

# Vulnerability and Climate Change Adaptation Planning: Heat and Floods in Portland, Oregon



*Photo credit: William Woodward, <http://www.wheretowillie.com>*

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## Executive Summary

Climate change is not just a problem for polar bears. The City of Portland's 2014 Climate Risks and Vulnerabilities Assessment identifies a list of local hazards that climate change will exacerbate; from floods and heat-related health problems to landslides and food insecurity. While these dangers affect all residents, the distribution of risks and harms is far from equal. Floods, wildfires, landslides and (to a lesser extent) extreme heat events all have geographically concentrated impacts. Elderly people and children, single parents, people living alone, people of low socio-economic status (Low SES) and communities of color are often especially vulnerable to hazards and less likely to have access to the resources needed to adapt to damaging events. The City's 2015 Climate Action Plan emphasizes the need for greater understanding of who, where and how future climate hazards will impact in Portland.

This project analyzes the intersections between climate vulnerability and resilience in Portland. We choose to focus on two climate hazards, extreme heat events and flooding, that will impact a diversity of areas around the city. We analyze vulnerability to these hazards by creating a Social Vulnerability Index (SoVI) to map the geographic distribution of vulnerable populations. To analyze resilience, we map the geographic distributions of food, transit, water and green space access and identify neighborhoods of concern.

Our findings reveal that many areas of the city with high concentrations of climate hazards also have high concentrations of vulnerable populations and low access to resilience-building amenities. Areas of concern we identify include North Portland along the Columbia River, Southeast Portland east of 82<sup>nd</sup> Avenue, and communities alongside major roadways such as Interstate 205, 82<sup>nd</sup> Avenue, Foster Road and Sandy Boulevard. Parts of the Central Eastside along the Willamette River, while more resilient overall, have high concentrations of specific vulnerabilities.

Infrastructure issues such as low walkability and limited transit service mean that crucial amenity access in our identified areas of concern, already low, will be dramatically lower during a flood or extreme heat event. Our recommendations for needed improvements the city should provide include sidewalks, street trees, water fountains, increased bus service and support for locally-owned food access sites such as grocery stores, community gardens and food pantries. Funding for these and other climate-resilience projects must focus on the neighborhoods where intersectional climate vulnerability is highest. We hope that this report will be a useful resource as the City and County ramp up their efforts to help residents prepare for and adapt to the challenges of climate change.



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## I. Introduction

The City of Portland and Multnomah County completed their most recent Climate Action Plan in 2015. This plan benefits from the completion of a comprehensive Risks and Vulnerabilities Assessment and corresponding Climate Preparation Strategy in 2014. Among the primary climate risks identified are drier summers with more high-heat days and warmer winters with the potential for more extreme precipitation and flooding events. The resulting city and county climate change preparation strategy highlights the importance of a coordinated effort to mitigate these dangers where possible while building adaptive resilience in the face of growing climatic instability.

Among the twelve *2030 Objectives* identified in the 2014 Risks and Vulnerabilities Assessment are several related to improving the city's capacity for identifying vulnerable areas and populations which climate preparedness programs should emphasize helping. Objective 9 calls for the city to "develop [emergency] response plans that minimize impacts on populations most vulnerable to heat and flooding." Objective 10 suggests that they "apply an equity lens to climate action efforts and where possible prioritize benefits to populations most vulnerable to the impacts of climate change" and "improve the understanding of local climate change impacts." In the Climate Preparation Strategy, Objective 10(d) specifies an urgent need to "develop maps, data resources and other tools to improve understanding of local climate change impacts, including disproportionate impacts to low-income populations and communities of color." In order to address this goal, this report displays figures and analyzes the consequences of the spatial distribution of risks, vulnerable people, and amenities in terms of climate adaptation planning.

The city government structure of Portland emphasizes neighborhoods as administrative units. Portland has over 95 neighborhood associations, organized into seven district coalitions (see Fig. 24, in the Appendix) which work with the Office of Neighborhood Involvement (ONI) on a variety of neighborhood-based livability and improvement projects (League of Women Voters of Portland Education Fund, 2006). The ONI has an annual budget of over \$7.8 million dollars, around a third of which it distributes via grants to Neighborhood Associations and District Coalitions (Office of Neighborhood Involvement, 2015). This report focuses on identifying risks and making recommendations at the neighborhood level in an attempt to aid the city in distributing resilience project funding to the areas and issues where it is most urgently needed.

## II. Overview of Relevant Literature

This report investigates heat and flooding as two climate hazards to which the city is particularly susceptible. Our research on community resilience lead us to identify a variety of demographic features, as well as three areas of urban amenities (food access, transportation, and green spaces) which are important in helping residents adapt to climate change. This section reviews the literature on each risk, characteristic, and amenity analyzed in the report.

### A. Hazards

#### *Urban Heat Island*

When vegetation is cleared and replaced by asphalt and cityscapes, the dark surfaces absorb solar radiation, causing temperatures to rise as compared to surrounding green spaces. This concentrated warming effect is known as an ‘urban heat island’ (UHI). During summer months, urban areas experience an average increase of 5°C as compared to nearby rural areas. The increase in electricity from air conditioning used to combat the heat further exacerbates the problem by increasing pollutant levels in the hottest places (Taha, 1997).

