CITY OF ST. LOUIS
CLIMATE VULNERABILITY ASSESSMENT
2018

Image credit: Climate Central

ACKNOWLEDGMENTS & CREDITS

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INTRODUCTION

Climate change is one of the most challenging and complex issues of the 21st century, with wide-ranging impacts predicted to impact cities in significant ways. Urban infrastructure, natural areas and people are all at risk to hazards associated with climate change. According to the Climate Science Special Report, the global average surface temperatures from the last 115 years were the warmest in the history of modern civilization.[1] Changes in surface, atmospheric, and oceanic temperatures - as well as melting glaciers, loss of snow cover, shrinking sea ice, rising sea levels, ocean acidification, and increasing atmospheric water vapor - are observable consequences of global climate change. With rising global temperatures, climate change has significantly increased occurrences of natural hazards and extreme weather events throughout the country.

All cities and their residents will be increasingly impacted by climate change in the coming decades. At the most general scale, climate change will affect the food we eat, the water we drink, the air we breathe, the place we live, and the weather we experience. Climate change will at some point impact every person's health and home. The impact of climate change is already being experienced by some people within the City of St. Louis, such as increased summer temperature and more frequent, longer heat waves. Worsening air quality and increased airborne allergens often impact the most vulnerable the greatest. Increased extreme weather –such as heavy precipitation, flooding, droughts, and storms– threaten human health and safety, and often creating severe financial repercussions. It is well accepted that the impact of climate change will be greater on those residents living in distressed neighborhoods. Therefore, the impact of climate change is likely to have a significant effect on both the current and future generations, in terms of public health and safety of residents, as well as the local economy. The challenges associated with climate change also present opportunities to grow the green economy and create jobs. The St. Louis Green Jobs Report revealed that half of all companies surveyed agree that "the growth of the green economy presents opportunities for growth for [their company]."

At the local level, cities have the ability to address climate impacts and adapt to impacts, such as temperature increases, so that the city remains safe and livable with the least disruption for all. It is more costly to postpone climate action than it is to take immediate and incremental actions to mitigate its impacts. Studies have found that costs increase with the length of delay, and the more ambitious the climate target, the greater the cost of delay. As such, addressing climate change through mitigation and adaptation strategies is a prudent approach to investing in a more green, healthy, inclusive and sustainable City of St. Louis.

[1] Wuebbles, D.J., Fahey, D.W., Hibbard, K.A., Deangelo, B., Doherty, S., Hayhoe, K., Horton, R., Kossin, J.P., Taylor, P.C., Waple, A.M., & Weaver, C.P. (2017). Executive summary. *Climate Science Special Report: Fourth National Climate Assessment, volume I,* pp. 12-34. doi: 10.7930/JODJ5CTG

Although the City of St. Louis is located inland and largely protected from coastal climate change threats commonly associated with sea-level rise and hurricanes, the City still faces many adverse effects of climate change. Higher global temperatures and increasingly frequent and severe extreme weather events threaten to disrupt life for urban dwellers, and have adverse impacts on people who are not protected or prepared. As a result of climate change, summer temperatures in St. Louis are expected to rise approximately 3.5 degrees Celcius, and experts predict an average change in precipitation of 4.5 percent.[2] St. Louis is at a high risk for a broad range of natural, weather-related disasters, including extreme heat and heat waves, cold waves, drought, tornadoes, and flooding. These events have the potential to negatively impact residents' health, property, and livelihoods. Not all St. Louisans will be impacted equally by these events. Some in the city are more vulnerable than others to the negative effects of extreme weather events.

This Climate Vulnerability Assessment has been developed to better understand the potential consequences of increasingly extreme weather events brought on by climate change, the conditions most likely to affect the residents of the City of St. Louis, and those who are most vulnerable to these events. Existing and potential climate mitigation strategies were researched with the help of the City of St. Louis Department of Health (DOH) and graduate students at Washington University in St. Louis. By studying the challenges that St. Louis will face as climate change intensifies, the City will be more informed and better prepared to take preventive measures, respond and adapt to climate change conditions.

Climate Vulnerability Assessment Methodology

This assessment was a collaborative effort of many individuals acknowledged in the Credit page. The climate hazards that form the basis of this report were identified as having either high or moderate probability of occurrence in the City of St. Louis in a Climate Hazards Report prepared by the East-West Gateway Council of Governments. The top five climate hazards are the ones highlighted in this Climate Vulnerability Assessment.

[2] Posey, J. (2014). Climate change in St. Louis: Impacts and adaptation options. *The International Journal of Climate Change: Impacts and Responses*, 5(2). Retrieved from bloximages.newyork1.vip.townnews.com/stltoday.com/content/tncms/assets/v3/editorial/1/dc/1dc83ac3-31b3-5acd-ba62-fa222e29d051/55973cfb870c7.pdf.pdf

EXECUTIVE SUMMARY: ST. LOUIS CLIMATE CHANGE SOCIAL VULNERABILITY

Global climate change has tremendous consequences for the economy, governmental processes, and public health. Conducting a climate change vulnerability assessment helps to define the risks posed and identify effective adaptation strategies to address broader health risks across different sectors.[3] A climate vulnerability assessment can be used to inform local government officials, public health practitioners, and other decision makers to identify the most vulnerable areas, sectors, and social groups to maximize climate resilience.

Climate vulnerability is a measure of exposure, sensitivity, and adaptive capacity.[4] This means that groups that are vulnerable to hazards include not only those who will be affected directly by events like droughts and floods, but also those who have less capacity regarding response and resiliency. Vulnerability indicates the complex interaction of social and physical factors that make up a city's ability to respond to the various consequences of climate change.[5]

Racial and economic inequalities can double adversity on climate change hazards.[6] One way to reduce severity of natural disaster events is to strengthen the ability for the City of St. Louis community to respond and build a capacity for resiliency; that is, how well our city system can be prepared for events before they occur and to eliminate negative impacts on vulnerable groups. In addition to disaster and response planning, community leaders can use climate vulnerability assessment information to anticipate and communicate with stakeholders for emergency preparedness. Preparedness efforts that focus on the most disadvantaged will pave the way for equitable climate action.

Rising global temperatures and increasingly frequent and severe extreme weather events threaten to disrupt life for those who live in the City of St. Louis. Reports indicate that St. Louis is at a high risk for a broad range of weather-related incidents, including extreme heat and heat waves, cold waves, drought, tornadoes, and flooding. These events have the potential to negatively impact residents' health, property, and livelihoods.

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[3] Nelitz, M., Boardley, S., & Smith, R. (2013). Tools for climate change vulnerability assessments for watersheds. *Report prepared for the Canadian Council of Ministers of Environment (CCME)*.

[4] Core Writing Team, Pachauri, R.K., & Reisinger, A. (Eds.). (2008). Climate change 2007: Synthesis report. *A Report of the Intergovernmental Panel on Climate Change*. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf.

[5] Fritzche, K., Schneiderbauer, S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, M., & Kahlenborn, W. (August 2014). The vulnerability sourcebook: Concept and guidelines for standardised vulnerability assessments. Obrigheim, Germany: GIZ. Retrieved from http://resilient-cities.iclei.org/fileadmin/sites/resilient-cities/files/Full_papers/Vulnerability_sourcebook_guidelines_for_assessments_adelphi_giz_2014.pdf.

[6] Morello-Frosch, R., Pastor, M., Sadd, J., & Shonkoff, S.B. (May 2009). *The climate gap: Inequalitites in how climate change hurts Americans & how to close the gap*. Los Angeles, CA: Program for Environmental and Regional Equity (PERE) USC Dornsife. Retrieved from https://dornsife.usc.edu/assets/sites/242/docs/The_Climate_Gap_Full_Report_FINAL.pdf.

Extreme Heat and Heatwaves

Extreme heat and heat waves, three or more consecutive days with hot air masses, are the deadliest natural disaster in the United States, surpassing hurricanes, lightning, tornadoes, earthquakes, and floods combined. Approximately 600 people die each year from heat and heat waves. Heat waves have been increasing across the globe over the last four decades. From January 2000 to September 2009 the number of record highs was more than doubled the number of record lows. Global climate models predict that heat waves will become more frequent, more intense, and last longer in Europe and North America. The effects of heat waves are exacerbated in urban areas, where large numbers of people live in close proximity in heavily built-up environments.

Extreme temperatures and heat waves can severely impact public health and infrastructure. High temperatures limit transmission line's ability to carry power, leading to possible black and brown outs. Extreme heat can worsen other natural disasters, and compound their damages. For example, a heat wave could exacerbate the effects of a drought.

St. Louis is not immune to this rise in global temperatures and the increased frequency of heat waves. By the end of the century, the average temperature in St. Louis is expected to climb by 7.2 degrees Fahrenheit. Already, St. Louis is experiencing four more heat waves each summer than it has it in the past. In 2015, for example, St. Louis recorded nearly 20 days of extreme heat, while in 1970 it was closer to 10. By 2030 the city is expected to experience 46 days of dangerously extreme heat, rising to 63 by 2050. Heat waves have already led to 1,075 deaths in Missouri since 1980, with a 21 day heat wave claiming 34 lives in 2007. Those numbers are expected to increase as temperatures rise.

Higher temperatures are exacerbated in urban areas like St. Louis. Absorption of heat by rooftops, roads and sidewalks an increase surface temperature between 18 and 27 degrees Fahrenheit higher than in surrounding areas during the daytime, and between 9F and 18F degrees during the nighttime. During the summer, St. Louis is on average 17 degrees Fahrenheit warmer than nearby rural areas. Urban areas also experience higher levels of air pollution and greenhouse gases, which can be particularly harmful to those with asthma and other respiratory diseases. Asthma is already the leading cause of hospitalization at St. Louis Children's Hospital, especially among African Americans. In 2008, African Americans were treated for asthma related emergencies at a nine times great rate than their white counterparts.

Children, older adults, those with chronic conditions, and low-income families are the most vulnerable to negative effects of extreme heat and heat waves. Children, especially those with asthma, are especially vulnerable to rising temperatures. They rely on others (parents and caretakers) to keep them cool and hydrated during periods of high heat. Those with chronic health problems are also reliant on others for their care, and may be taking medications or have

conditions that affect their ability to regulate body temperature. Similarly, adults over 65 may also have conditions or take medication that affects their body. They are also more likely to live alone and have limited mobility, affecting their ability to access medical care or resources during an emergency.

Low-income individuals and families are also vulnerable to extreme heat. While the wealthy can afford to cope with rising temperatures, low-income families do not have the means to mitigate heat's effects. Low-income individuals are more likely to live in poor quality housing, social isolation, and in neighborhoods with inadequate infrastructure. They may not be able to afford the high cost if an air conditioner, or the electricity needed to operate one. If electricity and water are disconnected because of inability to pay bills during a heat wave, vulnerabilities and exposures to heat-related illness and death could be intensified among low-income individuals.

Extreme Cold

Cold waves are rapid falls in temperature within a 24-hour period. Climate scientists predict that - though global temperatures are warming - changes in the jet stream will lead to shorter, but more intense, cold waves and heavier snowfall. Scientists also predict that ice storms are likely to increase in frequency and severity during the coming years. Extremely cold weather and sudden cold waves often have disastrous effects on public health and can lead to injury, hypothermia, respiratory illness, and cardiac events. Approximately 63 percent of temperature related deaths are due to cold exposure. Because cold waves can be sudden and occur outside of typical winter months, cities must be prepared for deaths from cold to occur year round.

Despite rising average temperatures, St. Louis must still prepare for the consequences of extreme cold and winter weather events. Within the past five years, St. Louis has experienced record low temperatures and record high levels of winter precipitation. While St. Louis is projected to have less overall days of extremely cold weather in coming years, it is expected to receive more volatile weather, such as cold waves and extreme weather events. High levels of mortality due to cold weather is often more severe in temperate regions than in colder regions because the former do not have the built environment to adapt to extreme cold. Missouri has experienced a significant increase in annual cold weather deaths in the past two decades; in 1998 there were 8 deaths reported, versus 29 deaths in 2016.

Cold waves and winter weather can have broad impacts on daily life. Even minimal amounts of ice can create unsafe conditions on roadways. On December 18, 2016, there were 1,500 car crashes statewide, according to the Missouri Highway Patrol, resulting in 171 injuries and 17 deaths due to one winter event. A heavy reliance on personal motor vehicles due to the dispersed region places the St. Louis region at particular risk of vehicular injury and death during extreme cold weather storms. Plant injury due to freezing cold temperatures and unanticipated frosts can drastically reduce crop production (USDA, 2014). A reduction in crop yields in Missouri and the

Midwest region may threaten the St. Louis food supply and cause increased prices due to sourcing from more distant suppliers.

Those most vulnerable to extreme cold and cold waves include the elderly, low-income individuals and families, children, and African Americans. Those with chronic illness, especially cardiovascular and respiratory issues, are also at a heightened risk from extremely cold temperatures. Many of these groups also have difficulties accessing healthcare and public infrastructure because of limited income or mobility.

The elderly are especially susceptible to sudden decreases in temperature. Increased mortality, and cardiovascular and respiratory disease associated with cold spells is stronger in those over 65. Nearly half of all hypothermia-induced deaths in Missouri are among those 65 and older. Low-income St. Louisans are also vulnerable to extreme cold and cold waves. They have less capacity and resources to adapt to extreme weather. They tend to live in lower-quality housing, where pipes are more likely to freeze, limiting access to water. Furthermore, low-income populations may not have the financial ability to afford consistent heating, regular housing, medical treatment for infections and hypothermia, or warm clothing during cold months. On days where schools are forced to close, children from low-income families who rely on school for meals and warmth may have to go without. The economic impacts will affect low-income workers the most as they are the most vulnerable to economic volatility. Those who work in restaurants are especially vulnerable to cold-related business closures due to the dependency on variable wages, which will reduce their income and limit their ability to adapt to cold weather events. Those within African American communities tend to be more susceptible to cold weather effects in the US. Rates of chronic disease including diabetes, cardiovascular disease, asthma and respiratory illness are higher among African Americans in St. Louis City.

Tornadoes and Strong Wind

Tornadoes are mobile, destructive vortexes of violently rotating winds that have the appearance of a funnel-shaped cloud and advancing beneath a large storm system. The majority of tornadoes in the United States (77%) are considered weak, ranking as only an F-0 or F-1 on the 0-5 Fujita scale of tornado intensity. Though few storms reach the intensity of the F-5 classification, these storms with winds over 200 miles per hour are responsible for 70% of tornado fatalities. On average, 57 people are killed each year by tornadoes in the United States, making it the second deadliest weather hazard after flooding. Tornadoes disproportionately affect those living in mobile homes, where 44% of tornado fatalities occur, despite their much smaller share of the housing stock.

Climate change is predicted to impact the frequency and intensity of tornadoes. While tornadoes are now most common between March and August, climate models show that peak tornado season will occur earlier in the year. The United States has already seen a steady increase in the

number of tornadoes per year since official tornado reporting began. Tornadoes have a broad range of negative effects. While the direct health impacts of tornadoes are generally related to falling trees, flying debris, and collapsed buildings, tornadoes can also damage public infrastructure, blocking access to emergency aid and severing power lines.

Missouri is located within "Tornado Alley," an area of the Midwestern and Southern United States where tornadoes most frequently occur. Tornado Alley includes parts of Texas, Oklahoma, Kansas, Nebraska, Missouri, Iowa, Arkansas, North Dakota, and South Dakota. In Tornado Alley, peak tornado season usually occurs in late spring/early summer. St. Louis is at a high risk for tornado impact. In the half-century between 1950-2006 there were 3 recorded tornadoes within the City of St. Louis. In the decade between 2007 -2017 there were 4 recorded within city limits. This dramatic increase over the last ten years shows that St. Louis should be prepared for a drastic increase in the frequency and intensity of tornado activity.

Those living in mobile or low-quality homes are most vulnerable to the effects of tornadoes. These homes are more susceptible to wind damage and rarely have basements, meaning residents must rely on publicly-available shelters. If people are not prepared or able to get to a shelter, it is more likely that they will be injured during the outbreak. The elderly and those with chronic illnesses and disabilities are also disproportionately more vulnerable to tornadoes. They may be unable to react immediately to tornado warnings and sirens, and may require additional help to evacuate. If they require medication, they are unlikely to have an adequate supply to last for the duration of an evacuation.

Low-income individuals and families are also vulnerable to tornadoes. They may be homeless or live in low-quality housing, which is less able to withstand severe winds and tornados. They may not have enough money to adequately prepare resources for an emergency preparedness kit, such as food and water. Low-income residents are also less likely to have purchased property insurance and would have financial difficulty recovering from a natural disaster.

Drought

Drought is characterized as "a dry condition with low rainfall," but drought conditions vary across the country depending on local average rainfall. Air temperature increases cause evaporation from water within the soil, leaving the soil dry. Rising global temperatures brought about by trapped greenhouse gases will worsen the severity and frequency of droughts worldwide. Global temperatures are on the rise. Since 1990, the global average annual temperature has risen by 1.5 degrees Fahrenheit. Communities that rely heavily on agriculture for income will be most directly impact by worsening drought, but the effects of rising food prices will be felt by everyone.

As of November 2017 it is estimated that 27.6 million people, or 11% of the population of the United States if affected by drought. This number is only expected to increase, with NASA warning areas of Arizona and Southern California to prepare for major droughts of a severity not seen since the twelfth century. The United States has already experienced the disastrous effects of drought. In 1988 a major drought affected 67% of the nation, destroying a third of corn agriculture and resulting in financial losses exceeding $4.7 billion. While it is impossible to predict the exact pattern of new droughts in the future, it is certain that will increase in severity and frequency as the nation's average temperature is expected to rise from between 2 - 11.5 degrees Fahrenheit by the end of the century.

Missouri and St. Louis are not immune to threats posed by worsening droughts. Within the last decade, Missouri has experienced repeated droughts, with the Department of Agriculture declaring all of Missouri in a state of emergency due to extreme drought in the summer of 2012. Five years later, in the summer of 2017, the City of St. Louis received less than half its average rainfall. Abnormally dry conditions like these can cause permanent plant wilt and crop failure, hurting a regional economy that relies heavily on agriculture. Droughts also have major impacts on the surrounding rivers, which move the barges responsible for transporting many of the industrial goods produced in St. Louis. High evaporation and low river flows as the result of drought impede river navigation and drive up shipping costs. In 2016 it was estimated that navigation problems in the region's waterways had a $300 million impact on the national economy.

Drought vulnerability is highest among those who rely on river navigation and agriculture for their livelihood. Droughts often lead to crop failures and can impede barge traffic along the region's waterways. Indirectly, droughts negatively affect a much broader population within the St. Louis region. Droughts drive up food prices and the price of goods shipped by river barges. The impact of these higher prices is most severe on low-income residents, who may have to make tough financial cutbacks if their cost-of-living increases even marginally.

