Wisconsin Department of Health Services

Wisconsin Heat Vulnerability Index

Wisconsin Department of Health Services
Bureau of Environmental and Occupational Health
Building Resilience Against Climate Effects (BRACE) Program
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Acknowledgements

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Introduction

Analysis of 60 years of weather trend data by the Wisconsin Initiative on Climate Change Impacts (WICCI) has indicated that Wisconsin has become warmer. In general, Wisconsin has experienced an increase in mean annual temperature of 1.5°F in the period from 1950 to 2006, with the greatest increase in average temperatures occurring during the winter months.[1] Across the Upper Midwest, temperatures were notably high in 2012.[2] Extreme heat is known to have negative impacts on human health in terms of morbidity[3] and mortality.[4,5] Many of the established risk factors for heat-related mortality disproportionately affect elderly populations, socially isolated individuals, and those with pre-existing chronic conditions such as cardiovascular disease.

Although limited in number, some studies have mapped heat vulnerability to identify potential areas of highest risk for public health interventions. Reid et al. created a national map of 10 heat vulnerability factors in the US.[6] San Francisco's Department of Public Health (SFDPH) also created an index of heat vulnerability but used a different set of 21 variables in the index and focused on a much smaller geographic area, the City of San Francisco.[7] In addition to SFDPH, a number of studies have mapped heat vulnerability for specific metropolitan areas,[8,9,10] but this is one of the few publications that is statewide in scope.

Utilizing the methodology developed by the San Francisco Department of Public Health (SFDPH), the Wisconsin Building Resilience Against Climate Effects (BRACE) staff conducted a geo-spatial analysis of heat-related vulnerability in both Wisconsin as a whole and the greater Milwaukee urban area, with assistance from the Wisconsin Department of Health Services (DHS) Bureau of Information Technology Services (BITS) Geographic Information Systems (GIS) staff. This project used existing population and census data, natural and built environment data, and health factors data to create a heat vulnerability index (HVI) to identify areas of greatest risk for negative health impacts due to extreme heat. The maps can help identify high-risk neighborhoods and populations to receive targeted messaging related to heat events and additional resources during extreme heat events.

As far as we know, this is the first study to create a heat vulnerability index (HVI) for the state of Wisconsin, and one of the few statewide HVI studies in the U.S.

Methods

Data Sources

Table 1 lists the variables, measures, data sources, geography, and years of the data that were included in the Wisconsin heat vulnerability index. Existing heat vulnerability studies were reviewed[6,7] to inform the 22 data layers that were selected, plus several Wisconsin-specific data sets. Variables were organized into four categories: population density (1 variable), health factors (8 variables), demographic and socioeconomic factors (7 variables), and natural and built environment factors (6 variables).

Population Density

The population density category consists of a single variable: population per square mile, which was acquired from the U.S. Census. High settlement density has been associated with higher temperatures.[11]

Health Factors

The health factors category consists of a set of eight variables:

- Diabetes prevalence
- Adult asthma prevalence
- Hypertension rate
- Percentage obese based on body mass index (BMI)
- Percentage uninsured
- Percentage of population that received public mental health services
- Percentage of population that received public substance abuse services
- Percentage of population that visited an emergency department for heat stress

The health factors were selected based on status as a risk factor for heat-related illness or death as well as data availability.

Diabetes is known to create a higher susceptibility to heat, likely due to impaired thermoregulation.[6,12,13,14] Diabetes prevalence data (unadjusted) were from the 2006-2010 Behavioral Risk Factor Surveillance System (BRFSS). Asthma was included as an indicator because heat events can exacerbate respiratory conditions such as asthma.[7,15] Adult asthma prevalence was also calculated from 2006-2010 BRFSS data.

Cardiovascular disease[16,17] and obesity[18,19] are known risk factors for heat-related mortality; hypertension was used as a proxy for cardiovascular disease. Obesity rate was defined as percentage of the population that was considered obese (body mass index ≥ 30). Hypertension and obesity rates were derived from BRFSS data.

