, road shoulders, parking lots, golf course paths, pedestrian paths, and bicycle trails (Scholz & Grabowiecki, 2007).

Clogging in older permeable pavements is often due to the presence of sand, either in the bedding layer or applied on the surface to improve wheel traction during the winter. Newer installations of permeable pavement use washed stone in the pavement openings and bedding layer because these resist breakdown into smaller particles with age, and the pore spaces are large enough to transmit fine particulate matter deeper into the coarser base layers, thereby reducing the potential for surface sealing. At a minimum, the base should be free of sand or other fine particles, and surfaces must be well protected from sediment transport during construction (University of Guelph, 2007).

Maintenance

The presence of void space may also lead to clogging of porous pavement, reducing the potential for water infiltration. This may result as sediments become trapped in the pores or as shear stress from vehicle weight causes the pores to collapse. If the void spaces become completely clogged, the pavement area would require complete replacement. To avoid this potentially costly issue, it is therefore necessary to develop maintenance regimes for street sweeping and pressure washing to clear debris from the void spaces (City of Calgary, 2007). The aim of maintenance, generally vacuum assisted sweeping and power washing, is to remove smaller particles that have accumulated in the surface voids (University of Guelph, 2012).

The University of Guelph tested various maintenance measures on seven permeable pavement parking lots. Infiltration rates were observed to increase after vacuuming and pressure washing treatments. Preliminary observations suggest that the most effective surface treatment is a two-part practice: dislodging compacted sediment followed by the permanent removal of sediment (University of Guelph, 2007).

Site Applicability

The ability to successfully use permeable pavement is dependent on characteristics such as climate and soil conditions. Within Windsor, the cold winter climate and high clay content of soils may pose some challenges with respect to the development of porous pavement projects. Conflicting reports exist regarding the impact that freeze-thaw cycles can have on the lifespan of porous pavements. Therefore, it is important for pilot projects to be carried out in order to better understand how porous pavement will function in local climatic conditions.

Typically, permeable pavement systems are not suitable for site with soils that have a clay content >30%. However, for the Ravinia Festival Parking lot construction in Highland Park, Illinois, structural modifications were made in order to facilitate water infiltration and exfiltration. The builders of the project constructed underground water detention areas beneath the permeable concrete block pavers. Up to 249,000 gallons of water can be stored in the detention area, and are then released slowly into the municipal storm sewer system (Landscape Architecture Foundation, 2011).

In situations where the clay content of soil is high, cost-benefit analysis should be carried out in order to assess if the additional construction modifications result in substantial stormwater management benefits (City of Calgary, 2007).

6.4 URBAN GREENING

Urban development and sprawl in Windsor have resulted in a landscape predominantly characterized by the replacement of vegetation with hard, impermeable surfaces. Differences in stormwater runoff and evapotranspiration rates in permeable versus impermeable landscapes can be seen in *Figure 19.* The loss of green space in urban areas contributes significantly to UHIE intensity through two mechanisms. Firstly, loss of green space results in reduced rates of evapotranspiration. Due to the reduction in the quantity of latent heat being converted into sensible heat through this process, the overall cooling effect of vegetation will be diminished. Furthermore, the loss of shading from vegetation, particularly large trees, will result in an increase in the temperatures of the surfaces below.

In order to mitigate the UHIE, the amount of green space in the City of Windsor should be increased. By increasing the amount of vegetative cover in Windsor, urban greening will help to diminish the UHIE. Increased vegetative cover will augment rates of evapotranspiration as plants absorb water and release it into the atmosphere as vapour, and vegetative shading will help prevent the absorption of solar radiation by surfaces. Mechanisms to enhance green space may include planting programs, naturalization procedures, and/or conservation. The full range of options for urban greening is discussed in section 6.4.2.

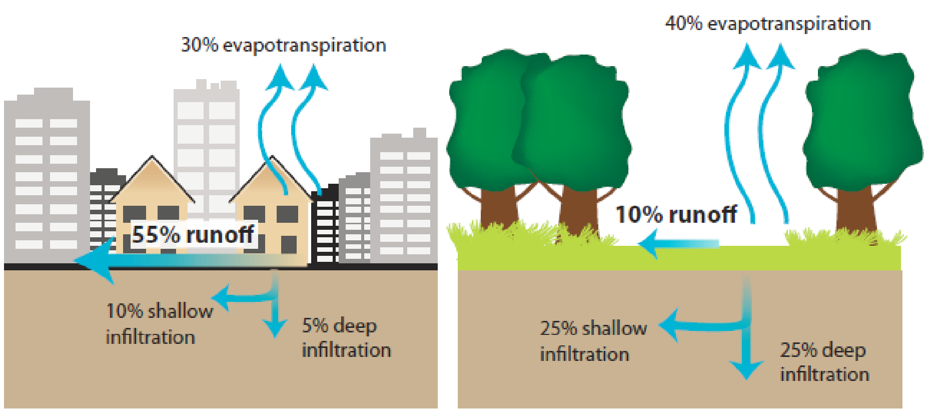


Figure 19: *Differences in runoff, infiltration, and evapotranspiration rates between urban (impermeable) and vegetated (permeable) landscapes (Environmental Protection Agency, 2008)*

6.4.1 BENEFITS

Stormwater Management

In addition to reducing the UHIE, increasing the amount of green space in the City of Windsor will also significantly improve stormwater management. On paved surfaces, stormwater runoff is diverted quickly into the sewer system. However, as the amount of tree coverage and green space increases, these surfaces will be converted back into impermeable surfaces. Vegetated areas also help to reduce the flow rate of runoff by facilitating infiltration and storage. Furthermore, stormwater runoff quantities may be reduced as plants absorb and convert liquid water into water vapour. As a result, the risk of flooding, CSOs, and pollutant washout into nearby sewers and water bodies may decrease. This may also help to lessen the demand on Pollution Control facilities by reducing peak flow and the number of times a facility will need to bypass sewage (Ordonez & Duinker, 2012).

This adaptation option will also help to improve stormwater quality, as filtration by vegetation helps to remove pollutants from runoff. The shift to naturalization from conventional landscaping will also minimize pollutant concentrations by reducing the release of contaminants from the use of fertilizers, pesticides, and herbicides that are used to maintain conventional landscaping features (Ingram, 2001).

Reduced Greenhouse Gas Emissions

Increasing the amount of green space may also help to reduce the quantity of GHG emissions. Trees and vegetation remove atmospheric CO_2, a greenhouse gas, through sequestration and storage in plant biomass. This will reduce the amount of GHG emissions by removing them from the atmosphere. The total mass of CO_2 that can be stored is proportional to overall plant biomass. Therefore, it is important to not only plant additional vegetation, but to ensure that mature trees are conserved, as they sequester the greatest quantities of carbon.

Furthermore, by naturalizing existing green spaces, the need for mechanical maintenance of these areas will be reduced. Conventional landscaping largely depends on intensive maintenance regimes to preserve neat, well-manicured areas. This requires significant use of machinery that release gases such as: CO, CO_2, NO_X, and volatile organic compounds (VOCs), which contribute to the greenhouse effect. Therefore, CO_2 sequestration combined with reduced mechanical maintenance will help to diminish the greenhouse effect that contributes to climate change and associated warming (Ordonez & Duinker, 2012).

Improved Air Quality
Similarly to GHG reductions, rates of atmospheric pollutants will decrease by enhancing tree coverage and vegetated land cover in Windsor. Absorption of air pollutants by vegetation occurs via uptake by leaf stomata and through the deposition of airborne particles on plant surfaces. Through these processes, plants can absorb pollutants such as O_3, NO_2, SO_2, CO, and particulate matter (Ingram, 2001).

Biodiversity
Increases in tree canopy and restoration of land into natural, vegetated areas will help to increase the total amount of habitat to support wildlife and other organisms. This will also help to restore ecosystem services and re-establish traditional landscape functions that support thriving ecosystems. As a result, increased biodiversity and species abundance in vegetated areas will likely be found. Additionally, the creation and expansion of green space will help to improve habitat linkages by increasing connectivity to other natural areas. This helps to facilitate migration, maintain productivity, maintain resilience to disastrous environmental events, and to maintain genetic diversity amongst populations (Ordonez & Duinker, 2012).

Energy Conservation
Increases in green space, and especially the amount of tree coverage may help to conserve energy by increasing urban shading, decreasing winter wind speeds, and reducing air temperatures (Nowak & Dwyer, 2007). Urban shading results in energy conservation by cooling urban infrastructure, therefore minimizing the demand on air-conditioning systems. The benefits of shading are best realized by strategically planting trees on the eastern and western sides of buildings. Urban trees may also aid in decreasing wind speeds in the winter, helping to reduce heating costs (Nowak & Dwyer, 2007).

A recent study revealed that the energy consumption required for indoor cooling increases by approximately 4% for every 1°C increase in temperature (Millward & Sabir, 2011). Therefore, reductions in overall air temperature will further minimize demands on heating and cooling systems, leading to increased energy savings. Research completed in the City of North Vancouver using the Street Tree Resource Analysis Tool for Urban Forest Managers (STRATUM) revealed that the city's 5,414 trees were responsible for $6,514 in energy savings annually (Wong & Gordon, 2011).