Flooding and Rain Storms

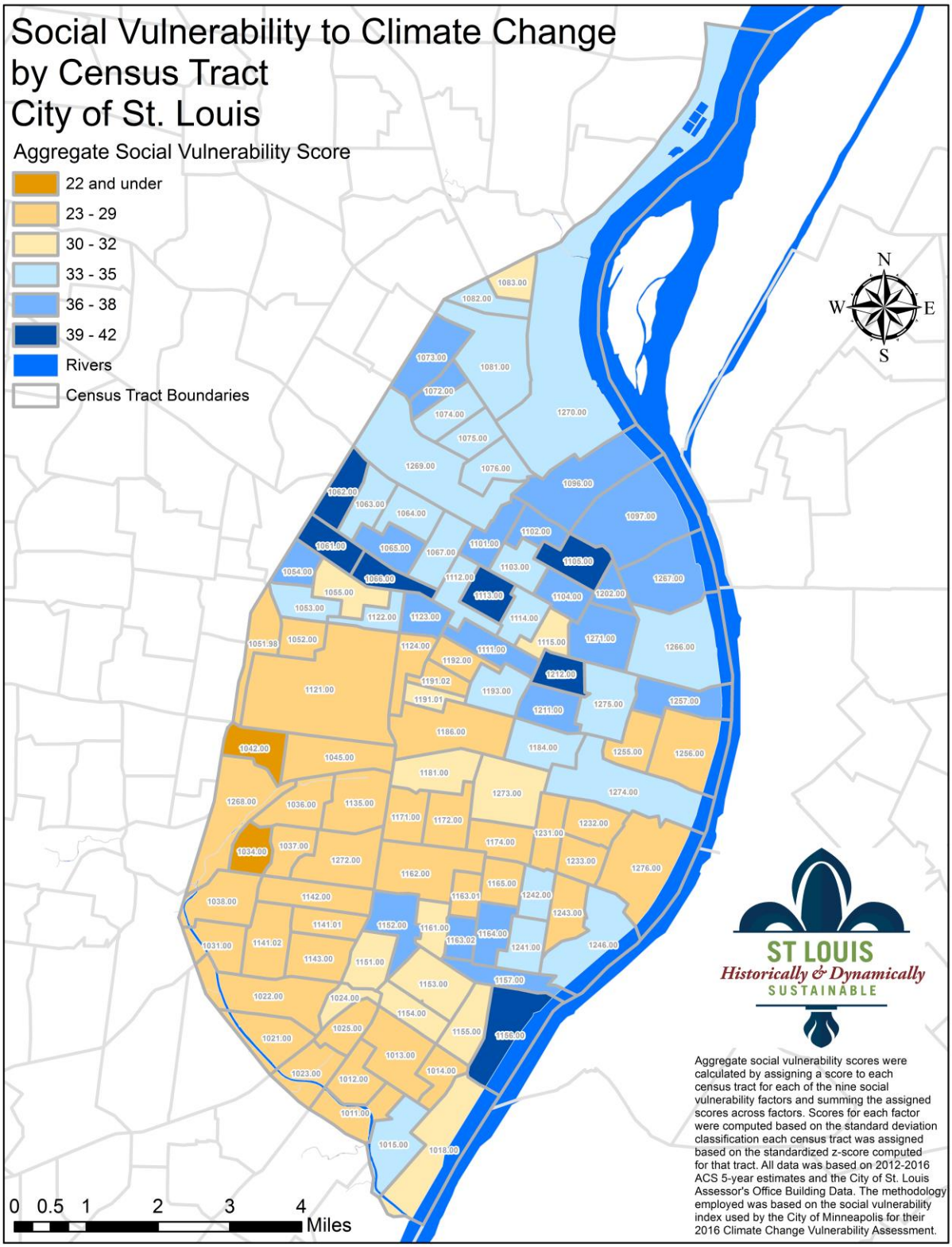
The risk of flooding is expected to rise significantly as global temperatures continue to climb. As air temperatures rise, more water evaporates from oceans, lakes, and rivers, condensing in the air, and forming rainstorms. If the global average temperature rises by the 7.2 degrees Fahrenheit anticipated, then the world could face a 500 percent increase in the risk of flooding, affecting 70 percent of the global population and GDP. Rising floodwaters and sea levels caused by heightened temperatures will inundate coastal communities and exacerbate inland river flooding. Permanent rises in water level will displace millions. Already, between 2008 and 2015 22.5 million people globally have been forced to relocate because of flooding.

Rainstorms are increasing in their intensity, leading to larger floods across the United States. Between 1958 and 2007 the largest 1% of rainstorms experienced a 20% average increase in rain volume. Flooding and stormwater can easily overload combined sewage systems and water treatment facilities. Areas with poor stormwater management and more frequent heavy rainfalls are more likely to see degradation in infrastructure, leading to costly repairs.

Flooding can lead to mental health problems, injuries, and even death. Most casualties from flooding are caused by the rapid rise of floodwater. The higher the water depth and the more rapid of the flow, the greater the lethality of a flood. People in flooded areas are at an increased risk from waterborne diseases, as studies have shown that when untreated water is discharged into surface water, the risk for outbreaks increases. Untreated standing floodwater can also cause an increase of mosquito-borne diseases. Floodwater often contains chemical hazards and can hide sharp objects made of metal or glass. Natural disasters like flooding and storms can exacerbate existing mental health problems and lead to the development of new ones. Studies have shown that flooding is associated with increased rates of depression, anxiety, and stress. Most mental issues are due to damage to the properties, loss of familial possessions and stress in dealing with home rebuilding and displacement in the aftermath of a flood.

The American Midwest has already experienced a 10% increase in average annual rainfall over the last 50 years. That number is only expected to rise. By 2050 the region's average annual rainfall is predicted to rise by another 4-5.1%. Future floods could lead to water elevations never before seen in the region. If waters rise even a few feet above historic highs, vast sections of the city could be inundated. Flooding already has a major impact on the St. Louis Region's economy and its residents' quality-of-life.

People living near rivers and coastal regions will be the most directly impacted by flooding, but vulnerability will vary due to quality of infrastructure, government emergency management, and individual factors. Especially vulnerable are the elderly and those with disabilities and chronic health problems, as they may have a more difficult time evacuating quickly during an emergency. Low-income individuals and families can also be severely impacted by the effects of flooding, and have a difficult time recovering financially.


Social Vulnerability to Climate Change
by Census Tract
City of St. Louis
Aggregate Social Vulnerability Score
22 and under
23 - 29
30 - 32
33 - 35
36 - 38
39 - 42
Rivers
Census Tract Boundaries
N
W
E
S
0 0.5 1 2 3 4
Miles
ST LOUIS
Historically & Dynamically
SUSTAINABLE
Aggregate social vulnerability scores were calculated by assigning a score to each census tract for each of the nine social vulnerability factors and summing the assigned scores across factors. Scores for each factor were computed based on the standard deviation classification each census tract was assigned based on the standardized z-score computed for that tract. All data was based on 2012-2016 ACS 5-year estimates and the City of St. Louis Assessor's Office Building Data. The methodology employed was based on the social vulnerability index used by the City of Minneapolis for their 2016 Climate Change Vulnerability Assessment.

ST. LOUIS CLIMATE ACTION & ADAPTATION PLANNNING

The City's Climate Action & Adaptation Plan was developed to take the climate protection sections of the City of St. Louis Sustainability Plan, and provide greater detail and direction. The City of St. Louis Sustainability Plan was adopted by the City Planning Commission in January 2013. In November 2015, former Mayor Francis Slay committed the City to the Compact of Mayors (now Global Covenant of Mayors for Climate & Energy). The Compact of Mayors requires a series of steps for a municipality to take to measure, assess, evaluate and plan its climate responses. The Compact of Mayors set a three year period in which to complete these steps. The creation of the 2015 Greenhouse Gas (GHG) Emissions Inventory, identification of potential climate related hazards, setting a reduction target, and developing a Climate Action & Adaptation Plan satisfied most of the Compact of Mayors expectations. This Climate Change Vulnerability Assessment has been prepared to further inform the City's Climate Protection Initiative, and to comply with the expectations of the Compact of Mayors pledge.

The Climate Action & Adaptation Planning process was developed to align with and build upon existing efforts by both City government and the entire community. The recommended target of the Climate Action & Adaptation Planning process is to achieve an 80% GHG emissions reduction by 2050 from 2005 baseline levels. The Climate Action & Adaptation Plan outlines recommended mitigation measures to take in order to reach that target, and provides a climate adaptation framework to help make the City more prepared and resilient in the face of climate change.

Implementation of the measures outlined in Climate Action & Adaptation Plan will provide an opportunity to improve public health and the quality of life in the. The Climate Action & Adaptation Plan was designed to fulfill two overarching climate-related goals:

Mitigation Goal: Build a Healthy, Prosperous & Low-Carbon City
The mitigation section of the document contains five objectives, each containing a number of strategies and actions intended to guide greenhouse gas mitigation efforts. These recommendations focus on improving the built environment, natural environment, and infrastructure to improve public health, economic prosperity, and community empowerment within the City of St. Louis.

Adaptation Goal: Build a Strong, Equitable & Climate Resilient City
Adaptation efforts help establish and build climate resilience in response to climate change. This section of the document contains three objectives, each containing a number of strategies and actions intended to guide adaptation efforts. These adaptation recommendations focus on building resilience to climate hazards to protect human health and safety, preserve ecology and

biodiversity, reduce the impacts of climate change on vulnerable populations, and ensure equitable protection of people in severe weather events.

The Climate Action & Adaptation Plan outlined triple bottom line co-benefits of climate protection, with a spotlight on the public health implications if not addressed.

Economic Benefits: Energy efficiency is the largest sector within the U.S. clean energy economy. Businesses located in the City of St. Louis currently employ 1,845 people in energy efficiency jobs, and 2016 market trends revealed a 13% growth rate nationwide. The solar industry has shown substantial job growth nationwide, and is growing nearly twenty times faster than the overall economy. Ameren's dependence on coal raised rates 43% between 2009 and 2014.[7] Climate action implementation presents an opportunity to grow the clean energy economy to create jobs, reduce utility costs for homes and businesses, and protect against the rising cost of coal dependent energy.

Environmental Benefits: A quality natural environment serves as a major asset to urban areas. Protecting natural resources, such as land, water, plants, and animals, from the harmful effects of climate change will help maintain a high quality of life with clean water, green trees, fresh food, and clean air to breathe. The existing urban tree canopy (UTC) in the City of St. Louis is 7,237 acres (18.2%), with the potential of increasing by 13,479 acres (33.9%). The UTC in the City of St. Louis and portions of the county are valued at more than $72 million for the ecosystem services it provides.

Social Benefits: Climate action and adaptation implementation often result in improved community vibrancy. The protection and restoration of natural systems provides a valuable public amenity that can be beneficial to health and well-being. Developing efficient and equitable transportation options empowers the community through increased access to jobs, education, and healthcare, while reducing pollution from vehicle emissions. Improved building energy efficiency and cleaner sources of energy production will greatly reduce air pollution and the associated negative health impacts.

Climate change has an adverse effect on public health, and is expected to create a number of adverse public health conditions, including the increased risk of contracting infectious diseases, exposure to heat stress, air pollution, and allergens, as well as negative impacts on mental health. Temperatures will continue to rise and extreme heat events will become the new normal. Higher temperatures will increase heat stress, the number one killer in the United States. Temperatures over 90 degrees Fahrenheit increase ground level ozone, a major component in smog, which negatively impacts air quality. Coal-burning power plants cause damaging air pollution that exacerbates asthma and other respiratory diseases, which can lead to heart attacks, lung

[7] Sierra Club, A Bright Future: Moving from Coal to Clean Energy in the St. Louis Region, 2016, page 9.

problems, and premature mortality. Asthma is the number one reason for hospitalizations of children at St. Louis Children's Hospital.[8] Climate action and adaptation implementation can help mitigate air pollution, and reduce the health implications of climate change and improve quality of life.

The effects of climate change disproportionately affect vulnerable populations, such as the elderly and children, as well as people in low-income communities and African Americans, "where residents confront daily the symptoms of historic inequities."[9] During extreme heat events, people in poverty often cannot afford to turn on the air conditioning or improve their homes with better insulation, which increases their risk of heat stroke or even mortality. Disadvantaged communities typically have less green space and tree cover to shade their community and reduce heat island effects. Air quality in St. Louis is one of the nation's poorest, making air unhealthy and increasing asthma rates in the City, especially for African American children. Climate protection will reduce the negative effects of climate change on vulnerable people and improve their health and well-being.

City of St. Louis 2015 Community GHG Emissions Inventory

A greenhouse gas (GHG) emissions inventory is a tool to identify and measure where emissions originate, establishing historical emission trends and tracking progress in reducing greenhouse gases. The Community GHG Emissions Inventory measures GHG emissions generated by the entire community within the political boundaries of the City of St. Louis, including government operations of the City of St. Louis. In 2015, the entire community was responsible for the GHG emissions of 7.2 million metric tons of carbon dioxide equivalent (mmtCO2e). This is an 11% reduction from the 2005 baseline year for measuring GHG emissions reductions. The City's 2015 Community GHG Emissions Inventory revealed that 97% of community-wide GHG emissions came from sources within the built environment (commercial, residential, and industrial sectors) and vehicles miles traveled. Structures within the existing built environment generated 77% of GHG emissions, and vehicle miles traveled generated 20%.

Community GHG Emissions Reduction Trends 2005-2015

Between 2005 and 2015 the Community reduced GHG emissions 11% (-862,248 mtCO2e). Between 2013 and 2015, however, GHG emissions increased 3% (+301,244 mtCO2e). The sectors with the greatest increase in GHG emissions were vehicle miles traveled, commercial buildings, and industrial facilities; combined these sectors increased +280,306 mtCO2e. The reason for this increase is currently unclear, but it could be correlated to an uptick in commercial activity in the City.

Compact of Mayors Climate Hazards Identification

[8] Sierra Club, A Bright Future: Moving from Coal to Clean Energy in the St. Louis Region, 2016, page 17.
[9] Kelly, Cathleen, Resilient Midwestern Cities Improving Equity in a Changing Climate, 2016, page 1.

As part of the City's commitment to the Compact of Mayors, an assessment of risks associated with climate hazards was prepared by staff of the East-West Gateway Council of Governments. Below is the resulting list of climate hazards that have been identified as having a higher probability of occurring in the City of St. Louis.

Temperature Extremes

- **Extreme Hot Days / Heat Waves:** The City is predicted to experience more days over 90 and 100 degrees Fahrenheit and longer lasting/hotter heat waves.
- **Extreme Winter Conditions / Cold Wave:** Overall winters are expected to be milder; however, cold snaps and cold waves will occur.
- **Vector-borne Disease:** Warmer temperatures globally will increase the geographic range and season length for disease carrying insects.
- **Insect Infestation:** Temperatures affect insect reproduction and mortality. Warmer temperatures can lead to increased insect populations and migration.

Precipitation Extremes

- **Rainstorm:** Heavy rainfall events are predicted to increase in frequency. The Spring season will see the greatest increase.
- **River flood:** The City's proximity to the confluence of the Missouri and Mississippi Rivers increase the City's vulnerabilities to river flooding during rain events.
- **Flash / Surface Flood:** Increased heavy precipitation will lead to more frequent flash flooding and surface flooding caused by storm water runoff and sewer overflows.
- **Hail / Heavy Snow:** Changing weather patterns and cold snaps will result in hail and heavy snow events.
- **Waterborne Disease:** Severe precipitation events can lead to outbreaks of waterborne diseases.
- **Drought:** Short-term droughts are projected to increase with hotter temperatures evaporating moisture from soil & plants.

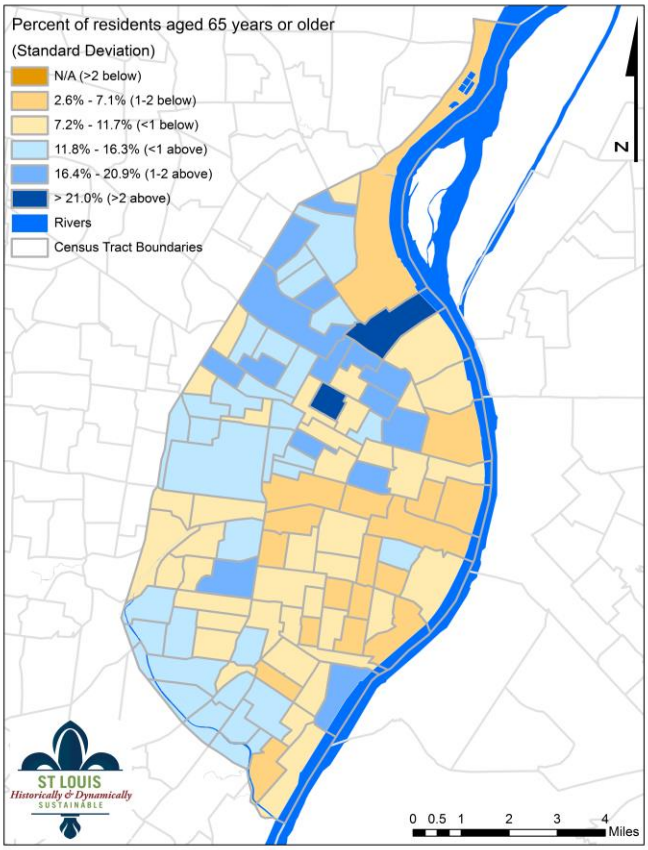
Severe Weather / Natural Disaster

- **Tornado / Severe Wind:** Strong storms are more likely with increased warming, which could increase the frequency of tornadoes due to the temperature patterns associated with climate change.
- **Earthquake:** The City of St. Louis is located near the New Madrid Seismic Zone. Although earthquakes are not directly related to climate change they create a great risk for the City.
- **Lightning / Thunderstorm:** More intense thunderstorms and lightning events may increase with global warming.

SOCIOECONOMIC VULNERABILITY FACTORS IN ST. LOUIS

This section examines the social vulnerability of various populations in St. Louis. Social vulnerability is defined as the social characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to environmental hazards. These characteristics include age, socioeconomic status, race, and disability status. Maps are included to generally reflect demographic distribution of social vulnerability factors in the City of St. Louis. Although everyone is likely to feel the effects of extreme weather events, some populations are inherently more vulnerable to the effects of climate change than others.

Percent of Population Over the Age of 65



The elderly population of St. Louis is one of the most vulnerable to the effects of climate change, as these individuals are more likely to have disabilities, chronic health problems, or limited mobility.[10] Due to these physiological variables, people over the age of 65 are particularly at risk due to the varying temperatures caused by climate change, namely extreme heat that can exacerbate pre-existing medical conditions, like cardiovascular disease and other common illnesses.[11] Natural disasters put the elderly at extreme risk, as they are less likely to mobilize and find shelter quickly.

Various social factors contribute to the vulnerability of the elderly in St. Louis. Elderly citizens are more likely to live alone and be socially isolated, which can restrict their access to immediate care in emergency situations.[12]

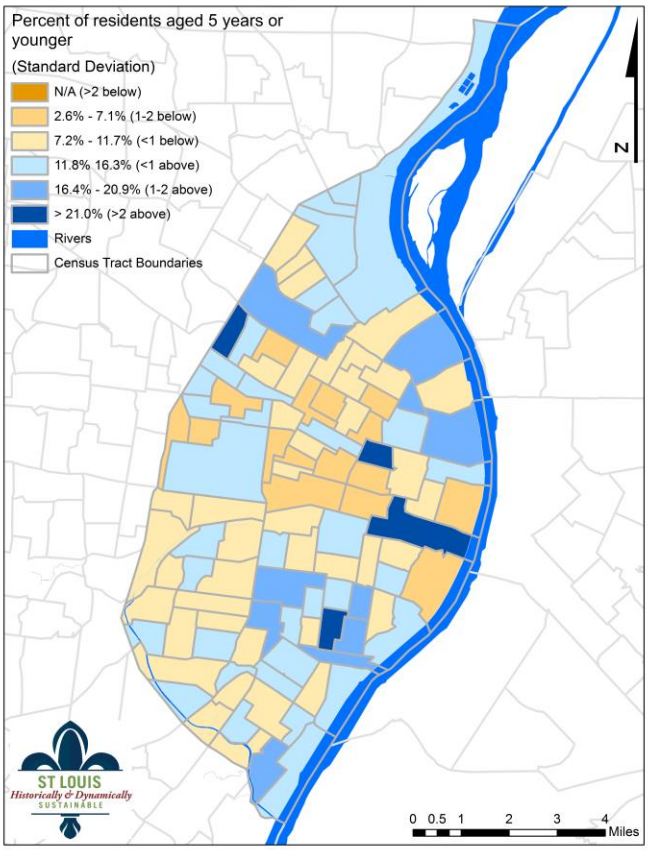
[10] Filiberto, D., Wethington, E., Pillemer, K., Wells, N.M., Wysocki, M., & Parise, J.T. (11 June 2011). Older people and climate change: Vulnerability and health effects. *Generations*. Retrieved from http://www.asaging.org/blog/older-people-and-climate-change-vulnerability-and-health-effects.

[11] United States Environmental Protection Agency. (May 2016). *Climate change and the health of older adults*. Retrieved from https://www.cmu.edu/steinbrenner/EPA%20Factsheets/older-adults-health-climate-change.pdf.

