Technical Report

Metropolitan Council Climate Vulnerability Assessment

May 2017

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Technical Report Purposes

This Technical Report details the process that went in to developing a Human Vulnerability Index relative to extreme heat and surface flooding within the seven-county metropolitan region. This Climate Vulnerability Assessment (CVA) uses a spatial analysis approach by looking at specific human vulnerability indicators in relation to place type vulnerabilities of extreme heat and surface flooding through the creation of maps. This CVA is being conducted for the Metropolitan Council (Council), a 17-member regional policy-making body and planning agency. The Council provides many services in achieving their mission of "fostering efficient and economic growth" for the region, include planning, regional parks, affordable housing, wastewater treatment services, Metro Mobility, Metro Transit's bus and rail system, and more. This report builds off the work that came out of the Metropolitan Council's THRIVE MSP 2040 initiative, which was developed to help the Council address new planning challenges and opportunities as they arise.

> *"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." – The Metropolitan Council*[1]

Thrive MSP 2040 prescribes policy goals for the CVA to address. 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 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 Technical 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. This is the second report of this type to come out of the Master of Urban and Regional Planning capstone project, and it follows closely to the methodology and structure as the previous team's work. The previous MURP team conducted a CVA for the City of Minneapolis and was consulted in creating this analysis. Our team also collaborated with many professionals and experts, which helped guide the creation of the human vulnerability indicators. We were encouraged to build from and rely on existing reports of this type but to adapt it to our specific region and indicators.

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[1] Metropolitan Council, (n.d.). THRIVE MSP 2040. Retrieved: https://metrocouncil.org/Planning/Projects/Thrive-2040.aspx

The Metropolitan Council asked that this Climate Vulnerability Assessment address these two main questions:

1. *Which areas within the metro 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 (human) vulnerability indicators?*

This Technical Report serves these purposes:

- To show the methodology behind the development of the Human Vulnerability Index as well as the spatial scale used, data sources, availability, and limitations.
- To provide documentation for how the assessment was performed for transparency and replicability.
- To provide data sets and maps, allowing staff to access the data used for this assessment for their own purposes.

Organization of Technical Report

Section 1 addresses the overall vulnerability assessment design. This section also provides background on the place-based vulnerabilities to extreme heat and surface flooding.

Section 2 details the human vulnerability indicators used in this analysis and the process behind their development. It also provides justification for the individual Human Vulnerability Indicators chosen for this CVA, including the data source, and level of analysis.

Sections 3 and 4 provide an explanation of the methodology the Council used in creating the Heat Hazard Index and Flood layer Basemaps used for this analysis.

Section 5 provides explanation of map creation processes and details data used in this analysis.

Section 6 provides all the Human Vulnerability maps created for this CVA, including both the aggregates and small multiples for both heat and flood, for a total of 30 maps.

Section 7 provides all the GIS data used for the creation of maps and PowerPoint presentations.

Appendix A provides a step-by-step description of the GIS map creation process

Appendix B provides explanation of the cooling center data acquisition. These data were not part of the formal analysis, but it helped provide information for overall recommendations.

Appendix C is the GIS data disclaimer provided by the Council for the Heat Vulnerability Basemap and Flood Layers.

Appendix D describes the development of the Social Network indicator and justification for its inclusion in climate vulnerability assessments.

1. Assessment Design

This section provides context and relevance for how climate vulnerability interacts with human vulnerability. This section also provides context for why this assessment is looking at climate events of extreme heat and surface flooding.

1.1 The 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 also look at those areas in terms of the human vulnerability. This enhanced awareness of human vulnerability in relation to place-based vulnerability will better inform adaptation and mitigation strategies for local municipalities.

Figure 1 shows the relationship of climate, sensitivity, and adaptive capacity as they relate to vulnerability.

> *"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."*[2]

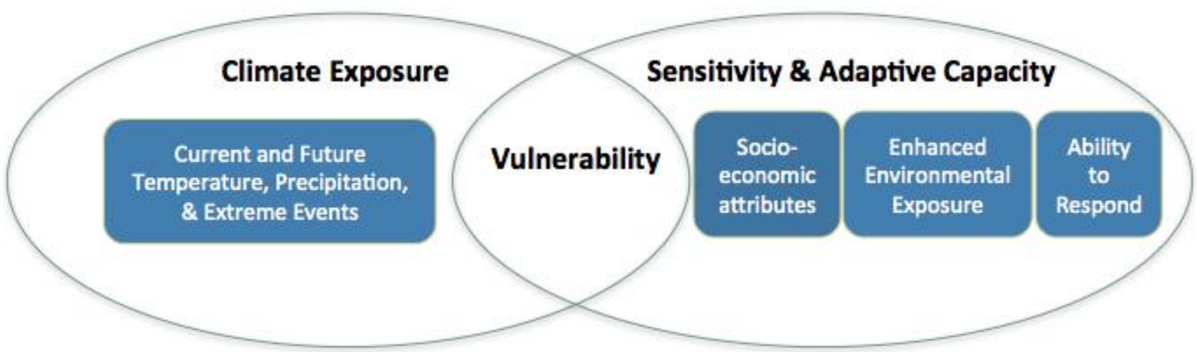

Figure 1: Climate Vulnerability

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[2] 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*, (Fall 2014) Volume 2.

This assessment aims develop a Human Vulnerability Index relevant to extreme heat and surface flooding events. The definition of vulnerability that will be used for 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.*[3]*-MDH*

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.

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

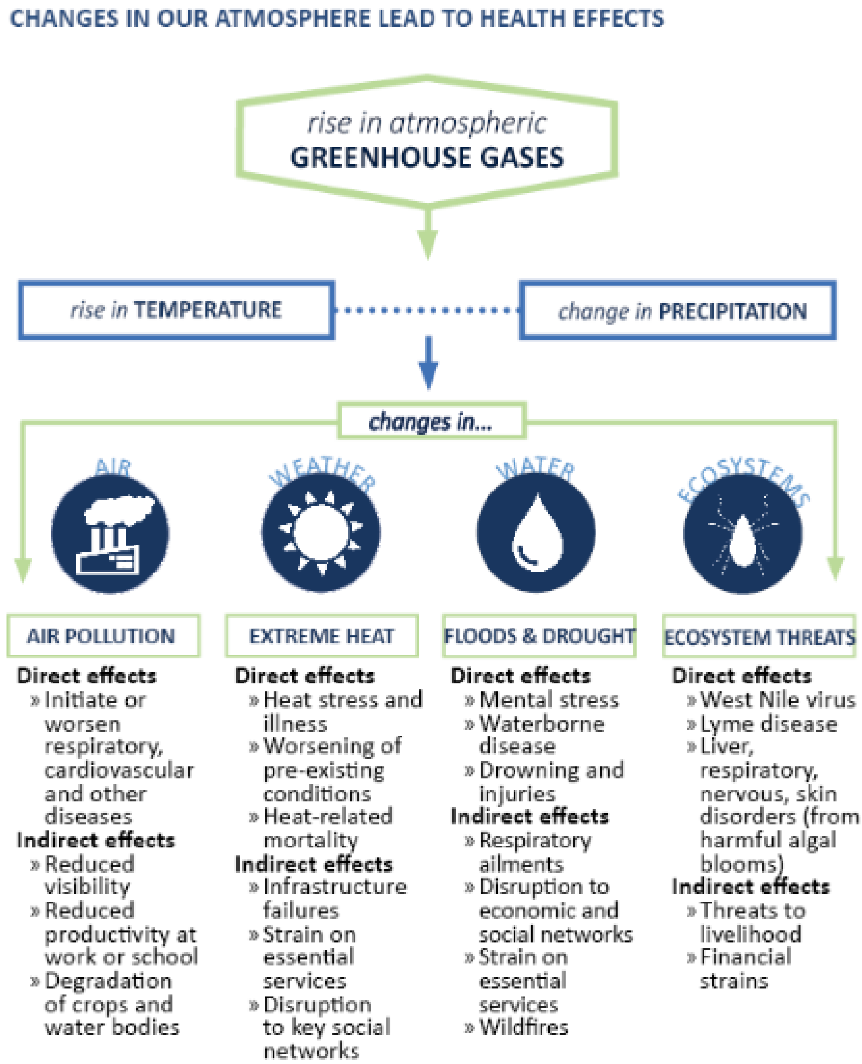


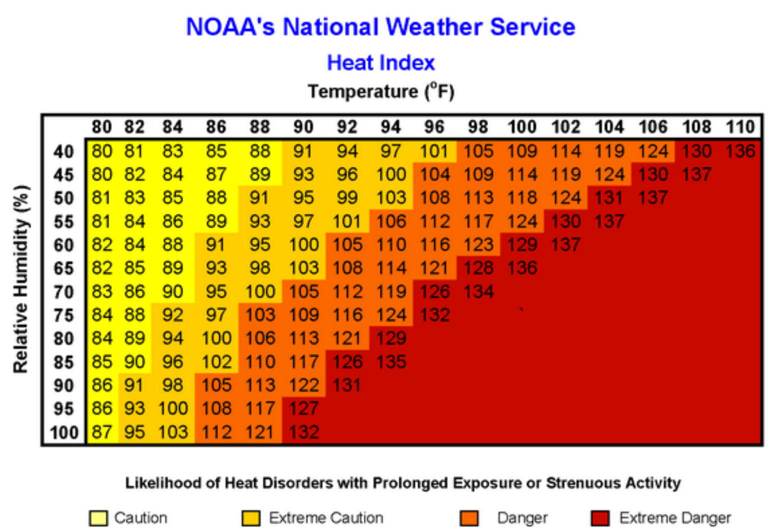
Figure 2: Source: http://www.health.state.mn.us/divs/climatechange/climate101.html

1.3 Analysis of Vulnerability to Extreme Heat

Climate and health are intricately connected and weather events such as extreme heat presents serious public health concerns. As climate change progresses, extreme weather events are expected to occur more frequently and with greater severity. While extreme heat presents a burden to built infrastructure and demand for increased cooling loads, certain populations are especially vulnerable due to limited income, mobility, race and ethnicity, health status, social factors, ability to communicate and access community resources. The Minnesota Climate and Health Program, which is part of Minnesota Department of Health, presents these key summary points in relation to Extreme Heat Events (EHE):

- Minnesota's climate has become warmer and more humid
- Minnesota may experience more frequent and/or intense EHE
- Minnesota may experience higher morbidity and mortality due to EHE
- Certain populations are more vulnerable to EHE
- Public Health practitioners should be aware of where those populations are located and know how to mitigate the risks to EHE[4]

The National Oceanic and Atmospheric Administration's National Weather Service has created a heat index map that is color coded to indicate the likelihood of heat disorders occurring. As can be seen in Figure 3, extreme caution is advised for prolonged exposure or strenuous activity in the 90-degree to 100-degree range.



	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Figure 2: NWS Heat Index sourced from http://www.nws.noaa.gov/om/heat/heat-images/heatindexchart.png

[4] MN Climate and Health Program. October 2012. *Extreme Heat Events, Climate Change and Public Health.* Minnesota Department of Health Environmental Impacts Analysis Unit.

Taking this into consideration, we obtained heat trend maps from the Great Lakes Integrated Sciences and Assessment Center (GLISA), based out of the University of Michigan. Figure 4 shows both a historical map of heat trends from 1971-2000 as well as a projected map for 2041-2070. When looking at these maps in relation to NOAA's Heat Index map, it is clear extreme heat is going to become a growing concern for the metropolitan area and populations that are the most vulnerable to episodes of extreme heat.

As can be seen in Figure 4 below, the number of days per year that will be over 90 degrees are expected to increase in frequency. Between the periods of 1971-2000, there was an average of 6 to 12 days per year in the metropolitan region that were above 90 degrees. That number is projected to increase to an average of 25 to 40 days above 90 degrees between the years of 2041 and 2070 if emissions remain high.

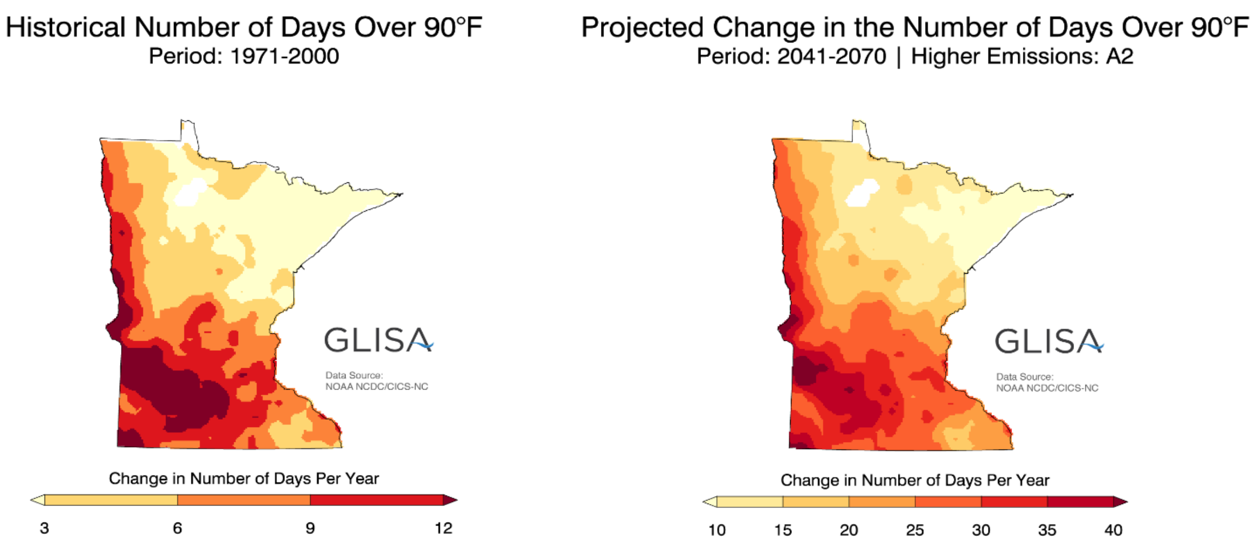


Figure 3: Data Source: Great Lakes Integrated Sciences + Assessment Center (GLISA)

This analysis of extreme heat in the region used a Heat Hazard Index Basemap created by staff at the Council. This approach normalized Land Surface Temperature values into an index from Very Low to Very High, which creates a means for comparing regions. This HHI map was overlaid with the aggregated and direct Human Vulnerability Indicators to assess human vulnerability to extreme heat events.

1.4 Analysis of Vulnerability to Surface Flooding

The Midwest has seen an increase in very heavy precipitation in the last 50 years. Understanding vulnerability to flooding presents different challenges than vulnerability to heat. However individual indicators have different degrees of vulnerability, or the vulnerability may occur at a different time in different extreme weather events. For example, an emergency room visit for asthma is more likely to occur during or shortly after an extreme heat event. In contrast, asthma can be triggered by mold growth, which is an after effect in flooding events. The following is a list of potential impacts from flooding provided by MDH:

- Physical Injuries and drowning
- Mold allergies
- Food and water-borne illnesses
- Temporary or permanent displacement from home
- Stress, anxiety, depression
- Damage to infrastructure, such as roads and bridges, may interrupt or delay emergency services[5]

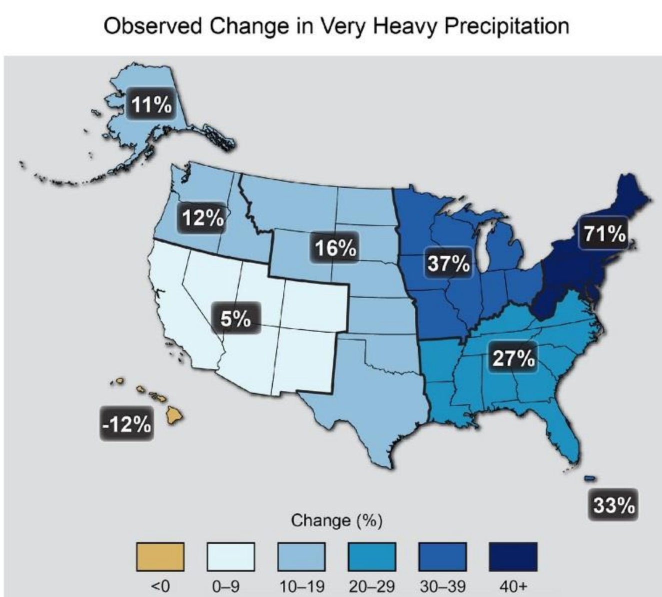


Figure 4 Map of Observed Changes in Very Heavy Precipitation, NCA

Minnesota has seen increasingly more rainfall since 1958, as shown in Figure 5. Intense rainfalls are expected to increase as an effect of climate change and shifting weather patterns. "The

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[5] MDH, (n.d.). *Water Quality and Quantity*. Retrieved online on April 15, 2017 from http://www.health.state.mn.us/divs/climatechange/water.html

map shows percentage increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. The trends are larger than natural variations for the Northeast, the Midwest, Puerto Rico, the Southeast, the Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawaii, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012."[6]

Heavy precipitation is defined as the 2% heaviest precipitation events in a given area. According to the projection maps provided by GLISA (Figure 6), the number of 2% heaviest precipitation events are projected to increase by about 1 day in Minnesota.

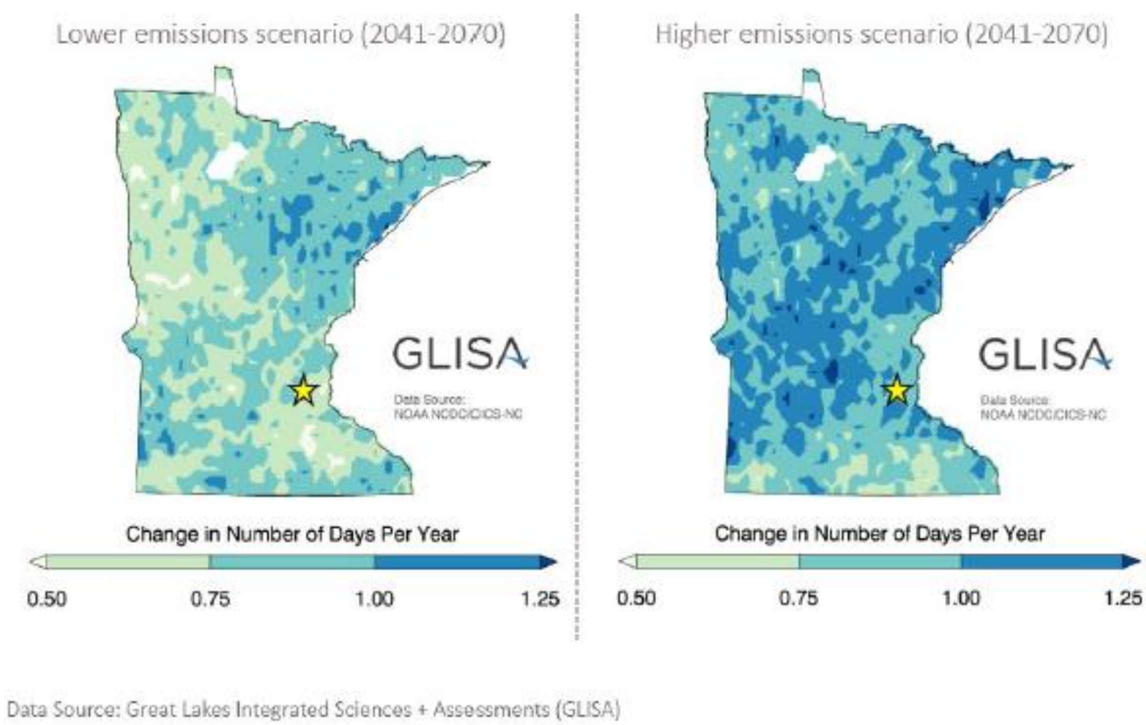

Figure 5 Scenarios for Increased Heavy Rainfall Events, GLISA

Staff at the Council created base maps for localized flooding events using LiDAR data. The shallowest flood layer of 0'-1' was overlaid with the aggregated and direct Human Vulnerability Indicators.

[6]NCA. 2014. "Figure 2.81: Observed Change in Very Heavy Precipitation." Retrieved online April 15, 2017 from http://nca2014.globalchange.gov/report/our-changing-climate/heavy-downpours-increasing

2. Human Vulnerability Index

When developing the Human Vulnerability Index, we first looked at other completed CVAs as well as academic literature. The amount of literature regarding climate and climate change vulnerability assessments has grown substantially over the past 10 years. Increasingly, CVAs are being conducted by governing bodies at varying scopes and scales as opposed to being a strictly academic endeavor. This expands the pool of resources, references, and ideas for developing CVAs. However, the Metropolitan Council is a unique governing structure in a Midwestern state, making some CVA variables and methodologies more relevant than others. Therefore, our literature review began with Minnesota specific and regional CVAs. Select statewide CVAs were also reviewed. Additionally, we 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. There have been three notable CVAs conducted in Minnesota:

- Minneapolis Climate Change Vulnerability Assessment
- St. Paul-Ramsey County Public Health Climate Change Vulnerability Assessment
- Minnesota Department of Health Climate Change Vulnerability Assessment

These three reports focused on issues relevant to Minnesota and provided insight as to what data are available through state resources as well as the possibilities for studying other geographic levels within the state. We relied heavily on these reports when developing our indicators.

The Minneapolis Climate Change Vulnerability Assessment, May 2016, was conducted at the city level examining urban heat island "hotspots" and flood vulnerable areas of Minneapolis. These geographic and infrastructure variables were compared alongside health and social vulnerabilities. Of all the literature reviewed, this CVA matched most closely with the climate and human variables the Council would like to consider. It also helped to determine the census tract level spatial scale of analysis. While finer geographies are available for American Community Survey data, the data also have higher margins of error. Minneapolis used census tracts, which decreased the margin of error and better mimicked the spatial breakdowns of neighborhoods in Minneapolis. We also used census tracts; however, some health-related data were only available at the county or zip code level.

The St. Paul-Ramsey County Public Health CVA (SPRCCVA), April 2016, was conducted at the county level. This is better suited to the Council's scale of analysis, but it focuses more on ecological changes as they relate to health. Additionally, the report discusses future population and demographic projections as well as their potential influence in creating climate action plans and reducing vulnerability. This fits within the Council's regional responsibilities; however, this analysis is not creating future demographic projections. Rather, this report creates a snapshot of current conditions and provides a duplicable methodology for future analyses.

The Minnesota Department of Health CCVA, 2014, focuses 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 CVAs and academic CVA research prior to 2013. This provided a foundation for our literature review, allowing us to focus on studies and reports completed from 2014 through present day. The report is thorough both in terms of the breadth of climate issues discussed and how vulnerable populations are identified for each climate event. This provides more detail to officials as opposed to grouping all vulnerable populations for all climate events into one "vulnerable population" measure.

Table 1 lists the indicators used in each Minnesota CVA in relation to heat and flooding. Some indicators such as age and level of poverty were used by all, while some indicators stand alone. This helped inform our process when choosing our indicators. The MDH CVA used more vulnerability indicators than what is listed below; the listed indicators were used specifically for vulnerability to heat and flooding.

Table 1: 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		

Table 1: Indicators Used in Existing Minnesota CVA Reports (continued)			
Indicator	**City of Minneapolis CVA, 2016**	**St. Paul-Ramsey County CVA, 2016**	**Minnesota Department of Health CVA, 2014**
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		

The indicators from the CVAs shown in Table 1 were useful in developing our set of indicators. However, we decided to structure our indicators slightly differently. Our original intent was to look at socio-economic vulnerability, but we felt that was too narrow of a lens when assessing vulnerability to extreme heat and flooding. Therefore, we created six categories, with two of those categories counting as direct indicators and the other four being aggregates of other vulnerability characteristics. This allowed us to use an aggregated approach to look at both individual vulnerability factors and composite conditions, providing a richer context to "vulnerability." Since this report focuses on the seven-county region, we felt this division would be useful for individual communities who may want to focus more on specific indicators or remove an indicator that is not a major factor in their community. This Human Vulnerability Index can be seen in Figure 7 on the following page and is the foundation of this assessment.

As mentioned above, the Human Vulnerability Index includes both direct and aggregated indicators. A direct indicator is a standalone variable. Through both climate vulnerability and non-climate research, these variables have been found to be main determining factors for disadvantage and vulnerability, often being correlated with other vulnerability factors. In this Index, direct indicators are race/ethnicity and poverty. Unlike some of the variables in aggregated categories (or indirect indicators), these variables do not need to be part of a larger lifestyle picture to greatly influence vulnerability and disadvantage. Additionally, these direct indicator variables are most requested to be examined on their own because of their connections to equity initiatives region wide.

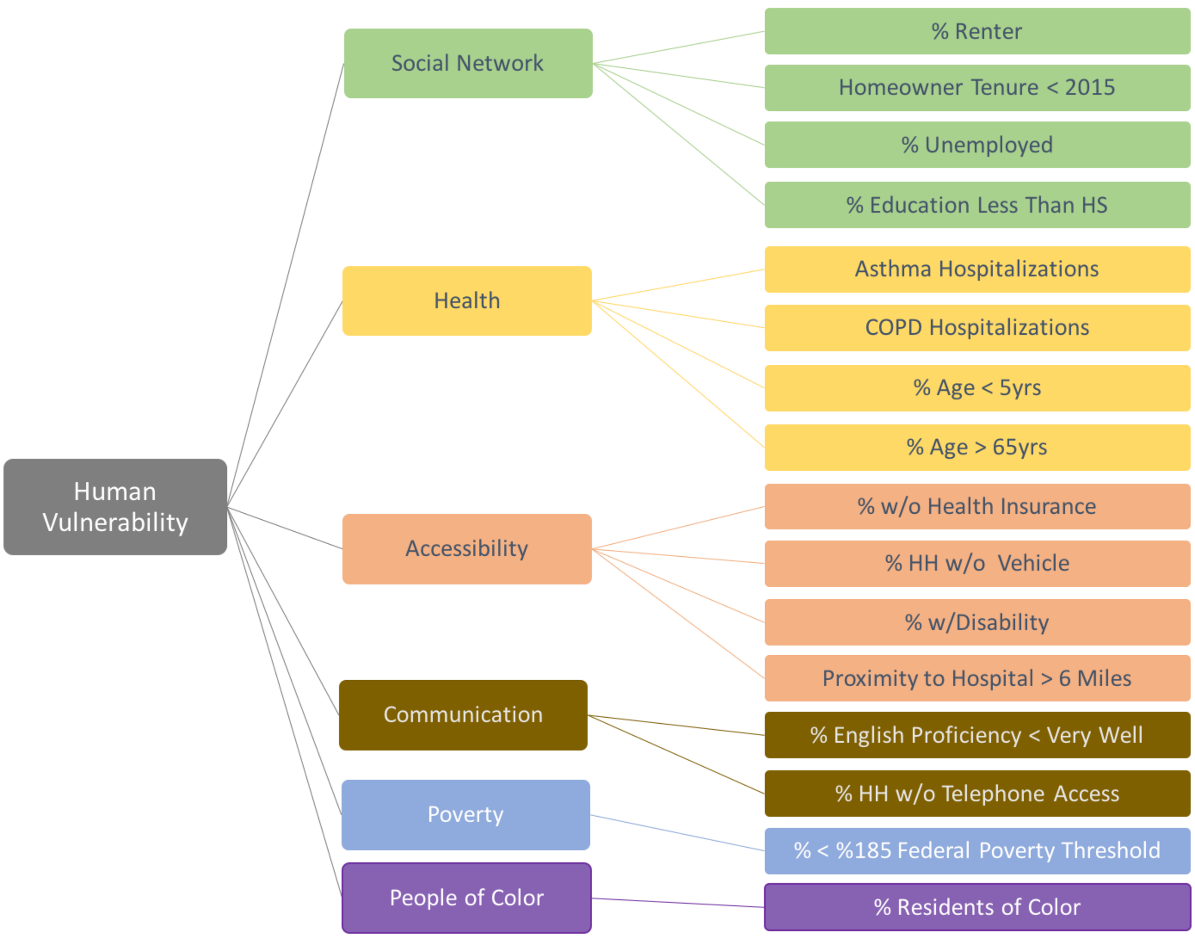

Figure 7: Vulnerability Indicators for the Metropolitan Council's CVA

The following pages provides both Table 2: Vulnerability as it relates to Extreme Heat, as well as Table 3: Vulnerability as it relates to Surface Flooding. These tables provide detail on each indicator, including the level of analysis that was used, the data source, and the section of the Technical Document where the corresponding map can be found. The remainder of this section provides rationale for each individual indicator in this Human Vulnerability Index.