Urban heat islands do not have uniform effects over entire cities. Factors like roadway density, vegetation cover, and traffic patterns all affect how urban places feel the impacts of this localized heating effect (Imhoff et al., 2010). A 2008 study performed in Portland found that commercial and industrial areas were the hottest areas in the city. The effect was somewhat mitigated in the downtown area due to the ‘urban canyon effect’ as tall buildings block sunlight from reaching the ground (Hart, Melissa A., and David J. Sailor. 2009). The same 2008 study found that the most important factor affecting urban heat was canopy cover. The warmest places in the city were air masses surrounding major arterial roadways. For this reason, areas like Sandy Blvd, César Chávez and SE 82nd Ave are the most impacted by the UHI effect.

The urban heat island effect can have deleterious health effects, especially on people under the age of 15 or over the age of 65 (Tan et al, 2010). Mitigating urban heat island effects often involves increasing vegetation, especially canopy cover. Another effective strategy is taking steps to increase the albedo (a measure of surface reflectivity) of urban areas, potentially through incorporating light-colored building materials in new urban projects (Bertz, 1998). However, some actions which attempt to address urban heat island effects actually increase local production of air pollution, which would introduce other harms (Rosenfeld, 1993).

#### *Urban Flooding*

Flooding in urban areas can take several forms, including river floods and flash floods. In Portland, river flooding results from overflow of the Willamette, Columbia, Sandy, and Tualatin Rivers and Johnson Creek (City of Portland, 2014). The 100-year floodplain is one way to predict flooding, and describes the area that has a 1% chance of flooding each year, although this data is gathered without the changes caused by climate change in mind (FEMA, 2017). The 100-year floodplain for the city of Portland encompasses the areas bordering the rivers and the Johnson Creek Watershed area (see Fig. 2).



Urban flooding is different from other types of flooding because it occurs quickly and over a more localized area, making it particularly difficult to predict and manage (Ochoa-Rodriguez, 2017). Urban flooding is the “flooding of streets, underpasses, low lying areas, or storm drains” (NOAA). Urban flooding is a result of low surface area of soil which decreases the amount of water absorbed into the ground during rainfall. Paved areas do not absorb water, so the water is forced into drainage systems. During high intensity rain events, water can overwhelm or clog drainage systems and cause flooding in the surrounding area.

For our analysis of flood risk in Portland, we used both the Federal Emergency Management Agency (FEMA) 100-year floodplain and a contour map indicating low elevation. In our consideration of urban flooding, we consider the low elevation areas as an extension of the floodplain because these are the areas most susceptible to urban flooding. This inclusion allows for an analysis of flooding which doesn’t only follow the patterns of the 100 year floodplain, but also points out risks to come as climate change increases flood hazards. Following the recommendation of previous literature, we have chosen to focus on elevations at or below 33 feet above sea level (corresponding to 10 meters) because these areas are, on average, five times more likely to experience major flooding events (Kocornik-Mina, 2016).

Managing and predicting flooding in Portland becomes more challenging as the climate changes. Although climate models predict that Portland’s *total annual precipitation* is not predicted to change significantly, when and where that rain falls is likely to change (City of Portland, 2014). As the impacts of climate change intensify in the next several decades the city will likely experience more intense rain events, characterized by increased volume of rainfall in shorter amounts of time. Because intense rain events are the main force of urban flooding, it is likely that the city will see more drastic and higher frequency urban flooding.

Flooding vulnerability is exacerbated in high density areas (Porio, 2015, Ignacio et al., 2015). Many of Portland’s high density neighborhoods lie directly in the floodplain including downtown, the Pearl District, Southwest Waterfront and the neighborhoods of Hayden Island, Sellwood, and Lents (Logan, 2014). Consequences of urban flooding on the city population can be significant: case studies of other cities reveal how densely populated areas can be negatively impacted by urban flooding events. London, for example, has highly concentrated areas and infrastructure which leads to greater flooding and greater impacts of flooding. A growing population combined with the impacts of climate change will increase both flooding, and the harms caused by floods (Ochoa-Rodriguez, 2017). As Portland continues to grow in population, forming an understanding of the distribution of flood risks and impacts will allow climate adaptation planning to prioritize the most vulnerable communities.

## **B. Humans**

### ***Social Vulnerability Index***

*“Disaster marks the interface between an extreme physical phenomenon and a vulnerable human population. It is of paramount importance to recognize both of these elements. Without people there is no disaster.” (O’Keefe et al. 1976)*

A landmark study in 1976 (ibid) called attention to the intersection between physical vulnerability and social vulnerability. Since then, researchers have focused not only on the distribution of physical hazards, but also on inequalities in the populations experiencing hazards. They have developed several quantification schemes which focus on understanding the combination of social factors which make a community particularly vulnerable to environmental hazards.