[12] City of St. Louis, Missouri (2017). Climate action & adaptation plan for the city of St. Louis sustainability plan. Retrieved from https://www.stlouis-mo.gov/government/departments/mayor/initiatives/sustainability/documents/upload/CAP_FINAL_2017-04-17_High-Res.pdf

In St. Louis City, those aged 65 years and older account for 11.9% of the population. However, as the St. Louis City population continues to age, the projected number of older adults is set to increase.[13] Of those with disabilities, those ages 65 and older account for 47.1% of the population.[14]

Percent of Children Under Age 5



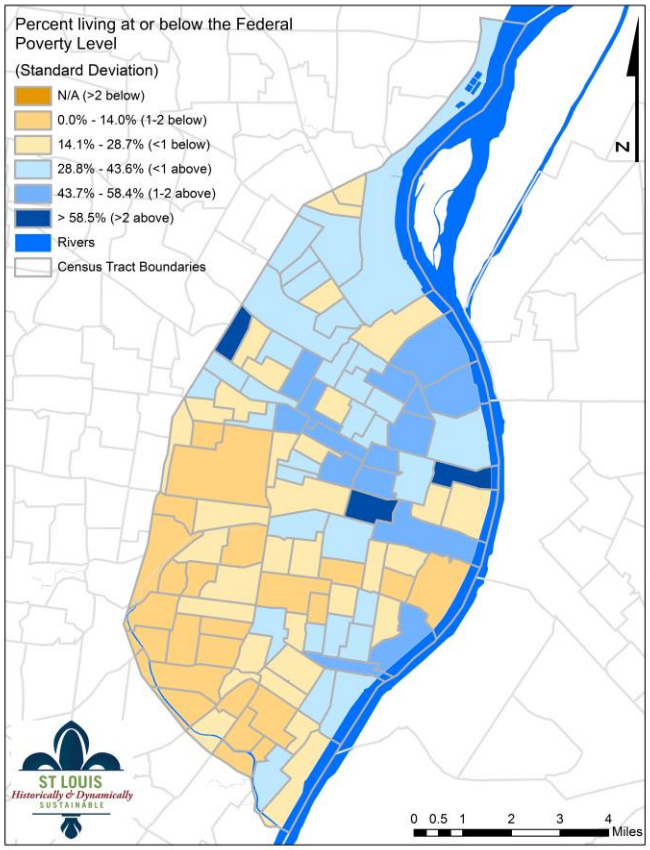
Knowing where young children reside throughout the city is important because their developing bodies and dependence on adults puts them more at risk for the health and environmental stressors of extreme weather and natural disaster events. Children also need specialized care after disasters due to their different size and psychological needs.[15] Children are particularly at risk when it comes to extreme heat and extreme cold, as they spend more time outside, are less able to regulate their temperature, and often lack the capacity to effectively communicate their needs.[16]

Additionally, children's underdeveloped immune systems put them at greater risk of contracting vector borne diseases and other illnesses that are also projected to rise due to climate change.[17] Asthma and other respiratory conditions are also extremely common among children in St. Louis, and adverse air quality is expected to worsen as temperatures rise.[18]

[13] Barnes-Jewish Hospital. (2016). 2016 Community Health Needs Assessment and Implementation Plan. Retrieved from https://barnesjewish.thehcn.net/content/sites/barnesjewish/Final_2016_BJH_CHNA_Report.pdf
[14] Barnes-Jewish Hospital (2016)
[15] United States Environmental Protection Agency. (December 2009). *Climate change and children's health*. Retrieved from https://www.epa.gov/sites/production/files/2014-05/documents/ochp_climate_brochure.pdf.
[16] Zivin, J.G., & Shrader, J. (2016). Temperature extremes, health, and human capital. *The Future of Children*, 26(1). Retrieved from https://www.researchgate.net/publication/303125807_Temperature_extremes_health_and_human_capital.
[17] Lawler, J. (2011). *Children's vulnerability to climate change and disaster impacts in East Asia and the Pacific.* Bangkok, Thailand: Unicef East Asia and Pacific Regional Office. Retrieved from https://www.unicef.org/media/files/Climate_Change_Regional_Report_14_Nov_final.pdf.
[18] Fann, N., Brennan, T., Dolwick, P., Gamble, J.L., Ilacqua, V., Kolb, L., Nolte, C.G., Spero, T.L., & Ziska, L. (2016). Air quality impacts. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. Retrieved from https://health2016.globalchange.gov/air-quality-impacts.

Increasing the resilience of the youth of St. Louis is an especially important concern because it provides grounding for healthier lifestyles in the future. Engaging children also often means that families as a whole become more committed to climate change preparedness efforts.

Percent Living Below Poverty Line

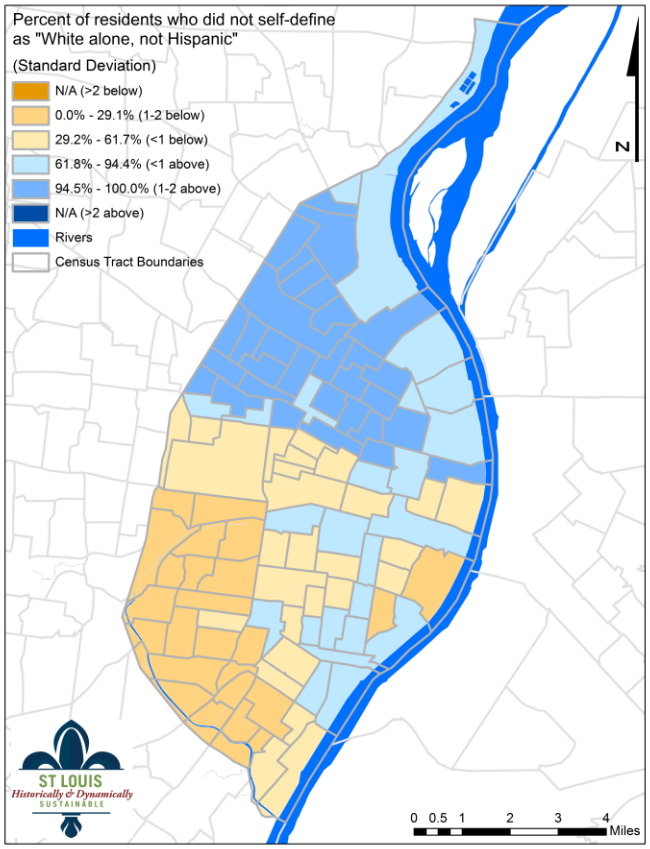


In 2016, the median household income was $38,397 in St. Louis, and 24.9% of St. Louis residents were in poverty.[19] Of those living in poverty, 72% were African American and 28% were White. Low-income status is one of the biggest indicators of climate change vulnerability, as the poor have limited access to health care and emergency resources, are more likely to live in inadequate housing, and often lack property insurance. Low-income status may impact response during emergency situations.[20] Lack of financial resources also affects an individual's capacity to respond to extreme weather or natural disaster events, as costs to rebuild after an event can be prohibitively high.

There are pockets of low-income areas throughout the City, but are more prevalent in North St. Louis City. The 63106 zip code has 60.1% of residents living below the federal poverty line.[21] The household income range in the southern part of the city is $41,800-$72,000, compared to $32,700-$41,800 in north St. Louis City.[22,23]

[19] Census Bureau. U.S. census bureau quickfacts selected: St. Louis city, Missouri. Retrieved from: https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_16_1YR_S1903&prodType=table
[20] White, G.B. (3 Aug 2015). A long road home. *The Atlantic*. Retrieved from https://www.theatlantic.com/business/archive/2015/08/hurricane-katrina-sandy-disaster-recovery-/400244/.
[21] Barnes-Jewish Hospital (2016)
[22] Data USA. (n.d.). St. Louis City, MO. Received from: https://datausa.io/profile/geo/st.-louis-city-mo/#category_coverage.
[23] United States Census Bureau. (12 Sep 2017). Income, poverty, and health insurance coverage in the United States: 2016. Received from: https://www.census.gov/newsroom/press-releases/2017/income-povery.html.

Percent Non-White Residents



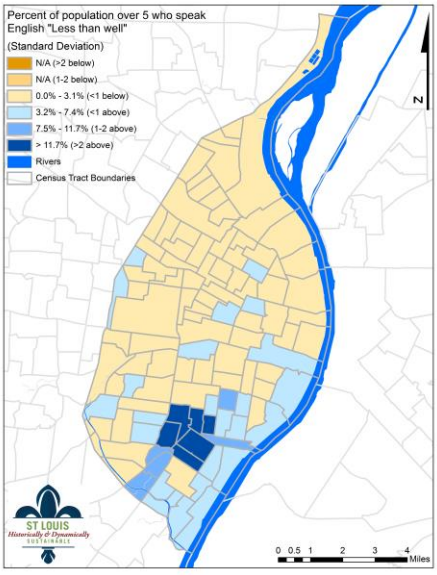
Race and ethnicity are strongly associated with economic and health disparities, and communities of color are often overburdened with environmental contamination and natural disaster impacts. Due to historical trends of segregation and discrimination, these populations are more likely to be socially isolated, live in adverse housing conditions, and lack access to resources, such as air conditioning and adequate shelter provisions.

In 2017, the racial/ethnic makeup of the St. Louis population was 46.5% African American, 43.9% non-Hispanic White, 3.9% Hispanic, 3.4% Asian, and 2.5% Multiracial.[24] Sixty to one hundred percent of the City's minority population resides in the northern region of the city.

Percent of Population Who Speak English as a Second Language

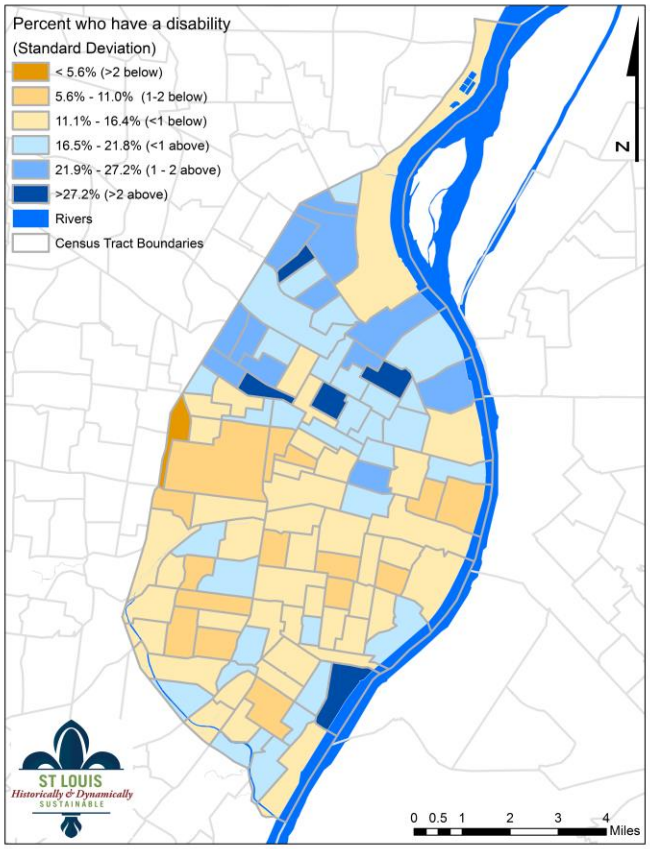
Emergency response procedures can be severely impacted by linguistic barriers. Access to preparedness programs and health resources as well as basic communication during emergencies become much more difficult when English is not one's primary language.

In St. Louis, 2.5% of households meet the US Census Bureau's definition of "linguistically isolated,"[25] where all adults speak a language other than English and none speaks English "very well."[26] Although 2.5% is smaller than the national average of 4.6%, linguistic challenges are important considerations for extreme weather response and preparedness resources.



[24] United States Census Bureau. (2017)
[25] Curtis, P., Garba, N., Kao, Y., & Edvalson, L. (Sep 2015). *Assessment of at-risk populations*. St. Louis, MO: City of St. Louis Department of Health.
[26] Siegel, P., Martin, E., & Bruno, R. (12 Feb 2001). *Language use and linguistic isolation: Historical data and methodological issues.* U.S. Census Bureau. Bethesda, MD. Retrieved from https://www.census.gov/hhes/socdemo/language/data/census/li-final.pdf.

Percent Disabled

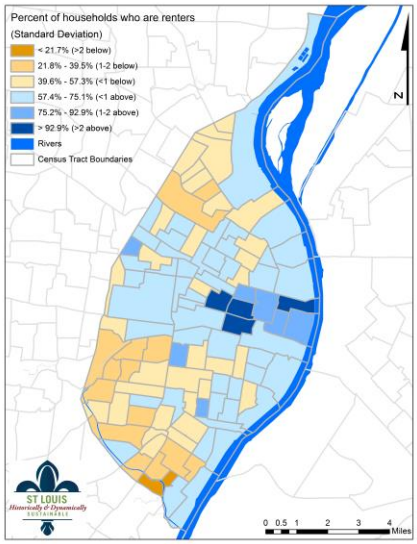


The percentage of persons with disabilities in the City (14.3%) is slightly higher than the national average of 12.1% of the population.[27] Individuals with disabilities are a primary concern when dealing with extreme weather events because their social and physical condition can become exacerbated due to environmental factors. Limited mobility, social isolation, or dependence on caretakers can also complicate the emergency response process and impede in evacuation efforts.

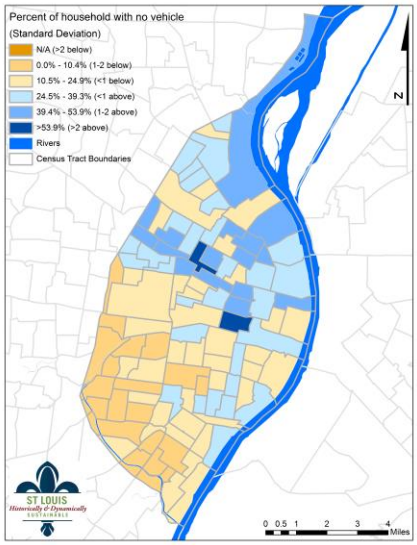
According to the 2015 Assessment of At-Risk Populations by the City of St. Louis Department of Health, disabled people are concentrated in the area codes 63147, 63155, 63113, 63107, and 63111.

Other Social Vulnerability Factors to Consider in St. Louis:

Renters

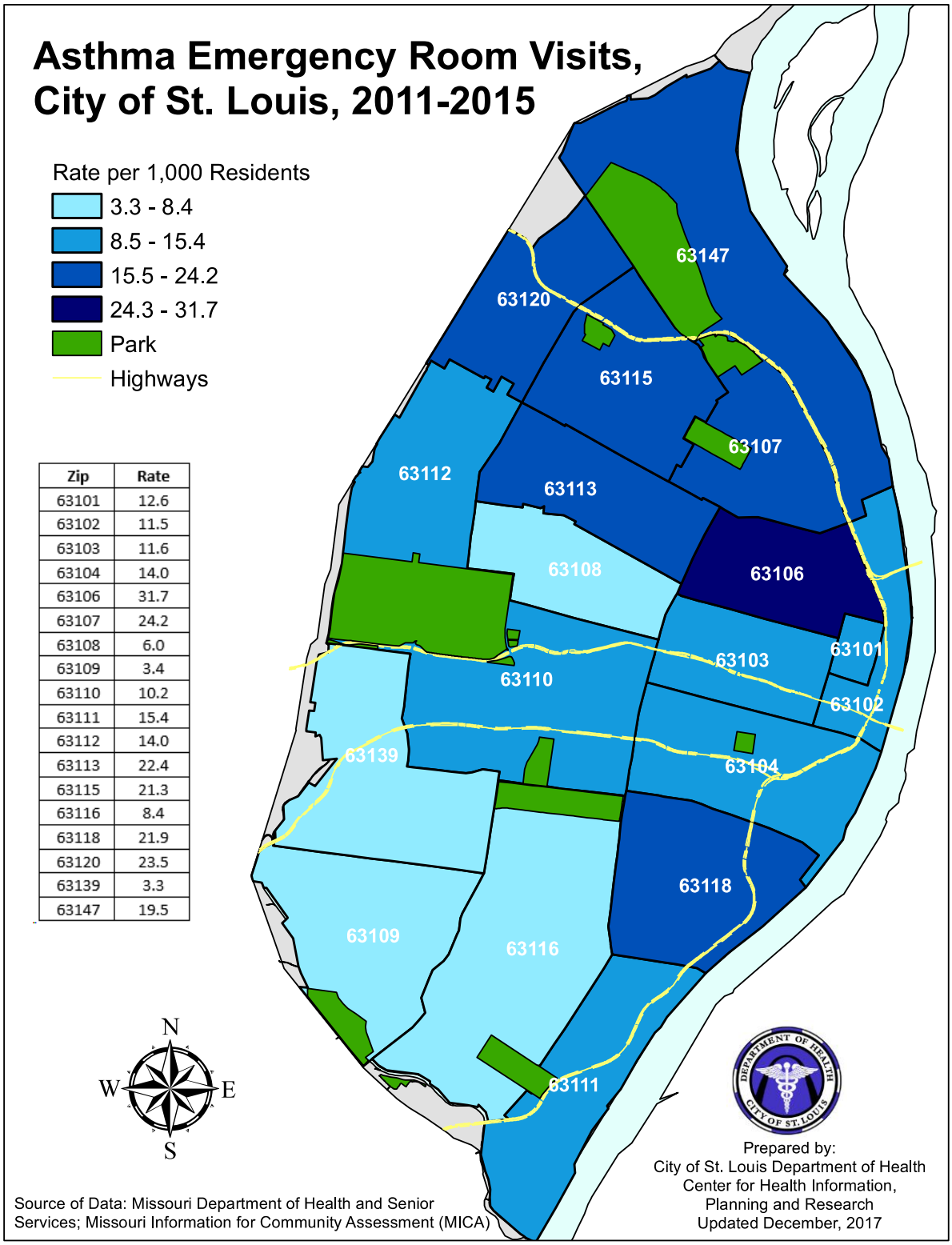


Households With No Vehicles

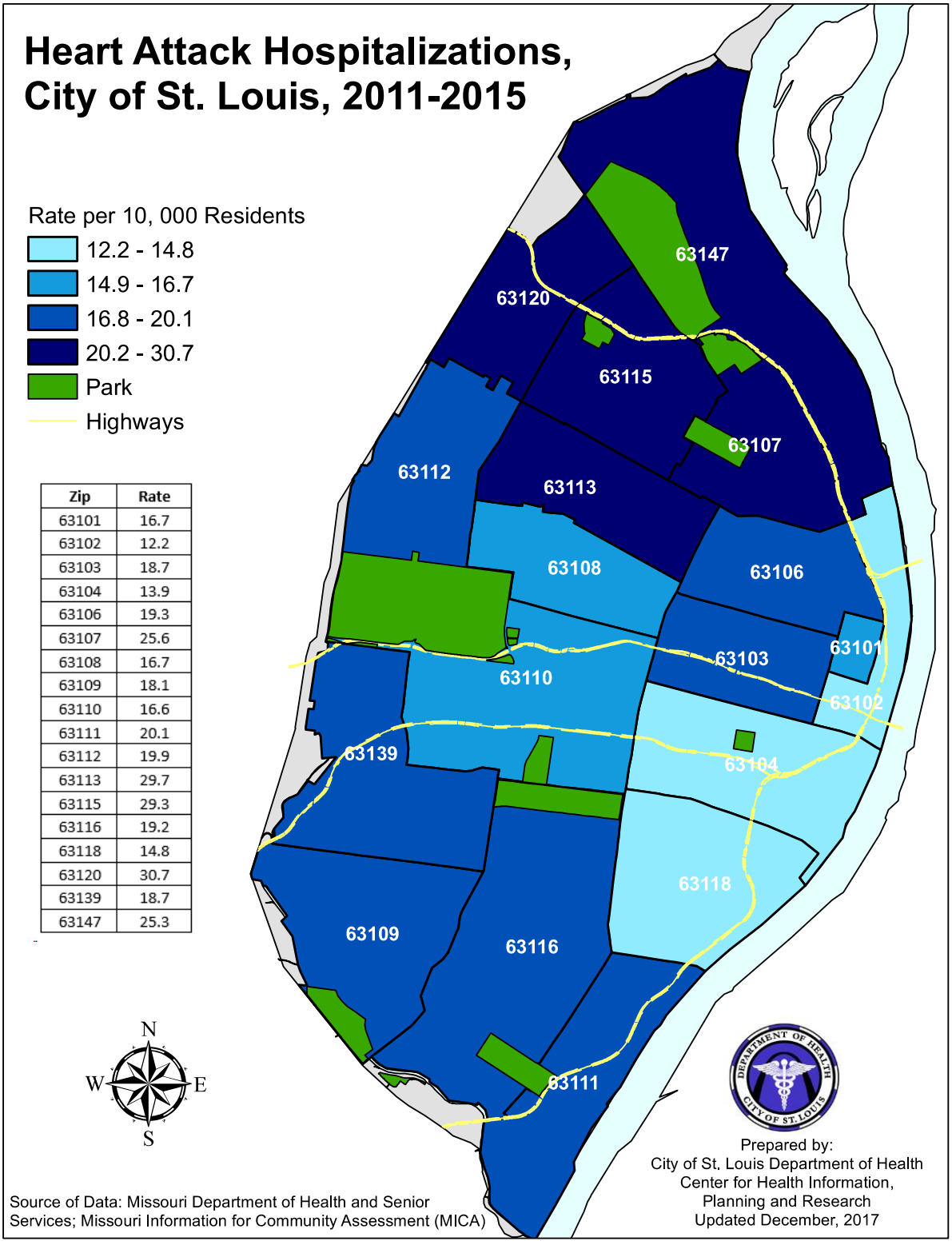


[27] Curtis, P., Garba, N., Kao, Y., & Edvalson, L. (Sep 2015). *Assessment of at-risk populations*.

