Metropolitan Council Climate Vulnerability Assessment

Narrative Report

Humphrey School of Public Affairs
Capstone Project, PA 8081, Dr. Greg Lindsey
May 2017

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PREFACE

The graduate student team from the Humphrey School of Public Affairs:

Vincent Ferguson

Vincent is pursuing a Master's of Urban and Regional Planning. He has over three years of experience working in planning and GIS for local government. Vincent is passionate about seeking equity, sustainability, and economic well-being through public policy.

Sadie Gannett

Sadie is pursuing a dual Master's of Urban and Regional Planning and Public Health, with specific interest in the intersection of climate and health. Her background is working in the housing field, helping low-income families address issues of health, energy efficiency and aging in place. She has a passion for considering the most vulnerable members of our population in planning efforts and feels strongly that good planning can improve health.

Emilie Hitch

Emilie is pursuing a Master's of Public Affairs. A classically trained anthropologist with over ten years of experience in applied anthropology for strategic planning and business development, Emilie has a passion for incorporating cultural models and knowledge into public policy and governance.

Sarah Strain

Sarah is pursuing a Master's of Urban and Regional Planning. She has a background in psychology and sociology and is passionate about social and environmental justice. She is excited about the growing attention on equity in resiliency policy and hopes to collaborate with communities in developing and adopting practices that improve quality of life for all residents.

EXECUTIVE SUMMARY

Thrive MSP 2040 prescribes policy goals for the Metropolitan Council. Namely, the document lists Sustainability as one of five desired outcomes that comprise a shared regional vision and identifies "Building in Resilience" as one of seven core land use policies. To address these two items and align with *Thrive*, the Metropolitan Council must respond to the effects of climate change in its planning and operational activities, identify and address potential vulnerabilities in regional infrastructure, and provide related information and assistance to local communities.

To fulfill these tasks, the Metropolitan Council is conducting a vulnerability assessment of assets as they relate to extreme heat events and surface flooding, which can be due to a combination of low elevations and topography as well as extreme rainfall events (intense or prolonged rainfall). As part of this larger vulnerability assessment, the Metropolitan Council asked a team of graduate students from the Humphrey School of Public Affairs to consider human vulnerability. For this report, the team has identified specific human vulnerability indicators as they relate to extreme heat, surface flooding, and the Twin Cities Metropolitan Area context and geography.

Purpose

The Metropolitan Council asked the Human Vulnerability portion of this Climate Vulnerability Assessment (CVA) address these two main questions:

1. *Which areas within the metropolitan region are most vulnerable to flooding and extreme heat?*
2. *How do these areas of vulnerability affect communities based on known socio-economic data and social vulnerability indicators?*

The team has expanded social and socio-economic vulnerability beyond their textbook definitions to better encompass the full spectrum human vulnerability and resilience. The Human Vulnerability Index developed in this report focuses on traditional vulnerability indicators such as income, race/ethnicity, and education but also addresses health, accessibility, communication, and social networks. Additionally, since extreme flooding from intense or prolonged rainfall cannot be predicted, flooding is considered solely through lower elevations and topographies, or areas that will be first to experience surface flooding should drainage fail or be absent.

Scope of Work

The Human Vulnerability portion of the CVA was informed by existing literature regarding climate, climate change and related vulnerability assessments as well as interviews with knowledgeable professionals in policy and data analysis who have conducted vulnerability assessments in Minnesota. All data used in this analysis were obtained from the Metropolitan Council, the US Census Bureau American Community Survey, and the Minnesota Department of Health.

This report uses a spatial analysis approach to examine specific human vulnerability indicators, developed and detailed in the Human Vulnerability Index, in relation to place-based climate vulnerabilities of extreme heat and surface flooding. Each human vulnerability indicator is considered on its own, as part larger vulnerability concepts like health and social networks, as part of overall human vulnerability, and in relation to extreme heat and surface flooding events. This multi-level analysis is intended to provide a deeper understanding of human vulnerabilities throughout the Twin Cities Metropolitan Areas and within smaller municipalities. Finally, this report provides added-value strategies for addressing key vulnerabilities and preparing local communities for extreme heat and flood events through adaption and mitigation strategies.

It is important to note this human vulnerability assessment is focused on people-based vulnerability, not place-based vulnerability. However, surface flooding and extreme heat events are place-based phenomena, meaning this analysis examines the current overlap of certain place-based vulnerabilities and human-based vulnerabilities. Human populations, particularly vulnerable populations, tend to be more mobile, meaning this report is a snapshot of the Twin Cities Metropolitan Area.

Strategies and Recommendations

Given the high level of this analysis and the nuance of both human vulnerability and climate event data, this report focuses on compatible mitigation and adaptation strategies for identified climate events. However, trees and stormwater management have been identified as "smart solutions" to effectively address several vulnerabilities. Recommendations for next steps in analysis, considerations, and applications are provided for the Metropolitan Council, the seven-counties of the metropolitan area, and municipalities. Including human and climate vulnerability into all Metropolitan Council departments is a crucial part of striving towards the "Sustainability" and "Equity" outcomes of THRIVE 2040.

Report and Project Deliverables

This report delivers several items to help address the research questions detailed above:

- Human Vulnerability Index to help stakeholders understand the human vulnerabilities present in populations in their areas
- Maps showing
    - areas of climate vulnerability (extreme heat and surface flooding)
    - areas of human vulnerability
    - the overlap between identified climate events and human vulnerabilities
- Mitigation and adaption strategies for the region, counties, and municipalities
- Recommendations for Next Steps

Additionally, this narrative report is part of a package of deliverables for the Human Vulnerability portion of this CVA, which includes:

- Technical Document that details processes, data, and presents all created maps
- PowePoint Presentations to assist the Metropolitan Council in communicating the processes, findings, and strategies identified in this report
- GIS spatial data of all indicators for the Twin Cities seven-county metropolitan area

INTRODUCTION

In Minnesota, severe rain storms, snow storms, and extreme heat events are projected to become increasingly frequent in the coming years. While severe weather causes problems for everyone living and working in the region, some people face greater difficulties adapting and responding to those events than others. Planning agencies from Portland to Miami are conducting climate vulnerability assessments to prepare for the future impacts of a changing global climate and of increasingly severe weather. This report details an effort by the Metropolitan Council and a team of students at the Humphrey School for Public Affairs at the University of Minnesota to do the same.

The Metropolitan Council's Climate Vulnerability Assessment (CVA) will be a tool for the Council and communities within the seven-county metropolitan region to help identify which areas are the most vulnerable to surface flooding and extreme heat. While climate change presents multiple, complex problems for human beings to address, climatic trends in this particular region show an increased incidence of extreme heat and flood-related events. Therefore, Council staff proposed limiting this study to surface flooding and extreme heat climatic events.

The Human Vulnerability portion of the Council's CVA is based on people-based vulnerability, not place-based vulnerability. However, surface flooding and extreme heat events are more place-based, so this analysis examines the current overlap of certain place-based vulnerabilities and human-based vulnerabilities. Of crucial importance to note, populations, particularly vulnerable populations, tend to be more mobile, meaning this CVA is a snapshot of the Twin Cities Metropolitan Area.

For this report, the Capstone Team has identified specific human vulnerability indicators and where the metropolitan area's vulnerable communities of people are located, and has analyzed these human vulnerabilities both on their own, and in relation to areas most susceptible to surface flooding and extreme heat. Finally, the report provides added-value recommendations for addressing key vulnerabilities and preparing local communities for extreme heat and flood events through adaption and mitigation strategies.

This report was prepared by a team of graduate students from the Humphrey School of Public Affairs at the University of Minnesota as a capstone project. The team includes graduate students in three master's programs: Master of Urban and Regional Planning (MURP), Master of Public Affairs (MPA), and Master of Public Health (MPH). The team was advised by a Humphrey School faculty member and a Council employee from the local planning division.

BACKGROUND

This human vulnerability assessment lies within a larger CVA undertaken by the Council, a 17-member regional policy-making body and planning agency. The Council provides many services in achieving its mission of "fostering efficient and economic growth" for the region. The Council's THRIVE MSP 2040 initiative was developed to help the Council as new planning challenges and opportunities arise and is defined by the Council in the following way: "THRIVE MSP 2040 is the vision for our region over the next 30 years. It reflects our concerns and aspirations, anticipates future needs in the region, and addresses our responsibility to future generations."[1]

In other words, the purpose of THRIVE MSP 2040 is to both formalize a vision *and* create a framework for achieving this vision over the next 30 years. THRIVE MSP 2040 addresses both why the vision exists - for desired outcomes in stewardship, prosperity, equity, livability, and sustainability - as well as how to work - integration, collaboration and accountability - to co-create a future desired by all who live and work in the region.

THRIVE MSP 2040 lists Sustainability as one of five desired outcomes that comprise a shared regional vision, and identifies "Building in Resilience" as one of seven core land use policies.[2] To address these two items and align with Thrive, the Council must respond to the effects of climate change in its planning and operational activities, identify and address potential vulnerabilities in regional infrastructure, and provide related information and assistance to local communities.

This report is the second CVA to come out of the Master of Urban and Regional Planning program as a capstone project, and it closely follows the methodology and structure of the previous team's work. The first CVA team was consulted for this project. The team also collaborated with professionals and experts from the Council and Minnesota Department of Health (MDH), who helped guide the creation of the social vulnerability indicators. Collaborators encouraged the team to build from existing reports of this type and to adapt it to this specific region and indicators.

Climate change presents multiple, complex problems with the potential to harm both metropolitan area residents and physical infrastructure. The most pertinent of these problems, as identified by the Council, are surface flooding and extreme heat events. As climate change

[1] Metropolitan Council, (n.d). THRIVE MSP 2040: One Vision, One Metropolitan Region. Retrieved from online source: https://metrocouncil.org/Planning/Projects/Thrive-2040.aspx
[2] Ibid.

progresses, severe heat and rainfall events are projected to occur more frequently in the contiguous 48 states. Among other indicators, weather and climate data show growing trends in the frequency of unusually hot days as well as in the percentage of yearly precipitation from intense single-day storms. Notably, nine out of the top 10 years on record for these severe single-day storms have occurred since 1990.[3] While the resulting damage to infrastructure and property burdens nearly all metropolitan area residents, certain populations are especially vulnerable due to limited income, mobility, and access to community resources.

The Metropolitan Council asked that this CVA address two main questions:

1. *Which areas within the seven-county metropolitan region are most vulnerable to present trends in extreme flooding and heat?*
2. *How do these areas of vulnerability affect communities based on known socio-economic data?*

The staff at Council has created base maps for surface flooding and heat, as well as conducted considerable research on demographics and social vulnerability. The work herein builds off their base maps using a CVA framework which was developed according to the literature and methodology outlined below.

[3] U.S. Environmental Protection Agency. 2016. *Climate Change Indicators in the United States*, 2016. Fourth edition. EPA 430-R-16-004. Web.

VULNERABILITY MODEL

Climate and weather impact not only the built environment and infrastructure, but the people who live there as well. In Minnesota, extreme rain events and extreme heat events are projected to become increasingly more frequent in the coming years. While severe weather causes problems for everyone living and working in the region, some community members face greater difficulties adapting and responding to those events than others. Understanding what areas of the region are most susceptible to extreme weather events is important, but it is critical to look at those areas in terms of the human vulnerability of the people who live there. This enhanced awareness of human vulnerability in relation to place type vulnerability will better inform adaptation and mitigation strategies for local municipalities. Peterson et al. (2014) characterize climate vulnerability in this way:

> *"Climate vulnerability depends on exposure, sensitivity, and adaptive capacity (adapted from IPCC 2012). Climate exposure is the extent and magnitude of a climate and weather event. Sensitivity is the degree to which the area of concern is susceptible to a climate impact. Adaptive capacity it the ability of the area of concern to adjust or respond to the changing conditions."*[4]

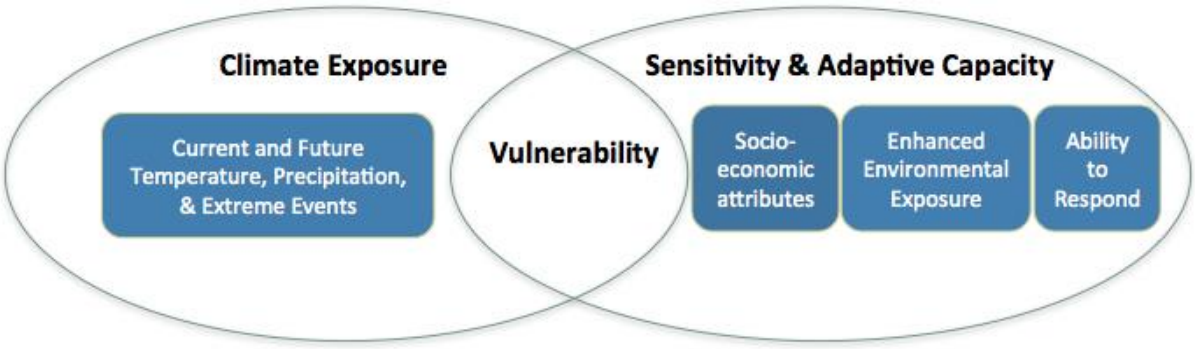

Figure 1: Climate Vulnerability Relationship to Exposure and Sensitivity

With the above model and framework informing the meaning of "vulnerability," the definition of vulnerability used in this report states:

> *"The characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard or other climate hazard".*[5]*-MDH*

[4] Petersen, A., Hals, H., Rot, B., Bell, J., Miller, I., Parks, J., Stults, M. (2014). "Climate Change and the Jamestown S'Klallam Tribe: A Customized Approach to Climate Vulnerability and Adaptation Planning." *Michigan Journal of Sustainability*, Vol. 2.

[5] Minnesota Department of Health. 2014. *Minnesota Climate Change Vulnerability Assessment 2014.* Minnesota Climate & Health Program. Web.

The ability to cope with, resist, and recover from climate events is multifaceted, encompassing both direct and indirect effects. While some populations may be better prepared for climate events themselves, they may be less equipped to handle and recover from indirect effects that arise post event. This is due in part to the ability to anticipate or see direct effects as they occur while indirect effects can arise weeks, months, or even years after the event itself. Figure 2 below from the Minnesota Department of Health illustrates some of the most pressing direct and indirect health effects of heat and precipitation climate events relevant to this Minnesota context.

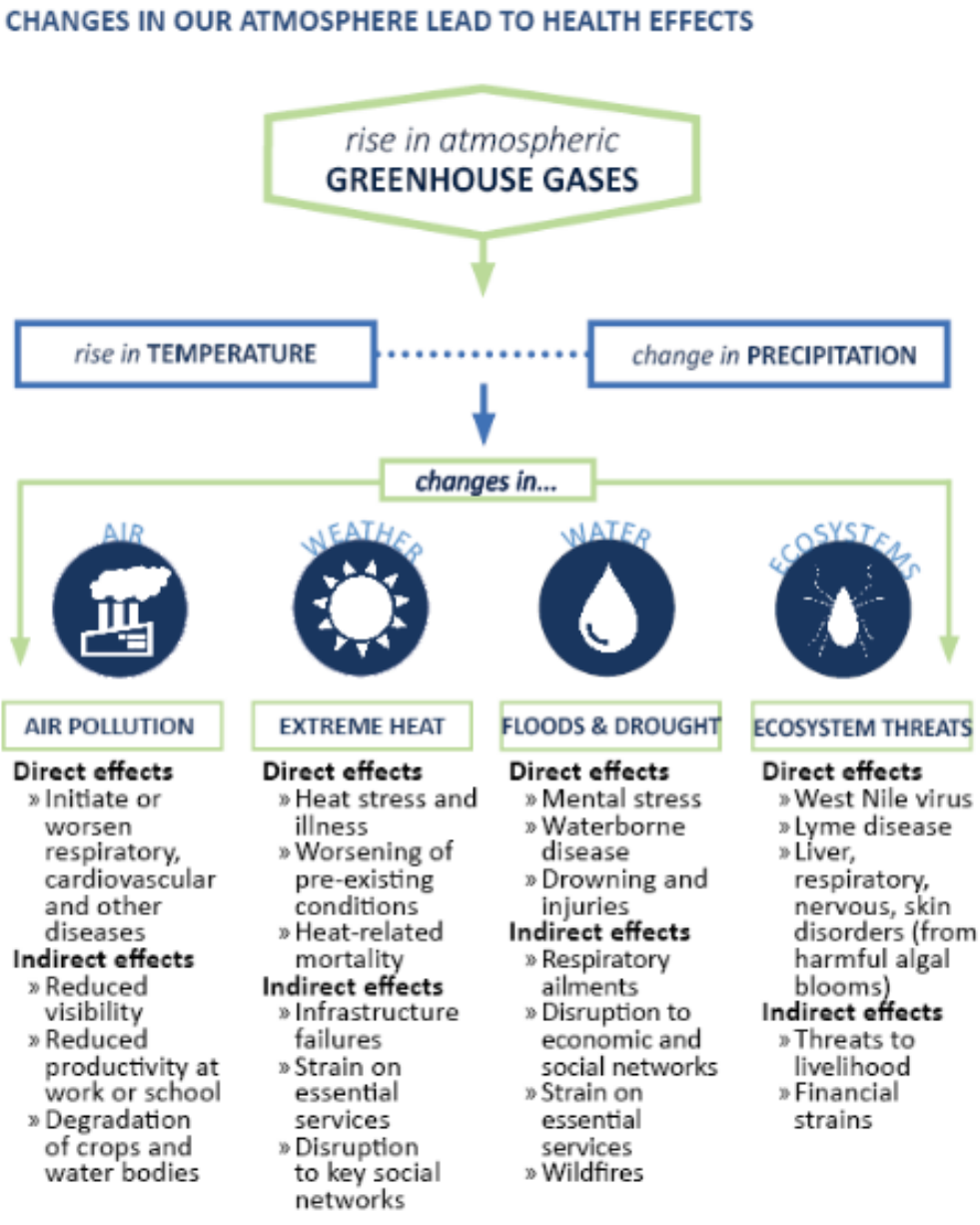

Figure 2: Minnesota Department of Health, http://www.health.state.mn.us/divs/climatechange/climate101

METHODOLOGY

The team assessed climate vulnerability as the sum of two main factors: climate exposure (represented by the Council's base maps of flooding and heat) and human sensitivity or vulnerability. To create a human vulnerability index, the team conducted considerable research on demographics and social vulnerability, and identified a set of human vulnerability indicators. These selected indicators were then organized into a conceptual framework specific to the metropolitan region. For a review of the indicators found in the literature, see Appendix A: Master List of Indicators.

The team created maps using spatial data for both climate events and human vulnerability. This mapping was done by overlaying extreme heat and surface flooding layers with human vulnerability layers to identify the areas with the greatest overlap of climate exposure and human vulnerability. The team conducted a county-by-county, visual analysis of these maps, and created a list of strategies and next steps. The specific methods leading to the identification of the human vulnerability indicators and development of the conceptual framework included the following:

- **Literature Review:** A brief review of existing literature and other CVAs was conducted to look at the social vulnerability indices that have been created and used elsewhere. Additional attention was given to Minnesota, heat, or flooding focused assessments. (See Appendix B: Indicators Used in Existing Minnesota CVA Reports)

- **Key Informant Interviews:** The team conducted key informant interviews with professionals from the Council, Minnesota Department of Health, and the project team that completed a CVA for the City of Minneapolis. These interviews focused on gathering input on how to create indices for social vulnerability as well as identify opportunities unique to this specific CVA. These individuals were involved with the production of similar documents and were asked for guidance regarding correlates, determinants of vulnerability, and lessons learned. Each interview/conversation lasted an average of one hour and was free flowing. The team took notes and extracted information to inform the selection of indicators along with other sources as detailed in Appendix A: Master List of Indicators.

- **Secondary Data Analysis:** Secondary data sources were used to map the social vulnerability indices within the seven-county metropolitan region. All demographic data were obtained from the American Community Survey, 2011-2015 census. Some health data were obtained from Minnesota Department of Health. The team compared and

created indicator maps of human vulnerability concepts with the existing base maps for flood and heat vulnerability. This level of comparison allowed an assessment of regional human population vulnerability in relation to climate event impacts.

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LITERATURE REVIEW

A brief review of existing literature and other CVAs was conducted to look at other vulnerability indices that deal with social, or people-based, factors which have been created and used elsewhere in relation to heat and flooding.

The literature regarding climate, climate change, and vulnerability assessments has grown substantially over the past 10 years. CVAs are being conducted by governing bodies at varying scopes and scales more frequently as opposed to being strictly academic endeavors. This expansion of scope increases the pool of resources, references, and ideas for developing CVAs. However, the Metropolitan Council is a unique governing body in a Midwestern state, making some CVA variables and methodologies more relevant than others. Therefore, the literature review began with Minnesotan and regional CVAs. Additionally, the team looked more specifically at heat and flooding vulnerabilities in CVAs; other studies also included air quality, sea level rise, and storm surge vulnerability, the latter of which are not pertinent to the Twin Cities' geography.