6.4.2 URBAN GREENING OPTIONS

To account for the diversity of potential urban greening options, they are presented in this section under the following categories:

- Green Space Acquisition and Development
- Conservation of Natural Areas
- Naturalization

GREEN SPACE ACQUISITION AND DEVELOPMENT

Land Acquisition and Redevelopment
In order to expand the amount of green space in a City, it is important for land acquisition to become a priority. This will ensure that additional natural areas are integrated into the urban greenway system as a whole, helping to increase the total amount of green space, as well as to improve linkages and connectivity between natural areas. The redevelopment of underutilized, vacant, or contaminated lands into green space should also become a priority in order to restore their ability to provide ecosystem services such as UHIE mitigation. An example of the successful redevelopment of a contaminated land area into a natural area consisting of trails, playing fields, woodlands, native plants, and open areas can be seen in *Figure 20.*

Figure 20: *Redevelopment of contaminated land in an industrial corridor into green space in Milwaukee, WI (Green Infrastructure Foundation, 2009)*

Increasing Tree Coverage

In comparison to other forms of vegetation, trees have the largest biomass and therefore the greatest potential to create a large cooling effect through evapotranspiration and shading. The development of aggressive tree canopy targets should be used to guide tree planting efforts by municipal forestry departments. A target has already been set in Windsor-Essex County to increase tree coverage from approximately 8% to 12.5%. Therefore, the City should refine their tree planting strategies to ensure that this target is attained. The development of specific annual tree planting targets can be used to guide efforts to increase the overall tree canopy and to attain the aforementioned canopy objective.

Expanding the use of Green Infrastructure

Green infrastructure refers to natural technologies that are used to provide ecosystem services and functions. Green infrastructure generally incorporates living components, are simple in their design, depend on natural energy systems to function, and become integrated into natural landscapes. Conversely, grey infrastructure is often developed in a complex manner, contains synthetic components, is structurally complex, and is independent from natural ecosystems (Green Infrastructure Foundation, 2009). In order to mitigate the UHIE, the development and use of green infrastructure projects that are vegetation based should be encouraged. Potential green infrastructure projects that would help mitigate the UHIE include:

- Rain gardens
- Bioswales
- Green roofs
- Green walls
- Community gardens

The development of guidelines on the design, construction, and use of various green infrastructure projects would help to increase the uptake of these technologies within municipalities. For instance, the City of Calgary developed a *Stormwater Source Control Practices Handbook* that provides guidelines on the use of green infrastructure such as bioswales and green roofs to aid in stormwater management.

Greenway Funds

The acquisition and development of new land areas into green space will require significant expenditures by the City. To reduce these costs, municipalities have developed greenway levy funds in order to support the expansion of greenway systems. For instance, within the City of Bellingham, WA, a Greenway Levy Fund was created through the development of a property tax levy that was designed to raise money for greening projects. These funds are used to secure land rights for the development of open space, trails, and ponds. To date, approximately 21 projects have been developed as a result of the distribution of these funds (Green Infrastructure Foundation, 2009).

CONSERVATION OF NATURAL AREAS

Development Guidelines

The ability of trees and vegetation to reduce the impact of the UHIE and to provide additional environmental services is dependent on their health and maturity. However, established areas of green space often come under threat by new development proposals. Such proposals often require significant land clearing in order to construct new buildings and infrastructure. In order to prevent land clearing practices that result in complete degradation of existing vegetation, the adoption of strict guidelines to protect green space from development pressures is an effective strategy.

These development guidelines may take many different forms, but will have the ultimate goal of conserving green space during and after new project construction. One example of a successful development guideline is section 10.3 (b) of the Town of Oakville's Official Plan. The plan states the objective to have no net loss of existing urban forests. To meet this requirement, all development projects must ensure that new trees are planted equal to the square metre of leaf area that is removed. This ensures that development does not result in disproportionate tree coverage due to differences between the leaf area of mature trees that are replaced by smaller trees. Developers must pay a sum equal to the value of trees they eliminate during construction, or plant new trees that will provide a canopy cover equal to that provided by the removed trees (Town of Oakville, 2006). Another common strategy is to require developers to submit landscape plans that must be approved prior to initiating construction.

Public Education

While municipal governments play a key role in conserving existing green spaces, members of the public can also make significant contributions that result in the preservation of natural areas. However, a lack of public knowledge regarding the value and maintenance necessary to grow trees may hinder the sustainability and growth of trees and green infrastructure located on private property. Therefore, it is critical to invest in educational programs regarding the maintenance of natural areas in order to provide residents with the skills to maintain thriving natural areas.

Public education initiatives may be completed in partnership with community organizations. For instance, in the Greater Toronto Area (GTA) multiple municipalities have partnered with the organization, Local Enhancement and Appreciation of Forests (LEAF), in order to deliver educational programs on the value of green space, maintenance of natural areas, and private tree planting.

NATURALIZATION

Increasing the Naturalization of Municipal Property

Traditionally, parks and other open space areas are maintained using conventional landscaping techniques. Conventional landscaping is associated with the use of high energy, chemical, and financial inputs to maintain well manicured green areas that lack native vegetation. In opposition to this strategy, naturalization is a planting method that involves minimal use of fertilizers, irrigation, and machinery. It improves the ecological integrity of urban areas by preserving native elements and requires minimal human interference (Ordonez & Duinker, 2012).

In comparison to conventional landscaping, naturalization will help to diminish UHIE intensity by increasing the concentration of biomass in an area. Therefore, municipalities should naturalize parks and open areas when it does not conflict with the planned use. Naturalization is also an effective strategy for the development of vacant lands, as they do not require maintenance after the initial three year establishment period. This practice will ensure that land areas that are underutilized by humans continue to provide valuable ecosystem services.

To facilitate naturalization, municipalities should consider developing specific targets. For instance, the Town of Oakville has set targets to encourage households and businesses to partake in ecological landscaping, to naturalize 25% of publically owned open space in Oakville by 2010, to ecologically landscape 25% of Oakville schools by 2010, to develop a Native Plant Salvage program, and to continue the efforts of Halton Partners for Naturally Green to reduce pesticide usage (Town of Oakville, 2005). An example of a successful naturalization project completed in the City of Waterloo is illustrated in *Figure 21.*

Figure 21: *Roxton park re-naturalization (City of Waterloo, 2007)*

7.0 URBAN HEAT ISLAND MAP ANALYSIS + RECOMMENDATIONS

7.1 DEVELOPMENT OF THE URBAN HEAT ISLAND MAP

Development of the UHIE map was initiated in order to generate a decision-making tool that could be used to visualize the impacts of the UHIE, to develop a mitigation strategy, and to inform heat alert and response planning in Windsor. The map was designed to represent the temperature differences throughout the city resulting from the UHIE, point data depicting the location facilities and businesses that are integral to heat alert and response, and socio-economic census data to account for the variance in heat vulnerability between different populations. The data selected for inclusion in the mapping was based on the detailed report "*Assessment of Vulnerability to the Health Impacts of Extreme Heat in the City of Windsor*" completed by Health Canada (Perry, 2011)

Map creation and analysis was a collaborative effort between the following parties:

- Health Canada (Jay Storfer)
- Institut national de santé publique du Québec (Allan Brand)
- City of Windsor (Karina Richters, Larisa Johnstone, Laura De Carolis, Chris Aspila)

A Landsat 7 satellite was used at a resolution height of 30 m in order to collect data and produce maps for: temperature, normalized vegetation index, and cloud cover. These maps were produced from 1998 to 2010, but some maps were compromised and excluded due to heavy cloud cover. It is also important to note that some data is missing due to shortcomings of the Landsat 7 satellite system. This has resulted in the appearance of several diagonal white lines throughout the map.

Upon obtaining the temperature maps from Health Canada, Larisa Johnstone combined them with point data layers regarding the location of relevant facilities that have a role in heat alert and response. In order to generate layers on socio-economic characteristics, Chris Aspila provided census data files (2006) that were also converted into layers using ArcGIS by Larisa Johnstone.

The combination of these data collection and mapping procedures yielded the final map *(Figure 22)*, which contains temperature, point, and socio-economic data layers. The full set of these maps are provided in Appendix A.

7.2 MAP FEATURES

The map layers represented in the final urban heat island map include:

Temperature Data

- Landsat 7 Thermal Image depicting temperature (°C) on August 16, 2005

Point Data

- *Community centres, Arenas*
- *Shelters/crisis centres*
- *Shopping centres and movie theatres*
- *Community health centres and medical clinics*
- *Seniors homes*
- *Police stations*
- *Pools and splash pads*
- *Hospitals*
- *Libraries*
- *Parks*

Socio-economic Data (2006 Census)

- *Age characteristics - infants (Age 0-4)*
- *Age characteristics - children (Age 5-9)*
- *Age characteristics - seniors (Age ≥ 65)*
- *Age characteristics - seniors (Age ≥* 85)
- *Total number of immigrants arriving between 2001-2006*
- *Total number of people over the age of 15 without a certificate, degree, or diploma*
- *Total number of families by prevalence of low income*