Table 2: Vulnerability as it relates to Extreme Heat			
Vulnerability Indicator	**Level of Analysis**	**Source**	**Section of Technical Document: Map**
Human Vulnerability: all indicators	Census Tract and modified zip code	All Listed Sources	6.1
Poverty @ 185%	Census Tract	ACS 5yr, 2011-2015	6.3.1
Residents of Color	Census Tract	ACS 5yr, 2011-2015	6.4.1
Social Network	Census Tract		6.5.1
% Renter	Census Tract	ACS 5yr, 2011-2015	6.5.3
Tenure < 5 years	Census Tract	ACS 5yr, 2011-2015	6.5.4
Unemployment	Census Tract	ACS 5yr, 2011-2015	6.5.5
% < High School Degree	Census Tract	ACS 5yr, 2011-2015	6.5.6
Health	Aggregate		6.6.1
Age <5 years	Census Tract	ACS 5yr, 2011-2015	6.6.3
Age > 65 years	Census Tract	ACS 5yr, 2011-2015	6.6.4
ER visits: Asthma	Census Tract modified zip code	MDH, ZIP code 2009-2013	6.6.5
Hospital: COPD	Census Tract modified zip code	MDH, COPD ZIP code 2010-2014	6.6.6
Accessibility	Census Tract		6.7.1
Health Insurance	Census Tract	ACS 5yr, 2011-2015	6.7.3
Car Ownership	Census Tract	ACS 5yr, 2011-2015	6.7.4
Disability	Census Tract	ACS 5yr, 2011-2015	6.7.5
Proximity to Hospitals	Census Tract	Hennepin County GIS open data	6.7.6
Communication	Census Tract		6.8.1
English Proficiency; less than very well	Census Tract	ACS 5yr, 2011-2015	6.8.3
Telephone	Census Tract	ACS 5yr, 2011-2015	6.8.4

Table 3: Vulnerability as it relates to Surface Flooding			
Vulnerability Indicator	**Level of Analysis**	**Source**	**Section of Technical Document: Map**
Human Vulnerability: all indicators	Census Tract and modified zip code	All Listed Sources	6.2
Poverty @ 185%	Census Tract	ACS 5yr, 2011-2015	6.3.2
Residents of Color	Census Tract	ACS 5yr, 2011-2015	6.4.2
Social Network	Census Tract		6.5.2
% Renter	Census Tract	ACS 5yr, 2011-2015	6.5.3
Tenure < 5 years	Census Tract	ACS 5yr, 2011-2015	6.5.4
Unemployment	Census Tract	ACS 5yr, 2011-2015	6.5.5
% < High School Degree	Census Tract	ACS 5yr, 2011-2015	6.5.6
Health	Aggregate		6.6.2
Age <5 years	Census Tract	ACS 5yr, 2011-2015	6.6.3
Age > 65 years	Census Tract	ACS 5yr, 2011-2015	6.6.4
ER visits: Asthma	Census Tract modified zip code	MDH, ZIP code 2009-2013	6.6.5
Hospital: COPD	Census Tract modified zip code	MDH, COPD ZIP code 2010-2014	6.6.6
Accessibility	Census Tract		6.7.2
Health Insurance	Census Tract	ACS 5yr, 2011-2015	6.7.3
Car Ownership	Census Tract	ACS 5yr, 2011-2015	6.7.4
Disability	Census Tract	ACS 5yr, 2011-2015	6.7.5
Proximity to Hospitals	Census Tract	Hennepin County GIS open data	6.7.6
Communication	Census Tract		6.8.2
English Proficiency; less than very well	Census Tract	ACS 5yr, 2011-2015	6.8.3
Telephone	Census Tract	ACS 5yr, 2011-2015	6.8.4

2.1 Poverty: Direct

Population below 185% federal poverty line
Table: S1701-Poverty status in the past 12 months

This indicator was used by all three of the existing Minnesota CVA reports reviewed for this CVA. For this indicator, we agreed with the rationale used in the Minneapolis Climate Change Vulnerability Assessment, which states:

> *"Living in poverty might be characterized by having fewer resources at one's disposal, in general and in times of crisis. Cutter et. al*[7] *describe the effect of socioeconomic status as 'the ability to absorb losses and enhance resilience to hazard impacts.' Poverty as an indicator represents a lack of the inherent resilience that comes with wealth and socioeconomic status. Poverty has been associated with overall higher rates of poor quality housing, more limited ability to respond to emergency warnings or make preparations in advance of impending hazards, greater dependence on social assistance, and greater difficulties in recovering livelihoods following a natural hazard event.*[8] *These and other associated factors combine to create the link between poverty and vulnerability. Communities with high levels of those living under the federal poverty line may also face a situation in the event of extreme heat or flooding where many are competing, 'in the moment,' for the same basic services to meet basic needs. Not only may people be less likely or able to seek medical help, those services available and accessible to them may be overwhelmed in an extreme heat or flooding event."*[9]
>
> *Limitations: "While the poverty vulnerability link is strong and may seem self-evident, Cannon warns that the two should not be seen as synonymous and that implying causality between poverty and vulnerability discounts the capacities that exist to create a greater resilience to natural hazards despite poverty".*[10]

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[7] 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
[8] Morrow, Betty Hearn. 1999. "Identifying and mapping community vulnerability." *Disasters* 23.1: 118.
[9] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016
[10] Cannon, Terry. 2008. Reducing people's vulnerability to natural hazards communities and resilience, Research paper /UNUWIDER,No. 2008.34, ISBN 9789292300807

2.2 Residents of Color: Direct

Percent people of color (self-identified); Percent of population identifying as anything except "white, non- Hispanic"
Table: B03002-Hispanic or Latino Origin by Race

Using race as an indicator for vulnerability was greatly supported by both academic literature and other CVAs. Cutter et. al (2003) described the vulnerability associated with race as "the lack of access to resources, cultural differences, and the social, economic, and political marginalization that is often associated with racial disparities".[11] Because of limited resources and cultural differences, etc., minorities are more likely to live in poverty, to live in areas vulnerable to climate hazards (due to real estate discrimination and poverty effects), to be geographically and economically isolated from jobs, services, and institutions, and to have strong trends of language and cultural barriers which affect access to post-disaster funding."[12]

Taking these factors into consideration, the limitations around this indicator need to be addressed. Here again, the language used in the Minneapolis Climate Change Vulnerability Assessment seemed appropriate for this Technical Report's purpose, which states:

> *"Limitations: In many ways, it is uncomfortable to ascribe vulnerability causality to race. A discerning view would see race as the canvas upon which socioeconomic and health disparities have played out throughout history, creating differences in access, mobility and life chances that express themselves through greater levels of vulnerability. Defining race in this assessment as all persons of color, or those who are persons of color by virtue of the fact that they do not identify as "White, Not Hispanic," creates a treatment of race that fails to honor significant differences, cultural and demographic, that exist between different nonwhite communities. Nonetheless, this assessment takes the view that it is important to recognize the reality that vulnerability does play out in the arena of race, especially in light of the fact that the Twin Cities Metro Area is forecast to see significant growth in populations of color over the coming decades".*[13,14]

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[11] 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
[12] Ibid.
[13] Phillips, Brenda D., and Betty Hearn Morrow. 2007. "Social science research needs: Focus on vulnerable populations, forecasting, and warnings." *Natural Hazards Review* 8.3: 6168.
[14] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016.

2.3 Social Network: Aggregate

The individual indicators that form the Social Network Aggregate include: Percent Renter, Homeowner Tenure since 2015, Unemployment, and Education Level less than a High School Diploma. Social Networks was chosen as a Vulnerability Indicator because the strength of a person's social network may impact their health outcomes during extreme heat or flooding events. Supporting literature explains how the level of social networks plays a role in mortality rates as well as resilience post event. A report issued by the Center for American Progress explicitly studies how social networks makes communities more resilient in the face of extreme weather events, specifically low-income communities:

> *"Just as the Chicago heat wave displayed the vulnerability of low-income communities during extreme heat events, it also spotlighted the resilience of socially cohesive communities in the face of extreme weather. Researchers found that 3 of the 10 Chicago neighborhoods with the lowest rates of heat-related deaths were low-income, African American communities. The reason that communities with similar demographics fared so differently was high levels of community interaction and organization that decreased isolation among residents. Put differently, socially cohesive communities in which people are engaged in social or civic events enjoyed increased resilience against extreme weather events."*[15]

Studies have created ways to measure social networks, which could also be referred to as community cohesion. However, there tends to be a heavy reliance on qualitative assessments of individual communities that are geographically bound, which is not realistic given the regional scale of this analysis. For example, one study out of Johns Hopkins University[16] 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 predictors. The findings of this study (Buckner et. al) were also useful in developing this indicator category.

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[15] Baussan, D. 2015, May. *Social Cohesion: The Secret Weapon in the Fight for Equitable Climate Resilience.* Center For American Progress.

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

Given the qualitative nature of these data and its exclusion from other reviewed CVAs, this was the most challenging indicator to develop. Further explanation of our development process can be seen in Appendix D: Social Network Indicator Rationale. Rationale for the individual indicators that make up the Social Network Indicator are in sections 2.3.1 through 2.3.4.

2.3.1 Renters

Percent renter occupied households
Table: B25003-Tenure of Occupied Housing Units

Renters were chosen as a vulnerability indicator because they tend to have less control over both the quality of their housing condition and the location of where they live. Cutter et. al (2003) also suggests that renting can be an indicator of limited resources "because they are either transient or do not have the financial resources for home ownership." [17] Vulnerability to both extreme heat and surface flooding can occur prior to the event, during, or post. Renters' vulnerability can often come after the impact of a natural disaster or major weather event, where renters tend to have fewer resources to put toward recovery and fewer financial options made available to them. Rentership represents an indirect factor of vulnerability and not an inherent characteristic.[18]

2.3.2 Homeowner Tenure: moved in 2015 or later

Percent of Homeowners that moved in 2015 or later
Table: B25038-Tenure by Year Householder moved into Unit

People who have not lived in the same location for long tend to have fewer resilient relationships in the neighborhood. They may have less awareness of where to access services and how to problem solve with resources available. This indicator was not used in any of the CVAs reviewed for this report, but this concept is supported by literature looking at the effect of community cohesion and a neighborhoods ability to handle the pre, during and post events of extreme heat or flooding. Buckner et. al (1988) found the demographic characteristics that are predictors of community cohesion are years lived in the neighborhood, and level of education. Level of education showed a negative relationship with community cohesion,

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[17] 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
[18] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016

whereas years lived in the neighborhood was positively correlated.[19] For that reason, we found data that would allow us to map homeowners that are new to the area, suggesting that their short tenure may negatively impact their level of social networks in their immediate area.

2.3.3 Unemployment

Percent unemployed
Table: S2301-Employment Status

In the literature reviewed, "employment" is typically included with "socioeconomic status." Cutter et. al described socioeconomic status as consisting of income, political power, and prestige,[20] meaning those who are unemployed have less income or status, and their ability to recover from disaster or other events is hindered. For flood and heat events, this report uncouples "employment" from "income" so that it is not part of socioeconomic status, but instead a contributing factor to "social networks."

We justify this concept with the idea that "income," considered in this index by poverty level, will cover the issues of access to wealth and status. In the Human Vulnerability Index, it is more meaningful to consider and account for how employment indicates connection to a network of people outside of family and social circles, and how "having a job" can be an asset in a way other than providing income or political status or power.

2.3.4 Educational Attainment; Percent less than a High School Degree

Educational Attainment
Table: S1501-Educational Attainment

Cutter et. al argues "Education is linked to socioeconomic status, with higher educational attainment resulting in greater lifetime earnings. Lower education constrains the ability to understand warning information and access to recovery information."[21] We have selected our threshold as "less than high school" to account for the latter element of Cutter's description.

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[19] Buckner, J. 1988. *The Development of an Instrument to Measure Neighborhood Cohesion.* Johns Hopkins University
[20] 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
[21] 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

"Income" covers earnings, and we see "lifetime earnings" being less meaningful in the case of specific flood and heat events.

2.4 Health - Aggregate

The individual indicators that form the Health Aggregate Indicator include: Age 5 years and Younger, Age 65 Years and Older, Asthma Hospitalizations, and chronic obstructive pulmonary disease (COPD) Hospitalizations. Determining a conceptual indicator for the overall "health" of the population in areas vulnerable to surface flooding and extreme heat is complex. Available data indicates only potential health vulnerabilities, like age, or past health history, like hospital visits. These data do not indicate the severity, length, or chronic impacts. Even so, understanding the role potential and past health history plays on the health outcomes during extreme heat or surface flooding events is important in understanding an area's overall vulnerability.

For these reasons, and to obtain spatial data to map populations vulnerable to climate events due to past health concerns, we chose to use data for overall hospital visits, not "ER visits." This decision was made because of a lack of available data from MDH:

> *"The reason that we do not publish outpatient (ER) hospital visits for heart attacks and COPD is because these events are generally sufficiently serious to be admitted as inpatient hospitalizations. The reliability of ER data for these outcomes is limited. They are also relatively rare. For these reasons, and some more technical aspects of case ascertainment, we do not use ER visits for these outcomes to understand population heath patterns."* - Minnesota Department of Health[22]

Rationale for the individual indicators that make up the Health Indicator are in the following sections 2.4.1 through 2.4.4

2.4.1 Age 5 Years and Younger

Age Five (5) Years and Under
Table: B01001-Sex by Age

For this indicator, we agreed with the Minneapolis Climate Change Vulnerability Assessment rationale, which states:

[22] MDH, e-mail message to authors, April 12, 2017.

"At the younger extreme of the age spectrum, greater vulnerability exists because of the limitations on "movement out of harm's way"[23]. The vulnerability of young children stems from their dependence on others for their wellbeing and livelihood, as well as their limited physical and[24] mental ability to respond effectively to emergency situations. Very young children represent these vulnerabilities to a greater degree than older children, and are especially vulnerable to extreme heat[25]. Also, like older adults, young children have greater biological susceptibility to extreme environmental conditions, specifically extreme heat because they are not as efficient at regulating their body temperature" (due to smaller body mass to surface area ratio).[26]"

"Limitations: The vulnerability of very young children is not only dependent upon biological factors related to age, but is also situational in nature and dependent upon a child's environment and family support[27]. This assessment assumes that young children are themselves vulnerable, but Morrow and Cutter et. al also highlight that children can be a causal factor of vulnerability in households with limited resources, such as single parent households, wherein the financial strain of raising a child in already compromised circumstances can impact resilience to a disaster.[28]"

2.4.2 Age 65 and Older

Age Sixty-Five (65) Years and Over
Table: B01001-Sex by Age

Elderly populations, specifically in our context of flooding and extreme heat events, have myriad health implications to consider. The elderly have the highest rates of heat-related illnesses and death, decreased ability to control body temperature, increased susceptibility to

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[23] 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
[24] Cannon, Terry. 2008. "Reducing people's vulnerability to natural hazards communities and resilience" Research paper /UNUWIDER.
[25] McGeehin, M., & Mirabelli, M. 2001. The potential impacts of climate variability and change on temperature related morbidity and mortality in the United States. *Environmental Health Perspectives*, 109, 185–189
[26] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016
[27] Morrow, Betty Hearn. "Identifying and mapping community vulnerability." *Disasters* 23.1 (1999): 118.
[28] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016

heat due to medications and chronic disease conditions, less likelihood and ability to leave their home following evacuation orders, and social isolation, which is important because people may not be checking on them during and/or after flooding or extreme heat events.[29] They are also more likely to lack the economic resources to be resilient to natural disaster impacts.[30]

Limitations acknowledged by the Minneapolis Climate Change Vulnerability Assessment regarding the vulnerability of persons 65 years and older states:

> *"Limitations: Assuming all elderly individuals have the same vulnerability to natural hazards disregards the complexity and heterogeneity that exists among populations of older age. Ngo observes this complexity and reminds us that "within the elderly population, the young old, aged, oldest old, and frail elderly demonstrate a broad diversity in health, level of function, and social standing."[31]*

2.4.3 Asthma: Hospitalizations

Asthma Hospitalizations per 10,000 people
Source: Minnesota Department of Health, MN Public Health Data Access Portal
Table: Asthma-ZIP code 2009-2013
Level of granularity: Zip Code

Vulnerability from health factors span from during the "moment" of the event to effects that can take hold well after an event. During heat events, people with asthma can experience flare-ups in times of high heat and humidity. Extreme temperature can cause air to become stagnant, trapping pollutants in the air, which can also cause an asthma flare-up.[32] An additional concern in relation to flooding is people with respiratory illnesses may be more vulnerable to mold development after a flood.[33]

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[29] Minnesota Department of Health. 2015. *Minnesota Climate and Health Profile Report, 2015, An Assessment of Climate Change Impacts on the Health & Well-Being of Minnesotans*

[30] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016

[31] Ngo, E. (2001). "When Disasters and Age Collide: Reviewing Vulnerability of the Elderly." *Nat. Hazards Rev*iew, 10.1061/(ASCE)15276988(2001)2:2(80), 80-89.

[32] The Lung Association, (n.d.). *Heat and Humidity, How to protect your lungs on hot and humid days.* Retrieved April 2017 from online source: https://www.lung.ca/news/expert-opinions/pollution/heat-and-humidity

[33] Minnesota Department of Health. 2015. *Minnesota Climate and Health Profile Report, 2015, An Assessment of Climate Change Impacts on the Health & Well-Being of Minnesotans.*

2.4.4 Chronic Obstructive Pulmonary Disease (COPD): Hospitalizations

COPD Hospitalizations per 10,000 people
Table: COPD ZIP code 2010-2014

Vulnerability from health factors span from during the "moment" of the event to effects that can take hold well after an event. Having COPD requires more energy just to breathe, and extreme heat requires extra energy to try to cool down. If heat is too extreme, this can affect a person's ability to breathe.[34] Increased heat and humidity can trap air pollutants. Exposure to air pollution is associated with the development and progression of COPD.[35]

2.5 Accessibility - Aggregate

The individual indicators that form the Accessibility Aggregate Indicator include: Without Health Insurance, No Car Ownership, Disability, and Distance from a Hospital. These indicators were selected to conceptually speak to whether a person would have a difficult time accessing help both during an extreme heat or flood event, such as evacuation or transport to emergency health care services, and the ability to respond after the event due to persistent health conditions that may result from these climate events. One example of a post event hazard would be the growth of mold due to flooding and standing water, which can negatively impact individuals with asthma or COPD. Rationale for the individual indicators that make up the Accessibility Indicator are in the following sections 2.5.1 through 2.5.4

2.5.1 Health Insurance

Percent without Health insurance
Table: B27001-Health Insurance Coverage Status by Sex and Age

Having health insurance impacts a person's ability and decision making for when and how to access medical care. The vulnerability that comes from not having health insurance is not widely addressed in other CVA literature. However, insurance (homeowner's insurance, flood insurance, etc.) was included in the context of socioeconomic status in Cutter et. al's social vulnerability framework.[36] Understanding the health insurance status of the community is a

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[34] The Lung Association, (n.d.). ibid

[35] Minnesota Department of Health. 2015. *Minnesota Climate and Health Profile Report, 2015, An Assessment of Climate Change Impacts on the Health & Well-Being of Minnesotans*.

[36] 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

meaningful indicator of vulnerability. People who are uninsured may be reticent or unable to access health care for salient conditions before, or slower moving ailments after, a flood or heat event. Extreme events may also trigger high usage of ER facilities or other urgent care resources. While Cutter et. al argues that low levels of "proximate medical services" will "lengthen immediate relief and longer-term recovery from disasters,"[37] we also argue that the lack of insurance might have a similar effect in lengthening recovery from flooding and extreme heat events as people are not able to afford healthcare.

2.5.2 Car Ownership: No Access

Percent households without a vehicle
Table: DP04-Selected Housing Characteristics

For this indicator, we agreed with the Minneapolis Climate Change Vulnerability Assessment rationale, which states:

> *"The implication of vehicle access is the capacity to remove one's self swiftly from a dangerous situation. Households with no vehicle have more limited mobility in a time of crisis, and are thus more vulnerable to extreme weather threats associated with climate change. Those without vehicle access may also have less ability to get oneself to health services.*
>
> *Limitations: Access to a vehicle represents an indirect factor of vulnerability, and not an inherent characteristic. Vehicle access or ownership is a more fluid characteristic than age, disability or other intrinsic variables.[38]"*

2.5.3 Disability

Percent with a disability
Table: S1810-Disability Characteristics of Noninstitutionalized Population

Having a disability can limit a person's ability to anticipate, prepare for, and respond to climate events, which increases their vulnerability to climate events. In some cases, assistance is required to ensure persons with disabilities are out of harm's way during climate events, which requires both coordination and resources. The American Community Survey collects data on six

[37] Cutter et. al. ibid
[38] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016

distinct disabilities, all of which are relevant to responses to climatic events. These disabilities are ambulatory, cognitive, hearing, independent living, self-care, and vision. The American Community Survey aggregates all disabilities into one measure, which was used in this analysis, but individual data for each disability are available in the same table (specified above) for deeper analysis. This indicator is also important to include as the Council's THRIVE MSP 2040 includes "ability" as one of the factors connected to "equity" outcomes.

2.5.4 Proximity to a Hospital

Proximity to hospital, further than six miles
Table: Extracted from MDH Health Care Facility and Provider Database, February 22, 2016

The longer it takes someone experiencing health effects from a heat or flooding event to get to a hospital, the more intense those effects might become. In medical response literature and survivorship analysis, six miles is the maximum emergency response range before noted decreases in survivorship probabilities.[39,40] Proximity to hospitals is important for communities and local government in planning responses to flood and extreme heat events. Implications could include high demand for EMS services, overwhelmed ERs and urgent health clinics, and high/heavy usage of hospitals themselves during these events. This creates a need to assess how many people live farther than six miles from hospitals and the vulnerable populations living in these areas.

2.6 Communication - Aggregate

The individual indicators that form the Communication Aggregate Indicator include: Speaks English "Less than Very Well" and No Telephone. Communication was designed as a category for similar reasons as selecting indicators in the "Accessibility" category. The two Communication indicators were selected to conceptually speak to whether a person would have a difficult time accessing help before the phenomena occurs (i.e. ability to read and understand preparation materials and signs), "in the moment" (i.e. can ask for help in evacuation, transport to emergency health care) and over time (i.e. able to communicate needs for recovery). Rationale for the individual indicators that make up the Communication Indicator are in the following sections 2.6.1 and 2.6.2

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[39] Currie, Janet and Patricia B. Reagan. 2007. Distance to hospital and children's use of preventative care: Is being closer better, and for whom? *Economic Inquiry*, 41(3), 378-391.
[40] Nicholl, Jon, James West, Steve Goodacre, and Jeanette Turner. 2007. The relationship between distance to hospital and patient mortality in emergencies: An observational study. *Emergency Medical Journal,* 24(9), 665-668.

2.6.1 Speaks English "Less than Very Well"

Percent English proficiency less than "very well"
Table: S1601-Language Spoken at Home

This vulnerability indicator was used in all three of the Minnesota specific CVAs reviewed for this CVA. For this indicator, we agreed with the Minneapolis Climate Change Vulnerability Assessment rationale, which states:

> *"Persons who lack fluency in the dominant language will struggle to find adequate information or respond appropriately when important information is disseminated in the dominant language…When it comes to responding to extreme weather conditions such as those predicted by climate change forecasts, systematic language related barriers stack the deck against those with limited English proficiency.*
>
> *Limitations: The ACS classification of those who speak English "less than very well" is overly general, and may not fully capture the range of limited English capacity that contributes to risk in the face of climate change. Furthermore, the ACS, based on sampling, is of questionable value when it comes to accurately capturing the population with limited capacities to participate in a verbal or written survey because of language limitations.[41]"*

Not only does a limited proficiency to speak English effect the ability to find and understand information about evacuation, it may also have an impact on inclination and ability to access healthcare, suggesting difficulties in long-term recovery when it comes to health effects. Additionally, these data do not account for which languages are present in the various regions of high "less than very well" data. Spanish, North African languages, Hmong and other Asian and South East Asian languages, and various Eastern European languages (among others) may be present in high concentrations in the seven-county region of this study.[42] Areas where many residents speak the same language have different networks and abilities to communicate than

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[41] Technical Report: Minneapolis Climate Change Vulnerability Assessment, 2016
[42] Zan Associates. "Rethinking I94: Summary of Desk Research, 2016." For Rabbit and the Minnesota Department of Transportation.

tracts with several different spoken languages or isolated non-English speakers. This limitation can be better addressed at a more local level.

2.6.2 No Telephone (Landline)

Percent households without telephone
Table: B25043-Tenure by Telephone Service Available by Age of Householder

Households without telephones are vulnerable as they may have limited communication options to receive warnings, ask for assistance, or check on others. Landlines are important in the event of an extreme weather event in case cell phone networks become overwhelmed. This was the case in the wake of the 35W bridge collapse on August 1st, 2007; many people were not able to make cell phone calls because the cell signals were overwhelmed.[43] This scenario is unlikely in the event of extreme heat or surface flooding, but does show the importance of phone communication and the limitations of cell phones.

Limitations: These data only consider landlines, as cell phone data are not currently collected by the US Census and are difficult to obtain from providers. As several houses only use cell phones for communication, the available data provide an incomplete picture of phone access.

3. Methodology of Flood Layers

This section describes the methodology the Council used to develop its flood layers base map. The justification for the flood layer used by our team is also provided below. The GIS data disclaimer provided by the Council can be found in Appendix C.

3.1 Metropolitan Council CVA Flood Layers

The Council gathered data on two types of flooding: riverine and shallow/surface flooding. For this CVA, we only examined shallow/surface flooding at a depth of 1 foot or greater as these areas are the most susceptible to flooding and the most likely to occur in an extreme rain event. In developing the surface flooding methodology, the Council followed an example from the Danish Road Institute in which they evaluated surface flooding and short-term flooding low spots on the landscape. The Danish Road Institute referred to these areas as bluespots (2010),

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[43] "Cell phone service falters after bridge collapse" http://www.twincities.com/2007/08/01/cell-phone-service-falters-after-bridge-collapse/ last accessed May 12, 2017.

which are the areas that are the most susceptible to flooding during a short-term, extreme rain event.[44] The bluespot analysis conducted by the Council relied on topography information that was obtained from the State of Minnesota's 3-meter digital elevation model (DEM), which was built from the state's LiDAR effort. Stormwater infrastructure data are not included in this analysis because the information does not currently exist at a regional scale. Therefore, this analysis is restricted solely to depressions in the DEM. 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.[45]

The bluespots are divided into 1 foot categories and range from shallow up to 10 feet or greater. Shallow bluespots have a max depth of 3 inches to 1 foot, and are generally low risk, however, 6 inches of fast moving water can knock over an adult and 12 inches of fast-moving water can carry away a small car. When considering the vulnerable populations for this report, we chose to map only bluespots at a depth of 1 foot, since this level of water poses risk to pedestrians and infrastructure damage can still occur with small depths of flooding. This is also the most likely level of flooding to occur during a short-term, extreme rain event.

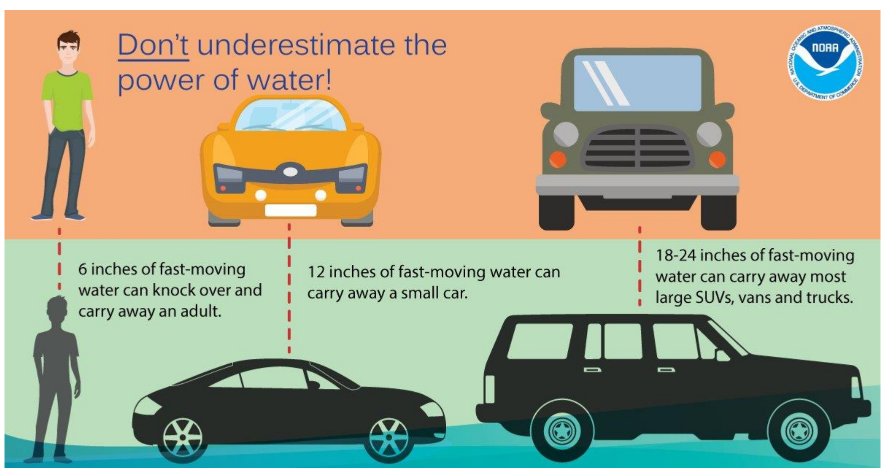
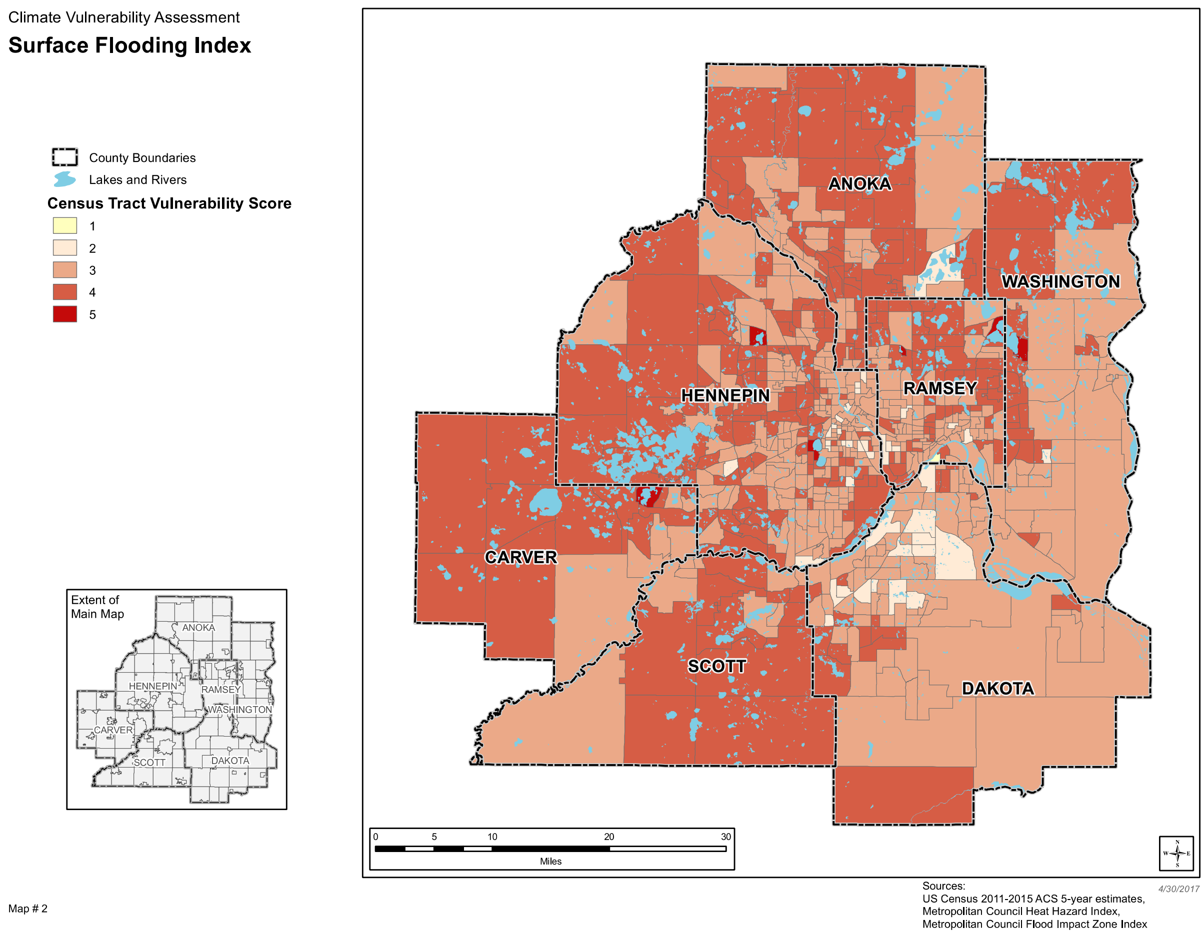


Figure 6 NOAA Description of Dangerous Water Levels[46]

[44] Danish Road Institute. 2010. *The Blue Spot Method: Development of a Screening Method to Assess Flood Risk on Highways.* Report 183-2010.
[45] The Metropolitan Council. (n.d.). *Metropolitan Council Climate Vulnerability Assessment Flood Layers.*
[46] National Oceanic and Atmospheric Administration, Weather Ready Nation. "Social Media: Flood Safety." http://www.nws.noaa.gov/com/weatherreadynation/social_media/spriing_flood.html

3.2: Surface Flooding Index Map



4. Methodology of Heat Layers

This section describes the methodology the Council used in developing the heat base map used for this assessment. The Council produced three products looking at regional vulnerability to extreme heat: land surface temperature, normalized heat vulnerability (also referred to as the heat hazard index), and interpolated air temperature. This assessment utilized only the heat hazard index, for reasons described in section 4.1 through 4.3. The Council's GIS data disclaimer can be found in Appendix C.

4.1 Land Surface Temperature

The Council provided a map of land surface temperature (LST) using a satellite image from Landsat 8. This 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, 2016. This 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…. 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 (Midwestern Regional Climate Center, 2016). 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.*
>
> *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.*
> 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."*[47]

Land Surface Temperature (LST) values without regional water bodies was the primary basis for the Council's heat hazard index. Regional water bodies were removed from the data set

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[47] The Metropolitan Council. (n.d.). *Metropolitan Council Climate Vulnerability Assessment Heat Layers.*

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.