Climate Vulnerability Assessments –Geographic Location in the Metropolitan Region

Three notable CVAs conducted in Minnesota are the Minneapolis Climate Change Vulnerability Assessment, the St. Paul-Ramsey County Public Health Climate Change Vulnerability Assessment, and the Minnesota Department of Health Climate Change Vulnerability Assessment. These three reports focus on issues relevant to Minnesota and provide insight as to what data are available through state resources as well as what kinds of possibilities exist for varying geographical level of analysis within the state. A full list of the vulnerability indicators considered by these reports, which were most influential in shaping the human vulnerability indicators in this analysis, is detailed in Appendix B: Indicators Used in Existing Minnesota CVA Reports.

The Minneapolis Climate Change Vulnerability Assessment[6]

Completed in May 2016, this assessment examined urban heat island "hotspots" and flood vulnerable areas of the city. These geographic and infrastructure variables were compared alongside health and social vulnerabilities, specified in Appendix A. While finer geographies were available for analysis, the data also have higher margins of error. Ultimately, census tracts were used to decrease the margin of error and to better mimic the spatial breakdowns of

[6] Minneapolis, Minnesota. 2016. *Technical Report: Minneapolis Climate Change Vulnerability Assessment.*

neighborhoods in Minneapolis. Of all the literature reviewed, the Minneapolis CVA matched most closely with the climate and human variables relevant to the CVA for the Council.

The St. Paul-Ramsey County Public Health CVA (SPRCCVA)[7]

Published in April 2016, the SPRCCVA was conducted at a county level, better suiting the Council's scale of analysis, but it focused more on ecological changes relating to health. Additionally, the report discussed future population and demographic projections and their potential influence in creating climate action plans and reducing vulnerability, fitting within the Council's regional responsibilities.

Vulnerability in the SPRCCVA was defined through five overarching categories: socioeconomic status, age, barriers to communication, mobility, and "additional factors," including variables like housing and outdoor employment. These categories were each made up a couple of components supported by nationally available data. The components within each vulnerability category are also furthered detailed in Appendix A: Master List of Indicators.

The Minnesota Department of Health Climate Vulnerability Assessment[8]

Published in 2014, the MDH assessment focused on potential health impacts and changing ecological conditions statewide. As part of their methodology, MDH staff conducted a thorough literature review, capturing large and significant CVA research prior to 2013. This literature review provided a foundation for the literature review in this report, allowing the focus to remain on studies and reports completed from 2014 through present day. The MDH report is thorough both in terms of the breadth of climate issues discussed and how vulnerable populations are identified for each climate event. The MDH research provides highly information to officials (as opposed to grouping all vulnerable populations for all climate events into one "vulnerable population" measure). Appendix A further details MDH's vulnerability variables for extreme heat and flooding, the climate events of interest in the Council's CVA.

However, the data in the MDH report are limited by the scale of analysis. Performing a statewide analysis led to the use of county-level data. Counties with lower populations typically do not have reliable data at smaller scales, particularly for American Community Survey data. The thoroughness and breadth of MDH's work could be applied to a smaller geography where reliable data are available.

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[7] Ramsey County. 2016. *Saint Paul-Ramsey County Public Health Climate Change Vulnerability Assessment.* Web.

[8] Minnesota Department of Health. 2014. *Minnesota Climate Change Vulnerability Assessment 2014.* Minnesota Climate & Health Program. Web.

Vulnerability Assessments – Academic

From the academic cannon of vulnerability assessments, Cutter et. al[9] is a widely cited, thorough analysis of social vulnerability factors. The all-encompassing nature of the definition of vulnerability therein lends itself well to most climate events. Now standard in the field of climate vulnerability and adaptation, the work has been cited over 900 times (including within the above Minnesotan CVAs). Binita et. al[10] have fewer vulnerability variables than Cutter et. al but enrich the analysis by considering "adaptive capacity." They argue an area may be home to more vulnerable populations but also have assets to mitigate climate events, decreasing overall vulnerability. Binita et. al consider physician to population ratio, educational attainment, per capita income, and acreage of irrigated land to be useful in adapting during and after a climate event.[11] In their analysis, these variables were added together to create an adaptive capacity score that was subtracted from the total vulnerability index. Acknowledging adaptive capacity and community assets can help to better target intervention and mitigation efforts in vulnerable communities with less adaptive capacity and resources. This point is of particular interest as it better encapsulates the lived realities of an area and offers a starting point from which recommendations and mitigation actions can arise.

Most of the CVAs reviewed, regardless of origin or geography, aggregated variables to create composite vulnerability scores – as opposed to other, more sophisticated methods of analysis. This procedure is conducted, and in many cases preferred, for a few reasons. First, it is the easiest method to explain, particularly if the data are intended to be shared with the general public. As much of the data are presented in map forms, it is easy to explain that darker areas on the map have more vulnerability indicators, as adding several colors (aggregating several layers) on top of each other produces darker color. This technique was used by all the CVA reports examined for the literature review. Second, reports that performed other methods of analysis found few differences between the aggregate results and their statistical modeling results. For example, the Minneapolis CVA performed an aggregate and a principal component method (with higher level statistics) analysis for their report[12] and found few differences; the Minneapolis project team advised against using a principal component method for this analysis. Third, running statistical models creates a confidence interval or margin of error. Depending on the geographical level of analysis and specificity of vulnerable population, the original data already had higher margins of error than typically desired. Creating another margin of error on

[9] Cutter, S. L., Boruff, F. J., and Shirley, W. L. 2003 "Social Vulnerability to Environmental Hazards." *Social Science Quarterly,* Vol 84(2), pp 242-264. DOI: 10.1111/1540-6237.8402002

[10] Binita, KC. Marshall Shepherd & Cassandra Johnson Gaither. 2015. "Climate change vulnerability assessment in Georgia." *Applied Geography* Vol 62, pp 62-74.

[11] Ibid.

[12] Minneapolis, Minnesota. 2016. Technical Report: Minneapolis Climate Change Vulnerability Assessment.

top of already sensitive data draws questions to the metadata and can impact results. It is important to note that in aggregating measures, some CVAs better controlled for duplication and correlation; for example, both MDH[13] and Ramsey County[14] consider "population over 65 living alone" and "population over 65" in their analysis, counting some elderly populations twice. The potential to count variables twice, which gives them more weight in the overall analysis, was an element discussed in detail during the development of the methodology used herein.

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[13] Minnesota Department of Health. 2014. *Minnesota Climate Change Vulnerability Assessment 2014.* Minnesota Climate & Health Program (health.mn.gov/climatechange/)

[14] Ramsey County. April 2016. *Saint Paul-Ramsey County Public Health Climate Change Vulnerability Assessment.*

DEVELOPMENT OF INDICATORS

The meaning of Vulnerability, as distilled down from various definitions throughout the literature review, is the increased probability of being harmed, or being disproportionately at risk to harm, from a set of phenomena. In the context of this project, the selected phenomena are associated with changes in climate. Therefore, this conceptual framework is meant to communicate which characteristics put humans disproportionately at risk to environmental change - specifically, extreme heat and surface flood events.

MASTER LIST OF INDICATORS

As indicated previously, a master list of all CVA indicators used in reports and literature reviewed for this report was developed. The team incorporated information from key informants by comparing indicators found in other studies to the information reinforced in the interviews. The master list of indicators extracted from the literature review, as well as from interviews, can be seen in Appendix A: Master List of Indicators. A few key observations and points of analysis from the master list of indicators can be found in Table 1 below.

Table 1: Key Findings from Literature Review of Indicators	
Indicators most frequently used:	Age > 65 years
	Age < 5 years
	Race/ People of Color
	Renters
	Poverty (though different thresholds used; 185%, 200%, households with children, etc.)
Indicators not frequently used, but interesting in the context of this study:	Unemployed
	Disability

PROCESS OF INDICATOR EVALUATION

Criteria, developed by the team and detailed below, were systematically applied to the master list of indicators (Appendix A: Master List of Indicators), narrowing the team's focus and assisting in the development of an index appropriate to the context of the Council's CVA.

Criteria for selection of the indicators themselves are described below:

- Can the team justify this indicator with logical and relevant rationale?
    - Is this indicator consistent across multiple sources?

- Is this factor relevant and interesting when thinking through vulnerability in heat and/or flood events?
- Does this indicator push the envelope for this specific phenomena and/or geographic region? Meaning, is it something other studies have not looked at in this context or considered at all?

- Does the team have the data?
  - Reliable source
  - Readily available source
  - Relatively easy to use
  - Census tract level data

- Does the team think this indicator is relevant to the Twin Cities geography?

THE HUMAN VULNERABILITY INDEX

The team systematically discussed each of the indicators in the master list, and associations between some of the indicators began to emerge. The team thus experimented with organizing the indicators in various ways according to how they might be bundled into meaningful categories based on how people live their lives and behave in their particular cultural context and geographic places.

The human vulnerability index was finalized through the above-mentioned process of experimentation once the team had reorganized the indicators found in the literature and used in this analysis to develop concepts (bundling meaningfully related indicators together) and identify which indicators would stand alone as individual "concepts," referred to here as direct indicators. The team decided that a direct indicator for the index herein is a standalone variable that is significant to both the Council's THRIVE 2040 framework and relevant CVA and vulnerability literature from other disciplines. In this analysis, then, concepts labeled as direct indicators are Poverty (percent below 185% federal threshold) and People of Color (percent residents of color). Through the literature review of both climate vulnerability and non-climate (social science) research, these variables were found to be stand-alone determining factors for disadvantage and vulnerability (see Appendix A: Master List of Indicators for the sources reviewed for this purpose), often intersecting, and/or correlated, with other factors. Unlike some of indirect indicators within the conceptual "bundles," direct indicators do not need to be part of a larger lifestyle picture to greatly influence vulnerability and disadvantage. Additionally, these variables are often requested to be examined on their own because of their connections to equity initiatives.

Bundles incorporate multiple relevant indicators to form one concept. For example, the Health concept is a bundle comprised of four indirect indicators: children 5 years and younger, adults 65 years and older, asthma hospitalizations, and chronic obstructive pulmonary disease (COPD) hospitalizations. However, this approach of both bundling indicators and using direct indicators posed a challenge for developing an even, fair composite/overall vulnerability score. Bundled concepts, having multiple indicators, have a larger range of possible values in a vulnerability index than a sole direct indicator; this causes the bundle to have more weight in the overall/aggregate vulnerability index, which is unfair and potentially misguiding of true human vulnerabilities. To ensure all concepts had the same weight in the final analysis, each bundled vulnerability concept was reclassified to a five-point scale using quintiles.

Six final concepts were developed for this CVA: Social Network, Health, Accessibility, Communication, Poverty, and People of Color. These six final concepts form the framework of human vulnerability as shown in Figure 3: Conceptual Framework of Human Vulnerability for Metropolitan Council CVA.

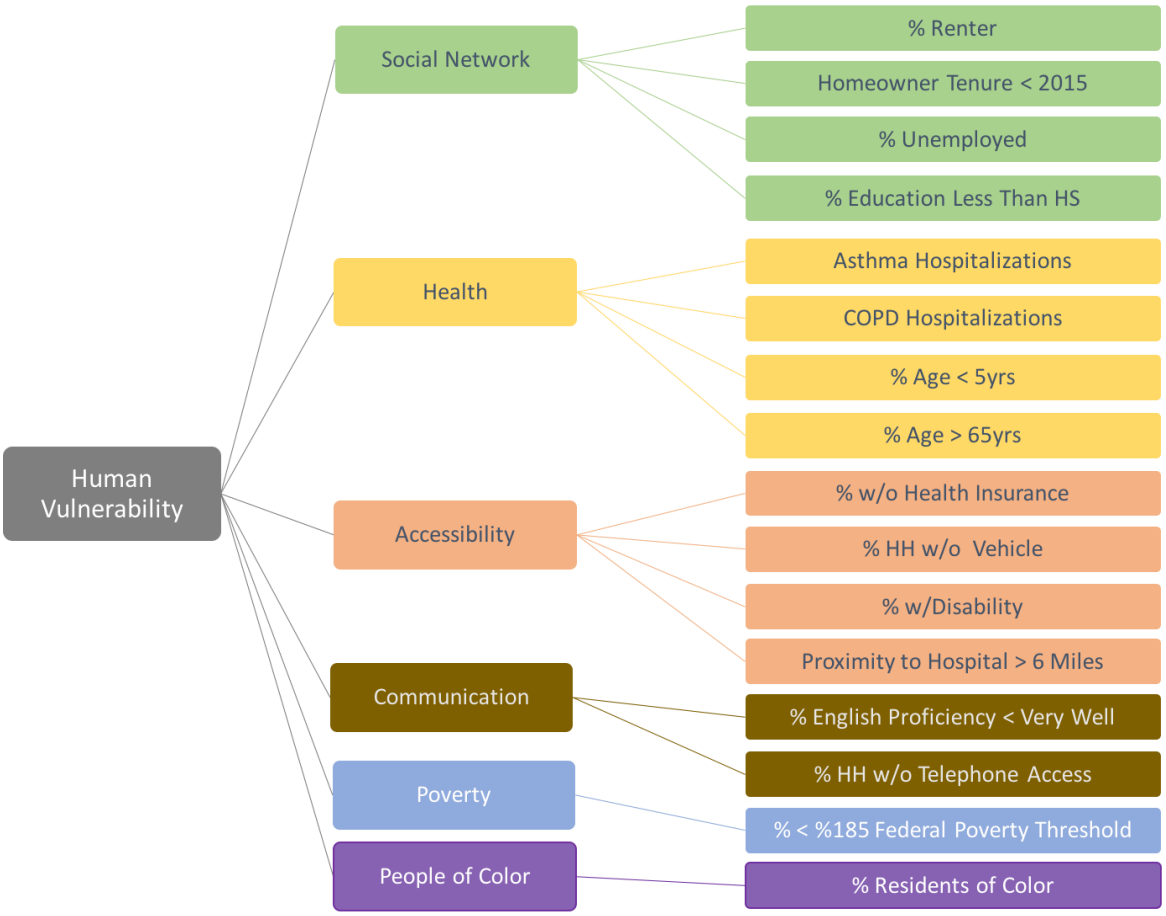


Figure 3: Conceptual Framework of Human Vulnerability for Metropolitan Council CVA

Table 2 below gives further detail on the concepts and indicators selected, their level of analysis, and the data source.

Table 2: Human Vulnerability Indicators		
Vulnerability Indicator	**Level of Analysis**	**Source**
Human Vulnerability: all indicators	Census Tract and modified zip code	All Listed Sources
Social Network		
% Renter	Census Tract	ACS 5yr, 2011-2015
Tenure < 5 years	Census Tract	ACS 5yr, 2011-2015
Unemployment	Census Tract	ACS 5yr, 2011-2015
% < High School Degree	Census Tract	ACS 5yr, 2011-2015
Health		
Age <5 years	Census Tract	ACS 5yr, 2011-2015
Age > 65 years	Census Tract	ACS 5yr, 2011-2015
ER visits: Asthma	Census Tract modified zip code	MDH, ZIP code 2009-2013
Hospital: COPD	Census Tract modified zip code	MDH, COPD ZIP code 2010-2014
Accessibility		
Health Insurance	Census Tract	ACS 5yr, 2011-2015
Car Ownership	Census Tract	ACS 5yr, 2011-2015
Disability	Census Tract	ACS 5yr, 2011-2015
Proximity to Hospitals	Census Tract	Hennepin County GIS open data
Communication		
English Proficiency; less than very well	Census Tract	ACS 5yr, 2011-2015
Telephone	Census Tract	ACS 5yr, 2011-2015
Poverty		
% < 185%	Census Tract	ACS 5yr, 2011-2015
People of Color		
% residents of color	Census Tract	ACS 5yr, 2011-2015

The team's list of indicators and concepts went through multiple rounds of selection and re-organization. Each draft was presented to the Council for review and feedback. At the final draft stage, the list of indicators selected was also submitted to staff at Minnesota Department of Health for review and feedback. Each reviewer made suggestions for improvement which were incorporated in subsequent drafts. Documentation of discarded indicators is included Appendix C: Drafts of Human Vulnerability Indicators

Index Development Processes of Note:

- The team wanted to include some measure of civic engagement to add strength to the community cohesion category, but reliable data at the census tract level were not available.
- The team originally developed a concept called "Equity" as to align with the THRIVE MSP 2040 principles within the outcome labeled "Equity" (race, ethnicity, income, and ability)[15]. However, as to avoid double counting with indicators in other concepts of the conceptual framework, the team made the methodological choice to include these indicators by utilizing them separately as either direct indicators/concepts or within the most relevant concept in the framework. Equity, in this framework, is not treated as a stand-alone concept. Instead, the team thought of the lived experiences of race, ethnicity, income, and ability as spread throughout people's lives and, therefore, purposefully positioned as intersecting with almost all the categories of human vulnerability comprising the framework presented in this report. Equity is being further addressed by defining "most vulnerable" populations through this Human Vulnerability Index. Identifying vulnerable populations and their locations in the seven-county metropolitan area allows for targeted mitigation and adaptation efforts, reducing inequities in vulnerability.
- At one time, the team developed a concept of "socio-economic status" as seen in reviewed literature.[16] The most common bundles of indicators for "socio-economics" include race, income, and employment. The team "unpacked" these indicators for the following reasons given the focus on extreme heat and surface flooding:
    - Race and income are strong indicators of vulnerability and should be examined as stand-alone, direct indicators.

[15] Metropolitan Council, (n.d.). THRIVE MSP 2040: EQUITY. Retrieved from online source: https://metrocouncil.org/Planning/Projects/Thrive-2040/Thrive-Indicator-Dashboard/Equity.aspx?source=child

[16] Cutter, S. L., Boruff, F. J., and Shirley, W. L. 2003 "Social Vulnerability to Environmental Hazards." *Social Science Quarterly,* Vol 84(2), pp 242-264. DOI: 10.1111/1540-6237.8402002

- The team decided “employment” fit best in the Social Network concept as it indicates connection with a network of people other than family and friends who could be supportive in an emergency.

After developing this index, the team mapped the data against the base maps for surface flooding and extreme heat events provided by the Council, and analyzed the findings.

METHODOLOGY FOR EXTREME HEAT AND SURFACE FLOODING BASE MAPS

This section explains how the Metropolitan Council developed the base maps used for the analysis of surface flooding and extreme heat.

Metropolitan Council Climate Vulnerability Assessment Heat Layers

The Metropolitan Council CVA examines which areas are most vulnerable to extreme heat events. The Council’s assessment produced three products examining regional vulnerability to extreme heat: land surface temperature, heat hazard index, and interpolated air temperature. This analysis utilized only the heat hazard index, for reasons described below.

Land Surface Temperature

The Council provided a map of land surface temperature (LST) using a satellite image from Landsat 8. This map shows the land surface temperature in degrees Fahrenheit, normalized by census tract, for the seven-county metropolitan region of the Twin Cities. The satellite image used for this map was taken at 11:59 am CDT on July 22, 2016. At that time, the air temperature was 90°F with a heat index of 90.3°F, as recorded from the Minneapolis-St. Paul International Airport. This day was the third day of a regional heat wave, which is defined by a period of three or more days with temperatures at or above 90°F. The overnight temperatures dipped down to around 74°F by roughly 5 a.m., but climbed up to a maximum temperature of 97°F by around 5-6pm. This climb resulted in a mean temperature of 86°F and minimum temperature of 74°F. The last time temperatures had risen to 97°F was on August 26, 2013, so July 22nd, 2016 was the hottest day in roughly three years.[17] The original thermal image was taken at a 100 x 100-meter resolution, but was re-scaled and processed with NDVI data at the 30 x 30-meter scale.[18]

The map package includes three layers at this scale:

1. Land surface temperature from noon, July 22, 2016, without regional water bodies.
2. Land surface temperature with regional water bodies.

[17] Midwestern Regional Climate Center, 2016. Daily data between two dates – Minneapolis/St. Paul Airport. Web.
[18] The Metropolitan Council, (2017). *Metropolitan Council Vulnerability Assessment Heat Layers.*

3. A layer highlighting the areas with LST values at or above the second deviation above the mean (calculated from the map without water bodies), broken up by natural breaks.

Land Surface Temperature (LST) values without regional water bodies were the primary basis for the Council's heat hazard index. Regional water bodies were removed from the data set because water has different heat retention properties than most land surfaces, and thus would have reduced the accuracy of land surface and air temperature calculations. Since the lowest original LST values were water bodies, their removal raised the minimum LST value by 0.6°F. While this change may seem insignificant, the effect is potentially more substantial when the temperatures are normalized by census tract in the third layer of this package.[19]

Heat Hazard Index

The Council's assessment converted mean census tract LST values into a heat hazard index of five equal intervals, as described in the excerpt from the Council's documentation below. This heat hazard index census tract layer formed the basis of this analysis's heat-related vulnerability assessment.