Cutter et al. 2003 developed the first widely-used quantifiable metric for social vulnerability: the Social Vulnerability Index (SoVI). This model used US Census data to perform factor analysis, eventually identifying 11 factors which best signify vulnerability: socioeconomic status, age, density of the built environment, dependence on a single economic sector, housing availability, race (African-American), ethnicity (Latino, Native American or Asian), occupation, and infrastructure dependence. Since Cutter et al. 2003 other scholars have refined and redefined the SoVI, but all new models follow the same general principle: when placed in concert with biophysical vulnerability, SoVI can be a strong indicator for overall hazard vulnerability. Local SoVIs help policy-makers locate high-risk communities and prioritize these communities in disaster response planning.

Community resilience is another metric which is paramount to consider when assessing the risk a hazard poses to a community (Sherreib et al. 2010). While vulnerability is defined *as how susceptible a community is to harm*, resilience is the capacity of the community to absorb harm and recover. Bergstrand et al. found that social vulnerability typically correlates with low resilience. However, even in instances with high correlation the distinction between vulnerability and resilience is important because the two demand different policy solutions and may utilize different resources.

Following the methodology of previous research (Cutter et al 2003), we created a Social Vulnerability Index (SoVI) for Portland. We chose 15 variables that were most consistent across the literature and publicly available with US Census data. (See Table A1 in the Appendix for our full list of indicators, our reasons for choosing them, and our sources.) In the absence of literature consensus about how to weight the variables, we used the approach of Cutter et al. and gave each variable a weight of +/- 1 (Cutter et al. 2013), making our SoVI is an equally-weighted aggregate of our 15 variables.

Our Portland SoVI is a first step in understanding the distribution of vulnerable populations in Portland. Because our data selection process was top-down, based on theoretical analysis of the literature, we feel that future studies could strengthen the validity of our SoVI with a statistical analysis of the chosen variables, e.g. to check for correlation or omitted variables. This report presents a preliminary survey of social vulnerability in Portland, drawing attention to the importance of this issue in the context of climate change in the region.

## **C. Impacts**

### ***Cool Green Spaces***

Vegetation and green spaces are crucial amenities when it comes to climate planning in two ways. First, plant life can be susceptible to climatic changes such as increased heat or dryness, as well as to increased risk for hazards such as flooding (Kleerekoper, van Esch, and Salcedo 2012). Planning urban green spaces to ensure their adaptability to a warmer climate can help ensure that these amenities will not degrade in the face of climate change. Second, green spaces are also a resource which can help people adapt to new climates. Vegetation, especially tall trees, has a well-documented ability to reduce the temperature of the surrounding environment (Önder and Akay 2014; Maimaitiyiming et al. 2014). Climate change adaptation efforts should thus pay attention to the both the distribution and accessibility of vegetation, such as street trees and parks.

Parks play an important role in cooling urban areas through temperature decreases (Kleerekoper, van Esch, and Salcedo 2012), and by improving the perceived heat comfort and well-being of residents (Lafortezza et al. 2009; Giannakis et al. 2016). Parks also confer a range of social benefits, including individual psychological and spiritual benefits (Svendsen, Campbell, and McMillen 2016) as well as strengthening social ties within communities (Kaźmierczak 2013). One study conducted in Portland showed that residents who reported both park proximity and park usage tended to feel that they lived in “socially healthy communities” more so than residents who could not or did not use parks (Tynon 2013). This correlation, however, could reveal causation not from parks to social health, but rather that parks in Portland have been mainly constructed in communities which were already socially healthy. Studies conducted in other cities in the US have noted that greater park usage and access is generally correlated with white and affluent residents (Wolch, Byrne, and Newell 2014). Correcting this inequality, however, is not as simple as placing more parks in low income communities, as green spaces planned without the input of residents have also lead to gentrification (Checker 2011). So while parks have the potential to help residents adapt to climate change, they are often distributed inequitably and in a manner that is difficult to address.

Although street trees do not often compose a majority of vegetation in an urban area (Heynen, Perkins, and Roy 2006), the city has the ability to install and regulate these trees, making them a key way for the city to regulate vegetation outside of parks. The presence of one vegetated area, such as a garden or tall tree can lower ambient temperature by 6°C on the hottest days (Oliveira, Andrade, and Vaz 2011). The distribution of street trees can also reveal problems in urban planning, as studies of other cities have shown that low income communities and communities of color often live in neighborhoods with fewer street trees (Heynen, Perkins, and Roy 2006). This finding is in agreement with other studies discussing the disproportionate number of people of color who live in areas at high risk for urban heat island effects (Jesdale, Morello-Frosch, and Cushing 2013). Urban planning with a goal of increasing vegetation can also help with mitigating climate change, as 5-10% of electricity use in downtown areas can be attributed to cooling made necessary by the urban heat island effect (Staley 2015). Increasing

plant life generally, and street trees in particular, has the possibility to both help mitigate climate change through reduced electricity dependence and help people adapt to hotter temperatures by lessening the urban heat island effect.