4.2 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 our team'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 (Tomlinson, Chapman, Thornes & Baker, 2011; Buscail, Upegui & Viel, 2012). 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)."*[51]

We chose to use this LST-based index 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 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 (Tomlinson et al., 2011)."*[48]

One significant caveat of our team's approach is that the heat hazard is underrepresented in small towns and rural population centers. A small town located in a large rural census tract

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[48] The Metropolitan Council. (n.d.). *Metropolitan Council Climate Vulnerability Assessment Heat Layers.*

could have a substantial heat island effect, but the average index value for the tract would remain relatively low. However, because much of the socio-economic data relevant to this assessment were not available in units smaller than the census tract, we found it necessary to keep census tracts as our unit of analysis.

Note: 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.

4.3 Interpolated Air Temperature

Interpolated air temperature 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."*[52]

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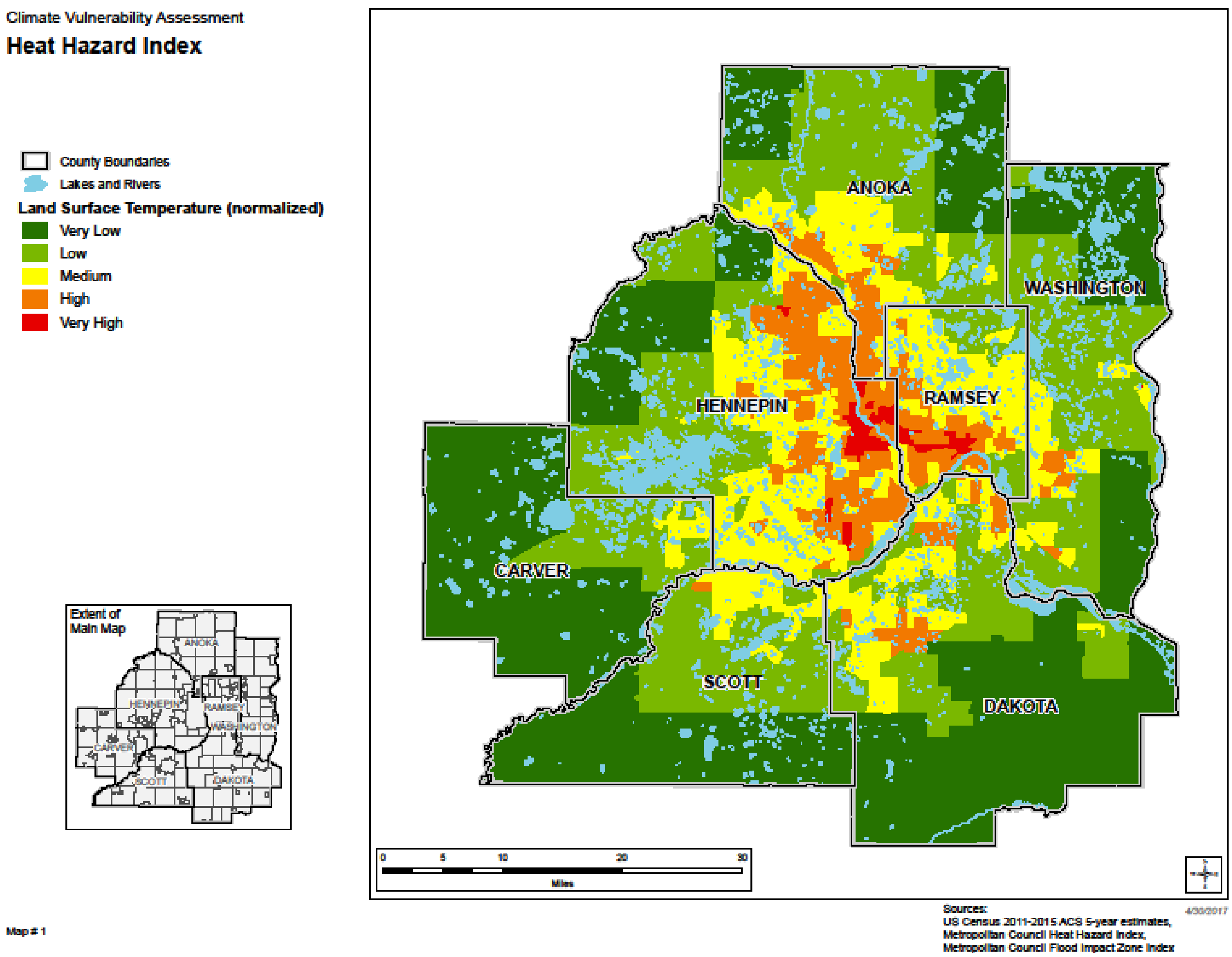
4.4 Heat Hazard Index Map



5. Data Preparation and Map Creation

This section describes the process of acquiring and preparing all data used in this analysis. It also provides a full description of the aggregate map creation process. More technical explanations and full GIS processes can be found in Appendix A: GIS Processes Step-by-Step.

5.1 Data Details

This section provides information on the acquisition of demographic data for each indicator used as well as the spatial scale chosen for this analysis. It also details how the data was formatted and converted to create maps using the ArcGIS software. Full GIS processes can be found in Appendix A: GIS Processes Step-by-Step.

5.1.1 Demographic Data

All demographic data was downloaded from the US Census Bureau, American Community Survey at the census tract level for all Metropolitan Council jurisdictions. Census tracts were selected as the level of spatial analysis because it offers a finer level of detail than city level data while having lower margins of error than block group data. Additionally, given the regional approach of this analysis, block group data were very similar to census tract data for most suburban and rural communities. Census tracts in outer suburban and rural areas are large, which limits the level of detail and analysis we can provide.

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, detailed on the following page in Table 4: Demographic Data Sources. This join operation was based on the GEOId2 Field, which provides a unique code for each census tract.

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Table 4 Demographic Data Sources

Indicator	2011-2015 ACS Table	Attribute used for analysis	GIS Table attribute code
Poverty	S1701 - Poverty status in the past 12 months	Population below 185% poverty level	PerPov185
Residents of Color	B03002 - Hispanic or Latino Origin by Race	Persons of Color	PerPOC
Age	B01001 - Sex by Age	Age 5 and under Age 65 and over	Und5Per Per65Up
Renters	B25003 - Tenure of Occupied Housing Units	Percentage of Renter Households	PercRent
Education	S1501 - Educational Attainment	Population with Less than High School Diploma or equivalent	Per_LessHigh
Homeowner Tenure	B25038 - Tenure by Year Householder moved into Unit	Moved into Home since 2015	PerOwnMove15
Unemployment	S2301 - Employment Status	Percent Unemployed	Per_Unemp
Disability	S1810 - Disability Characteristics of Noninstitutionalized Population	Percent of population with any disability	PercDisablePop
Vehicle Access	DP04 - Selected Housing Characteristics	Occupied Households without Vehicle Access	Per_NoCar
Health Insurance	B27001 - Health Insurance Coverage Status by Sex by Age	Percent of Population with no Health Insurance Coverage	Per_NoHI
Phone Access	B25043 - Tenure by Telephone Service Available by Age of Householder	Percentage of households without phone service	Per_NoPhone
Language Proficiency	S1601 - Language Spoken at Home	Speaks English less than “very well,” over 5 years old	Per_LessEng

5.1.2 Hospitalization Data

All hospitalization data were downloaded from the Minnesota Department of Health Data Portal. Unlike the demographic data described in Table 4, hospitalization rates were not represented as a percentage of total tract population. Instead, these data describe hospitalizations per 10,000 residents for asthma symptoms from 2009 to 2013, and for COPD symptoms from 2010 to 2014. Zip-code-level was the finest geography publicly available, which does not align with census tracts. Our team calculated hospitalization estimates by census tract using the process detailed in Appendix A: GIS Processes Step-by-Step.

5.1.1 Hospital Location Data

Note: A full step-by-step outline of these processes are provided in Appendix A: GIS Processes Step-by-Step

Hospital location data for the State of Minnesota was obtained through the Hennepin County GIS Data Portal. Then, all hospitals located in the seven-county metropolitan region were selected using ArcGIS's "Select" Tool. All selected hospitals were exported to create their own shapefile, named "Metro_Hospitals." An additional two hospitals outside of the seven-county metropolitan area were included in this analysis as they were located within the determined six-mile buffer range of metropolitan area census tracts.

A six-mile buffer was created around each hospital location. In medical response literature and survivorship analysis, six miles is the maximum emergency response range before noted decreases in survivorship probabilities.[49,50] This was done using the ArcGIS "buffer" tool, set at a six-mile radius. Once the buffer was established, the Intersect Tool was used to determine the portions of census tracts within the buffer, which were then exported to its own shapefile, "TractinBuff."

To calculate the percentage of each census tract within a hospital buffer, we first needed to calculate the areas of both the census tracts and the intersected/buffer overlap portions. Before we could perform calculations, we needed to change the data projection to allow the area calculation function to work. This was done using the "Project" data management tool. This was done in the Attribute Table. A new double field, "Area," was created in each attribute

[49] Currie, Janet, and Patricia B. Reagan. (2007). Distance to hospital and children's use of preventative care: Is being closer better, and for whom? *Economic Inquiry*, 41(3), 378-391

[50] Nicholl, Jon, James West, Steve Goodacre, and Jeanette Turner. (2007). The relationship between distance to hospital and patient mortality in emergencies: An observational study. *Emergency Medical Journal,* 24(9), 665-668.

table. Then, the geometry was calculated by right clicking on the created “Area” field and selecting “Calculate Geometry.” The area was calculated in square meters given the very small areas of some of the census tracts; area calculations returned “0” values when calculated in square miles.

Once both areas were calculated, the tables were “Joined” so all data attributes were visible in one table. To finish the calculations, the joined table was converted into an Excel Spreadsheet using the “Table to Excel” conversion tool. Within the Excel Spreadsheet, unnecessary data that was not relevant to our analysis was deleted to simplify organization. Then, the percentage of each census tract falling within a hospital buffer was calculated by dividing the census tract area by the intersect/overlap area. This yielded a percentage, formatted as a decimal to facilitate conversion back into GIS. All 0 percentages were checked against their location in the GIS map outlay to ensure there was indeed no portion of the census tract within a hospital buffer.

However, more vulnerable census tracts are outside of these buffers or have small intercept/overlap areas. To maintain similar scaling as other indicators, we calculated the inverse of the percentage intercept/overlap to show the percentage of census tract area not within 6 miles of hospital. These inverse percentages were used in the standard deviation scaling, with more vulnerable populations having high percentages of their area outside of a hospital buffer. The “Excel to Table” conversion tool was used to bring these calculations back into GIS for spatial analysis. To show these calculations spatially, the converted Excel table was “Joined” with the census tract layer. The “Project” data management tool was used again to ensure the spatial data matched the output of other layers.

5.2 Map Creation

This section provides a full description of the individual and aggregate map creation processes. Technical explanations and full GIS processes are included in this section given the importance of the scaling and map creation processes to this report and analysis.

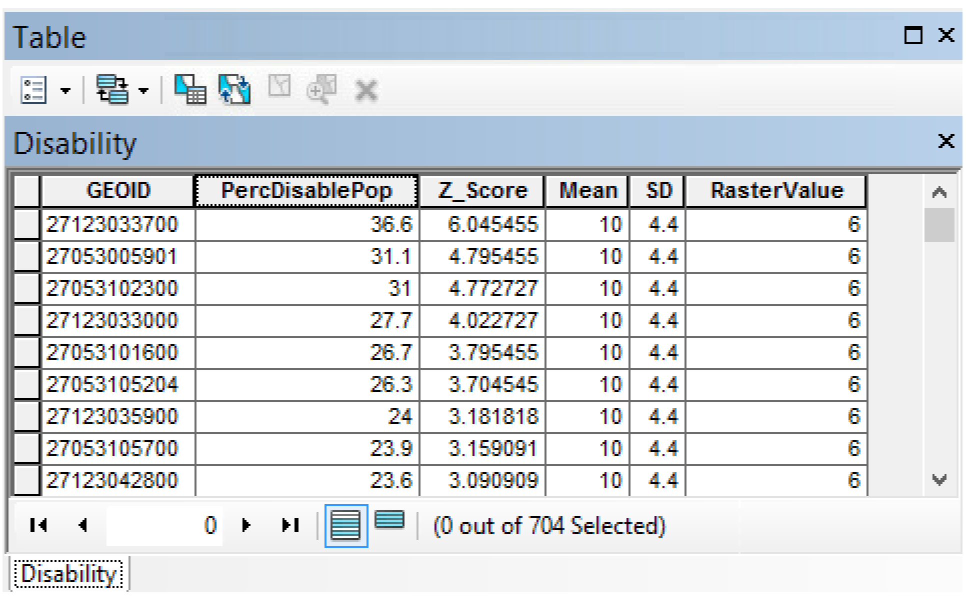
5.2.1 Individual Indicator Maps

Choropleth maps of each vulnerability indicator were created in ArcGIS, classified by standard deviations from the mean. Quintiles were originally considered but decided against for this stage of the analysis. Since the quintile method creates classes with an equal number of data points, regardless of their similarity or dissimilarity, the range of values in each quintile varies widely depending on the distribution of data. This variation caused some tracts with very different percentages of a given indicator to be classified in the same quintile. In contrast, the standard deviation method allows for a consistent measure and display of all indicators, which is important in this analysis given that distributions differ between indicators.

Census tract feature classes were created for each individual indicator by joining the indicator table to Tract_Metro (a feature class comprised of all census tracts within the seven-county metropolitan region). GeoID2 was used as the join field.

For each indicator, the Statistics function in ArcGIS was used to calculate regional mean and standard deviation of the percentage field. The percentage field for each indicator is shown in Table 4 above, under the field “GIS table attribute code.” In the case of Asthma and COPD hospitalizations, the “Count” field was used in place of the percentage field. Fields were added to each table for the mean, standard deviation (SD), and RasterValue.

Next, the z-score of each tract was calculated using the formula [$z = (x-\mu)/\sigma$], where x is the tract’s percentage value (PercDisablePop in the picture below), μ is the regional mean, and σ is the standard deviation.



GEOID	PercDisablePop	Z_Score	Mean	SD	RasterValue
27123033700	36.6	6.045455	10	4.4	6
27053005901	31.1	4.795455	10	4.4	6
27053102300	31	4.772727	10	4.4	6
27123033000	27.7	4.022727	10	4.4	6
27053101600	26.7	3.795455	10	4.4	6
27053105204	26.3	3.704545	10	4.4	6
27123035900	24	3.181818	10	4.4	6
27053105700	23.9	3.159091	10	4.4	6
27123042800	23.6	3.090909	10	4.4	6

Figure 7: Example of Z-Score Calculation

RasterValue was calculated according to Table 5 below. The RasterValue represents the tract’s score on a 6-point scale, where 6 indicates a much higher-than-average proportion of the vulnerable population in question, and 1 indicates a much lower-than-average proportion.

Table 5 Standard Deviation Classification

Classification	Attribute table query	RasterValue
>2 SD below mean	Z_score < -2	1
1-2 SD below mean	Z_score >= -2 AND Z_score < -1	2
<1 SD below mean	Z_score >= -1 AND Z_score < 0	3
<1 SD above mean	Z_score >= 0 AND Z_score < 1	4
1-2 SD above mean	Z_score >= 1 AND Z_score < 2	5
>2 SD above mean	Z_Score > 2	6

Using both percentages and standard deviation to describe population data provides a detailed picture for both census tracts and the 7-County Metropolitan Area. It shows how many people within each census tract are included in each vulnerable population variable while putting the census tract in the regional context, detailing whether a specific population composition is above, at, or below regional averages.

Each category of variables was given a color-scheme to help differentiate data. Green to red color schemes, and variations of this scheme, were avoided as this color scheme is often connotated with "good" or "bad" classifications. We do not believe any area is "good" or "bad" based on population composition and chose color schemes to discourage this connotation.

5.2.2 Aggregate Vulnerability Maps

A full description of GIS processes used to develop the aggregate vulnerability maps is provided here given its central importance to the overall analysis.

<u>Polygon to Raster Conversion</u>

To combine vulnerability scores and create aggregate vulnerability maps later in the process, all indicator census tract features had to be converted to raster files. The "Polygon to Raster" geoprocessing tool was used for this conversion.

Cell size: 15 meters
Value field: RasterValue
Output raster Dataset: Tract_Disability_R

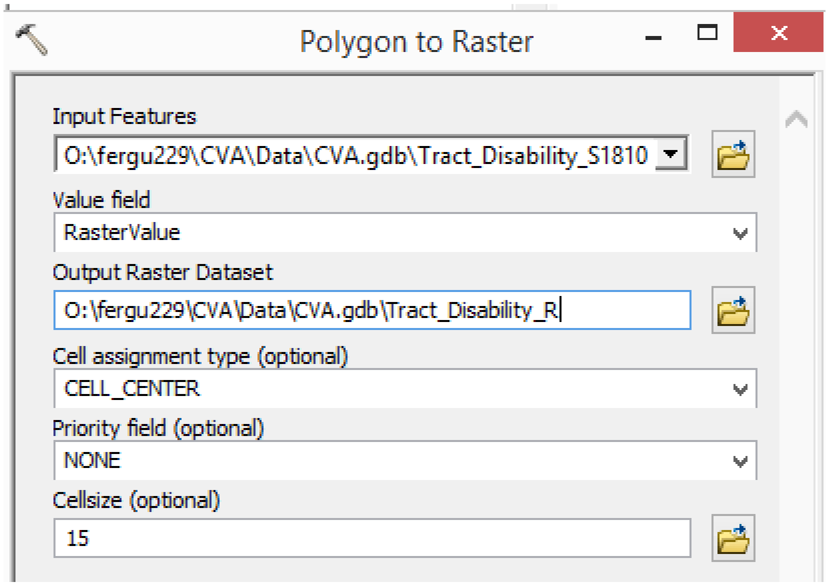


Figure 8: Screenshot of GIS Polygon to Raster Conversion Process

<u>Creating Category Rasters</u>

Next, the indicator rasters within each category (accessibility, communication, health, and social network) were summed using the Raster Calculator tool. An additional "human vulnerability" raster was also created as the sum of all six human vulnerability indicators. The example below shows the operation used to create the Communication raster.

Map Algebra expression: "Tract_English_R" + "Tract_Phone_R"
Output Raster: Rcalc_Communication

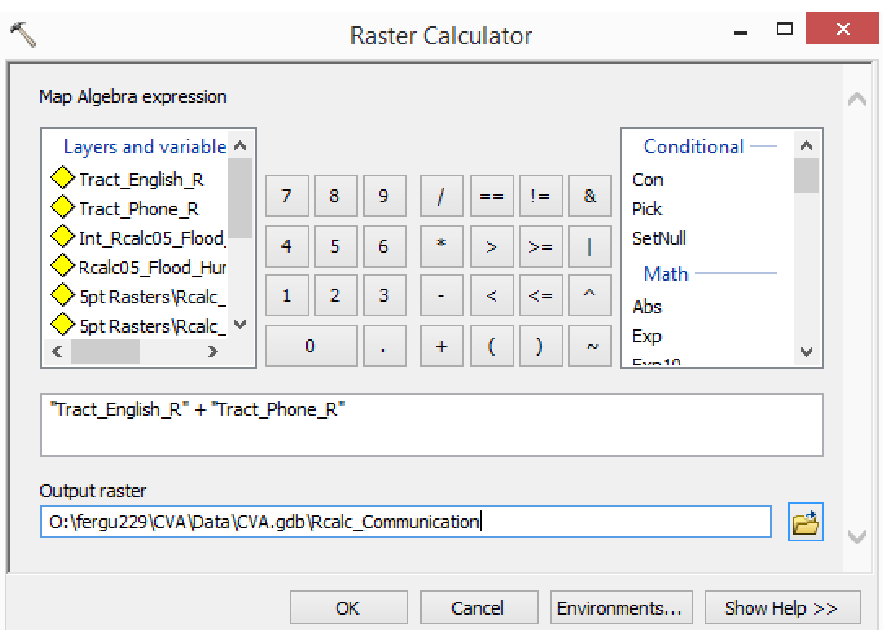


Figure 9: Screenshot of GIS Raster Calculator Process

Reclassifying Rasters to a Five-Point Scale

Then, the Reclassify tool was used to reclassify each category raster by quintiles. While this method does cause some loss of precision for the reasons described in section 5.1.1 above, the resulting classes were much closer to the standard deviation classes than they were to quintiles alone. Our team found that this 5-point scale was necessary to ensure that our aggregate vulnerability maps could be easily understood, allowing us to show aggregate heat and flooding vulnerability on an intuitive 10-point scale.

Input raster: Rcalc_Social
Reclass field: Value
Output raster: Quint_Social
To classify by quintiles: Click "Classify…", set "Method" to "Quantile" and set "Classes" to 5.

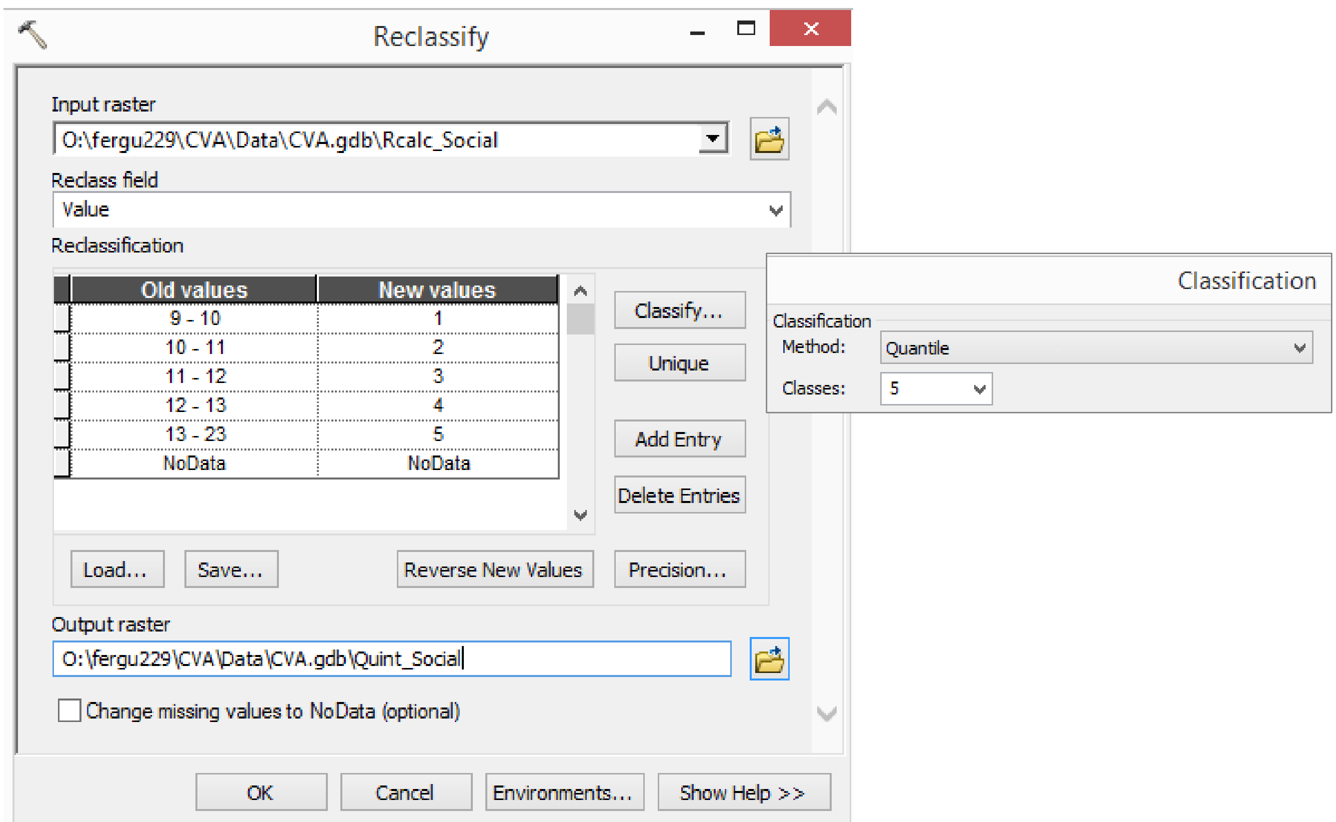


Figure 10: Screenshot of GIS Raster Reclassification Process

The two direct indicators (poverty and residents of color) were not compatible with the quintile Reclassify operation because of their insufficient range of values (five values from 2 through 6). Instead, these two rasters were converted to a 5-point scale using the Raster Calculator expression ["Tract_Poverty_R" – 1] and ["Tract_Race_R" - 1]. It should be noted that this method causes a minor loss of precision when comparing direct indicator scores to category indicators, but has little effect on the final distribution of vulnerability scores.

Create Aggregate Rasters

The Raster Calculator was used again to create 12 aggregate rasters of heat/flooding and each of the six category indicators. Two additional aggregates were also created of heat/flooding and human vulnerability (the sum of all six categories).

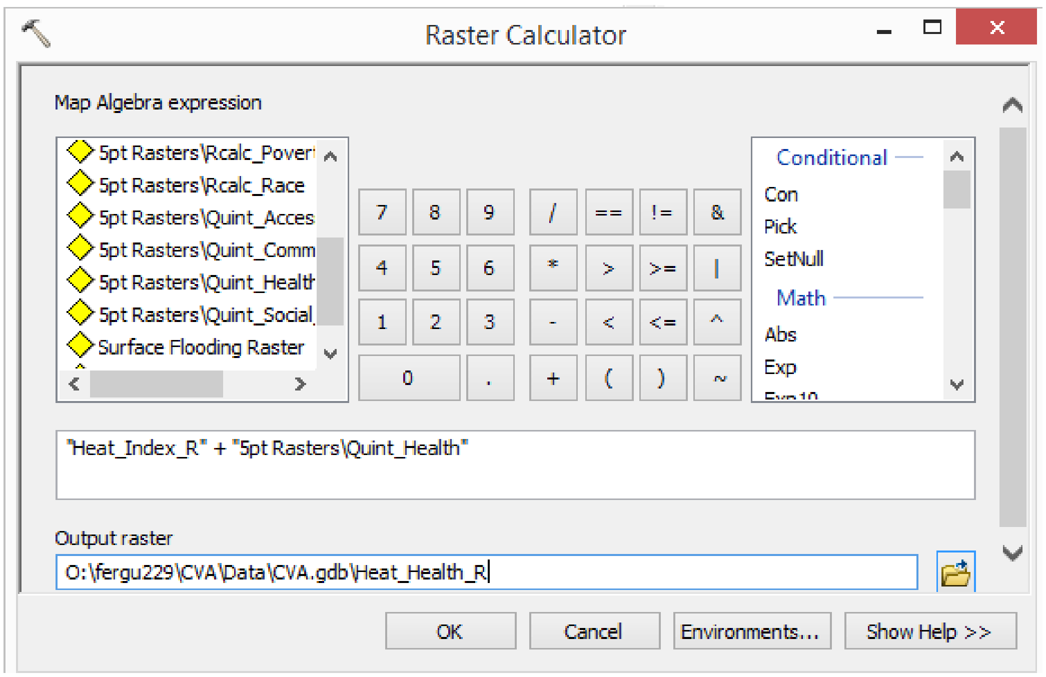


Figure 11: Screenshot of GIS Raster Calculator Process

Raster to Polygon using Zonal Statistics

To convert the final rasters back into census tract polygons, our team chose the following method instead of the Raster to Polygon Conversion tool in ArcGIS. Since square raster cells don't line up perfectly with polygon tract boundaries, the Conversion tool often creates superfluous tiny polygons in the output feature class, which must then be selected and deleted. In contrast, the Zonal Statistics method described below avoids this issue entirely while serving the same function. This sequence was repeated for all 14 aggregate maps.

1. Use the "Zonal Statistics as Table" geoprocessing tool to create a table of vulnerability scores by tract. The output table will list the vulnerability score of the majority of raster cells within each tract's boundaries. This method was selected because the input rasters are already normalized by census tract, meaning that the cell values are generally the same within each tract area. The majority statistic allows us to easily discount any cells that straddle tract borders and avoid resulting decimal values in the output.