> "Following examples from heat risk assessments done in Birmingham, England and Rennes, France, our Heat Hazard Index Map aggregated LST values from July 22, 2016 (without water bodies-- the first map in the first product) to the census tract.[20,21] These mean LST values for each census tract were then normalized to a scale of 0 – 1, which was subsequently broken down into five equal intervals and displayed as range between "Very Low" (0 - 0.2) to "Very High" (0.8 - 1)."[22]

Interpolated Air Temperature

The Air Temperature Map provides a map of air temperature for 12 pm CDT, July 22, 2016, courtesy of the University of Minnesota. The data represent one of the largest metropolitan air-sensor networks in the country. The sensors were placed in volunteers' backyards, with its densest network concentration by the urban core, and progressively few sensors the farther away from the urban core; these more distant censors were also father apart from each other. All the sensors were placed in grassy areas to keep the baseline relatively similar. As such, no sensors were placed in downtown Minneapolis or St. Paul. The network provides temperatures

[19] The Metropolitan Council, ibid.
[20] Tomlinson, C. J., Chapman, L., Thornes, J. E., & Baker, C. J. (2011). "Including the urban heat island in spatial heat health risk assessment strategies: a case study for Birmingham, UK." *International Journal of Health Geographics*, 10(1), 42.
[21] Buscail, C., Upegui, E., & Viel, J. (2012). "Mapping heatwave health risk at the community level for public health action." *International Journal of Health Geographics*, 11(1), 38.
[22] The Metropolitan Council, ibid.

at each volunteer's location from which, based off those points, a generalized map estimating the temperatures between the points was created. This map represents an estimation of the heat impacts that people would likely have experienced throughout the metropolitan area.

Strengths and Weaknesses of Each Approach

The LST-based index was used for this analysis instead of interpolated air temperature because peer-reviewed research has demonstrated that LST is a more reliable metric for human temperature exposure and stable long-term temperature trends. From the Council's 2017 heat layer documentation:

> "As White-Newsome et al. (2013) discuss, "LST is better suited for representing physical properties that are stable over time and can affect human temperature exposure rather than as a proxy for actual ambient air temperature at a particular point in time" (p. 929). In the ideal world, we would be using *in-situ* measurements equidistant throughout the entire region. However, at the present moment, that is impossible and so, in order to get the best temporal and spatial quality data, we have to use satellite data. Though the relationship between LST and air temperature is not fully understood, the use of satellite imagery to map the spatial extent of the urban heat island effect is common practice.[23]"[24]

Interpolated air temperature, in contrast, approximates the temperatures that residents feel on a daily basis. As a result, air temperature maps may be preferable to LST when communicating with the public about the urban heat island effect.

> "The Air Temperature Map is very useful as an intuitive visual prompt for an audience, but should be used with caution when analyzing a local area. The variable density of the sensor network means that the map's resolution is lower than what is possible with satellite imagery (such as in the other maps), and the sensor placement in grassy areas means that the air temperature estimates are cooler and more conservative than perhaps what was felt that day."[25]

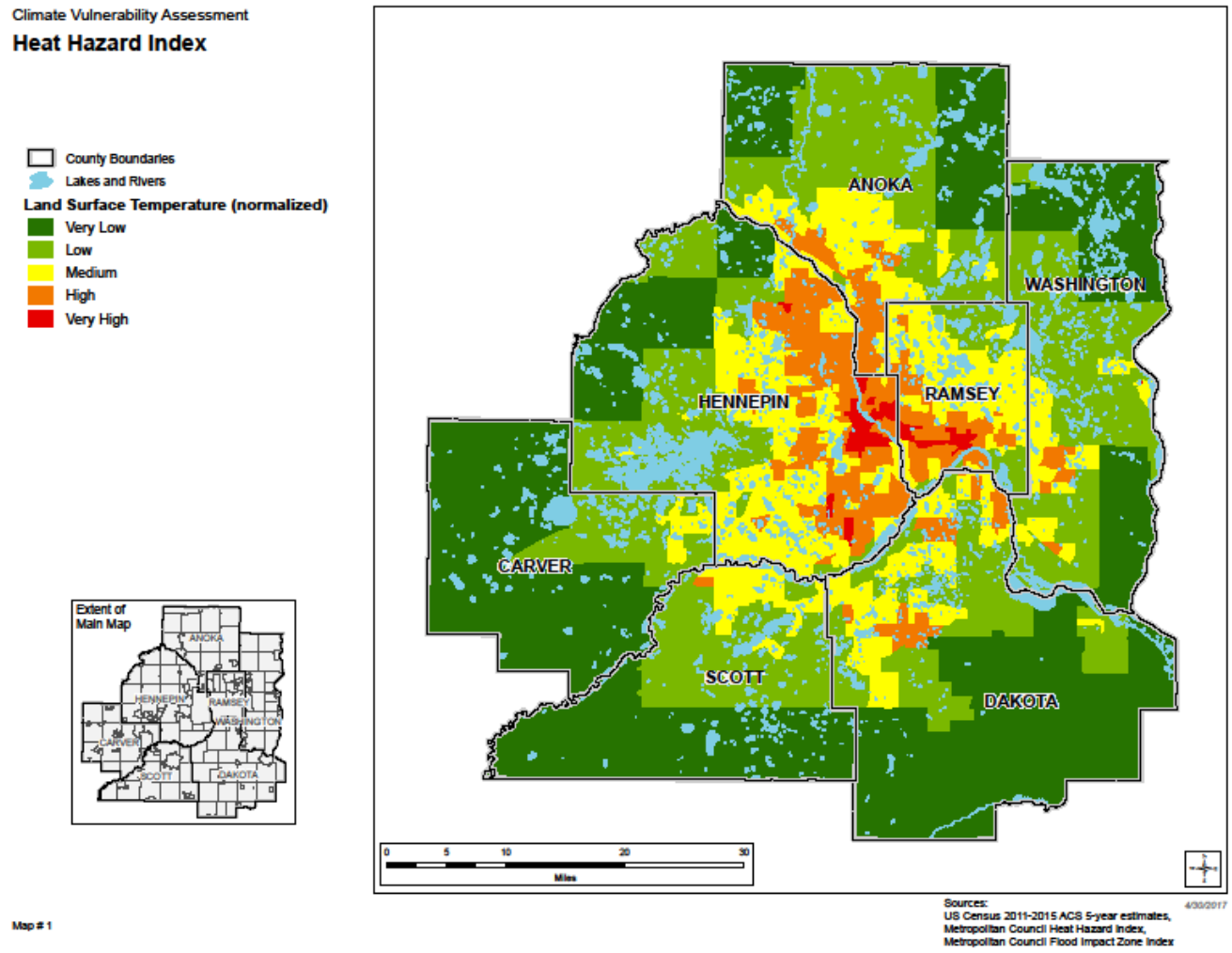
One significant caveat of this approach is that the heat hazard is underestimated in small towns and rural population centers. A small town located in a large rural census tract could have a substantial heat island effect, but the average index value for the tract would remain relatively

[23] Tomlinson, C. J., Chapman, L., Thornes, J. E., & Baker, C. J. (2011). "Including the urban heat island in spatial heat health risk assessment strategies: a case study for Birmingham, UK." *International Journal of Health Geographics*, 10(1), 42.
[24] The Metropolitan Council, ibid.
[25] The Metropolitan Council, ibid.

low. However, because much of the human vulnerability data relevant to this assessment were not available in units smaller than the census tract, it was necessary to keep census tracts as the unit of analysis. *Those using this report in the context of rural population centers should refer to the 30 x 30 meter LST map to better evaluate residents' exposure and vulnerability to extreme heat.*

Heat Hazard Index Map

The heat base map used for this analysis is shown below as "Heat Hazard Index." As described above, it was provided by the Council and shows land surface temperature (LST) normalized by census tract.



Map 1: Heat Hazard Index Map

Metropolitan Council Climate Vulnerability Assessment Flood Layers

The Council gathered data on two types of flooding: riverine and shallow/surface flooding. For this CVA, the analysis looked only at shallow/surface flooding at a depth of 1 foot or greater as the team was informed by the Council that these areas are the most susceptible to flooding and the most likely to occur in an extreme rain event. As per the direction of the Council again, riverine flooding was not used as policies are already in place to prevent development in floodplains, and there is typically more warning when rivers flood, which allows populations to adapt and prepare.

To develop their surface flooding methodology, the Council followed an example from the Danish Road Institute which evaluated surface flooding and short-term flooding low spots on the landscape. The Danish Road Institute referred to these areas as bluespots,[26] which are the areas that are the most susceptible to flooding during a short-term, extreme rain event. The bluespot analysis conducted by the Council relied on topography information obtained from the State of Minnesota's 3-meter digital elevation model (DEM), which was built from the state's LiDAR effort. It should be noted that stormwater infrastructure data are not included in this analysis as that information does not currently exist at a regional scale. Therefore, this analysis is restricted solely to depressions in the DEM and not actual pooling or drainage. Low points in the landscape are identified using the hydrology toolset within Spatial Analyst of ArcGIS 10.3.1, from which maximum water rise is determined for each bluespot as well as the surface area that will flood when the water in a bluespot rises to a certain height. The Council's assessment divided bluespots into four categories, arranged from least hazard to greatest: Shallow, Tertiary, Secondary, and Primary. These categories are described in further detail in the Technical Document of this report, as well as in the Council's 2017 flood layer documentation.[27]

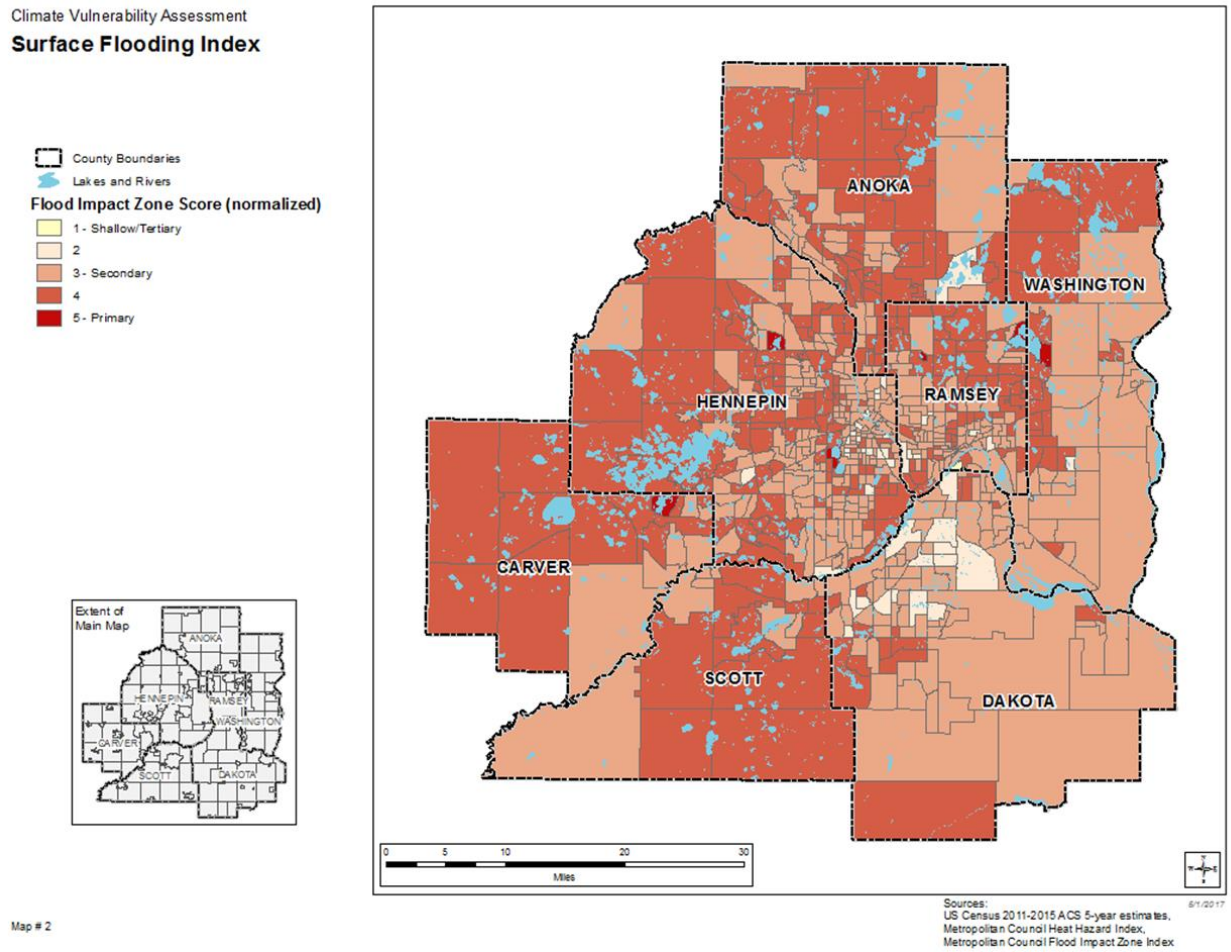
Surface Flooding Index

The Surface Flooding Index map, shown below, represents the "bluespot" or Flood Impact Zone categories in numerical form and normalized by census tract. Shallow and Tertiary spots were assigned a value of 1 due to the low hazard posed to humans and vehicles. Secondary spots were assigned a value of 3 due to their mid-level hazard and likelihood of flooding, and Primary spots were assigned a 5 due to their high hazard and high likelihood of flooding. While it is worth noting that fast-moving shallow water can carry away a human or car, it is unlikely that a significant portion of the shallow bluespots would cause such rapidly moving flood water.

[26] Danish Road Institute. 2010. *The Blue Spot Method: Development of a Screening Method to Assess Flood Risk on Highways*. Report 183-2010.

[27] The Metropolitan Council, (2017). *Metropolitan Council Vulnerability Assessment Flood Layers.*

Instead, deeper spots would be more likely to cause more rapid, forceful flow than spots with a maximum depth of one foot or less.



Map 2: Surface Flooding Index

DATA PREPARATION AND MAP CREATION

All demographic data were downloaded from the US Census Bureau 2011-2015 5-year American Community Survey for all census tracts within the seven-county metropolitan region. Census tracts were selected as the level of spatial analysis because they offer a finer level of detail than city-level data while having lower margins of error than block group data. Additionally, given regional approach to this analysis, block group data were very similar to census tract data for most suburban and rural communities. Unfortunately, census tracts in outer suburban and rural areas are large, which limits the level of detail and analysis that could be provided.

The Census data were then formatted to facilitate the conversion to spatial association in ArcGIS software, including the assignment of Field Names that fit the parameters of ArcGIS software. The formatted tables of census data were joined to census tract shapefiles using the GeoID field (a unique code assigned to each tract by the Census bureau). All hospitalization data were downloaded from the Minnesota Department of Health Data Portal. Zip code level was the finest data geography publicly available, which does not align with census tracts. As a result, the zip code data needed to be converted to the census tract format. The team used the "Create Random Points" and "Zonal Statistics" tools in ArcGIS to approximate the number of hospitalizations in each census tract, based on the number in each zip code. For more detail, refer to the Technical Document under Appendix A: GIS Processes Step-By-Step.

All social and health data are presented as a percentage of total census tract population. This method helps to balance the differences in populations between census tracts and provide context within each census tract.

MASTER LIST OF MAPS

The team created 32 maps in total, which are detailed in Table 3. Please refer to the Technical Document to see the individual maps. A sample set of maps is provided in the next section.

Table 3: Master List of Maps

Map #	Vulnerability Indicator	Data Source	Map Color Designation
1	Heat Hazard Index	Metropolitan Council	Red
2	Surface Flooding Index	Metropolitan Council	Blue
3	Accessibility - Disability	ACS 5yr 2011-2015	Orange
4	Accessibility - Health Insurance	ACS 5yr 2011-2015	Orange
5	Accessibility - Hospital Proximity	ACS 5yr 2011-2015	Orange
6	Accessibility - Vehicle Access	ACS 5yr 2011-2015	Orange
7	Communication - English Proficiency	ACS 5yr 2011-2015	Brown
8	Communication - Phone Access	ACS 5yr 2011-2015	Brown
9	Health - Age 5 and under	ACS 5yr 2011-2015	Yellow
10	Health - Age 65 and over	ACS 5yr 2011-2015	Yellow
11	Health - Asthma Hospitalization	ACS 5yr 2011-2015, MDH Zip Code 2009-2013	Yellow
12	Health - COPD Hospitalization	ACS 5yr 2011-2015, MDH Zip Code 2010-2014	Yellow
13	Poverty	ACS 5yr 2011-2015	Cyan
14	Residents of Color	ACS 5yr 2011-2015	Purple
15	Social Network - Education	ACS 5yr 2011-2015	Green
16	Social Network - Homeowner Tenure	ACS 5yr 2011-2015	Green
17	Social Network - Renter-occupied households	ACS 5yr 2011-2015	Green
18	Social Network - Unemployment	ACS 5yr 2011-2015	Green
19	Aggregate - Heat and Accessibility	ACS 5yr 2011-2015, Metropolitan Council	Orange
20	Aggregate - Heat and Communication	ACS 5yr 2011-2015, Metropolitan Council	Brown
21	Aggregate - Heat and Health	ACS 5yr 2011-2015, MDH Zip Code, Metropolitan Council	Yellow
22	Aggregate - Heat and Poverty	ACS 5yr 2011-2015, Metropolitan Council	Cyan
23	Aggregate - Heat and Residents of Color	ACS 5yr 2011-2015, Metropolitan Council	Purple
24	Aggregate - Heat and Social	ACS 5yr, 2011-2015, Metropolitan Council	Green

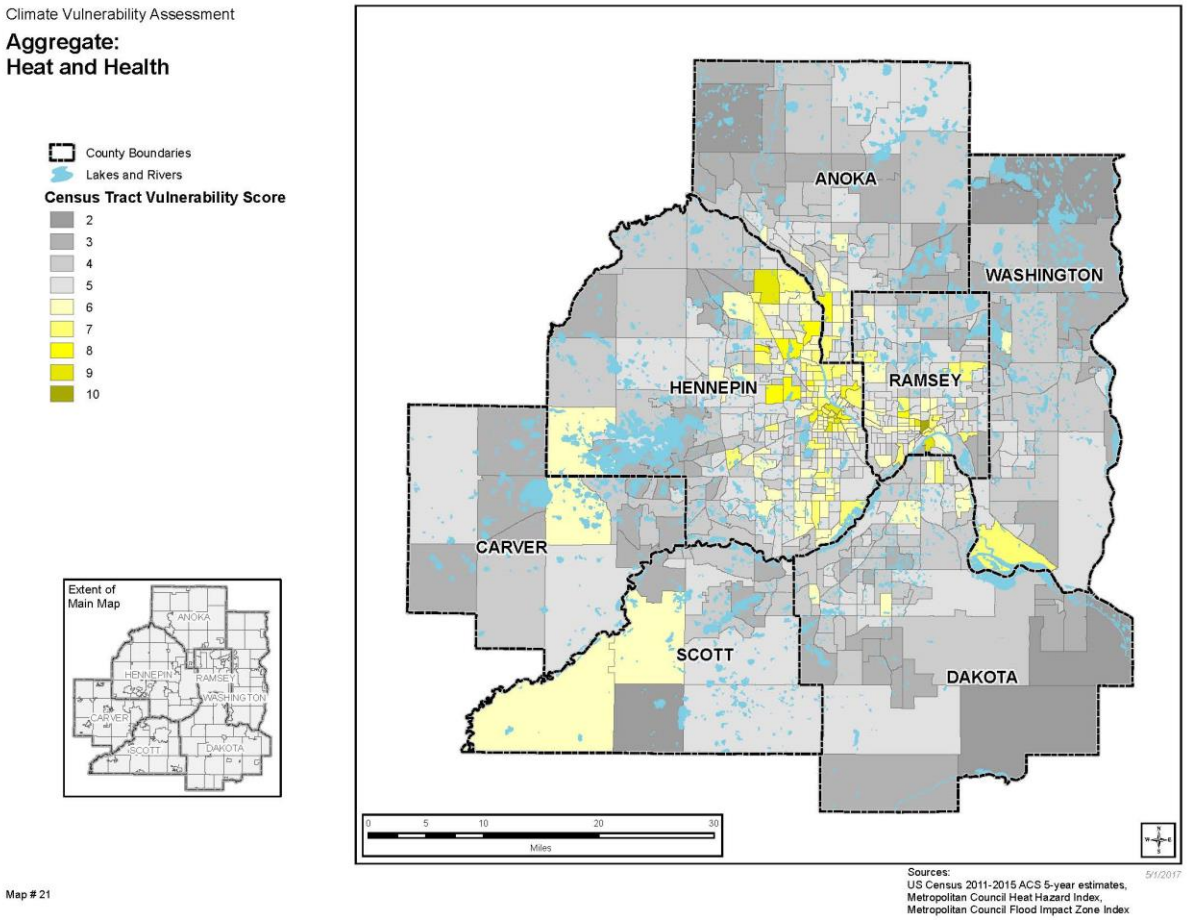
Map #	Vulnerability Indicator	Data Source	Map Color Designation
25	Aggregate - Flooding and Accessibility	ACS 5yr 2011-2015, Metropolitan Council	Orange
26	Aggregate - Flooding and Communication	ACS 5yr, 2011-2015, Metropolitan Council	Brown
27	Aggregate - Flooding and Health	ACS 5yr 2011-2015, MDH Zip Code, Metropolitan Council	Yellow
28	Aggregate - Flooding and Poverty	ACS 5yr 2011-2015, Metropolitan Council	Cyan
29	Aggregate - Flooding and Race Ethnicity	ACS 5yr 2011-2015, Metropolitan Council	Purple
30	Aggregate - Flooding and Social	ACS 5yr, 2011-2015, Metropolitan Council	Green
31	Aggregate - Heat and Human Vulnerability	All listed sources	Red
32	Aggregate - Flooding and Human Vulnerability	All listed sources	Blue

