
Used with permission/LWG


Sandor Zaldivar


Used with permission/LWG

Climate Change Vulnerability in Louisville, Kentucky

March 2020

OFFICE OF
ADVANCED PLANNING
AND SUSTAINABILITY
A Division of Develop Louisville


Used with permission/LWG

Louisville Slugger/ StevenW.

This report prepared by the Geos Institute

For more info. contact
Dr. Marni Koopman, Climate Change Scientist
marni@geosinstitute.org
541-482-4453 x303

GEOS INSTITUTE

More information about this project and a pdf of this report can be downloaded at:
http://www.climatewise.org/projects

Bridge/ Censusdata

TABLE OF CONTENTS

Park/ LuAnn Snawder

EXECUTIVE SUMMARY

Like cities all around the U.S. and the world, Louisville, Kentucky is experiencing changes in the frequency and magnitude of extreme weather related to climate change. These impacts are expected to worsen for many decades. If emissions are reduced quickly and aggressively, many of the most extreme impacts can still be avoided.

This vulnerability assessment describes how Louisville's residents and resources are already being impacted by climate change, as well as how they will be impacted in the future. Preparing for both near term and long-term impacts will create a more resilient community. Overall resilience throughout the community can only be achieved

Climate Trends Snapshot – *Louisville, KY*

HISTORICAL TRENDS (change 1961-1990)

- ↑ Temperature +2.2° F
- ↑ Minimum temp. +5.5° F
- ↑ Precipitation +9%
- ↓ Snowfall –25%
- ↓ –14 days/yr. below freezing
- ↑ +12 days/yr. above 90° F
- ↑ 3 wettest years on record all within the last decade

**Assuming continued higher emissions. By reducing emissions substantially, many of the late-century trends can be reduced.*

MID-CENTURY TRENDS 2040–2069 projections

Averages:

- ↑ Temperature +5-8° F
- ↑ Summer temp. +4-11° F
- ↑↓ Precip. –9% to +16%
- ↑↓ Summer precip. –17% to +11%
- ↑↓ Winter precip. –10% to +31%

Extremes:

- ↑ Extreme max. temp. +3-14° F
- ↑ Extreme min. temp. +6-10° F
- ↑ Extreme heat and ozone formation
- ↓ –35-57 days/yr. below freezing
- ↑ +6% to +88% drought stress

LATE-CENTURY TRENDS 2070–2099 projections*

Averages:

- ↑ Temperature +7-12° F
- ↑ Summer temp. +7-17° F
- ↑↓ Precip. –2% to +21%
- ↑↓ Summer precip. –9% to +14%
- ↑↓ Winter precip. –12% to +48%

Extremes:

- ↑ Extreme max. temp. +5-20° F
- ↑ Extreme min. temp. +9-15° F
- ↑ Extreme heat and ozone formation
- ↓ –53-75 days/yr. below freezing
- ↑ +3% to +124% drought stress
- ↑ 100-year floods every 25-30 yrs.

through cuts in greenhouse gas emissions (mitigation) AND implementation of measures to protect people and resources (adaptation).

Climate change impacts are not equally distributed. The populations that are most vulnerable include lower income residents, people who work or live outdoors, the elderly, and those with existing illnesses. Flood-prone neighborhoods, and those with aging infrastructure, and those with less tree canopy cover were also identified as particularly vulnerable.

This vulnerability assessment was conducted to inform the development of robust adaptation strategies that work across all sectors, including health, emergency preparedness, business, nature, infrastructure, neighborhoods, and culture. Of particular focus is how to build strategies that not only combat climate impacts, but also address historical inequities and stressors to create a more equitable and vibrant city for all.

Louisville's Climate Change Vulnerabilities

Louisville's climate change vulnerabilities were assessed for each sector, but many are cross-cutting issues that affect diverse populations and resources. A holistic approach to building solutions that reduce impacts and create a more resilient and equitable community will be vital.

Health and Emergency Services

High vulnerability:	▪ Exposure to hazardous materials ▪ Electrical outages
Medium-high vulnerability:	▪ Increase in heat waves and heat-related illnesses and mortality ▪ Air quality declines ▪ Spread of pests and disease ▪ Overburdening of health care industry ▪ Overburdening of emergency response

Infrastructure

High vulnerability:	▪ Collapse and damage to aging infrastructure, especially sewer systems ▪ Damage to homes and businesses from floods, wind, and other extreme events ▪ Increasing cost of energy ▪ Potential energy outages with higher demand
Medium-high vulnerability:	▪ Less availability of affordable housing ▪ Increasing transportation disruptions and congestion

Business and the Economy

High vulnerability:	▪ Increasing cost of energy affecting businesses
Medium-high vulnerability:	▪ Increasing transportation disruptions and congestion
Medium vulnerability:	▪ Business costs associated with distribution, insurance, energy, and disaster losses

Natural Systems

High vulnerability:	▪ Spread of pests and disease affecting fish, wildlife, trees, gardens, and agriculture ▪ Loss of green spaces, especially affecting lower income neighborhoods ▪ Loss of native ecosystems and species, also affecting outdoor recreational opportunities
Medium-high vulnerability:	▪ Degradation of aquatic systems, leading to loss of important services such as flood abatement and filtration ▪ Tree canopy loss from disease and extreme events, exacerbating heat impacts ▪ Degradation and loss of nature leading to less interest in conservation

Neighborhood Values and Culture

High vulnerability:	▪ Exacerbated tensions and inequities ▪ Increasing cost of energy affecting lower income residents
Medium-high vulnerability:	▪ Increasing violence and crime with heat ▪ Less availability of affordable housing ▪ Increasing transportation disruptions and congestion ▪ Impacts to food availability and cost ▪ Quality of life declines
Medium vulnerability:	▪ Lack of sustainability lifestyles and options ▪ Need for strong local climate leadership

Louisville/ flickrized

INTRODUCTION

Louisville, Kentucky has experienced changes in temperature, precipitation, and extreme weather events over the last few decades. As changes in the local and regional climate continue, we can expect increasing severity and frequency of extreme heat, larger storms with more precipitation, periods of drought, fewer freezing nights, and less snow than was seen historically. These changes are expected to become increasingly severe over the course of the century. Many of the most severe impacts, however, can be avoided by reducing greenhouse gas emissions quickly and aggressively.

Cities and counties throughout the nation and world are working to reduce greenhouse gas emissions in efforts to prevent warming more than 1.5°C (2.7° F). This level of warming has been recognized by the international scientific community as an important threshold, below which we can avoid catastrophic and runaway climate change.

In addition to reducing greenhouse gases, however, communities need to respond to the changes already being felt and plan for those still to come. Because greenhouse gases can remain in the atmosphere for decades (some as long as a century) after release, we will continue to warm and experience impacts for many decades, even if we reduce emissions today.

Fountain/ LuAnn Snawder

While greenhouse gases are measured globally, climate change impacts are locally specific. Each community feels climate change in a different way, depending on historic conditions and locally-specific climatic conditions and patterns of change. As these local impacts and changes worsen over time, we will need to prepare and protect our most vulnerable resources and populations from the impacts.

Determining which resources and populations are most vulnerable to ongoing and future impacts of climate change is the first step in developing effective strategies and sound solutions.

While this Climate Change Vulnerability Assessment presents sector-specific vulnerabilities to the community, it is important to also look at Louisville in a holistic way. Many of the vulnerabilities identified here cross diverse sectors and affect people of all different walks of life.

Vulnerability vs Resilience

Vulnerability – the extent to which people and resources are likely to experience harm due to impacts related to climate change. Vulnerability is a function of both the impacts to people and/or resources, as well as existing capacity to adapt and/or respond to those impacts.

Resilience – the ability of people and resources to respond positively to, cope with, recover from, and adapt to disruptions and impacts. Resilience comes from resources, policy, culture, historical factors, and other sources.

Social resilience – the social characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to disruptions and impacts. Examples would include church networks able to mobilize during emergencies, schools that double as community centers and shelters, and immigrant community groups that provide a safe space for information and support.

METHODS

Vulnerabilities to the five major systems of the Louisville Metro region were assessed during a day-long working session involving local experts from diverse sectors of the community. The five systems included the built environment (buildings, roads, energy, etc.), social (health, social services, emergency response, etc.), cultural (youth, immigrant communities, Kentucky Derby, etc.), economic (industry, business, and tourism), and the natural environment (urban trees and parks, fish and wildlife)

Local experts and residents were asked to consider scientific information on climate change, and in response identify impacts that are already underway and those that are expected to affect people and resources in the future. Current and future impacts were ranked by how serious they are to the Louisville community, as well as the timeframe and existing adaptive capacity. Any positive changes associated with a changing climate were also noted.

Specific impacts already occurring or expected to occur in the future were identified by participants. For each identified impact to the community (including people, resources, and culture), the following information was collected:

Exposure – The specific climate trend or projection that is already causing or is expected to cause the impact

Timeframe – When the impact is expected to occur in Louisville

Near-term = current to 2030s

Mid-term = 2040s to 2060s

Long-term = 2070s to 2090s and beyond

Certainty – (High, Medium, or Low) How certain we are that the impact will occur, given our current knowledge of climate change projections and our understanding of the impact itself

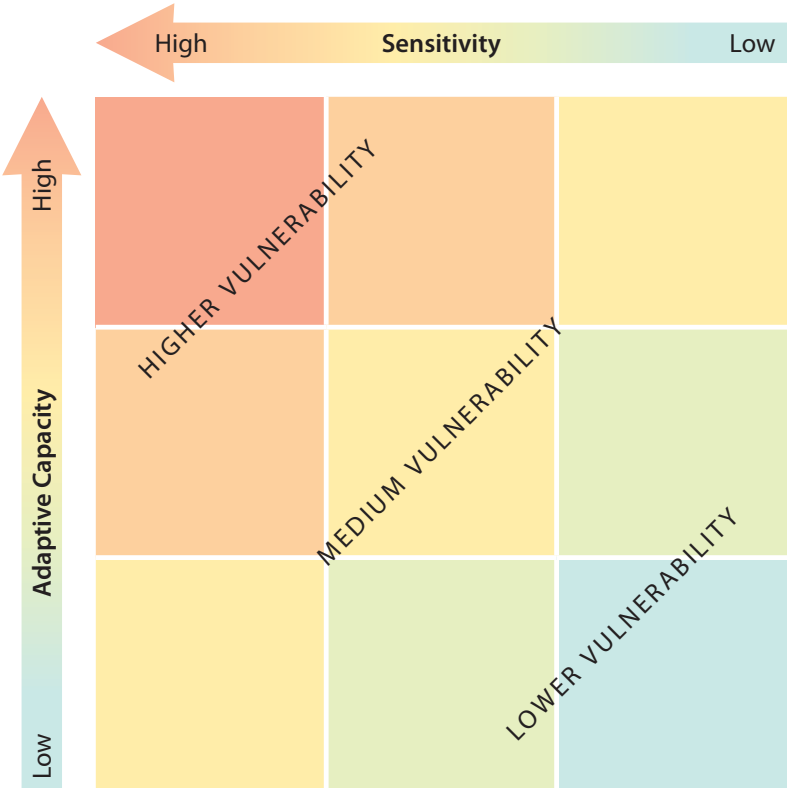
Sensitivity – (High, Medium, or Low) Given our understanding of the specific sector for each given impact, how much of a response or how great of an impact is expected (e.g. how disruptive it is, how serious the consequences are, and how much overall change is expected)

Adaptive Capacity – (High, Medium, or Low) Whether there are already existing resources, programs, or policies in place to protect people or to respond to the changes with little disruption

Focal Populations – The specific neighborhood, population, area, or category of resources or people that are expected to be especially affected by the impact, as well as any that are expected to be buffered due to special circumstances

Other Stressors – Additional and ongoing stressors to the population or resource to be affected

Secondary Vulnerabilities – Other potential responses to or effects related to climate change that are likely to affect the impact under consideration



Once specific impacts to the community were assessed, they were ranked based on their relative level of vulnerability. Most impacts identified in this vulnerability assessment are important to address, but action on some is considered more urgent than on others, which is reflected in the ranking. Additional populations and resources may be vulnerable as well.