Input feature zone data: Tract_Metro
Zone field: GEOID
Input value raster: Heat_Health_R
Output table: Zonal_Heat_Health
Statistics type: MAJORITY

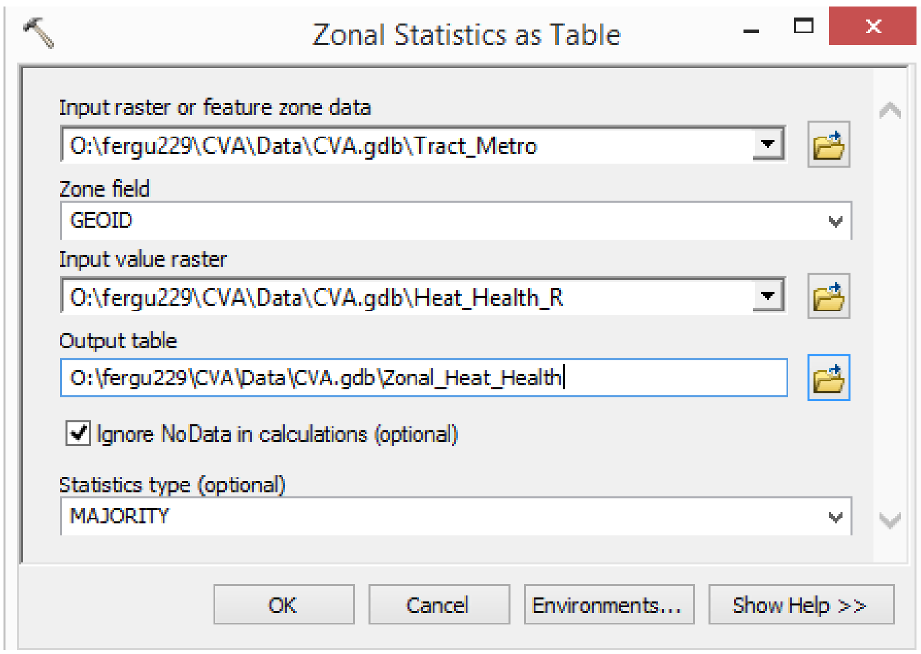


Figure 12: Screenshot of GIS Zonal Statistics Process

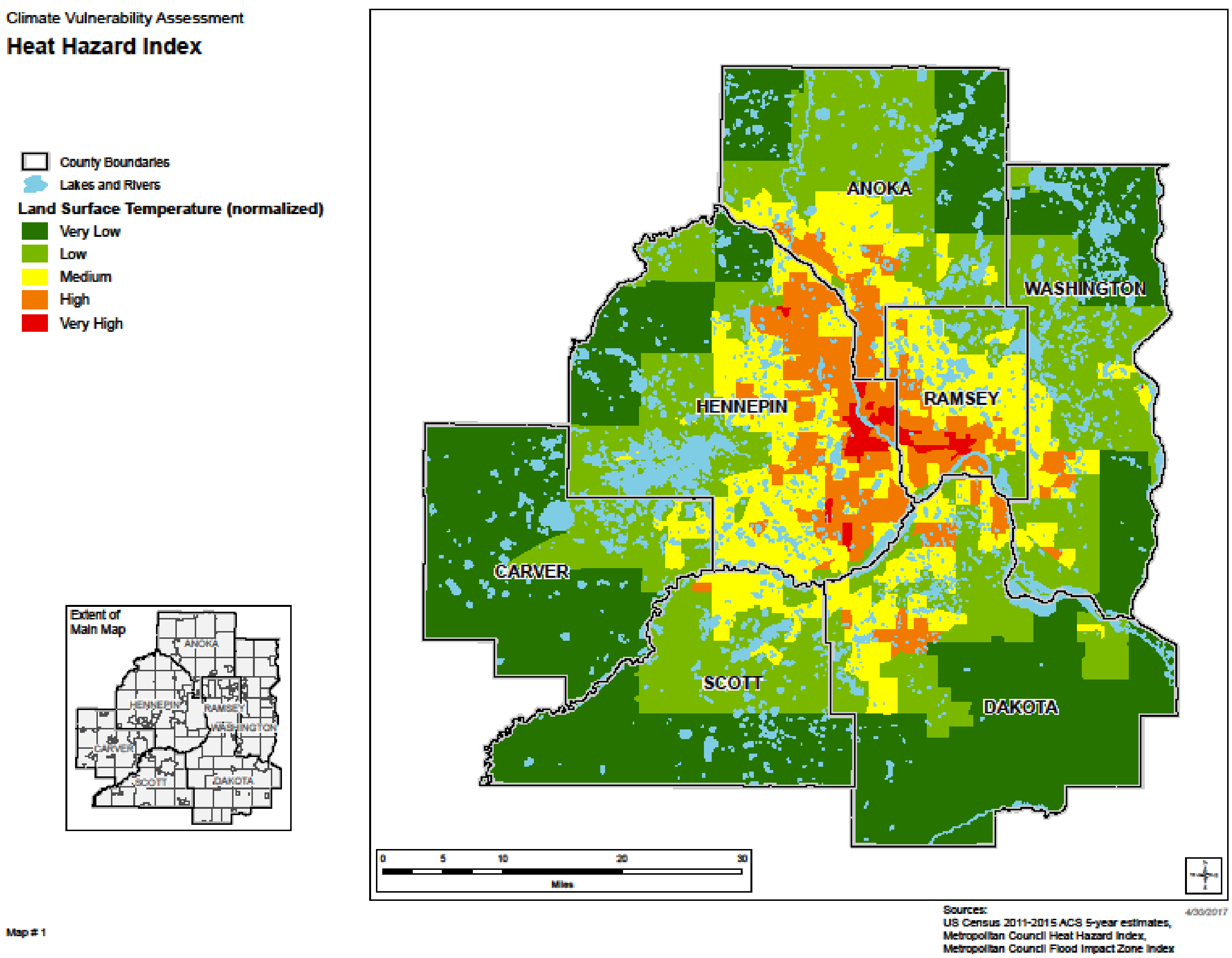
2. Join Zonal_Heat_Health to Tract_Metro using GeoID2 and GeoID as the join fields.
3. Export the joined feature as Heat_Health_Tract.

6. Maps

The following section is a collection of all the maps created for this CVA. This includes both the aggregate maps as well as the small multiple maps for each individual human vulnerability indicator.

6.1 Heat and Flooding Basemaps

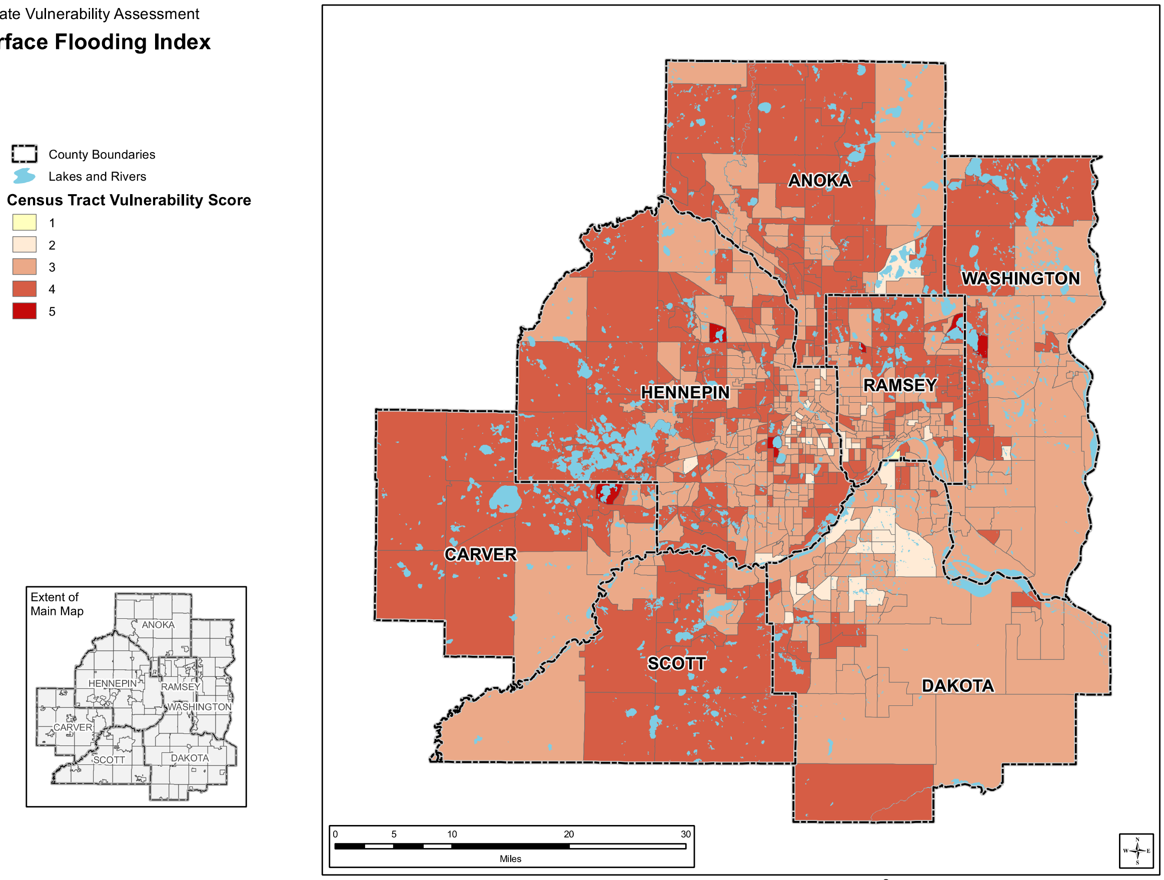
6.1.1 Heat Hazard Index Map



6.1.2 Surface Flooding Index Map

Climate Vulnerability Assessment

Surface Flooding Index

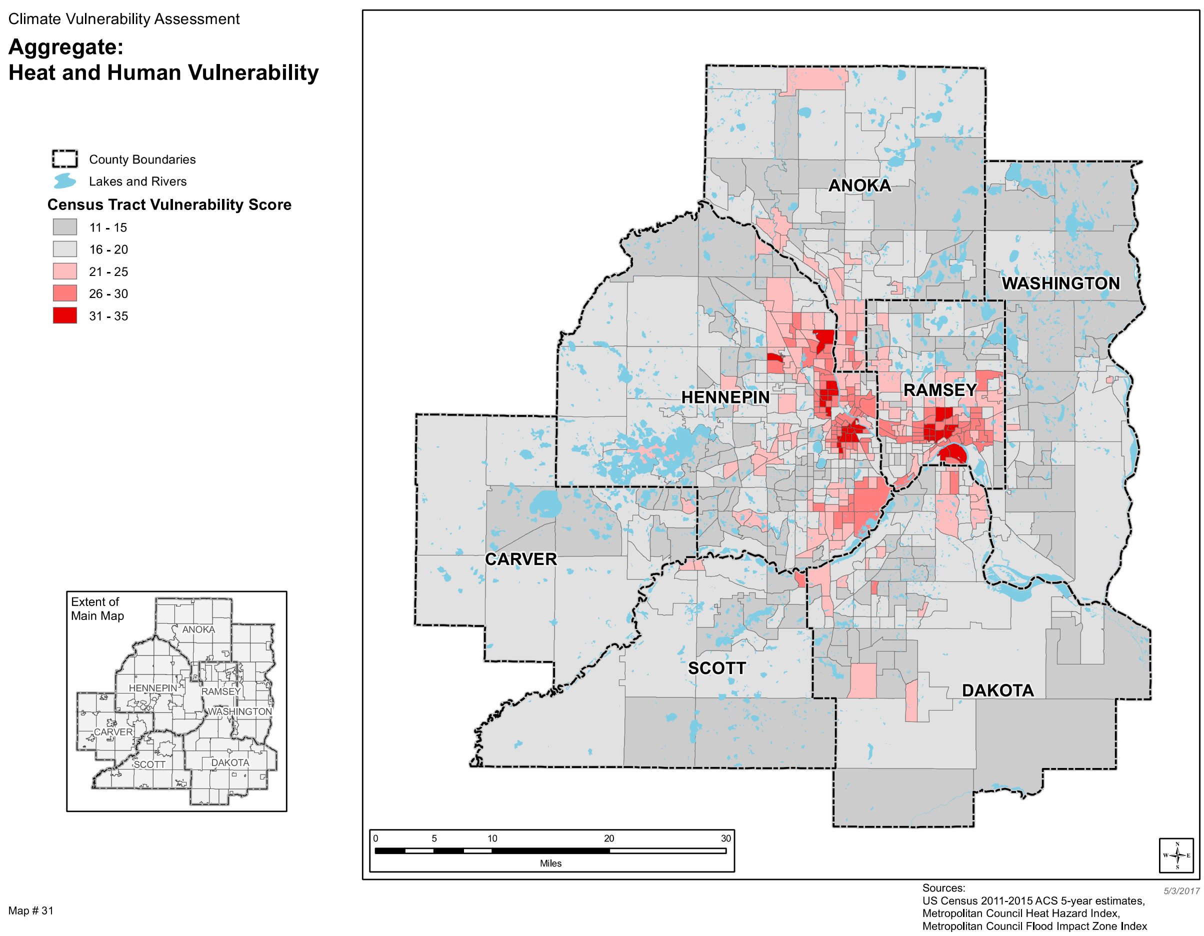


Sources:
US Census 2011-2015 ACS 5-year estimates,
Metropolitan Council Heat Hazard Index,
Metropolitan Council Flood Impact Zone Index

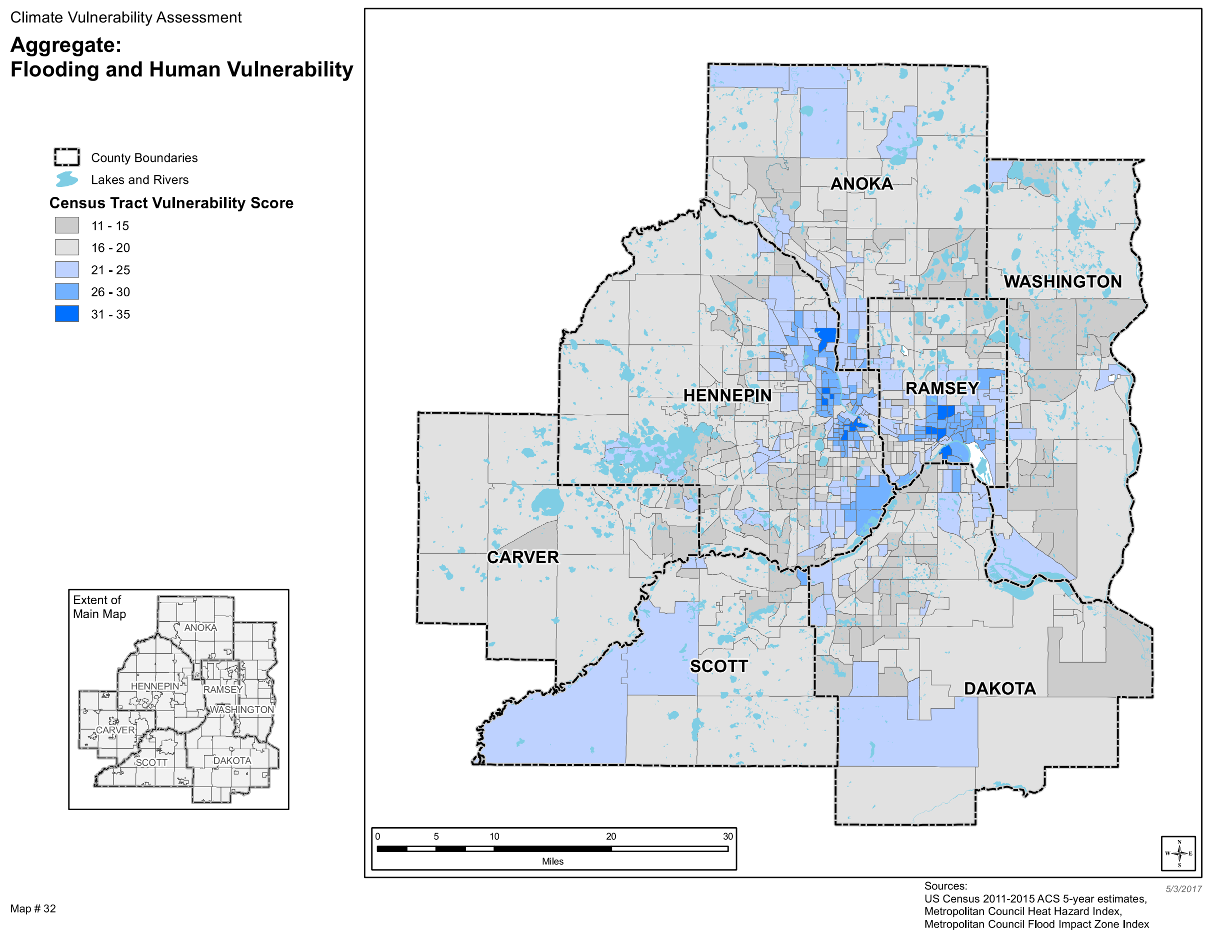
Map # 2

6.2 Human Vulnerability Aggregate Maps

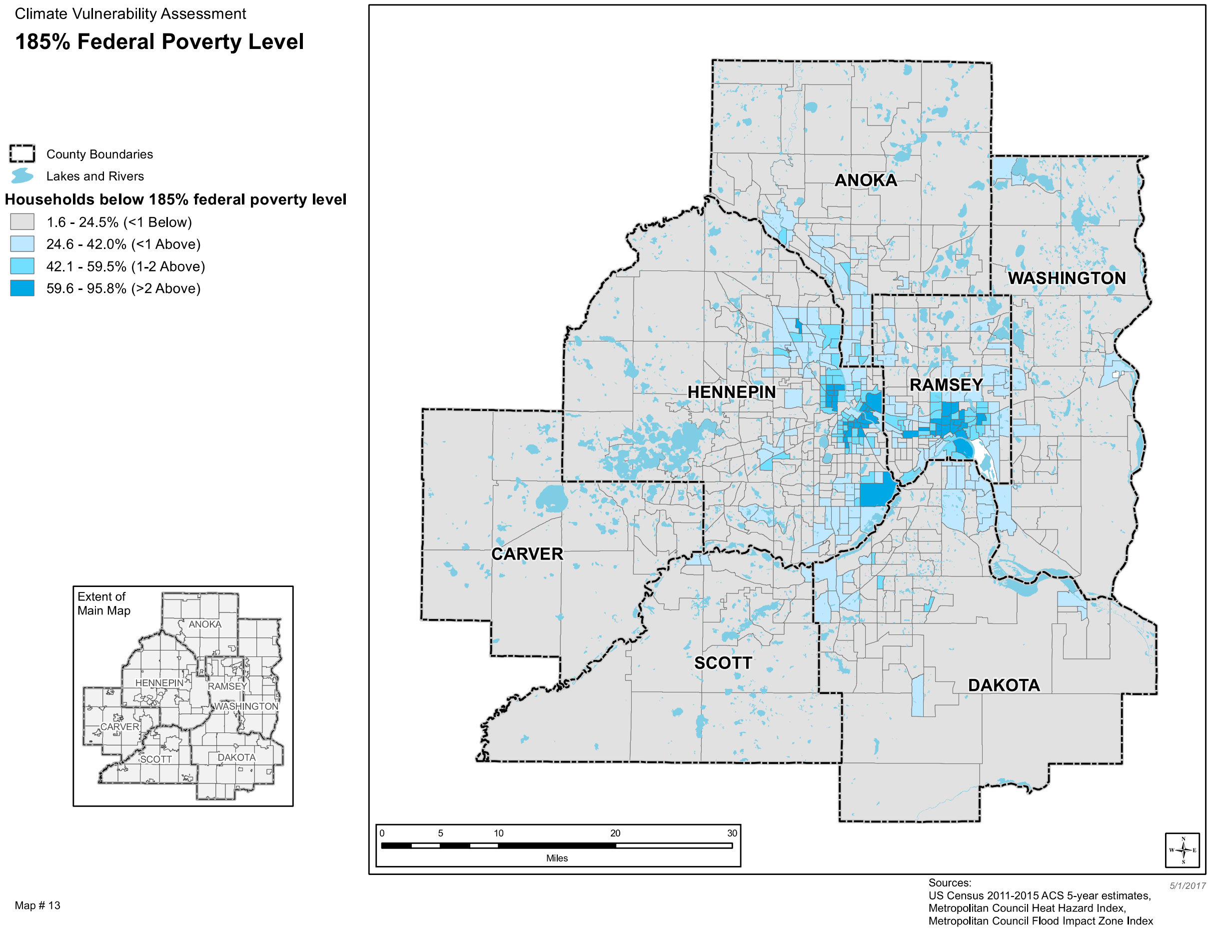
6.2.1 Human Vulnerability: Aggregate with Extreme Heat Vulnerability



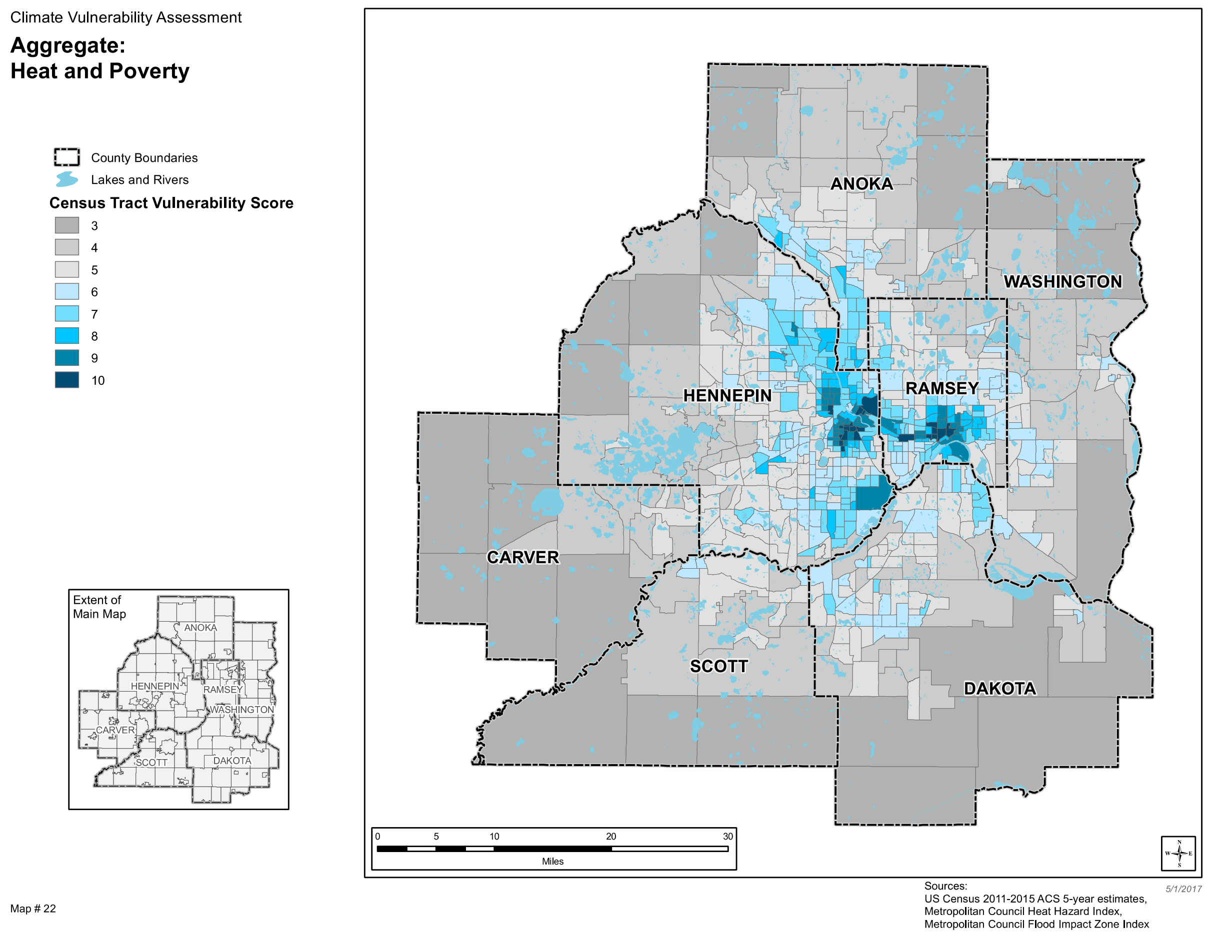
6.2.2 Human Vulnerability: Aggregate with Surface Flood Vulnerability



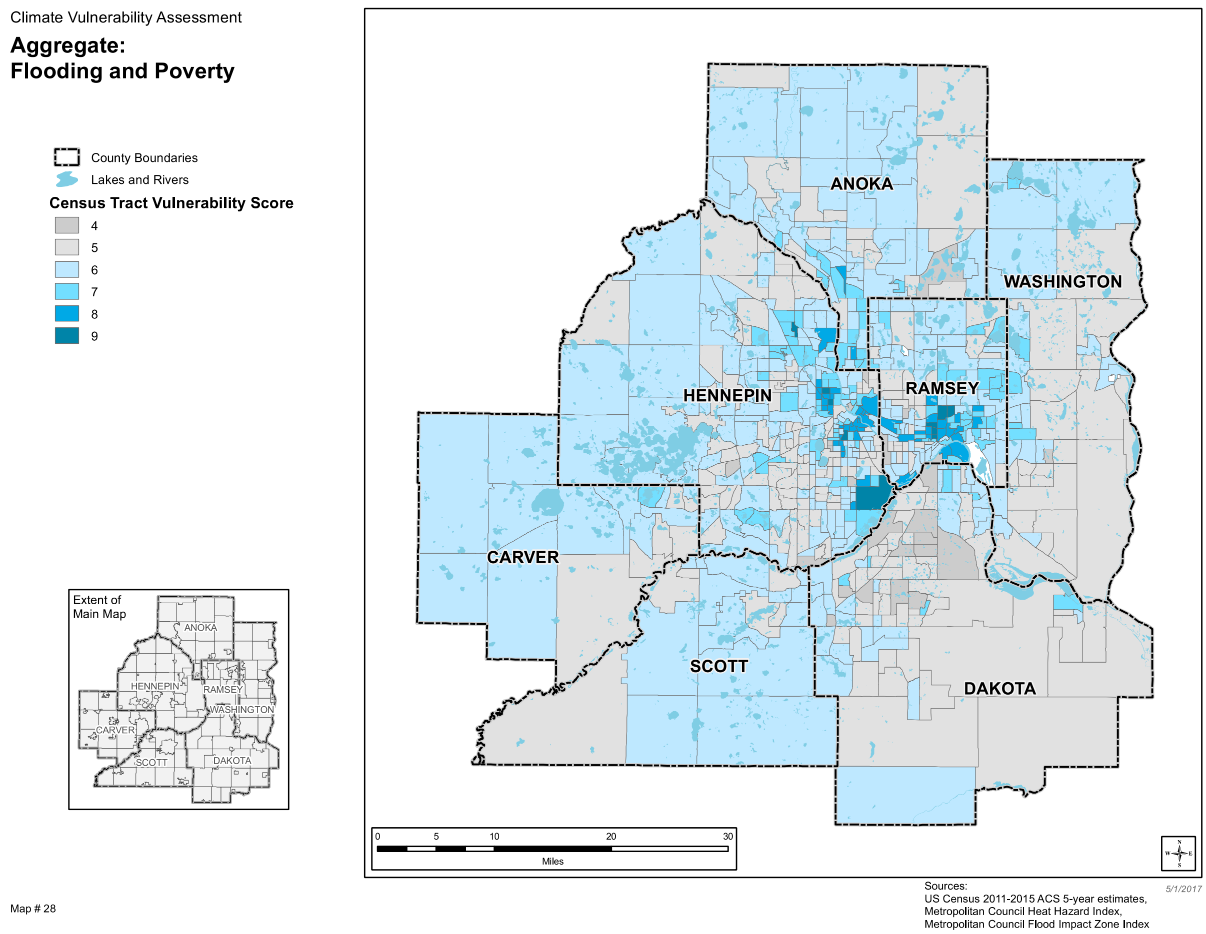
6.3 Poverty Indicator



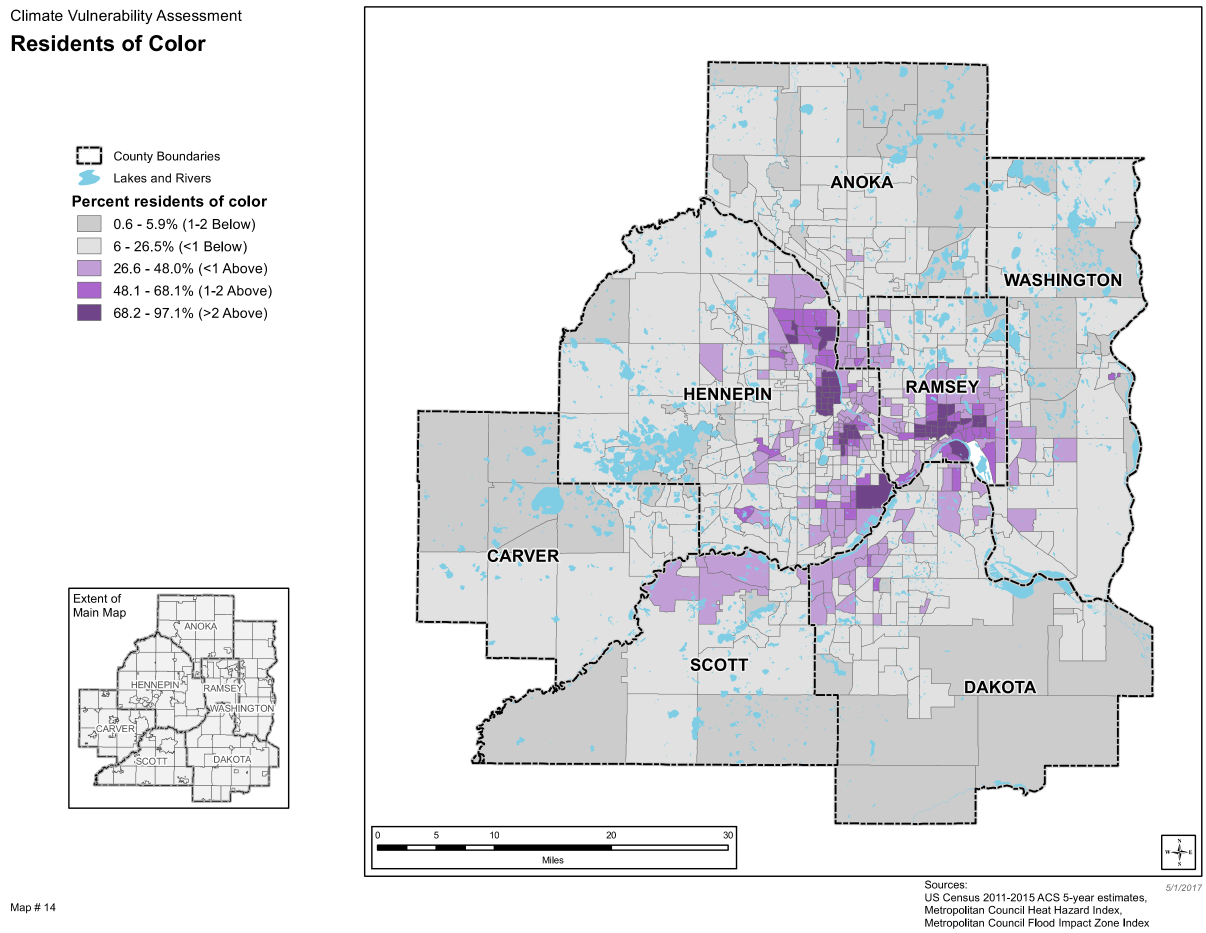
6.3.1 Poverty Indicator: Aggregate with Extreme Heat Vulnerability



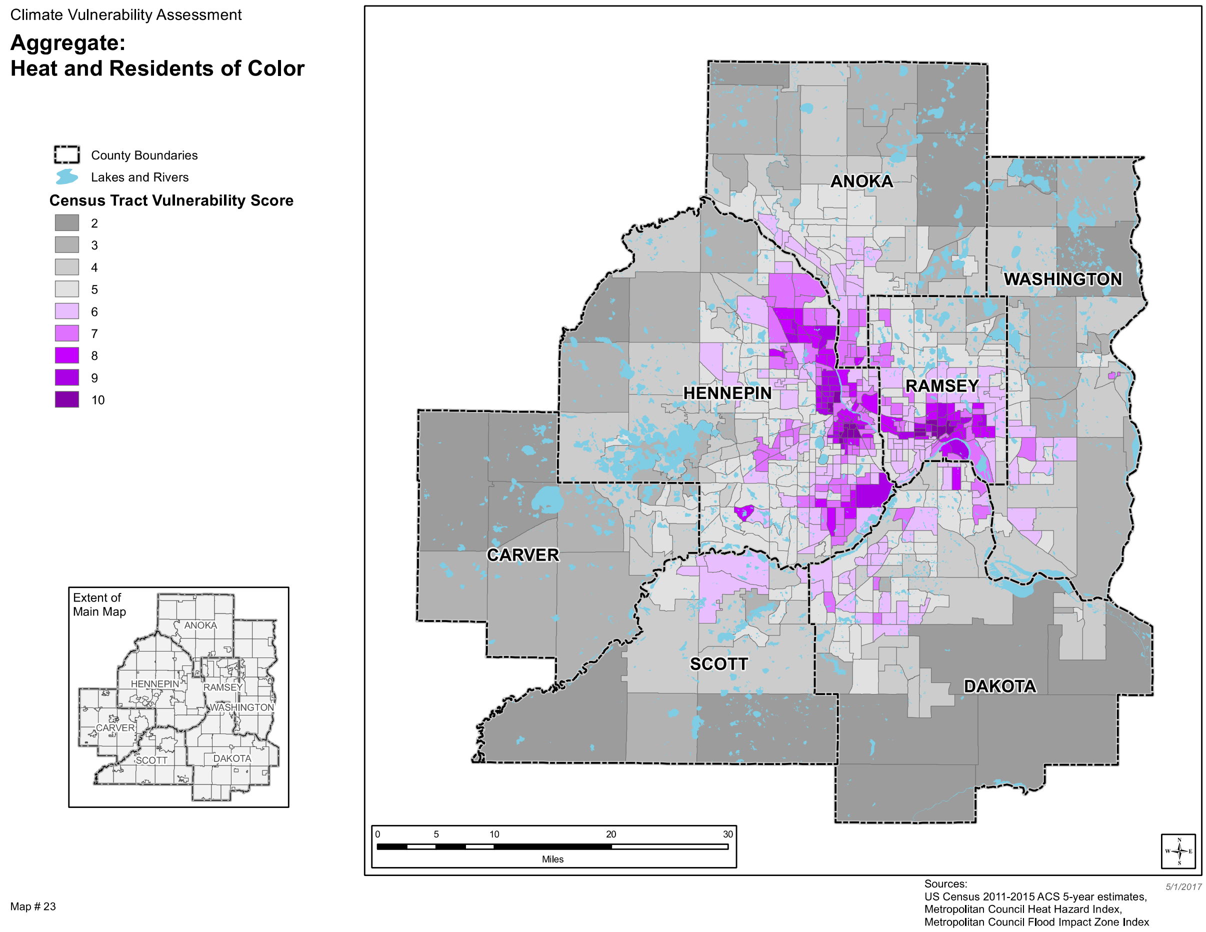
6.3.2 Poverty Indicator: Aggregate with Surface Flood Vulnerability