Studies have shown that some mental health medications and conditions[20,21] and substance abuse[22,23] can increase the risk of heat-related illness and mortality. The mental health variable in this HVI represented the percentage of the population that receives county mental health services. Likewise, the substance abuse variable represents the percentage of the population that was admitted for county-provided substance abuse treatment services. The mental health and substance abuse variables were obtained from the Wisconsin Division of Mental Health and Substance Abuse Services' (DMHSAS) data systems named the Human Services Reporting System (HSRS) Mental Health Module and the HSRS Substance Abuse Module, respectively.

In a report sponsored by the Cover Missouri Project, Hadley found that uninsured individuals are less likely to seek preventive services and less likely to seek medical care when seriously ill compared to insured individuals.[24] The low use of medical care services among the uninsured is related to poor health status. Furthermore, the uninsured have higher rates of all-cause mortality than the insured.[24] For the HVI, the percentage of county population that is uninsured came from BRFSS data.

Heat stress is considered a condition along a spectrum of heat-related conditions, which increase in severity from heat exhaustion to heat stroke and death. The definition of heat stress cases for the indicator were those cases seen in an emergency department in summer months (May-September) with any of the following ICD-9 codes as a principal diagnosis, injury cause, or other diagnosis: 992.0, 992.1, 992.3, 992.4, 992.5, 992.6, 992.7, 992.8, 992.9, E900.0, E900.9. The heat stress data came from the Wisconsin Hospital Patient Data System.

Demographic and Socioeconomic Factors

Older adults[25] and very young children[26] are at increased risk for heat-related morbidity and mortality. In this context, percentage of the population aged 0-4 and percentage of the population aged 85+ were included in the index as two distinct variables.

The percentage of households in poverty was included as a data layer since low-income status is associated with increased susceptibility to extreme heat.[16] The impoverished are less likely to afford air conditioning, a strong protective factor.[16,21] Minority populations[27] and subjects with a high school diploma or less[28] have also been shown to have elevated vulnerability to heat, so this HVI included the percentage of the population identifying as “non-white,” and the percentage with less than a high school education, as variables in the analysis.

Social isolation has been found to be a risk factor for heat-related mortality,[5,16] so the percentage of population living alone was included as an indicator of this source of vulnerability.

All of the demographic and socioeconomic variables in the index were obtained from the American Community Survey (ACS), conducted by the U.S. Census Bureau.

Natural and Built Environment Factors

Extremely hot temperatures are associated with higher mortality.[29] SFDPH 2013 used a day of surface temperature measurements in both May and September to represent conditions in spring and summer in their HVI.[7] We altered this methodology slightly to reflect conditions during a heat wave: air surface temperature on July 6, 2012, was included as an indicator because this day was during a heat wave in the hottest year on record for the contiguous United States. The temperature data were acquired from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate mapping system.

Air pollutants such as ozone have been associated with higher temperatures and increased daily mortality,[30] even at low concentrations of the pollutant.[31] Though the effects of climate on air pollutants such as particulate matter are not well understood, there is some evidence that particulate matter (PM_{10}) interacts with temperature to have a large effect on mortality on hot days.[32] Assuming a similar temperature-air pollution interaction with fine particulate matter ($PM_{2.5}$), we used $PM_{2.5}$ as a variable in the index because exposure to the air pollutant is associated with respiratory and cardiovascular diseases,[33] including asthma, chronic obstructive pulmonary disease, and cardiac dysrhythmias, and increased school and work absences, emergency department visits, and hospital admissions.[34] Airborne particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$) poses a health risk because the small size of the particles (approximately 1/30th the average width of a human hair) allows them to lodge deeply into the lungs.[35] The recently released International Panel on Climate Change (IPCC) Working Group II report considers the health risks caused by synergistic effects of extreme heat and degraded air to be a significant vulnerability, especially with an aging population and the global shift to urbanization.[36] For this heat vulnerability study, air quality data from the Environmental Protection Agency (EPA) from July 2012 were included to reflect ambient air conditions during a heat wave.