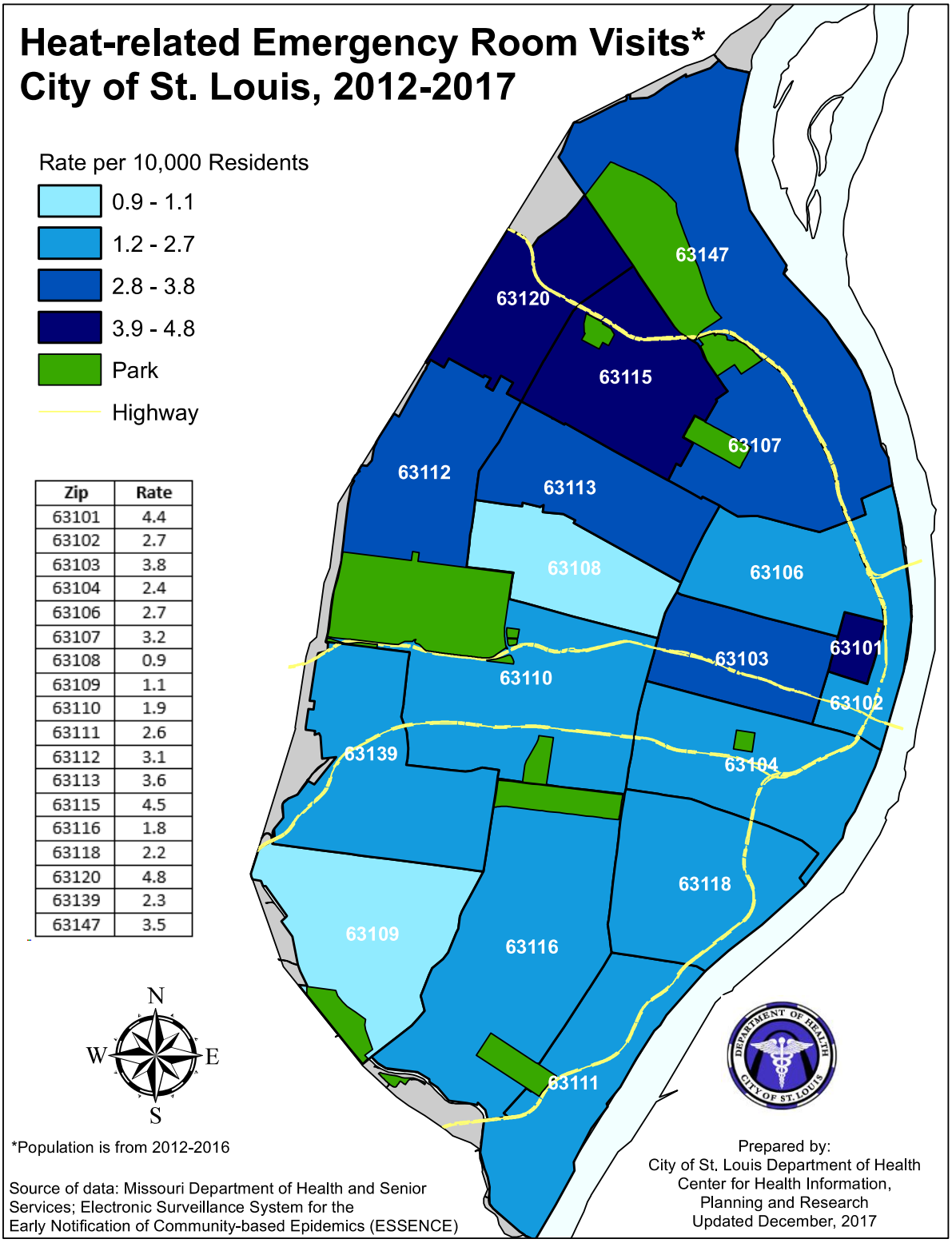
HEALTH CONDITIONS & VULNERABILITY IN ST. LOUIS



Zip	Rate
63101	12.6
63102	11.5
63103	11.6
63104	14.0
63106	31.7
63107	24.2
63108	6.0
63109	3.4
63110	10.2
63111	15.4
63112	14.0
63113	22.4
63115	21.3
63116	8.4
63118	21.9
63120	23.5
63139	3.3
63147	19.5



Zip	Rate
63101	16.7
63102	12.2
63103	18.7
63104	13.9
63106	19.3
63107	25.6
63108	16.7
63109	18.1
63110	16.6
63111	20.1
63112	19.9
63113	29.7
63115	29.3
63116	19.2
63118	14.8
63120	30.7
63139	18.7
63147	25.3

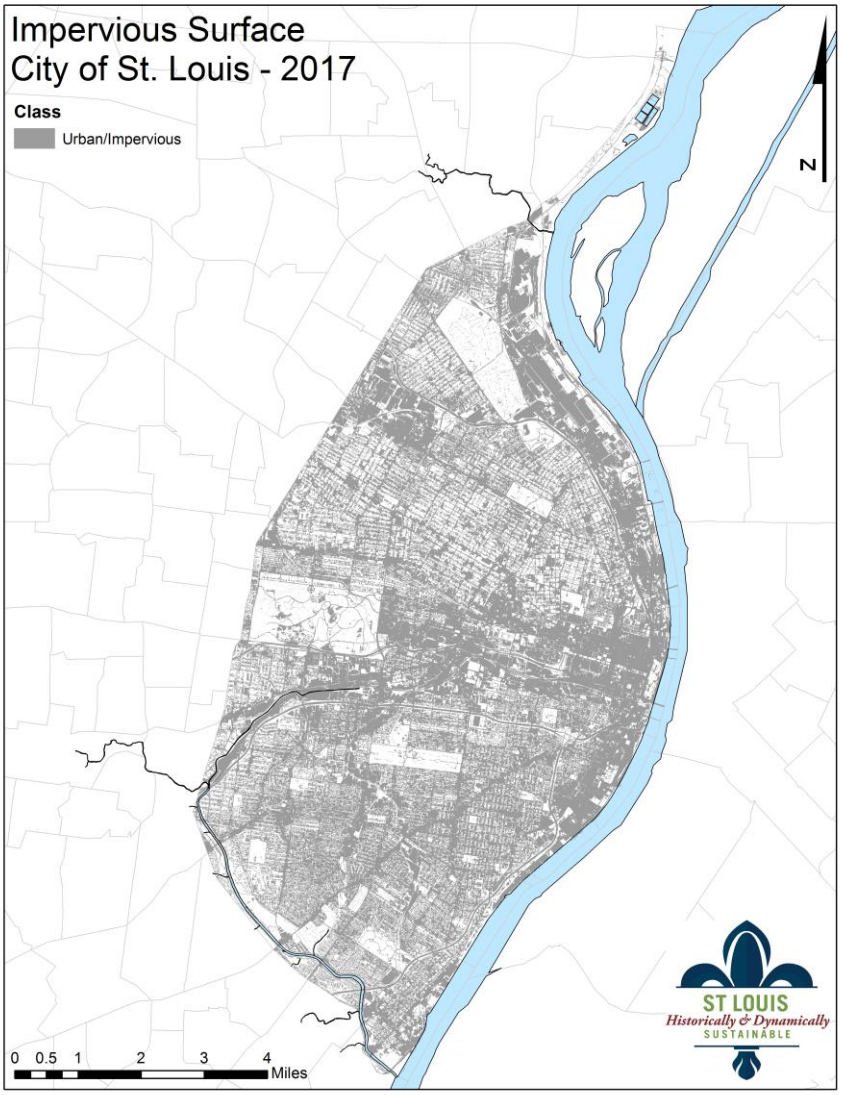


Zip	Rate
63101	4.4
63102	2.7
63103	3.8
63104	2.4
63106	2.7
63107	3.2
63108	0.9
63109	1.1
63110	1.9
63111	2.6
63112	3.1
63113	3.6
63115	4.5
63116	1.8
63118	2.2
63120	4.8
63139	2.3
63147	3.5

LANDSCAPE CONDITIONS & VULNERABILITY IN ST. LOUIS

Impervious Surfaces, Vegetation And The Urban Heat Island Effect

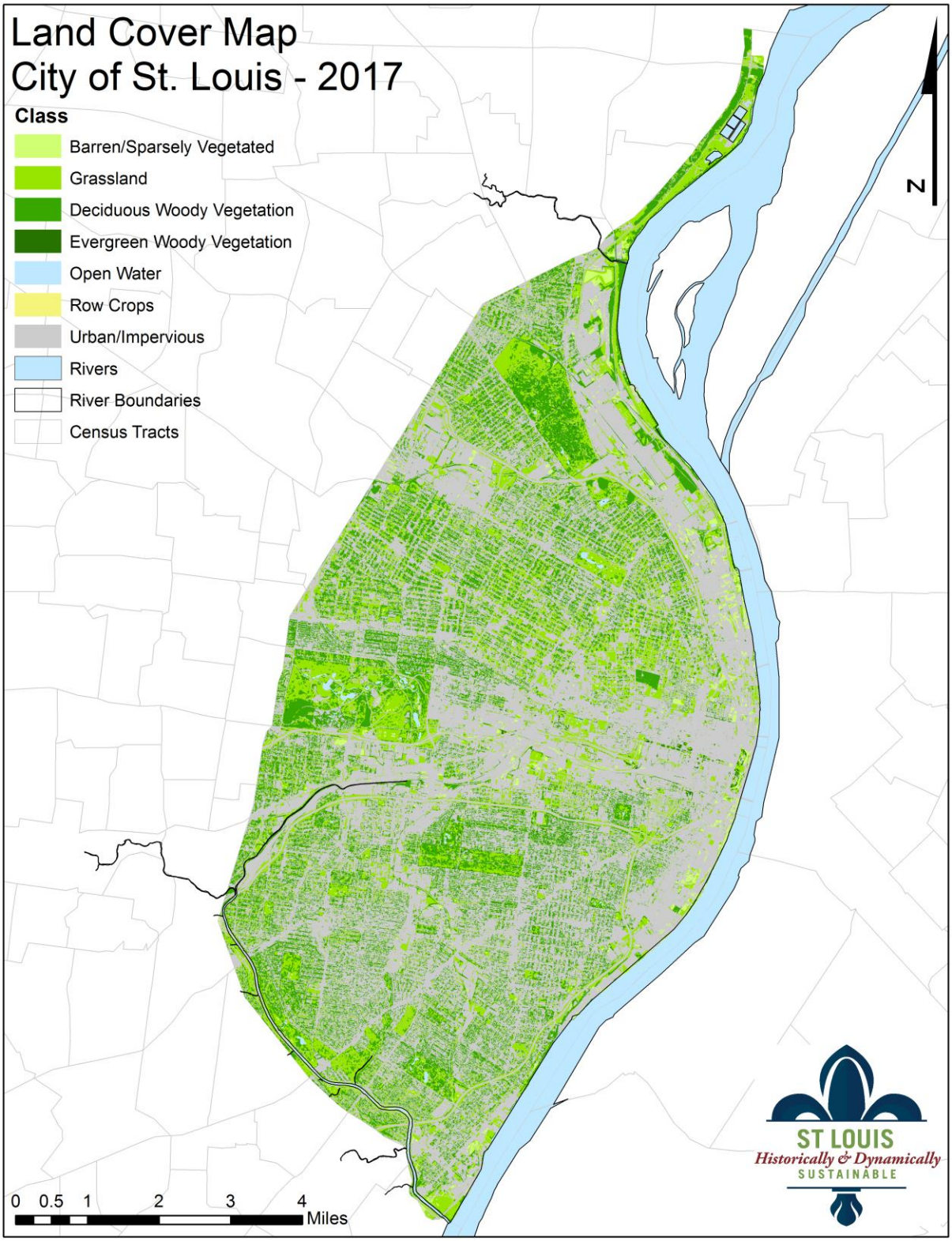
The urban heat island effect occurs when the higher thermal storage capacity of an urban environment, in addition to a relatively high concentration of heat sources, contributes to an increase in temperatures relative to its surrounding areas.[28] Absorption of heat by rooftops, roads, and sidewalks can increase surface temperature between 18 and 27°F higher than in surrounding areas during the daytime, and between 9 and 18°F during the nighttime.[29]

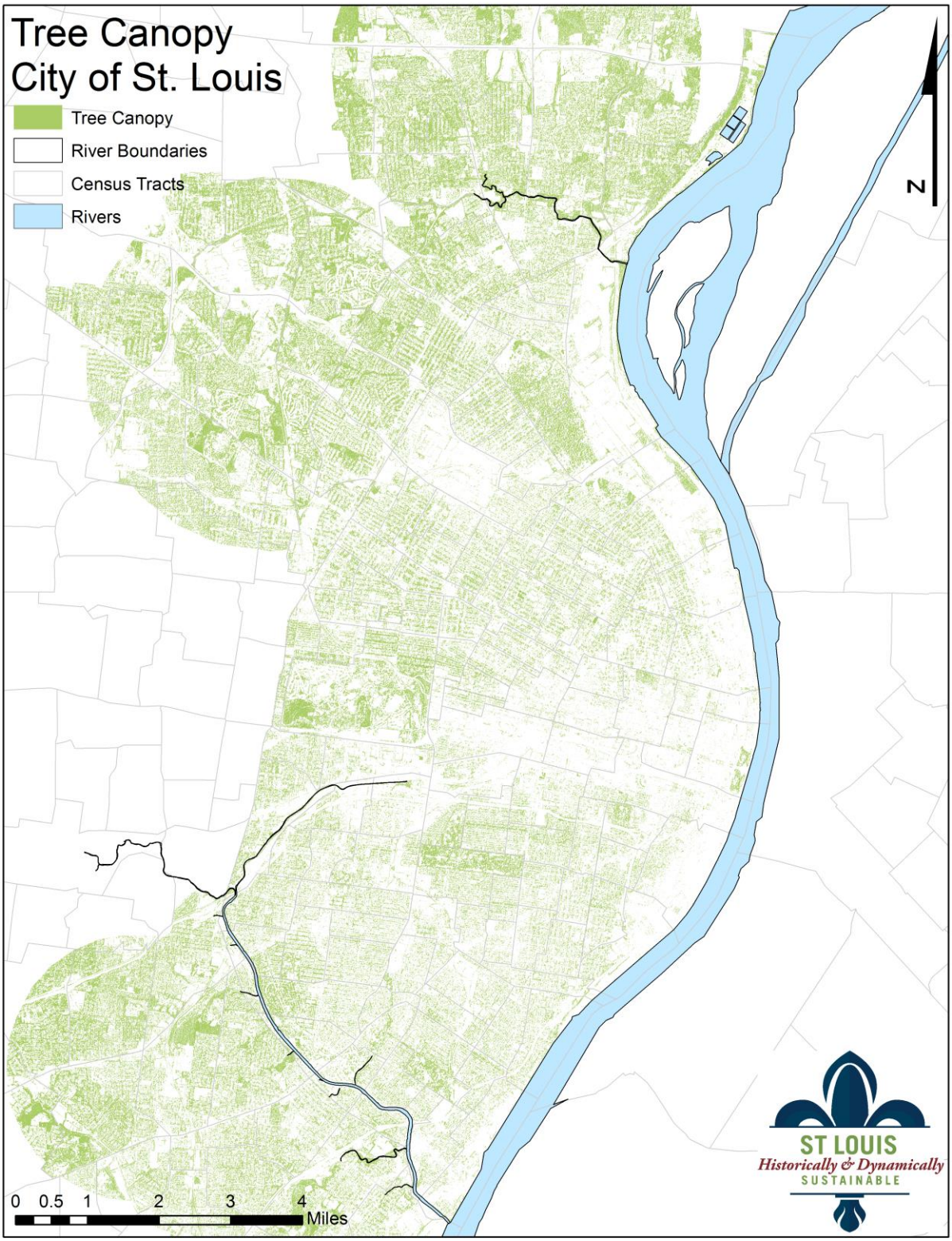


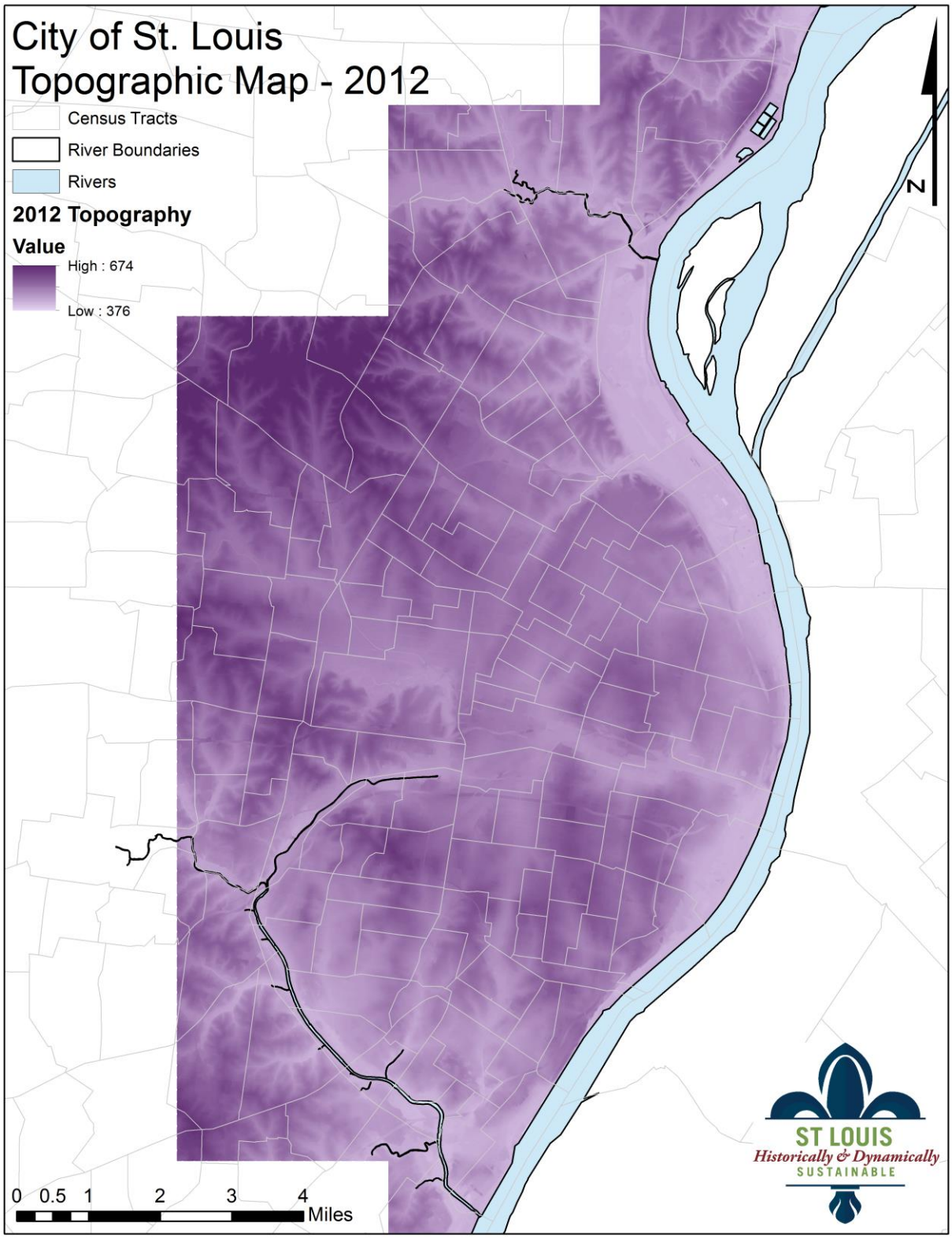
Urban areas are especially susceptible to the effects of extreme heat due to the large numbers of people living in physical infrastructures that intensify the effects of extreme heat.[30] St. Louis City can get up to 17°F hotter than nearby rural areas in the summer.[31] On average, City summers are 4°F hotter than those in rural areas.[32]

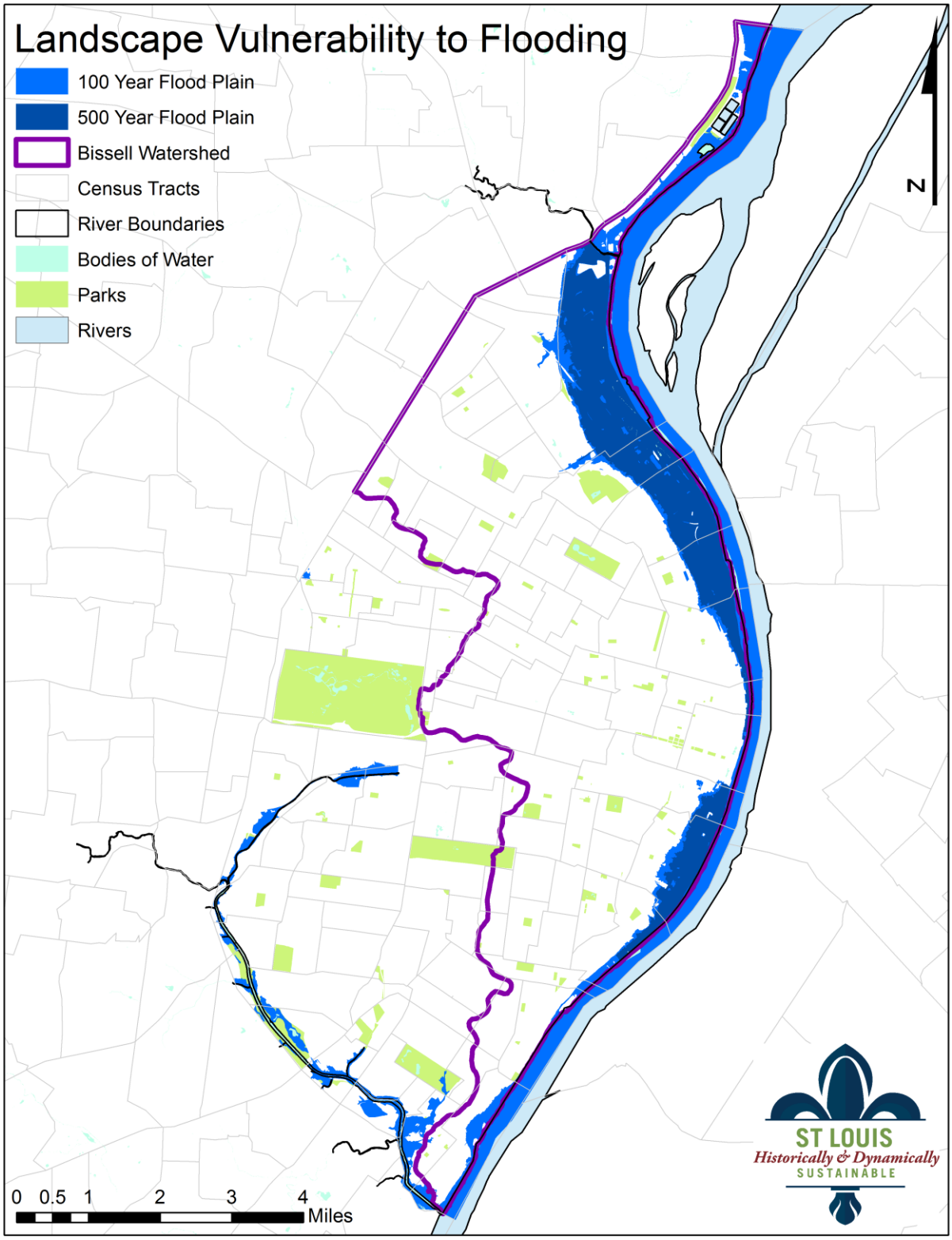
While impervious surfaces contribute to Urban Heat Island Effect, urban landscape vegetation and tree canopy can help reduce the Urban Heat Island Effect and lessen the impact of flooding.