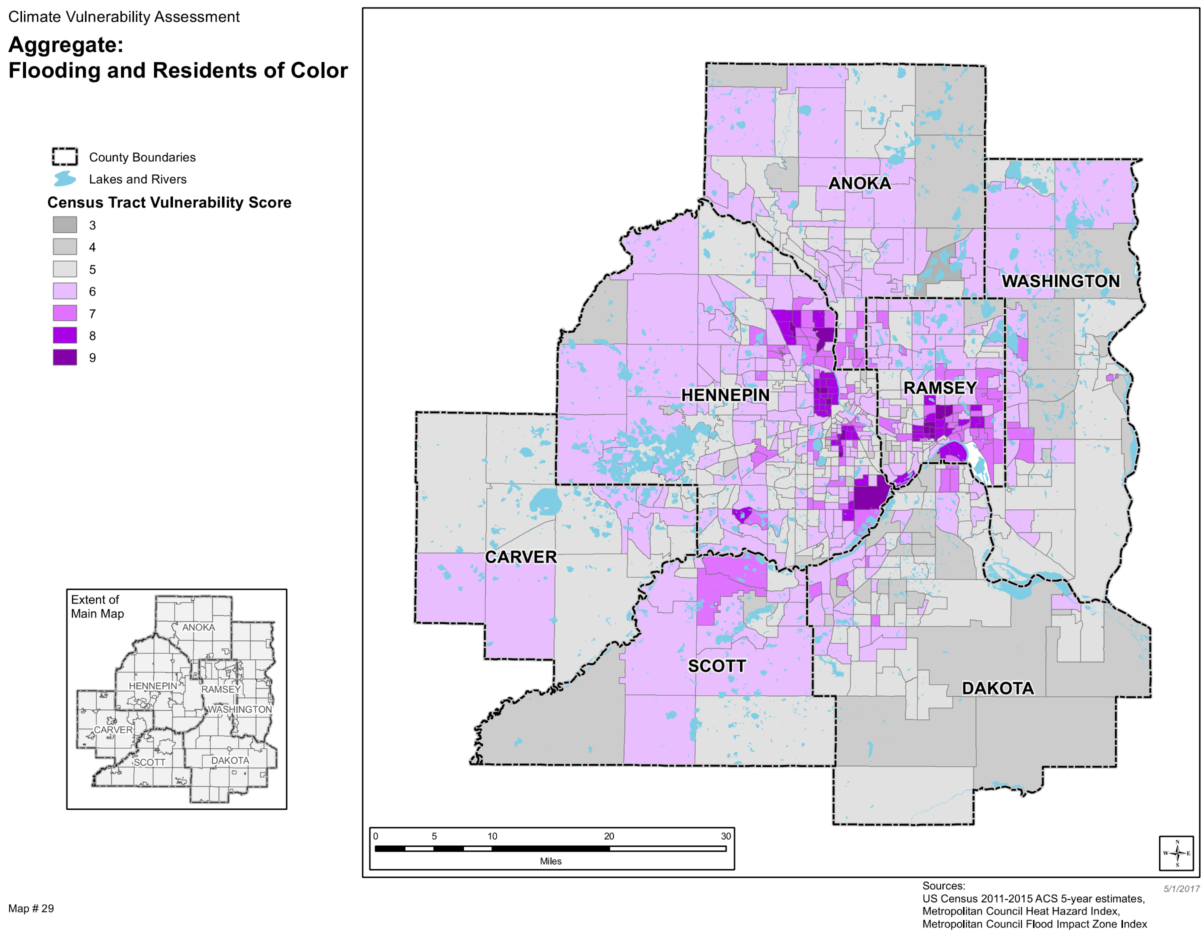
6.4 Residents of Color Indicator



6.4.1 Residents of Color Indicator: Aggregate with Extreme Heat Vulnerability



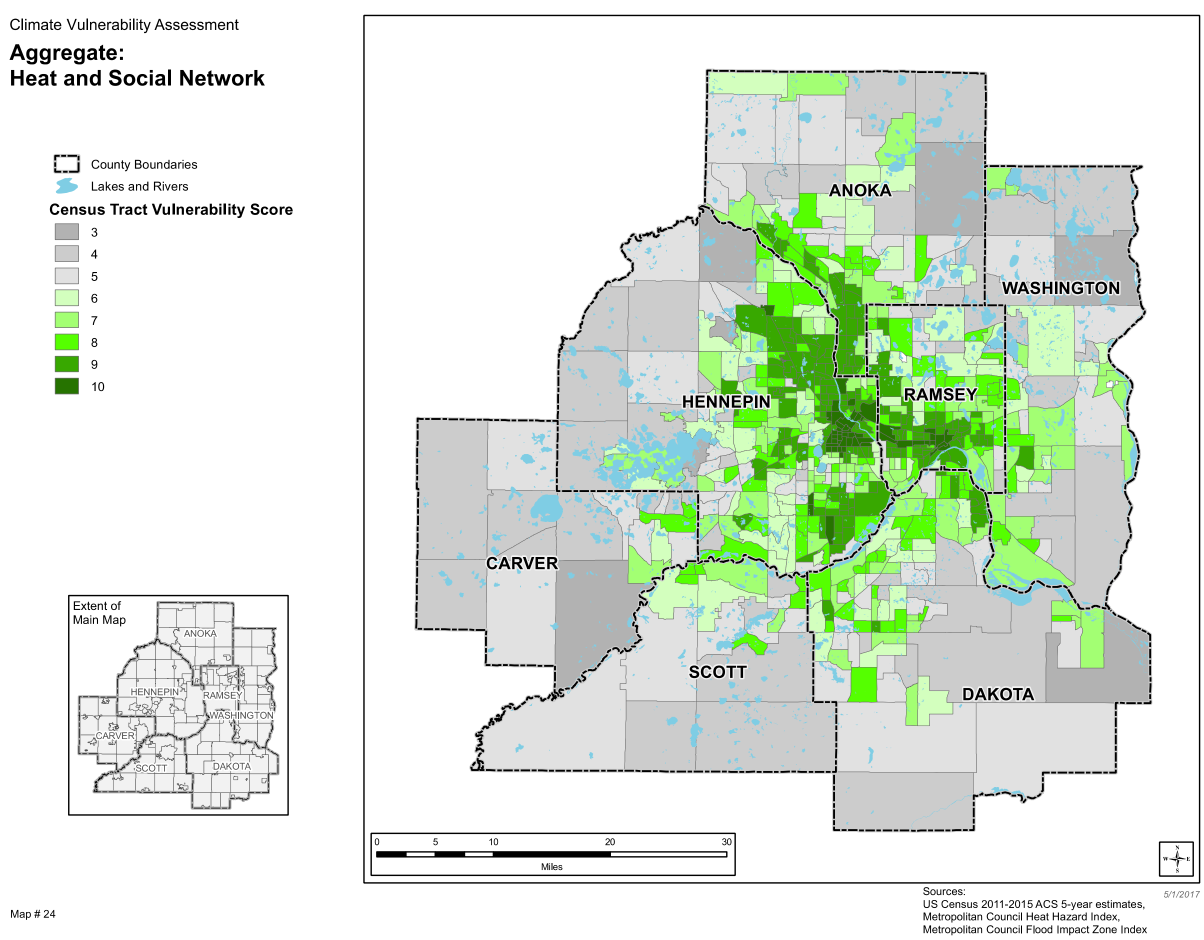
6.4.2 Residents of Color Indicator: Aggregate with Surface Flood Vulnerability



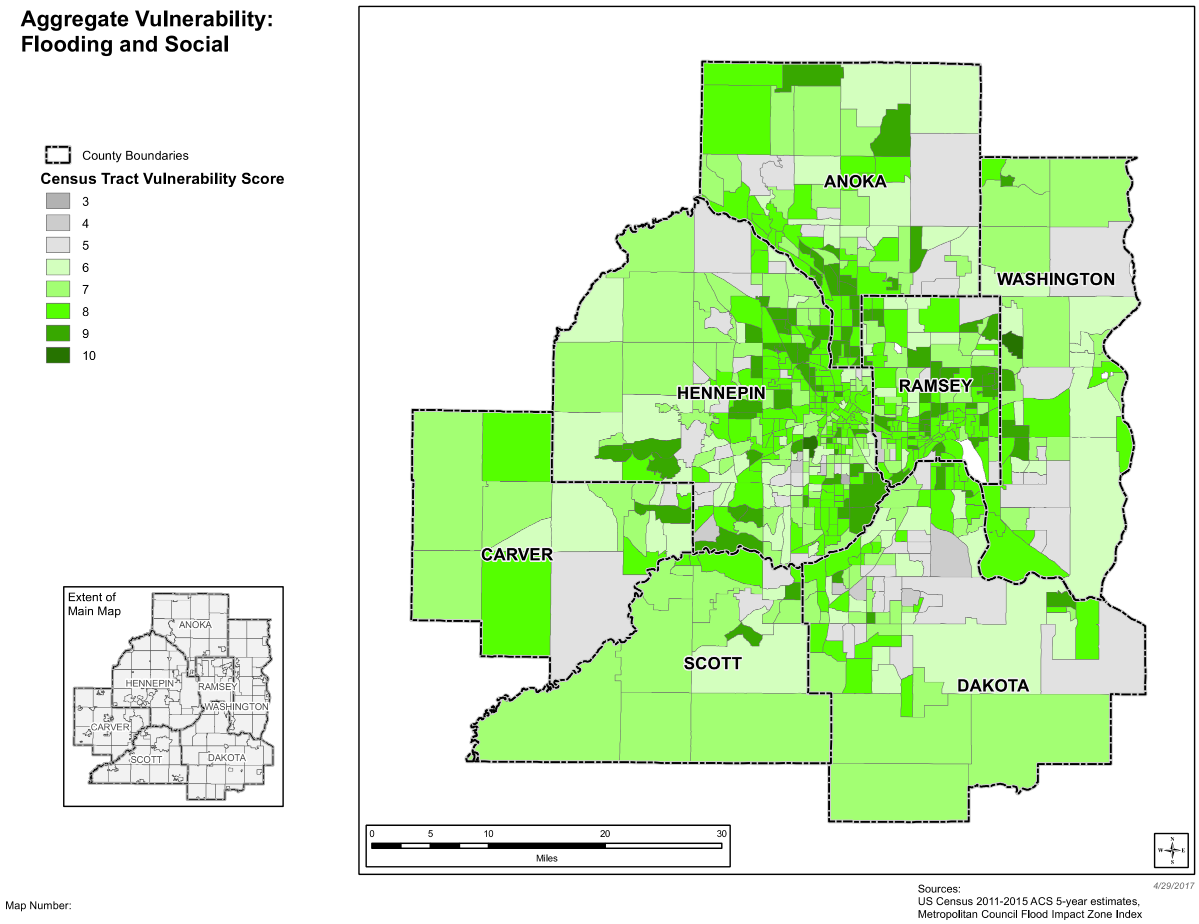
6.5 Social Network Indicator

The social network indicator developed for this CVA is made up of four variables: percent renter, homeowner tenure 2015 or less, unemployment, and educational attainment less than a high school degree. There are aggregate maps for both heat and flood vulnerability as well as individual maps for each small multiple.

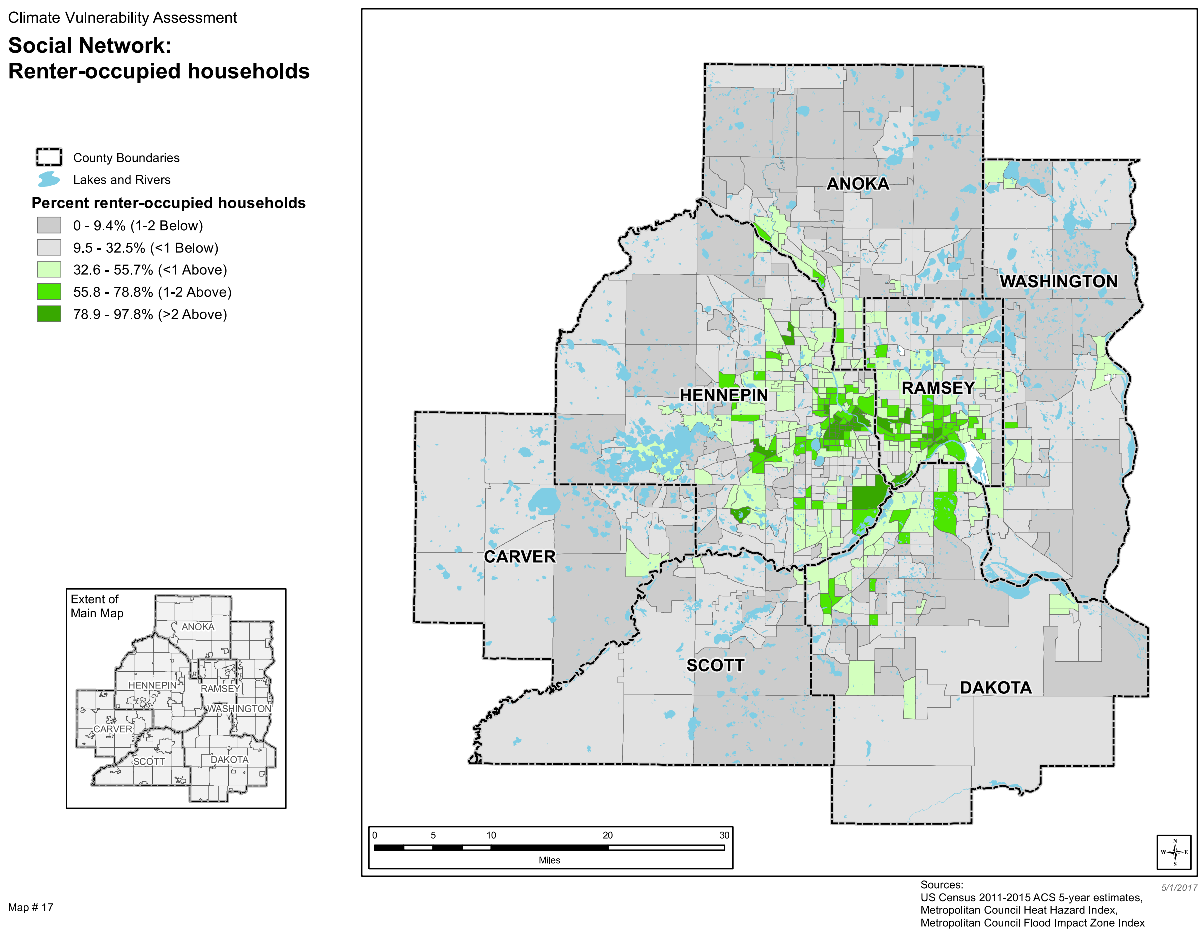
6.5.1 Social Network Indicator: Aggregate with Extreme Heat Vulnerability



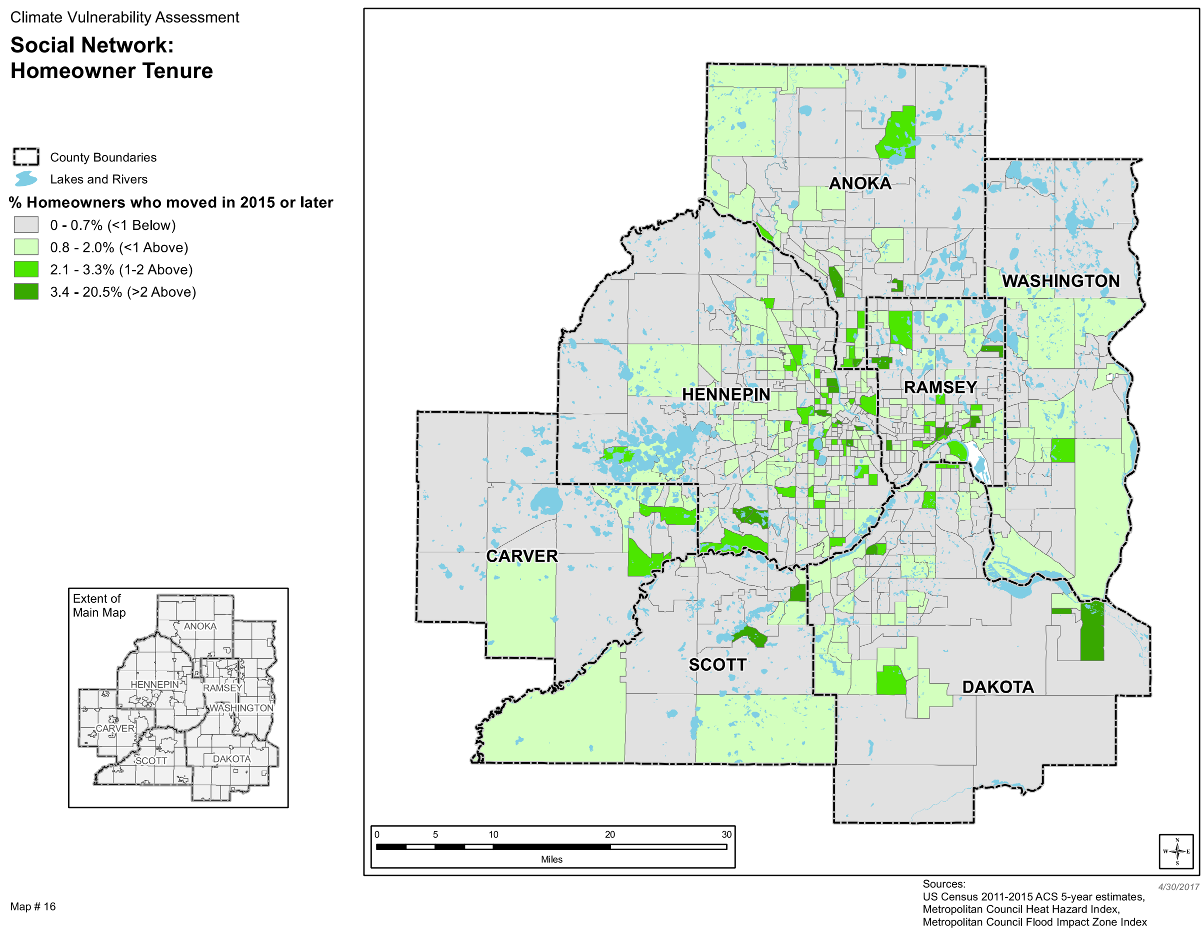
6.5.2 Social Network Indicator: Aggregate with Surface Flood Vulnerability



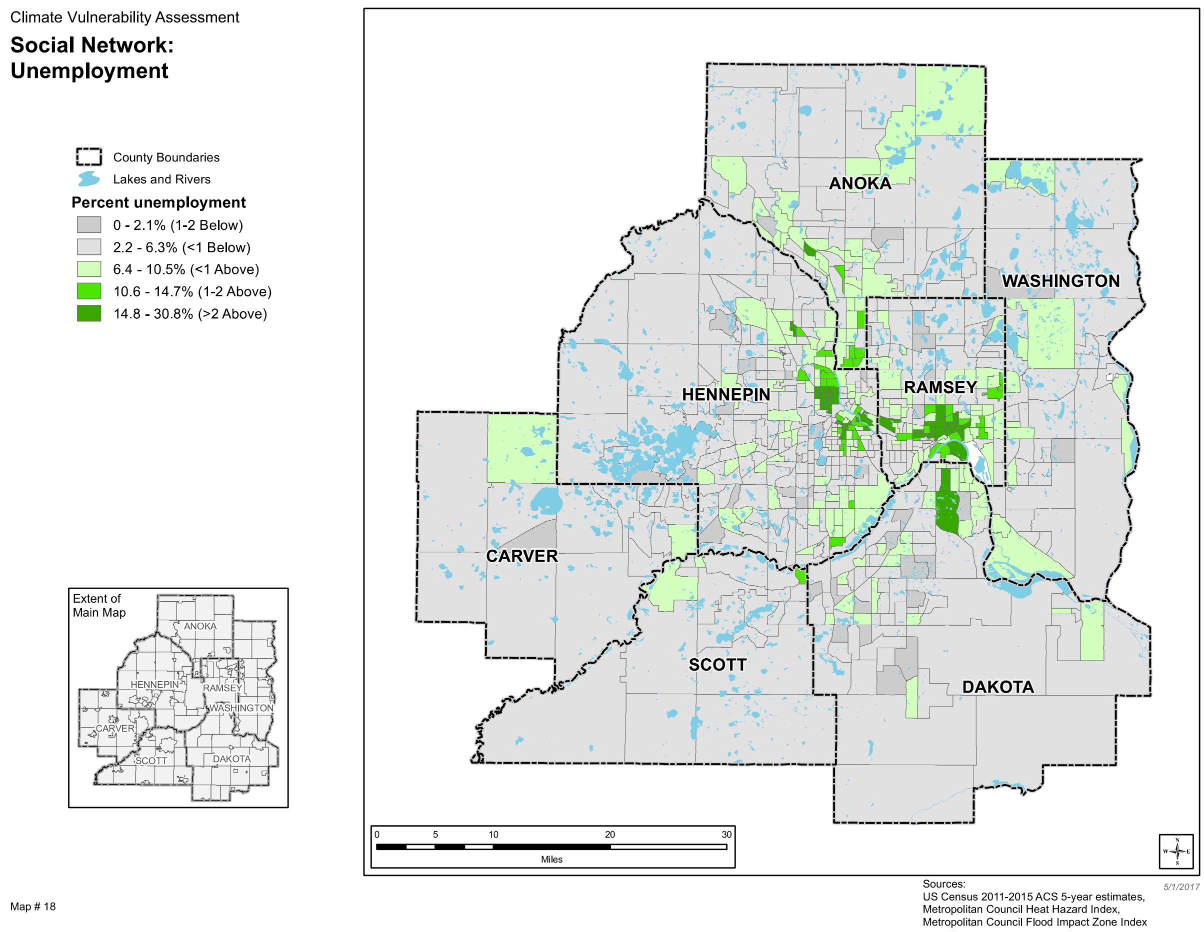
6.5.3 Social Network Indicator: Percent Renter



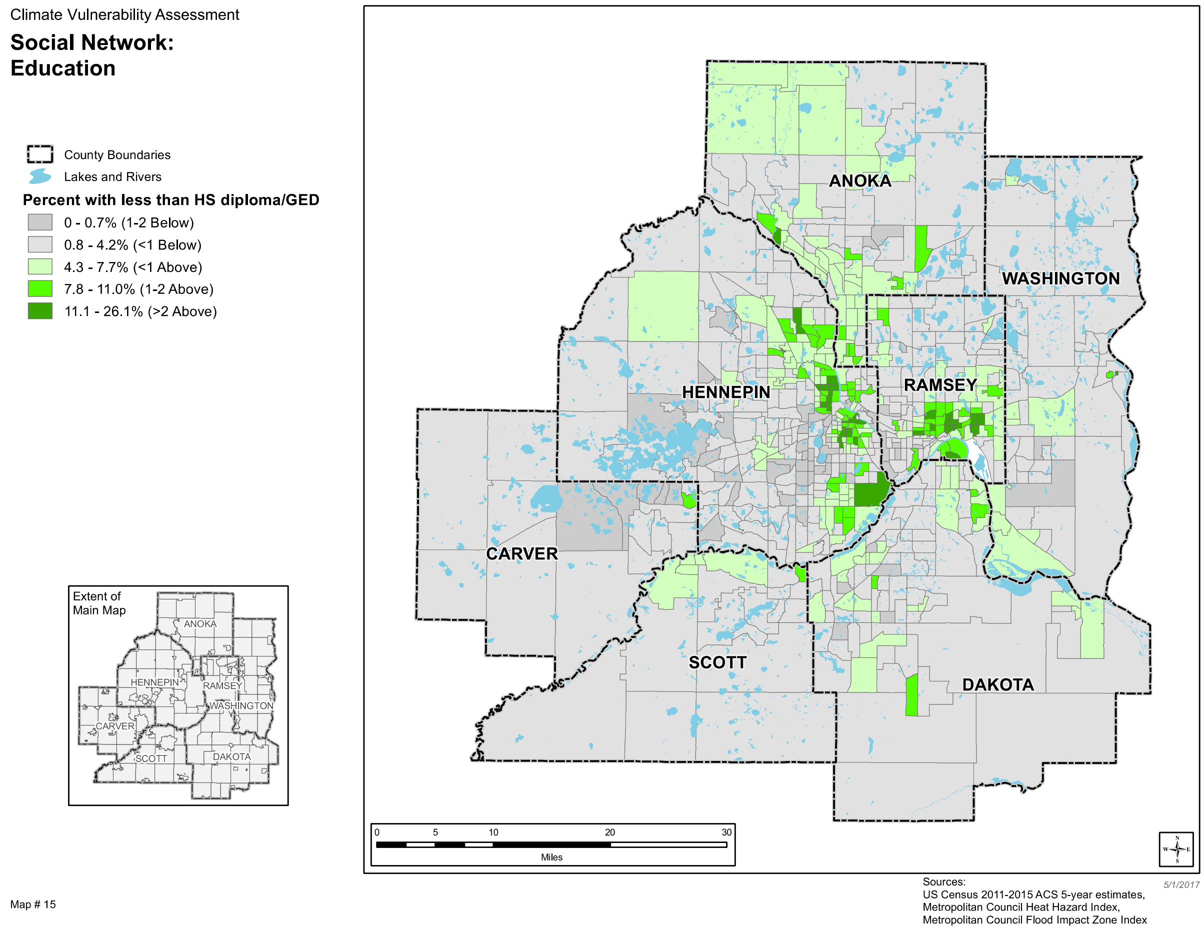
6.5.4 Social Network Indicator: Homeowner Tenure



6.5.5 Social Network Indicator: Unemployment



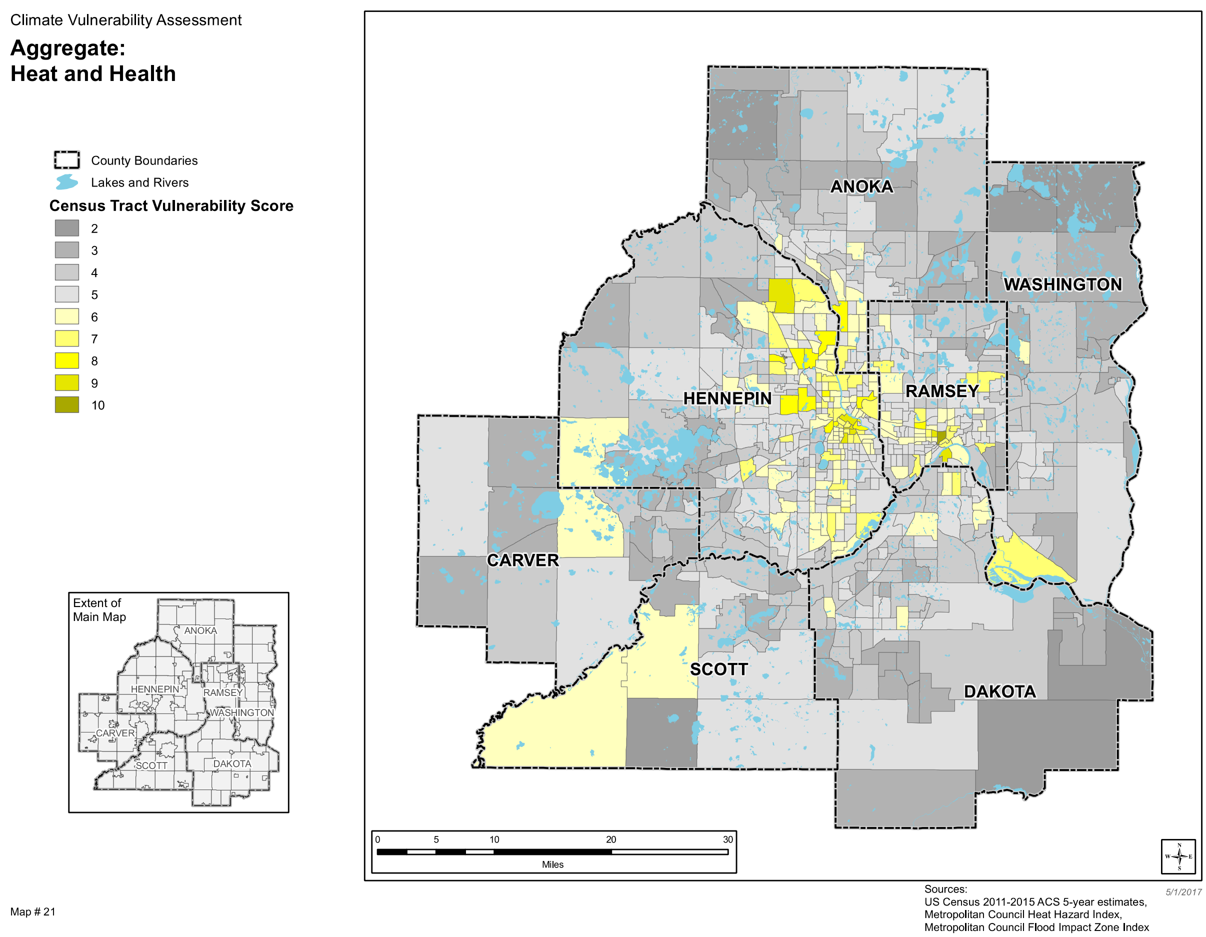
6.5.6 Social Network Indicator: Educational Attainment Less than H.S. Degree



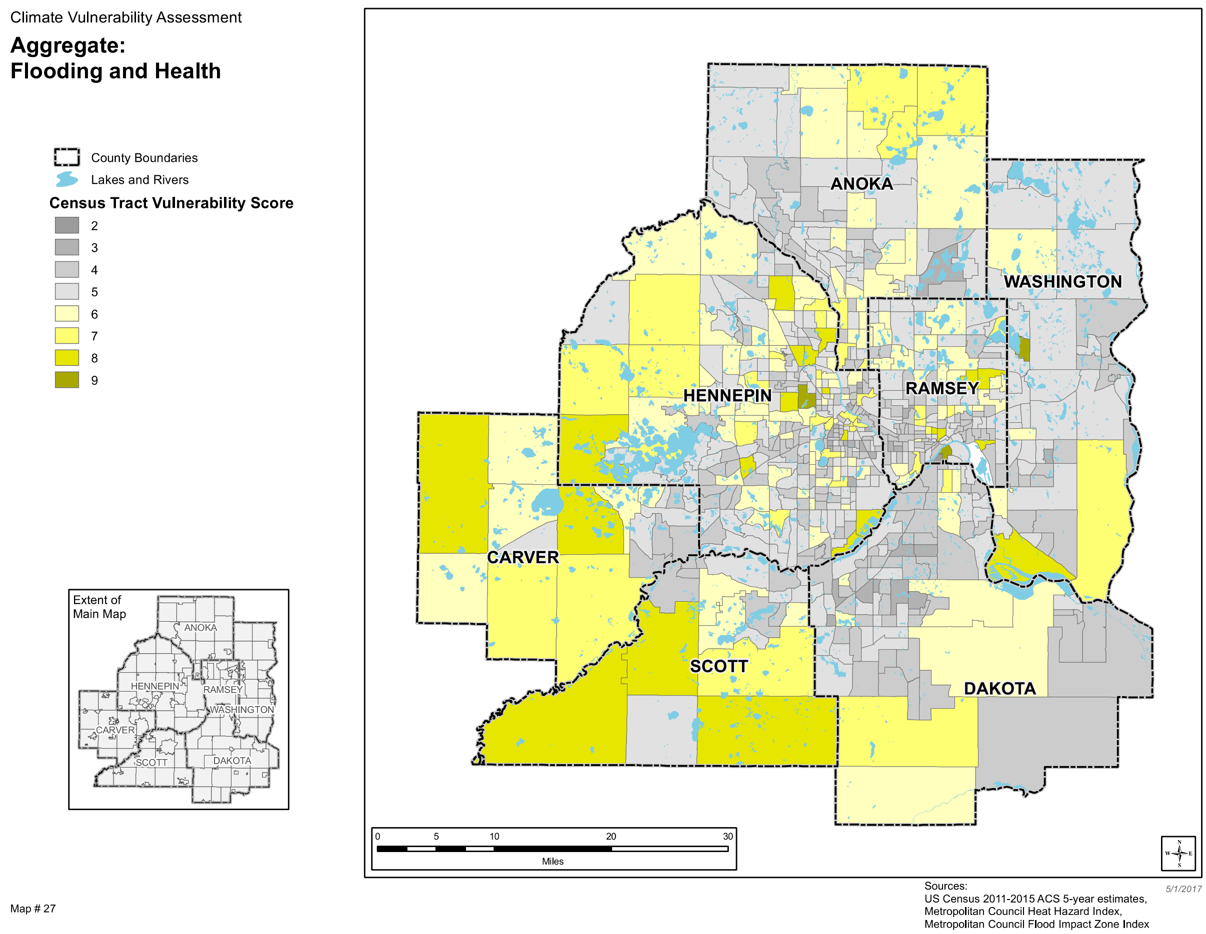
6.6 Health Indicator

The health indicator that we developed for this CVA is made up of four small multiples: Children 5 years and younger, Adults 65 years and older, Asthma hospital visits, and COPD Hospital visits. There are aggregate maps for both heat and flood vulnerability as well as individual maps for each small multiple.