Photo: Marni Koopman

Participants at the vulnerability assessment session


Fountain/ Mike Worley

CLIMATE TRENDS AND IMPACTS

Climate change is already occurring around the globe. In Louisville, temperatures have increased by 2.2° F, on average (since 1961-1990). The number of days above 90° F has increased by 12 days per year. Overall precipitation has increased 9%, but due to warmer temperatures, snowfall has declined by 25%.[1] The three wettest years on record have all occurred in the last decade.

Climate change projections from a suite of global models[2] indicate that warming of 4-7° F by mid-century and 7-12° F by late-century is expected in Louisville, assuming continued greenhouse gas emissions trends. If greenhouse gas emissions are aggressively reduced at the global scale, temperature rise could level off at 5-8° F by late-century.

Continued warming at higher levels is expected to result in many changes to the local climate. These include much hotter extreme temperatures, greater and more frequent drought, larger storms, and many fewer days below freezing. Heat waves are expected to worsen substantially as temperatures continue to rise.

Climate Trends Snapshot – *Louisville, KY*

HISTORICAL TRENDS (change 1961-1990)

- ↑ Temperature +2.2° F
- ↑ Minimum temp. +5.5° F
- ↑ Precipitation +9%
- ↓ Snowfall –25%
- ↓ –14 days/yr. below freezing
- ↑ +12 days/yr. above 90° F
- ↑ 3 wettest years on record all within the last decade

**Assuming continued higher emissions. By reducing emissions substantially, many of the late-century trends can be reduced.*

MID-CENTURY TRENDS 2040–2069 projections

Averages:

- ↑ Temperature +5-8° F
- ↑ Summer temp. +4-11° F
- ↑↓ Precip. –9% to +16%
- ↑↓ Summer precip. –17% to +11%
- ↑↓ Winter precip. –10% to +31%

Extremes:

- ↑ Extreme max. temp. +3-14° F
- ↑ Extreme min. temp. +6-10° F
- ↑ Extreme heat and ozone formation
- ↓ –35-57 days/yr. below freezing
- ↑ +6% to +88% drought stress

LATE-CENTURY TRENDS 2070–2099 projections*

Averages:

- ↑ Temperature +7-12° F
- ↑ Summer temp. +7-17° F
- ↑↓ Precip. –2% to +21%
- ↑↓ Summer precip. –9% to +14%
- ↑↓ Winter precip. –12% to +48%

Extremes:

- ↑ Extreme max. temp. +5-20° F
- ↑ Extreme min. temp. +9-15° F
- ↑ Extreme heat and ozone formation
- ↓ –53-75 days/yr. below freezing
- ↑ +3% to +124% drought stress
- ↑ 100-year floods every 25-30 yrs.

CLIMATE HAZARDS

The 2016 Louisville Metro Hazard Mitigation Plan[3] (HMP) is a thorough assessment of hazards threatening the jurisdictional area of Louisville Metro (covering the combined areas of Louisville and Jefferson County). In 2019, a Climate Change Addendum outlining how climate change is expected to affect (exacerbate or lessen) existing hazards to the people, resources, and infrastructure of the Metro area was developed in conjunction with this vulnerability assessment.

Out of 13 hazards described in the HMP, four (extreme heat, flooding, drought, and severe storms) are highly likely to worsen in the near term and over the next 30 years (previous page). Six hazards (tornadoes, hailstorms, karst/sinkholes, landslides, wildfire, and dam/levee failure) are likely to worsen, but are associated with longer timeframes and/or more uncertainty. Earthquake hazard was determined to be unaffected by climate change. The relationship between hazardous materials and climate change was uncertain. Only one hazard (severe winter storm) is likely to lessen with warming associated with climate change, but still remain a hazard into the foreseeable future. Finally, one hazard (air quality) was added to the "already occurring" list due to the link between increasing temperatures and the formation of ground-level ozone.

Climate Hazards

The 13 hazards identified in the 2016 Louisville Metro Hazard Mitigation Plan (HMP) and their potential response to climate change. One additional climate change hazard was identified (air quality). Hazards are ranked by the level of response to climate change, timeframe, and likelihood. The overall risk of each hazard to Louisville Metro is available in the HMP. Additional data and projections will need to be incorporated into the next iteration of the HMP to provide a more complete assessment of future risk.

Highly Likely / Already Occurring

Extreme Heat – Increase in frequency and severity with warmer daytime and nighttime temperatures

Severe Winter Storm – Decrease in frequency and severity with warmer temperatures but still a risk

Flood – Increase in frequency and severity with increasing precipitation and larger storms

Air Quality* – Increasing ozone formation due to temperature rise

Highly Likely / Occurring Mid-Century

Drought – Increase in frequency and severity

Severe Storm – Increase in frequency and severity

Likely / Occurring Mid-Century (unless otherwise noted)

Tornado – Increase in clustering, or the number per occurrence (already occurring)

Hail Storm – Increasing size of hail documented, trend unclear (timeframe uncertain)

Karst/Sinkhole – Increasing risk from precipitation and larger storms

Landslide – Increasing risk from precipitation and larger storms

Wildfire – Increase in wildfire risk with warming and drought

Dam/Levee Failure – Increasing risk from precipitation and larger storms

Unknown or Unlikely

Hazardous Materials – Increasing risk from larger storms, flooding, and heat likely, but timeframe unknown

Earthquake – Local risk associated with climate change unknown and unlikely

* Air quality was not included in the original 2016 Louisville Metro Hazard Mitigation Plan, but was added to the addendum due to high risk associated with climate change.

Extreme Heat – Heat is the number one cause of mortality among all weather-related disasters. Both the frequency and duration of heat waves have increased in Louisville. The number of days above 90° F has increased steadily in Louisville.[4] Warm nights (above 75°F) are especially dangerous, and could increase from just a few per year to between 50-75 per year if emissions are not reduced.[5]

As temperatures rise 5-8°F by mid-century and 7-12°F by late century[6], heat stress and heat stroke will become increasingly common. Researchers have calculated that each additional degree of warming is associated with an increase in heat related deaths during heat waves.

Climate Risk = Already increasing; highly likely to continue to increase

Severe Winter Storm – Extreme snow, blizzards, and ice storms are all considered severe winter storms. Extreme snowfall has declined more than 20%[7] and is expected to continue to become less common, as are blizzards. Snowfall is projected to decline 77-91% by the 2080s. Conditions amenable to ice storms could occur 63-75 fewer days/yr.[8]

Climate Risk = Risk is highly likely to decline in coming decades

Flood – Floods are caused by excessive precipitation. Precipitation has been increasing in Louisville. Regionally, the amount of precipitation in large storms has increased by 27%, and is expected to continue to increase.[9]

Flood frequency modeling indicates that, with continued higher greenhouse gas emissions, the very largest 1% of flood events, which occurred about once every 100 years during the historical period (1950-2000), could become 2.5 to 3.5 times more frequent by mid-century (occurring every 25-30 years instead of every 100 years). If emissions are reduced, however, these 100-year floods can be limited, saving $4 billion per year in flood damages at the national level.[10]

Climate Risk = Risk already increasing and highly likely to worsen

Bridge/laserbub_Drew

Air Quality – Higher temperatures associated with climate change lead to the formation of ground-level ozone.[11] As Louisville works to improve air quality and reduce greenhouse gas emissions, the effectiveness of such efforts will be impaired as temperatures rise. Air quality impacts to human health include respiratory and heart disease and are associated with significant medical costs and mortality.

Climate Risk = Already occurring and highly likely to worsen over time

Drought – Even with increasing rainfall, drought stress can increase across a region due to higher temperatures, evaporation and evapotranspiration (water use by plants). Models show the Louisville region will become increasingly drought stressed due to higher temperatures. Drought stress is expected to increase by 47% by the 2050s and 63% by the 2080s.[12]

Climate Risk = Likely to increase in frequency and intensity

Severe Storm – Severe thunderstorms are a major source of catastrophic loss. Increasing convective potential energy and strong winds associated with climate change indicate that severe thunderstorms are likely to increase.[13] In the Southeast specifically, the most violent and severe storms could become more common.

Climate Risk = Highly likely to increase in frequency and intensity

Tornado – Tornadoes are spawned by thunderstorms and produced when cool air overrides a layer of warm air, forcing the warm air to rise rapidly. Scientists are unclear about how atmospheric instability and wind shear will respond to climate change. Tornadoes have been increasing in Kentucky over the last decade. Also, clusters of tornadoes are becoming more common.

Climate Risk = Already occurring and risk is likely to continue to worsen

Hailstorm – Hailstorms are also related to thunderstorms, and occur when storms have strong updrafts that bring water into the cold region of a cloud. Warm and moist conditions promote these updrafts. Hail has been increasing in size in some parts of the U.S. Not a lot of study has been done, however, on the likely response of hailstorms to climate change. Stronger thunderstorms are likely to cause increased hail size.

Climate Risk = Hail sizes increasing, but future risk unknown

Karst/Sinkhole – 55% of Kentucky sits upon karst-prone substrate, which can collapse or cause sinkholes and lead to dam leakage or radon. Due to the link between climate change and larger storms, climate change could worsen karst hazards. One study found that for every global temperature increase of 0.2° F, sinkholes increased by 1-3%.[14] Precipitation is expected to increase by 9% in Louisville. 100-year storms are expected to occur every 20-30 years.[15] Both are likely to contribute to increasing karst and sinkhole hazards.

Climate Risk = Increased risk is likely but uncertain

Disaster Assistance/US Coast Guard

Landslide – Landslides are activated by storms, fires, and human modification of the land. Precipitation has been increasing in recent years — the 3 highest years on record all occurred within the last decade.[16] Regionally, the amount of precipitation in large storms has increased by 27%, and is expected to continue to increase.[17] The likelihood of landslides may increase.

Climate Risk = Increased risk likely. More information needed

Wildfire – Wildfires can include grass, scrub, or forest fires, and most are human-caused. Weather, climate, topography, wind, drought, surface fuels, and fire behavior all affect wildfire risk. Most attention is focused on surface fuels, but climate and weather have a large role. Studies indicated significant variation across the Southeast in likely future changes in wildfire frequency and intensity.[18]

Climate Risk = Risk likely to worsen. More information needed

Dam/levee Failure – Extreme precipitation can lead to dam and levee failure. Precipitation has been increasing in recent years — the three highest years on record all occurred within the last decade.[19] The number of large storms increased by 58% in the Southeast since 1901.[20] The likelihood of dam and levee failure may increase with continued high greenhouse gas emissions.