EXAMPLE OF MAP ANALYSIS – HEALTH CONCEPT

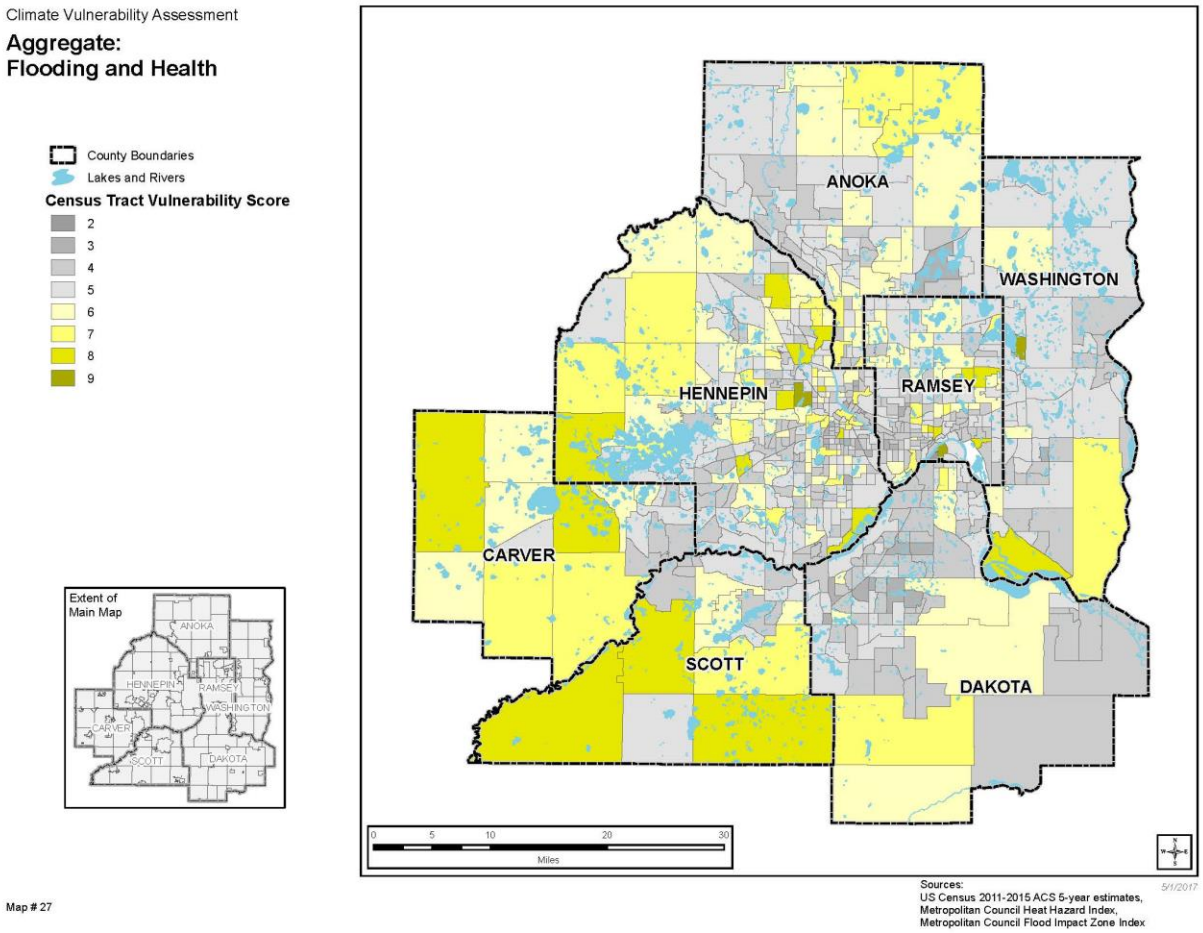
This section illustrates the process that our team used to analyze the maps listed in the previous section. Maps were first grouped according to our six human vulnerability concepts (in this example, Health). Each concept was mapped to analyze its overlap with extreme heat and surface flooding. Additionally, each constituent indicator of that concept (such as population 5 years and younger) was mapped on its own. (See Technical Report for all maps). These maps show locations of vulnerable populations without surface flooding or extreme heat vulnerability. This separation can help determine which indicator(s) are the main contributors to a tract's aggregate vulnerability score. This also allows for more direct consideration of possible solutions; for example, instead of simply noting health vulnerabilities, a more precise context of vulnerability (such as elderly populations) can be considered.

The following set of maps, and all maps in the Technical Report, follow the same order of presentation: an aggregate map of extreme heat vulnerability and aggregate concept vulnerability; an aggregate map of surface flooding vulnerability and aggregate concept vulnerability; and individual maps for each vulnerability indicator that comprise the larger concept. In this example, individual maps displaying only persons age five and younger, persons age 65 and older, asthma hospitalizations, and COPD hospitalizations are presented as these four indicators make up the larger Health vulnerability concept that is overlaid with extreme heat and surface flooding vulnerability.

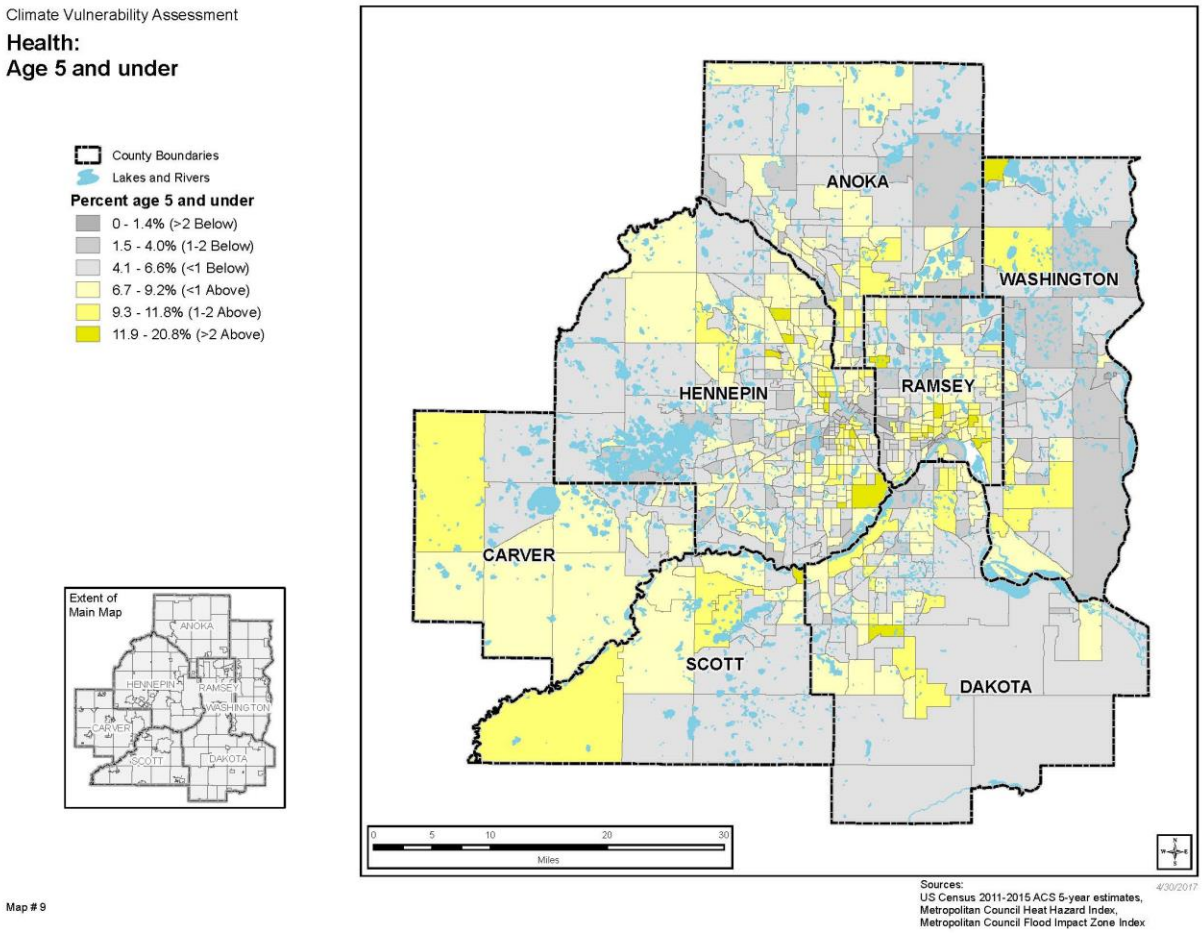
Map 21 - Health Aggregate with Extreme Heat



Map 27 - Health Aggregate with Surface Flooding



Map 9 - Health Indicator: Age 5 years and younger



Map 10 - Health Indicator: Age 65 years and older

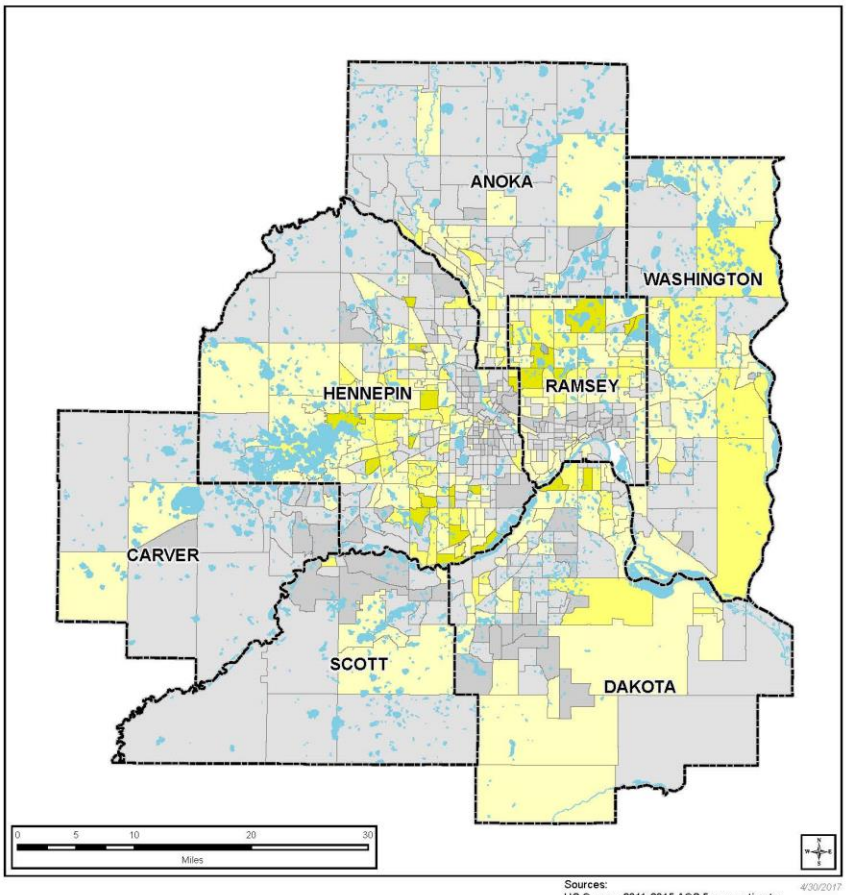
Climate Vulnerability Assessment

Health:
Age 65 and over

County Boundaries
Lakes and Rivers

Percent age 65 and over

- 0 - 1.2% (>2 Below)
- 1.3 - 6.4% (1-2 Below)
- 6.5 - 12.2% (<1 Below)
- 12.3 - 18.0% (<1 Above)
- 18.1 - 24.0% (1-2 Above)
- 24.1 - 45.8% (>2 Above)

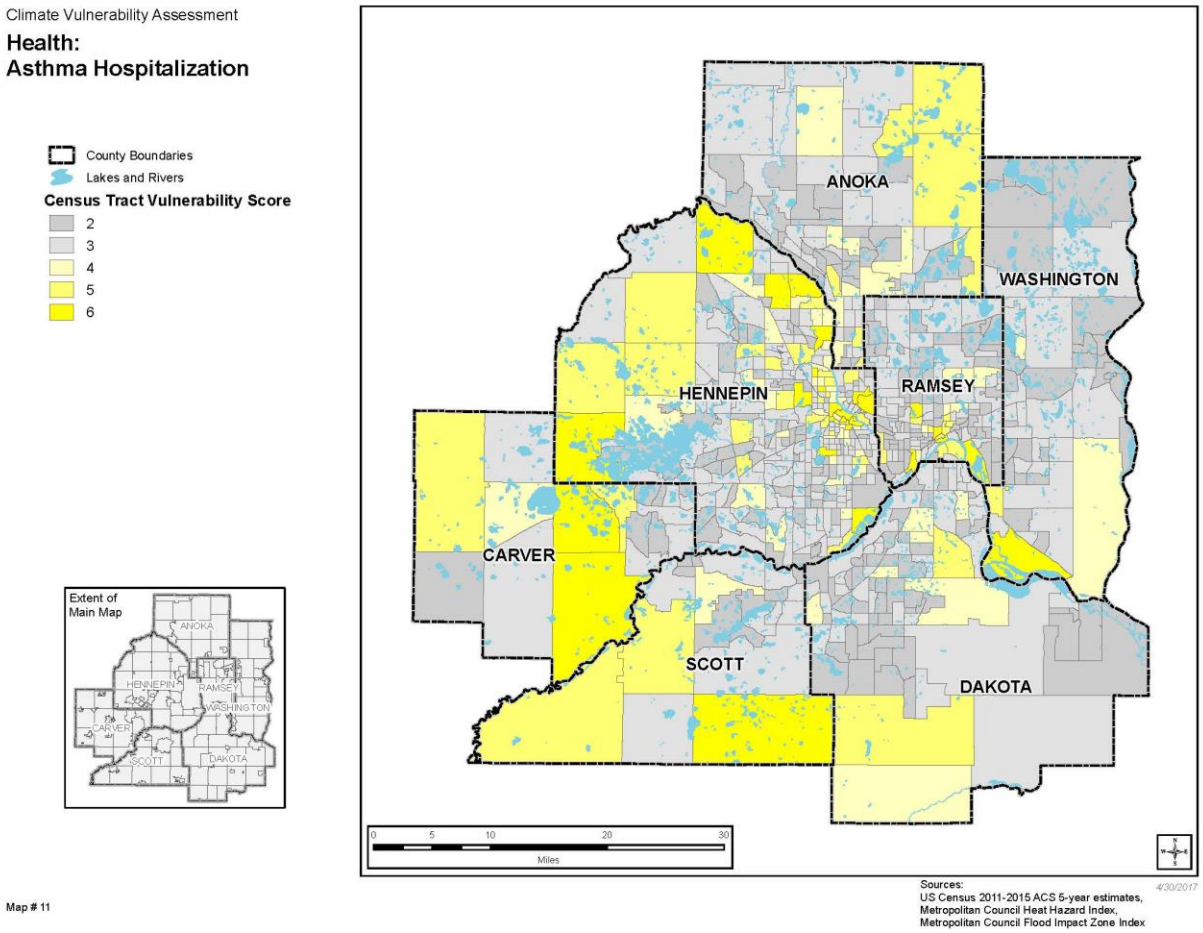


Sources:
US Census 2011-2015 ACS 5-year estimates,
Metropolitan Council Heat Hazard Index,
Metropolitan Council Flood Impact Zone Index

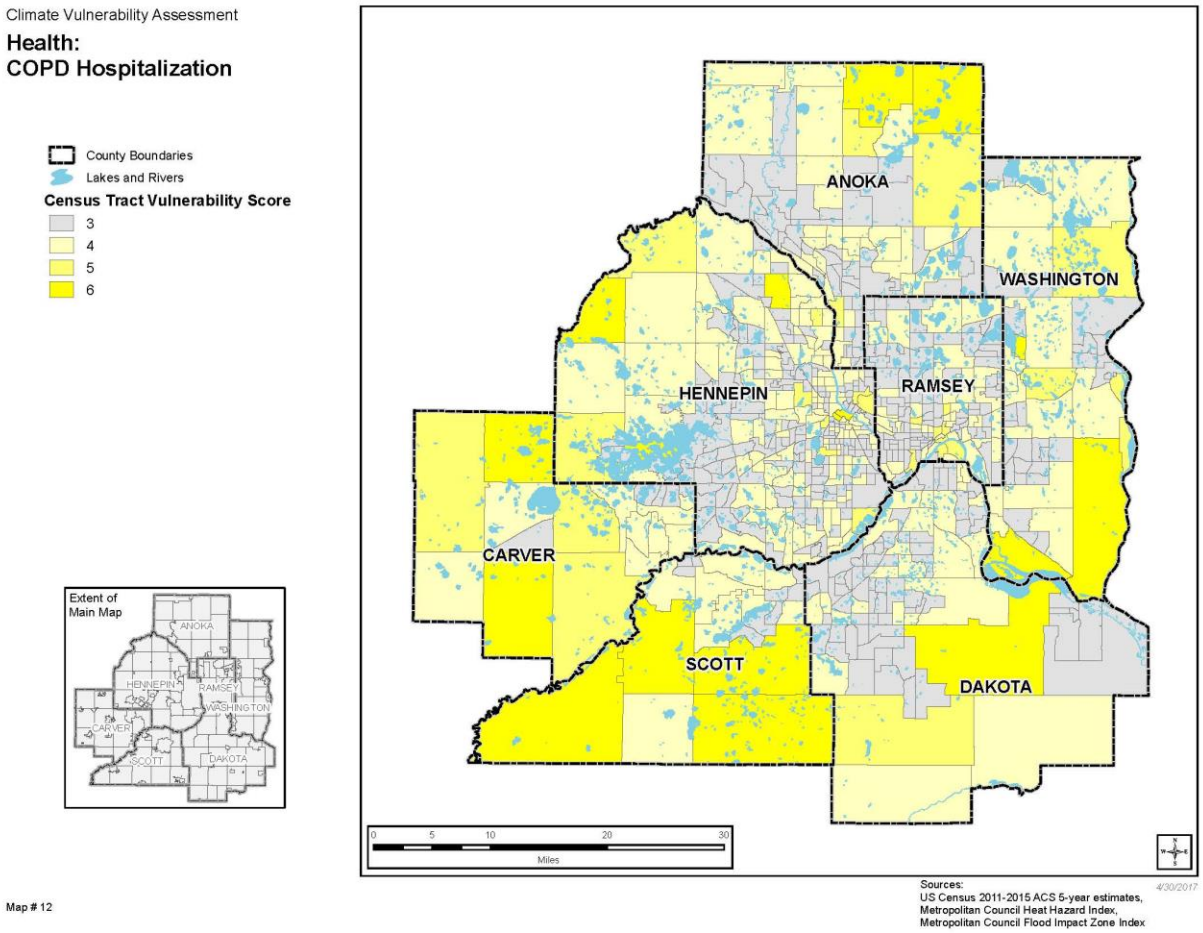
4/30/2017

Map # 10

Map 11 - Health Indicator: Asthma Hospitalizations



Map 12 - Health Indicator: COPD Hospitalizations



FINDINGS, STRATEGIES, AND RECOMMENDATIONS

The Human Vulnerability Index and maps, created for the Council's CVA, are intended to be tools for the Council to use in its efforts to prepare for and adapt to events associated with climate change. These findings can aid the Council and communities to better plan for infrastructure improvements that can withstand and respond to episodes of extreme heat and surface flooding. Additionally, this portion of the CVA has revealed, based on human vulnerability indicators, what populations are most vulnerable to extreme heat and surface flooding and where they are generally located within the seven-county region.

In responding to climate events like extreme heat and flooding, there are typically two responses: mitigation and adaptation. Mitigation is defined by FEMA as "the effort to reduce loss of life and property by lessening the impact of disasters."[28] The Council already acknowledges the importance of mitigation in the Thrive 2040 Plan for Resilience, stating "climate mitigation strategies such as promoting land use and development patterns will contribute toward achieving Minnesota's adopted greenhouse gas emissions goals."[29] While mitigation is important and is considered in these suggestions, this section focuses primarily on adaptation strategies. Adaptation is an "adjustment or preparation of natural or human systems to a new or changing environment which moderates harm or exploits beneficial opportunities.[30] By implementing a combination of mitigation and adaption measures, it is hoped that municipalities can build resilience, the "capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment."[31] Mitigation, adaption, and resilience have benefits beyond the environment, helping to create more stable economies and social networks within communities, building thriving neighborhoods, cities, and region.

There has been a great deal of research about and implementation of mitigation, adaptation, and resiliency practices, policies, and programs. Strategies were compiled from a wide variety of existing resources, guides, and examples for municipal and regional use, most notably the Environmental Protection Agency (EPA). These strategies and recommendations are intended for Council staff and officials that comprise the 188 regional communities of the Metropolitan Council. This section on findings, strategies and recommendations is organized into five subsections, each building off of previous sections and strategies:

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[28]Federal Emergency Management Agency, United States Department of Homeland Security. 2017. "What is Mitigation." Web. https://www.fema.gov/what-mitigation

[29] Metropolitan Council, 2017. "Resilience" in *Local Planning Handbook.* Web. https://metrocouncil.org/Handbook/Plan-Elements/Resilience.aspx

[30] United States Environmental Protection Agency. *Glossary of Climate Change Terms,* 2017. Web.

[31] Ibid.