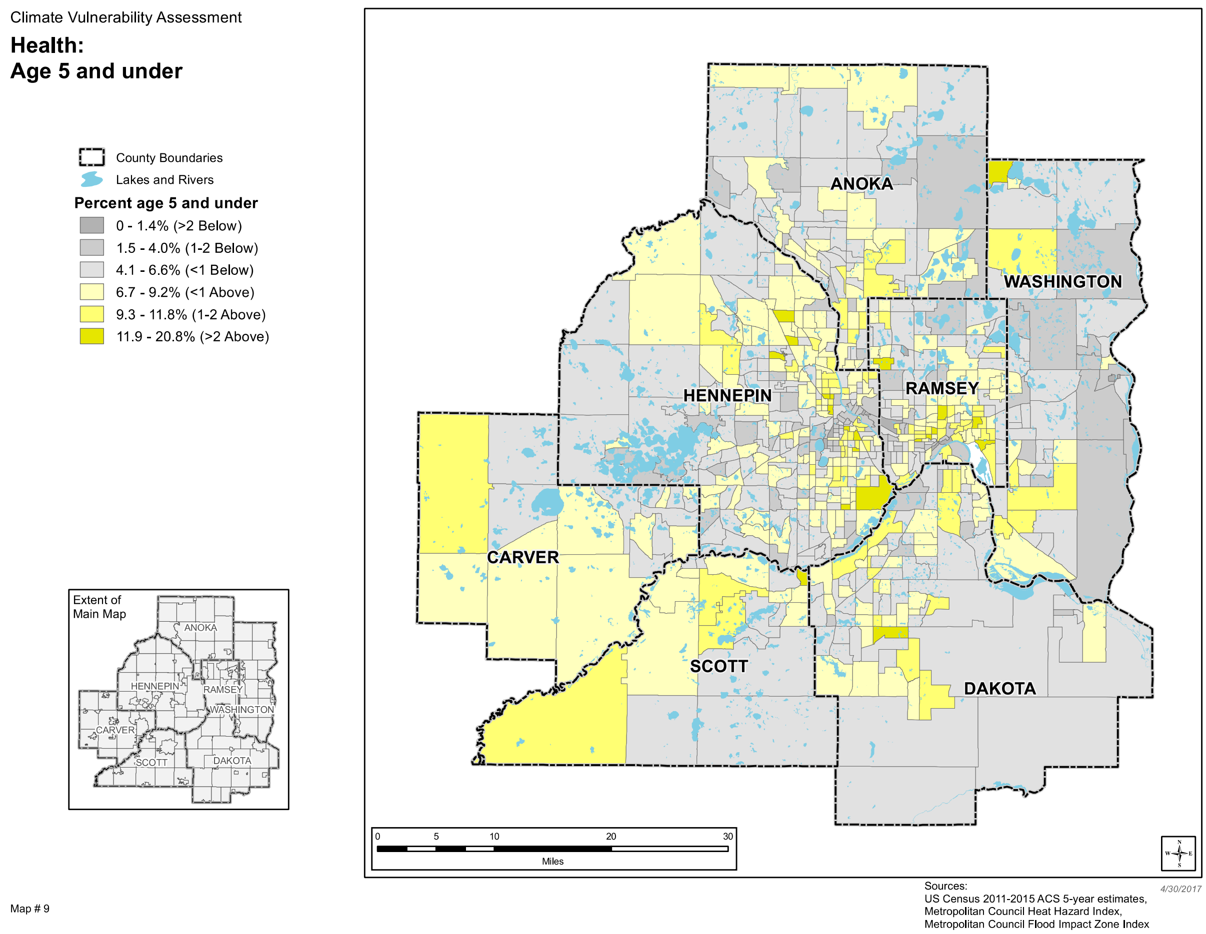
6.6.1 Health Indicator: Aggregate with Extreme Heat Vulnerability



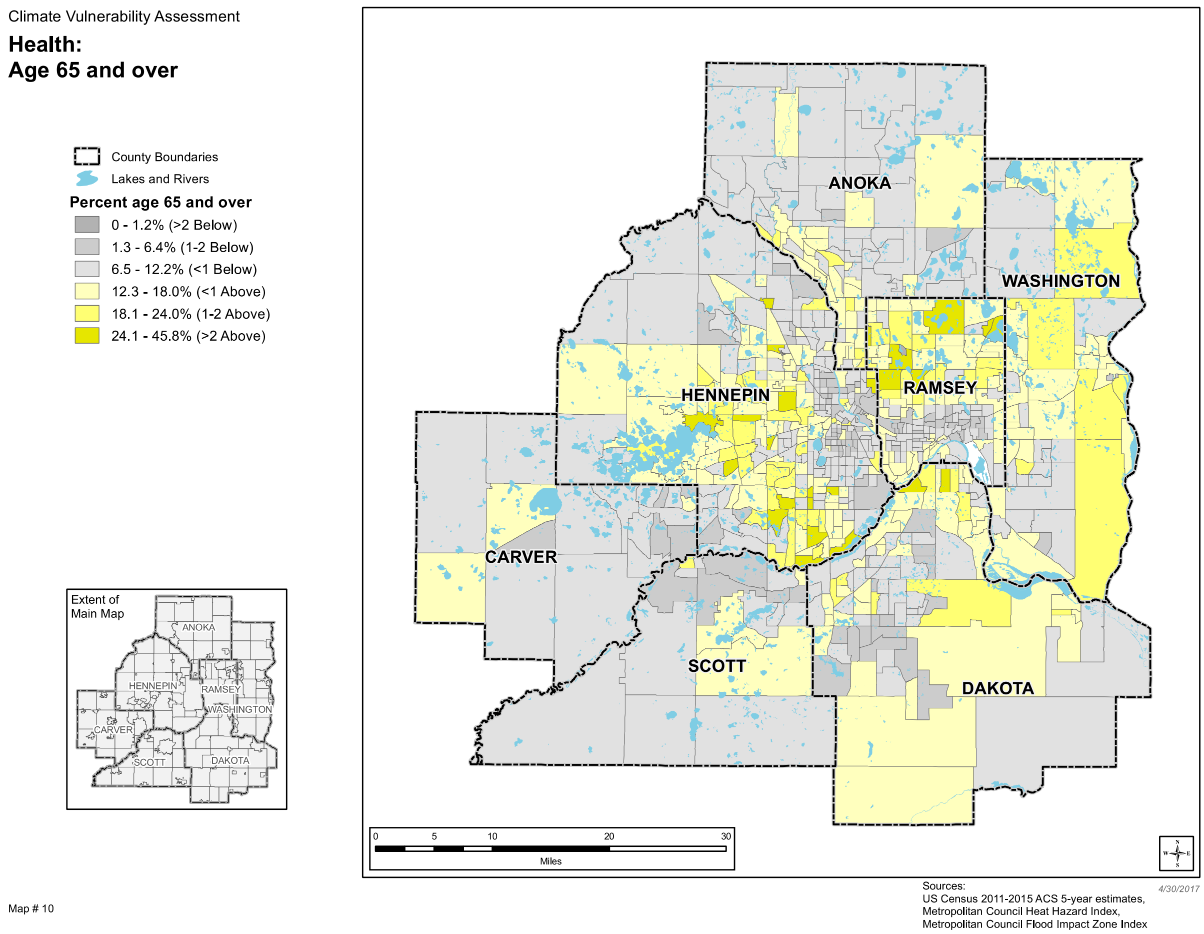
6.6.2 Health Indicator: Aggregate with Surface Flood Vulnerability



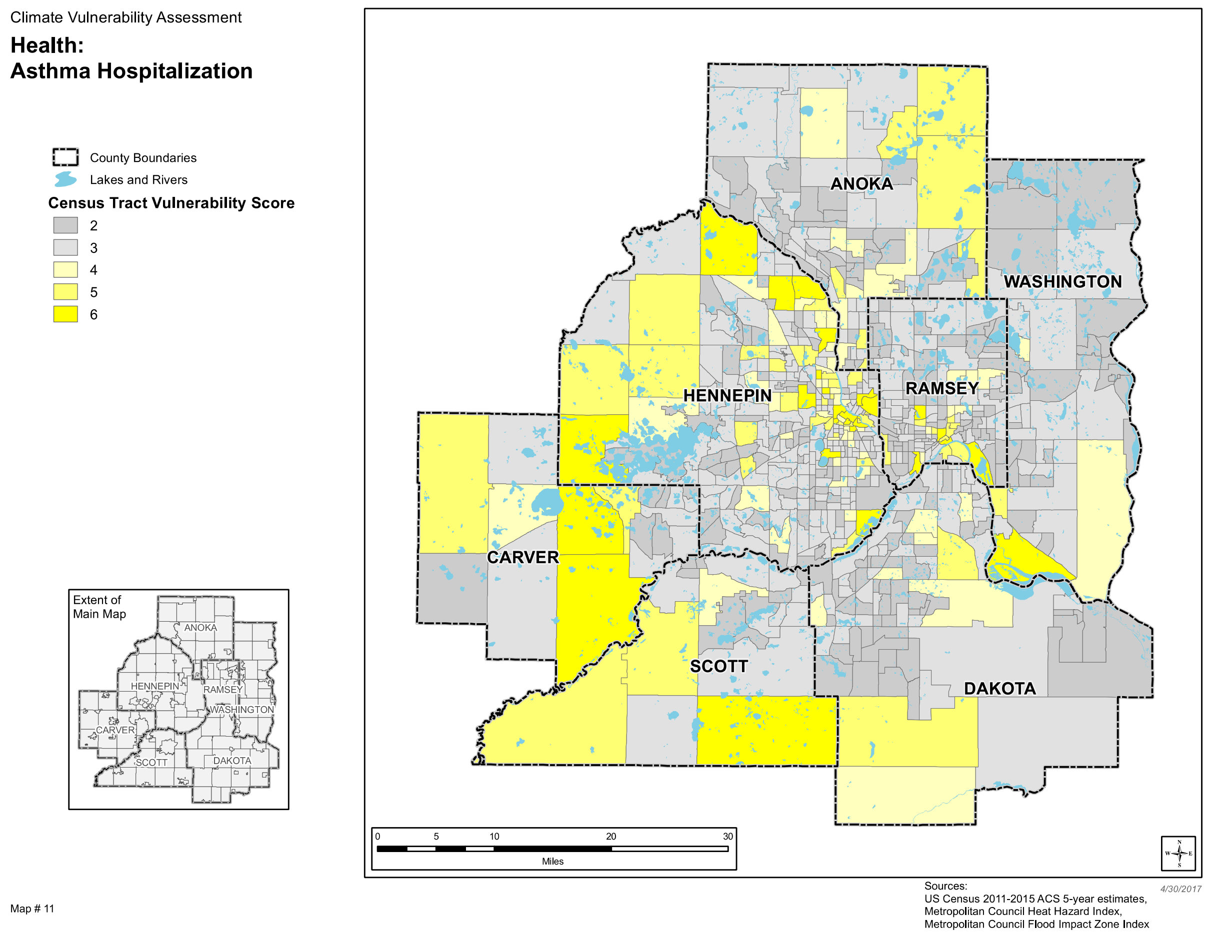
6.6.3 Health Indicator: Age 5 years and younger



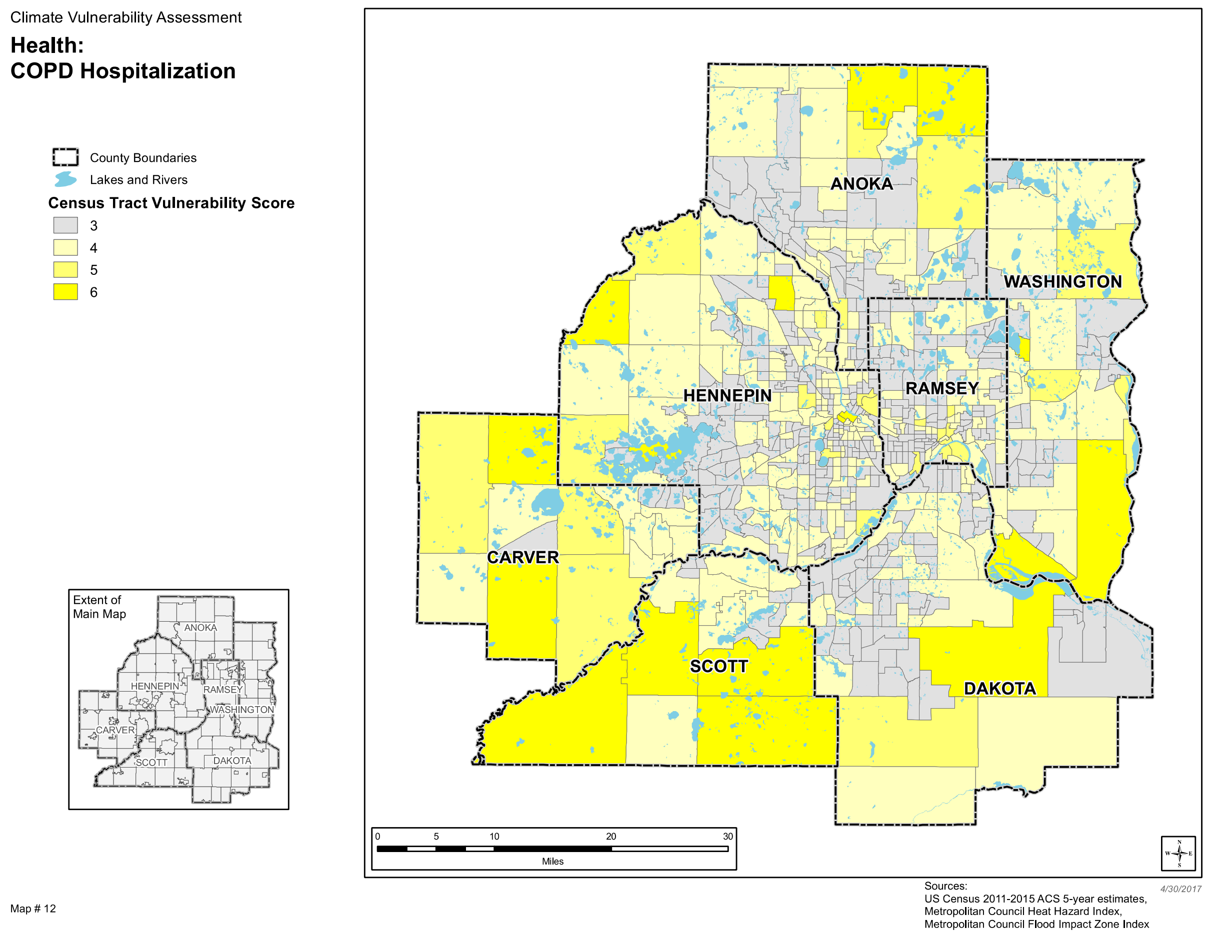
6.6.4 Health Indicator: Age 65 years and older



6.6.5 Health Indicator: Asthma Hospital Visits



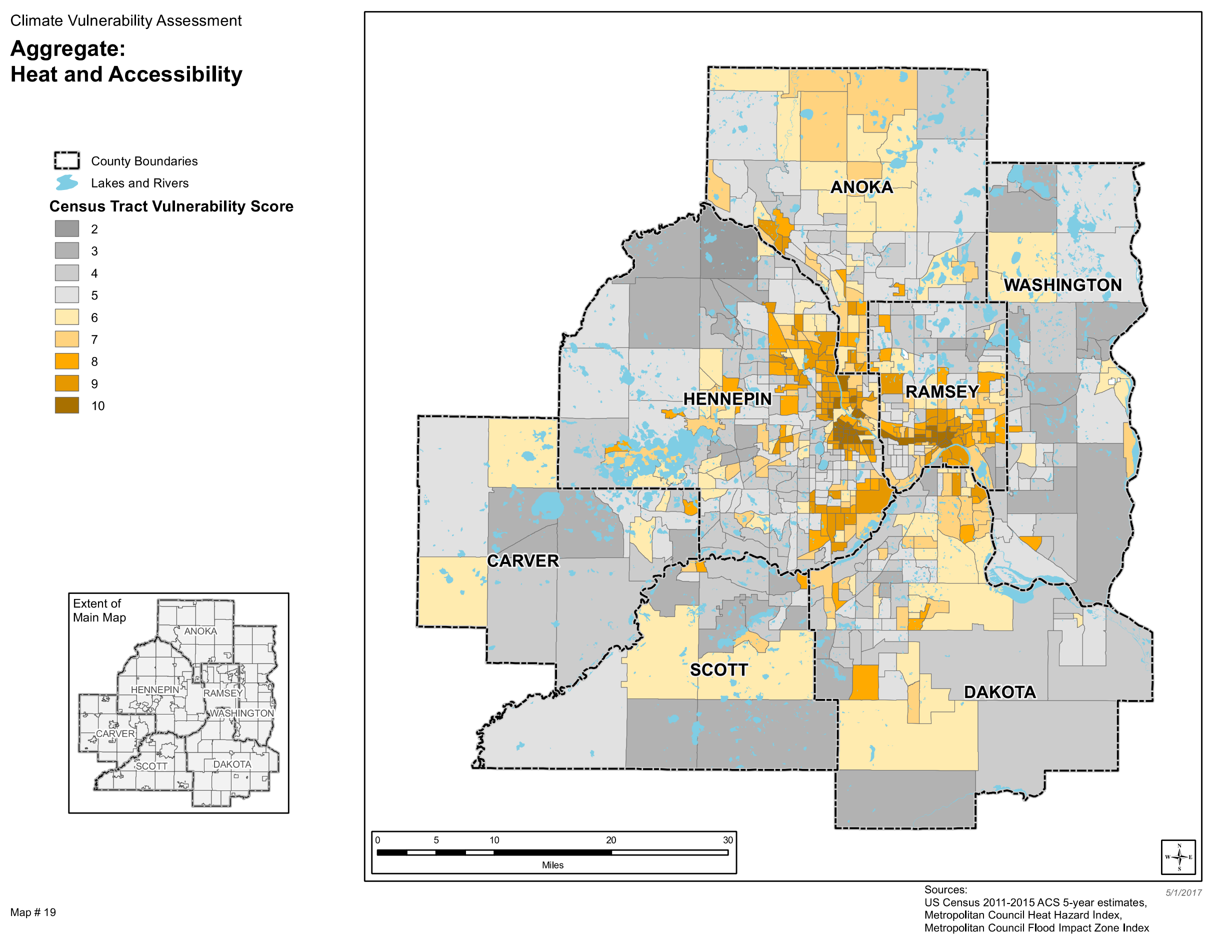
6.6.6 Health Indicator: COPD Hospital Visits



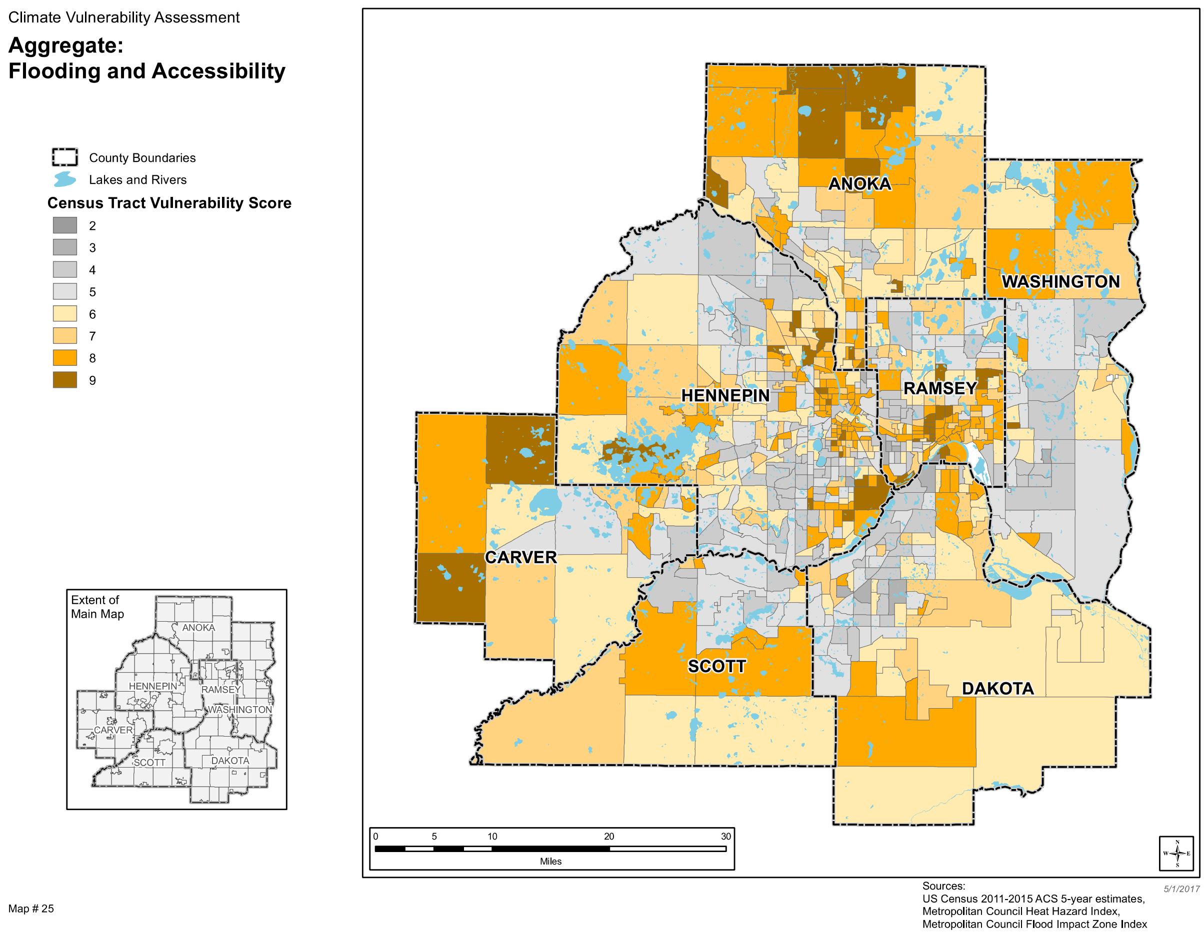
6.7 Accessibility Indicator

The accessibility indicator that we developed for this CVA is made up of four small multiples: without health insurance, no car ownership, has disability, proximity to a hospital more than 6 miles. There are aggregate maps for both heat and flood vulnerability as well as individual maps for each small multiple.

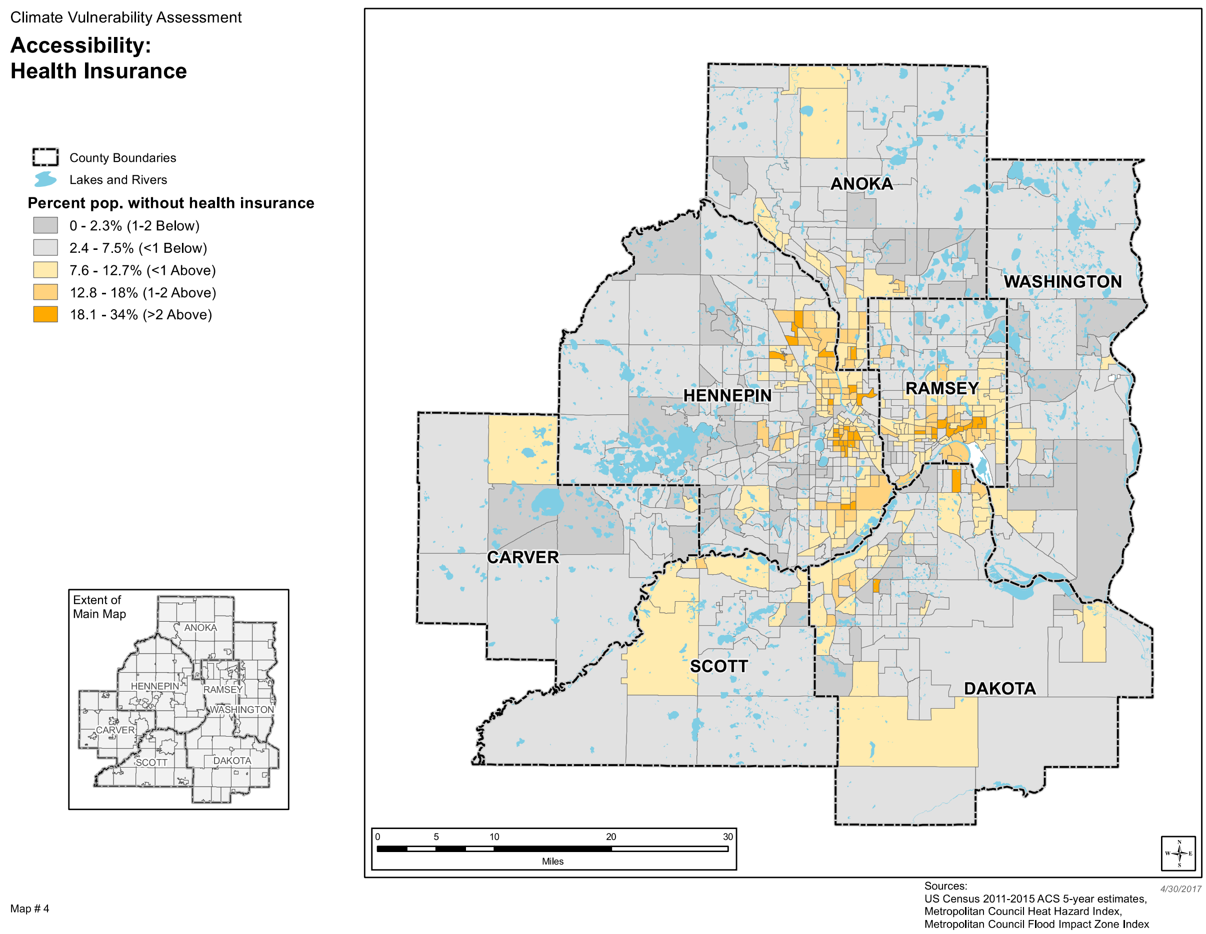
6.7.1 Accessibility Indicator: Aggregate with Extreme Heat Vulnerability