While public green spaces are one valuable way to lessen the adverse impacts of the urban heat island effect, another important public amenity to help people adapt to heat is the presence of drinking fountains. Adaptation to urban heat island effects and sudden heatwaves requires access to safe drinking water, and drinking fountains can play an important role in that access, especially for homeless populations (Lowe, Ebi, and Forsberg 2011; Tarasuk et al. 2009). A study on walking habits in urban areas in Australia also showed that the greater presence of amenities such as drinking fountains increased walking activity by residents (Giles-Corti et al. 2005). Therefore, increasing water fountain access would help improve the walkability of neighborhoods as well as help manage heat increases, both of which could contribute to climate change mitigation as more residents walk.

Adaptation to the heat impacts of climate change will be easier for residents who have access to parks and other public green spaces. The cooling benefits of such areas will likely become increasingly important to help mitigate the urban heat island effect.

### ***Non-Car Transit***

Transportation is essential for individuals to access everyday resources and amenities. Extreme weather and environmental hazards as a result of global warming will place additional demands on transportation infrastructure (Stamos et al. 2015). There are many uncertainties surrounding the ultimate effects of climate change, which cause difficulties for transportation infrastructure planning (Wall et al. 2015). These uncertainties necessitate long-range planning that is adaptive and resilient to changing circumstances in order to handle emerging risks. In this report, we consider the potential impacts of climate change on active transportation and public transit and the role of the city in reducing these climate harms. Walking and bicycling are defined as active transportation, while public transportation is a form of passive transportation.

More than 80% of all trips occur close to one's home within reasonable walking distances (Saelens et al. 2003). Most of these trips are taken by car; however, the creation of walkable neighborhoods could promote access to resources and amenities without requiring individual car travel. Neighborhood environments that are highly walkable increase the frequency of active transportation, while areas without developed walkable infrastructure discourage walking as a primary means of transportation (Saelens et al. 2003). The pedestrian network is an important consideration when planning for accessible communities and response to climate change.

While there are many benefits of active transportation as a means of neighborhood connectivity, these benefits are often not equally distributed throughout the community. Areas with low socioeconomic status (SES) residents are less likely to have active transit projects implemented (Cradock et al. 2009). Low SES individuals and people of color are predominantly more reliant on walking and bicycling, but often low SES communities lack the infrastructure supporting these modes of transportation. Low SES communities will be more negatively affected

by increases in temperature and urban heat islands due to global warming (Karner et al. 2015). Currently, few transportation plans consider equity when proposing future development (Lee et al. 2017). In contrast, Portland’s Transportation System Plan for 2035 does include equitable access to transportation as a goal (City of Portland, 2016). The city should work toward this goal when developing and improving climate-adaptive active transportation infrastructure such as sidewalks and bikeable streets.

Public transportation allows people to travel outside of areas that are within walking or biking distance. Additionally, use of public transportation increases physical activity (Saelens et al. 2014). Public transportation, however, does not offer the same level of connectivity as car transportation. Vulnerable populations may not have access to transit within a reasonable walking distance from their homes. Multiple transportation options encourage individuals to reduce car travel (Beuhler et al. 2014). Development of highly interconnected, multimodal transportation will reduce car usage and increase transport accessibility, for if a resident cannot make use of transportation option, a multimodal system will provide several others.

Development of resilient public transportation infrastructure will help cities mitigate and adapt to the challenges posed by climate change. Reducing reliance on cars is an important step in climate change mitigation, as vehicle use is a major source of greenhouse gas emissions. Climate adaptation plans must consider the ease and accessibility of transportation in order to help residents continue their daily activities in conditions of climate change. Transportation amenities, however, are also susceptible to the impacts of climate change. Studies show that weather conditions impact transportation choices, and in conditions of extreme heat options like bicycling, walking, and even waiting for a bus will become less comfortable (Hofman and O’Mahony 2005, Nankervis, 1999). In this report, we consider pedestrian districts, bus lines, MAX lines, bike streets, bike lanes, and sidewalk density in calculating the effects of climate hazards on transportation in Portland.

### ***Food Access***

Climate change will create unpredictable and potentially significant disruptions in global food production and distribution networks. The City of Portland’s 2014 Climate Risks and Vulnerabilities Assessment found a need for more research on the local impacts of food system disruption and identified “addressing existing issues around hunger and food insecurity” as an important way of building climate resilience (City of Portland, 2014).

Drought and natural disasters may reduce the availability of imported produce, raising local food prices (Burke and Lobell, 2010). The impacts of any price increases will fall most heavily on low-income communities, especially those who already fall within areas that could be classified as “food deserts”. The USDA (2009) defines food deserts as areas where access to healthy and affordable food is severely limited, either because of a lack of outlets selling affordable food or outlets having prices that are unaffordable for a high percentage of local residents. The USDA identifies food deserts by locating areas where over 40% of the population makes an income at or below 200% of the federal poverty level and lives over half a mile from a supermarket without access to a personal vehicle. While access to supermarkets and grocery stores is an important

indicator of overall access to healthy produce, this report also considers access to alternative sources such as farmers markets, food pantries and community gardens.