Climate Risk = Increased risk likely. More information needed

Hazardous Materials – Releases of hazardous materials can be deadly, and can occur in conjunction with natural disasters and human-caused events. Severe heat can cause train derailments and spills.[21] Extreme temperatures are expected to increase by 8.3° F by the 2050s and 12.6° F by the 2080s.[22] Also, 100-year floods are expected to become 2.5-3.5 times more common over the next 60 years.[23]

Climate Risk = Risk likely to worsen, but more information needed

Train/lircmatt92

Louisville/Sandor Zaldivar

VULNERABILITIES

HEALTH AND EMERGENCY SERVICES

Louisville Metro is not immune to global health risks from climate change. Existing health threats are expected to be exacerbated with climate change, while new and emerging threats also take hold. Extreme events are already occurring more frequently, and emergency services will be increasingly taxed as these events become even more common.

Heat-Related Illnesses and Mortality – One of the biggest health threats facing Louisville residents is the increasing incidence, severity, and longevity of heat waves. The number of days per year above 90° F has increased by almost 2 weeks since the 1961-90 historical period. The year with the highest number of severe heat days was 2010, with 85 days above 90° F (the historical average is 30 days per year). Projections indicate that summers in Louisville will be 5° to 11° F warmer by the middle of this century and 7° to 17° F warmer towards the end of the century. Studies project

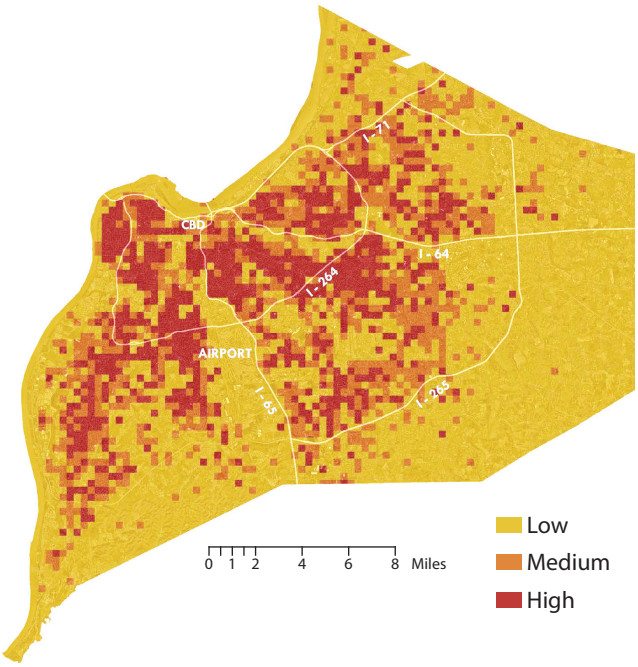


Figure 1. Distribution of heat-related deaths during May-Sept. 2012. Map from the Louisville Urban Heat Management Study 2016, conducted by the Urban Climate Lab of Georgia Institute of Technology.

"Climate change is among the greatest health risks of the 21st Century. Rising temperatures and more extreme weather events cost lives directly, increase transmission and spread of infectious diseases, and undermine the environmental detriments of health, including clean air and water, and sufficient food." —*World Health Organization*[27]

between 50-100 days on average above 100° F throughout Kentucky by the middle of this century (2036-2065).[24] If emissions are not reduced, extreme maximum temperatures could increase by as much as 20° F[25] and a new "super heatwave" could emerge, threatening human life.[26]

Even more important than daytime highs are nighttime low temperatures. When nighttime temperatures do not cool below 75° F, peoples' bodies are unable to find relief from the heat, which can lead to increased mortality. People who already suffer from chronic disease are particularly vulnerable.

Many of Louisville's residents are already vulnerable to heat waves (Fig. 1), and with increasing temperatures, more people will become vulnerable. People in areas with less tree canopy coverage and less access to air conditioning are highly vulnerable. Lower income neighborhoods and communities of color often have fewer trees, putting these communities at higher risk. Elderly people are very sensitive to heat, as are infants and people with existing health conditions.

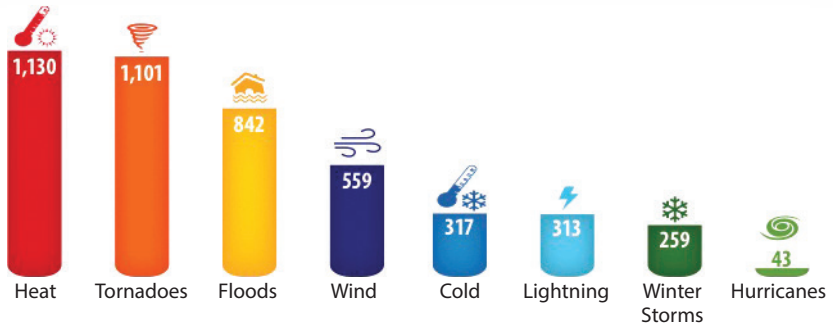
Ground-Level Ozone – Higher temperatures can also increase the formation of ground-level ozone, a key component of smog. Ground level ozone causes many health impacts, including increased incidence of asthma and increased incidence of premature death from heart and lung disease. While the EPA and Louisville Metro Air Pollution Control District are working to reduce ozone, progress could be stymied by higher temperatures that lead to even more ozone formation over time.

Heat-related Fatalities

Extreme heat causes more deaths than any other climate-related hazard. In addition, thousands of people experience heat-related illnesses each year. The most serious heat-related illnesses include heat exhaustion and heat stroke. Heat can also exacerbate existing health conditions. Extended periods of heat can deter people from outdoor activities, reducing overall health and wellness.

Cities are often up to 10° hotter than the surrounding rural areas, due to heat-absorbing materials, heat-producing activities, and declining tree and vegetation cover.

Total number of fatalities in the U.S., by hazard, from 2006-2015 (from NOAA National Weather Service 2016).



Disaster response/ U.S. Air National Guard

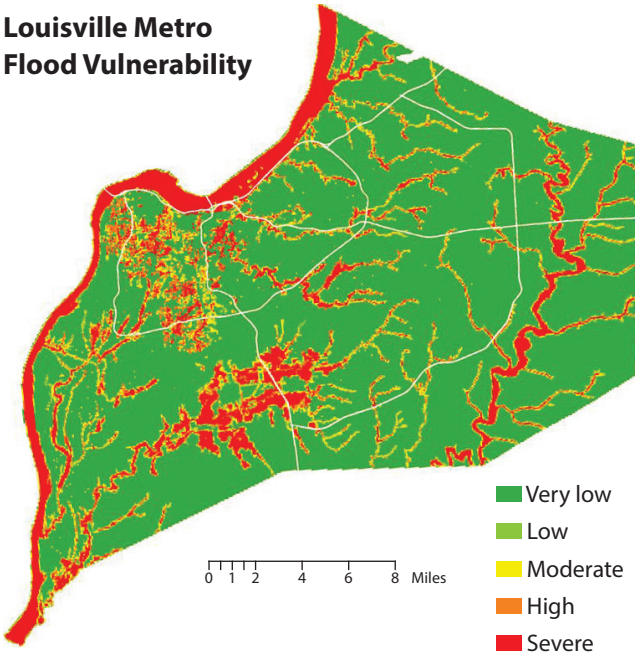


Figure 2. Distribution of flood vulnerability in the Louisville Metro region. Map from the 2016 Louisville Metro Hazard Mitigation Plan.

Flooding and Hazardous Materials Exposure

– Severe thunderstorms are a major source of catastrophic loss. Increasing convective potential energy and strong winds associated with climate change indicate that severe thunderstorms are likely to increase. Severe storms can cause energy outages and flooding. During energy outages, some of the most vulnerable populations include medically-sensitive populations and elders, because the loss of power can lead to exposure to extreme heat or cold, as well as failure of vital medical equipment.

Flooding affects many neighborhoods throughout Louisville Metro (Fig. 2). Flood waters often become contaminated with hazardous materials that can impact human health and contaminate drinking water. People most vulnerable to flood impacts include those living in high flood risk areas, and especially those with limited mobility, such as elders, homeless, and people without vehicles. Some vulnerable areas include South and West Louisville, and areas near Prospect/ Ohio River adjacent, Beargrass Creek, and Mill Creek neighborhoods.

Used with permission/LMG

Pests and Disease – In the last 13 years, the number of disease cases from mosquito, tick, and flea bites has tripled in the U.S.[28] Many disease-causing organisms and insect pests experience natural control during winter months, when freezing temperatures reduce populations. The number of days below freezing is now two weeks shorter, on average, then it was historically.

Model projections indicate 46 fewer days below freezing by the 2050s, and 64 fewer by the 2080s.[29] With warmer and wetter winters, diseases such as mosquito-borne West Nile Virus, dengue, and Zika, as well as tick-borne Lyme disease, and Ehrlichiosis, could become more prevalent. Insect pests and disease organisms that reinvade Kentucky each year from the southern regions are likely to begin to overwinter in the region. Many vector-borne diseases seriously

affect domestic animals and livestock, so climate change could impact food security as well as human health.[30] Water-borne diseases, such as *cryptosporidium*, are strongly linked with increasing rainfall extremes such as those experienced in the region in recent years.

State and local health agencies and vector control organizations are responsible for detecting and responding to diseases. Increasing capacity will be needed for continued tracking, diagnosing, and reporting of cases of known and new illnesses.

Health Care Capacity – A primary climate change vulnerability identified for Louisville Metro's residents is the potential for an overburdened health-care industry tasked with responding to multiple or increasing threats of outbreaks and extreme events. A recent outbreak of Hepatitis A provided a test for the Louisville Health Department's response capacity. The existing network of community partners (including government, non-profit, and private organizations with consistent and coordinated messaging, buy-in, and trust) proved key to quickly vaccinating Louisville's most vulnerable residents against the disease. Metro's

Identified Vulnerabilities – Health and Emergency Services

The vulnerability assessment identified the following health-related vulnerabilities to the communities of Louisville Metro:

High

Electrical outages during extreme events (heat waves, flooding, severe storms) potentially disrupting medically-sensitive populations and elderly people

Exposure to hazardous materials (HazMat) during flood events, especially in neighborhoods already at risk for hazardous materials

Medium-high

Health emergency events from heat waves, and high nighttime temperatures, particularly affecting people with compromised health, mental health issues, elderly, low income, people residing in high crime areas, outdoor workers, homeless people, and immigrants (especially non-English speaking).

Air quality declines due to higher temperatures and ground level ozone formation, leading to more respiratory and heart disease

Spread of pests and disease, including vector-borne diseases associated with mosquitoes and ticks

Overburdened health care industry unable to provide comprehensive care due to recurring extreme events and ongoing trauma care

Mental health impacts as certain populations become increasingly isolated, due to inhospitable outdoor temperatures, lack of transportation, poor urban planning, and degraded natural areas, parks and open spaces. At-risk populations include children, women, elderly, communities of color, immigrants, homeless, healthcare and emergency workers, and LGBTQ+

Note: Overall vulnerability ranking is determined from the combined scores for time frame, sensitivity, and adaptive capacity.

response was considered the "gold standard" by the CDC, however if climate change increases the frequency or duration of events, current levels of capacity would prove inadequate. Potential challenges include limited funding and response resources, slower response and recovery time, and overburdened staffing and volunteer constraints. These shortfalls should be used to inform the development of new strategies to address the impacts of climate change.