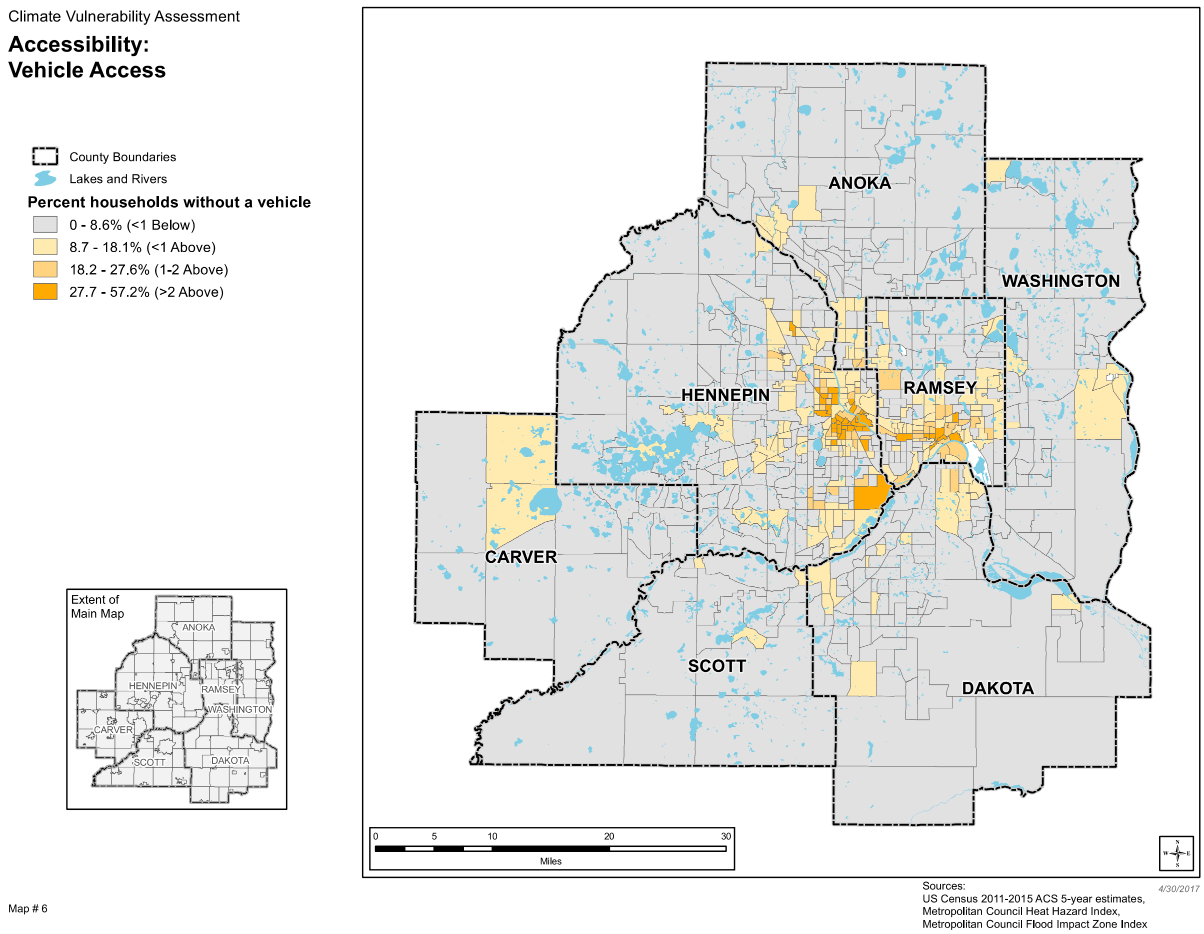
6.7.2 Accessibility Indicator: Aggregate with Surface Flood Vulnerability



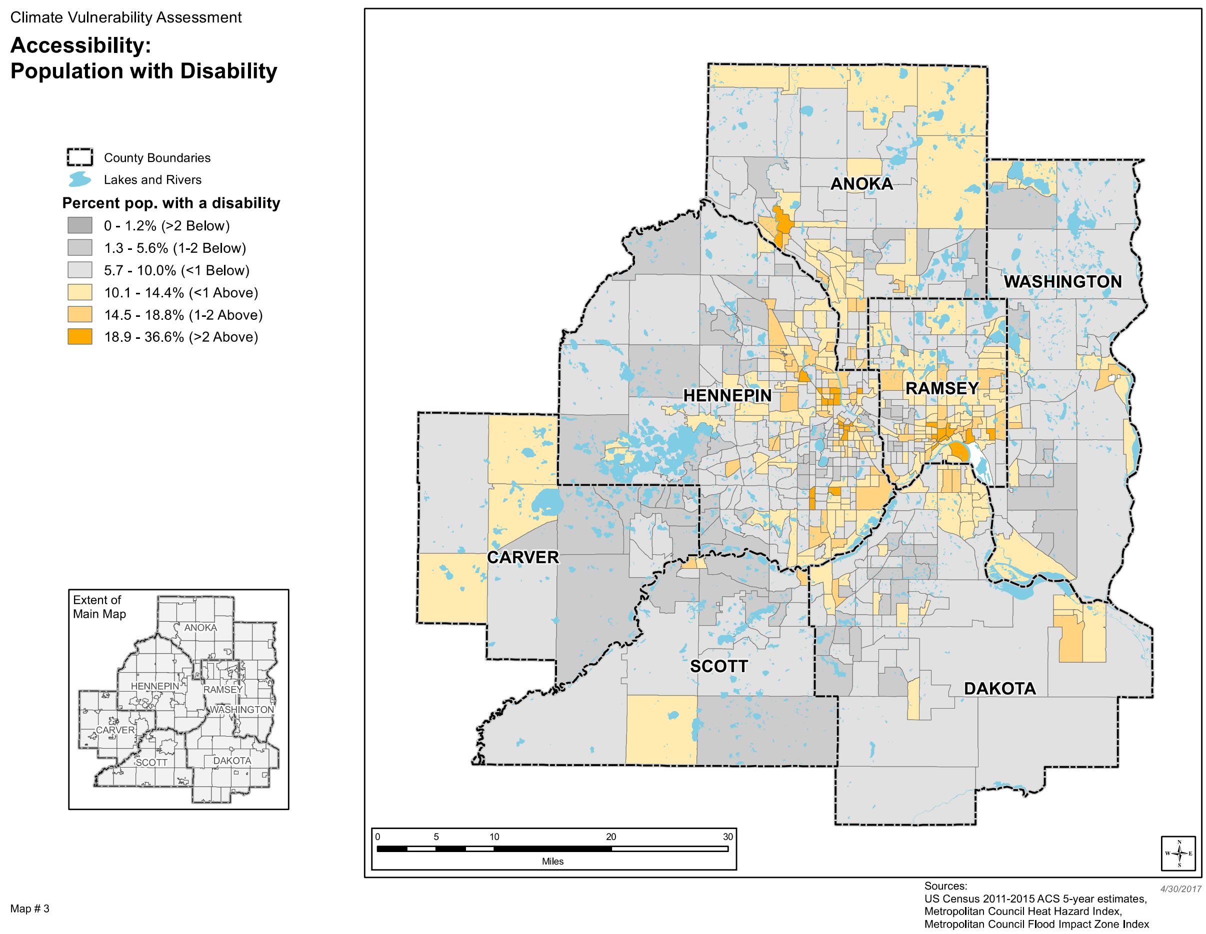
6.7.3 Accessibility Indicator: No Health Insurance



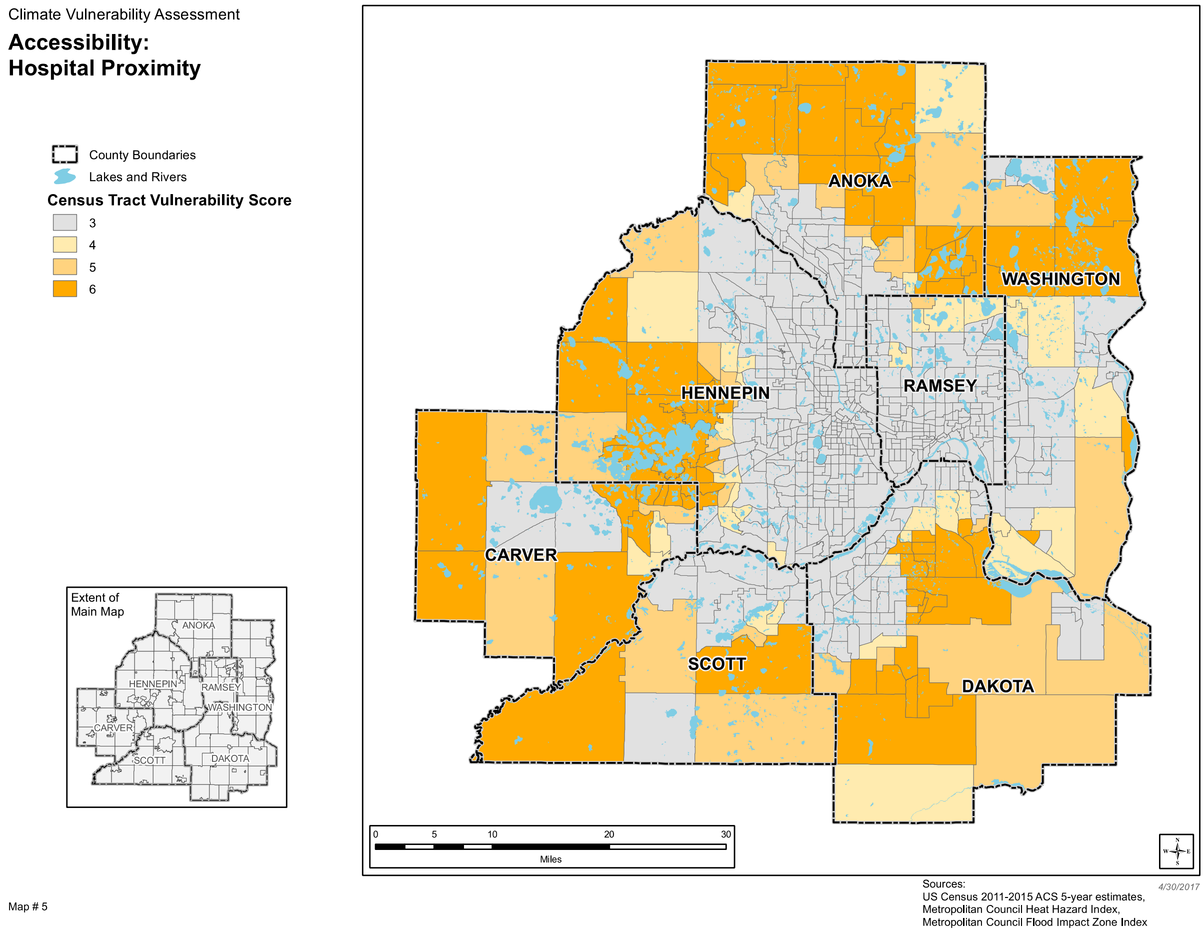
6.7.4 Accessibility Indicator: Car Ownership; No Access



6.7.5 Accessibility Indicator: Disability



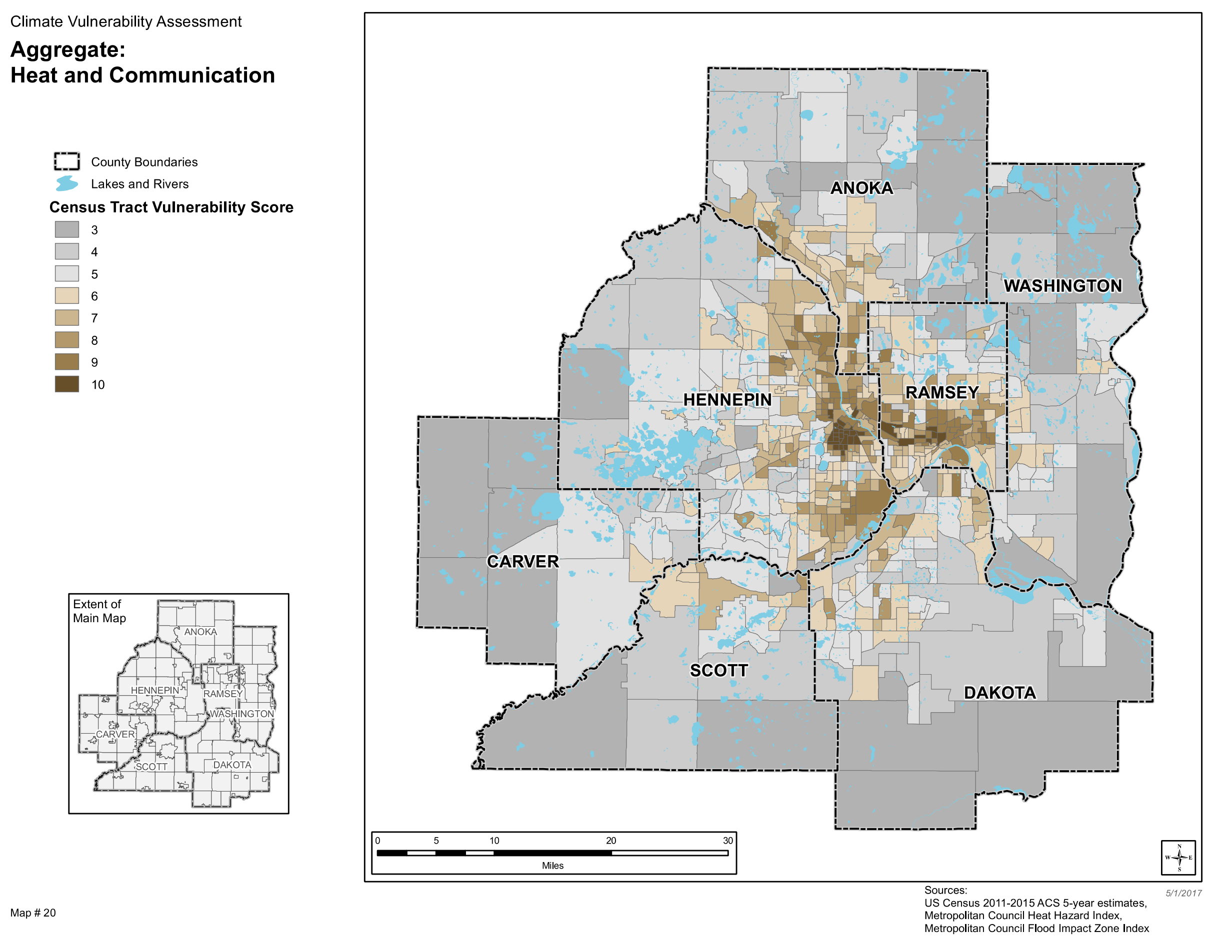
6.7.6 Accessibility Indicator: Proximity to a Hospital; more than 6 miles



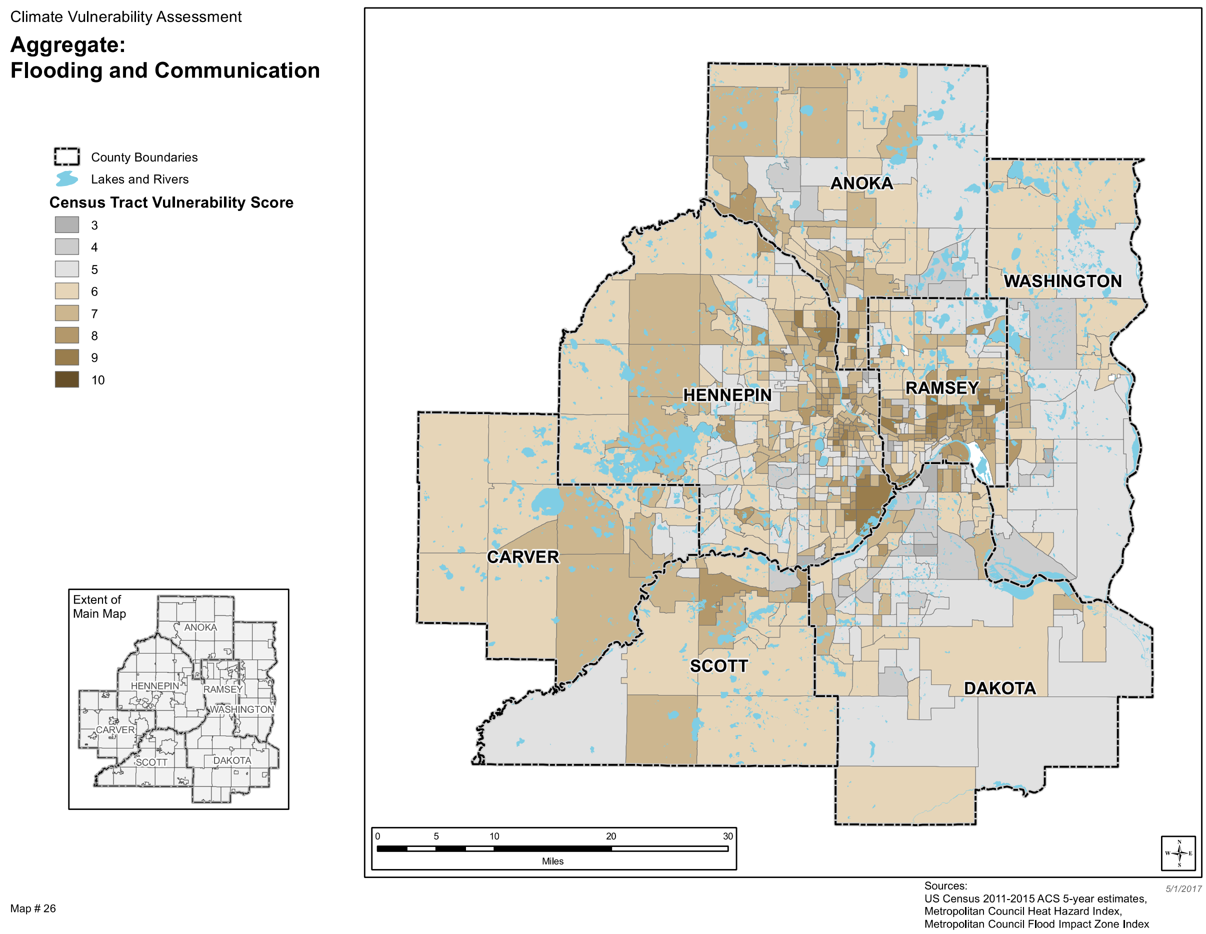
6.8 Communication Indicator

The communication indicator developed for this CVA is made up of two small multiples: Speaks English less than 'very well', and no telephone. There are aggregate maps for both heat and flood vulnerability as well as individual maps for each small multiple.

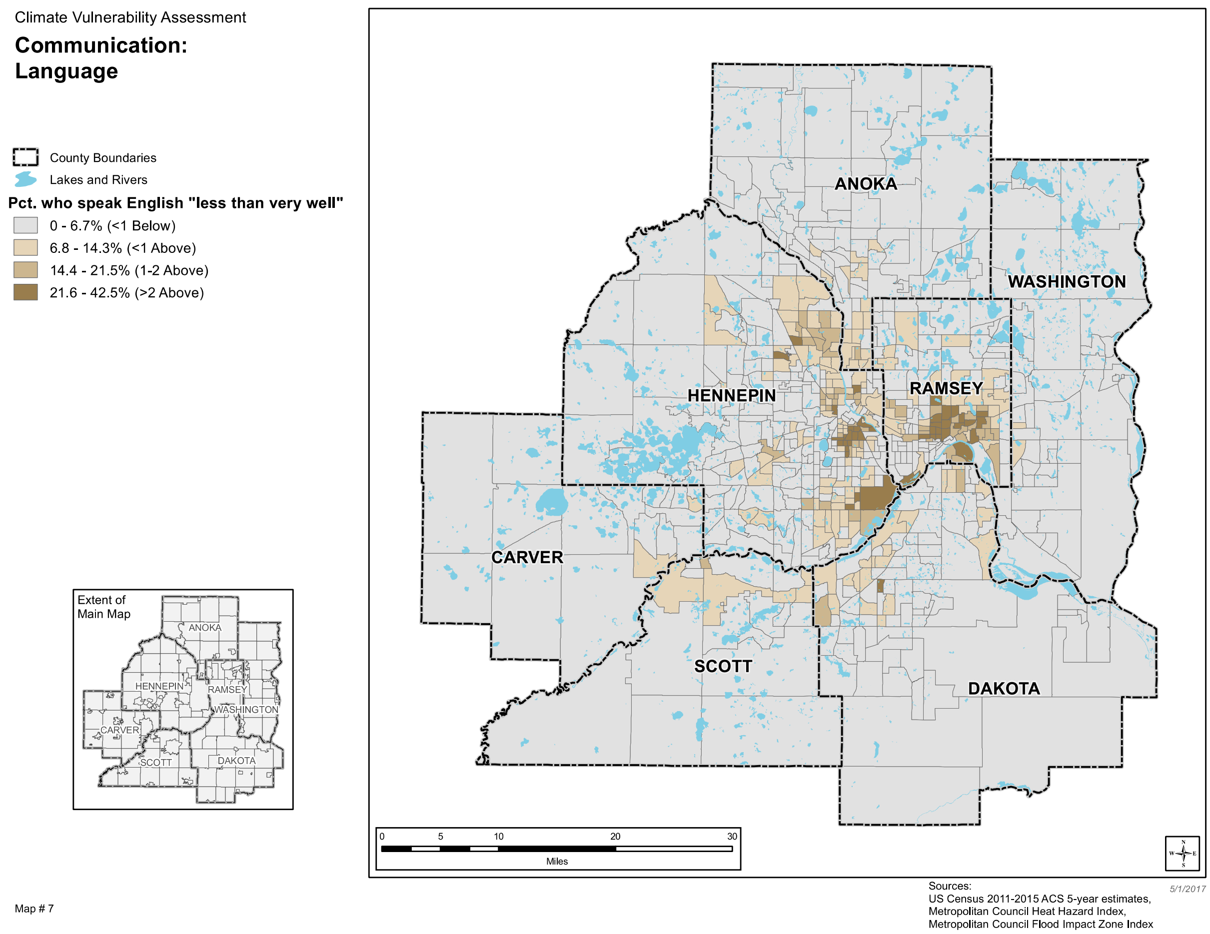
6.8.1 Communication Indicator: Aggregate with Extreme Heat Vulnerability



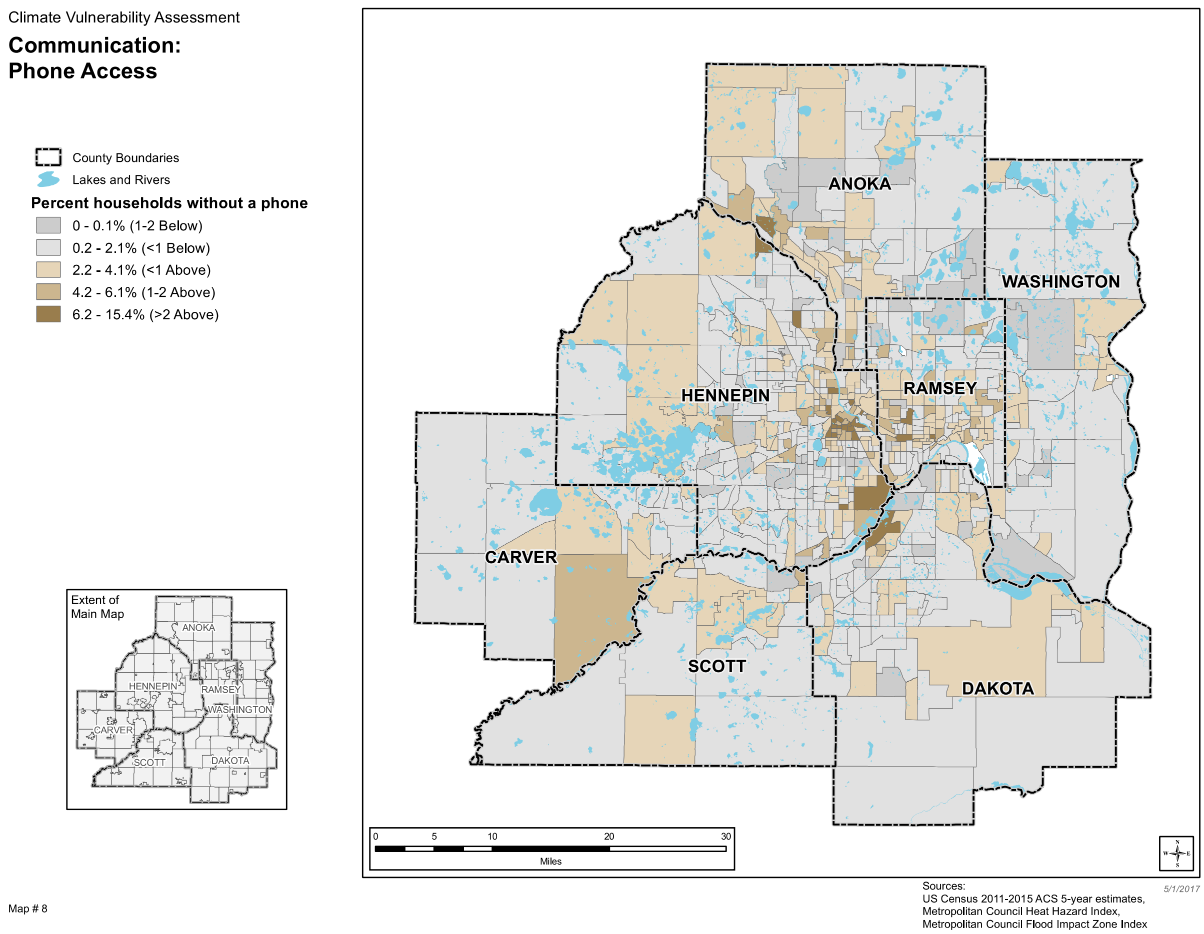
6.8.2 Communication Indicator: Aggregate with Surface Flood Vulnerability



6.8.3 Communication Indicator: Speaks English Less Than Very Well



6.8.4 Communication Indicator: No Telephone



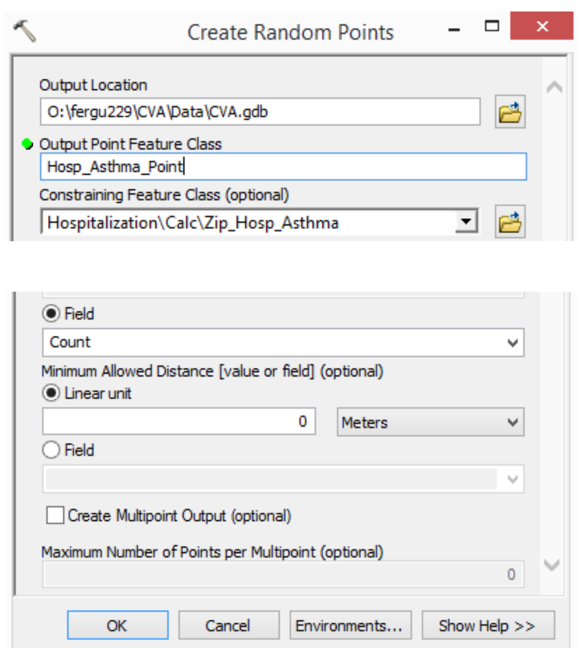
Appendix A: GIS Processes Step-By-Step

Zip Code to Census Tracts Conversion for Hospitalization Data

Note: This sequence was applied twice- once for asthma hospitalizations and once for COPD.

1. Join the asthma/COPD hospitalization tables to the 2015 TIGER Zip Code Tabulation Area shapefile, using zip code as the join field. After the join has completed successfully, export this layer to a new feature class: Zip_Hosp_Asthma

2. Use the Create Random Points geoprocessing tool to create points within each zip code boundary equal to the number of asthma/COPD hospitalizations.
    a. Under “Number of Points [value or field]”, select the ‘Field’ radio button.
    b. In the “Field" drop-down menu, select ‘Count’.
    c. Output point feature class: Zip_Hosp_Asthma
    d. Constraining feature class: Hosp_Asthma_Point



3. Use the “Spatial Join” geoprocessing tool to count the number of asthma/COPD points within each census tract. The ‘Count’ field in the resulting census tract feature class will show the number of hospitalization points in each tract.

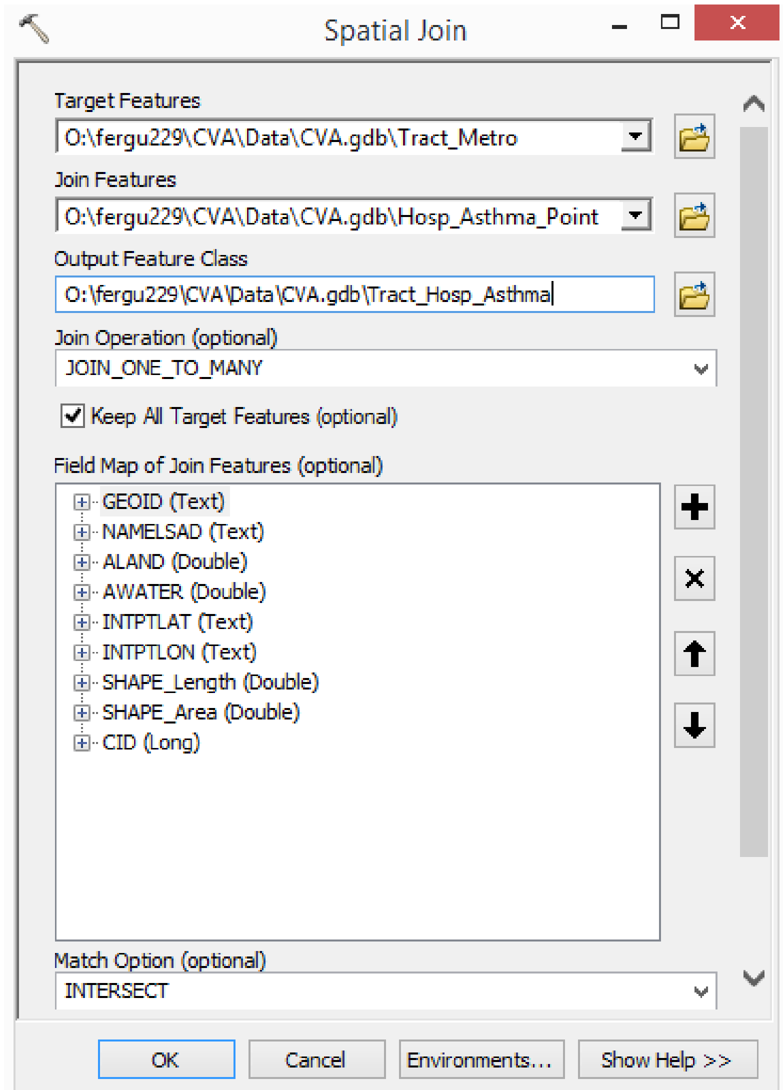
   Target Feature: Tract_Metro
   Join Feature: Hosp_Asthma_Point

Output Feature: Tract_Hosp_Asthma

Join Operation: JOIN_ONE_TO_MANY

Check the "Keep All Target Features" checkbox.