While prices at farmers' markets are sometimes higher than those at local grocery stores, their products are often more nutritious and, because of their emphasis of organic and local produce, more sustainably grown and distributed (Schupp, 2016). Farmers markets that accept food stamps have been shown to increase produce access and consumption for low-income communities, helping mitigate the food desert problem (Jones and Bhatia, 2011). Most Portland farmers markets currently accept WIC and SNAP credits (Partners for a Hunger-Free Oregon, 2017), making farmers markets a potentially important tool for improving food security. Presently, farmers markets tend to cluster in affluent and white neighborhoods (Schupp, 2016). This trend presents an equity issue, as the food deserts where farmers markets are most needed tend to be found in low-SES communities and communities of color (USDA, 2009, Morales, 2011). Ensuring that farmers' markets are an accessible, affordable and culturally appropriate option for these communities is a difficult and important challenge.

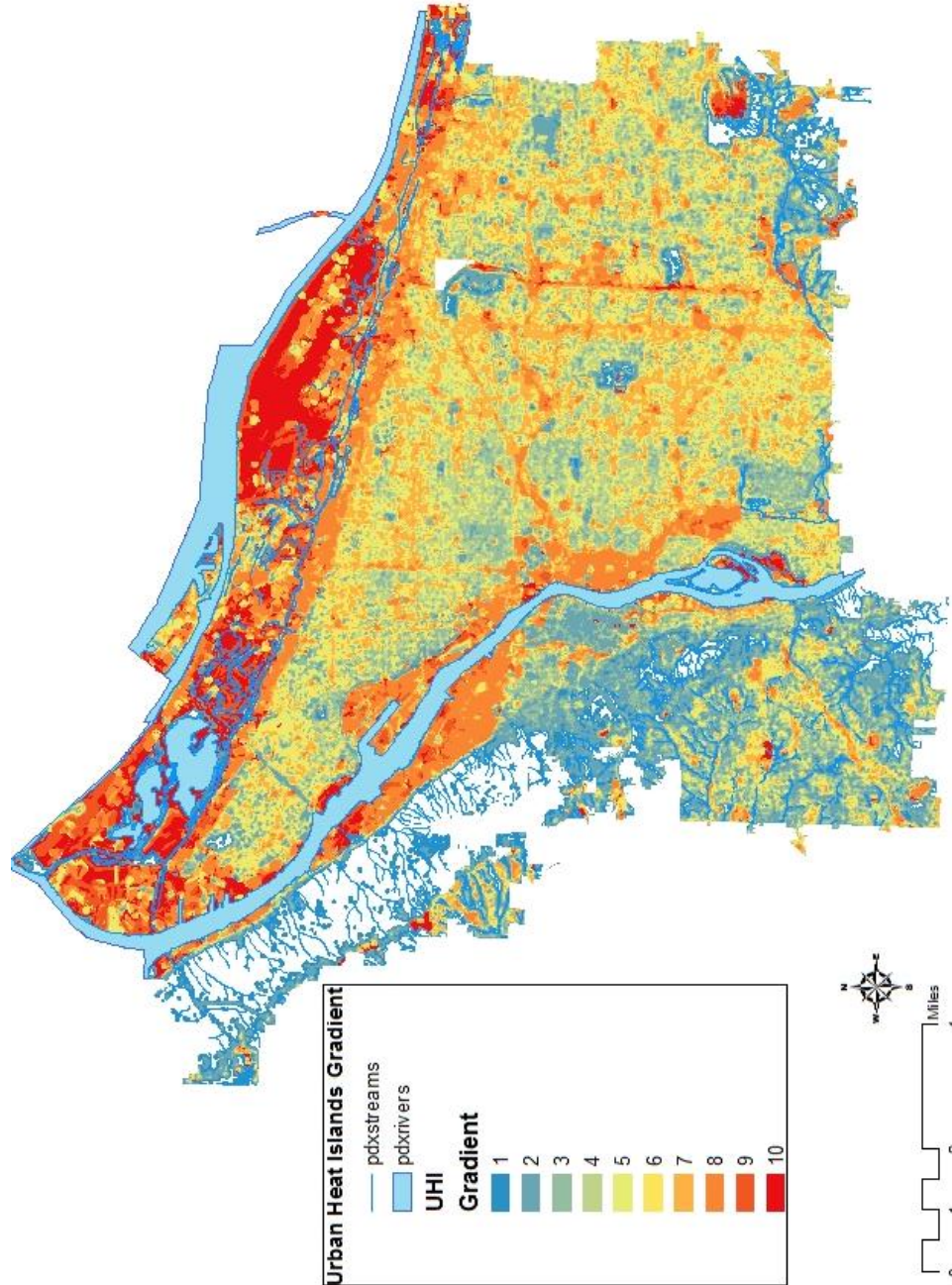
A growing movement advocates expanding definitions of community food security from simple access and affordability to include the idea of "food sovereignty." According to this paradigm, food security (especially in low-SES communities and communities of color) can only be achieved when communities control their own local sources of food production (Hamm and Bellows, 2003, Mares and Peña, 2011). The City of Portland's 2015 Climate Action Plan partly addressed this by calling for an integrated strategy to support a "community-based" food system (Objective 12) (City of Portland, 2015).