Mental Health Impacts – Mental health impacts from climate change are expected to develop gradually and cumulatively. Exposure to extreme events, sometimes repeatedly, can cause displacement, instability, lack of access to support services, and loss of employment or possessions, all of which affect mental health. Stress, anxiety, and fear can last for years after disruptions, and often lead to substance abuse or post-traumatic stress disorder (PTSD).

INFRASTRUCTURE

Louisville was founded in 1778, making it one of the oldest cities west of the Appalachians. From the 1930s to 1950s, redlining practices created neighborhoods that had little access to development and investment funds, due to racial and income characteristics of the residents. Redlining, in addition to other policies rooted in race and income inequality, created discriminatory infrastructure legacies still highly prevalent in Louisville today.

Similar to other older U.S. cities, Louisville experienced suburban growth in the 1960s and 70s, leading to new freeways and highways outside the city center. These new arteries often left the older areas to decline as local factories closed. While many areas have been revitalized, aging infrastructure and inefficient transportation corridors contribute to some of the city's infrastructure problems today.

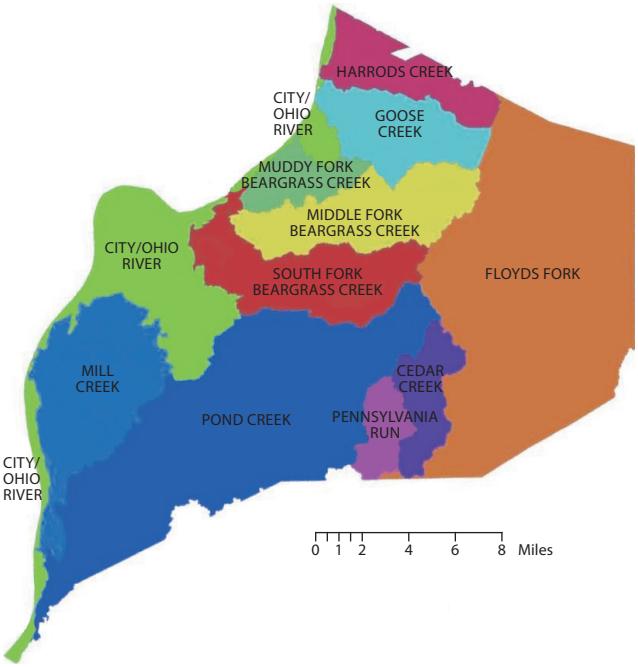
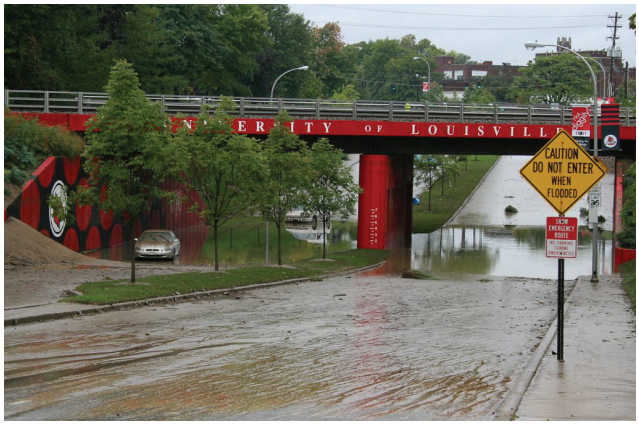


Figure 3. Watersheds of the Louisville Metro area. Figure from Louisville 2016 Hazard Mitigation Plan.

Downtown/Orin Blomberg

Aging Infrastructure and Flooding – One of the major disruptions to infrastructure, which is already being impacted by climate change, is



Flooding/laserbub_Drew

flooding. Flooding along the Ohio River occurs in the winter months, while flash flooding can occur any time due to precipitation events. Flooding is the costliest natural disaster in Kentucky, and is expected to worsen with climate change. The Louisville Hazard Mitigation Plan provides a comprehensive overview of flood risk throughout the 11 watersheds of the Louisville Metro area (Fig. 3). Records show that serious flooding has occurred in the Louisville area about once every 10 years. Flooding is expected to become more severe and frequent with climate change.

Urban areas are susceptible to flooding because a high percentage of the surface area is composed of impervious streets, roofs, and parking lots where runoff occurs very rapidly. Flash floods can occur year-round, and affect all parts of the city. For example, a flood in 1997 affected 2,500 homes in Okolona and Fairdale (southern part of the County). In 2006, Beuchel, Lake Forest Area, and Jeffersontown were affected by flooding (northern part of the County). In 2009, the northwest and central part of Louisville Metro flooded, including Churchill Downs, the downtown library, several hospitals, and University of Louisville campus. Finally, in 2013, central Louisville, including Beuchel, Hikes Point, Newburg, and Okolona were impacted by flash flooding. Areas with repetitive losses include Pond Creek, South Beargrass Creek, and City/Ohio River watersheds (Fig. 3).[31]

Large floods are often associated with sewer backups and collapsing combined sewer infrastructure. Some sewer infrastructure was built of brick in the mid- to late-1800s, yet is still in use. Hundreds of sewer system collapses occur each year, with numbers peaking during wet years. When the combined sewer and stormwater systems get overwhelmed, some sewage can go untreated. As climate change worsens and storms become even more extreme, dropping larger quantities of precipitation in shorter periods, older and outdated infrastructure will become even more at risk, also creating a risk for health and safety. Models indicate that 100-year floods could occur every 25 to 30 years towards the middle of this century.[32]

As older infrastructure is updated, prices for housing are expected to increase. Increased mandates for energy efficiency, sewer upgrades, extreme heat resistance, water conservation, natural shading, and other sustainability measures associated with combating climate change could result in fewer housing opportunities for lower income residents, unless efforts are made to provide sustainable yet affordable housing units.

Hazardous Materials – Increases in flood risk to the area also result in increased Hazardous Materials (HazMat) risk. Water pollution, soil pollution, and air pollution in Louisville will be exacerbated by climate change. For example, many sites downtown are classified as a brownfield, or "abandoned, idled, or underutilized industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived contamination."[33] Hazardous substances in the soil include herbicides, pesticides, cleaning chemicals, heavy metals, and others. Remediation involves removal of soil, potentially down to the groundwater. Rubbertown is another area with high soil contamination levels. Some chemicals found in soils include 1,3 butadiene, acrylonitrile, chloroprene, chloroform, formaldehyde, perchloroethylene, ethyl acrylate,

and benzene. Also contributing to Louisville's HazMat risk are DuPont, Dow Chemical, Stauffer Chemical, Hexion, and other plants, as well as a superfund site.[34]

As the potential for large storms and floods increases, it becomes increasingly likely that these pollutants will be released from the soils and contaminate waterways, contaminate homes and businesses, and affect human health.

Transportation Disruption – Situated along the Ohio River, the Louisville Metro region is a major thoroughfare for ground, air, river, and rail traffic, each with different climate-related risks.

Rail and River Shipping – In relation to river shipping, Louisville ranks as the 7th largest inland port in the U.S. Jefferson Riverport International (AKA Riverport) is a planned industrial community on the Ohio River, also serviced by three railroads. Companies in Riverport are in manufacturing fields such as plastics, steel processing, filtration systems, and materials production. Shipping via the Ohio River can be disrupted by drought and low flows, as well as extreme precipitation events and flooding. Rail traffic can be disrupted by severe heat, which leads to buckling (sun warping) and derailments.[35]

Roads and Highways – Louisville's central location in the U.S. also makes it practical for transfer of cargo along major interstate routes. Louisville is within one day's drive of 2/3 of the nation's population. Three major interstate highways intersect in Louisville, the I-64, I-65, and I-71. These three interstates are susceptible to flood impacts within Louisville Metro. Increasingly with rising temperatures, asphalt may begin to soften and melt during heat waves. With projected extreme maximum temperature increases of 3-20° F, roads and highways will increasingly need to be engineered to withstand extreme heat.

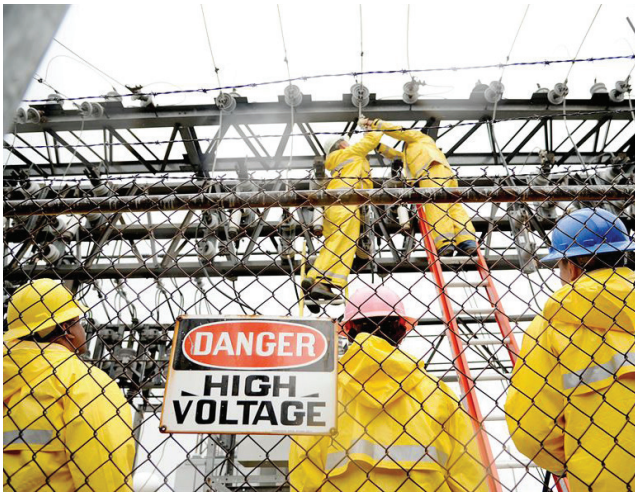
Used with permission/LMG

Air Cargo – The Louisville International Airport is the global air cargo hub for UPS. Extreme temperatures associated with climate change can lead to lower weight limits on air cargo. Because warm air is less dense, planes have a harder time taking off in triple-degree heat, leading to less cargo and weight capacity per flight. More frequent and severe heat waves can increase costs of shipping and disrupt air travel, sometimes grounding all planes until temperatures cool again.[36] Longer runways and different aircraft could be needed to adapt to warmer temperatures.

Energy Disruption and Pricing – More than 60% of Louisville Metro's greenhouse gas emissions comes from the use of electricity in homes and businesses. Louisville's electricity is largely supplied by LG&E. In 2016, electricity from LG&E came from the following sources: 60% from coal, 37% from natural gas, and 3% from hydroelectric.[37] As temperatures rise, electrical use is expected to rise with increased demand for air conditioning. New investments in energy production and distribution will be needed in order to meet peak demand. Because of the community's heavy reliance on fossil fuel-based energy, replacement of fossil fuels with renewable energy sources

(in addition to energy conservation) is necessary to meet Louisville's greenhouse gas emissions targets. These new investments could result in higher prices, depending on the cost of new infrastructure and energy prices. Lower income residents could be impacted by increasing energy prices.

Extreme temperatures also reduce the efficiency and reliability of energy production and distribution. In addition, power outages are common during heat waves, due to overburdening of the power grid. Power outages can put peoples' lives at risk as they leave people vulnerable to soaring temperatures. Older adults, low-income residents, and people with existing health problems are all at risk. If electric prices increase, even more residents will be unable to afford to cool their homes, putting them at risk during periods of severe heat.