Access to transportation can reduce one's risk of heat-related mortality.[5] Therefore, households without a vehicle, were included as an indicator representative of a population that may not have consistent access to transportation. These data were acquired from the ACS of the U.S. Census.

Studies have shown that people in neighborhoods with less green space are at higher risk to heat-related health outcomes.[37] Increased green space can help reduce the urban heat island effect. Our study captured urban areas spatially by creating an indicator of developed land cover, which includes areas of medium- and high-intensity classification, according to the National Land Cover Database (NLCD).

As noted above, older adult populations are at particular risk for heat-related health outcomes; nursing home populations represent a vulnerable subgroup of this population.[38] We obtained nursing home bed count data from the Wisconsin Division of Long Term Care to include in the HVI.

Analysis

Census block groups were used for spatial analysis due to the availability of demographic and household characteristics at that level of geography. They also provided a way to compare vulnerability within local jurisdictional boundaries. Most of the health factors were available at the county level, so the value for a given county was applied to each census block in that county for those health factors. Several analyses were used to extrapolate and calculate environmental data variables for each census block group. Land cover raster data were converted to vector data and measured by the percentage covered in the developed land classification. Air quality data values were assigned to block groups from the monitoring stations based on a nearest neighbor analysis. Nursing home bed counts were applied to the block groups in which the facility was physically located.

The range of data for each variable was standardized using z-score methodology. The z-scores were calculated so that increasing values correspond to increasing vulnerability. The z-score values for all variables were summed to create the vulnerability index score under the assumption that each variable has an equal impact on the overall vulnerability. The index scores were categorized into quantiles for data display and presentation purposes.

To transform the data into a visually appealing statewide map, the summary z-score values were categorized into quantiles. The top 20% quantile represents the geographic areas with "high" heat vulnerability risk based on the analyzed variables. Likewise, the bottom 20% quantile represents the areas of “low” heat vulnerability risk. The three middle quantiles are then representative of “moderate high” heat vulnerability, “moderate” heat vulnerability, and “moderate low” heat vulnerability. The geographic areas represented by the index are at the census block level. The color scheme of the map corresponds to the risk values, with the dark magenta and pink representing the “high” and “moderate high” heat vulnerability areas, light gray representing the “moderate” areas, and yellow and gold representing the “moderate low” and “low” heat vulnerability census blocks. State parks and forests (green color scheme) and larger bodies of water (blue) are also represented. County boundaries, larger cities, and major highways are included to aid in referencing location.

The Wisconsin Heat Vulnerability Index Map is displayed in Appendix A.

Table 1. Variables included in the Wisconsin heat vulnerability index

Variable	Measure	Year	Data Source	Geography
Population Density				
Population density	Population per square mile	2011	U.S. Census	Block group
Health Factors				
Diabetes	Diabetes prevalence	2006-2010	Behavioral Risk Factor Surveillance System (BRFSS)	County
Asthma	Adult asthma prevalence	2006-2010	BRFSS	County
Hypertension	Hypertension rate	2006-2010	BRFSS	County
Obesity	Percentage obese based on BMI	2009-2011	BRFSS	County
Uninsured	Percentage uninsured	2006-2010	BRFSS	County
Mental health	Percentage of population receiving public mental health services	2011	Division of Mental Health and Substance Abuse Services (DMHSAS)	County
Substance abuse	Percentage of population receiving public substance abuse services	2006-2010	DMHSAS	County
Heat stress	Percentage of population that visited an emergency department for heat stress	2002-2012	Wisconsin Hospital Patient Data System	Zip Code Tabulation Area (ZCTA)
Demographic and Socioeconomic Factors				
Poverty	Percentage of households in poverty	2007-2011	U.S. Census, American Community Survey (ACS)	Block group
Age 0-4	Percentage of population aged 0-4	2007-2011	U.S. Census (ACS)	Block group
Age 85+	Percentage of population aged 85+	2007-2011	U.S. Census (ACS)	Block group
Age 65+ living alone	Percentage of population 65+ living alone	2007-2011	U.S. Census (ACS)	Block group
Living alone	Percentage of population living alone	2007-2011	U.S. Census (ACS)	Block group
Non-white	Percentage of non-white population	2007-2011	U.S. Census (ACS)	Block group
Less than high school education	Percentage of population with less than high school education	2007-2011	U.S. Census (ACS)	Block group
Natural and Built Environment				
Air surface temperature	July 6, 2012, air temperature	2012	Parameter-elevation Regressions on Independent Slopes Model (PRISM)	Raster, 4 k resolution
Air quality, $PM_{2.5}$	July 2012, average of $PM_{2.5}$ concentration (ug/m^3)	2012	Environmental Protection Agency (EPA) Air Quality Index (AQI)	Lat/long (extrapolated)
Air quality, ozone	July 2012, maximum recorded ozone level (ppb)	2012	EPA AQI	Lat/long (extrapolated)
Households without vehicle	Percentage of households without a vehicle	2007-2011	U.S. Census (ACS)	Block group
Developed land cover	Medium and high intensity classification	2006	National Land Cover Database (NLCD)	Raster, 30 m resolution
Nursing home	Nursing home bed count	2013	Division of Long Term Care	Lat/long