An important strategy for building community-based food systems is supporting community gardens. Portland already has 50 recognized community gardens supported by Portland Parks and Recreation. Only 5 have unused plots as of April 2017 (Portland Parks and Recreation website), indicating demand for more locations. Community gardens help build community-based food systems by creating spaces where neighbors can come together to grow their own nutritious organic produce. Local government support of community gardens has been shown to be effective at improving food access equity in cities around the country (Hou, et al., 2009). Community gardens also provide important flood hazard mitigation by offering pervious surfaces that absorb stormwater runoff, with gardens that use raised beds shown to be particularly effective (Gittleman et al, 2017). However, community gardens struggles when local residents are not provided with the training and resources needed to take advantage of gardens in their neighborhoods (Gregory, et al., 2016). As climate change will bring on increasingly wet winters and dry summers (City of Portland, 2014), educating users in cultivating more resilient plants must be a priority in community garden management. In many cities, problems have been identified with community garden plots being quickly filled by high-income and white residents, making them effectively inaccessible for low-SES people of color (Guthman, 2011). A final consideration regarding community gardens is ensuring their long-term stability, which in many growing cities has been threatened as garden plots on previously unused land are displaced by new housing development (Hou, et al., 2009).

Among the community agriculture projects which have been the most successful in improving food access equity are those whose production is directly tied to food banks, food pantries or other supplementary food sites which primarily serve low-SES community members (Vitiello, et al., 2015). Because supplementary food sites are a primary food procurement site for many individuals isolated from grocery stores, farmers' markets and community gardens, they are an essential missing piece in the food equity puzzle. As Feeding America's disaster relief work has shown, supplementary food sites are also potentially important hubs for emergency supply distribution in the wake of an extreme flood (News Bites US, 2014). Unfortunately, because of their necessary reliance on donations and cheap non perishables, food banks in many cities have been shown to provide inadequate nutrition to their clients (Irwin, et al., 2007). This issue can be mitigated by linking food banks to community gardens. One promising example is Portland's Produce for People Program, which already includes gardeners at over 42 community garden locations donating produce to over 24 supplementary food sites (Portland Parks & Recreation website).