Power outage repairs/US Air Force


Sunset/Vicky Vinch

Dam Stability – There are 40 Louisville Metro dams maintained by the Army Corps of Engineers and the Kentucky Cabinet for Natural Resources and Environmental Protection, Division of Water. Nine dams are classified as Class C, or high hazard class. An additional 13 are classified as Class B, or moderate hazard class. Most of the risk is located along the length of the west end of the Louisville Metro area. The total number of structures at risk is 53,679.[38]

Risk of dam and levee failure, due to larger and more frequent storms, as well as delayed and inadequate dam maintenance, is increasing. The region has experienced a 16% increase in the amount of rain falling during extreme storms. The number of days with more than 3 inches of precipitation has also increased across the region.[39] According to the National Climate Assessment, there is high confidence that extreme rainfall will continue to worsen with climate change. With continued higher emissions, model projections show a doubling in the number of heavy rainfall events and 21% increase in the amount of rain falling during those events. In addition, the largest flood events, historically occurring every 100 years (100-year flood events), could occur every 25-30 years throughout much of the Louisville Metro region, potentially resulting in dam and levee breaches.

Identified Vulnerabilities – Infrastructure

The vulnerability assessment identified the following infrastructure-related vulnerabilities to the communities of Louisville Metro:

High

Aging infrastructure and especially sewer systems that are unable to withstand high amounts of precipitation, leading to collapse, flooding, and the potential for exposure to hazardous materials

Damage to homes and businesses from extreme precipitation events and flooding

Increasing cost of energy, due to storm and heat damage, aging infrastructure, and higher demand, affecting local businesses, government, and lower income residents

Potential energy outages due to aging infrastructure and extreme events like heat waves and flood events

Medium-high

Fewer affordable housing units for lower income residents

Transportation disruptions and traffic congestion (as a result of poor land use planning and practices) especially during flood emergencies, affecting suburbs and businesses

BUSINESS AND THE ECONOMY

Louisville's economy is built on many different types of businesses and industries, ranging from large industrial hubs to small local and diverse businesses. It has served as a shipping and cargo hub for over a century. The Louisville Muhammad Ali International Airport serves as a global air freight hub for UPS. Louisville is also a major center of manufacturing in the U.S., with two major Ford plants, GE headquarters and home appliance factory, and numerous chemical plants like Dow and DuPont.

The distilling industry represents an important area of growth for Kentucky, and specifically for Louisville, which is home to 15 large distilleries and numerous smaller ones. Even as other manufacturing industries have declined over the last decade, distillery employment and wages have increased by 175-200% throughout the state.[40] Bourbon production has increased more than 115% over the last 5 years.[41] Tourists come to Louisville to enjoy small independent businesses and restaurants, the urban bourbon trail of more than 50 restaurants serving local spirits, and the many downtown museums and restored waterfront area.

Palace Theater/Michelle Spomer

Climate change is expected to affect the local economy in numerous ways. Not only are transportation routes expected to be interrupted more frequently (see the Infrastructure section) but the cost of doing business is expected to rise.

Identified Vulnerabilities – Business and the Economy

The vulnerability assessment identified the following economic-related vulnerabilities to the communities of Louisville Metro:

HIGH

Increasing cost of energy, due to higher demand coupled with aging distribution infrastructure, affecting local businesses and lower income residents

MEDIUM-HIGH

Transportation disruptions and traffic congestion (as a result of poor land use planning and practices) during flood emergencies, affecting suburbs and businesses

MEDIUM

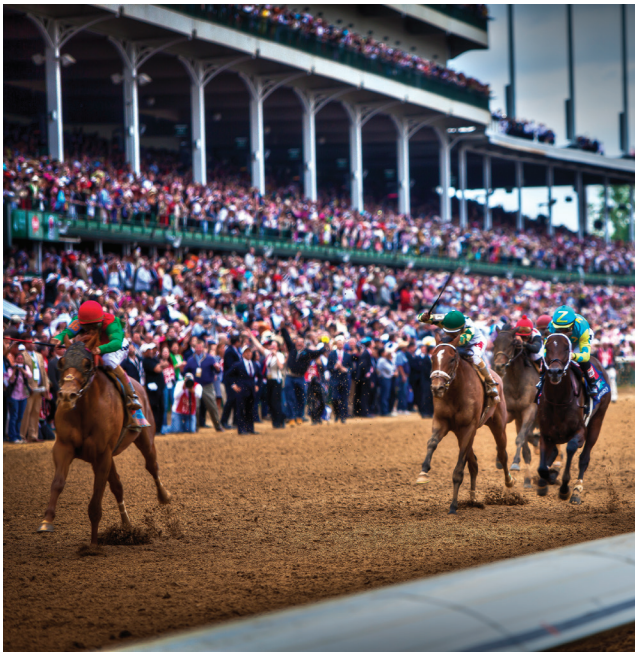
Higher cost of doing business, due to rising energy and insurance costs, as well as disaster losses

Energy Costs – The cost of energy is likely to increase in Louisville, potentially affecting the cost of doing business in the region. With higher temperatures, demand for electricity is expected to increase as local residents and businesses increasingly need air conditioning. Studies indicate that electrical demand is expected to increase by more than 25% across the southern U.S.[42] and that industry and businesses contribute most to this increase. Because of the need to shift from fossil fuel based energy sources to renewable energy, Louisville's heavy reliance on coal and natural gas leaves the region vulnerable. As demand increases and renewable energy comes online, costs could increase substantially in order to meet the need for new infrastructure investments.

Transportation Interruptions – Louisville businesses and industry rely heavily on inexpensive, reliable, and efficient distribution of products throughout the nation. As detailed in the infrastructure chapter, businesses and industry are increasingly vulnerable to disruptions in transportation by river shipping, air cargo, rail, and interstate shipping. As shipping reliability is increasingly impacted by extreme events, overall cost and profitability could be negatively affected.

Insurance Costs – Insurance costs are directly linked to the level of risk involved. As the risk of flooding, hail, severe storms, and wildfire increase, premiums will also increase. Munich Re, one of the world's largest re-insurance companies, already links premiums to climate change risk. In fact, the insurance industry has some of the best climate change model projections information available, so that they can identify vulnerable areas and estimate current and future risk.

According to a new industry survey, actuaries (the people who calculate insurance risks and premiums based on available data) ranked climate change as the top risk for 2019, beating



Kentucky Derby/Louisville Images

out concerns over cyber damages, financial instability, and terrorism.[43] As climate-induced risk continues to rise, some areas may become uninsurable, transferring the full financial risk to individual property and business owners.

Credit rating agencies have added "resiliency" in their rating criteria for city and state governments, affecting the ability of local governments to raise bond funds and the rates that taxpayers pay for those funds. For instance, Standard and Poor's regularly publishes extensive research on the climate-related risks to cities. They also evaluate environmental, social, and governance risks as a key part of their ratings methodology.

Barges/Smythe Richbourg

NATURAL SYSTEMS

Louisville Metro has 122 city parks covering more than 13,000 acres. These parks are vital to quality of life for local residents, as well as attracting tourists to the area. About half the city's park acreage is found in Jefferson Memorial Forest, which is designated as an Audubon Society wildlife refuge. Jefferson Memorial Forest has more than 30 miles of hiking trails, and is the largest urban forest in the U.S. Also, a municipal project called the Louisville Loop aims to create a 110-mile paved walking and biking trail around Louisville Metro, as well as adding new park land and floodplains to the city's system.

Historically, the Ohio River and the network of creeks and rivers making up Louisville's 11 watersheds have been used as dumping grounds for sewage waste, other debris, and chemicals. More recently, they have been severely impacted by urban runoff and development. As a result, none of Louisville's surface streams are able to meet state water quality standards, and all are posted as "No Swimming." Significant strides have been made, however, in restoring important ecosystem functions and improving water quality, and plans are in place to continue to improve. Climate change poses a significant threat to restoration and conservation efforts focused on ecosystems and water quality.

Climate change can have significant impacts to natural systems, through increases in both extreme storms and drought. Flash floods can wash out aquatic insects that are the source of food for fish, and result in bank erosion, adding to the silt that smothers surviving organisms. These can be exacerbated by construction of impervious surfaces, reducing groundwater recharge and resulting in lower (or even no) stream flows during dry, summer months. Lower stream flows further stress aquatic life, reduced dissolved oxygen levels, and concentrate toxic substances in the water. Riparian vegetation that normally provides shade and acts as a source of food for aquatic life is removed, threatening the biological integrity of streams.

Watersheds that are especially vulnerable, due to already stressed and degraded habitat and aquatic communities, include Muddy Fork and

Used with permission/LMG

Urban Trees, Climate Change, and the Emerald Ash Borer

Louisville's trees are vitally important. They provide shade, increase property values, reduce severe heat, save energy and money, improve air quality, and store carbon. As temperatures increase and the city works to lower greenhouse gas emissions, tree canopy will only become even more vital for the health and well-being of Louisville's residents. The city's tree canopy is shrinking, however, and is projected to continue to shrink from 40% cover in 2004 to only 25% by 2052. Making matters worse, an invasive pest called the Emerald Ash Borer is causing even greater loss of trees and is spreading and multiplying with climate change. Other pests are expected to invade as temperatures continue to rise and native vegetation becomes increasingly stressed.

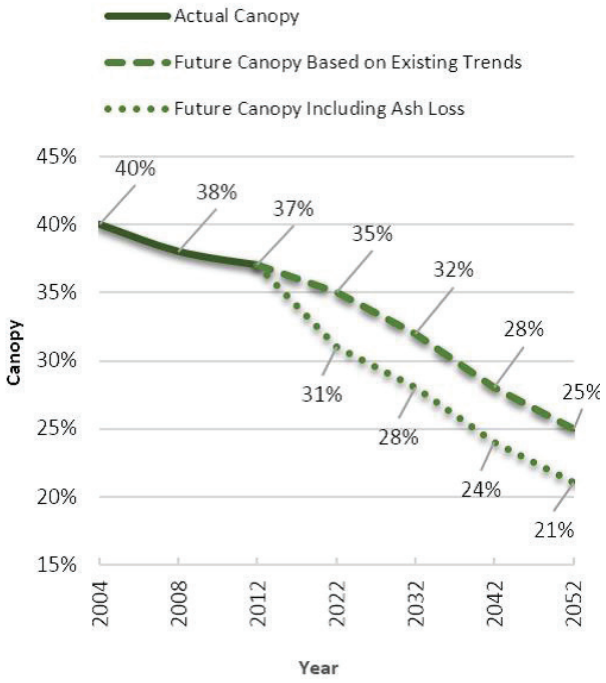


Figure 4. Ongoing and projected decline in tree canopy throughout Louisville Metro. From the 2015 Urban Tree Canopy Assessment

South Fork of Beargrass Creek, Mill Creek, and Mill Creek Cutoff. Bacteria are a significant concern, especially during and after large storms,[44] which could be exacerbated by warmer temperatures and more frequent large storms associated with climate change. Streams within urban sections of Louisville generally had lower water quality related to bacteria pollution, and this was linked to sewer overflows. The urban heat island effect also increases water temperature of runoff, thereby exacerbating issues with bacterial contamination.

Cherokee Park/ LuAnn Snawder

Spread of Pests and Disease – Climate change is also expected to lead to increases in pests and disease, affecting natural areas, urban trees, and fish and wildlife. Gardens and crops could also experience reduced production due to extreme events, as well as pests and disease. With increase in temperatures, fewer nights below freezing, and stressed native vegetation, invasive species such as bark beetles could decimate urban tree canopies and other vegetation.