- County Analysis
- Notable Smart Solutions
- Policy
- Site Design
- Next Steps: Sustaining our Learning

The strategies should not be thought of as traditional recommendations. Given the multi-county scale of this analysis, it is difficult to capture the nuanced realities within each community. Without knowing the "on the ground" context, it is disingenuous to make traditional recommendations. Instead, this section looks to "match" mitigation and adaption strategies to the geography and vulnerabilities of the Twin Cities Metropolitan Area. All strategies outlined here have been implemented somewhere in the United States, and many have been implemented within the metropolitan area. Furthermore, many of these strategies have become resiliency standards nationwide. These strategies are intended to be a starting place when considering mitigation, adaptation, and reviewing policy related to resiliency.

Additionally, these strategies are based on "smart practices," not "best practices." Each municipality is unique, and there is no one objectively "best" way to address climate events. The strategies and policies in this report are designed to be broadly applicable given the northern, Midwest geography and context within the Twin Cities Metropolitan Area and Metropolitan Council. To align with the community typology used by the Council, these strategies are suggested based on urban/suburban/rural geographies. Most strategies are applicable throughout the metropolitan area and are more dependent on individual site characteristics and existing infrastructure. Since each municipality and each site has existing different conditions, a true cost-benefits analysis of strategies cannot be performed; instead Table 4 in the Site Design section below details the main of costs and saving anticipated with each strategy, allowing municipalities to begin estimating costs base on their goals and conditions.

One point worth mentioning again is that this team's portion of the Council's CVA is focused on *human-based* vulnerability, not *place-based* vulnerability. However, surface flooding and heat are more place-based, meaning this analysis examines the current overlap of certain place-based vulnerabilities and human-based vulnerabilities. Populations, particularly vulnerable populations, tend to be more mobile, meaning this CVA is a snapshot of the Twin Cities Metropolitan Area.

COUNTY ANALYSIS

To help guide prioritization of resources and efforts, and to better facilitate conversations in counties and municipalities, the team conducted a quick visual county analysis. This first level analysis examined areas in each county and the metropolitan area as a whole that "popped out" visually, meaning they were darker colored in the spatial analysis. Again, in this analysis, variables were "layered" on top of one another, meaning darker areas on the maps have more vulnerability variables or greater proportions of vulnerable populations. Composite maps were compared with individual indicator and vulnerability maps to determine the likely reasons an area appeared particularly vulnerable (darker in color) on the composite maps. We included this check to avoid falsely attributing a high vulnerability score to the wrong combination of factors. In the case of surface flooding, we examined tracts with moderately high aggregate vulnerability scores and found that several them had low human vulnerability scores, meaning they weren't as vulnerable as they appeared for the purpose of our analysis.

Additionally, the data for surface flooding vulnerability indicate areas where stormwater is likely to accumulate based on elevation and topography. It does not show stormwater systems, natural vegetation, or other water infiltration systems that help move water away from sites. While this creates an incomplete picture of surface flooding potential, it models what can happen when systems are overwhelmed by intense, prolonged, or frequent rainfalls. Low-lying areas are likely to flood given water's downhill flow and are the first to fill when water pools, creating hazards for residents in these areas.

It should be noted that this first visual analysis did not critically consider the total population of census tracts; observations and analysis were based on general knowledge of the area, not hard data. The unequal distribution of populations among census tracts means some census tracts are weighted more heavily than others; for example, census tracts with small populations may have fewer individuals in a vulnerable population than more populous tracts, but that vulnerable group may comprise a greater percentage of the tract population.

Furthermore, human vulnerability scores for each indicator are relative to the metropolitan regional average. For example, a 7% rate of no phone access would raise the vulnerability score more so than a 7% rate of no health insurance, because the regional average and distribution of values for these indicators are substantially different from each other. This scoring system was designed to be understood in a regional context, without requiring the reader to know reference values for each indicator. However, this system loses some granularity and nuance in the process. Those interested in analyzing the underlying data in more detail should refer to the GIS files our team provided to the council, as well as the original Census ACS data. Our team's analysis is intended to provide a starting point for the Council and counties; this analysis is not a

complete list of all vulnerable areas within the Twin Cities metropolitan area. A deeper analysis using GIS is needed to help sort through identified areas and census tracts to provide a more detailed and quantifiable analysis.

Metropolitan Council and Potential Multi-County Partnerships

The noticeable areas of vulnerability outlined here transcend county boundaries, meaning the Metropolitan Council and/or cross-county partnerships are needed to more effectively address the vulnerabilities in these areas.

- There are a handful of tracts throughout the metropolitan area that are highly vulnerable across almost all human vulnerability indicators. These tracts deserve special consideration when developing and implementing mitigation, adaptation, and emergency response plans and are noted below.
- The border of Northern Hennepin County and Southern Anoka County share many of the same human vulnerabilities, mainly in relation to extreme heat.
- Southern Ramsey and Northern Dakota County both have larger Hispanic populations. There could be greater community and social cohesion in this area than this analysis indicates. These areas also share similar vulnerabilities, which creates culture and community-based opportunities for mitigation and preparedness plans.
- East-central Dakota County and Southwest Washington County both have higher proportions of persons age 65 and older and COPD hospitalizations in areas vulnerable to surface flooding. A cross-county collaboration may ensure these vulnerable populations can access resources and are taken care of in surface flooding events.
- The greatest communication indicator vulnerabilities, both in relation to extreme heat and flooding, tend to follow the Minnesota River corridor, creating partnership opportunities for Scott, Dakota, and Hennepin County.
- While health insurance status is measured as an accessibility indictor, given its influence as to whether or when a person is likely to seek medical, the most the Council and Counties can do to help with health insurance coverage is to provide guidance through MNsure and other health care systems. This accessibility vulnerability is more about creating awareness as it relates to the larger picture of health and well-being, highlighting populations who will wait to visit health clinics until conditions worsen, which is more expensive for all involved parties.

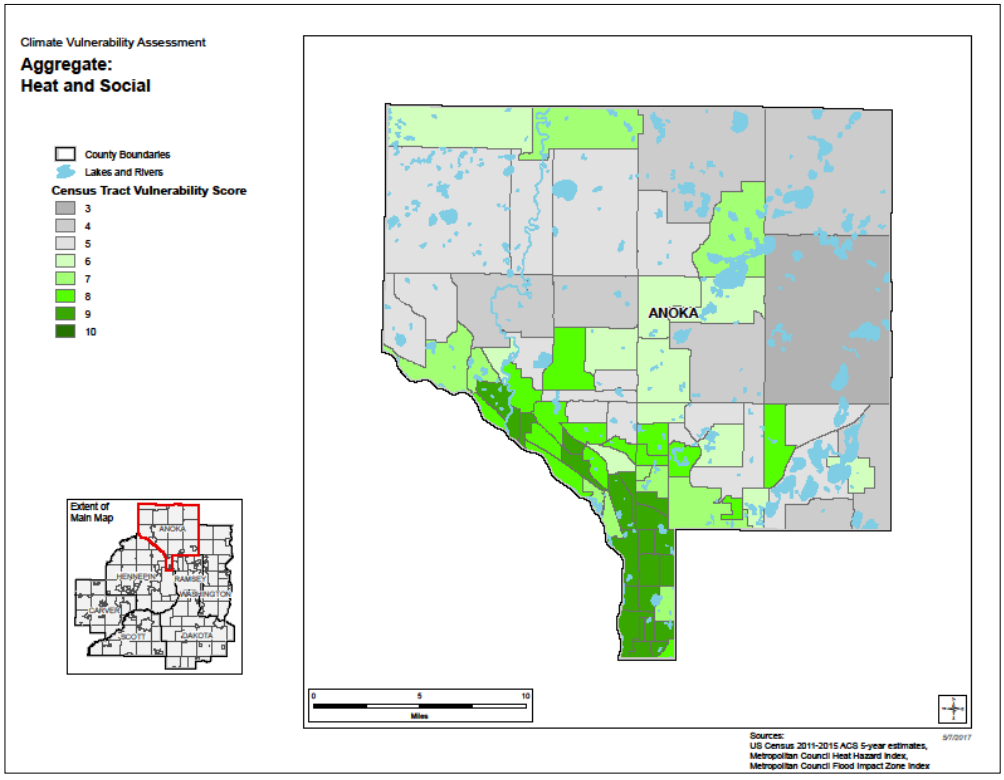
Anoka County

Overview: Tracts along the southern and southwestern edges are of the greatest concern for Anoka County, due to high vulnerability scores in heat and several human vulnerability indicators. The northwestern corner and central tracts also show a fair degree of human vulnerability. Interestingly, the portions of the County with the highest COPD and asthma hospitalizations are also more than six miles away from hospitals.

FINDINGS

Accessibility: Multiple tracts with high scores in disability overlap with high vulnerability to heat, primarily along the western edge. According to this analysis, a great portion of central and northern Anoka County is further than six miles from hospitals. There may be nearby hospitals outside of the seven-county metropolitan area not included in this analysis. Inaccessibility to hospitals is the main accessibility indicator that overlaps with surface flooding; this is particularly an issue in north central and northwestern areas of the County. There is also a moderate percentage of persons with disabilities in these northern areas, overlapping with surface flooding vulnerability.

Social Networks:



The northwest corner "pops" on two indicators: a high percentage of these tracts' populations moved to area since 2015 and have lower high school education attainment. This northern portion of the County, along with the areas bordering Hennepin County, are most susceptible to surface flooding events when overlain with human vulnerability. These areas both have higher unemployment rates and greater proportions of the population with less than a high school education, relative to the metro region. The southern and southwestern borders of Anoka County are most

susceptible to extreme heat, have high unemployment, and have higher proportions of population without a high school diploma.

Health: The most vulnerable portion of the County to both extreme heat and flooding is the southernmost tip of the County; this area has the most overlap between persons over 65, children under 5, and both climate events. There are also noticeable rates of COPD and asthma hospitalizations along the southwestern edge of the County. However, the most vulnerable area in the County for both types of hospitalization is in northeast. Because of these higher hospitalization rates, this portion of the County has the strongest relationship between surface flooding and health. The central portion of the County has strong overlaps between COPD hospitalizations, children age five and younger, and surface flooding.

Communication: The highest proportions of populations with limited English proficiency are in the southernmost area of the County, which lines up with the highest levels of extreme heat and moderate surface flooding vulnerability. Additionally, phone access is a concern in the western portion of the County, which also have greater overlap with surface flooding. The eastern half of the County largely does not have communication concerns.

Poverty: There is a strong relationship between poverty and the hottest portions of the County, specifically in the southern tip. This area also has noted vulnerability overlap with surface flooding.

Race: There is a strong relationship between race and the hottest portions of the County, specifically in the southern tip. This area also has noted vulnerability overlap with surface flooding.

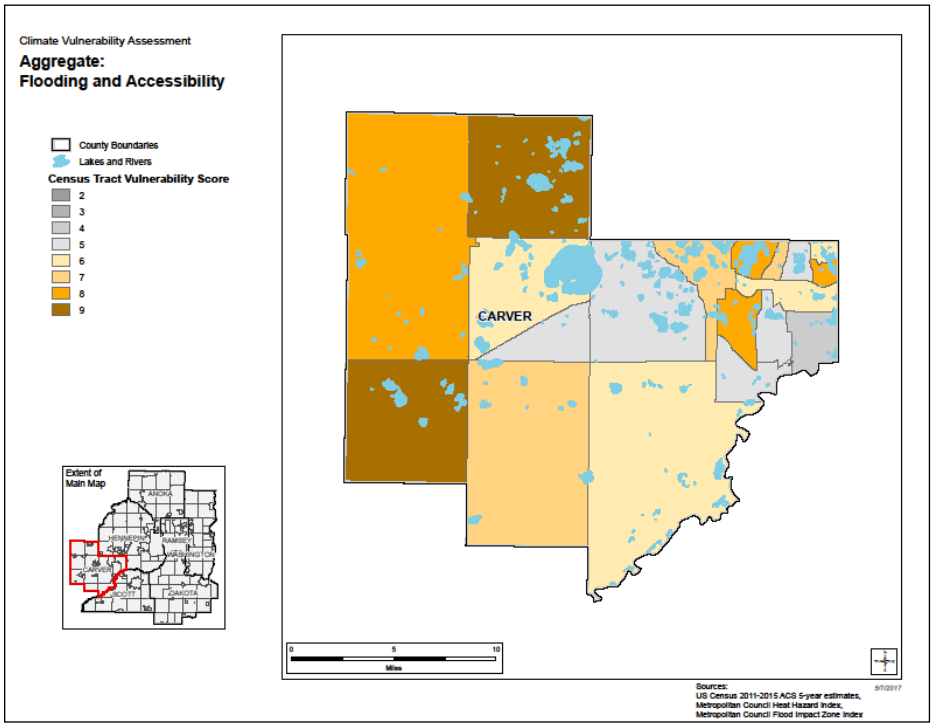
KEY TAKEAWAYS and RECOMMENDATIONS:

- The southern and southwest borders of the County, shared with Hennepin County, are the biggest concern for extreme heat and human vulnerabilities. This portion of the County has the highest social networks, communication, race, and poverty vulnerabilities and is the warmest portion of the County.
- Anoka County contains a high proportion of low-lying areas, making surface flooding potential a concern throughout the northern and southwestern parts of the county.
- The northwest corner of the County “pops” for several social network vulnerabilities and has high proportions of census tracts with low-lying areas, which have greater surface flooding potential. However, it does not come across as vulnerable to extreme heat. This is an area to monitor as development and land uses change.
- The tracts with the highest proportions of households without phone access match the tracts with the highest percentages of disabilities. However, this analysis does not include cell phone access. Until phone coverage of both types can be determined, emergency services should seek out alternative channels to keep residents informed.

Carver County

Overview: Carver County has low vulnerability to extreme heat events at the census tract level, due largely to the County's rural character. However, since this analysis method often underestimates the heat vulnerability of towns located in rural tracts, these areas should be re-examined at a smaller geographic scale. Carver County also has one of the highest surface flooding vulnerabilities, based on elevation, in the metropolitan area. This vulnerability overlaps more with the County's vulnerable populations. Carver County is anticipated to continue developing, which could increase heat islands or impact of surface flooding, exacerbating conditions for vulnerable populations.

FINDINGS



Accessibility: Carver County has large areas where accessibility indicators overlap with surface flooding vulnerability. All four accessibility indicators "pop" with surface flooding throughout the County but is of particular concern in the northcentral portion of the County. Accessibility does not have a strong relationship with extreme heat, but two tracts in the north-central portion of the County are more vulnerable in regards to disability and vehicle access and should be monitored as development occurs.

Social Networks: Among social network indicators, the greatest overlap with surface flooding vulnerability appears to be with homeowners who have moved in 2015 or later. This overlap appears to be highest in the eastern quadrant of the County. This area could get warmer as it continues development, but residents will likely increase tenure and hopefully develop cohesion, reducing vulnerability. The portions of the County most susceptible to extreme heat do not align with the few social network vulnerabilities in the County.

Health: Carver County has very high prevalence of COPD hospitalization and is the County's main concern regarding extreme heat. The rural portions of the County have the strongest relationship between surface flooding and health due to higher proportions of children under age five and COPD and asthma hospitalizations.

Communication: There is one tract with higher percentages of both limited English proficiency and low phone access located on the southeastern edge of the County. This tract has high overlap with surface flooding and is a watch spot for extreme heat vulnerability depending where development occurs. Other communication vulnerabilities in central Carver County are due to greater proportions of household without phone access, which overlaps with surface flooding vulnerability.

Poverty: Carver County does not have notable poverty concerns based on a first level analysis regarding either extreme heat or surface flooding events.

Race: Carver County does not have notable race concerns based on a first level analysis regarding either extreme heat or surface flooding events. The northeast corner of the County should be monitored for potential surface flooding vulnerabilities.

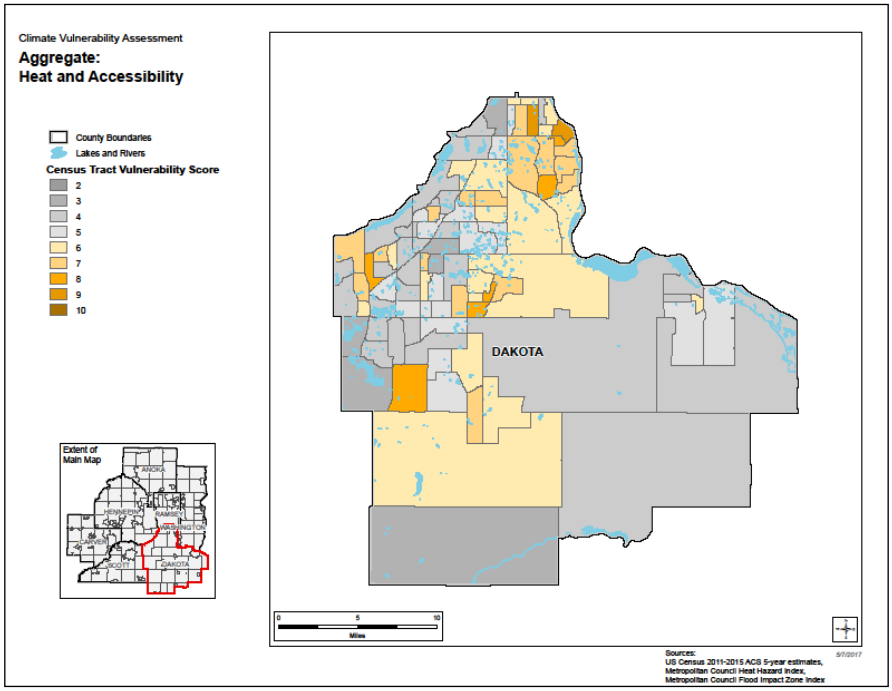
KEY TAKEAWAYS and RECOMMENDATIONS:

- Implement cool pavement/high albedo surfaces to mitigate heat island and keep extreme heat vulnerability low. While the County currently does not have many extreme heat issues, future development could warm communities and exacerbate existing vulnerabilities. It is much more cost effective to develop with green infrastructure than to retrofit.
- Implement impervious surfaces and "water smart" infrastructure to reduce risks of surface flooding, especially in the western, wetter, lower elevation areas of the County. Most of the County's vulnerabilities overlap with surface flooding vulnerability, and any effort to move and infiltrate water quickly and safely will help protect the County's vulnerable populations.
- The northcentral tract along the border with Hennepin County should be monitored, as it has several accessibility vulnerabilities, higher rates of COPD and asthmas hospitalizations, and higher percentages of children under five. This tract also has higher potential for surface flooding. It currently registers for low heat island effect, but this could increase as development spreads westward from the County's core cities.

Dakota County

Overview: The north and northwestern portions of Dakota County have several social network, communication, race, and poverty vulnerabilities, and these tracts overlap with both extreme heat and surface flooding vulnerability. Overlapping high vulnerability scores in Accessibility and extreme heat are a concern in population centers throughout the northwestern half of the county.

FINDINGS:



Accessibility: Accessibility factors are an important consideration for Dakota County in an extreme heat event. Several tracts throughout the County have higher-than-average percentages of residents without health insurance, with a disability, or households without access to a vehicle. These tracts tend to overlap with vulnerability to extreme heat in the county's urban tracts, which could impact residents' ability to access medical care and cooling centers during an extreme heat event. In the southwest and central quadrants of the County, distance from hospitals and low-lying areas make surface flooding a potential concern.

Social Network: The northern edge of the County has several social network vulnerabilities, including relatively high unemployment, percentage of renters, and percentage of population with less than a high school education. These vulnerabilities overlap with both surface flooding and extreme heat, creating a key concern in the County. Some tracts in the west-central portion of the County also show overlap between low-lying areas, higher proportions of homeowners who moved to their home since 2015, and persons with less than a high school education.

Health: The greatest degree of overlap between extreme heat and health indicators in Dakota County are residents age 65 and older or age five and younger. Particularly, there is a strong relationship between persons over 65 and heat vulnerability in the northern portion of the County. The most vulnerable area regarding surface flooding and health is the two

southwestern-most tracts, which have high scores in all indicators except for children under 5. The east-central tracts bordering Washington County have higher proportions of persons age 65 and older, COPD hospitalizations, and overlap with surface flooding.

Communication: The overlap of extreme heat and limited English proficiency is most pronounced on northern most edge of the County. This area also has more vulnerability to surface flooding. There is one tract in north-central Dakota County that has a stronger relationship between surface flooding and proportion of households without phone access.

Poverty: The northeastern portion of the County has a strong relationship between extreme heat and poverty and is a main area of concern for extreme heat vulnerability in the County. The northern tip and the western edge of the County have the strongest relationship between poverty and surface flooding. Notably, there are a couple of tracts in the north and northeast with higher poverty rates that overlap both types of climate events; these tracts should be further analyzed to best determine sites and strategies for effective mitigation.

Race: A few tracts in the northern tip and northwest edge of the County have strong relationships between race and both extreme heat and surface flooding vulnerabilities. For surface flooding specifically, vulnerable tracts with high percentages of residents of color are located along the border of Scott and Hennepin Counties.