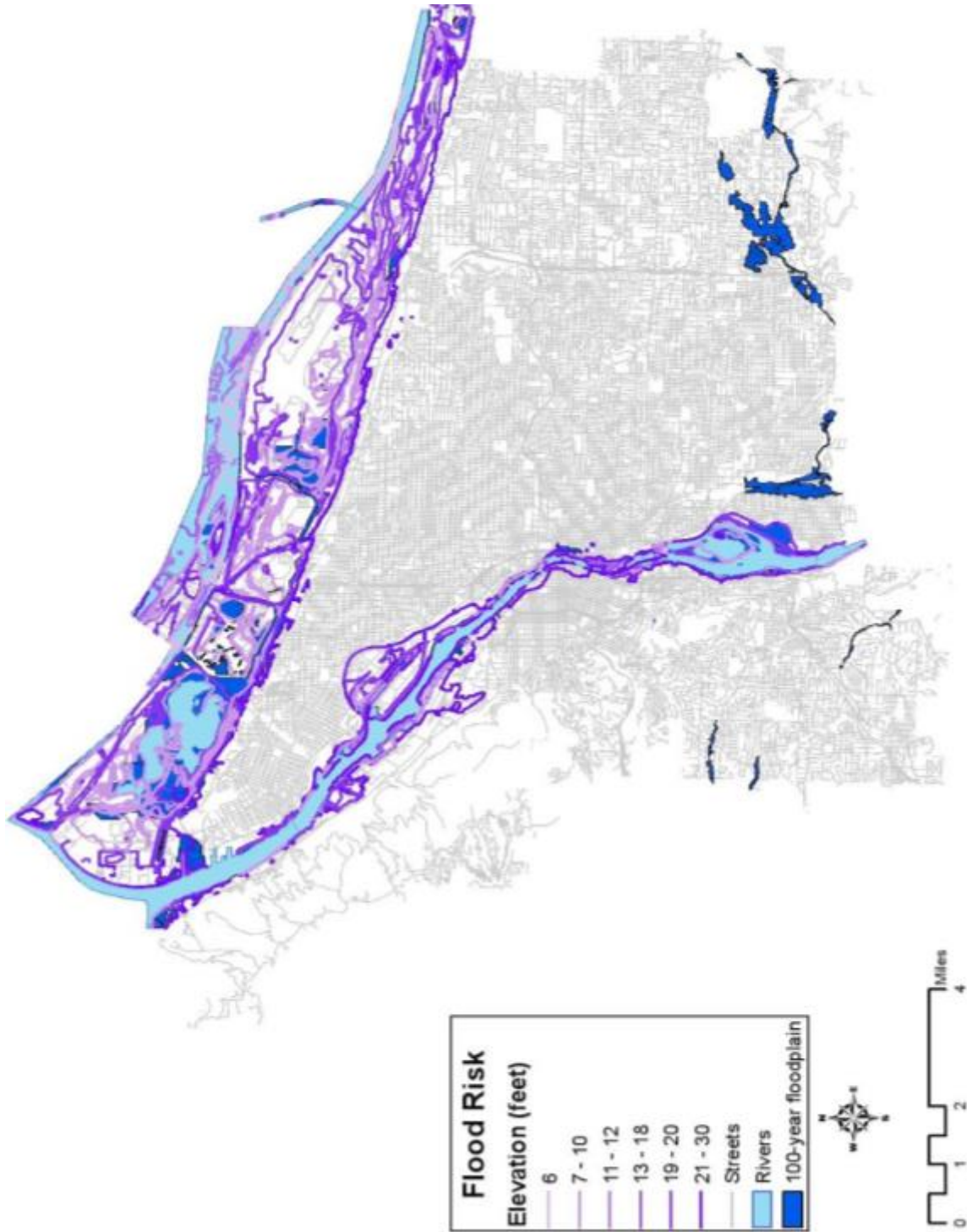
### Vulnerability Core Maps

The figures in this section introduce the climate hazards and Social Vulnerability Index that we use to address climate vulnerability in Portland.