Results

Counties with the highest heat vulnerability classification in the HVI map are Menominee County and Milwaukee County. Areas of low heat vulnerability include much of the northern half of the state as well as a few southern counties.

In order to help identify the underlying factors contributing to an area's vulnerability index score, additional, independent analysis of each of the four categories of the index was completed. Again, data for the HVI were organized into four topical categories: population density, health factors, demographic and socioeconomic factors, and natural and built environment factors. Each category was mapped (Appendix B), following the same process as described in the Methods. The health factors and demographic/socioeconomic maps display the most spatial variation in heat vulnerability. Because seven of the eight health factors were available at the county level, the health factor category map displays heat vulnerability at the county level instead of the block group level. The category maps show how population density does not have spatial variation in terms of heat vulnerability since most of the map except for Milwaukee County is categorized as low vulnerability. Similarly, the natural and built environment category map shows less spatial variability in the index.

Discussion

Strengths

By mapping at a state and county level, the heat vulnerability index may be used to identify census blocks where the residents are most vulnerable to heat-related health outcomes. Adaptation and prevention strategies may then be targeted to those at-risk areas. Specific messages may be targeted to the residents within those communities, and existing social support networks may be used to assist with identifying and protecting vulnerable neighbors. State, county, and municipal agencies may use the HVI maps to ensure that resources are provided in the areas deemed most vulnerable and that protective strategies, such as opening cooling shelters, are located where they are most needed.

By analyzing the four categories within the HVI, factors that are driving increased vulnerability become more clear. For example, for Menominee and Jackson Counties, it appears that demographic and socioeconomic factors and health factors notably increase vulnerability. Ethnic variation and lower incomes are especially indicative of higher heat risk, as evidenced by the high vulnerability in areas with large non-white populations and locations with lower household income levels. Conversely, areas in the northern and western parts of the state, which have lower populations and more undeveloped green space, appear to offer a protective factor for the residents living there.

Limitations

While the analysis conducted in this study did not weight the variables, additional studies using similar methods may wish to consider this option. A literature review completed during this project was not able to identify a strong methodology for effectively weighting variables, so the weighting option was rejected. However, as noted above, the health and demographic/socioeconomic variables appear to play a large role in determining vulnerability to heat-related outcomes. Additional review of new and future HVI studies may further clarify weighting methods in future analyses.

This study did not run a regression analysis to attempt to determine which variables contributed to the most variability. Again, future heat vulnerability indices may consider this analysis to further clarify the driving forces behind increased vulnerability.

Our analysis was limited by data availability; for example, air conditioning is a known protective factor for heat-related mortality, but we did not have access to these data. Another potential limitation is the differing levels of geography of the variables. In particular, the county-level specificity of the health variables is quite broad, so it does not reflect sub-county variation within a health factor. Furthermore, the HVI health factors from the Behavioral Risk Factor Surveillance System were not age-adjusted, potentially introducing confounding caused by age.