Loss of Green Spaces – The mental health benefits of open spaces, vegetation, parks, and nature are well proven. Access to green spaces

and nature improve mood, ability to concentrate, school test scores, and many other metrics. Unfortunately, these spaces are often considered a luxury, rather than a necessity. For example, existing urban tree canopy in Louisville is higher in higher income neighborhoods and those with newer homes and higher levels of education. In lower income areas, often with higher percentages of people of color, there is less natural habitat and fewer parks. Climate change will only exacerbate this disparity, degrading existing natural areas and diversity, thereby leading to more anxiety, less exercise, fewer meeting places for community connections, and more isolation.

A state-of-the-art project to learn how to design a neighborhood to support human health is the Green Heart Project.[45] A collaboration among the University of Louisville, Nature Conservancy, and other partners, this project examines the link between neighborhood greenery and physical and mental health.

Used with permission/LMG

Identified Vulnerabilities – Natural Systems

The vulnerability assessment identified the following vulnerabilities to natural systems in the Louisville Metro area:

High

Spread of pests and disease (ticks, plant diseases, etc.) that affect fish and wildlife, natural vegetation, street trees, gardens, and crops

Loss of green spaces, thereby further exacerbating inequities among race, income, and neighborhood

Important ecosystems and native species impacted by climate extremes (floods, heat) as well as overall climatic change (shifts in timing, species range shifts northward or to higher elevations, lack of connectivity). Loss of ecosystems and species leading to fewer outdoor opportunities for local residents.

Medium-high

Degradation of aquatic systems, leading to loss of wildlife habitat and ecological function (water filtration, flood abatement, recreational opportunities, etc.)

Impacts to urban trees and tree canopy from insects, disease, drought, severe storms, and heat

Degradation and loss of nature due to flood damage exacerbated by poor land use practices, leading to less connection between younger generations and nature and thereby less interest in conservation

NEIGHBORHOOD VALUES AND CULTURE

Louisville Metro is home to 760,000 people. In 2003, the city of Louisville and Jefferson County governments merged to become Louisville Metro. About 20% of the population lives in 84 neighborhoods (previously incorporated cities) with their own tax systems, governance, and services. The rest live in 64 previously unincorporated areas. Together, these make up Louisville's neighborhoods.[46] Louisville Metro is increasingly diverse, as the percentage of Black, Asian, Hispanic/Latino, and multiple races continue to increase in recent years.

Much of Louisville's local culture revolves around its neighborhoods and the great diversity within and amongst them. Historical practices, policies, trends, and events have shaped Louisville's neighborhoods. These include immigration, slavery, the Civil Rights movement, redlining, suburban sprawl, gentrification, the Louisville Metro merger, and others. These and other historical events and policies formed the neighborhoods that are present today, with continued legacies in culture, race, education, and opportunity.

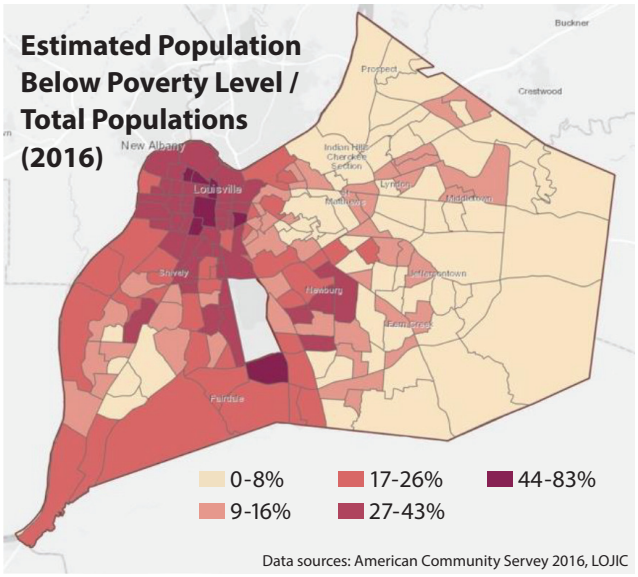


Figure 5. Population distribution of households below the poverty line in Louisville Metro.

As climate change increases the frequency and intensity of severe storms, flooding, drought, and heat waves, many of Louisville's neighborhoods are far more vulnerable to those impacts than others. Existing vulnerabilities, associated with low income, chronic health conditions, exposure to pollution, gentrification, crime levels, urban

Used with permission/LMG

Used with permission/LMG

heat, lack of access to healthy foods, and others, will be exacerbated by climate change. Many of the vulnerabilities are concentrated within certain areas of the Louisville Metro region, such as those associated with poverty (Fig. 5) or immigration, race, or disability (Fig. 6).

Tension and Inequities Around Race, Income, and Gentrification – Louisville's climate change vulnerabilities have a significant intersection with race and income. A long history of racism at the systemic level has led to divisions within the community. Climate impacts such as flooding, heat-related mortality, respiratory illnesses and mortality, and exposure to increasingly extreme conditions are all expected to exacerbate existing inequities. One such stressor is gentrification, or the investment in certain neighborhoods causing displacement of lower income residents by wealthier residents more likely to be white. Tensions around gentrification are likely to be exacerbated by climate change as neighborhoods are rebuilt after disasters. For example,

Used with permission/LMG

New Orleans neighborhoods that experienced the worst impacts of hurricane Katrina were far more likely to experience gentrification.[47]

Increasing Cost of Energy – As described in the infrastructure section, the cost of energy could rise in the coming years, as demand increases and renewable energy comes on line. Increasing costs of energy, in addition to those for food and housing, can have devastating impacts for residents already living near or below the poverty line.

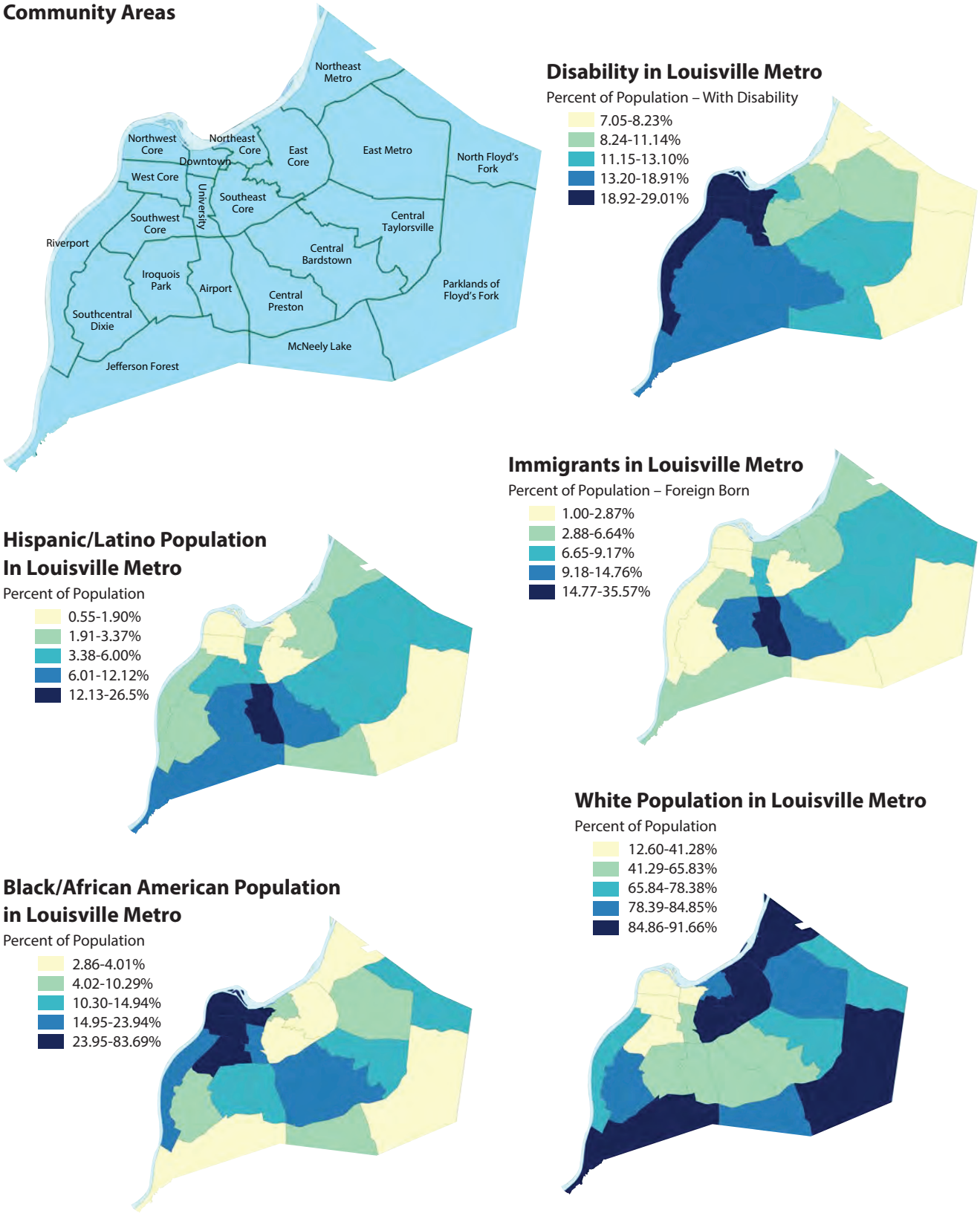


Figure 6. Distribution of Louisville residents based on disability, immigration history, and race in Louisville Metro. Maps adapted from the 2017 Louisville Health Equity Report. Community areas are aggregations of Louisville neighborhoods.

Increasing Violence and Crime – Domestic assault and violent crime both increase with higher temperatures.[48] While the specific mechanisms behind this relationship are not entirely understood, the correlation is robust across cultures, regions and time. A study in L.A., for example, found that violent crime increased almost 6% on days over 85° F. Lower income neighborhoods showed a greater increase in violent crime than wealthy neighborhoods.[49]

Increasing Homelessness – Homelessness is expected to increase with climate change, as more and more people are displaced and/or experience economic hardship and insecurity. Higher costs for housing, insurance, food, and energy are expected to take a toll on lower income households and individuals. In addition, extreme events such as floods and large storms could force people into homelessness. This is likely to put pressure on organizations and government services that support members of the homeless community.

Worsening Traffic Congestion – Many parts of Louisville already experience traffic congestion. Much of this comes from inadequate planning during the 1960s and 1970s, when people were moving to the suburbs. Recent large construction projects contributed to the problem for many years, but have since helped to alleviate some congestion. Traffic congestion is expected to increase with climate change as temperatures soar, affecting the stability of roads and rail lines, as well as increasing rain and flooding, affecting the suburbs.

Food Availability – Climate change is already affecting crops around the world. Floods and droughts harm crops and reduce yields. During California's extended drought, for example, the state lost $2.7 billion in agricultural revenue in 2017. Considering that California grows 1/3 of the nation's vegetables and 2/3 of the nation's fruit and nuts, this was a serious loss. Weeds, pests, and fungi also thrive under warmer temperatures, wetter climates, and higher CO2 levels. As climate change continues to worsen, global food security could be at risk.