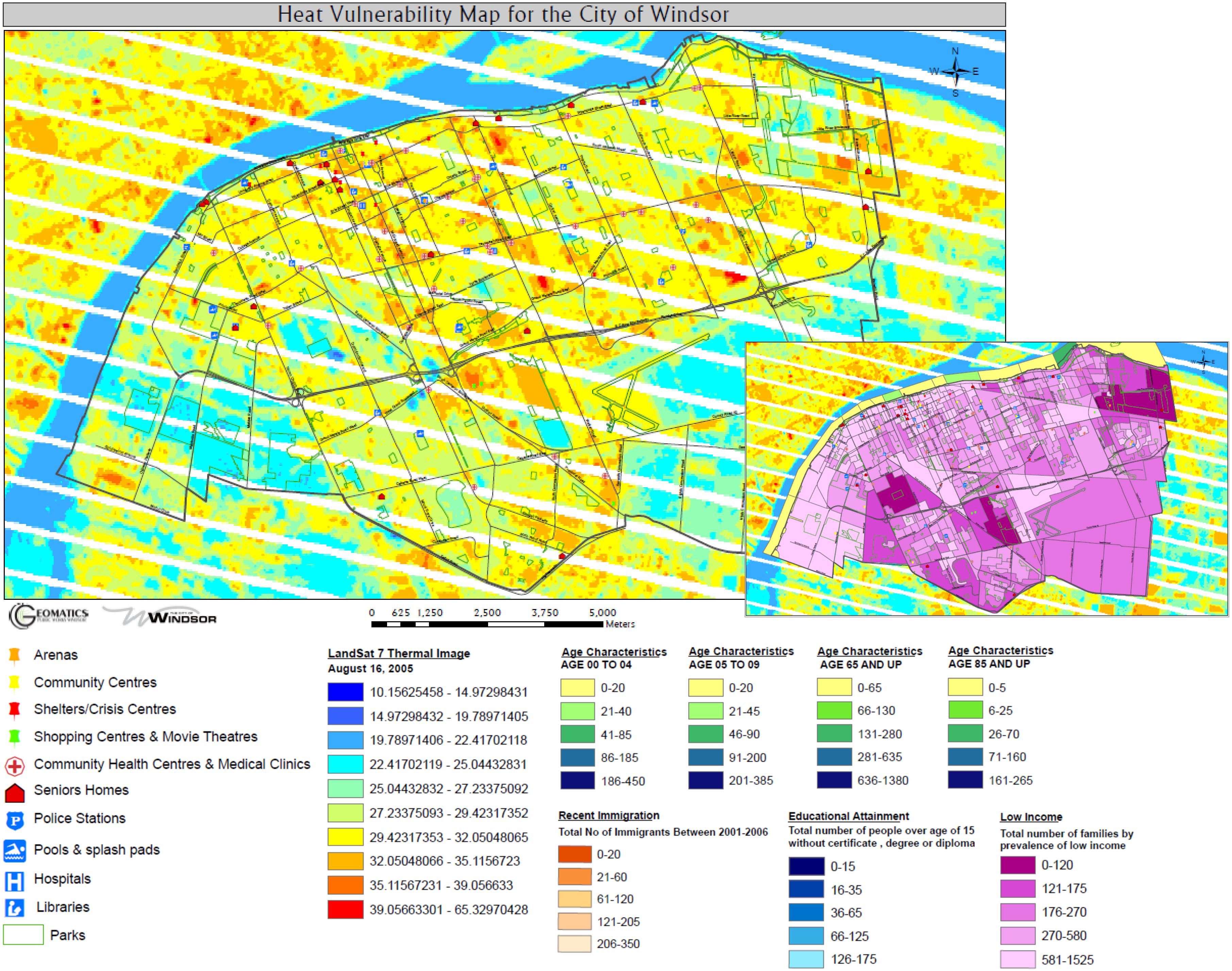


Figure 22: *Heat vulnerability map for the City of Windsor (August 16, 2005). Thermal image (left), low income sublayer (right), and legend (bottom).*

7.3 MAP ANALYSIS + RECOMMENDATIONS

The data and trends presented by the urban heat island map should be used by the City of Windsor in order to inform decision-making and strategy development with respect to UHIE mitigation, as well as heat alert and response planning efforts. The following section outlines recommendations on how the map should be used to inform the development and maintenance of infrastructure and green space in the City of Windsor that can be designed to mitigate the UHIE. Additional recommendations are provided regarding how the UHIE should inform decision-making and procedures for land development. Finally, recommendations are provided on how trend analysis of these maps should be used to strengthen heat alert and response planning efforts.

7.3.1 ROOFING

As outlined in sections 6.1 and 6.2, roofs comprise approximately 20-25% of exposed surfaces in urban environments, and exhibit significantly high surface temperatures. This is an issue within the City of Windsor, where residential, commercial, and industrial development have resulted in a large amount of building construction. The significant impact exposed roof surfaces can have on the UHIE is illustrated in *Figure 23.* In this figure, it is clear that the industrial rooftops of Chrysler, General Motors, and Ford exhibit some of the highest surface temperatures in the City. This is especially concerning due to the expansive size of these operations. The concentration of these industrial centres results in a significant increase in the intensity of the UHIE within the boundaries of Grand Marais Road East, Central Avenue, Riverside Drive, and Walker Road. The surface temperatures of the rooftops in this area are at a minimum, 10°C higher than those found in the vicinity of the Ojibway Prairie Nature Centre. Roof temperatures of these facilities fall within the 32.0-65.3°C range, likely resulting in a significant contribution to UHIE intensity.

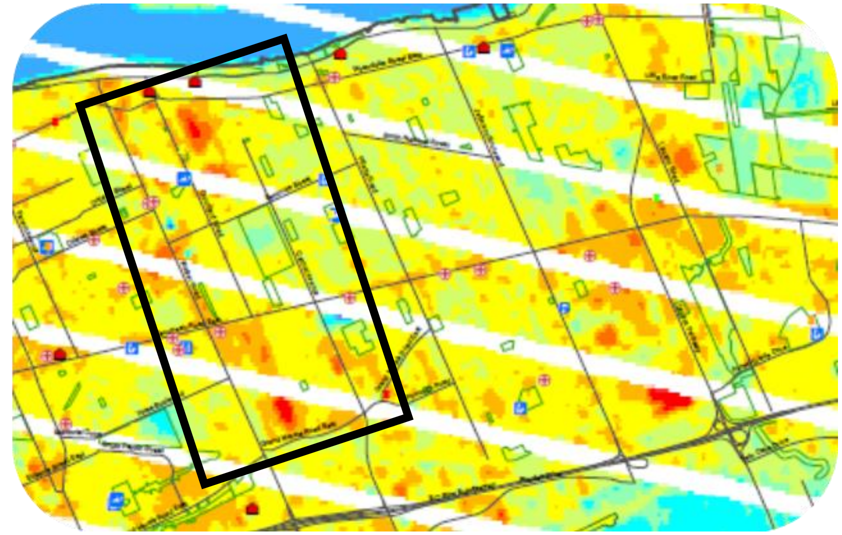


Figure 23: *Extremely high surface temperatures of the Chrysler, GM, and Ford plants (~32.0°C-65.3°C)*

RECOMMENDATION 1

To reduce the impact that roof surfaces can have in contributing to the UHIE, the City of Windsor should incorporate cool and/or green roof options into the roof design of City-owned buildings. Special consideration should be given to the use of these mitigation methods within high priority areas. High priority areas will be determined in consultation with other departments, and will represent areas of the city where the UHIE and vulnerability is strongest. Modifications to improve the solar reflectance of roofs in these areas may include any of the previously listed cool roof (Section 6.1.2) or green roof (Section 6.2.2) options.

7.3.2 PAVEMENT

Similar to rooftops, hard and impermeable pavement surfaces also contribute significantly to the UHIE. This is because common paving materials such as asphalt and concrete have low solar reflectance values ranging between ~0.05-0.40. Traditional pavement materials also lack void spaces, reducing the potential for cooling through evaporation and convective air flow. The impact that pavement can have on the UHIE can be seen through examining the thermal temperature of the parking lot surrounding Devonshire Mall *(See Figure 24).* As illustrated in the screen caption, the rooftop of the mall has the greatest surface temperature ranging between 35.1-39.0°C, and the adjacent parking lot's surface temperature ranges between 32.0-35.1°C. As the parking lot temperature is amongst the upper values in the thermal image map, mitigation of the UHIE using cool pavement technologies should be considered.

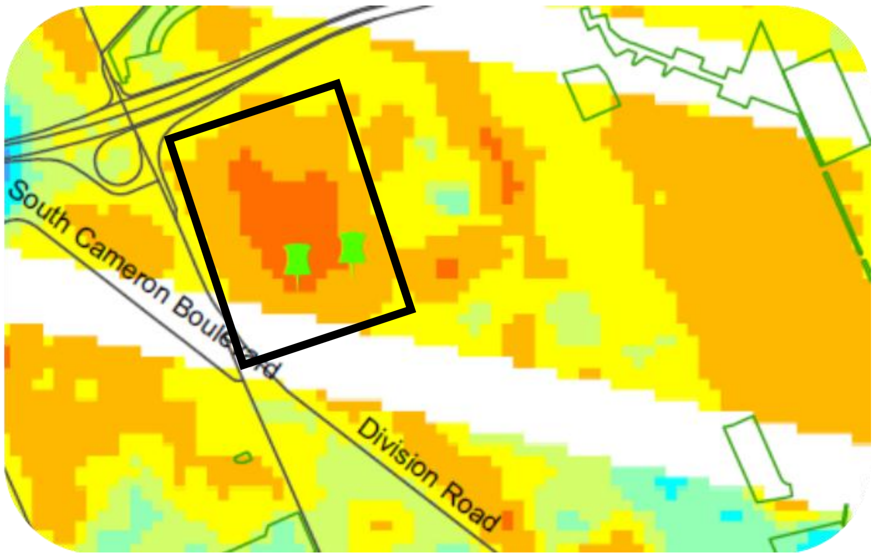


Figure 24: *High surface temperatures exhibited in the Devonshire Mall parking lot (~32.0°C-35.1°C)*

RECOMMENDATION 2

Within cities, pavement accounts for approximately 45% of exposed surfaces. Therefore, mitigation using cool pavement technologies presents a significant opportunity to reduce the strength of the UHIE. Therefore, the City of Windsor should consider developing cool pavement pilot projects when City parking lots or other paved areas are scheduled for maintenance. By developing these pilot projects the City will be able to evaluate if cool pavement technologies that increase albedo are feasible in Windsor. With respect to permeable pavement in particular, it would be useful to conduct pilots on a variety of soil types to better understand how soil content impacts infiltration rates. If these technologies prove to be effective strategies in light of Windsor's climate and geology, they should be considered for development in high priority areas.