Anyone using this Wisconsin Heat Vulnerability Index as a tool for prevention and preparedness planning must be aware that this is a relative index and does not measure or indicate absolute vulnerability. However, as a visual representation of potential heat vulnerability, it provides a useful and engaging way to transfer knowledge of the spatial distribution of vulnerable populations to both professionals and the general public.

Recommendations

The effects of extreme weather events may lead to many significant public health impacts. The ability of state, county, and municipal agencies to identify, plan for, and respond to these events will lead to increased resiliency within our communities. Adaptation strategies must be aligned with current scientific knowledge, and information must be shared with key stakeholders and partners. The transfer of this knowledge in a meaningful way will prepare residents to adapt to and cope with anticipated future events.

Statistical analysis of the factors included in this Wisconsin Heat Vulnerability Index, such as factor analysis and multivariate regression, may lead to a better understanding of the risk factors and may identify gaps in our existing support structures. Social factors in this HVI clearly indicate that ethnicity, social disparity, and low income play a part in poor health outcomes. Similarly, population density and lack of green space contribute to increased vulnerability. Planning efforts at the local level, which are flexible and built upon partnerships with faith organizations, neighborhood associations, civic organizations, and at-risk population service providers, will be necessary to reduce heat-related health outcomes, eliminate the high vulnerability drivers, and initiate and build local environmental strategies to reduce the impact of extreme heat on Wisconsin residents and visitors.

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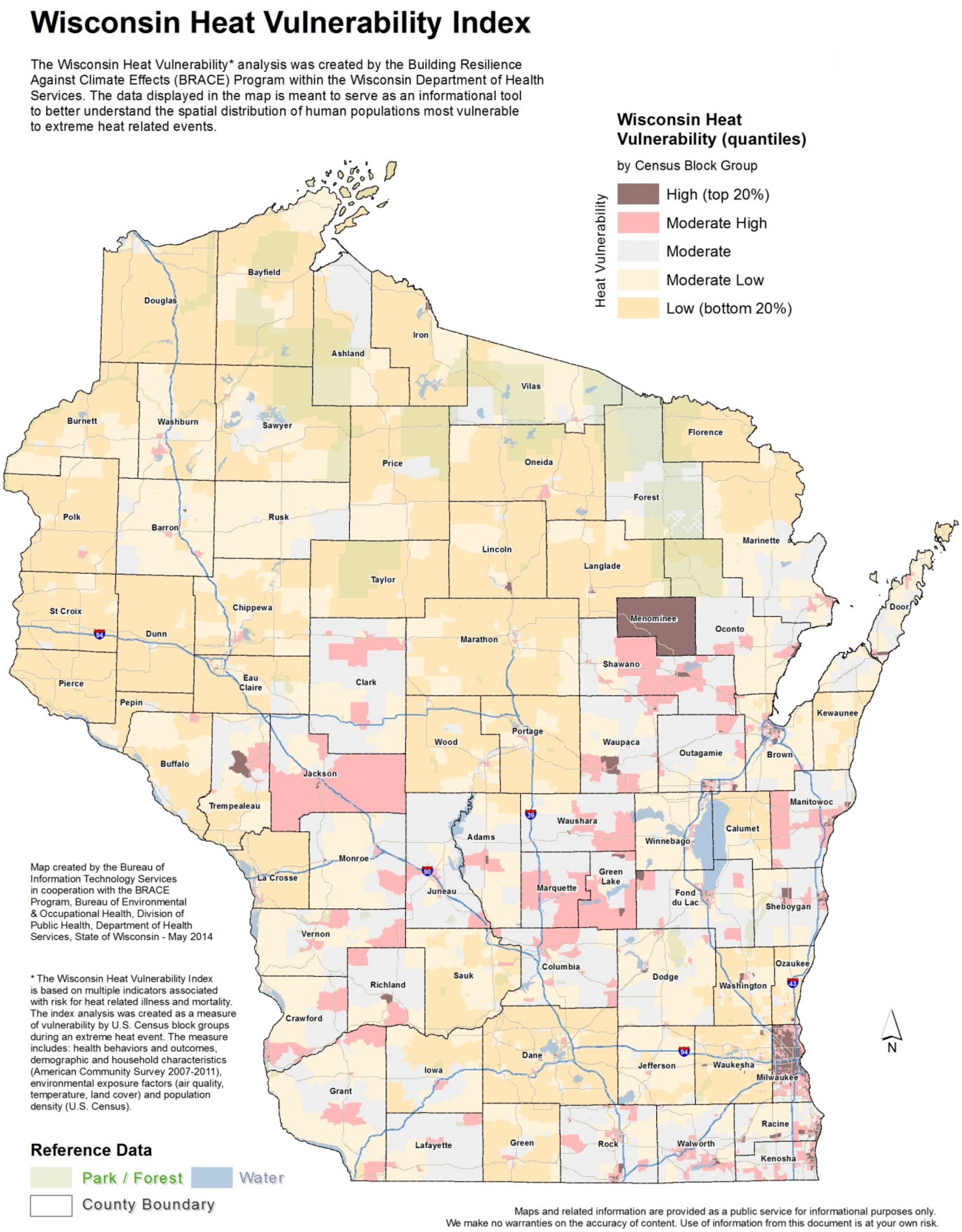
Appendix A