Bardstown Market/stlbites.com

Quality of Life and Sustainable Lifestyles – Louisville's overall quality of life is vulnerable to climate change impacts. Heat and severe storms could keep people indoors, reduce their

An Opportunity for Equity

As climate change solutions are developed, an opportunity arises to develop adaptation strategies that prioritize equity as a major outcome. Careful consideration of governance systems and policies, as well as entrenched systems of power that create relative advantage and disadvantage and make certain populations more and/or less vulnerable to climate change is vital. This demands that resilience strategies be developed that not only address climate change vulnerabilities, but also the intersecting factors that make some populations more prone to experiencing direct and indirect impacts, along with the intentional allocation of resources to support sustainable solutions and enhanced resilience capacity for populations that need it most.

connection with nature, and negatively impact their mental health. Tourism may decline, resulting in less revenue and fewer government services. If schools are impacted, families may move away from the area, further exacerbating the issue. Finally, residents that are paying more for housing, energy, and food, may not have the capacity to invest in more sustainable lifestyles, like energy efficient windows, electric cars, and locally-produced food.

Local Leadership – Action on climate change is difficult to accomplish without passionate and visible leaders. Louisville is moving forward with its climate action planning, and has set aggressive greenhouse gas emissions targets. Strategies are being identified for both reducing emissions (mitigation) and protecting people and resources from impacts (adaptation). Implementing these new strategies quickly will be vital to creating momentum, gaining buy-in, and reaching important milestones. Sustaining momentum will depend on systemic levels of change in how people live, work, and travel. Louisville Metro's success depends on highly effective and respected leaders and organizations to move the needle.

Identified Vulnerabilities – Neighborhood Values and Culture

The vulnerability assessment identified the following neighborhood values and cultural vulnerabilities to the communities of Louisville Metro:

HIGH

Tensions and inequities around gentrification, race, and income exacerbated by climate impacts to vulnerable populations, including hazardous materials exposure, flood risk, declining affordability, and loss of nature/green spaces.

Increased cost of energy due to aging infrastructure and the need to shift to more diverse energy sources and renewable energy

MEDIUM-HIGH

Increasing violence and crime associated with higher temperatures and extreme events

Loss of affordability and housing opportunities for lower income residents, pushing more people into homelessness or inadequate housing

Worsening traffic congestion in suburbs due to extreme precipitation and flooding

Potential for declining food availability for lower income residents, due to increasing crop failures and reduced production, exacerbated by food deserts

Overall quality of life declines with heat, flooding, soil and water contamination, and loss of tourism. Lower tax revenue if people move away, leading to stressed schools and government services

MEDIUM

Lack of sustainability lifestyle and behaviors, leading to overall lower resilience to challenges and extreme events, such as drought, heat, and flooding

Lack of local leadership (especially a champion) on climate change. State and federal leadership also lacking and often hostile to climate action

Cross-Sector Considerations

Many of the climate change vulnerabilities identified for the Louisville Metro region were similar and/or closely related across different sectors of the community. For instance, the potential increase in the cost of energy is likely to affect businesses and the economy, as well as lower income households. Strategies to develop clean and renewable energy will need to address cost and funding issues, especially to ensure that vulnerable populations benefit from new investments in clean energy. Some areas of cross-sector consideration included:

Workforce capacity was important for a variety of businesses and healthcare. Workforce capacity could decline because of impacts to quality of life, making Louisville a less attractive place to live and work. This will also affect schools and government services. Of concern was the ability of Louisville to attract young people and families as climate impacts make the region less hospitable.

Inequities based on neighborhood, income, and race are important for many vulnerabilities identified across different sectors of the community. For instance, the health impacts associated with heat waves affect lower income neighborhoods and some races more than others. Heat also leads to higher violent crime rates in lower income neighborhoods. The groups most vulnerable to climate change are often the same groups that are vulnerable to other societal stressors. Because of this, basic strategies to improve income level, health, educational opportunities, and housing availability can double as climate change adaptation strategies.

Transportation disruptions affect infrastructure, economics, businesses, most residents and people of many different backgrounds and income levels. Because of its importance as a distribution hub, as well as a tourist destination and community heavily reliant on cars, transportation issues affect all sectors of Louisville. Transportation disruptions are expected to affect car, barge, plane, and rail traffic.

Hazardous materials risk from flooding and heat was identified as a vulnerability to health, nature, infrastructure, and neighborhoods and culture. Hazardous materials are found in soils and waterways throughout Louisville Metro, but especially concentrated in certain areas. They are especially at risk in older construction and areas with chemical production facilities.

Affordability was a great concern for housing, energy, health, and business expenses. Affordability is perceived as affecting the ability of the community to become more sustainable and resilient over time, with sustainability linked to higher costs and loss of revenue. Because sustainability requires near term investment, but with significant return in the form of long term savings, addressing the ability of residents to afford sustainability investments could create greater resilience over time.

Cost of energy affects businesses, low income residents, government, and others. Investments in renewable energy sources will need to be designed to support those who are already struggling. Providing job training and subsidies in clean energy and building a clean energy economy can be one way to build resilience across many different sectors at the same time.

The Belvedere / Jessica Dillree

CONCLUSIONS

Climate change is a global threat with locally unique impacts for communities. Because each region is affected differently, and each community has a unique combination of existing vulnerabilities and assets, it is vital to develop climate change solutions at the local level. Some of the most important impacts to Louisville include disruptions to major transportation hubs, failure of aging infrastructure, health impacts associated with heat and air quality, exacerbated impacts to populations and resources already under stress, and degradation of natural systems that are vital to the health and well-being of local residents. The most vulnerable residents and resources are generally those with the least adaptive capacity to deal with the additional impacts of climate change.

The international scientific community is in agreement that keeping average warming at the global level below 1.5°C (2.7° F) is vital to protect young people and future generations from catastrophic and runaway climate change. Emissions reductions are the first and most important step to preventing many of the worst impacts to the community. The severity and cost of large storms and flooding, for instance, can be substantially reduced by reducing greenhouse gas emissions quickly and aggressively. Many impacts are already occurring, however, and need to be addressed to protect people and resources throughout the community.

Because climate change affects all sectors and resources, coordinated actions are needed to increase overall resilience. Without coordination, actions in one sector or population could shift impacts to other sectors or populations, especially those who are already most vulnerable. Truly co-beneficial solutions to climate change would address economic and social inequities, increase ecological health and resilience, and collaborate across diverse groups and resources.

RISK MATRIX – NEAR TERM (current to 2030s)

Sensitivity \ Adaptive Capacity	Low Adaptive Capacity	Medium Adaptive Capacity	High Adaptive Capacity
High Sensitivity	**Aging infrastructure** failure leading to sewer system collapse and hazardous materials (HazMat) exposure **Damage to homes and businesses** from flooding and HazMat exposure **Increased cost of energy** impacts lower income and other vulnerable residents and businesses, exacerbated by storm damage, aging infrastructure, dependence on fossil fuels, and lack of energy diversity **Energy outages** due to heat and storms, affecting elderly, infants, medically-sensitive people, business, and others **Spread of pests and diseases** affecting fish and wildlife, natural vegetation, street trees, gardens, and crops. Examples include ticks and crop/plant diseases.	**Health events** from heat waves, affecting vulnerable populations including elders, homeless, lower income residents, and those with compromised health **Worsening air quality** from heat-induced formation of ozone, leading to respiratory and heart disease **Loss of housing opportunities** for lower income residents as disasters or sustainability and resilience measures increase housing prices **Degradation of aquatic systems**, from storms, pollution, drought, and overall climate change, leading to loss of ecological function (water filtration, flood abatement, etc) and wildlife habitat **New emerging public health risks**, especially related to vector- and water-borne disease **Impacts to urban trees and tree canopy** from insects, disease, drought, extreme storms, and heat **Land use practices** exacerbate flood damage, traffic congestion, social isolation, loss of nature, and affordability issues **Food availability** for vulnerable populations. Crop failures and reduced production increase prices while food deserts exacerbate availability.	**Inequity will be exacerbated** with continued gentrification, racism, and community tension, in addition to climate impacts to vulnerable populations, including HazMat exposure, flood risk, declining affordability, and loss of green spaces **Lack of leadership** on climate change affects success of planning and implementation
Low Sensitivity	**Transportation disruptions and congestion** affecting everyone, especially suburbs, businesses, and mass transit		

RED type indicates highest priority for strategy development

RISK MATRIX – MID TERM (2040s-2060s) *unless otherwise noted*

Sensitivity \ Adaptive Capacity	Low Adaptive Capacity	Medium Adaptive Capacity	High Adaptive Capacity
High Sensitivity	**Increased cost of energy** impacts lower income and other vulnerable residents and businesses; exacerbated by storm damage, dependence on fossil fuels, lack of energy diversity, and aging infrastructure **Native species impacted** by phenology mismatch and loss of resilience	**Health care industry** overburdened by health-related events such as disease outbreaks and/or disasters **Emergency response sector** overburdened by increasing number of extreme events **Increase in violence and crime** with heat and extreme events	**Lack of sustainability behaviors and lifestyle** lead to lower resilience to ongoing change and extreme events
	Mental health impacts from increased isolation and lack of outdoor access **Loss of overall quality of life** from heat, flooding, soil and water contamination, and loss of tourism. Loss of workforce. Decline in $$ for schools and govt. services. (LONG TERM – 2070s-2090s)	**Important ecosystems impacted** leading to loss of species and populations, as well as fewer opportunities for outdoor recreation in natural areas **Displaced people** migrating from other areas	**Increasing cost of doing business** from rising energy and insurance costs, disaster losses
Low Sensitivity			

RED type indicates highest priority for strategy development

Glossary

100-year floods – a flood event that has a 1 in 100 chance of being equaled or exceeded in any given year.

Clean energy – Energy used by people and businesses that doesn't cause pollution. Includes electricity, transportation, buildings, and food systems.

Climate Change Adaptation – Actions that protect people or nature from, or prepare them for, the current and future impacts of climate change.

Climate Change Mitigation – Actions that reduce greenhouse gas emissions (primarily from fossil fuels combustion) or increase the storage of carbon (primarily in soils, forests, and other natural systems).

Climate Equity – Removing obstacles to climate resilience such as discrimination, poverty and their consequences.

Contaminant/toxin/pollutant – a substance that makes something less pure or makes it poisonous (contaminant); any substance poisonous to an organism (toxin); any substance, as certain chemicals or waste products, that renders the air, soil, water, or other natural resource harmful or unsuitable for a specific purpose (pollutant).

Ecosystem services/function – Represent the many and varied benefits of a healthy natural environment. They include the production of food and water, the control of climate and disease, nutrient cycles and oxygen production, and spiritual and recreational benefits.

Energy efficiency – is the reduction of the amount of energy required to provide the same level of products and services.

Equity – Achieving the same level of opportunity based on variable levels of support and assistance depending on the difference in historical disparity and current need. Some types of equity of concern include racial, economic, social, and intergenerational.

Food Desert – Underserved areas that lack fresh, healthy food options.

Food Insecurity – An economic or social condition of limited or uncertain access to adequate food supply.

Fossil fuels – a group of energy sources that were formed when ancient plants and organisms were subject to intense heat and pressure over millions of years. There are three major types of fossil fuels: coal, oil, and natural gas.

Gentrification – a process of changing the character of a neighborhood through the influx of more affluent residents and businesses, often shifting a neighborhood's racial/ethnic composition and average household income by developing new, more expensive housing, businesses and improved resources.

Green Building design – the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction.