[28] Luber & Lemery (2015)
[29] Environmental Protection Agency (2008). Reducing urban heat islands: Compendium of strategies. Washington, DC: Environmental Protection Agency.
[30] Luber, G., & Lemery, J. (2015). Global climate change and human health: From science to practice. John Wiley & Sons.
[31] Climate Central (2014). Hot and getting hotter: Heat islands cooking U.S. cities. Retrieved from: http://www.climatecentral.org/news/urban-heat-islands-threaten-us-health-17919
[32] Climate Central (2014)


Land Cover Map
City of St. Louis - 2017
Class
Barren/Sparsely Vegetated
Grassland
Deciduous Woody Vegetation
Evergreen Woody Vegetation
Open Water
Row Crops
Urban/Impervious
Rivers
River Boundaries
Census Tracts
N
0 0.5 1 2 3 4
Miles
ST LOUIS
Historically & Dynamically
SUSTAINABLE


Tree Canopy
City of St. Louis
Tree Canopy
River Boundaries
Census Tracts
Rivers
N
0 0.5 1 2 3 4
Miles
ST LOUIS
Historically & Dynamically
SUSTAINABLE


City of St. Louis
Topographic Map - 2012
Census Tracts
River Boundaries
Rivers
2012 Topography
Value
High : 674
Low : 376
N
0 0.5 1 2 3 4
Miles
ST LOUIS
Historically & Dynamically
SUSTAINABLE


Landscape Vulnerability to Flooding
100 Year Flood Plain
500 Year Flood Plain
Bissell Watershed
Census Tracts
River Boundaries
Bodies of Water
Parks
Rivers
N
0 0.5 1 2 3 4
Miles
ST LOUIS
Historically & Dynamically
SUSTAINABLE

ASSESSMENT OF ST. LOUIS CLIMATE CHANGE HAZARDS

The hazards identified as the most likely to impact the St. Louis region are extreme heat, extreme cold, drought, tornadoes, and flooding. By doing an in-depth analysis of each phenomenon, including predicted health outcomes and possible impact on vulnerable populations, the City of St. Louis will be better prepared in the face of the most significant threats of climate change.

Extreme Heat

Heat waves are defined as three of more days of extremely hot weather, often accompanied by high humidity.[33,34] It is usually measured by comparing the relative temperature to the normal temperatures for that season.[35] Extreme heat days, days above 95 degrees Fahrenheit (°F), and heat waves are a significant public health problem in the U.S.[36] Extreme heat events are exacerbated by the synergistic effects of a warming climate, urbanization, and a growing population.[37] Based on a global coupled climate model, heat waves are expected to be more frequent, more intense and last longer in Europe and North America.[38]

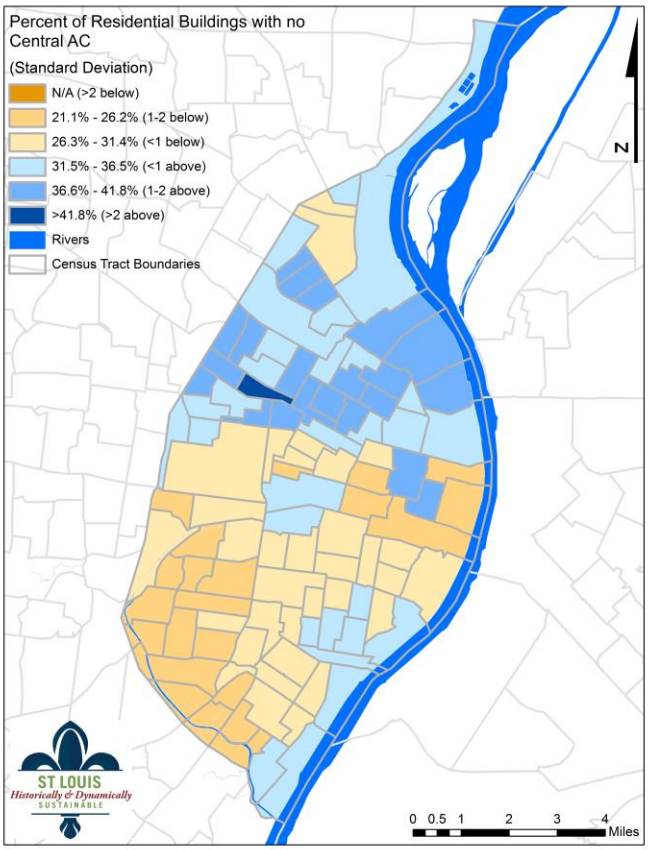
Extreme hot days or heat waves are considered the one of the deadliest natural disasters in the United States, killing more people on average than hurricanes, lightning, tornadoes, earthquakes, and floods combined.[39] Approximately 600 people die each year from extreme heat.[40] Since 1980, the number of deaths that can be attributed to extremely hot weather and humidity in Missouri is 1,075.[41] In 2007, a 21-day heat wave in Missouri resulted in 34 deaths.[42]

The effects of extreme heat are predicted to grow. On average, St. Louis experiences four more heat waves each summer than it has in the past.[43] Since 1970, the number of extreme heat days in St. Louis has increased by 6.4 days.[44] By 2030, St. Louis is expected to experience 46 danger days, and 63 danger days by 2050.[45] Taking higher GHG emissions into account, a study

[33] Robinson, P. J. (2001). On the Definition of a Heat Wave. *Journal of Applied Meteorology*, 40 (4): 762–775.
[34] Union of Concerned Scientist. (2012). Heat in the heartland; 60 years of warming in the midwest. Climate change and your health. St. Louis & Columbia, MO.
[35] Meehl, G. A., & Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, 305(5686), 994-997.
[36] Luber, G., & McGeehin, M. (2008). The health impacts of climate change; climate change and extreme heat events. *American Journal of Preventative Medicine, 35,* 429-435.
[37] Luber & McGeehin (2008)
[38] Meehl & Tebaldi (2004)
[39] Center for Climate and Energy Solutions. (2017). Extreme weather: heat waves and climate change. Retrieved from: https://www.c2es.org/content/heat-waves-and-climate-change/.
[40] Center for Climate and Energy Solutions (2017)
[41] Bakhsh, H. (2015). Mapping social vulnerability and exposure parameters to extreme heat events in Missouri. *(Unpublished doctoral dissertation).* University of Illinois at Chicago, Chicago, Illinois.
[42] State Emergency Management Agency (SEMA). (2014). Heat wave: Extreme heat. State Emerg Manag Agency, Missouri Dep Public Saf. Retrieved from http://sema.dps.mo.gov/plan_and_prepare/heat_wave.asp.
[43] Union of Concerned Scientist (2012)
[44] Climate Central (2016). U.S. faces dramatic rise in extreme heat, humidity. Retrieved from: http://www.climatecentral.org/news/sizzling-summers-20515#dangerdays
[45] Climate Central (2016)

conducted in 2009 predicted that St. Louis could face six weeks (43 days) of temperatures exceeding 100°F every year.[46] If GHG emissions are lowered, the number of extreme heat days could be limited to rising by 11 days each year.[47] In general, the City is likely to experience an increase in the number of days over 90 and 100°F.

Extreme Heat Vulnerable Populations



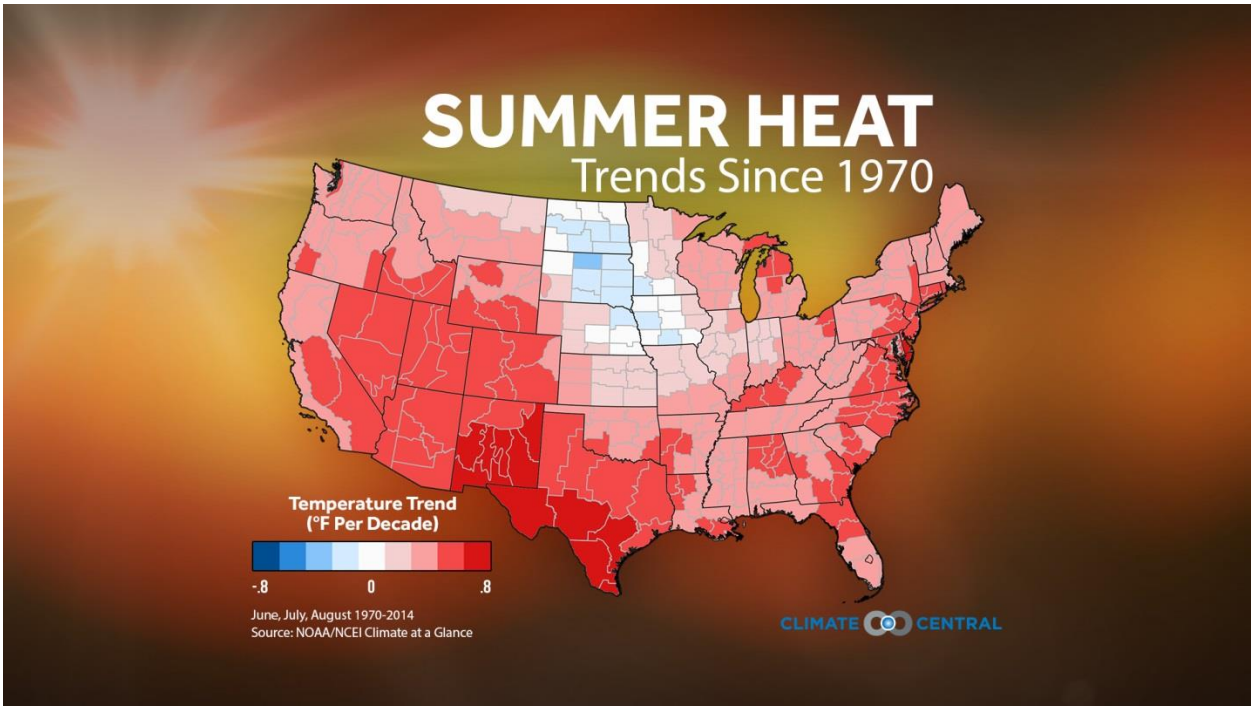
The longer heat waves last, the more detrimental effects they can have on vulnerable communities, due to the lack of emergency health care preparedness.[48] Adults 65 years and older are some of the most vulnerable to heat-related negative health outcomes because they are more likely to have chronic medical conditions which require prescription drug medications that affect the body's ability to respond to extreme heat.[49] Individuals with chronic conditions who are *not* elderly may also be at risk for heat-related illness because medications for conditions such as heart disease, mental illness, and obesity affect the body's ability to recognize and respond to changes in temperature.[50] Heat-related illnesses are also more common among people who drink alcoholic beverages, use narcotics, and participate in strenuous outdoor physical activity within hot weather.[51]

Low-income individuals are vulnerable to the effects of extreme heat because of their diminished capacity to anticipate, cope with, resist and recover from the heat-induced health impacts that can be mediated by financial support. Low-income and minority individuals are more likely to live in poor quality housing, inadequate neighborhood infrastructure, and social isolation, which contribute to the vulnerability of heat stress already present among different levels of

[46] Union of Concerned Scientist (2012)
[47] Union of Concerned Scientist (2012)
[48] Atkins, C. (2013). Feeling the heat: Heatwaves and social vulnerability in Victoria. (Vol 17). Melbourne, VIC: Victorian Council of Social Service.
[49] Centers for Disease Control and Prevention (2017). Heat and older adults. Retrieved from: https://www.cdc.gov/disasters/extremeheat/older-adults-heat.html
[50] Centers for Disease Control and Prevention (2017). Heat and people with chronic medical conditions. Retrieved from: https://www.cdc.gov/disasters/extremeheat/medical.html
[51] Luber & McGeehin (2008)

socioeconomic status and race.[52,53] Individuals living in poverty often believe they cannot afford to turn on their air conditioner during times of extreme heat, and may not have access to news outlets for tips to stay cool. Health impacts could be reduced with improvements to housing, management of chronic diseases, and institutional care of the elderly and low-income.[54]

In St. Louis, individuals residing in the northern region of the city are more vulnerable to the effects of extreme heat due to the high concentrations of minority, specifically African American, and low-income populations. While there are already a number of climate adaptation and mitigation strategies in place to address extreme heat, efforts can be improved to further engage and involve diverse stakeholders.



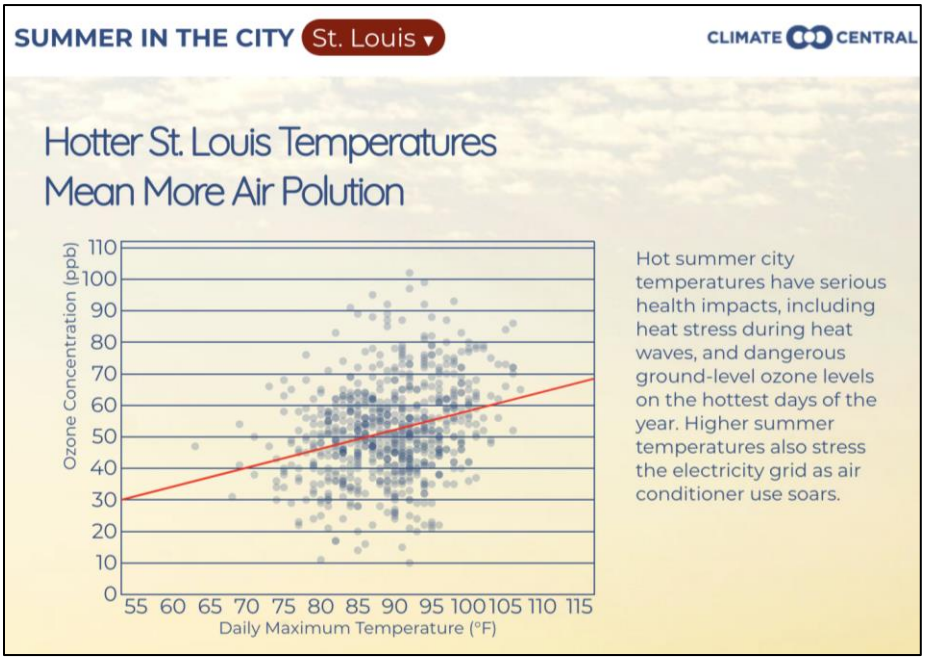
Extreme Heat Predicted Health Outcomes

Heat stress can occur in humans, and results when the body is unable to cool itself effectively.[55] This mainly occurs during the day, but can also occur during the evening when humidity and nighttime temperatures are elevated.[56] Prolonged exposure to high temperatures can cause heat-related illnesses, including heat cramps, heat syncope, heat exhaustion, heat stroke, and death.[57]

[52] Committee on Public Health Strategies to Improve Health (2011). For the public's health: revitalizing law and policy to meet new challenges. Washington DC: National Academies Press.
[53] Balbus, J. & Molina, C. (2009). Identifying vulnerable subpopulations for climate change health effects in the united states. *Journal of Occupational and Environmental Medicine*, 51(1), pp 33-57.
[54] Kovats, R., & Hajat, S. (2008). Heat stress and public health: a critical review. *Annual Review of Public Health, 29,* 41-55.
[55] Center for Climate and Energy Solutions (2017).
[56] Center for Climate and Energy Solutions (2017).
[57] Luber & McGeehin (2008).

Heat exhaustion is the most common heat-related illness.[58] Extreme heat can disrupt cellular processes by redistributing blood flow to peripheral blood vessels. Meanwhile, loss of electrolytes accompanying the loss of sweat can place a huge burden on the heart. Eventually, this tremendous burden can result in inadequate cardiac output, and finally cardiovascular collapse.[59]

Higher urban temperatures are also associated with higher levels of air pollution and greenhouse gases, like ground-level ozone, which exacerbate asthma and other respiratory diseases.[60,61] Asthma is the number one reason for hospitalization of St. Louis children at St. Louis Children's Hospital.[62] In 2015, the rate of asthma-related emergency room visits among African American children was 8.5 times greater than that of White children.[63] Due to the projected increase in number of extreme heat days and heat waves, children with asthma, specifically African American children, will become extremely vulnerable to the adverse health effects associated with rising temperatures.[64,65] In general, children and infants are vulnerable to extreme heat because of their reliance on others (*i.e.*, parents and caretakers) to keep them cool and hydrated in such circumstances.[66] Health impacts related to extreme heat include heat stress and exhaustion, exacerbated asthma and respiratory illness, dehydration, and in some



[58] Luber & McGeehin (2008).
[59] Helman, R., & Habal, R. (2014). Heatstroke. Retrieved from http://emedicine.medscape.com/article/166320-overview#showall.
[60] Luber & Lemery (2015)
[61] Sierra Club (2016). A bright future: Moving from coal to clean energy in the St. Louis region. Retrieved from: https://content.sierraclub.org/creative-archive/sites/content.sierraclub.org.creative-archive/files/pdfs/1287_StLouis_CoaltoClean_v7_Pages_web.pdf
[62] Sierra Club (2016)
[63] Sierra Club (2016)
[64] Bunyavanich, S., Landrigan, C.P., McMichael, A.J., & Epstein, P.R. (2003). The impact of climate change on child health. *Ambulatory Pediatrics*, 3. Retrieved from https://pdfs.semanticscholar.org/2c4d/2573c688b94ed299d0486a2942a521da8eaa.pdf.
[65] *Confronting climate change in the U.S. midwest.* (July 2009). Union for Concerned Scientists. Retrieved from https://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/climate-change-missouri.pdf.
[66] Centers for Disease Control and Prevention (2017). Heat and infants and children. Retrieved from: https://www.cdc.gov/disasters/extremeheat/children.html

cases death. Populations that are more susceptible to the adverse health outcomes associated with extreme heat include: the elderly, children and infants, individuals with limited mobility and chronic conditions, low-income individuals, and minority groups.