7.3.3 GREEN SPACE

The presence of green space helps to mitigate the UHIE through cooling surface temperatures by providing shade, and through evapotranspiration. The results of the heat mapping study indicate that green spaces in the City of Windsor exhibit significantly lower surface temperatures than their surrounding developed areas. This can be seen in *Figure 25,* where both the Ojibway Prairie Nature Reserve and the South Cameron Woodlot have significantly cooler surface temperatures ranging between 19.7-27.2°C, however predominantly within the 22.4-25.0°C range.

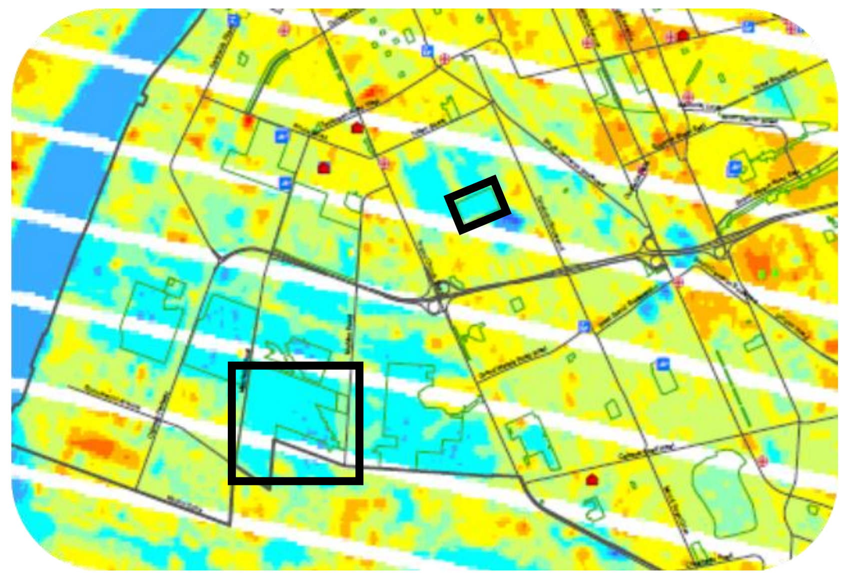


Figure 25: *Cool surface temperatures (~22.4°C-25.°C) in Windsor's green spaces: Ojibway Nature Reserve (left) and South Cameron Woodlot (right)*

RECOMMENDATION 3

The cool temperatures seen in Windsor's natural areas represent a significant departure from the extremely high surface temperatures of roof and pavement surfaces. Therefore, based on the results of this study, the City should prioritize actions that seek to fulfill the green space objectives outlined in the Environmental Master Plan (EMP). Priority actions should include the naturalization of underutilized lands and park spaces which can no longer be maintained. Specifically, this recommendation could be implemented by naturalising any surplus parkland that the city is unable to sell. This will help the City to conserve resources by minimizing maintenance requirements while ensuring that green space is conserved. Furthermore, the City should seek to acquire additional lands to integrate into the Greenway System, and avoid actions which propose to develop these areas. Finally, the City of Windsor should develop a strategy to support Windsor-Essex County's objective to increase natural area coverage from 8% to 12.5%.

7.3.4 SPORTS FIELDS

Traditionally, sports fields have been developed using natural turf grass, and all City owned sports fields currently have natural grass surfaces. However, in recent history the use of artificial turf has become an increasingly popular alternative. This alternative was recently chosen by the University of Windsor when developing Alumni Field.

Supporters of artificial turf use often cite the following advantages: quick installation, ability to withstand all-weather use, increased durability, reduced maintenance costs, reduced water consumption, and reduced hydrocarbon emissions from machinery use (Jackson, 2008). However, one potentially significant disadvantage of artificial turf that relates to the UHIE is that artificial fields commonly exhibit surface temperatures up to 16°C warmer than natural turf (Simon, 2010). This significant difference can be seen by comparing the thermal images taken in 2005 versus 2010 *(See Figure 26).* By comparing these images it is clear that the surface temperature of Alumni Field increased following conversion from natural grass (~29.4-32.0°C) to artificial turf (~°32.0-39.0C).

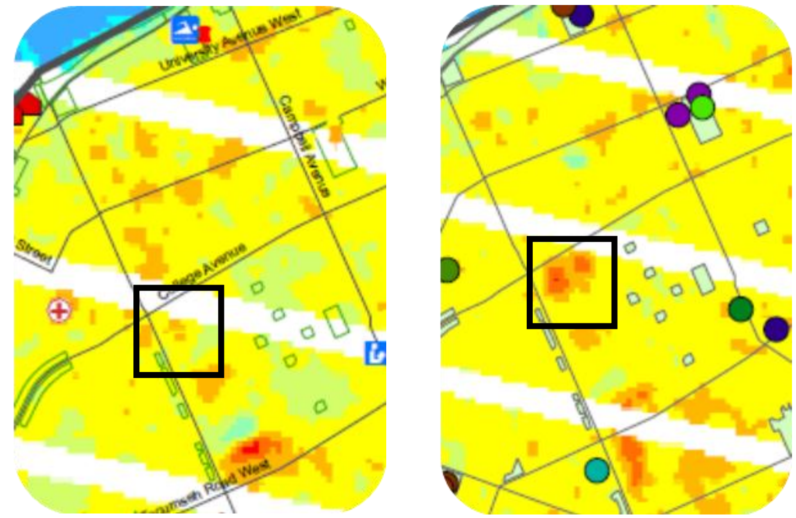


Figure 26: *Surface temperatures of Alumni Field before (~29.4-32.0°C) and after (~32.0-39.0°C) artificial turf installation in 2009*

RECOMMENDATION 4

When considering the future restoration of existing sports fields, as well as proposals for the development of new sports fields, the impact that the field will have on the UHIE should be evaluated as part of the decision-making framework. In areas where the UHIE is already high, caution against artificial turf development should be exercised. Additionally, if artificial turf fields are constructed, appropriate measures should be taken in order to ensure that natural and constructed shade structures are included in design plans. This will ensure that areas are provided for athletes and spectators to seek relief from the warmer temperatures resulting from the absorption of solar radiation by the artificial turf.

7.3.5 SHADE STRUCTURES

The intensity of solar radiation combined with the UHIE has the potential to cause a wide range of adverse impacts on human health.

These risks are heightened in areas that receive direct sunlight and lack either natural or constructed features to provide shade. In addition to protecting human health, the use of shade structures may help to reduce the Urban Heat Island Effect (UHIE). Natural shade structures include vegetation, and therefore help reduce the UHIE through evaporative cooling. Additionally, constructed shade structures may help induce cooling by minimizing the direct absorption of solar radiation on hard surfaces with low albedo (Toronto Cancer Prevention Coalition, 2010).

RECOMMENDATION 5

The City of Windsor should utilize the heat vulnerability map in order to inform the strategic location of shade structures. With respect to natural structures, namely trees, they should be planted in priority areas where surface temperatures and heat vulnerability are significant. In areas where it is not feasible to plant additional trees, the City should consider using constructed features in order to provide adequate shade *(See Figure 27).*

Figure 27: *Constructed shade features may help to reduce the adverse health impacts of the UHIE*

7.3.6 DEVELOPMENT PRACTICES

Development results in the conversion of natural, permeable landscapes into hard, impermeable surfaces that contribute to the strength of the UHIE. The impact this process can exhibit on surface temperature is illustrated in *Figure 28*, where new development in east Windsor resulted in a significant temperature change after land clearing, from approximately 27.2-32.1°C to 32-35.1°C.

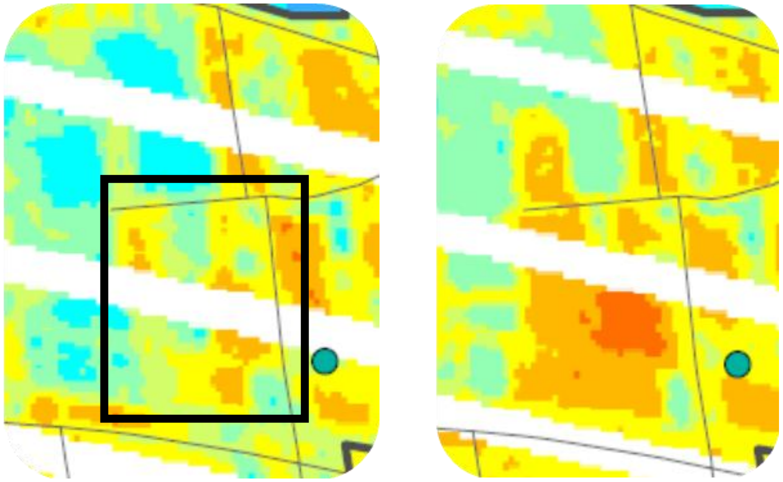


Figure 28: *Surface temperatures before (~27.2-32.1°C) and after (~32.0-35.1°C) land clearing for residential development*