Wisconsin Heat Vulnerability Index
The Wisconsin Heat Vulnerability* analysis was created by the Building Resilience Against Climate Effects (BRACE) Program within the Wisconsin Department of Health Services. The data displayed in the map is meant to serve as an informational tool to better understand the spatial distribution of human populations most vulnerable to extreme heat related events.
Wisconsin Heat Vulnerability (quantiles)
by Census Block Group
Heat Vulnerability
High (top 20%)
Moderate High
Moderate
Moderate Low
Low (bottom 20%)
Bayfield
Douglas
Iron
Ashland
Vilas
Burnett
Washburn
Sawyer
Florence
Price
Oneida
Forest
Polk
Barron
Rusk
Marinette
Lincoln
Langlade
Taylor
St Croix
Chippewa
Menominee
Door
Dunn
Marathon
Oconto
Shawano
Pierce
Eau Claire
Clark
Pepin
Kewaunee
Portage
Wood
Waupaca
Outagamie
Brown
Buffalo
Jackson
Trempealeau
Manitowoc
Waushara
Adams
Calumet
Winnebago
Monroe
La Crosse
Green Lake
Marquette
Juneau
Fond du Lac
Sheboygan
Vernon
Columbia
Ozaukee
Sauk
Dodge
Richland
Washington
Crawford
Dane
Jefferson
Waukesha
Iowa
Milwaukee
Grant
Racine
Lafayette
Green
Rock
Walworth
Kenosha
N