Extreme Heat Mitigation and Adaptation Strategies

Adaptation strategies are those that adjust to, reduce or prevent adverse health effects from actual or expected climate effects, particularly extreme heat, in this case. For instance, at the individual level, use of air conditioning in homes and buildings can be an effective adaptation strategy to respond to extreme heat.[67] Additional efforts may be required to assist populations living in poor housing condition, who lack air conditioning or the financial resources to afford efficient cooling techniques in their homes. That is why the City of St. Louis Department of Health (DOH) takes careful steps in assuring all residents, especially ones vulnerable to extreme heat, have the resources needed to stay safe during an event.

During an Excessive Heat Advisory, active surveillance of heat-related illnesses and enhanced educational messaging are initiated. Active surveillance is when health departments, or those in charge of the surveillance system, reach out to providers of data, like hospitals to collect data. During an Excessive Heat Warning, the principle activities are active surveillance, the distribution of press releases, and consideration begins on whether a VoiceShot campaign should be initiated. The VoiceShot campaign is intended to get in contact with each of the 5800 members of the Functional Needs Registry (FNR). If there are still members who have not been reached and all strategies to reach them have been exhausted, canvassing efforts are coordinated by DOH, Department of Human Services (DHS), the Building Division, Neighborhood Stabilization Team, and the City Emergency Management Agency (CEMA). Through the collaboration of these agencies, the remaining individuals on the FNR are reached within a few hours.

Through active surveillance, epidemiologists are alerted by local hospitals when city residents are sick with a heat-related illness. The epidemiologist then performs an initial review of each case, and any cases that need follow-up are sent to the Public Health Educator for Severe Weather and Community Resiliency. Environmental Health Officers will go to the cases' places of residence to assess their environment. The DOH has a long-standing partnership with Heat Up St. Louis/ Cool Down St. Louis. This organization offers utility assistance through a consortium of partners. During the hot summer months, DOH and Cool Down St. Louis provide qualified city residents with A/C units and/or utility billing assistance.

The City has been experimenting with community-scale techniques to reduce the Urban Heat Island Effect in St. Louis. Cooling strategies in place that could be expanded include using

[67] Plumer, B., & Popovich, N. (2017). 95-degree days: how extreme heat could spread across the world. *The New York Times.* Retrieved from: https://www.nytimes.com/interactive/2017/06/22/climate/95-degree-day-maps.html.

reflective rooftop coatings, vegetative roofs, efficient building materials, and adding green spaces.[68,69] These cooling techniques reduce the urban heat island effect, and some will also improve visual aesthetics or habitat. Energy-efficient efforts that reduce demand on the electricity grid, especially during heat waves, and action to reduce heat-trapping emissions from the burning of fossil fuels will serve to decrease the number of extreme hot days.[70,71]
Targeted outreach to vulnerable populations is critical to reaching the socially isolated.[72] Surveillance on weather, hospital, ambulance use, medical examiner reports, electric and water supply and demand, and outreach efforts using multiple channels are critical to determining the effectiveness of interventions within cities.[73] There are a wide variety of heat watch/warning systems (HWWS) that can be incorporated to warn the general public.[74] Some specific interventions of HWWS include: media announcements (radio, television, bulletins or websites), leaflets, telephone help-line, opening of cooling centers, alerting hospital emergency rooms and ambulance services, evacuation of vulnerable persons from their homes to cooling centers, outreach to homeless, and fan distribution.[75]

Extreme Cold

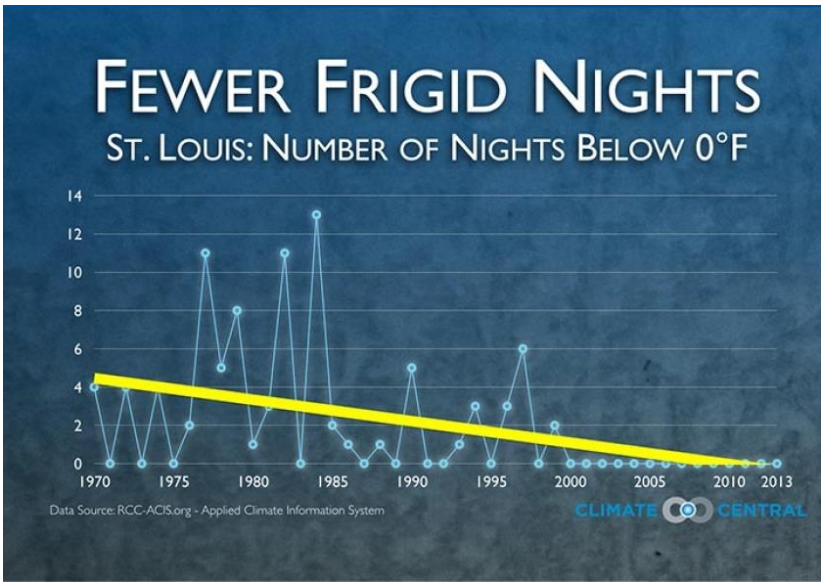
While a large proportion of climate change research has focused on the effects of heat waves and a warming climate, research regarding the public health effects of cold weather highlight the importance for cities to remain prepared. The U.S. National Weather Service defines a cold wave as a rapid fall in temperature within a 24-hour period, requiring substantially increased protection to agriculture, industry, commerce, and social activities.[76] Research reveals a potential for increased cold waves and extreme snow events.[77,78] When cold waves occur, adverse public health effects can linger for periods of days to weeks, making the impact on public health a greater concern and less predictable than those of extended periods of low temperatures.[79]

Approximately 63% of temperature related deaths are due to cold exposure.[80] Aside from mortality risk due to cold weather exposure outside, cooler weather and increased time spent

[68] Plumer & Popovich (2017)
[69] Center for Climate and Energy Solutions (2017)
[70] Center for Climate and Energy Solutions (2017)
[71] Union of Concerned Scientist (2012)
[72] Bernard, S. & McGeehin, M. (2004). Municipal heat wave response plans. *American Journal of Public Health, 94,* 1520-1522.
[73] Bernard & McGeehin (2004)
[74] Kovats, R., & Ebi, K. (2006). Heatwaves and public health in Europe. *European Journal of Public Health, 16,* 592-599.
[75] Kovats & Ebi (2006)
[76] World Meteorological Organisation. (2016). WMO statement on the state of the global climate in 2016. Retrieved from https://public.wmo.int/en/media/press-release/provisional-wmo-statement-status-of-global-climate-2016
[77] Hajat, S., & Gasparrini, A. (2016). The Excess Winter Deaths Measure: Why Its Use Is Misleading for Public Health Understanding of Cold-related Health Impacts. Epidemiology, 27(4), 486–491. https://doi.org/10.1097/EDE.0000000000000479
[78] Ryti, N. R. I., Guo, Y., & Jaakkola, J. J. K. (2015). Global Association of Cold Spells and Adverse Health Effects: A Systematic Review and Meta-Analysis. Environmental Health Perspectives, 124(1). https://doi.org/10.1289/ehp.1408104
[79] Ryti et al. (2015)
[80] Anderson, B. G., & Bell, M. L. (2009). Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology (Cambridge, Mass.), 20(2), 205–213. https://doi.org/10.1097/EDE.0b013e318190ee08

indoors leads to higher risk of infectious disease.[81,82] The cold and dry air can lead to dehydration of the nasal passages and respiratory system, which increases susceptibility to respiratory infections such as influenza and pneumonia, and can trigger chronic pulmonary disease.[83] The associated increase in infectious disease and need for medical care places a stress on public health and medical infrastructures.[84]

Although the trend is for fewer frigid nights, Missouri has experienced a significant increase in annual cold weather deaths in the past two decades; in 1998 there were 8 deaths reported, versus 29 deaths in 2016.[85] The City of Saint Louis has historically had relatively moderate yet variable winters.[86] Record low winter temperatures and record high levels of winter precipitation, however, have been reported in the St. Louis region and surrounding areas as recently as 2014 and 2015, respectively.[87] As recently as 2013, St. Louis experienced five severe winter storms in one season,[88] which is above the usual 1-2 events. St. Louis is thus not an area of particular concern for extended periods of extreme cold temperatures, but rather more volatile weather, such as cold waves and extreme weather events. High levels of mortality due to cold weather is often more severe in temperate regions than in colder regions because the former do not have the built environment to adapt to extreme cold.[89,90]



[81] Anderson & Bell (2009)
[82] Kinney, P. L., Schwartz, J., Pascal, M., Petkova, E., Tertre, A. L., Medina, S., & Vautard, R. (2015). Winter season mortality: will climate warming bring benefits? Environmental Research Letters, 10(6), 064016. https://doi.org/10.1088/1748-9326/10/6/064016
[83] Giesbrecht, G. G. (1995). The respiratory system in a cold environment. Aviation, Space, and Environmental Medicine, 66(9), 890–902.
[84] Barnett, J., & Adger, W. N. (2007). Climate change, human security and violent conflict. Political Geography, 26(6), 639–655. https://doi.org/10.1016/j.polgeo.2007.03.003
[85] National Weather Services. (2016). *Extreme Cold*. Retrieved from https://www.weather.gov/media/lsx/wcm/Winter2008/Extreme_Cold_stats_16.pdf
[86] Mayes Boustead, B. E., Hilberg, S. D., Shulski, M. D., & Hubbard, K. G. (2015). The Accumulated Winter Season Severity Index (AWSSI). Journal of Applied Meteorology and Climatology, 54(8), 1693–1712. https://doi.org/10.1175/JAMC-D-14-0217.1
[87] Southern Regional Climate Center. (2017). Weather Extreme Maps. Retrieved November 16, 2017, from http://extremes2.srcc.lsu.edu/
[88] National Weather Services (2016)
[89] Anderson & Bell (2009)
[90] Seltenrich, N. (2015). Between Extremes: Health Effects of Heat and Cold. Environmental Health Perspectives, 123(11). https://doi.org/10.1289/ehp.123-A275

Additionally, increased precipitation in the winter and spring months is anticipated through 2069 in the region, which will increase the frequency of cold weather events and ice storms.[91,92] Winter temperatures are also projected to rise, which will likely create earlier melting of snow and contribute to flooding and over-saturation of soil, in conjunction with the anticipated increases in precipitation.[93]

Cold waves and winter weather can have broad impacts on daily life. Even minimal amounts of ice can create unsafe conditions on roadways. On December 18, 2016, there were 1,500 car crashes statewide according to the Missouri Highway Patrol, which resulted in 171 injuries and 17 deaths due to one ice event.[94] A heavy reliance on personal motor vehicles due to the dispersed region places the St. Louis region at particular risk of vehicular injury and death during extreme cold weather storms. Plant injury due to freezing cold temperatures and unanticipated frosts can drastically reduce crop production.[95] A reduction in crop yields in Missouri and the Midwest region may threaten the St. Louis food supply and cause increased prices due to sourcing from more distant suppliers.

Extreme Cold Vulnerable Populations

Populations that are particularly vulnerable to cold weather events and susceptible to adverse outcomes include the aging population, low-income individuals, younger populations, and African Americans. Oftentimes, these populations overlap, leaving some individuals at much greater risk than the general population. In addition, people driving during icy conditions become vulnerable to vehicle incidents and accidents.

Individuals with pre-existing health conditions, including metabolic and cardiovascular conditions, are more susceptible to physical changes in the body due to cold weather.[96] Those with chronic respiratory diseases are at increased risk of death during extreme weather conditions. In St. Louis City, 45.1 deaths out of 100,000 persons were attributed to chronic respiratory diseases, more than the United States average of 40.1 deaths out of 100,000 persons, for the years 2011-2015.[97] These subgroups also tend to have increased difficulty accessing health care and public health infrastructure during extreme weather events.[98]

[91] Mayes Boustead et al. (2015)
[92] National Resource Defense Council. (2011). St. Louis, Missouri: Identifying and Becoming More Resilient to Impacts of Climate Change. Retrieved from https://www.nrdc.org/sites/default/files/ClimateWaterFS_StLouisMO.pdf
[93] The National Resource Defense Council (2011)
[94] Giegerich, J. B., Steve. (2016). A year later, scars from winter flooding remain. Retrieved November 20, 2017, from http://www.stltoday.com/news/local/metro/a-year-later-scars-from-winter-flooding-remain/article_1de7adad-5f78-56b1-8bf3-93cd7cfd6599.html
[95] USDA/NASS 2014 State Agriculture Overview for Missouri. (2014). Retrieved November 20, 2017, from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MISSOURI&year=2014
[96] Seltenrich (2015)
[97] J. Barnett & Adger (2007)
[98] J. Barnett & Adger (2007)

The aging population has an increased vulnerability to severe cold weather events.[99] Increased mortality, as well as, rates of respiratory and cardiovascular disease associated with cold spells is stronger in those aged 65 and older.[100] Older citizens also account for almost half of hypothermia-induced deaths in St. Louis.[101]

In addition to age, disability places this group at increased risk for adverse health outcomes due to limited mobility and ability to access health services. These populations are also more susceptible to injury during cold weather storms, as they are more likely to fall on ice, and may not be able to seek help.[102] Individuals with dementia and severe mental illness often have trouble finding their way home, seeking shelter, and finding help, which can lead to increased exposure to cold weather and higher rates of hypothermia.[103]

Lower income individuals and areas with high concentrations of these individuals also have less capacity and resources to adapt to extreme weather.[104] There are significant associations between vulnerability to cold weather and poverty.[105] Housing and infrastructure in these areas are less likely than higher income neighborhoods to be properly retrofitted to handle extreme weather changes, which could lead to freezing of pipes, limiting access to water.[106] Buildings that are not properly fitted for extreme cold and weather events may not be able to operate during these periods, limiting access to lifesaving care and services for lower income populations.[107] Low-income populations may not have the financial ability to afford consistent heating, regular housing, medical treatment, or warm clothing during cold months, which will make them more susceptible to hypothermia, respiratory disease, and cardiac events.

An increased frequency of cold waves and extreme snow events will result in more school closures. This could have lasting consequences, especially among the impoverished who rely on schools as a safe space that provides hot meals (Black, 2015). Also, individual absences induced by cold weather when schools remain open are likely to increase. There is evidence that this type of absence has a greater impact on learning than full school closures do, due to punitive effects and falling behind in school work.[108]

Extreme cold also has economic impacts. Winter weather can disrupt supply chains, which leads to inventory management issues. This impacts not only individual spending, but causes

[99] Hajat & Gasparrini (2016)
[100] Ryti et al. (2015)
[101] Mayes Boustead et al. (2015)
[102] Mayes Boustead et al. (2015)
[103] Mayes Boustead et al. (2015)
[104] Seltenrich (2015)
[105] Anderson & Bell (2009)
[106] Dijkstra, L., Maseland, J., Europäische Kommission, & Centre for Human Settlements (Eds.). (2016). The state of European cities 2016: cities leading the way to a better future. Luxembourg: Publications Office of the European Union.
[107] Dijkstra et al. (2016)
[108] Goodman, J. (2015). In defense of snow days. *EducationNext*, 15(3). Retrieved from https://www.educationnext.org/defense-snow-days/.

companies to purchase less inventory than they otherwise would.[109] The economic impacts will affect low-income workers the most, as they are the most vulnerable to economic volatility. Those who work in restaurants are especially vulnerable to cold-related business closures, as they are often dependent on variable wages. Reduced income could further limit their ability to adapt to cold weather events.

African Americans tend to be more susceptible to cold weather effects in the U.S.[110] In St. Louis City, although African Americans are not isolated to low-income areas, the rate of African American residents in such areas is higher than the state average.[111] Rates of chronic disease - including diabetes, cardiovascular disease, asthma and respiratory illness - are higher amongst this population in St. Louis City.[112]

Extreme Cold Predicted Health Outcomes

Cold weather deaths and adverse outcomes can occur for a variety of reasons. The frequency and severity of ice storms are likely to increase in the coming years, along with winter precipitation and increased temperature variability.[113] Ice storms cause damage to crops, which limits food supply, and compromise infrastructure, which can limit access to public services, such as healthcare and social services. Winter storms can also cause adverse health outcomes, such as injuries sustained due to exposure to icy conditions.

Physical changes to the body during cold temperature make individuals more susceptible to disease and infection. Various threats to health include, but are not limited to, hypothermia, cardiovascular events, and respiratory illness.[114] Cold weather causes the body to lose heat at a faster rate than it can produce, which can lead to hypothermia.[115] Hypothermia occurs when the body temperature drops to less than 94.1°F.[116] It is a concern in extreme cold weather and during cold snaps when temperatures drop to freezing or below freezing. The colder temperatures can lead to cardiovascular events due to narrowing of the arteries and veins as well as increased viscosity of the blood, which can adversely impact the function of other organs.[117] About 10-15 deaths per year have occurred due to hypothermia in St. Louis, though temperature related outcomes are difficult to measure, due to the many other risk factors for disease and thus may be understated.[118]

[109] Matthews, C. (2015). *The cost of winter storms: Should we believe economists?* Fortune. Retrieved November 18, 2017, from http://fortune.com/2015/02/12/the-cost-of-winter-storms-should-we-believe-economists/
[110] Anderson & Bell (2009)
[111] Barnes-Jewish Hospital (2016)
[112] Barnes-Jewish Hospital (2016)
[113] Mayes Boustead et al. (2015)
[114] Zhang, X., Zhang, S., Wang, C., Wang, B., & Guo, P. (2014). Effects of Moderate Strength Cold Air Exposure on Blood Pressure and Biochemical Indicators among Cardiovascular and Cerebrovascular Patients. International Journal of Environmental Research and Public Health, 11(3), 2472–2487. https://doi.org/10.3390/ijerph110302472
[115] Zhang et al. (2014)
[116] Zhang et al. (2014)
[117] Zhang et al. (2014)
[118] Seltenrich (2015)

Extreme Cold Mitigation and Adaptation Strategies

Better insulation of homes is associated with better health outcomes during extreme cold events.[119] Updating buildings to better prepare for snow loads and extreme cold temperatures can help to reduce burden during extreme cold weather events. Other advisable strategies include offering educational programs for those identified as more vulnerable to extreme weather events, and protecting power lines and transportation infrastructure. Increasing permeable areas is a mitigation technique to help address stormwater and lessen stress on roads.[120]

Another proven mitigation strategy is to improve buildings' energy efficiency. A recent study found simple techniques such as solar shading, window glazing, air tightness, and insulation can reduce energy consumption by an average of 33%.[121]

Adaptation strategies include distribution of warm clothing to low income populations or subsidies for heat bills to help reduce the burden by moderating the exposure.[122] In St. Louis City, the Cold Weather Rule helps protect vulnerable populations during extreme cold events.[123] The Cold Weather Rule prohibits heat services from being disconnected in extreme cold conditions including days that drop below 32°F.[124] This rule allows for flexible payment schedules and provides assistance to those who face challenges paying for utility costs.

The City's Department of Health extreme cold efforts are similar to those offered in times of extreme heat. When temperatures are forecasted to be 15°F or below, or when a Wind Chill Advisory/Warning is issued by the National Weather Service, an active surveillance for cold-related illnesses, enhanced educational messaging, distribution of press releases, and the VoiceShot campaign are initiated. Letters are sent to the managers of senior living centers to provide information and resources about extreme weather and its health effects. If there are cold-related illnesses, there is a follow-up investigation by Environmental Health Officers. Utility assistance is provided to qualified city residents by Heat Up St. Louis and DOH.

Tornadoes And Strong Winds

Tornadoes are the most concentrated, powerful, and destructive forms of weather that result in considerable damage, including human casualties. A tornado is a vortex of rapidly rotating air that extends from the base of a thunderstorm and makes contact with the ground.[125] Tornadoes are formed when warm, humid air collides with cold, dry air, causing imbalances in the

[119] Seltenrich (2015)
[120] The National Resource Defense Council (2011)
[121] El-Darwish, I., & Gomaa, M. (2017). Retrofitting strategy for building envelopes to achieve energy efficiency. Alexandria Engineering Journal.
[122] Seltenrich (2015)
[123] Missouri Public Service Commission. (n.d.) *Cold weather rule*. Retrieved from https://psc.mo.gov/Forms/Cold%20Weather%20Rule
[124] Missouri Public Service Commission. (n.d.)
[125] East-West Gateway Council of Governments. (2015). St. Louis Regional Hazard Mitigation Plan: Update for 2015-20.

atmosphere that form rotating columns of air.[126] Depending on wind intensity, tornadoes could be categorized as weak, strong, or violent.[127]

The majority of tornadoes in the United States (77%) are considered weak, ranking as only an F-0 or F-1 on the 0-5 Fujita scale of tornado intensity. Though few storms reach the intensity of the F-5 classification, these storms with winds over 200 miles per hour are responsible for 70% of tornado fatalities. On average, 57 people are killed each year by tornadoes in the United States.[128] Tornadoes disproportionately affect those living in mobile homes, where 44% of tornado fatalities occur, despite their much smaller share of the housing stock.[129]

Climate change is predicted to impact the frequency and intensity of tornadoes. While tornadoes are now most common between March and August, climate models show that peak tornado season will occur earlier in the year.[130] The United States has already seen an increase in the number of tornado clusters per year since official tornado reporting began.[131] Tornadoes have a broad range of negative effects. While the direct health impacts of tornadoes are generally related to falling trees, flying debris, and collapsed buildings, tornadoes can also damage public infrastructure, blocking access to emergency aid and severing power lines.[132]

Missouri is located within "Tornado Alley," an area of the Midwestern and Southern United States where tornadoes most frequently occur.[133] Tornado Alley includes parts of Texas, Oklahoma, Kansas, Nebraska, Missouri, Iowa, Arkansas, North Dakota, and South Dakota.[134] The City of St. Louis is at a high risk for tornado impact. In the half century between 1950 to 2006, there were three recorded tornadoes within the City of St. Louis.[135] In contrast, during the decade between 2007 and 2017, there were four tornadoes recorded within city limits.[136] This increase over the last ten years shows that St. Louis must be prepared for a great increase in the frequency and intensity of tornado activity.