RECOMMENDATION 6

The temperature differential shown in the above figure largely occurs due to planning practices that do not hold developers accountable for either preserving or planting trees and vegetation in order to conserve green space. As a result, residential development often results in a significant reduction in the amount of biomass during and after construction. In order to ensure that a larger proportion of biomass is conserved, the City of Windsor should modify the Official Plan and development guidelines to include measures that more stringently protect existing trees and encourage low impact development. Examples of best practices for the conservation of green space during developed are presented in *Table 5.*

Table 5: *Best practices for the conservation of green space by developers*

MUNICIPALITY	DESCRIPTION OF BEST PRACTICE
Town of Oakville – Official Plan	Under section 10.3(b) of the *Official Plan,* the Town states the objective to have no net loss of existing urban forests. To meet this requirement, all development projects must ensure that new trees are planted equal to the square metre of leaf area that is removed. This ensures that development does not result in disproportionate tree coverage due to differences between the leaf area of mature trees that are replaced by smaller trees (Town of Oakville, 2006). Developers must pay a sum equal to the value of trees they eliminate during construction, or plant new trees that will provide a canopy cover equal to that provided by the removed trees.
Town of Richmond Hill – Development Guidelines	The Town of Richmond Hill requires a detailed community landscaping plan to be submitted prior to granting approval for new subdivision developments. The plan must include provisions concerning: boulevard tree planting, entrance features, buffer planting zones, pedestrian walkways, and the maintenance of community connectivity. Developers must also pay the Town's boulevard Tree Planting Fee.
City of Brampton – Woodlot Development Guidelines	As outlined in Brampton's *Official Plan* all development proposals adjacent to the City's woodlots must be accompanied by a *Woodlot Management Plan.* Such plans must outline conservation and management actions necessary to protect against the destruction of woodlands. The plans must also include an assessment of significant vegetation in the woodlands and the identification of specific measures for their protection before, during, and after construction (City of Brampton, 2006).

7.3.7 HEAT ALERT AND RESPONSE PLANNING

By analyzing the temperature maps in conjunction with point data and socio-economic data, one can observe trends that should be considered when planning heat alert and response strategies. Point data provides information regarding the location of facilities that will help individuals adapt to the effects of extreme heat, and to prevent adverse health outcomes from occurring. An example of the integration of these data layers is provided in *Figure 29*, which illustrates the location of an area with a significant elderly population (>65) relative to nearby places to stay cool and medical facilities.

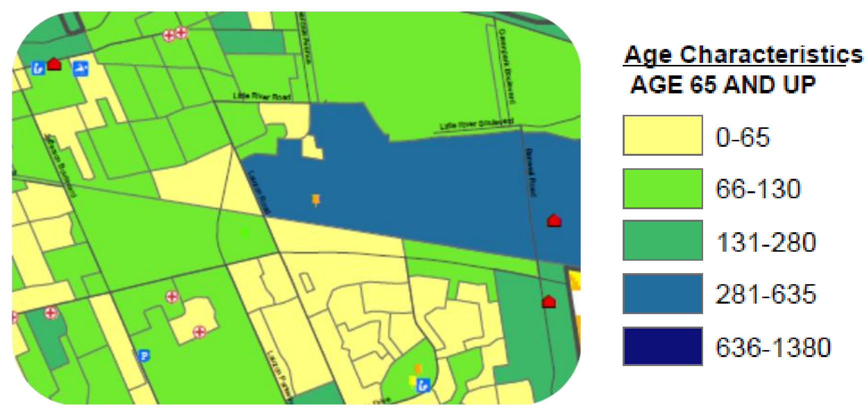


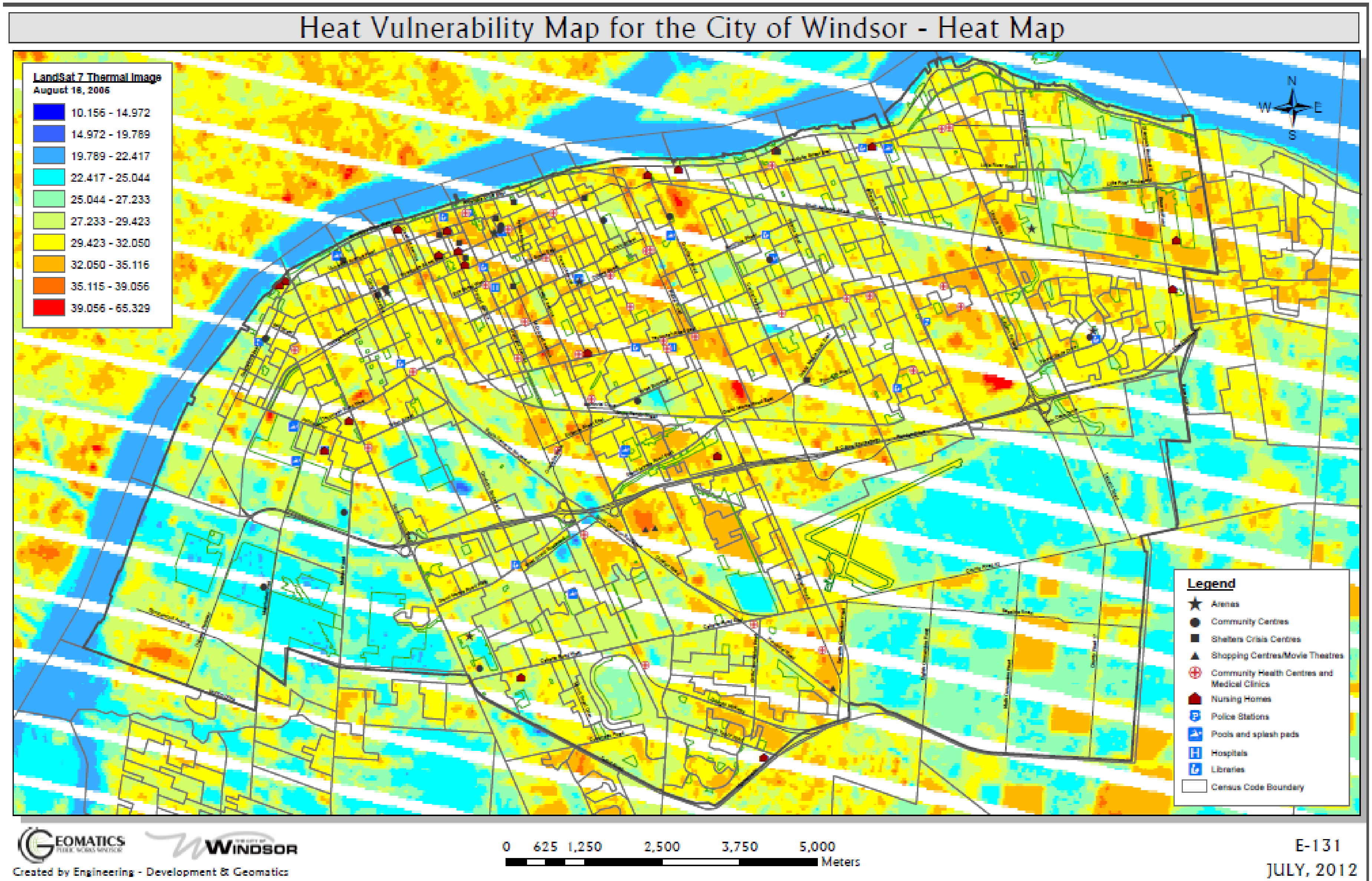
Figure 29: *Locations of areas with a significant elderly population (>65) relative to nearby places to stay cool and medical facilities*

RECOMMENDATION 7

When developing heat alert and response plans, the urban heat island vulnerability mapping results should be consulted and incorporated into decision-making. For instance, the maps may be used to strategically locate new cooling centres or medical facilities in areas where high concentrations of vulnerable populations exist. Additionally, they may be used to build a case for the development of new Stay Cool Windsor-Essex programs to reduce heat-health vulnerability. For example, the map results may be used to provide rationale for the development of a transportation service to bring elderly or disabled individuals to cooling centres when heat alerts are issued.