KEY TAKEAWAYS and RECOMMENDATIONS:

- Designate official cooling centers throughout the County to ensure access and communicate their location widely to County residents.
- The northwestern portion of the County for poverty and extreme heat vulnerability. This area is currently hot and will likely become hotter as it continues to develop. However, poverty in the northwest is not as pronounced as it is along the northeastern edge of the County.
- The County has higher COPD hospitalization rates and persons over 65 in areas more vulnerable to surface flooding. This issue could become a more pressing problem depending on development patterns.

Hennepin County

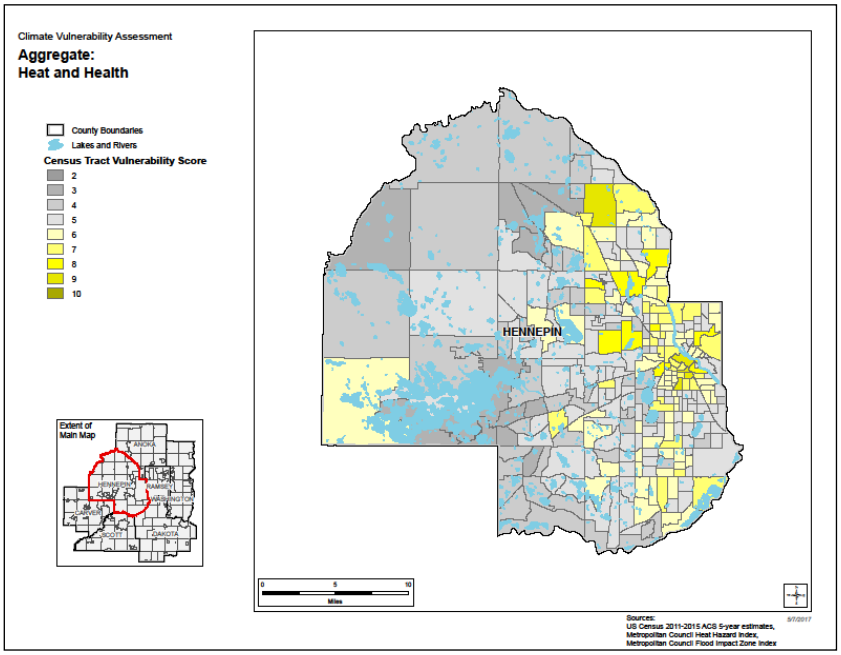
Overview: The eastern half of Hennepin County has the strongest relationship between human vulnerabilities and both climate events with extreme heat being a more notable concern. Surface flooding vulnerability is more evenly dispersed throughout the County. Generally, the eastern half of the County is vulnerable due to greater proportions of human vulnerability, but the western half is more vulnerable to surface flooding because of health and accessibility indicators. Specifically, western Hennepin County has greater distances from hospitals, COPD and asthma hospitalizations, and higher proportions of persons age 65 and older. Overall, asthma hospitalizations are one of the biggest health vulnerabilities for the County.

FINDINGS:

Accessibility: Hennepin County's accessibility indicator overlap with extreme heat are disability and persons without health insurance. For surface flooding, distance from hospitals is a noted concern in the western half of the County. The eastern half of the County has more prevalence of persons without health insurance and households without access to a vehicle in areas that overlap with surface flooding vulnerabilities.

Social Network: The eastern half of the County has strong relationships between social network vulnerability and both extreme heat and surface flooding vulnerability. These vulnerabilities are largely due to higher renter populations and proportions of residents with less than a high school education. There is also noticeable overlap between surface flooding, renters, and residents with less than a high school education in the northwest and southeast areas of the County.

Health: There is a strong relationship between asthma hospitalizations, children age five and younger, and extreme heat throughout Hennepin County. The western half has more overlap between asthma and COPD hospitalizations and surface flooding; this area should be monitored as development and growth occur, which could add extreme heat vulnerabilities or exacerbate surface flooding. Countywide,



areas most vulnerable to surface flooding overlap primarily with asthma and COPD hospitalizations. There is also notable but less overlap between surface flooding and persons age 65 and older. While the biggest "pop" for COPD hospitalizations is in western and northern sections of the County, this may be due to the larger tract sizes in these areas relative to tract population.

Communication: There is notable overlap between extreme heat and populations with limited English proficiency. Vulnerability to surface flooding mostly overlaps with limited English proficiency in the east and households without phone access in the west. There is a noticeable pocket of households without phone access in the urban core, but it is very concentrated. This area could be considered for future analysis, but given its location and overlap with renter populations, these households are likely student renters. Students and young adults are less likely to have landlines and rely solely on their cell phones. This issue should be taken into consideration as the County develops climate event communications and preparedness plans.

Poverty: There is a strong relationship on the far eastern edge of the County between extreme heat and poverty. The northeast and southeast areas also have a strong relationship with surface flooding. This relationship is due in part to the lower elevations in these areas and their proximity to rivers.

Race: There is a strong relationship between extreme heat, surface flooding, and race in the northeast and southeast portions of the County. This relationship is partially due to lower elevations in these areas and their proximity to rivers. There is one tract in the center of the County that has a moderate relationship between residents of color and surface flooding. This area should be monitored as populations change and/or surface flooding becomes more frequent or intense.

KEY TAKEAWAYS and RECOMMENDATIONS:

- One tract in the southeast corner markedly stands out with vulnerable populations for nearly every human vulnerability indicator. This tract is also susceptible to extreme heat and surface flooding events. This tract likely has very low populations given its geographic location (near the international airport), which could be skewing the data. A more thorough analysis is needed to determine if the high vulnerability found by this analysis are true or skewed.
- Incorporate green infrastructure into existing development in the eastern portions of the County to mitigate heat island.
- Focus mitigation dollars on the northeast and southeast portions of the County, which are the most vulnerable across all events and indicators considered.

Ramsey County

Overview: Overall, Ramsey County has high vulnerability to both extreme heat and surface flooding. The northeast portion of the County is more vulnerable to surface flooding and the southern half is more vulnerable to extreme heat. Specifically, the south-central area of the County has the strongest relationship between human vulnerability and extreme heat. Most human vulnerabilities are in the south half of the County, making extreme heat and human vulnerability a key concern.

FINDINGS:

Accessibility: The area of Ramsey County most susceptible to extreme heat (south half) also has greater presence of all accessibility indicators. Most of the County also has above average disability rates. There is little overlap between accessibility and surface flooding except for a few tracts in south-central Ramsey County with the main vulnerability overlap being disability.

Social Network: There is a strong relationship between social network indicators and extreme heat in southern Ramsey County. This area has above average vulnerability for all social network indicators except for homeowners who moved since 2015. Since most social network vulnerabilities are in the south and most surface flooding vulnerability is in the north, there is not much overlap between these two vulnerabilities. However, there a two social network "watch spots" in the north; there is a greater proportion of homeowners who moved since 2015, and the northwest corner of the County has all social network indicators present. While this area does not "pop" given its lower overall vulnerability, it should be monitored to prevent increasing vulnerability.

Health: There is overlap between health vulnerability and extreme heat throughout the County with different health indicators "popping" between the north and south. The north has higher proportions of residents age 65 and older while the south has higher portions of residents age 5 and younger. The County has low asthma hospitalization rates compared to other metropolitan area Counties, and COPD hospitalization rates are evenly distributed throughout the County. Surface flooding and health vulnerabilities do not overlap much, the biggest overlap being with persons age 65 and older in the north.

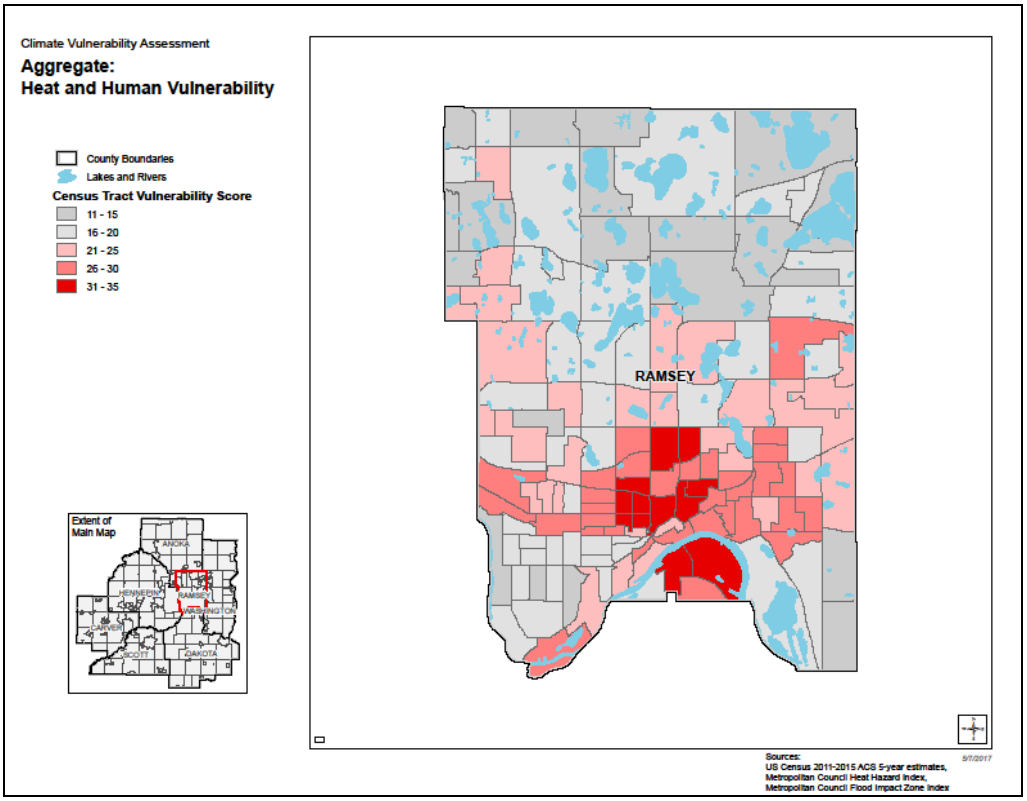
Communication: There is a strong relationship between extreme heat and limited English proficiency. There is also a relationship between surface flooding and limited English proficiency, though this relationship is not as pronounced. A few tracts "pop" for lack of phone access, but these tracts are mainly around the University of Minnesota campus. Many residents in these tracts are students and likely to have cell phones to receive communication, which these data do not capture.

Poverty: There is a very strong relationship in the southern half of the County between extreme heat, surface flooding, and poverty. The most notable area for surface flooding and poverty is along the border of Ramsey and Washington Counties.

Race: There is a strong relationship in the southeastern quadrant of the County between extreme heat, surface flooding, and race.

KEY TAKEAWAYS and RECOMMENDATIONS:

- Focus on disability access in mitigation strategies and emergency response plans.
- Focus heat island mitigation resources in the southern half of the County where the overwhelming majority of the County's human vulnerabilities exist.
- Surface flooding mitigation could be dispersed throughout the County, focusing on social network and communication indicators.
- Building stronger social networks, or studying community cohesion at a municipal level, could reduce the high levels of social network vulnerabilities seen throughout the County.



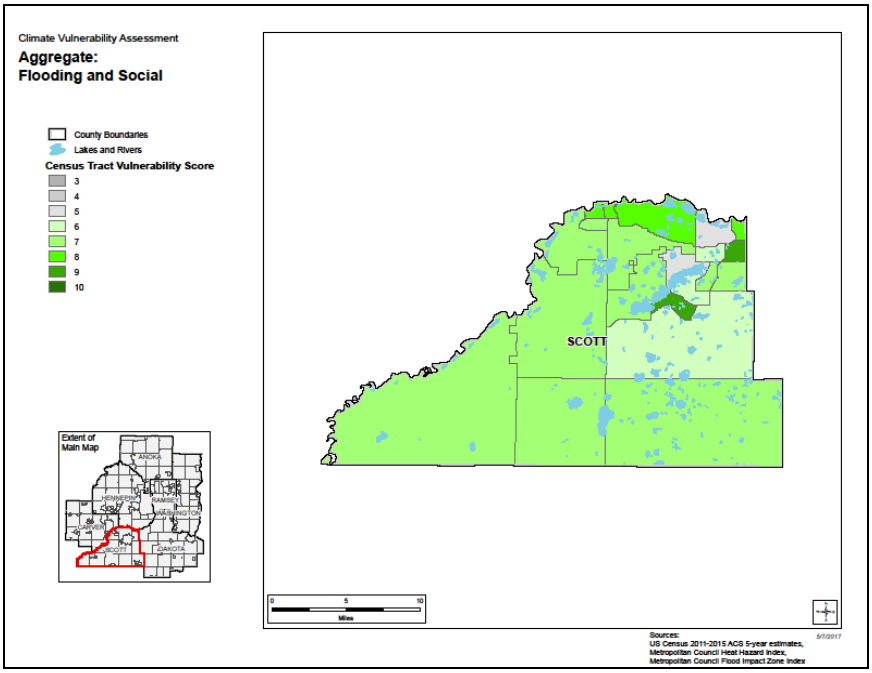
Scott County

Overview: Overall, Scott County has little vulnerability to extreme heat, largely due to the rural character of the County. However, the portions of the County vulnerable to extreme heat are vulnerable across several human indicators. Planned and anticipated development, particularly in the north, could create hotter or larger extreme heat vulnerabilities, negatively impacting vulnerable populations. The County as a whole is vulnerability to surface flooding given its lower elevations, but these areas largely do not overlap with human vulnerabilities yet.

FINDINGS:

Accessibility: In northern Scott County, the urban centers are most vulnerable to extreme heat. These areas overlap with disability and persons without health insurance. Most surface flooding vulnerability is south of the urban areas with the most overlap being between surface flooding and distance from hospitals.

Social Network: The hottest areas along the northern edge also overlap with persons with less than a high school education. One of these hotter northern tracts also overlaps with surface flooding vulnerability. The southeast and southwest corners of the County have stronger relationships with surface flooding and homeowners who moved into their homes since 2015.



Health: Scott County has very pronounced prevalence of COPD hospitalization and is the most prevalent vulnerability indicators in the County among selected health indicators. There is more

overlap with COPD hospitalizations and surface flooding than with extreme heat, but these areas have fewer total vulnerabilities. Populations age 5 and under have the most overlap for both surface flooding and extreme heat, though extreme heat vulnerability is still very low. There is little overlap for extreme heat and other health indicators.

Communication: The hottest areas along the northern edge overlap with both higher percentages of limited English proficiency and households without phone access. This area is also vulnerable to surface flooding. Developing several means of communication will be important, specifically in northern municipalities.

Poverty: There is a small cluster of tracts on the very northwestern edge of the County that has a strong relationship between poverty and extreme heat. Scott County does not have other notable poverty concerns for either extreme heat or surface flooding based on a first level analysis.

Race: There is a slight relationship between race, surface flooding, and extreme heat along the very northern edge of the County. This area should be monitored as the area continues to develop and more residents of color potentially move into the area. Incorporating mitigation strategies into development will help keep both vulnerabilities low.

KEY TAKEAWAYS and RECOMMENDATIONS:

- Focus heat island mitigation along the northern edge of the County, where several human vulnerability indicators are present.
- Develop communication strategies to communicate vulnerabilities and extreme weather events specific to the northern portion of the County, which has the most overlap between communication vulnerabilities and climate events.
- The northern portion of the County currently has low overall vulnerability, but this could change with development and migration. The largest vulnerabilities in this area, which could become more pressing depending on development, are race, social networks, and communication indicators. Targeting resources to these vulnerabilities and this area of the County may help keep overall vulnerabilities low.
- The most widespread vulnerability indicators across the County are health indicators. Consider partnerships with urgent care clinics to be more equipped in emergencies given greater distances from hospitals throughout much of the County.
- Develop with impervious surfaces and other “water smart” designs to maintain and improve water retention and infiltration. These measures can help prevent surface flooding vulnerabilities from becoming worse.

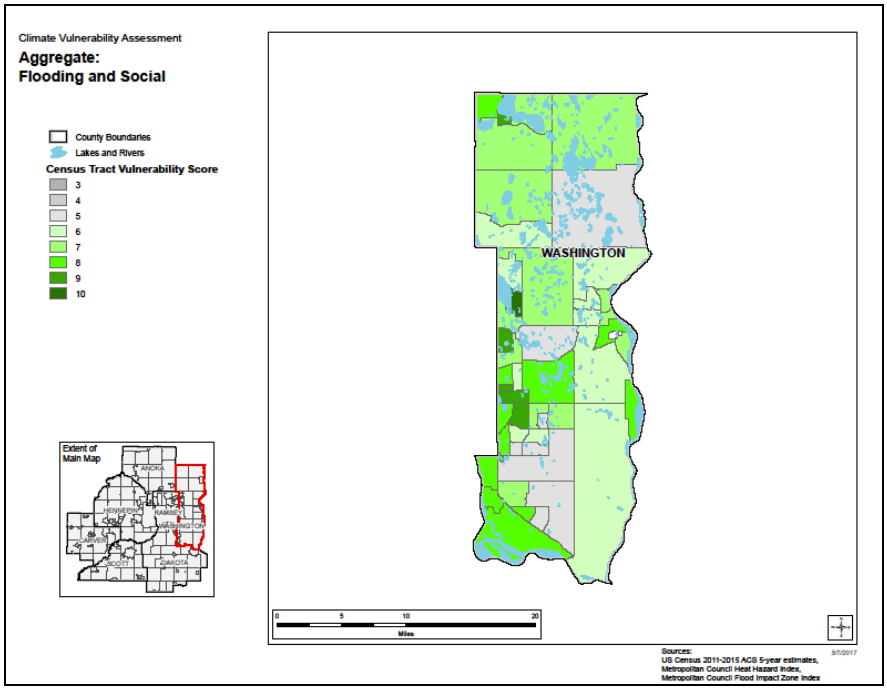
Washington County

Overview: Overall, Washington County has little vulnerability to extreme heat, largely due to the undeveloped nature of the County. The County is more vulnerable to surface flooding, specifically in the north half of the County, but these areas do not overlap much with human vulnerabilities. The western edge of the County has the greatest prevalence of human vulnerabilities, specifically among social network indicators and of residents of color.

FINDINGS:

Accessibility: The west-central portion of the County has the most overlap between accessibility vulnerability to extreme heat, but it is still a low overall vulnerability. Overlap between surface flooding vulnerability and accessibility is most noticeable in the north and is mainly due to the distance from hospitals.

Social Networks: There is a slight overlap with social network indicators and surface flooding on the western edge of the County. Otherwise, most social network and flooding vulnerabilities do not align. There is the most overlap between extreme heat and homeowners who moved to the area since 2015. Depending on development plans, this vulnerability could decrease as residents create community cohesion and become more familiar with the area. This vulnerability could also shift within the County depending where development takes place.



Health: In general, Washington County has little extreme heat vulnerability, but the indicators overlapping extreme heat persons age 65 and older and COPD hospitalization. The southern tip of the County "pops" for the overlap of health and surface flooding vulnerability, specifically with children age five and under. Otherwise, most health vulnerabilities in the County do not align with surface flooding vulnerabilities. Washington County has more prevalent COPD hospitalization rates, but this vulnerability does not align with extreme heat or surface flooding vulnerabilities.

Communication: Washington County does not have notable communication vulnerabilities based on a first level analysis for either extreme heat or surface flooding. There is one tract on the western edge with more pronounced communication vulnerabilities that should be monitored moving forward.

Poverty: There are a few tracts along the western edge of the County with a relationship between poverty, extreme heat, and surface flooding. The northwest corner of the County should also be monitored for poverty and surface flooding vulnerability. This overlap between flooding and poverty is not as strong as it is along the western edge of the County, but this vulnerability could worsen depending on development patterns in the area.

Race: There are a few tracts along the western and southern edges of the County (border with Ramsey County) with a relationship between extreme heat, extreme flooding, and race. There is also one small tract on the eastern border with greater overlap between race and extreme heat.

KEY TAKEAWAYS and RECOMMENDATIONS:

- Implement cool pavement and high albedo surfaces in development to mitigate heat island effects and keep extreme heat vulnerability low.
- Further study and monitoring is needed in the northern portion of the County for flooding and health vulnerabilities. This area does not "pop" on the composite health indicator and surface flooding map but has higher vulnerabilities in most individual health and flooding indicators (likely due to the way the data are factored with the area being right on the border of "popping" and not "popping" for vulnerabilities). Additional health problems or more intense and frequent flooding could worsen vulnerabilities in the northern portion of the County.

NOTABLE SMART SOLUTIONS

Throughout the literature review, research, and professional experiences, two strategies emerged that encompass mitigation, adaptation, and resiliency while providing economic and social benefits. These smart strategies are outlined here given their many applications across municipalities and sites and for their incorporation of both policy and site design.