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[126] Fujita, T. T. (1973). Proposed mechanism of tornado formation from rotating thunderstorms. *Eighth Conference on Severe Local Storms*, 15-17.

[127] Snodgrass, E. (Producer). (2013, June 26). *Introduction to Tornadoes*. Retrieved from https://www.youtube.com/watch?v=5z1wLRYQPp8

[128] Snodgrass, E. (Producer). (2013). *Tornado fatalities in the U.S.* Retrieved from https://www.youtube.com/watch?v=y3NLeBGMPgw.

[129] Snodgrass (2013b)

[130] Thompson, A. (24 Sep 2014). Peak of tornado season shifting earlier in tornado alley. *Climate Central.* Retrieved from http://www.climatecentral.org/news/tornado-season-shifting-earlier-in-tornado-alley-18073.

[131] Brooks, H.E., Carbin, G.W., Marsh, P.T. (17 Oct 2014). Increased variability of tornado occurrence in the United States. *Science*, 436(6207). Retrieved from http://science.sciencemag.org/content/346/6207/349.

[132] Tornado outbreak of 2011 in Alabama, Georgia, Mississippi, Tennessee, and Missouri: Mitigation assessment team report. (n.d.)

[133] National Centers for Environmental Centers for Environmental Information (n.d.) *Tornado Alley*. National Oceanic and Atmospheric Administration. Retrieved from https://www.ncdc.noaa.gov/climate-information/extreme-events/us-tornado-climatology/tornado-alley

[134] Kuhne, Michael. *What is Tornado Alley?*. Accuweather. Retrieved from https://www.accuweather.com/en/weather-news/what-is-tornado-alley/70001107.

[135] National Centers for Environmental Information. (2017). *Storm Events Database*. Retrieved from https://www.ncdc.noaa.gov/stormevents/.

[136] National Centers for Environmental Information. (2017)

Tornadoes and Strong Winds Vulnerable Populations

The St. Louis Regional Hazard Mitigation Plan (2015) evaluated the St. Louis Region's vulnerability to tornadoes in three ways: the likelihood of future tornado impacts, average annual property loss ratio (building exposure/average annual historic losses), and population change and housing unit change. Overall, the vulnerability to tornadoes is moderate in City of St. Louis and is high in St. Louis County.[137]

People who live in mobile homes are particularly vulnerable to tornadoes. Mobile homes often have poor construction, making it difficult for them to stay intact when tornadoes hit. As a result, people who live in mobile homes have to rely on public tornado shelters for protection. If they are not prepared and cannot find a shelter, it is more likely that they will be injured during the outbreak. Previous studies have shown that the 45% of fatalities during a tornado occurred in mobile homes, and 26% in traditional site-built houses.[138] According to the 2009-2015 American Community Survey, 0.3% of the total residential structures in the City of St. Louis are mobile homes.[139] Although this percentage is relatively low compared to nearby regions, the potential severity of destruction to mobile homes is quite high.

The elderly and people with chronic illnesses or disabilities may not be able to react immediately to a tornado siren due to a lack of mobility or ability; they may require additional help during the evacuation process. It is hard for people with limited mobility to go out because of the debris on the road. People with chronic illnesses and disabilities are less likely to have a three-week supply of prescription drugs after a major disaster.[140]

Low-income individuals and families are also vulnerable to tornadoes. They are often homeless or live in lower cost homes, which are less able to withstand severe winds and tornados.[141] Furthermore, they may not have enough money to prepare resources such as food and drinks during a tornado outbreak. Low-income residents are less likely to purchase property insurance[142] and will not be eligible to receive financial reimbursement for their property loss after the tornado outbreaks.

In addition to physical vulnerability, various social factors, including population density, poverty, education, the elderly and disabled population ratio, and housing structures, all

[137] East-West Gateway Council of Governments. (2015)
[138] American Meteorological Society. (2008). NIU researchers say nighttime tornadoes are worst nightmare. *Northern Illinois University News*. Retrieved from https://www.ametsoc.org/ams/index.cfm/about-ams/news/news-releases/niu-researchers-say-nighttime-tornadoes-are-worst-nightmare/.
[139] United States Census Bureau (2017). *American Community Survey 5-Year Data (2009-2015)*.
[140] Insurance Institute for Business & Home Safety. (2017). *Vulnerable Populations*. Retrieved from https://disastersafety.org/ibhs-public-policy/vulnerable-populations/.
[141] Insurance Institute for Business & Home Safety. (2017).
[142] Fothergill, A., & Peek, L. A. (2004). Poverty and disasters in the United States: A review of recent sociological findings. *Natural Hazards*, *32*(1), 89–110.

contribute to increased vulnerability to tornado hazard.[143,144,145,146] Various human activities, such as aircraft operations and outdoor recreation, might also place people at higher risk to convective winds.[147]

Tornadoes and Strong Winds Predicted Health Outcomes

The health impacts of tornadoes are classified into two main groups of direct and indirect effects. The direct health impacts are related to the injuries and mortalities caused by severe windstorms. Casualties associated with windstorms have mostly resulted from direct blow injuries, or injuries incurred from collapsed parts of buildings or from road traffic accidents.[148] Other direct factors - such as fallen trees and flying debris - can cause injuries, including penetrating or blunt traumas. The indirect health impacts are secondary effects on human health caused by destruction of public infrastructures because of severe windstorms.[149] The post impact health effects could include limited access to medical care due to destruction of public infrastructures. The other main secondary impact results from a loss of electricity. Due to power outages, individuals might be forced to use other alternative sources of energy that might increase respiratory asphyxiation and carbon-monoxide poisonings.[150] In addition, windstorms pose a significant risk of death and morbidity due to electrocution.[151]

Tornadoes and Strong Winds Mitigation and Adaptation Strategies

The St. Louis region has already developed several adaptation plans targeted on reducing the negative impact of severe winds and tornado outbreaks. In terms of the preparation, several strategies have been implemented to make the public is aware of the severe weather coming, and educate citizens what to do when the tornado outbreaks come. In the City, the St. Louis Emergency Management Agency (CEMA) operates 60 outdoor tornado sirens that are activated when a tornado warning is issued for the City of St. Louis. CEMA also provides warnings from the National Weather Service through social media a mass notifications system. The City participates in the Missouri Statewide Tornado Drill each Spring, so that citizens can practice what they will do when there is a tornado in the area.[152] The National Oceanic Atmospheric

[143] Brooks, H. E., & Doswell, C. A. (2002). Deaths in the 3 May 1999 Oklahoma City Tornado from a Historical Perspective. *Weather and Forecasting*, *17*(3), 354–361.
[144] Boruff, B. J., Easoz, J. A., Jones, S. D., Landry, H. R., Mitchem, J. D., & Cutter, S. L. (2003). Tornado hazards in the United States. *Climate Research*, *24*(2), 103-117.
[145] Merrell, D., Simmons, K. M., & Sutter, D. (2005). The determinants of tornado casualties and the benefits of tornado shelters. *Land Economics*, *81*(1), 87–99.
[146] Hall S. G., & Ashley W. S. (2008). Effects of urban sprawl on the vulnerability to a significant tornado impact in Northeastern Illinois. *Natural Hazards Review*, *9*(4), 209–219.
[147] East-West Gateway Council of Governments (2015)
[148] Goldman, A., Eggen, B., Golding, B., & Murray, V. (2014). The health impacts of windstorms: A systematic literature review. *Public health*, *128*(1), 3-28.
[149] Goldman et al. (2014)
[150] "Avoid carbon monoxide poisoning during power outage". (2015, October 18). *The Times and Democrat*. Retrieved from http://thetandd.com/lifestyles/avoid-carbon-monoxide-poisoning-during-power-outage/article_5d3e316c-27b3-55a3-9f19-7925b0df53a3.html
[151] Goldman et al. (2014)
[152] City of St. Louis. (2017). *Outdoor Warning Sirens.* Retrieved from https://www.stlouis-mo.gov/government/departments/public-safety/emergency-management/OWS.cfm.

Administration (NOAA) weather radio broadcasts daily weather and alerts for all emergencies, including tornado warnings. It is available at retail stores throughout the City and the price ranges from $20 to $100.[153]

Additional efforts and strategies can be done to raise public awareness on the severity of tornado and educate the public how to protect themselves during the tornado outbreaks. The Federal Emergency Management Agency (FEMA) has guidelines on improving public awareness of severe winds by advancing such activities as informing local residents of public shelter locations and evacuation routes and educating homeowners on the benefits of installing wind mitigation techniques on their properties. CEMA provides the FEMA brochures and presents preparedness to the population of the city.

For people with limited mobility and chronic illnesses, it is vital to ensure that they receive proper help during the tornado evacuation. Each person in need could be assigned with a physically-abled person nearby, such as a family member at the same address or a neighbor. When a tornado alert sounds, the designated helper would assist the person in need to move to a safe area. The FEMA handbook suggests that buildings include wind mitigation,[154] like roof foundation anchoring, that reinforces the wall of the housing to the roof to resist the outer structure from heavy severe winds,[155] and window and door covering protect the openings from severe winds and flying debris.[156]

Drought

Climate change plays a crucial role in drought, as rising temperatures indicate future drought occurrence. Drought has distinct characteristics compared to natural disasters like earthquakes, floods, and wildfires. While most natural disasters occur in a short period of time with sudden consequences, the onset, impact, and recovery period for drought varies. Drought is categorized as a period of abnormally dry conditions with low rainfall and depends on the "typical" climate and weather patterns in a particular location.[157]

Climate change can also worsen the intensity of drought.[158] As more greenhouse gases release, air temperature increases, causing more evaporation from bodies of water, land, and soil in order

[153] City of St. Louis. (2017). *NOAA Weather Radio*. Retrieved from https://www.stlouis-mo.gov/government/departments/public-safety/emergency-management/NOAAradio.cfm.
[154] Federal Emergency Management Agency (2013). *Mitigating ideas: A resource for reducing risk to natural hazards*. Retrieved from https://www.fema.gov/media-library-data/20130726-1904-25045-0186/fema_mitigation_ideas_final508.pdf.
[155] Florida's Foundation. (n.d.). *Make mitigation happen*. Retrieved from http://www.floridadisaster.org/Mitigation/Documents/Wind%20Mitigation%20Booklet% 20.pdf.
[156] Florida's Foundation (n.d.)
[157] IPCC, 2012: Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation Field, C.B.et al.. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). pp. 555-564.
[158] Trenberth, Kevin E. et al. (2014). Global Warming and Changes in Drought. *Nature Climate Change*. Retrieved from https://www.nature.com/articles/nclimate2067

to reduce the heat. Continuous hot weather also causes excessive evaporation and leaves the soil dry.[159,160] Climate change will increase the atmospheric temperature and duration of heat waves, thereby leading to more frequent occurrences of drought. The temperature increase brings substantial changes to the water cycle and causes instances of rainfall and drought to become more abrupt.[161] As a result of atmospheric temperature, water temperature and water evaporation also increase.[162]

River shipping plays an important role in industry in the City of St. Louis and is likely to be severely impacted by drought.[163] As shown during the severe drought of 2012, high evaporation and low summer rainfall caused low river flows in the Mississippi River, resulting in additional costs and navigation problems of almost $300 million.[164] Drought is a complicated issue involving social, economic, political environments and institutions.

Drought intensity in the Midwest, including Missouri, was relatively low due to above average rainfall between 1958 and 2007.[165] However, in mid-July 2012, the U.S. Department of Agriculture declared the entire state of Missouri in a state of emergency due to drought, as the temperature neared 100°F. At the time, 93% of Missouri suffered from extreme drought, 99% of pastures had poor and very poor qualities, and 84% of the state suffered from a water shortage.[166]

During the summer of 2017, St. Louis received less than half of its average rainfall.[167] Abnormally dry conditions can cause premature plant wilt and crop failure, especially during harvest season in the Fall. Furthermore, soil moisture takes a year or two to recover from drought, but may take longer if rainfall does not come afterwards. Deeper soil also takes longer to recover, and would benefit from the help of continued and stable rainfall.[168] The St. Louis area experienced drought approximately twice in the past twenty years, in 2005 and 2012.[169] Drought

[159] National Aeronautics and Space Administration. (n.d.). Physical process that cause drought. *Earth Observatory.* Retrieved from https://earthobservatory.nasa.gov/Features/NAmerDrought/NAmer_drought_2.php.
[160] Boxall, B. (2015). Rising temperatures are amplifying drought effects, study finds. *The LA Times.* Retrieved from http://www.latimes.com/science/la-me-0305-drought-watch-20150305-story.html.
[161] Wang, Guiling. (2017). The Peak Structure and Future Changes of the Relationships between Extreme Precipitation and Temperature. *Nature Climate Change*. Retrieved from https://www.nature.com/articles/nclimate3239
[162] Thomas R. K., Jerry M. M., Thomas C. P. (2009). Global climate change impacts in the United States. *Cambridge University Press*.
[163] Lloyd, Tim. (2012). Drought Starting to Impact Shipping Along the Mississippi River. *St. Louis Public Radio*. Retrieved from http://news.stlpublicradio.org/post/drought-starting-impact-shipping-along-mississippi-river#stream/0
[164] Environmental Protection Agency. (2016). *Drought response and recovery: A basic guide for water utilities*. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/epa_drought_response_and_recovery_guide.pdf.
[165] Thomas et al. (2009)
[166] National Centers for Environmental Information. (2012, September 17). *Drought-August 2012.* Retrieved from https://www.ncdc.noaa.gov/sotc/drought/201208.
[167] Heffernan, E. & Colburn, A. (2017, July 17). Oppressive heat expected to grip St. Louis metro most of this week. *St. Louis Post-Dispatch*. Retrieved from http://www.stltoday.com/news/local/metro/oppressive-heat-expected-to-grip-st-louis-metro-most-of/article_a7d8d013-b810-5487-8492-31cb5aff05ef.html.
[168] Gustin, G. (2013, March 12). Historic drought is over in the St. Louis area — for now. *St. Louis Post-Dispatch*. Retrieved from http://www.stltoday.com/business/local/historic-drought-is-over-in-the-st-louis-area-for/article_3c8b86f7-4559-5324-b17f-5444d577f271.html.
[169] East-West Gateway Council of Governments. (2015)

in St. Louis is projected to happen more frequently in the future as the climate changes and extreme weather becomes more severe.

Drought Vulnerable Populations

Drought is an emergency that may threaten the livelihoods and basic living conditions of people. Droughts directly influence those whose livelihoods depend on water, such as those who work in agriculture, landscape gardening, and river transportation. Drought reduces the amount of water available for farmland irrigation, resulting in reduced crop yields. Local farmers who have congregated farms or less crop variation may face higher risks during droughts.

Racial segregation and underinvestment in low-income communities exacerbate threats on both physical and mental health brought on by droughts to people of color and people in poverty.[170] Based on the demographic patterns of the City of St. Louis, it may be that those who will be the most vulnerable to increased frequency and severity of drought are African Americans living below the poverty line. Poor housing quality and infrastructure plus financial instability place impoverished people of color in a more dangerous situation when hazards like drought occur.

Drought Predicted Health Outcomes

The impacts of drought on human health are broad, ranging from immediate compromised water quality to long-term diminished living conditions related to energy, air quality, and hygiene.[171] Although many of the effects of drought are indirect, various social, environmental, and health factors are severely complicated during periods of drought. Considerations should be made for malnutrition, water-related diseases, and increasing risk of wildfires in the event of a severe drought in the region.[172]

Drought Mitigation and Adaptation Strategies

Given the intensity of past droughts in the region, investments could be made in surveillance of drought frequency, intensity, soil moisture, temperature, precipitation, climate modeling, variability, and patterns in order to improve predictive capabilities of the city to be prepared for future drought events.[173] Additional study of drought, drought-resistant crops, and other adaptive actions would help prepare the City of St. Louis in times of future droughts.

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[170] Ortiz, W. (2015, August 19). *Lessons on climate change and poverty from the California drought*. *Center for American Progress.* Retrieved from https://www.americanprogress.org/issues/poverty/reports/2015/08/19/119446/lessons-on-climate-change-and-poverty-from-the-california-drought/

[171] Centers for Disease Control and Prevention. (2018). Drought and Your Health. Retrieved from https://www.cdc.gov/features/drought/index.html.

[172] Stanke, Carla et al. (2013). Health Effects of Drought: a Systematic Review of the Evidence. Nature Climate Change. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3682759/

[173] Posey, J. (2016, December 5). *City of St. Louis compact of mayors climate hazards reporting technical documentation*. East-West Gateway Council of Governments. Retrieved from https://www.stlouis-mo.gov/government/departments/mayor/initiatives/sustainability/air.cfm.

Aging water infrastructure results in water loss during treatment, pumping, and distribution throughout the city. The City of St. Louis Water Division has been monitoring pipes at both the Chain of Rocks Plant and Howard Bend Treatment facilities – facilities that provide over 380 million gallons of water per day to the City.[174] There are also several utility-based water efficiency measures. There are numerous opportunities to install high efficiency, low-flow fixtures and appliances in building structures of all types.

Potential adaptive strategies that can be implemented along the river include decreasing suburban development along the west side of the city, near the riverfront, promoting sustainable land use changes and diversified local food production with the introduction of water-tolerant crops in agricultural lands around the confluence of the rivers, digging a channel east of the river to relieve pressure on the Mississippi and provide new port opportunities east of St. Louis, and implementation of safety systems, including reservoirs, to store water and operate based on water levels and flow conditions.[175] Neighborhood-based awareness campaigns to support environmental literacy around water conservation and encouraging behavioral change related to water usage may be effective.[176]

Many vulnerable and low-resource communities in St. Louis are disproportionately impacted by food deserts and rely on community gardens for fresh fruits and vegetables.[177] When drought occurs, these communities will need to adapt to the high cost of water, which has the potential to exacerbate food insecurity. There are a variety of strategies to address this,[178] such as using recycled water for the irrigation of yards and gardens, composting plant material, and incorporating drought-tolerant vegetables, native plants, and low-water grass varieties into community gardens.

Potential mitigation and adaptation strategies to prepare for the impact of drought offer both benefits and challenges. Many initiatives focus on preservation and enrichment of the natural environment while also being visually-appealing – promoting enhancement of public mental health and environmental literacy. Behavioral changes can help citizens save money on utility bills and reduce the amount of water entering the wastewater system each day. However, many steps that need to be taken come at a cost and require major resource investment in order for implementation and infrastructure change to be possible.

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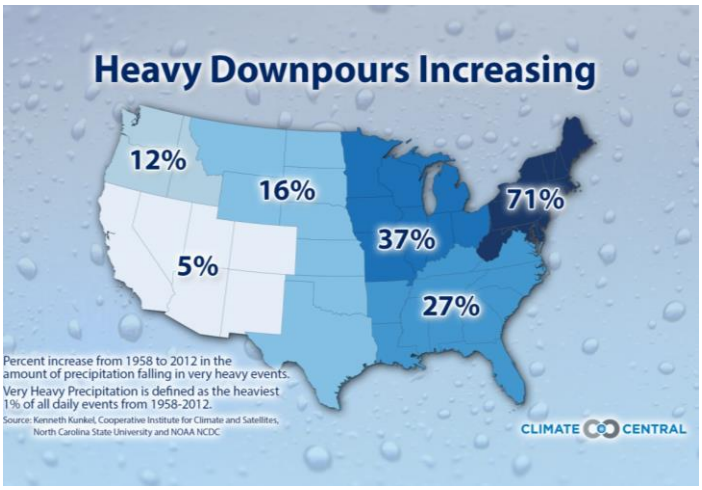
[174] City of St. Louis Water Division. (n.d.). Water treatment. Retrieved from http://www.stlwater.com/treatment.php.
[175] Bentley C. (2013, May 24). A Dutch approach to flood and drought management takes root in St. Louis. *Next City*. Retrieved from https://nextcity.org/daily/entry/a-dutch-approach-to-flood-and-drought-management-takes-root-in-st.-louis.
[176] City of St. Louis Water Division. (n.d.). Conservation. Retrieved from http://www.stlwater.com/conservation.php.
[177] St. Louis Food Policy Coalition, Missouri Coalition for the Environment, Gateway Greening, & Lincoln University. (n.d.). *Want to start an urban garden? A guide to urban agriculture and farming in St. Louis*. Retrieved from http://moenvironment.org/files/STLUrbanGardenToolkitFINAL.pdf.
[178] Aurora Water. (n.d.). Water conservation tips for community gardens in drought or anytime. Retrieved from https://www.auroragov.org/UserFiles/Servers/Server_1881137/File/Residents/Neighborhood%20Liaisons/Community%20Gardens/015636.pdf.