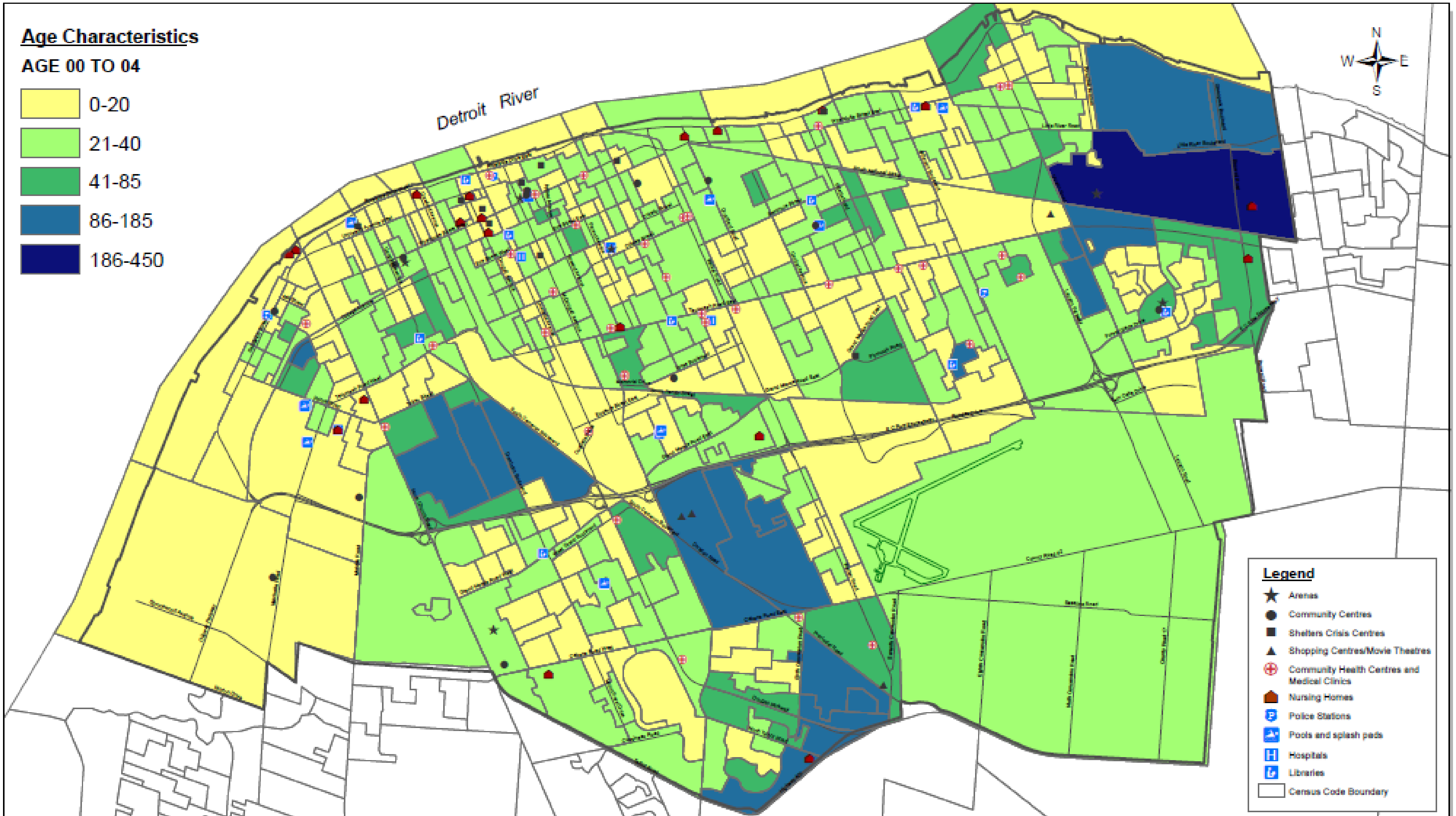
This mapping can also be used to prioritize emergency response and communications during a heat emergency.

APPENDIX A



Heat Vulnerability Map for the City of Windsor - Heat Map
LandSat 7 Thermal Image
August 16, 2006
10.156 - 14.972
14.972 - 19.789
19.789 - 22.417
22.417 - 25.044
25.044 - 27.233
27.233 - 29.423
29.423 - 32.050
32.050 - 35.116
35.115 - 39.056
39.056 - 65.329
N
W
E
S
Legend
Arenas
Community Centres
Shelters Crisis Centres
Shopping Centres/Movie Theatres
Community Health Centres and Medical Clinics
Nursing Homes
Police Stations
Pools and splash pads
Hospitals
Libraries
Census Code Boundary
GEOMATICS
WINDSOR
Created by Engineering - Development & Geomatics
0 625 1,250 2,500 3,750 5,000
Meters
E-131
JULY, 2012

Heat Vulnerability Map for the City of Windsor - Age Characteristics infants (Age 0-4)



GEOMATICS WINDSOR

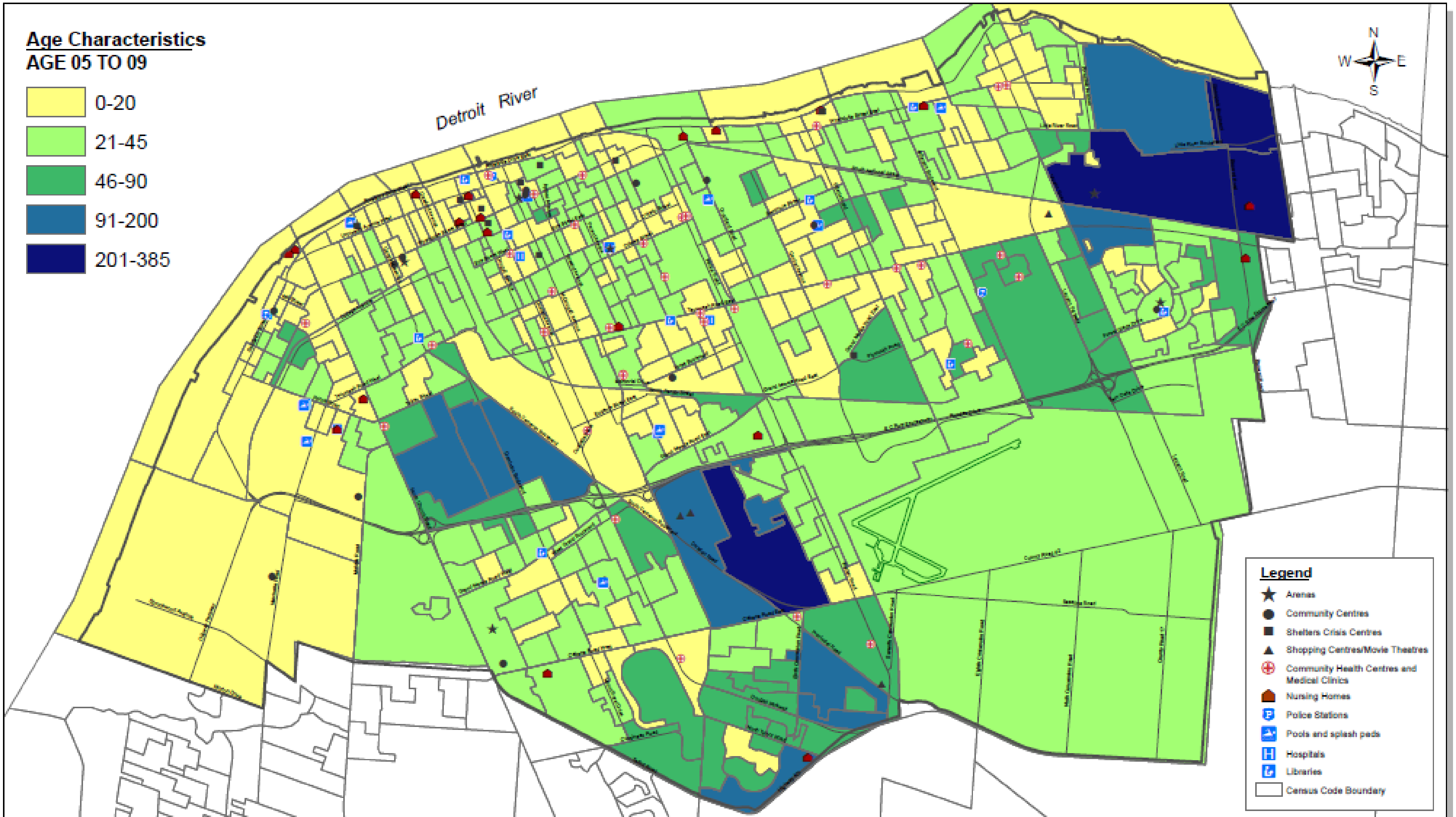
Created by Engineering - Development & Geomatics

0 625 1,250 2,500 3,750 5,000 Meters

E-131

JULY, 2012

Heat Vulnerability Map for the City of Windsor - Age Characteristics children (Age 5-9)



GEOMATICS WINDSOR

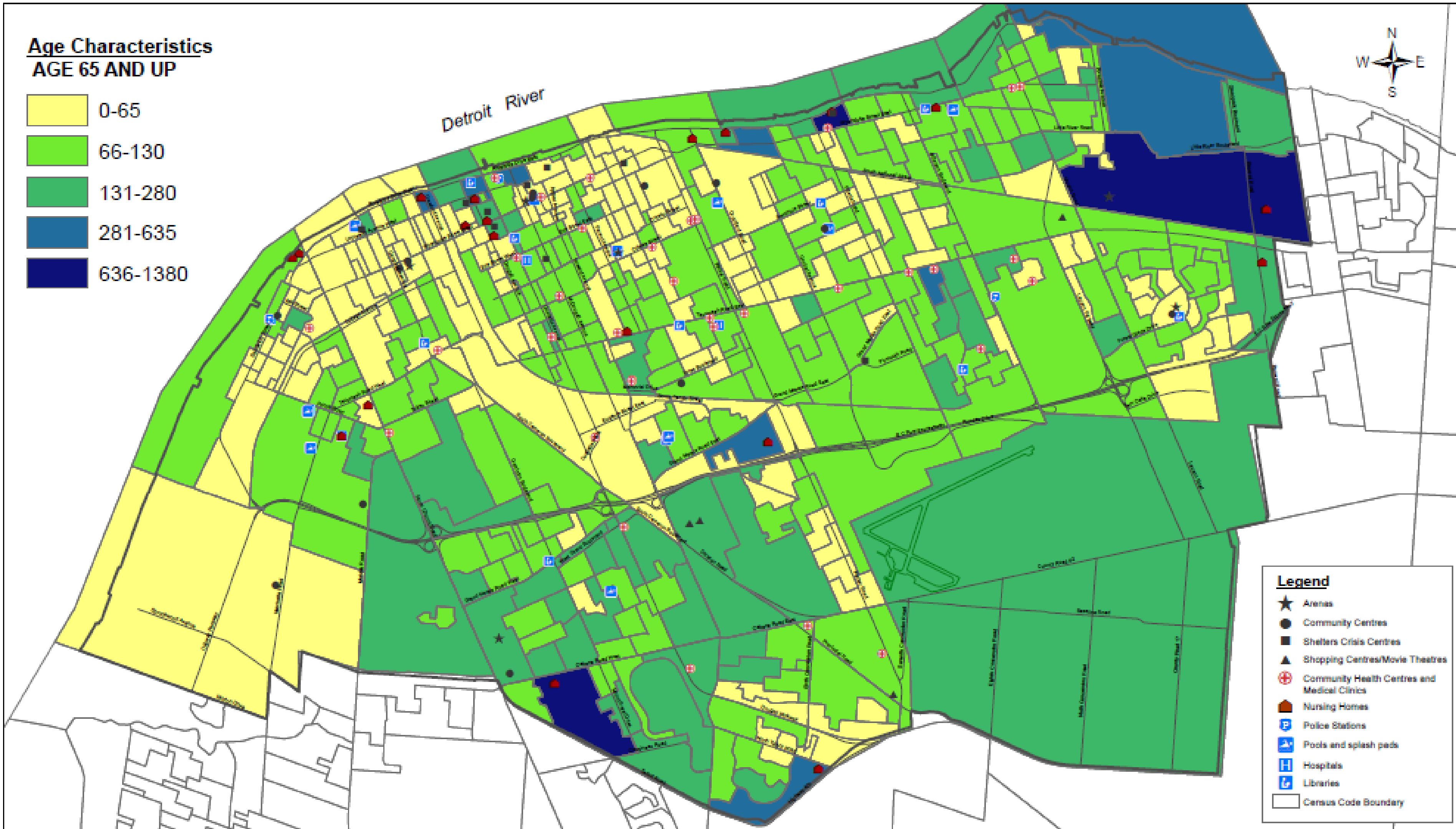
Created by Engineering - Development & Geomatics