Trees

Trees, when planted properly and cared for, have one of the biggest returns on investment for climate mitigation, adaptation, and community cohesion. Trees mitigate extreme heat through shade and evapotranspiration.[32] These features prevent heat from building up, reduce average air temperature, and allow areas to cool down faster after the sun sets.[33] Shade trees can also help keep buildings cool, reducing the amount of cooling energy needed. Trees also offer great benefits to stormwater management by increasing infiltration, reducing through fall, intercepting rain before it reaches the ground, and through transpiration.[34] By reducing the amount of water reaching the ground, and reducing the flow of water moving through and on the ground, trees help reduce overflows to stormwater systems and reduce surface flooding events. In fact, over 60% of financial benefits associated with trees are due to stormwater management.[35] In addition to reducing heat and increasing stormwater infiltration, trees also sequester carbon[36], decrease air pollution[37], raise property values[38], create community gathering spaces[39], and improve overall quality of life.[40] However, the many benefits of trees are contingent upon proper planting and care. To make tree investment worthwhile, they need space to grow free from infrastructure conflicts, and watering must occur during in the first couple of years after planting. Early years are establishment years and can make or break the health, and therefore benefit potential, of trees. In addition to extreme heat and flooding mitigation, trees can provide energy savings in the winter of roughly 10-15% by serving as windbreaks.[41]

[32] US EPA, 2008
[33] US EPA, 2003
[34] Ibid.
[35] US EPA, 2013
[36] US EPA, 2008
[37] Ibid.
[38] Sander, Polasky, and Haight, 2010
[39] Dinnie, Brown, and Morris, 2013
[40] US EPA, 2008
[41] Akbari, 2005

Tree and Landscape Ordinances

To effectively manage investments in trees and the urban forest/municipal tree canopy, counties and municipalities can implement the following policies:

- *Tree Protection in Ordinances*: Prohibit pruning or removing trees without a permit. Some ordinances and policies are extensive to include the root systems below ground, which can limit above ground development and activity. Specify the types of protective measures to be taken during construction to protect trees and develop enforcement mechanisms. This type of ordinance is best for larger, old growth trees. It should not be applied to all trees since some trees may be poorly placed, creating more longer-term problems, and it can limit the types of activities on a parcel, which can become burdensome to owners.
- *Street Trees*: Specify how trees should be planted and removed along right-of-ways, parking lots, and publicly accessible lands. The more specific these directions, the more you can support the urban forest/tree canopy. Such direction includes noting preferred species, preferred planting techniques, and maintenance. Consider using silva cells for urban planting to reduce the need for planting in compacted soils, which affects tree health and maintenance. Additionally, tree trenches create space in the street for trees to grow and thrive by integrating tree roots into stormwater drainage.
- *Tree Canopy or Urban Forestry Master Plan* – An overarching vision for the urban forest/tree canopy (like a comprehensive plan). This vision should be supported with ordinances and other more direct, specific policies.

Implementing any of these policies effectively will take staff and volunteer time and the designation of someone to monitor and promote trees in the community, such as a parks committee, separate tree committee, land use committee, environmental planner, urban forester, natural resource manager, etc. To ensure lasting health of trees, leadership must be taken in this conversation, even if all work is done with volunteers or interns. There are several resources to help municipalities plan, monitor, and care for their trees, and a few of the most widely used and tested are listed in Appendix D: Trees.

Stormwater Management

In extreme rainfall events, stormwater systems can be quickly overloaded, causing or exacerbating surface flooding. Engineered systems that mimicking natural systems, such as forests, swales, bioretention ponds, and rain gardens, can help slow the flow of water, allowing for more rain to stay where it falls rather than running into the stormwater system. Permeable

pavement and asphalt are infrastructure improvements that can also help water stay on site rather than overwhelming the stormwater system.[42]

To accommodate effective stormwater management in policy, require new and redevelopment activities to keep and treat stormwater on site by keeping and treating the amount of water that would be infiltrated with a vacant, vegetated lot on the lot post-development. This practice can be facilitated through rain barrels, permeable pavement, bioswales, and other "water smart" designs, detailed in the Site Design portion of this section in Table 4 (below). Currently, MPCA requires 1 inch to be retained onsite for new development, filtered, and/or infiltrated within 48 hours.[43] This requirement aligns with EPA best management practices for stormwater management, which recommends the first 1-1.5 inches from a storm be captured and treated on site – it could be extended or modified to include redevelopment projects. Given the wide range of actions, the Metropolitan Council, counties, and municipalities should work to incorporate stormwater practices on their sites and projects. Both MPCA and EPA have extensive storm and wastewater best management practice guides.

POLICY

To effectively implement mitigation and adaptation practices to communities, policy should be the primary approach. Populations are transient, both within cities and the metropolitan area. Site design is an effective and visible way to manage climate events and bring solutions to impacted vulnerable populations, but their benefits are focused on vulnerable *places* and whomever lives near those places. Policy, on the other hand, encompasses all *people* and all *places*, wherever they move or whatever the project. This feature allows the municipalities to leverage tools and resources wherever vulnerable populations live to reduce vulnerability to climate change and climate events.

Additionally, for site design to be effective within a municipality, it should be supported by policy. If developers need to apply for variances and go through several additional processes to implement these recommended strategies, it will deter developers, especially if there are few incentives offered. Creating policy to support and encourage smart, ecologically-minded site design encourages and enables new development and even redevelopment to implement these strategies in a simpler and more time and cost savings manner.

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[42] McPherson, E.G., et. Al., (n.d.) *Midwest Community Tree Guide: Benefits, Costs, and Strategic Planning.* U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station

[43] Minnesota Stormwater Manual, Section III.D.e-f. 2017.

General Policy Strategies

For Metropolitan Council, Counties, and Municipalities

- Target mitigation and adaptation strategies toward vulnerable populations. Develop funding priority criteria based in environmental justice that put green and resilient practices and investment in historically exploited communities. This should be a priority in allocating resources to best align with THRIVE 2040 goals and begin addressing several vulnerabilities.

- Develop communication and response plans that prioritize the most vulnerable populations and neighborhoods.

- Develop sustainable, long term funding sources for energy-smart, water-smart, and sustainable retrofits.

- Invest in and expand weatherization programs. Properly air-sealed and insulated homes help keep buildings cool during extreme heat, which reduces the cooling load, thus reducing GHG emissions. Thorough weatherization also addresses many indoor air quality issues that can exacerbate respiratory issues. Indoor air quality issues are mainly caused from moisture, mold, particulate matter and improperly vented or poorly performing mechanical systems. There are several programs in the state to help with these costs, especially for low income and elderly homes, which may make this a lower priority item.[44]

- *Grants:* Provide or offer assistance in applying for grants for retrofits and upgrades. Funding offers incentives to implement "smart solutions" and reduces upfront costs for businesses, which are a prohibiting factor in renewable and sustainable development. For example, Chicago has up to $6,000 available annually for green roof grants to qualifying applicants, and Austin, TX has a rebate program for green roof installation.[45]

For Counties and Municipalities

- *Resolutions*: The adoption of resolutions, official acknowledgments of an issue signed by the city council, planning or environment committee, mayor, and/or commissioners, that focus on climate change and its impacts can serve as a springboard for future actions by showing awareness and intent. Resolutions can be an effective way to start conversations in your community about climate change and climate events.

[44] Minnesota Department of Commerce, 2017.
[45] US EPA, 2008

- *Procurement:* During the procurement processes for municipal building projects, place greater preference on bids that consider cool technologies and retrofits.

- *Zoning Codes:* Codes provide guidelines and frameworks for development and land use. The following code recommendations can be applied at the county or municipal level.
    - Keep and treat stormwater runoff on-site
    - Require native plantings and tree coverage in public/municipal landscaping
    - Energy efficiency standards for municipally owned buildings
    - Regulations permitting urban agriculture

  The Georgetown Climate Center offers a range tools to help municipalities incorporate green infrastructure into existing sites or redevelopment, which is typically more complicated than incorporating green infrastructure into new development.[46]

- *Law Enforcement*: During extreme heat events, lessen loitering restrictions. Allow people, particularly minors who are frequently subject to loitering inquiries, to safely access cool places.

- *Cooling Centers*: Identify easily accessible buildings in neighborhoods to be designated as cooling centers in an extreme heat event. Ensure cooling centers in the most vulnerable areas are stocked with emergency supplies.

<u>For Municipalities</u>

- *Comprehensive Plans:* Including mitigation, adaptation, and resiliency goals into comprehensive plans is beneficial for showing long-term commitment and provides support for plans and policies. Comprehensive plans set community, municipal, and regional visions, aims, objectives, and context for community development for the next 30 years. As part of the Metropolitan Council, all municipalities are required to update comprehensive plans every ten years, which includes inter-municipal collaboration and review of plans. The comprehensive plan can be a great resource to prompt inter-municipal projects benefitting vulnerable populations. The comprehensive plan itself does not set policies, but it prompts review of existing policies to ensure compliance – presenting a key opportunity to include adaptive design preferences and create opportunities for resilient development, even if development or political will does not currently align with resiliency goals. Currently, resiliency is not required in the comprehensive planning process, but the Council provides several resources to help

[46] Georgetown Climate Center. "Green Infrastructure Toolkit." 2017.

communities plan for mitigation, adaptation, and resiliency.

- *Zoning Code:* While some municipal zoning codes are outlined above under "Counties and Municipalities," the following codes work best at a municipal scale because they provide better control over the locations and types of developments.
    - Permeable pavement for overflow parking, alleys, patios, and sidewalks
    - Develop and enforce green/living/complete street design standards
    - Density bonuses for incorporating desired green design features
    - Energy efficiency standards for new development and redevelopment

- *Community Gardens:* Evidence suggests a strong correlation between the natural environment and social cohesion within communities. Findings indicate:
    - Positive effect on social cohesion
    - Lower crime
    - Sense of connection with the outside world and the people in it[47]
    - Perception of supply, quality of green space can allow for greater community attachment[48]

  Moreover, intentional spaces such as community gardens hold the potential to strengthen a range of social processes such as collective decision-making, reciprocity, mutual trust, civic engagement, and community building. These social aspects are associated with improving the health of individuals as well as strengthen neighborhoods.[49] Community gardens also help to absorb water in flood prone areas and, as a vegetated space, offer lower ambient air temperatures in heat islands.
    - Allow community gardens and urban agriculture in zoning code

SITE DESIGN

The design, layout, and function of cities, counties, and metropolitan area have an immense impact on the quality of life for all residents. While zoning codes can help keep incompatible uses separate, site design is a more tangible way to bring mitigation and adaptation into communities. Site design and community structure are experienced on a day-to-day basis in a way zoning is not and can play an important role in creating community cohesion and in

[47] Amano, T., Balmford, A., Bradbury, R., Gladwell, V., Haan, C., Weinstien, N. (2015). Seeing Community for the Trees: The Links among Contact with Natural Environments, Community Cohesion, and Crime. American Institute of Biological Sciences. *BioScience* 65: 1141–1153.

[48] Arnberger, A., & Eder, R. (2012). The influence of green space on community attachment of urban and suburban residents. *Urban Forestry & Urban Greening*, 11(1), 41-49. http://dx.doi.org/10.1016/j.ufug.2011.11.003

[49] Teig, E., Amulya, J., Bardwell, L., Buchenau, M., Marshall, J. A., & Litt, J. S. (2009). Collective efficacy in Denver, Colorado: Strengthening neighborhoods and health through community gardens. *Health & Place*, 15(4), 1115-1122.

preparing and responding to climate events. The EPA's *Smart Growth Fixes for Climate Adaptation and Resilience* handbook[50] illustrates a powerful example of the importance of site and community design:

> "*The design of a neighborhood affects how its residents cope with extreme heat in less obvious, indirect ways as well. In the 1995 Chicago heat wave that killed more than 700 people, neighborhoods with similar percentages of African-American residents and elderly residents, and similar levels of poverty, unemployment, and crime, had very different death rates.[51] Research found that the neighborhoods with lower death rates in the heat wave had stores and restaurants where elderly residents felt safe, meaning they could easily get to nearby places with air-conditioning. These commercially healthier places also built more social capital by drawing more residents out onto the sidewalks. By contrast, in the neighborhoods with higher death rates, the businesses largely consisted of liquor stores and check-cashing shops, and elderly residents likely did not feel safe leaving their homes.[52] A thriving, walkable neighborhood with amenities that bring people together can help build a sense of community that can encourage residents to check on each other in emergencies—not to mention its everyday quality of life benefits for everyone in the community*."

The following are recommended site design strategies for both extreme heat and surface flooding.

- *High Albedo and Cool Surfaces*: Light colored surfaces help reflect light and do not become as hot as normal pavement or hold heat as long. High albedo roofs are a subtle but effective way to reduce cooling costs and heat island effects. The reflective surface does not absorb as much heat, keeping buildings cooler. This surface reduces cooling costs and energy consumption, which contributes to reduced heat island effects beyond the building itself. Many roofs are not visible to passersby, making high albedo a good option when aesthetics is a concern. Since roofs need resurfacing and replacing, this practice can be implemented as part of routine maintenance. The selection of light colored materials may create aesthetic disagreements when the roof is visible to the public, and there may be concern about the level of glare in an area if implemented on a large scale. Additionally, to maintain high albedo, roofs may need to be recoated on a regular basis, which can add costs.[53]

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[50] United States Environmental Protection Agency. (2017). *Smart Growth Fixes for Climate Adaptation and Resilience*. EPA 231-R-17-001. www.epa.gov/smartgrowth

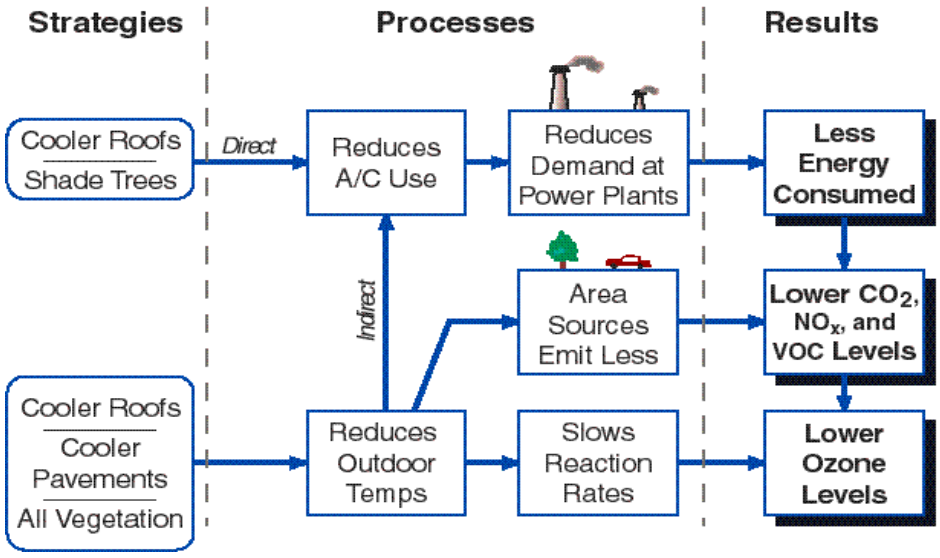
[51] Klinenberg, Eric. "Adaptation." The New Yorker, Jan. 7, 2013.

[52] Browning, Christopher R., et al. "Neighborhood Social Processes, Physical Conditions, and Disaster-Related Mortality: The Case of the 1995 Chicago Heat Wave." American Sociological Review 71.4 (2006): 661-678.

[53] Akbari, 2005

High albedo or cool pavements have fewer heat reduction benefits than cool roofs since they only impact ambient temperatures. However, high albedo surfaces can create safer streets; "street lighting is more effective if pavements are more reflective, which can lead to greater safety; or alternatively, less lighting could be used to obtain the same visibility" which reduces municipal energy costs.[54] **An albedo of 0.35 is recommended**, roughly the same albedo as cement concrete. High albedo surfaces can be applied to existing roads during resurfacing/reconstruction projects, which can lower costs.

High albedo surfaces can also help extend the life of infrastructure. Infrastructure is more prone to failure in extreme heat (warping, bucking, etc.). Reducing the amount of heat absorbed by infrastructure can help preserve investments and extend its lifespan while reducing overall heat island effect. For example, pavement may crack less and roofs may not need replacing as soon as they normally do.[55] Cooler, high albedo roofs also lessen the energy load on hot days by keeping buildings cooler. This effect reduces the overall strain on the electrical grid on hot days due to increased cooling demands.[56]



Source: Akbari, 2005[57]

- *Green Roofs*: Green roofs are an effective way to cool buildings while increasing stormwater infiltration. They can also add visual interest to the skyline and streetscape.

[54] Akbari, 2005
[55] Ibid.
[56] MN Dept. of Health Climate Report:http://www.health.state.mn.us/divs/climatechange/docs/mnprofile2015.pdf
[57] Akbari, H. 2005.

Green roof installation and maintenance can be expensive, but studies have examined the most beneficial locations for reducing heat effects and found green roofs in town centers have the largest effect toward reducing heat island effects, followed by manufacturing districts, high density residential areas, storage buildings and facilities, and retail areas.[58] Green roofs also lessen the energy load on hot days by keeping buildings cooler. This effect reduces the overall strain on the electrical grid on hot days due to increased cooling demands.[59]

- *Parking*: Reducing parking requirements can reduce the amount of hot, impervious surface in an area, mitigating both heat island and surface flooding effects. Reducing the amount of paved land frees up land for other developments or plantable park space. If parking is a concern in commercial and retail areas, shared parking agreements are an option to reduce the number of spaces. Many parking lots are used during specific times of the day or week and can be shared with establishments with different schedules. For example, churches and movie theatres are visited at different times than banks or offices and could share parking lots with little overlapping use.

- *Design Guidelines*: While codes should not dictate exactly how developments should look, they can influence key design features to reduce energy, conserve water, or manage water on-site. Some design guidelines are unseen, dealing more with insulation, plumbing, electricity, and other core building functions. There are already established green building codes, both in Minnesota and nationally. Minnesota has developed B3: Buildings, Benchmarks, and Beyond to guide sustainable construction. This green building standard is used for all new state buildings. Nationally, LEED (Leadership in Energy and Environmental Design) standards provide levels of sustainable construction based on several energy and resource savings measures, which enables more buildings to achieve some level of green certification. Other green design guidelines are more aesthetic and can help to create a community identity or unique point of interest. Design guidelines can be set for most recommended strategies, including:

[58] Gill et. al, 2007
[59] MN Dept. of Health Climate Report: http://www.health.state.mn.us/divs/climatechange/docs/mnprofile2015.pdf

- Permeable pavement
- High albedo pavement
- Green infrastructure
- Trees
- Stormwater management
- Parking lots

In some cases, design guidelines can be requirements. In other cases, they can be incentivized to encourage incorporation into site plans.

Table 4 (below) provides a quick, table reference for the policy and site design strategies detailed in this section. Strategies are categorized by type of climate event and type of tool (noted with icons) and are suggested for consideration based on urban, suburban, and rural contexts. These suggestions are based on general land uses and vulnerability in each community typology and may not be appropriate or applicable for all municipalities in a given community typology. Additionally, since actual costs and savings associated with any mitigation or adaption project are very site and context specific, a true cost-benefit analysis cannot accurately (or fairly) be performed. Instead, Table 4 offers typical costs and benefits associated with each strategy. This table is not exhaustive of all strategies, tools, costs, or benefits and is meant to offers municipalities a starting point and options when considering vulnerabilities in a specific area, available resources, and potential savings or pay-backs.

Table 4: Mitigation, Adaptation, and Resiliency Strategies

Key:  = Extreme Heat  = Localized Flooding  = Policy  = Site Design

Strategy	Event Type	Tool Type	Urban	Suburban	Rural	Types of Costs	Types of Savings
Trees/Urban Forestry			Yes	Yes	Yes	Installation, maintenance, monitoring	Energy (heating/cooling), stormwater, infrastructure, property values, health (air pollution)
Green Roof			Yes	In Dense Areas	In Developed/ Growing Areas	Installation, maintenance	Energy, stormwater, potential recreation incomes (gardens, bars, cafes, etc.), health (air pollution)
Green/Living Streets			Yes	Yes	Yes	Installation, maintenance	Energy, stormwater, infrastructure, property values, health (air pollution), traffic calming (fewer accidents)
Community Gardens			Yes	Yes	Dependent on Community Character	Land acquisition, installation, maintenance, potential loss of taxes	Stormwater, health

Parking Lots			Yes	Yes	Yes	Installation maintenance	Infrastructure, stormwater, sediment filtration
Zoning Codes			Yes	Yes	Yes	Execution	
Parks/Open Space			Yes	Yes	Dependent on Community Character	Land acquisition, maintenance, potential loss of taxes	Avoided property damages, energy, health, potential recreation
High Albedo Pavement			Yes	Yes	Yes	Installation, maintenance	Infrastructure, energy
High Albedo Roof			Yes	Yes	Yes	Installation, maintenance	Infrastructure, energy
Bioswales			On Large Lots/ Sites	Yes	Yes	Installation, minimal maintenance, monitoring	Stormwater, sediment filtration
Rain Gardens			Yes	Yes	Yes	Installation, minimal maintenance	Stormwater, sediment filtration

Rain Barrels			Yes	Yes	Yes	Materials and Installation	Stormwater

Sources:
EPA Smart Growth Fixes for Climate Adaptation and Resilience: www.epa.gov/smartgrowth
EPA Reducing Urban Heat Islands: Compendium of Strategies: https://www.epa.gov/heat-islands/heat-island-compendium
Naturally Resilient Communities: http://nrcsolutions.org/strategies/?fwp_hazards=stormwater&fwp_region=greatlakes%2Cmidwe

Next Steps: Sustaining Our Learning

Community engagement and communication is critical for creating and sustaining community cohesion and better understanding the needs and concerns of residents. Developing effective communication with neighborhoods and residents can help keep residents informed about municipal services and resources, climate events, and emergency response plans. All climate plans and mitigation efforts should be carried out in partnership with the impacted neighborhoods and communities to foster community cohesion and ensure mitigation measures are best suited for the impacted populations.