Flooding And Rain Storms



Global warming is strongly associated with future flood risk.[179] In a study which analyzed and estimated the frequency and magnitude of river floods and their impacts under future scenarios with a 4°C increase in global temperature, the world will confront a 500% increase in the risk of flooding which would affect more than 70% of the global population and GDP.[180]

Climate change is likely to result in more instances of rain and flooding in St. Louis.[181,182,183] Due to global warming, more intense and severe forms of precipitation, like rain and snow storms are occurring more frequently. As flooding and rain storms become more frequent and more intense, there are damaging impacts on many aspects of human life, the economy, and the environment.

According to Climate Central, Missouri is among the top ten states with the biggest increases in heavy downpours, with an increase of 36 percent compared to 1950-1959. Flooding and rain storms exert more direct influences on water quality and stormwater management for most cities. Flooding and stormwater can overload combined sewage systems and water treatment facilities. Areas with poor stormwater management and more frequent heavy rainfalls are more likely to see degradation in infrastructure, which would lead to even more destructive damage threatening property and safety. Heavy rainfall and floods also increases river contamination. The contaminated runoff and warmer waters mobilize pollutants stored in sediment and contaminates fish. Warmer water temperatures mean the water may contain greater nutrient

Top 10 States With Biggest Increases in Heavy Downpours

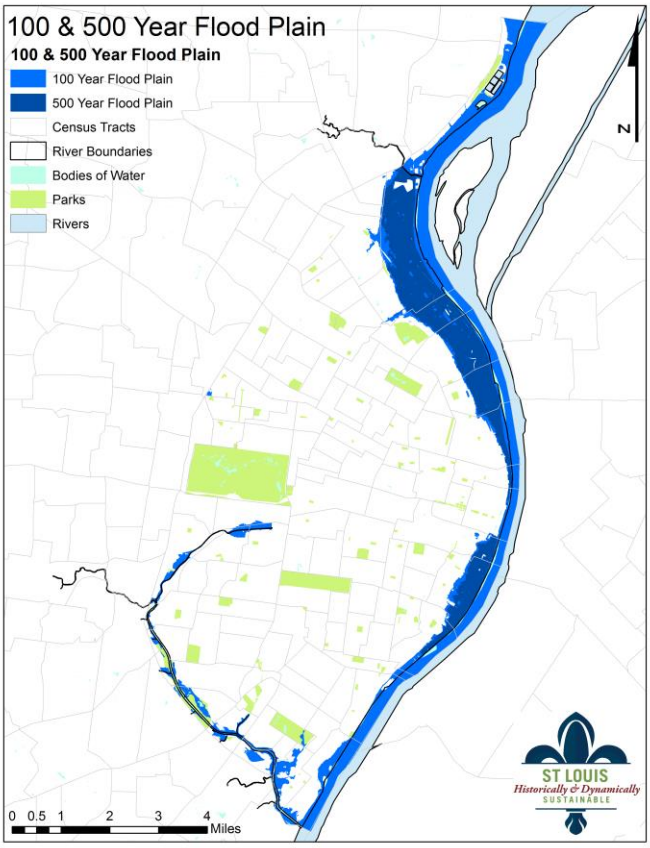
Rank	State	Percent Increase*
1	Rhode Island	104
2	Maine	61
3	Wyoming	58
4	New Hampshire	56
5	Connecticut	43
6	Missouri	36
7	Vermont	35
7	Alabama	35
9	New York	34
10	Iowa	28

* between indexed number of heavy downpours from 2005-2014 compared to 1950-1959

CLIMATE CENTRAL

[179] Alfieri, L., Bisselink, B., Dottori, F., Naumann, G., Roo, A. D., Salamon, P., . . . Feyen, L. (2017). Global projections of river flood risk in a warmer world. *Earths Future*, 5(2), 171-182. doi:10.1002/2016ef000485
[180] Alfieri et al (2017)
[181] What climate change means for Missouri. (2016). *Environmental Protection Agency*. Retrieved from https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-mo.pdf
[182] Hazards: Flooding. (2017). *St. Louis-MO.gov*. Retrieved from https://www.stlouis-mo.gov/government/departments/public-safety/emergency-management/Threats-Flooding.cfm
[183] Barker, J. (2015). St. Louis's 2050 forecast calls for rain and rising rivers. *St. Louis Post Dispatch*. Retrieved from http://www.stltoday.com/business/local/st-louis-s-forecast-calls-for-rain-and-rising-rivers/article_83154fee-8a0e-5dfc-8598-89abc50b46a6.html

loading, which increases the occurrence of toxic algal blooms and oxygen depleted dead zones.[184]



The American Midwest has experienced an increase of 10% in average annual precipitation over the last 50 years.[185,186] In fact, St. Louis just had its wettest year on record in 2015 when the region received over 61 inches of rainfall in a year.[187] It is also predicted that rainfall in the region will continue to increase to be 4 to 5.1% higher than now by the year 2050.[188]

More heavy rain is likely to mean more flooding. As a city located near the confluence of the two largest rivers in North America, St. Louis has always had to cope with the possibility of floods. With precipitation increases, flooding events will be exacerbated. Increasing precipitation will not only make floods more common but researchers are also predicting that future floods could reach higher elevations.[189]

The St. Louis Region is vulnerable to floods. For example, the Meramec River, which runs near the southwestern border of St. Louis County, overflowed its banks in record-setting floods twice in a span of 16 months.[190] The first of those massive floods was in late December of 2015 and the flood waters rose so high that they covered two interstates, I-44 and I-55, forcing both to shut down. The second happened in early May of 2017 and it also forced I-44 to shut down.[191] Highways are a primary means of transportation into and out of St. Louis; without those

[184] Hayhoe K., Weubbles D.J. (2008) Climate Change and Chicago: Projections and Potential Impacts. Report for the City of Chicago.
[185] St. Louis, Missouri: Identifying and becoming more resilient to impacts of climate change. (2011). *Natural Resources Defense Council*. Retrieved from https://www.nrdc.org/sites/default/files/ClimateWaterFS_StLouisMO.pdf
[186] What climate change means (2016)
[187] Climatological data for St. Louis, Columbia, and Quincy. (2016). *National Weather Service*. Retrieved from https://www.weather.gov/lsx/cli_archive
[188] Barker (2015)
[189] Barker (2015)
[190] Gray, B. (2017). Two catastrophic floods in less than two years wasn't just a case of bad luck. *St. Louis Post Dispatch*. Retrieved from http://www.stltoday.com/news/local/two-catastrophic-floods-in-less-than-two-years-wasn-t/article_33e07bfa-16dd-575b-8e18-9a6e2a2eebd0.html
[191] Gray B. (2017)

highways, access to St. Louis from the south and southwest was blocked, preventing people from going to work and making it much harder for goods and services to go into or out of St. Louis.

Costs associated with floods include cleaning up the damage. Flooding along the Mississippi river has resulted in over $50 billion in natural disaster impacts since 2011.[192] There have been four Missouri flood events in the last decade, with damage costing over a billion dollars for each. There is also the human health risk posed by floods. Floods encourage the spread of disease, increase the likelihood of injury, damage health infrastructure, and the struggle of having to deal with the damage or homelessness after a flood exacts a mental health toll.[193]

Flooding and Rain Storm Vulnerable Populations

The elderly or those with a disability are more vulnerable to injury or death during a flood, because they may have a harder time evacuating a flooded area. Other groups, such as people living in poverty, are vulnerable to the effects of floods because they have a difficult time recovering from the financial damage a flood causes.[194]

Flooding and Rain Storm Predicted Health Outcomes

Human health impacts of floods include deaths, injuries, and mental health repercussions from disasters. Most impacts from floods are attributed to the rapid rise of floodwater. The higher the water depth and the more rapid of the flow, the greater the lethality of a flood. However, the adverse human health consequences of flooding and storms are intricate, and difficult to attribute to the flood event itself. The damage of water quality and water management from flood and rain storms would lead to an increase of waterborne diseases. When untreated water is discharged into surface water, the risk for waterborne disease outbreaks also increases.[195,196,197] Untreated standing floodwater can cause an increase of mosquito-borne diseases like Zika and West Nile. According to CDC, after Hurricane Katrina, cases of West Nile dramatically increased in areas directly impacted by Hurricane floodwater.

Floodwater often contains chemical hazards and can hide sharp objects made of metal or glass. Sharp objects in flowing floodwater can directly cause injury or even death. Exposure to chemical hazards in the floodwater can also increase risk for skin rashes and burning, ear, nose and throat problems and conjunctivitis.[198]

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[192] Gray B. (2017)

[193] Du, W., Fitzgerald, G., Clark, M., & Hou, X. (2010). Health impacts of floods. *Prehospital and Disaster Medicine, 25(3)*: 265-72. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20586021

[194] Bolstad, E. (2017). Trump country is flooding, and climate ideas are shifting. *E & E News*. Retrieved from https://www.eenews.net/stories/1060054536

[195] Hayhoe K. & Weubbles D.J (2008)

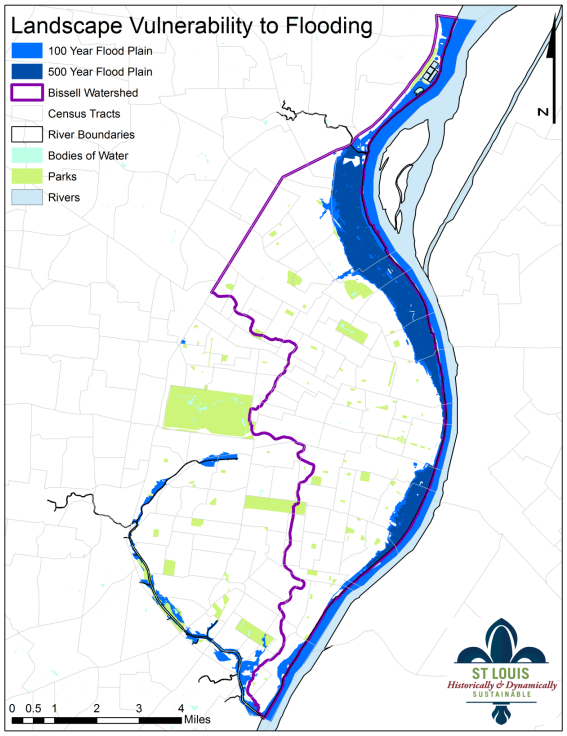
[196] Thomas R. et al (2009)

[197] Walsh, J., et al. (2014): Chapter 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, T. C. Richmond, and G. W. Yohe, Eds., *U.S. Global Change Research Program*, 19-67. doi:10.7930/J0KW5CXT.

[198] CDC, Flooding and communicable diseases fact sheet. (n.d.). Retrieved from http://www.who.int/hac/techguidance/ems/flood_cds/en/index1.html

Another health concern with flooding is mental health issues. Natural disasters like flooding and storms can exacerbate existing mental health problems and cause new ones. Flooding is significantly associated with increased rates of depression, anxiety, and stress.[199,200,201,202] Most mental issues are due to damage to the properties, loss of familial possessions and stress due to home rebuilding and displacement in the aftermath of a flood.[203] A study analyzed effects of displacement on the association between flooding and mental health in the UK and found that people who were displaced from their homes were significantly more likely to have depression, anxiety, and post-traumatic stress disorder than people who were not displaced.[204] The increased risk of depression was significant even after adjustment for severity of flooding.[205]

Flooding and Rain Storm Mitigation and Adaptation Strategies

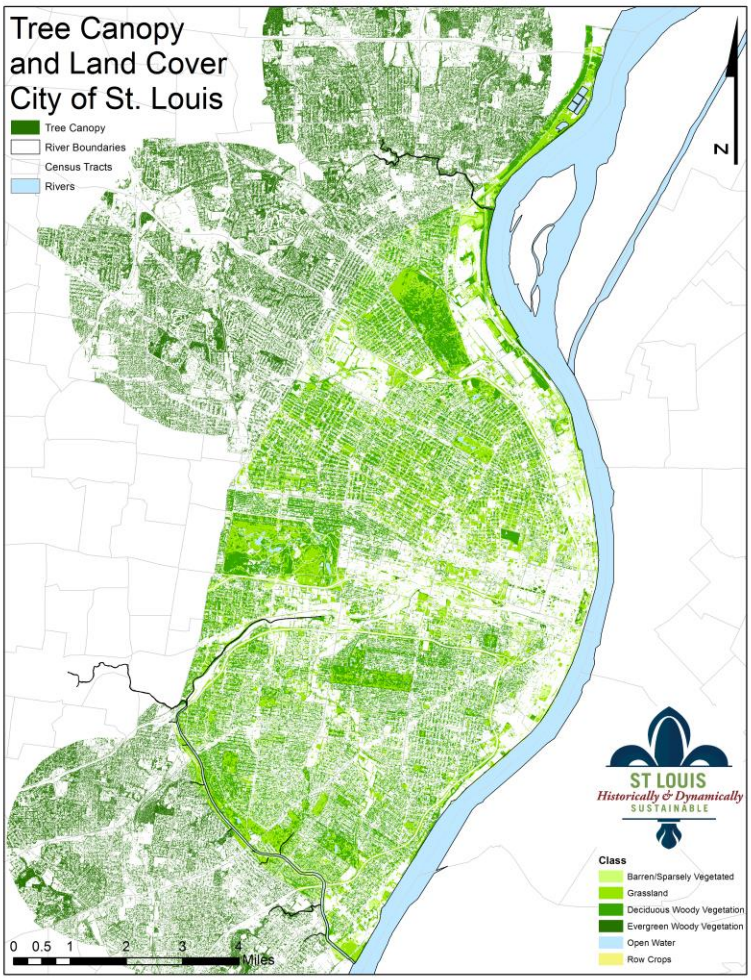


The City coordinates with the US Army Corps of Engineers and FEMA to revisit flood maps, to stay current on the flood threats in the City. CEMA encourages the purchase of home or renter insurance, and the National Flood Insurance Program. Continued and expanded regional collaboration can be a significant help. Weather is not the only cause of flood events; levees often constrict the river and development in floodplains.[206,207] The Mississippi river has only surpassed a 40-foot flood stage ten times since 1785 but three of those ten times have occurred in the last 5 years; 2013, 2016, and 2017.[208] Some are critical of levee systems that have been "overbuilt" beyond the recommended height. In some instances, different municipalities build levees to protect their

[199] Hajat S, et al. The human health consequences of flooding in Europe and the implications for public health: a review of the evidence. *Applied Environmental Science and Public Health*, 2003, 1(1):13-21. (http://www.openmindjournals.com/EnvSci1-1-Hajat.pdf. Accessed 10 December 2004)
[200] Du W., et al. (2010)
[201] Alderman K, Turner LR, Tong S. Floods and human health: a systematic review. Environ Int. 2012;47:37–47.
[202] Fernandez A, Black J, Jones M. Flooding and mental health: a systematic mapping review. PLoS One. 2015;10:e0119929.
[203] Hajat S et al, (2003)
[204] Munro, A., et al., (2017). Effect of evacuation and displacement on the association between flooding and mental health outcomes: a cross-sectional analysis of UK survey data. *The Lancet. Planetary Health*, 1(4), e134–e141. http://doi.org/10.1016/S2542-5196(17)30047-5
[205] Munro A, et al., (2017)
[206] Bolstad, E. (2017). Irony: Levees could make river flooding worse. *E & E News*. Retrieved from https://www.scientificamerican.com/article/irony-levees-could-make-river-flooding-worse/
[207] Gray, B. (2017). Overbuilt levees upstream reignite skepticism about ones near St. Louis. *St. Louis Post Dispatch*. Retrieved from http://www.stltoday.com/news/local/overbuilt-levees-upstream-reignite-skepticism-about-ones-near-st-louis/article_8b060bb3-21cf-50df-b7f6-becac7089b3f.html
[208] Gray, B. (2017b)

section of the river without considering the consequences downstream.[209] Effective communication and organization when it comes to designing levee systems for the region could help mitigate the damage from floods.

An important mitigation strategy is to discourage development in floodplains.[210,211] This technique has the obvious benefit of putting fewer people at risk of having their home flooded. It also has the benefit of better controlling rain water and rain swollen rivers because floodplains and wetlands act as natural absorbers of excess rain, but when they are built on and covered with pavement, all of the water gets channeled into sewers and streams which ultimately drain into rivers.



Channeled water entering the river increases the risk of flooding, but can be avoided by using green infrastructure and by preventing development in floodplains.[212]

Green infrastructure is the term for utilizing landscape and natural features as a stormwater best management technique. There are several existing St. Louis green infrastructure programs – such as Project Clear of the Metropolitan St. Louis Sewer District – designed to specifically address the combined sewer overflow problems.[213]

Community outreach and engagement is another valuable strategy for improved resilience. By involving, informing, and maintaining open communication

[209] Bolstad (2017b)
[210] Barker, J. (2015). St. Louis region doing little to prepare for climate change. *St. Louis Post Dispatch*. Retrieved from http://www.stltoday.com/business/local/st-louis-region-doing-little-to-prepare-for-climate-change/article_f8c8a787-0b9d-5749-8a30-77f2ef12a4fa.html
[211] Dhakal, K. P., & Chevalier, L. R. (2016). Urban stormwater governance: The need for paradigm shift. Environmental Management, 57(5), 1112-1124. doi:10.1007/s00267-016-0667-5
[212] Dhakal & Chevalier (2016)
[213] Landscapes with purpose: Green infrastructure and St. Louis sewers. (2016). *Missouri Coalition for the Environment*. Retrieved from http://moenvironment.org/11-clean-water-program/275-rain-gardens

channels with stakeholders, it is anticipated that the City can become more resilient to the anticipated social, health, and structural damage associated with flooding.

SUMMARY: ADDRESSING CLIMATE VULNERABILITY IN ST. LOUIS

Climate change presents significant challenges and severe consequences to the people of the City of St. Louis. While climate change impacts are already being felt, measures can be taken to anticipate, prepare, and lessen the impact, especially on vulnerable populations. When combined with physical risk indicators like proximity to floodplains, socioeconomic factors can help point the City to the populations most in need of support and critical preparedness infrastructure.

Intentional measures involving multiple stakeholders throughout the city will help equitably combat the projected impacts of climate change. Intervention plans should be tailored for local needs, and require coordination between the local health agencies, social services, voluntary agencies, education ministries, universities, professional bodies, trade associations, and the National Weather Service.[214] Engaging a wide range of stakeholders is crucial to having the desired impact.[215] In St. Louis, these stakeholders may include the St. Louis City Emergency Management Agency, City of St. Louis Department of Health, City of St. Louis Department of Human services, City of St. Louis Planning and Urban Design Agency, Washington University in St. Louis, Saint Louis University, Ameren, United Way of Greater St. Louis, The American Red Cross, St. Louis Area Foodbank, nonprofits, elected officials, the media, and others.

The City's Climate Protection targets of reducing greenhouse gas emissions will go a long way towards addressing both the root of climate change patterns and the associated health risks. High levels of greenhouse gases are associated with higher temperatures and more erratic weather patterns, so initiatives to reduce vehicular emissions and building energy consumption help immensely with mitigating the harmful effects of climate change. Reduction in greenhouse gas emissions will also have widespread benefits regarding air quality in St. Louis.

Supporting community well-being is not limited to target reductions of greenhouse gas emissions, as actions can include opportunities to improve health, safety, and economic prosperity of citizens. Increasing the resiliency of St. Louis communities through initiatives like adding more greenspace and permeable areas, creating jobs programs, and providing increased access to healthcare will help people respond and adapt to extreme weather events.

[214] World Health Organization Europe. (2007). Improving public health responses to extreme weather/heat-waves- EuroHEAT, meeting report.
[215] WHO Europe (2013)