0 625 1,250 2,500 3,750 5,000 Meters

E-131

JULY, 2012

Heat Vulnerability Map for the City of Windsor - Age Characteristics children (Age ≥ 65)



GEOMATICS WINDSOR

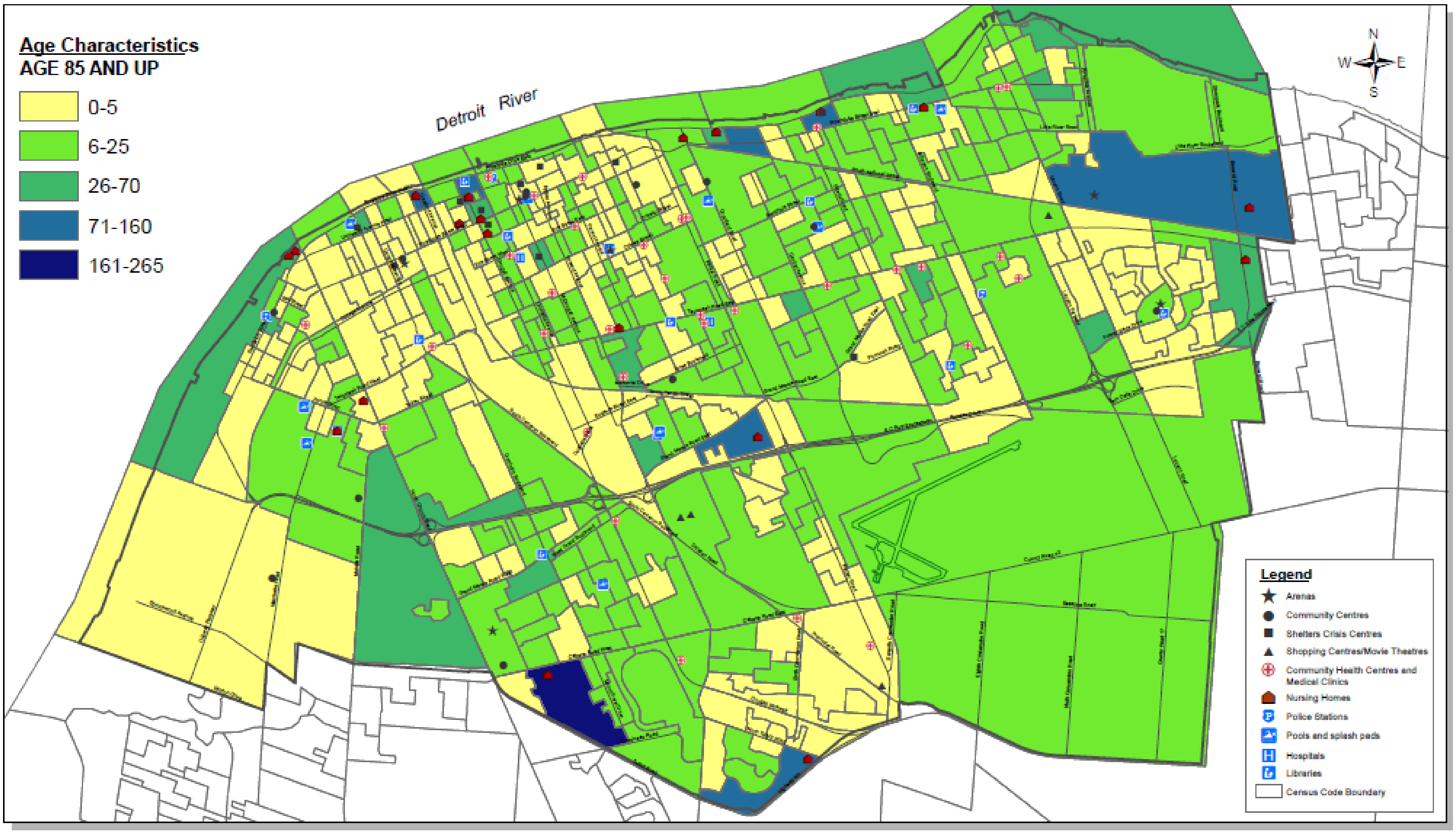
Created by Engineering - Development & Geomatics

0 625 1,250 2,500 3,750 5,000 Meters

E-131

JULY, 2012

Heat Vulnerability Map for the City of Windsor - Age Characteristics children (Age ≥ 85)



GEOMATICS WINDSOR

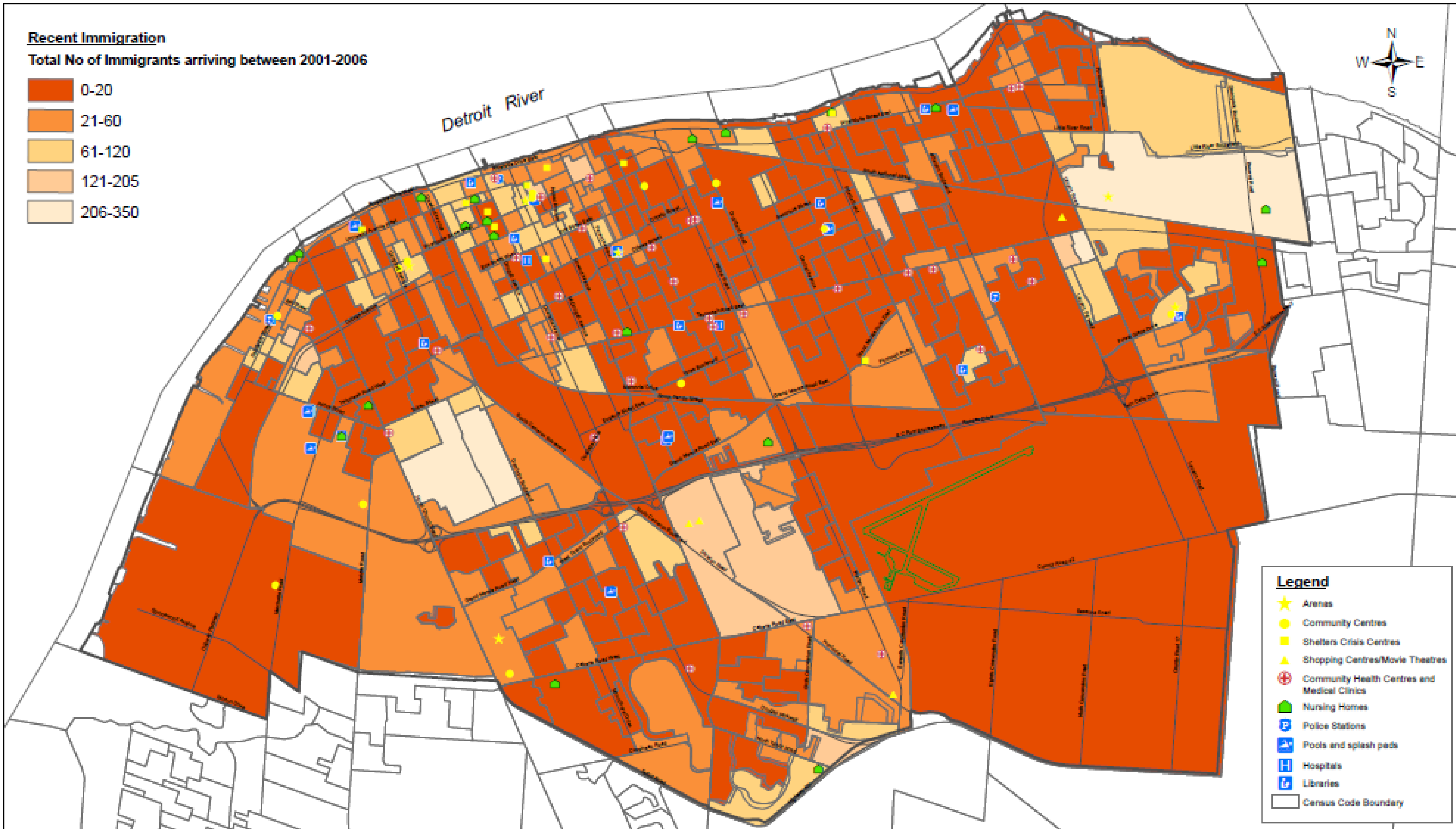
Created by Engineering - Development & Geomatics