Map created by the Bureau of Information Technology Services in cooperation with the BRACE Program, Bureau of Environmental & Occupational Health, Division of Public Health, Department of Health Services, State of Wisconsin - May 2014
* The Wisconsin Heat Vulnerability Index is based on multiple indicators associated with risk for heat related illness and mortality. The index analysis was created as a measure of vulnerability by U.S. Census block groups during an extreme heat event. The measure includes: health behaviors and outcomes, demographic and household characteristics (American Community Survey 2007-2011), environmental exposure factors (air quality, temperature, land cover) and population density (U.S. Census).
Reference Data
Park / Forest
Water
County Boundary
Maps and related information are provided as a public service for informational purposes only.
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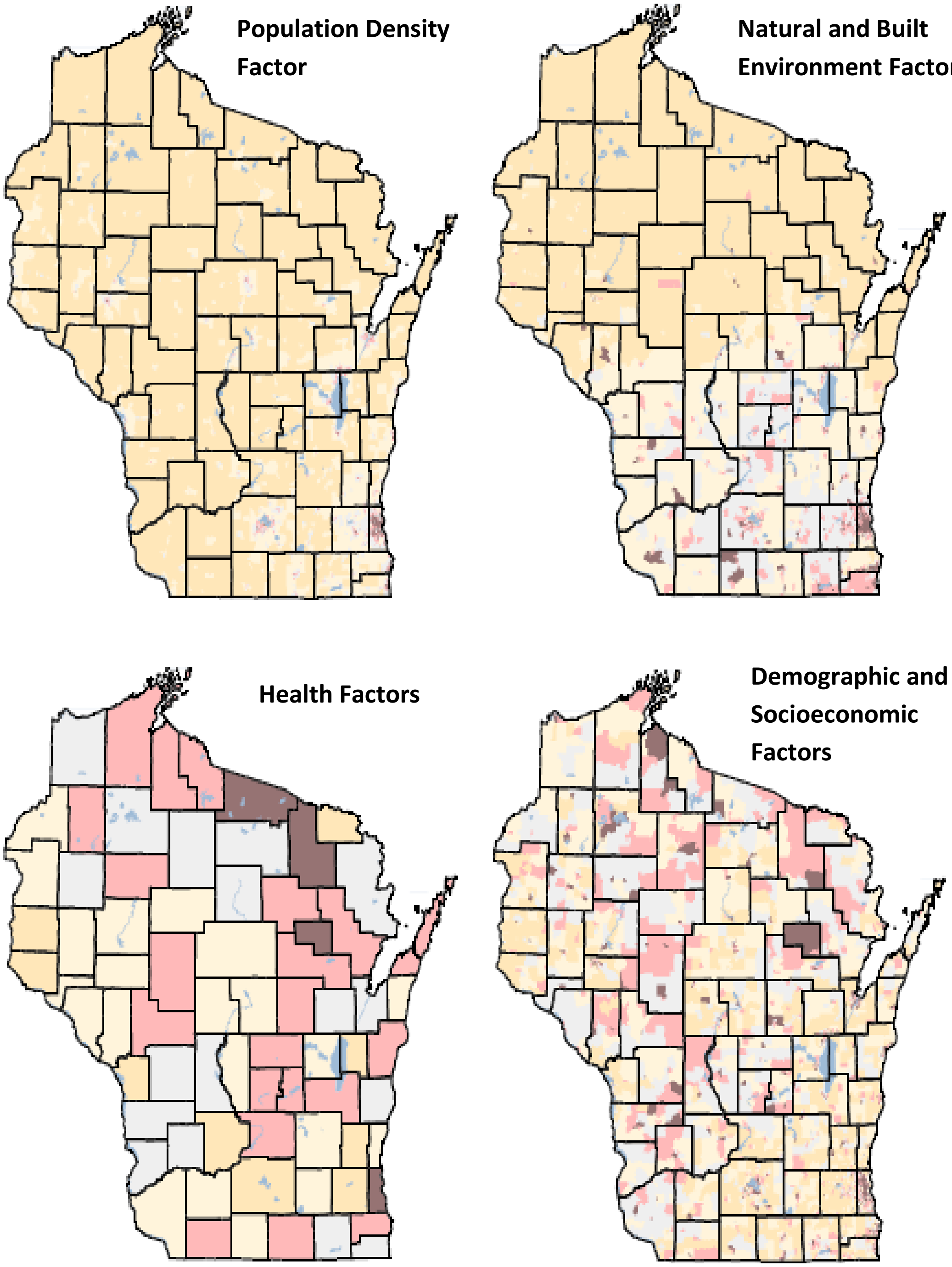
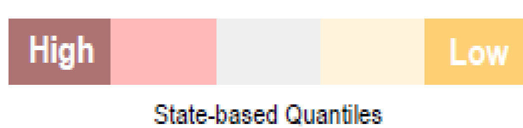
Appendix B: Wisconsin Heat Vulnerability Index Factor Categories





Map created by the Bureau of Information Technology Services in cooperation with the BRACE Program, Bureau of Environmental and Occupational Health, Division of Public Health, Department of Health Services, State of Wisconsin - May 2014