Greenhouse Gas (GHG) – A gas that absorbs infrared radiation (heat) in the atmosphere and contributes to climate change. Greenhouse gases include carbon dioxide, methane, water vapor, nitrous oxide, and others.

Impervious surfaces – These are land surfaces that repel rainwater and do not permit it to infiltrate (soak into) the ground. Impervious surfaces are mainly artificial structures—such as pavements that are covered by water-resistant materials such as asphalt, concrete, brick, stone—and rooftops. Soils compacted by urban development are also highly impervious. (Also see "Pervious surfaces").

Infrastructure – refers to the built environment such as buildings, energy generation and distribution systems, water delivery, storm- and wastewater, floodwalls, roads and highways, bridges, culverts, and many other basic structures.

Pervious surfaces – Surfaces that allow water to percolate through to the area underneath rather than becoming runoff (Also see "Impervious surfaces").

Redlining – In the United States and Canada, redlining is the systematic denial of various services by federal government agencies, local governments as well as the private sector, to residents of specific neighborhoods or communities, either directly or through the selective raising of prices.

Resilience – the ability of people and their communities to anticipate, accommodate and positively adapt to or thrive amidst changing climate conditions and hazard events.

Renewable electricity – Electricity that: (1) can be extracted, generated, and consumed with neutral carbon emissions or no emissions at all, and with no current or future threat to life and the natural environment; and (2) is generated and stored from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, geothermal, tides, and, conditionally, bio-matter and various forms of hydropower (definition per the LMG 100% resolution).

Renewable energy – Energy produced from sources that do not deplete or can be replenished within a human's life time. The most common examples include wind, solar, geothermal, biomass, and hydropower.

Riparian vegetation – Refers to the plants along the river margins and banks, and are characterized by plants that like water.

Sustainability – A broad concept that refers to meeting the needs of the present without compromising the ability of future generations to meet their needs.

Urban Heat Island – The increase in temperature within an urban area as compared to the surrounding rural and naturally vegetated areas. This additional heat comes from heat-absorbing buildings, impervious surfaces, channelization of waterways, and the removal of canopy cover.

List of Sector Experts

This report is part of a larger effort to build climate resilience across the Louisville Metro region. The entire process was guided by Strategy Team, representing the various sectors and communities across the Metro region.

Prepare Louisville – Strategy Team

Betty Adkins, Louisville Metro Office of Performance Improvement & Innovation

Rebecca Cash, Louisville Gas & Electric

Hannah Crepps, Center for Neighborhoods

Sarah Lynn Cunningham, Louisville Climate Action Network

James Graham, Louisville Metro Public Works

Gordon Garner, Center for Neighborhoods

Arnita Gadson, NAACP Kentucky

Angela Graham, Louisville Metro Public Health & Wellness

Nick Hart, Louisville Metro Public Health & Wellness

Andrew Gray, Jefferson County Public Schools

Mark Jeziorski, Louisville Metro Emergency Management Agency

Michelle King, Louisville Metro Air Pollution Control District

Dave Marchal, Louisville Metro Develop Louisville

Jeff OíBrien, Louisville Metro Develop Louisville

Marc Thomas, Metropolitan Sewer District

Ray Yeager, University of Louisville Envirome Institute

This report was also provided to participants at a day-long working session on June 21, 2019 who helped to identify and prioritize the impacts expected in Louisville due to climate change. The participants of this session represented the following entities:

BIA (Building Industry Association)

Center for Neighborhoods

Chemours

Coalition for the Homeless

GLI (Greater Louisville, Inc.)

Jefferson Memorial Forest

Jewish Hospital

Kentuckians for the Commonwealth

Kentucky Refugee Ministries

Kentucky Waterways Alliance

Kentucky Youth Advocates

Kentucky Youth Advocates

KentuckyOne Health

KIPDA (Kentuckiana Regional Planning and Development Agency)

La Casita

LG&E (Louisville Gas and Electric Company)

LMG Develop Louisville

LMG Emergency Management Agency

LMG Office of Advanced Planning & Sustainability

LMG Office of Advanced Planning & Sustainability

LMG Office of Resilience and Community Services

LMG Planning and Design Services

LMG Public Health & Wellness

LMG Public Works

Louisville Climate Action Network

Louisville Metro Air Pollution Control District

Louisville Metropolitan Housing Coalition

Louisville Sustainability Council

Louisville Sustainability Council

Metropolitan Sewer District (MSD)

Parkville Neighborhood Association

Partnership for a Green City

Portland Now

Promise Housing

REACT (Rubbertown Emergency Action)

Restorative Justice Louisville

Sierra Club, Greater Louisville Chapter

Sunrise Movement, Louisville Hub

True Up

UofL Envirome Institute

UofL students

UofL Sustainability

USDA

YouthBuild

Special thanks to those who served as facilitators for the session:

Rebecca Cash, Louisville Gas & Electric

Sarah Lynn Cunningham, Louisville Climate Action Network

Michelle King, Louisville Metro Air Pollution Control District

Dave Marchal, LMG Develop Louisville

Gretchen Milliken, LMG Office of Advanced Planning & Sustainability

Allison Smith, LMG Office of Advanced Planning & Sustainability

References

1. NOAA National Centers for Environmental Information Daily Summaries for the Louisville Kentucky Airport Weather Station

2. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

3. Louisville Metro. 2016 Louisville Hazard Mitigation Plan. Prepared by Stantec.

4. NOAA National Centers for Environmental Information Daily Summaries for the Louisville Kentucky Airport Weather Station

5. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

6. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

7. NOAA National Centers for Environmental Information Daily Summaries for the Louisville Kentucky Airport Weather Station

8. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

9. Fourth National Climate Assessment (nca2018.globalchange.gov)

10. Wobus, C. et al. 2017. Climate change impacts on flood risk and asset damages in mapped 100-year floodplains of the contiguous U.S. Natural Hazards and Earth Systems Science 17:2199-2211.

11. Fourth National Climate Assessment (nca2018.globalchange.gov)

12. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

13. Fourth National Climate Assessment (nca2018.globalchange.gov)

14. Meng, Y. and J. Long. 2018. Global warming causes sinkhole collapse – Case study in Florida, USA. Natural Hazards and Earth Systems Science Discussions. In Review.

15. Meng, Y. and J. Long. 2018. Global warming causes sinkhole collapse – Case study in Florida, USA. Natural Hazards and Earth Systems Science Discussions. In Review.

16. NOAA National Centers for Environmental Information Daily Summaries for the Louisville Kentucky Airport Weather Station

17. Easterling, D.R., et al. 2017. Precipitation change in the United States. In Climate Science Special Report: Fourth National Climate Assessment, Volume I. Wuebbles, D.J., et al. (Eds.). U.S. Global Change Research Program, Washington, DC, USA.

18. Liu, Y., J. Stanturk, and S. Goodrick. 2010. Trends in global wildfire potential in a changing climate. Journal of Forest Ecology and Management 259: 685-697.

19. NOAA National Centers for Environmental Information Daily Summaries for the Louisville Kentucky Airport Weather Station

20. Carter, L., et al. 2018. Southeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. Reidmiller, D.R., et al. (Eds.). U.S. Global Change Research Program, Washington, DC, USA.

21. Chinowsky, P. et al. 2019. Impacts of climate change on operation of the U.S. rail network. Transport Policy 75:183-191.

22. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

23. Wobus, C. et al. 2017. Climate change impacts on flood risk and asset damages in mapped 100-year floodplains of the contiguous U.S. Natural Hazards and Earth Systems Science 17:2199-2211.

24. Dahl, K. et al. 2019. Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century. Environmental Research Communications 1 (2019) 075002.

25. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

26. Russo, S., J. Sillmann, and A. Sterl. 2017. Humid heat waves at different warming levels. Nature Scientific Reports 7: 7477.

27. World Health Organization. 2016. WHO Programme on Climate Change and Health. https://www.who.int/globalchange/mediacentre/news/globa l-programme/en/

28. CDC Report Rosenberg R, et al. Trends in Reported Vector-Borne Disease Cases—United States and U.S. Territories, 2004-2016. MMWR Morb Mortal Wkly Rep. Vol. 67, 2018. (https://www.cdc.gov/media/releases/2018/p0501-vs-vector-borne.html)

29. ClimateNA v5.21 software package, available at http://tinyurl.com/ClimateNA, based on methodology described by Hamann, A. T. Wang, D. L. Spittlehouse, and T. Q. Murdock. 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. Bulletin of the American Meteorological Society 94: 1307–1309.

30. Caminade, C., K. M. McIntyre, and A. E. Jones. 2019. Impact of recent and future climate change on vector-borne diseases. Annals of the New York Academy of Sciences ISSN 0077-8923.

31. Louisville Metro. 2016 Louisville Hazard Mitigation Plan. Prepared by Stantec.

32. Wobus, C. et al. 2017. Climate change impacts on flood risk and asset damages in mapped 100-year floodplains of the contiguous U.S. Natural Hazards and Earth Systems Science 17:2199-2211.

33. Barnett, R. A. 2011. Environmental Issues. Louisville, Kentucky. Kentucky Institute for the Environment and Sustainable Development.

34. Barnett, R. A. 2011. Environmental Issues. Louisville, Kentucky. Kentucky Institute for the Environment and Sustainable Development.

35. U.S. EPA. 2015. Climate impacts on transportation. Accessed at https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-transportation_.html

36. Coffel, E. D., T. R. Thompson, and R. M. Horton. 2017. The impacts of rising temperatures on aircraft takeoff performance. Climatic Change 144:381-388.

37. Louisville Metro. 2018. Louisville 2016 Greenhouse Gas Emissions Inventory Report. Prepared for the Office of Sustainability by Stantec.

38. Louisville Metro. 2016 Louisville Hazard Mitigation Plan. Prepared by Stantec.

39. Fourth National Climate Assessment (nca2018.globalchange.gov)

40. Coomes, P. and B. Kornstein. 2019. The Economic and Fiscal Impacts of the Distilling Industry in Kentucky. Prepared for the Kentucky Distillers' Association.

41. Coomes, P. and B. Kornstein. 2019. The Economic and Fiscal Impacts of the Distilling Industry in Kentucky. Prepared for the Kentucky Distillers' Association.

42. Van Ruijven, B. J., E. De Cian, and I. S. Wing. 2019. Amplification of future energy demand growth due to climate change. Nature Communications 10:2762.

43. Rudolph, M. J. 2019. 12th Annual Survey of Emerging Risks: Key Findings. CIA, CAS, SIA Joint Risk Management Section Report.

44. MSD. 2016. State of the Streams: 2016 Water Quality Synthesis Report.

45. https://louisville.edu/greenheart

46. Center for Health Equity. 2017. Louisville Metro Health Equity Report 2017.

47. Van Holm, E. J. and C. K. Wyczalkowski. 2018. Gentrification in the wake of a hurricane: New Orleans after Katrina. Urban Studies https://doi.org/10.1177/0042098018800445.

48. Clayton, S., C. Manning, K. Krygsman, and M. Speiser. 2017. Mental health and our changing climate: Impacts, implications, and guidance. American Psychological Association and EcoAmerica. Washington D.C.

49. Heilmann, K. and M. E. Kahn. 2019. The urban crime and heat gradient in high and low poverty areas. National Bureau of Economic Research Working Paper No. 25961.