0 625 1,250 2,500 3,750 5,000 Meters

E-131

JULY, 2012

Heat Vulnerability Map for the City of Windsor - Arriving Immigrants

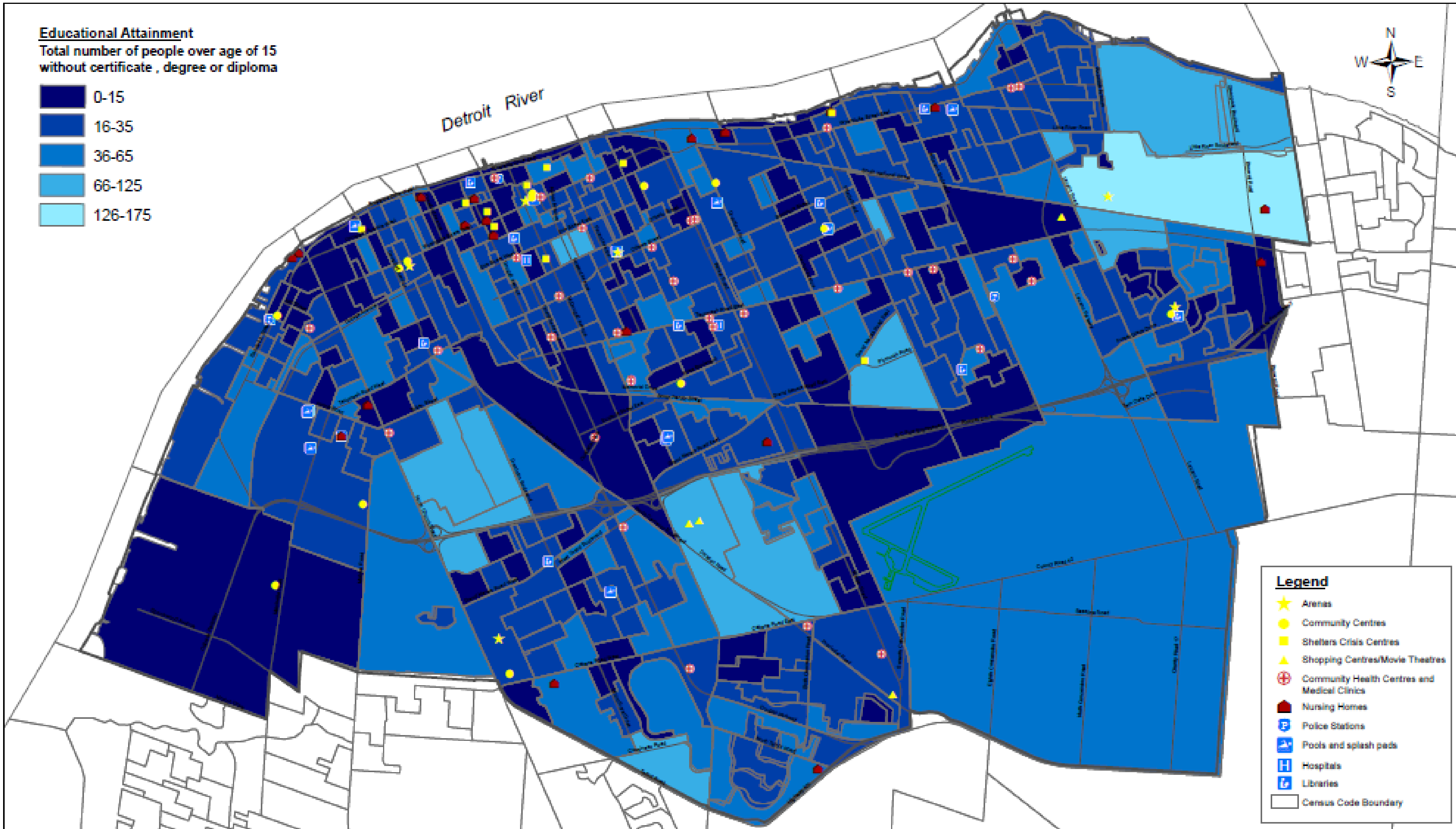


GEOMATICS WINDSOR
Created by Engineering - Development & Geomatics

0 625 1,250 2,500 3,750 5,000 Meters

E-131
JULY, 2012

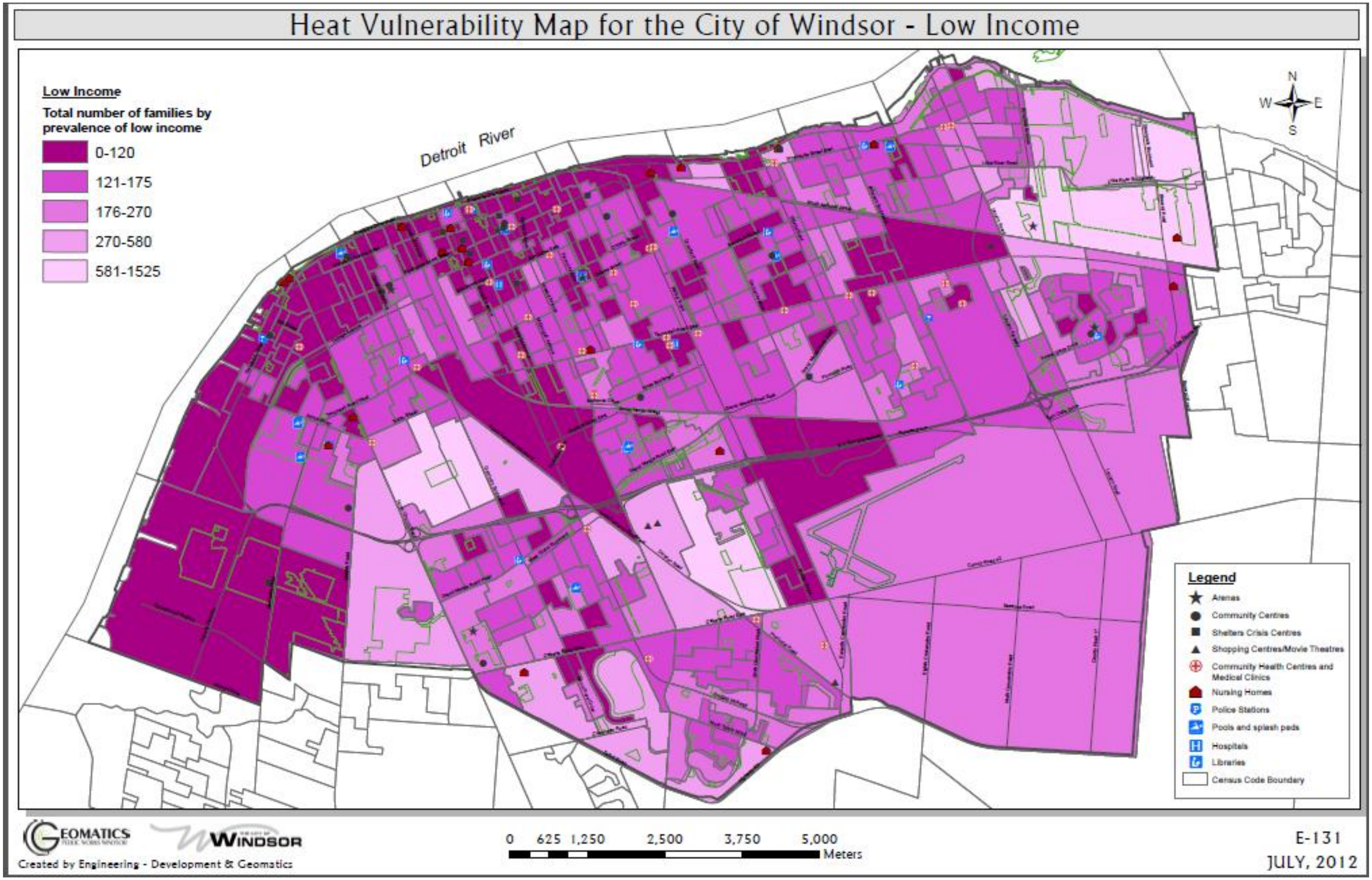
Heat Vulnerability Map for the City of Windsor - Educational Attainment



GEOMATICS WINDSOR

Created by Engineering - Development & Geomatics

E-131
JULY, 2012



Heat Vulnerability Map for the City of Windsor - Low Income
Low Income
Total number of families by prevalence of low income
0-120
121-175
176-270
270-580
581-1525
Detroit River
N
W
E
S
Legend
Arenas
Community Centres
Shelters Crisis Centres
Shopping Centres/Movie Theatres
Community Health Centres and Medical Clinics
Nursing Homes
Police Stations
Pools and splash pads
Hospitals
Libraries
Census Code Boundary
GEOMATICS
WINDSOR
Created by Engineering - Development & Geomatics
0 625 1,250 2,500 3,750 5,000
Meters
E-131
JULY, 2012

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