Metropolitan Council

To better assist municipalities and to coordinate climate mitigation and adaptation on a regional scale, the following actions are recommended:

- Create a searchable online climate action database for the seven-county metropolitan region, like the US EPA's Community Action Database[60], allowing municipalities to see examples and sort through options based on community goals and resources.

- Perform an in-depth county analysis. This analysis can be facilitated through either GIS or statistical software. A deeper analysis would yield hard numbers to better support policies designed to implement mitigation and adaptation measures in the most vulnerable areas of each county. The first level analysis can serve as a starting point for where to dive deeper into quantitative analysis.

- Combine this analysis with work from Regional Parks and Trails. "Proximity to parks" was an indicator discussed in early versions of analysis because parks offer cooler, more vegetated spaces to cool off during extreme heat events, impervious surfaces to absorb stormwater, and provide a public gather space to foster community cohesion. Based on discussions with Council staff, this indicator was excluded from this analysis because it was being considered in other ways in the Regional Parks department. Combining the two data sets, and incorporating any gaps in municipal parks, can add to the understanding of community cohesion, heat island mitigation, and accessibility to valuable park infrastructure.

- Develop a Culture and Risk assessment tool or "framework" following the guidelines in the IFRC World Disaster Report. The rapidly changing demographics of the metropolitan area present a strong argument for considering culture in policy and organizations handling climate events. The metropolitan area has many diverse cultures, and these

[60] US EPA, 2016. https://www.epa.gov/heat-islands/heat-island-community-actions-database

groups are growing. Examples of prominent cultures in the Twin Cities region include: Chinese, Hmong, southeast Asian, Somali, north African, Karin, and eastern European. Additionally, new immigrants are a highly vulnerable population and were somewhat captured indirectly through indicators such as home ownership tenure and limited English proficiency. A more in-depth examination of immigrant communities is needed to ensure these populations are well provided for in mitigating and adapting to climate events.

- People perceive and respond to risk and efforts to mitigate or adapt to it differently depending on their cultural background and patterns of behavior and belief. Therefore, true adaption of the recommendations and addressing the root causes of vulnerability will depend, in part, on understanding culture. Regardless of a strong response plan, reducing vulnerabilities themselves and acting in the interest of the vulnerable will have more impact over time to reduce the effects of climate change on vulnerable populations and the organizations that serve them. Some questions a Culture and Risk Tool might help to answer include:

    - Why will people adopt or resist changes and/or recommendations?
    - What challenges might the culture(s) in your area experience during a heat or flood event?

    "The one thing that is certain is that we will have less sustained impact if we do not adequately take account of people's cultures, beliefs and attitudes in relation to risk. With climate change leading to damaged livelihoods, and therefore more vulnerability, and making hazards more extreme and/or frequent, we have to get this right."[61]

For Municipalities

- Measure community cohesion at the neighborhood level. During the literature review, it came up often how community cohesion is an important component for how a neighborhood or area prepares for and responds to extreme weather events. Social or community cohesion is hard to measure and the studies that have created ways to measure it rely heavily on qualitative assessments of individual communities that are geographically bound. One study out of John's Hopkins University worked to develop an instrument that could measure an aggregate of individual-level variables, which are found to be related to community cohesion. While this study primarily used qualitative methods, they also collected demographic information to see if they could determine

[61] International Federation of Red Cross and Red Crescent Societies. 2014. "World Disaster Report: Focus on culture and risk." (p. 8).

predictors. This study found that the demographic characteristics that are predictors of community cohesion are years lived in the neighborhood, which is positively correlated, and level of education, which is negatively correlated.[62] Below is a table of the questions that were used for the qualitative study on neighborhood cohesion from the John Hopkins report. This level of qualitative analysis at the city or neighborhood level would better help city planners and public health officials understand their communities' assets by understanding the level of social cohesion.

Table II. Corrected Item–Total Scale Correlation Coefficients for Items Constituting the Neighborhood Cohesion Instrument[a]

Item	37-item scale	Final scale
1. Overall, I am very attracted to living in this neighborhood.	.79	.75
2. I feel like I belong to this neighborhood.	.84	.83
3. I visit with my neighbors in their homes.	.68	.70
4. The friendships and associations I have with other people in my neighborhood mean a lot to me.	.79	.80
5. Given the opportunity, I would like to move out of this neighborhood.	.72	.66
6. If the people in my neighborhood were planning something I'd think of it as something "we" were doing rather than "they" were doing.	.70	.70
7. If I needed advice about something I could go to someone in my neighborhood.	.71	.72
8. I think I agree with most people in my neighborhood about what is important in life.	.57	.57
9. I believe my neighbors would help me in an emergency.	.63	.60
10. I feel loyal to the people in my neighborhood.	.83	.83
11. I borrow things and exchange favors with my neighbors.	.65	.66
12. I would be willing to work together with others on something to improve my neighborhood.	.60	.57
13. I plan to remain a resident of this neighborhood for a number of years.	.75	.71
14. I like to think of myself as similar to the people who live in this neighborhood.	.65	.65
15. I rarely have neighbors over to my house to visit.	.66	.69
16. A feeling of fellowship runs deep between me and other people in this neighborhood.	.84	.84
17. I regularly stop and talk with people in my neighborhood.	.65	.67
18. Living in this neighborhood gives me a sense of community.	.87	.85

[a]Response alternatives for all items are (1) *strongly agree,* (2) *agree,* (3) *neither agree/nor disagree,* (4) *disagree,* (5) *strongly disagree.* Except for Item 5 and Item 15 which are negatively keyed, all other items require recoding before means are computed (e.g., 1 = 5; 2 = 4; 4 = 2; 5 = 1). After recoding the sense of community/cohesion variable is equal to the mean of all 18 items. Items 1, 5, and 13 were originally written to measure attraction-to-neighborhood; items 3, 7, 11, 15, and 17 to measure neighboring; and items 2, 4, 6, 8, 10, 12, 14, 16, and 18 to measure psychological sense of community.

- Currently, there is no metropolitan wide definition or standard for a cooling center. However, to help reduce extreme heat vulnerabilities, easily accessible buildings should be identified and designated as cooling centers. Depending on the location, size, and capacity of the cooling center, it should also be stocked with emergency supplies. Cooling centers offer opportunities for public-private partnerships, since many private facilities, such as ice arenas, private schools, and shopping centers may be more convenient and accessible for vulnerable populations than government buildings. Additionally, designating a few non-government buildings as cooling centers may encourage some residents who distrust or have strained relationships with the government to feel more safe accessing and using the facility.

[62] Buckner, J. (1988). *The Development of an Instrument to Measure Neighborhood Cohesion.* The Johns Hopkins University

- Unfortunately, due to the limited availability of demographic data at finer geographic scales, the team found it necessary to perform the analysis at the census tract level. Rural centers looking to use this report should use the 30 x 30-meter map and local understandings to make better estimates of what is happening in their area.

Appendix A: Master List of Indicators

Type of Indicator	Reports using factor?	Minneapolis	Ramsey County	MDH	Portland	Boston	Bridgeport, CT	Vermont	Cutter et. al 2003	Binita et. al	Key Informants
Scale of Report Analysis		*City Report*	*County Report*	*State Report*	*City Report*	*City Report*	*City Report*	*State Report*	*National Report*	*State Report*	
Population Traits											
Elderly Over 65	5	Census Tract				Census Tract		Census Tract	County	County	MDH & Baris/Met Council
Elderly Over 80	1		Block Level								
Youth Under 5	7	Census Tract	Block Level	County		Census Tract		Census Tract	County	County	MDH & Baris/Met Council
Youth Under 18	1						Census Tract				
Median Age	1								County		
People of Color	6	Census Tract		County	Census Tract	Census Tract			County	County	MDH & Baris/Met Council
Disability	2	Census Tract				Census Tract					Aggregate Disability Type - Baris/Met Council
Birth Rate	1								County		
Gender	2					Census Tract			County		
Female Headed Households	2								County	County	
Net Migration	1								County		
Householder 65 + Living Alone	4		Block Group	County		Census Tract		Census Tract			Used and aggregated w/Elderly - MDH
Household Traits											
Single Parent Households	1					Census Tract					Too correlated with other variables, omit - Baris/Met Council
Number Occupied Housing Units w/o Phone Service	1		Block Group								

Type of Indicator	Reports using factor?	Minneapolis	Ramsey County	MDH	Portland	Boston	Bridgeport, CT	Vermont	Cutter et. al 2003	Binita et. al	Key Informants
Number Occupied Housing Units w/o Vehicle Access	4	Census Tract	Block Group	County		Census Tract					MDH & Baris/Met Council
Number of Occupied Mobile Homes	4		Block Group	County					County	County	
Average People per Household	1								County		
No Central Air Conditioning	1	Parcel Level/ Census Tract									
Median Housing Value/Rent	1								County		
Renters	5	Census Tract			Census Tract	Census Tract			County	County	MDH & Baris/Met Council
Multi-Family Housing Units	1		Block Group								
Housing Units per sq Mile	2							Census Tracts	County		
Number Residential Housing Permits per Square Mile	1								County		
Socioeconomic Status											
Poverty											
At or Below Federal Level	4	Census Tract		County				Census Tract	County		MDH & Baris/Met Council
Families with Children	1			County							
Below 150%											
Below 200%	1		Block Group								
Unspecified	2					Census Tract				County	
Income at or Below 80% AMI	1						Census Tract				
Household Income at or Below 80% MFI	1				Census Tract						

Type of Indicator	Reports using factor?	Minneapolis	Ramsey County	MDH	Portland	Boston	Bridgeport, CT	Vermont	Cutter et. al 2003	Binita et. al	Key Informants
Less than High School Education, 25+	3		Block Group					Census Tract	County		Baris/Met Council
Less than Bachelor's Degree, 25+	1				Census Tract						
Unemployed	2								County	County	Need to make case/connection outside of poverty - Baris/Met Council
Employed People Working Outside	4		Block Group	County					County	County	Most work place take precautions and risk is low-MDH. Hard to get the data you want, be careful if including - Baris/Met Council
Speaks English											
Less than "very well"	3		Block Group	County		Census Tract					Baris/Met Council
Less than "well"	1	Census Tract									
Not at All	1									County	
Health											
Heat-Related ER Visits	1							Census Tract			
Age Adjusted per 100,000 people	1	Zip Code									
Asthma Related ER Visits	1	Zip Code									
Asthma Cases per 100,000	3					Census Tract	Census tract	Census Tract			
Heart Attack Hospitalizations	1	Zip Code									

Type of Indicator	Reports using factor?	Minneapolis	Ramsey County	MDH	Portland	Boston	Bridgeport, CT	Vermont	Cutter et. al 2003	Binita et. al	Key Informants
Number of Community Hospital	1								County		Hard in Metro given U and larger clinics. Gives spatial proximity but not access to care there. – MDH
Diabetes	2					Census Tract		Census Tract			
Hypertension	2					Census Tract		Census Tract			
Obese	1							Census Tract			
Fair/Poor Health	1							Census Tract			
Warm Season Deaths	1							Census Tract			
Cancer	1					Census Tract					
Other Diseases (Liver, kidney, bronchitis, emphysema)	1					Census Tract					
No Health Insurance	1							Census Tract			Sometimes more telling descriptive of health conditions. *Access can be everything.* - Baris/Met Council; MDH
Institutionalized Residents											
Inmate Population	1									County	
Residents in Nursing Home	1					Census Tract					
Residents in College/Student Housing	1					Census Tract					

Type of Indicator	Reports using factor?	Minneapolis	Ramsey County	MDH	Portland	Boston	Bridgeport, CT	Vermont	Cutter et. al 2003	Binita et. al	Key Informants
Other											
Walk or Bike to Work	1		Block Group								
Urban/Rural Population	1									County	
Vote Cast for President	1								County		Need to be able to make connections - Baris/Met Council
Commercial/Industry Per Square Mile	1								County		
Social Security Recipients	1								County		
No Social Memberships	1					Census Tract					
Physician to Population Ratio	2								County	County	No - Baris/Met Council
Adaptive Capacity											
Per Capita Income	2								County	County	
All Education Levels	1									County	
Bike Connectivity**	1				City Data						
Transit Connectivity**	1				City Data						
Proximity to Elementary School**	1				City Data						
Sidewalk Density**	1				City Data						
Access											
Food	1				City Data						
Recreation**	1				City Data						
Commercial Services**	1				City Data						
5 Minute Walk to Park	1						In House Calculation				

** Denotes part of "Complete Community" Index/Measure

Appendix B: Indicators Used in Existing Minnesota CVA Reports

Indicators Used in Existing Minnesota CVA Reports			
Indicator	City of Minneapolis CVA, 2016	St. Paul-Ramsey County CVA, 2016	Minnesota Department of Health CVA, 2014
Aged 65 years or older	X	X	X
Population Over 80 years		X	
Aged 5 years or younger	X	X	X
% living at or below the federal poverty level	X	X	X
Proportion of Families with Children Living at or Below Poverty			X
Speak English less than "very well"	X	X	X
Percent of People of Color (non-White, non-Hispanic)	X		X
All Occupied Housing Units in Multi-Family Housing		X	
Renters	X		
Proportion of Mobile Homes		X	X
Air Conditioning (percent of resident parcels with central air conditioning)	X		
Employed People aged 16 or Older Who Work Outside		X	
% of Workers Employed Outdoors by Industry			X
Disability - noninstitutionalized population who report a disability	X		
Occupied Housing Units without Telephone Service		X	
People 16 years or older who walk or bike to work		X	
Less than High School Diploma, aged 25 years or older		X	
Heat Related Emergency Department Visits	X		
Asthma Emergency Department Visits	X		
Heart Attack Hospitalizations	X		

Appendix C: Drafts of Human Vulnerability Indicators

Have data		Where else is it in the literature?	What is the data source?	Justification / Our rationale for choosing this indicator	Comments from Reviewers
	COMMUNITY COHESION			Sadie researching literature on this category for definitions and comparisons	We'd like to see an expansion of indicators in this category. For example, what does the literature say about the presence of community assets (green space, community institutions, churches, schools)?
*	-% Renter (Homeowner)			● Tend to have lower incomes ● Less likely to have AC ● Repairs may not be taken care of quickly	Consider looking at mobile homes
*	-Short tenure (less than 5yrs)			● Fewer resilient relationships in the neighborhood ● Less awareness of where/how to access services	
*	-single adult with children			● More difficulty evacuating ● More difficulty coordinating a hospital visit ● More likely to live in poverty ● More likely to have low-level service jobs	Eliminate this unless the literature clearly supports. If it is included, consider moving it to a more appropriate category…perhaps it should be paired with another indicator, such as income?
	HEALTHY POPULATION			-- Hospital - captures overall health - which could become ER visits putting pressure on the health system in a floor or heat event therefore we don't need both hospital AND ER -- Looking into if ER visits are included in the "hospital visits" data we will be using. -- Currently leaning towards going with straight rates as an	Clarify if you're seeking feedback on this. Right now, it's organized with the Healthy Population category header, but it also looks like an indicator. Generally, ER visits are a better indicator than hospitalizations, especially for heat, but it may depend on the health issue. Looking just at

				indicator of the health of the population (not ER)	hospitalizations may muddle the data unless you're able to parse out scheduled vs. unscheduled incidents.
*	-Persons 5 years and younger	MPLS, MDH, SPRCCVA	ACS census data	• Dependency on other people for care (MDH) • Smaller body mass to surface area ratio (MDH) • Blunted thirst response (MDH) • Produce more metabolic heat per lb. of body weight (MDH) • Lower cardiac output (MDH) • Exposure to mold (caused by flooding) at less than 1 year of age can increase risk of developing asthma (MDH, Mendell et al. 2011)	
*	-Persons 65 years and older		ACS census data	• Have the highest rates of heat-related illnesses and deaths (MDH) • Decreased ability to control body temperature (MDH) • Chronic disease conditions and certain medications can make older individual more susceptible to heat (MDH) • May need assistance to evacuate in a flood • Less likely to leave their home following evacuation orders(MDH) • Social isolation means that people may not be checking in on them during extreme heat or flooding (MDH)	
*	-Hospital		MDH,	• People with	

	Visits - asthma		downloadable	respiratory illnesses may be more vulnerable to mold development after a flood (MDH) ● People with asthma can experience flare-ups in times of high heat and humidity. (The Lung Association) ● Extreme temperature can cause air to become stagnant, trapping pollutants in the air, which can also cause an asthma flare-up. (The Lung Association)	
*	-Hospital Visits -COPD		MDH, downloadable	● Having COPD requires more energy just to breathe and extreme heat requires extra energy to try to cool down (Lung Association) ● If heat is too extreme, this can affect a person's ability to breathe (Lung Association) ● Increased heat and humidity can trap air pollutants. Exposure to air pollution is associated with the development and progression of COPD (MDH)	
*	-Hospital Visits -Heart Attacks		MDH, downloadable	● Certain heart medications can exaggerate the body's response to heat (ALA) ● Extreme temperature can affect air quality by trapping pollutants in the air, leading to harmful cardiovascular effects (MDH)	
	ACCESS				

*	- Health Insurance Status		Sadie knows the source...		
*	-Car ownership			• Less ability to evacuate • Less ability to get to health services	
*	Public transportation			• (Consider adding a public transportation indicator as this is a back-up or primary mode of transportation in the metro area.)	
*	ABILITY impairment			• May need assistance to evacuate during a flood (MDH) • May be unable to adequately care for themselves without assistance (MDH) • COMBINING: Hearing, vision, ambulatory, cognitively impaired	
	SOCIO-ECONOMIC STATUS			We're still discussing how to unpack this category… in relation to the cultural indicators and the "community cohesion" indicators	
*	-Percent of Poverty (income)	THIS MIGHT BE A STANDAL ONE - "DIRECT" indicator	Below 185 poverty threshold	• Less ability/likelihood to seek medical help • Many competing priorities for basic needs • less ability to absorb losses from hazards	Consider looking at areas of concentrated poverty vs. areas of concentrated wealth. See our MnDOT HIA report for additional detail about this comparison. http://www.health.state.mn.us/divs/hia/docs/mndothiafinalreport.pdf
*	-Level of Education			• higher educational attainment affects lifetime earnings • limited education constrains the ability to understand	

				warning information and access recovery information	
	CULTURAL				
*	-Race/ Ethnicity	THIS MIGHT BE A STANDAL ONE - "DIRECT" indicator		• Minorities more likely to live in poverty • More likely to live in hazard prone areas (due to real estate discrimination and poverty effects) • Ethnic communities often geographically and economically isolated from jobs, services, and institutions • language and cultural barriers and affect access to post-disaster funding and occupation of high-hazard areas	This vulnerability is about institutional racism and the impacts of race as a multiplier. Reword the rationale points to encompass this framing. Consider weaving in environmental justice literature points as well.
*	-Ability to Speak English		Less than "very well" (note that this is self-evaluated)	• Less ability to understand and receive health messages in crisis (access healthcare, evacuate, etc.) • (does this go in community cohesion?? Might depend on native language isolation too? - living in a cultural community that speaks vs. not...can we get data on that?)	The revised framing reflects the issue that many healthcare messages and facilities assume English as a primary language. The system is creating this vulnerability, not the population. Check the literature on this. With the above, revised language this might even be a better fit under "Access"

MAYBES

	Internet access		Having trouble finding	• Limited communication options to receive warnings, find assistance
*	Landline		Available	• Limited communication options to receive warnings or ask for

			through ACS	assistance/check on others

DELETED

*	ER visits - asthma Drop indicator		MDH, downloadable	• Rates of asthma ED visits are consistently higher among children age 17 and under living in the 7-county Twin Cities metropolitan area than children living in Greater Minnesota. (MDH) *Not sure what to put here as there doesn't seem to be a correlation with heat...possibly air quality. "The greatest number of ED visits are seen in the fall months, and the fewest number of ED visits are seen in the summer. A major contributor to the fall increase in asthma ED visits is thought to be increasing rates of respiratory infections among with children going back to school. Other possible contributing factors include pollen and mold." (MDH)
*	ER visits - heat related Drop indicator			• There was an increase in the frequency and rate of heat-related illness ED visits for the summers 2001, 2006, 2011, and 2012. (MDH) There are contradictions to assumptions about heat and the metro: https://apps.health.state.mn.us/mndata/heat_ed

no	Hospital visits - hypertension			

Appendix D: Trees

There are several resources to help municipalities plan, monitor, and care for their trees, a few of the most widely used and tested are listed here:

- The Urban Forests Interactive Adaptation Workbook hosted by the USDA and USFS offers specific recommendations and step-by-step processes based on geographic location and other input information. https://adaptationworkbook.org/

- I-Tree is also a well-known forestry resource offered through USDA full of great tools for enhancing and maintaining the urban canopy. There are different programs to best suit the need of your municipality, some running from downloaded desktop applications and other being web-based. https://www.itreetools.org/

- Open Tree Map is another helpful online forestry tool that anyone can access. Municipalities can create an account for a low monthly fee and document the locations, conditions, and benefits of up to 25,000 trees. Additional packages allow for more trees or green infrastructure tracking like rain barrels, rain gardens or bioswales. https://www.opentreemap.org/

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