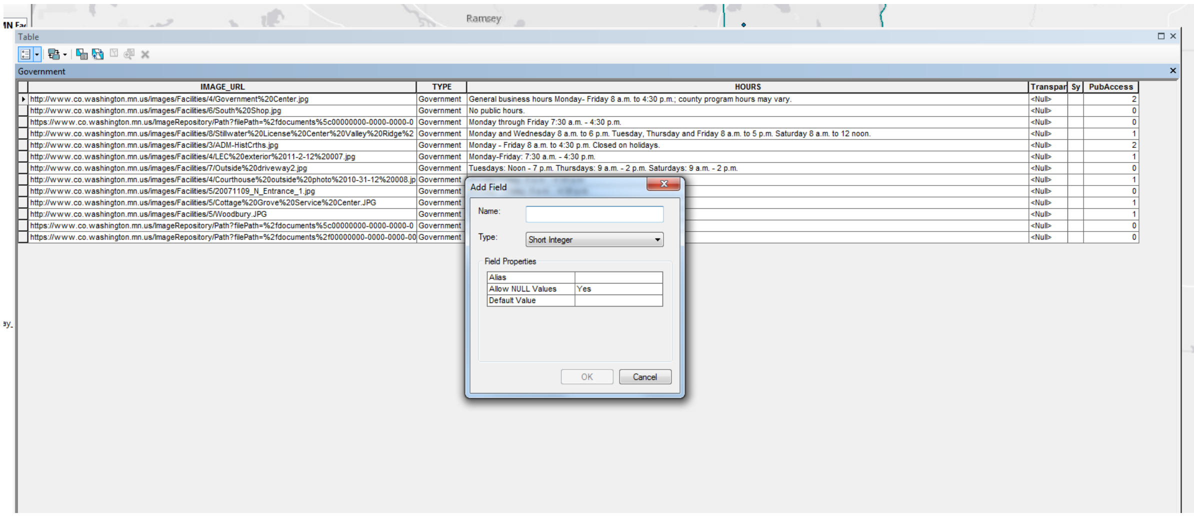
Match Option: INTERSECT



Creating a Short Integer Field (for sorting building types)

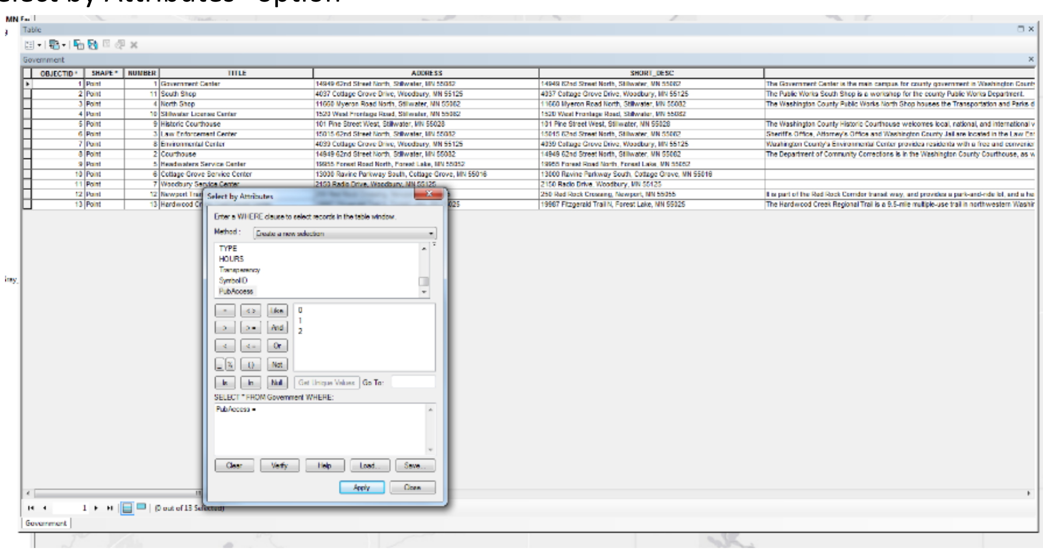
1. Right Click the target layer
2. Select "Open Attribute Table."
3. Open the drop-down menu in the upper left hand corner of the attribute table. If you hover over the icon, it is called "Table Options"
4. Select the "Add Field" option
5. Names of fields are specified in the Technical Document. To fit GIS preferred naming conventions, underscores were used instead of spaces and names were kept at or below 10 characters

6. Select “Short Integer” as the type of field
7. If prompted with the option, select “Allow Null Values”



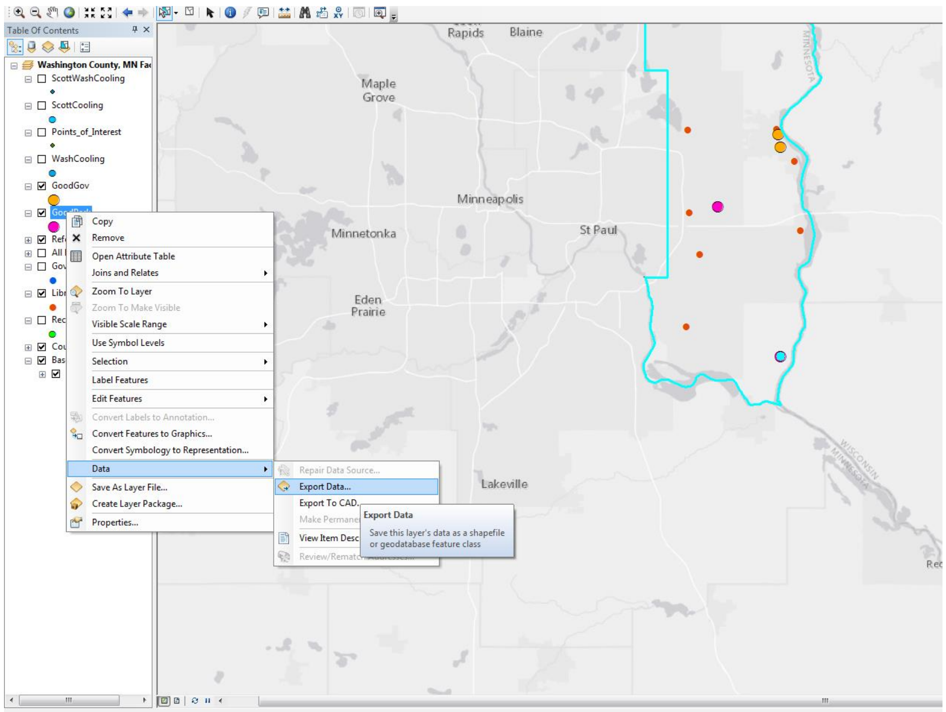
Creating a Layer with Only Desired/Selected Features

1. Right Click the target layer
2. Select “Open Attribute Table.”
3. Open the drop-down menu in the upper left hand corner of the attribute table. If you hover over the icon, it is called “Table Options.”
4. Select the “Select by Attributes” option
5. Double Click the target attribute name
6. Select the “=” button on the calculator interface on the left side of the window

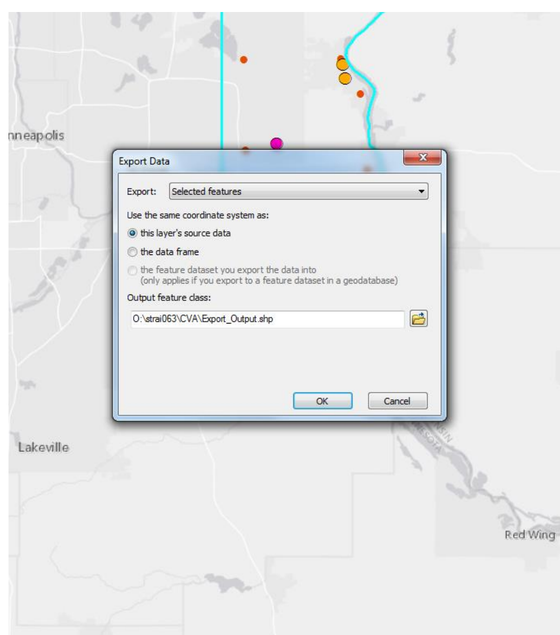


7. To select by specific values within the target attribute, select “Get Unique Values,” located to the lower right of the calculator interface. Once the values in the target attribute appear, double click the attribute value you want to sort by. A correct equation will look something like this: PubAccess = 2

8. Select the “Apply” button to run the selection process. You may close out of the attribute window without losing your selection to better view selected items on your map layout.
9. With desired attributes of the target layer selected, right click the layer name in the Table of Contents
10. Scroll down to “Data” and select “Export Data”

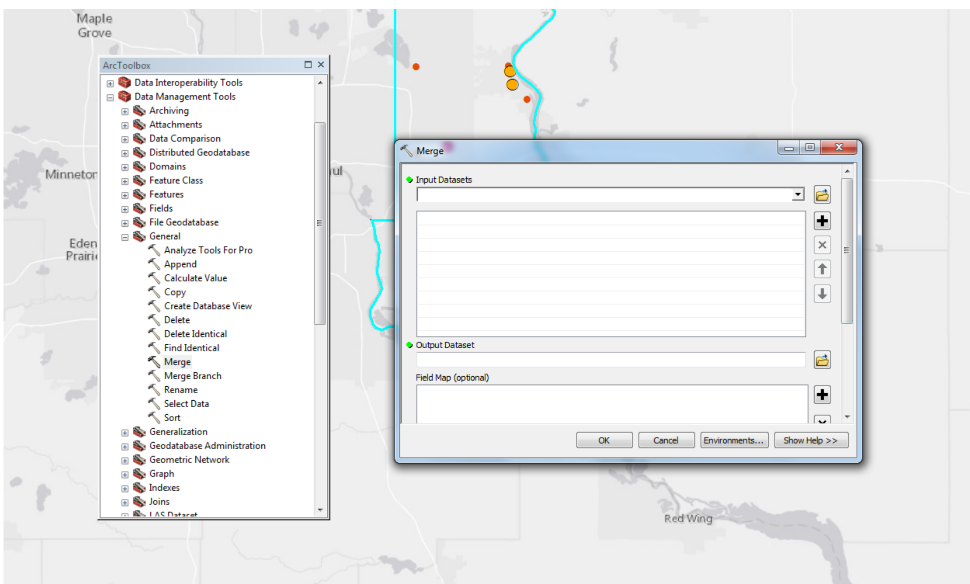


11. At the top of the window, ensure the Export option reads “Selected Features”
12. Select “this layer’s data source” for the coordinates of the new layer. This will ensure your new layer has the same spatial constraints as the other layers in your workspace.
13. Select where you want the data for this layer saved, and hit “OK”
14. When successfully processed, another window will pop-up asking you if you would like to add your new layer to your workspace. Select “Yes” to add. You can always add this data layer later using regular “Add Data” options.



Merging Data Layers to Create One Layer

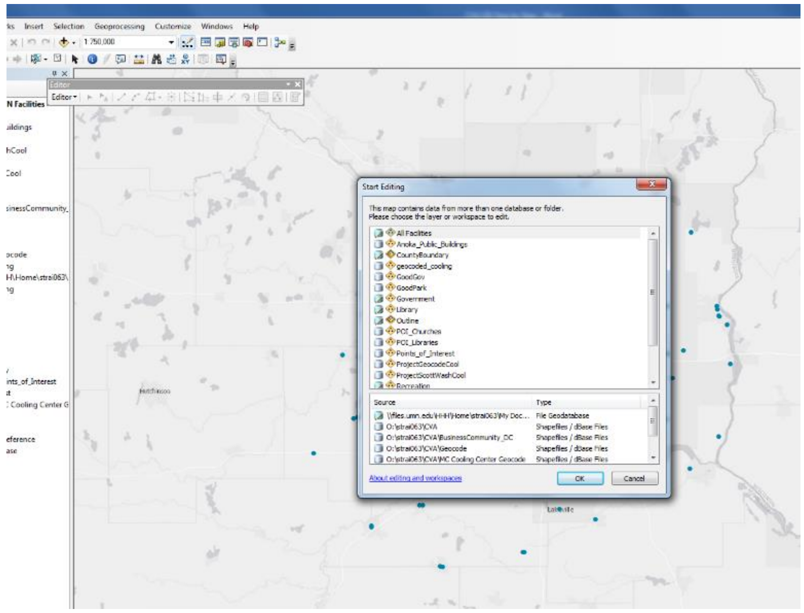
1. Open the ArcToolbox, either through the shortcut icon at the top of the screen or from the drop-down “Geoprocessing” menu.
2. Select “Data Management Tools”
3. Select “General”
4. Double Click “Merge”
5. A new window will pop-up. In the “Input Features” bar, select each layer you wish to merge. You have to select them one at a time, but they will save in the table below. This table also lets you remove and edit your selections.
6. In the “Output Dataset,” select where you would like your data to save
7. Select “OK”
8. When successfully processed, another window will pop-up asking you if you would like to add your new layer to your workspace. Select “Yes” to add. You can always add this data layer later using regular “Add Data” options.



Deleting Points

1. In the toolbar running across the top of the screen, select “Customize”. Within the “Customize” window, select “Toolbars.”
2. Select the “Editor” toolbar option. A new small toolbar will pop-up on the screen.
3. Within this new Editor toolbar, select the “Editor” drop-down menu and select the first option, “Start Editing”.
4. This will prompt a new window to open, allowing you to select which layer to edit. Once the layer is selected, you can maneuver around as you normally do.

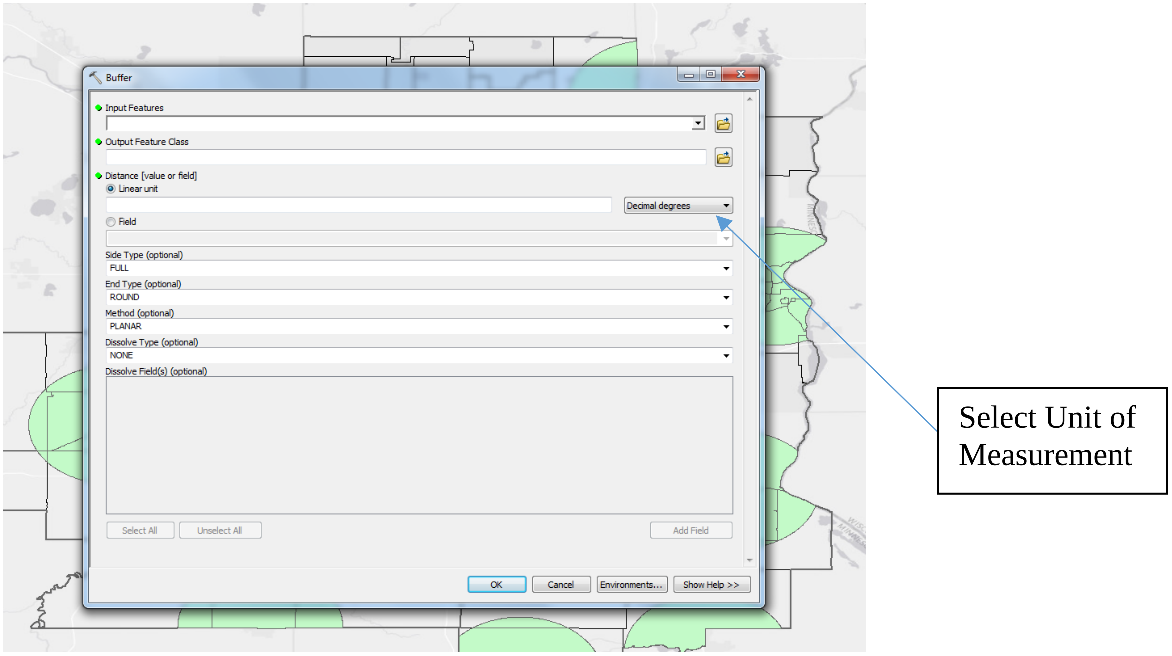
5. To remove geocoded data points within an editing session, select the “Select Features” option in the toolbar on the top of the screen, to the upper right of the “Table of Contents.”



6. Select the data point on the map. Ensure it is highlighted.
7. Press “Delete” on the keyboard.
8. To save these changes, return to the small, pop-out editor toolbar. In the “Editor” drop-down menu, navigate to “Save Edits”. Once all changes are made and saved, select “Stop Editing” within this same drop-down menu. If you forget to save before “Stop Editing,” GIS will prompt you to save your edits before exiting the session.

Creating a Buffer

1. Select the “Buffer” analysis tool. This tool is in the ArcToolbox under “Analysis Tools,” in the “Proximity” toolbox.
2. Select the layer you want to create a buffer for in the “Input Feature Class.” In our case, we selected “Metro_Hospitals.”
3. Select where you would like the new data layer saved in the “Output Feature Class.”
4. Type the desired distance of the buffer in the box and select the unit of measurement from the drop-down menu to the right of the box. In our case, we typed “6” and selected “miles” as the unit of measurement.
5. Select “OK.” When successfully processed, another window will pop-up asking you if you would like to add your new layer to your workspace. Select “Yes” to add. You can always add this data layer later using regular “Add Data” options.



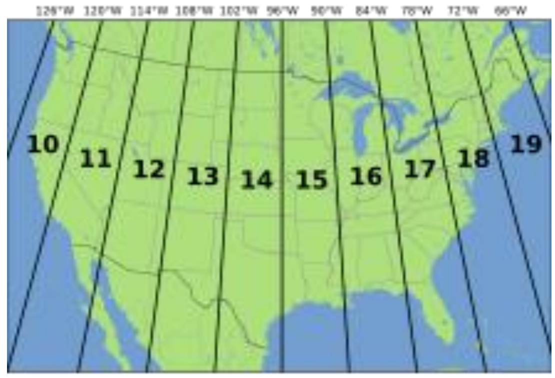
Calculate Geometry (Area)

1. Follow the steps outlined above to create a Short-Integer Field in the attribute table called “Area.”
2. Right-click the new “Area” field and select “Calculate Geometry.”
3. You will be prompted by a warning that you will be making changes out of an editing session. Click Ok.
4. In the “Property” drop-down menu, select “Area”. Depending on the spatial projection of your layer, you may need to change the projection first. Follow the “Spatial Projections” steps below to change to a Projected Coordinate System.
5. Select the coordinate system to match the spatial coordinates of your base map and other layers.
6. Select units of measurements from the drop-down menu at the bottom of the box.
7. Select “Ok.”

Spatial Projections

1. Select the “Project” tool. This tool is in the ArcToolbox under “Data Management Tools,” in the “Projections and Transformations” toolbox.
2. Select the layer you want to project in the “Input Dataset of Feature Class” drop-down menu.
3. Select where you would like the new data layer saved in the “Output Feature Class.”

4. Select the small box to the right of "Output Coordinate System" to pick the new projection for your data layer. To "Calculate Geometry," you will need a Projected Coordinate System. Throughout this project, we use "UTM, NAD 1983, UTM Zone 15 N" which is appropriate for most projections involving Minnesota, shown in the picture to the right.



Source: Wikipedia

5. Once the desired projection is selected in the "Spatial Coordinate Properties," click "OK." Click "Ok" again in the "Project" window to run the function.
6. A new layer will be created, but you will not be prompted to add the data layer upon completion. You will need to add it to your workspace using any "Add Data" process.

Joining Attribute Tables

1. Right-click one of the layers you want to include in the attribute table join and select "Joins and Relates," then "Joins."
2. In the first drop-down box, select "Join attributes from a table."
3. In the second drop-down box, numbered 1 in the box, select the attribute you want to be the basis for the join. The attribute needs to be present in both attribute tables for the join to work.
4. In the next drop-down box, numbered 2, select the layer you want to join to the table you have selected.
5. In the next drop-down box, numbered 3, select the attribute you want to be the basis for the join.
6. Make sure "Keep all Records" is selected to ensure no data or attributes are lost in the join process.
7. Click "Validate Join" to ensure the join will work smoothly. If GIS experiences any errors in validating the join, it will produce yellow warning icons next to the issue. This allows you to exit the join and go back to the original attribute tables to fix any errors. Do not select "OK" to perform the join until the join has been completely validated and no errors occur.
8. To view successfully joined tables, open the attribute table of either table involved in the join.

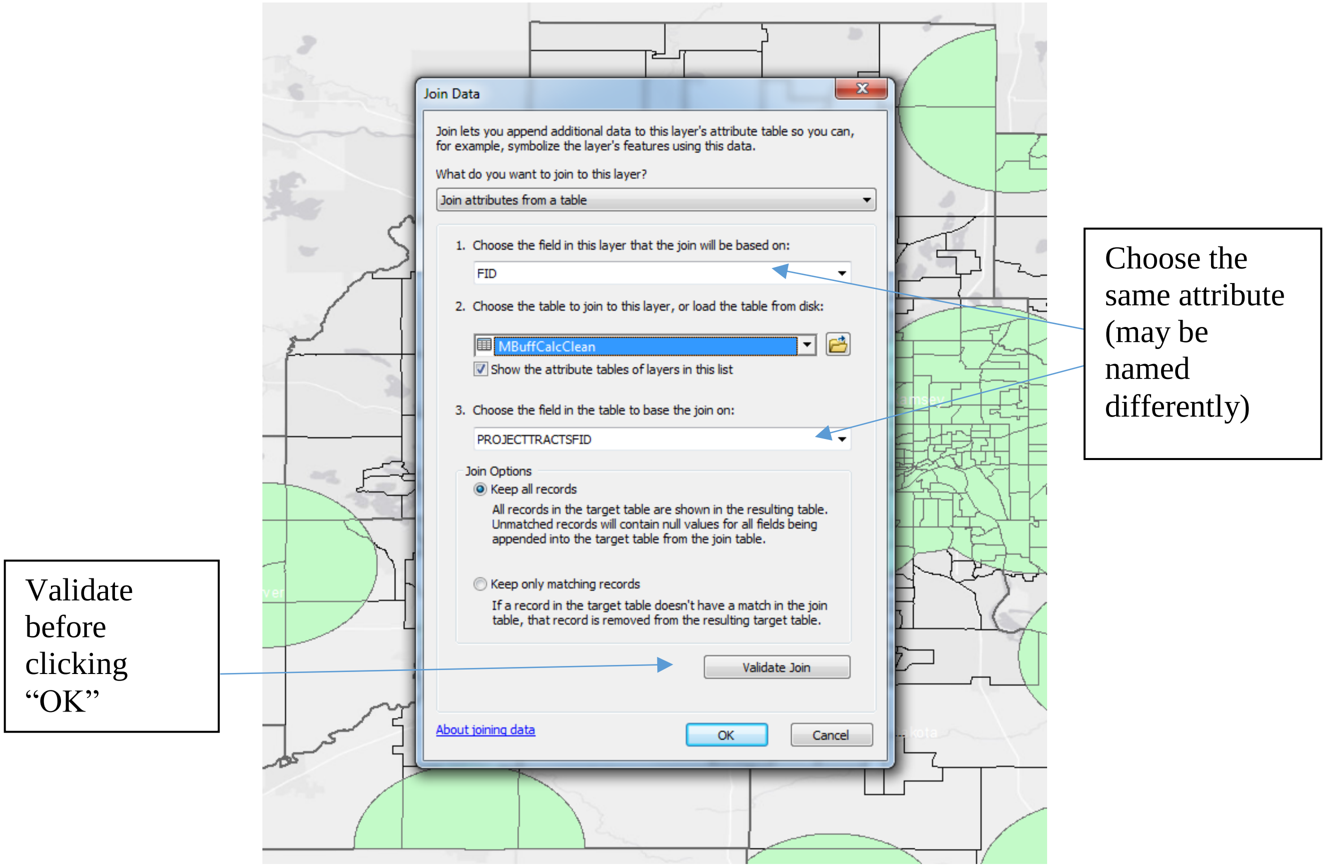
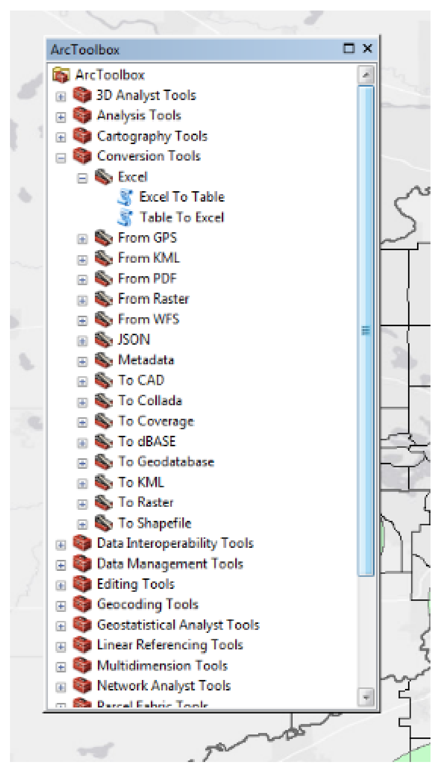


Table to Excel/Excel to Table



1. Select the "Table to Excel" tool. This tool is in the ArcToolbox under "Conversion Tools," in the "Excel" toolbox.
2. Select the attribute table you want to convert into an Excel spreadsheet by selecting the layer from the drop-down menu.
3. Specify where the created Excel spreadsheet should be saved.
4. Click "OK."

Note: "Excel to Table" works the same way, instead creating a GIS compatible table from an Excel spreadsheet.

Appendix B: Cooling Center Data: Acquisition and Layer Creation

There is no standard definition of a “cooling center” in the seven-county metropolitan area. As such, each county self-determines publicly accessible cooling centers. Four counties, Anoka, Carver, Hennepin, and Ramsey provided cooling center data to the Council, though these data vary in its thoroughness and completion. Dakota, Scott, and Washington Counties reportedly do not have data on cooling centers. This makes it difficult to assess community’s preparedness for extreme heat events or to conduct an even and fair analysis across the metropolitan area. For the purpose of this analysis and starting conversation in counties and cities, publicly available data from these three counties were obtained to highlight potential cooling centers.

The cooling center data provided by the Council for Anoka, Carver, Hennepin, and Ramsey County consisted of a list of addresses and building types or functions. This list was geocoded using ArcGIS software and ArcGIS Online databases to convert each address into a spatial data points. Two points were miscoded and were deleted from analysis using the Editor Function in the GIS Toolbar.

Washington County

Data on county facilities were obtained from Washington County. These data contained three categories of county facilities: county government buildings, parks, and libraries. County government buildings were sorted based on their public accessibility since some facilities, like Public Works and Recycling Centers, are open to the public but not designed for prolonged visits. To show this difference, a short-integer field called “PubAccess” was created within the layer attribute table. Values were assigned to government buildings based on their accessibility with 2 values being the most accessible, meaning members of the public are encouraged within the building and would have some type of activity to do, 1 values indicating public accessibility with limited activity, and 0 values indicating limited or discouraged public accessibility. This allowed us to select the buildings we wanted based on attribute, facilitated through the “Select by Attributes” function in the Attribute Table. We selected our created “PubAccess” field as the attribute and “2” as the desired value. These desired data were exported into a new shapefile called “GoodGov.”

Conversations with a Washington County Parks Department employee helped to identify which park facilities have air-conditioned shelters that may be accessible during heat events. To show this difference, a short-integer field called “AirCondition” was created within the layer attribute table. Values were assigned to park facilities based on the presence of an air-conditioned building with 1 values indicating air conditioning and 0 values indicating no air conditioning. All parks with Air Conditioning were selected and exported into a new shapefile, “GoodPark”.

Libraries were similarly sorted through, since Washington County has a few “Express” Libraries that offer pick-up lockers and book returns but are not full services libraries. To show this difference, a short-integer field called “Real_Build” was created within the layer attribute. Values were assigned to libraries based on the presence of a full service, physical library with 1 values indicating a library and 0 values indicating “Express” libraries. All libraries returning a 0 value were deleted from the table, leaving only full service, physical libraries.

With all desired cooling centers selected and in their own layers, the Merge Function was used to create one layer of all cooling centers in Washington County, called “WashCooling.” This layer result of a merge of “Libraries,” “GoodGov,” and “GoodPark.”

Scott County

Data regarding “points of interest” in Scott County were obtained from the County’s public GIS portal and online mapping tool. This GIS shapefile is the most comprehensive list of building types and functions in the county, including government buildings, schools, and private entertainment venues. However, not all of these buildings would be considered “cooling centers” in an extreme heart event. Without guidance from a Scott County employee, it is difficult to know which structures to include. *These data should be considered as potential cooling center locations within Scott County and are meant to start conversations about accessibility and response in Scott County cities.* We selected building types and functions that were common in the list of cooling centers provided by the Council. In Scott County, a building was considered a “cooling center” if it was a city hall, library, community center of equivalent (i.e. YMCA), or an indoor, publicly accessible entertainment venue (entry fee of some type required). We did not include township city halls since these structures tend to be older and are less likely to be air conditioned. Additionally, many township city halls have infrequent hours, are small, and are not likely to be prepared to host people longer than an hour in an event.

To create a separate shapefile/data layer with only the identified potential cooling centers, a short-integer field called “CoolCenter” was created within the layer attribute table. Values (1) were assigned to all identified cooling centers. All other structures not identified as cooling centers were given a 0 value. This allowed us to select the buildings we wanted based on attribute, facilitated through the “Select by Attributes” function in the Attribute Table. We selected our created “CoolCenter” field as the attribute and “1” as the desired value. These desired data were exported into a new shapefile called “ScottCooling.”

Dakota County

Data regarding "business and community" in Dakota County were obtained from the County's public GIS portal, DCGIS. This layer displays libraries and places of worship, which are freely accessible to the public. However, the layer is not updated regularly, and it does not include any information regarding air conditioning. As in the example of Scott County, these data represent a potential starting point for a more comprehensive list of cooling centers.

Appendix C: GIS Data Disclaimer

Metropolitan Council Climate Vulnerability Assessment Heat Vulnerability Basemap and Flood Layers

Disclaimer

This data is (i) furnished 'as is' with no representation as to completeness or accuracy; (ii) is furnished with no warranty of any kind; (iii) **is in draft form and for the City's internal use only** and (iv) is not suitable for legal, engineering or surveying purposes. Metropolitan Council shall not be liable for any damage, injury or loss resulting from this data.

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Appendix D: Social Network Indicator Rationale

The conceptual category for social networks and (assumed) neighborhood cohesion was difficult for the team to develop. The aggregate category of "Social Network" was developed following the description given by Maskrey[51] of the concept "social territory of risk," which refers to "locally specific patterns of exposure, vulnerability, adaptive capacities and solutions." In other words, vulnerability does not individually tell the whole story; there are other existing constraints for Disaster Risk Reduction (DRR) which can hinder or catalyze the adaption of recommendations and practices and achievements in preparedness.

We originally called the concept "community cohesion," due to literature on the term and its meaning in past studies. However, further discussion and (in particular) review of the International Federation of Red Cross and Red Crescent Societies' World Disasters Report: Focus on culture and risk led to renaming the category "Social Network." While the data used to represent the concept reflects current literature, it is a narrow reflection of what social networks and community cohesion can be. Still, we felt that the concept and the characteristics of this indicator were important to include in our analysis. The question of how "culture" or "social relations" influences vulnerability and the ability of various populations to respond to flood and extreme heat events requires more consideration and research.

We shied away from using the word "community" for this category due to compelling arguments for "the myth of community" in the IFRC's report, which made sense in the regional scope of this analysis. For example, community is not always used to refer to a geographically bounded concept, such as various populations of Hmong or Somali throughout the Twin Cities metropolitan area. These populations might consider themselves to be a "community" despite living in geographically disperse and distant census tracts and/or in large rental housing buildings. Without specific data to explain "communities" and how they relate within each other and to each other, we could not justify using the term to describe the concept of social relatedness or cohesion in our framework. For this reason, and due to a lack of applicable and available descriptive data, we also decided against the term "culture."

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[51] Maskrey, A. 2011 'Revisiting community-based disaster risk management' in Environmental Hazards: Human and Policy Dimensions, Vol. 10, No. 1, pp. 42–52.

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