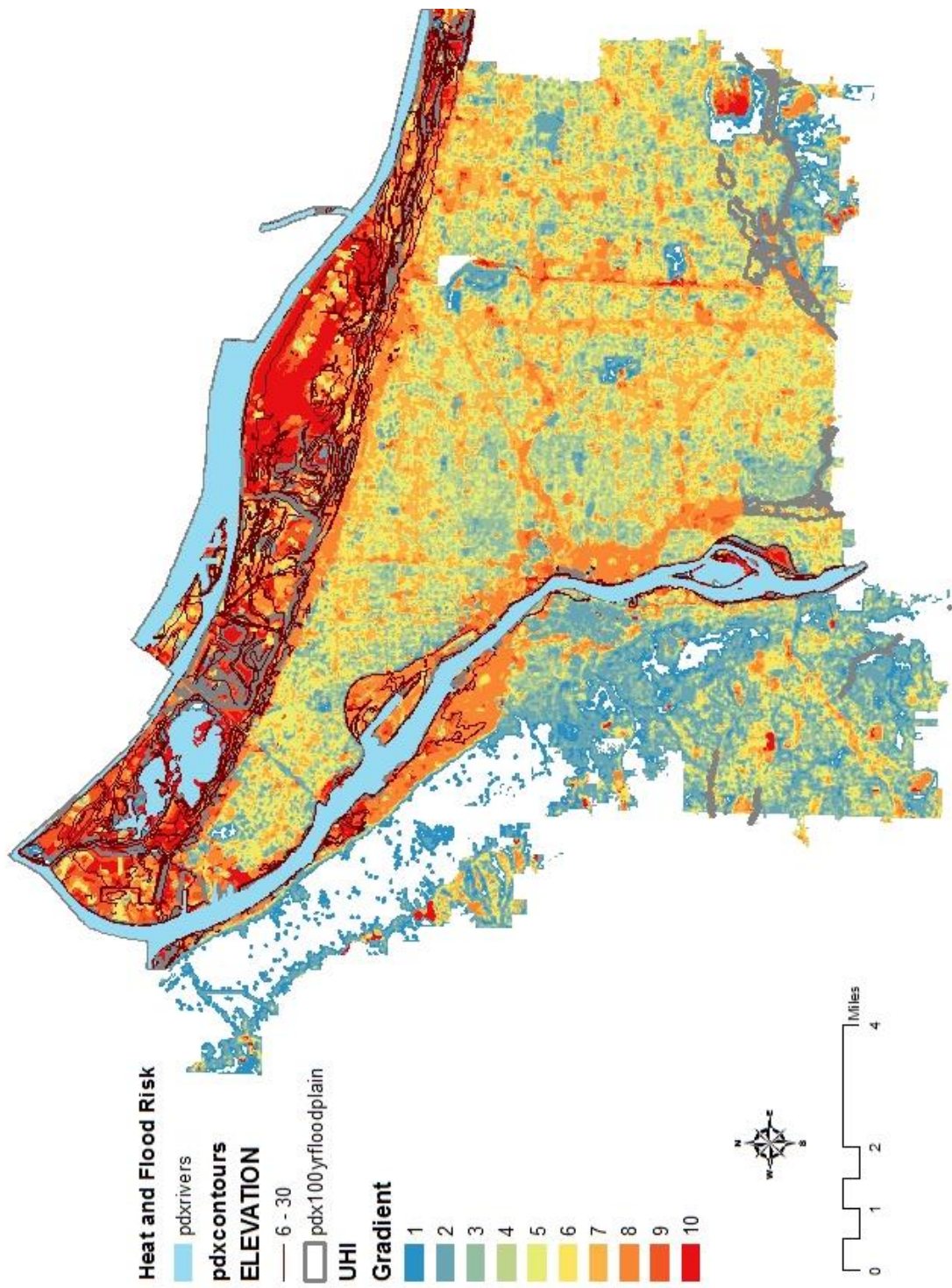


**Figure 1: Urban Heat Island Effect.** Urban Heat Island (UHI) effects represented along a scale of 1 to 10 for the city of Portland, using a gradient of the coolest (dark blue) to warmest (bright red) places in Portland. Gradient represents a 5°F range, deviating from the median regional temperature, from -0.5°F to 4.6°F. Creator credit: Hunter Wise and Anna Miller. Contributor credit: PSU Sustaining Urban Places Research Lab, Portland Bureau of Planning and Sustainability.

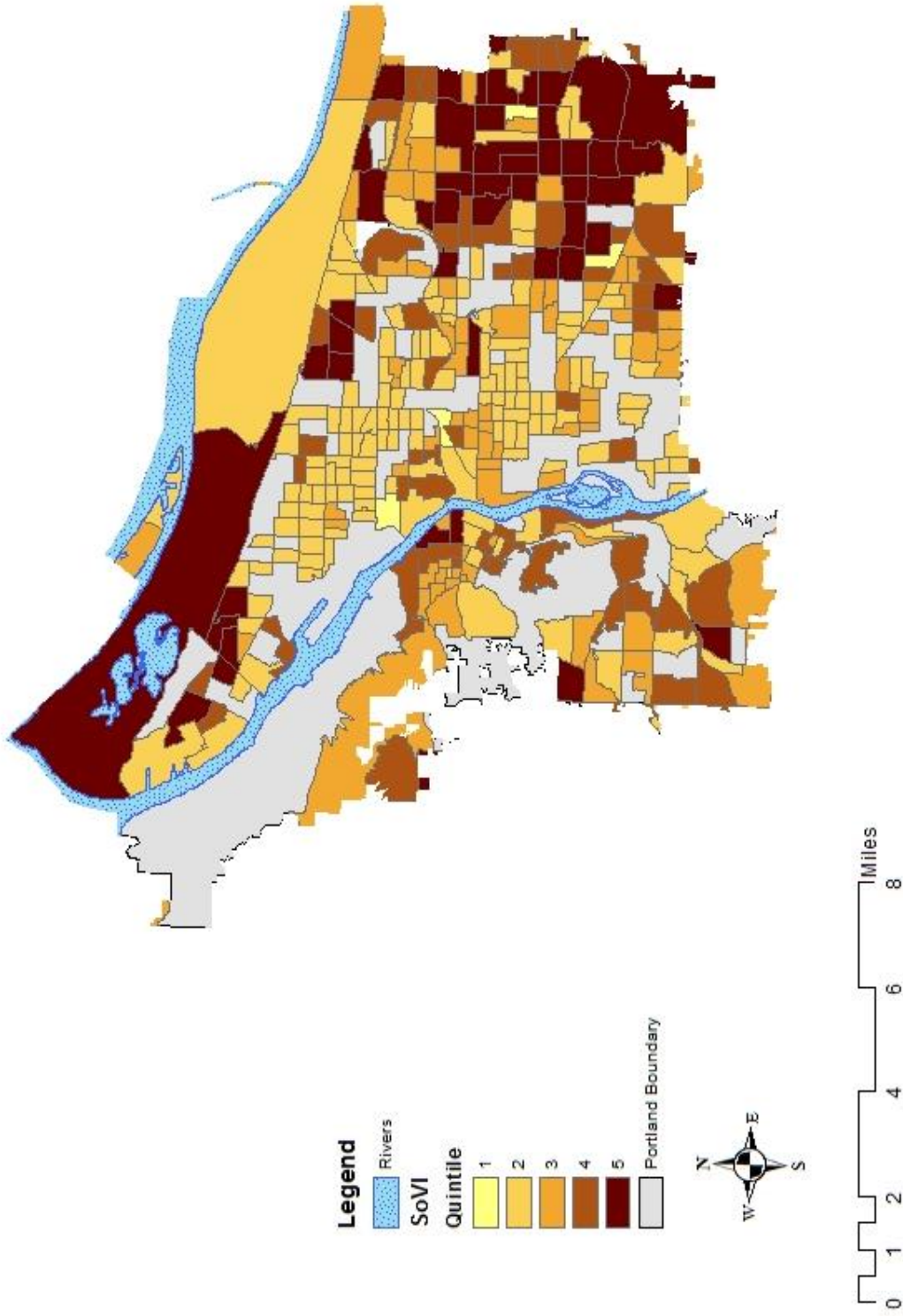




**Figure 2: Flood Risk Areas.** Risk determined by the FEMA 100-year floodplain (dark blue) and elevation less than 30 feet (purple scale). Creator credit: Anna Miller and Hunter Wise. Data sources: PortlandMaps.com, Portland Bureau of Planning and Sustainability, 2007 LiDAR data.



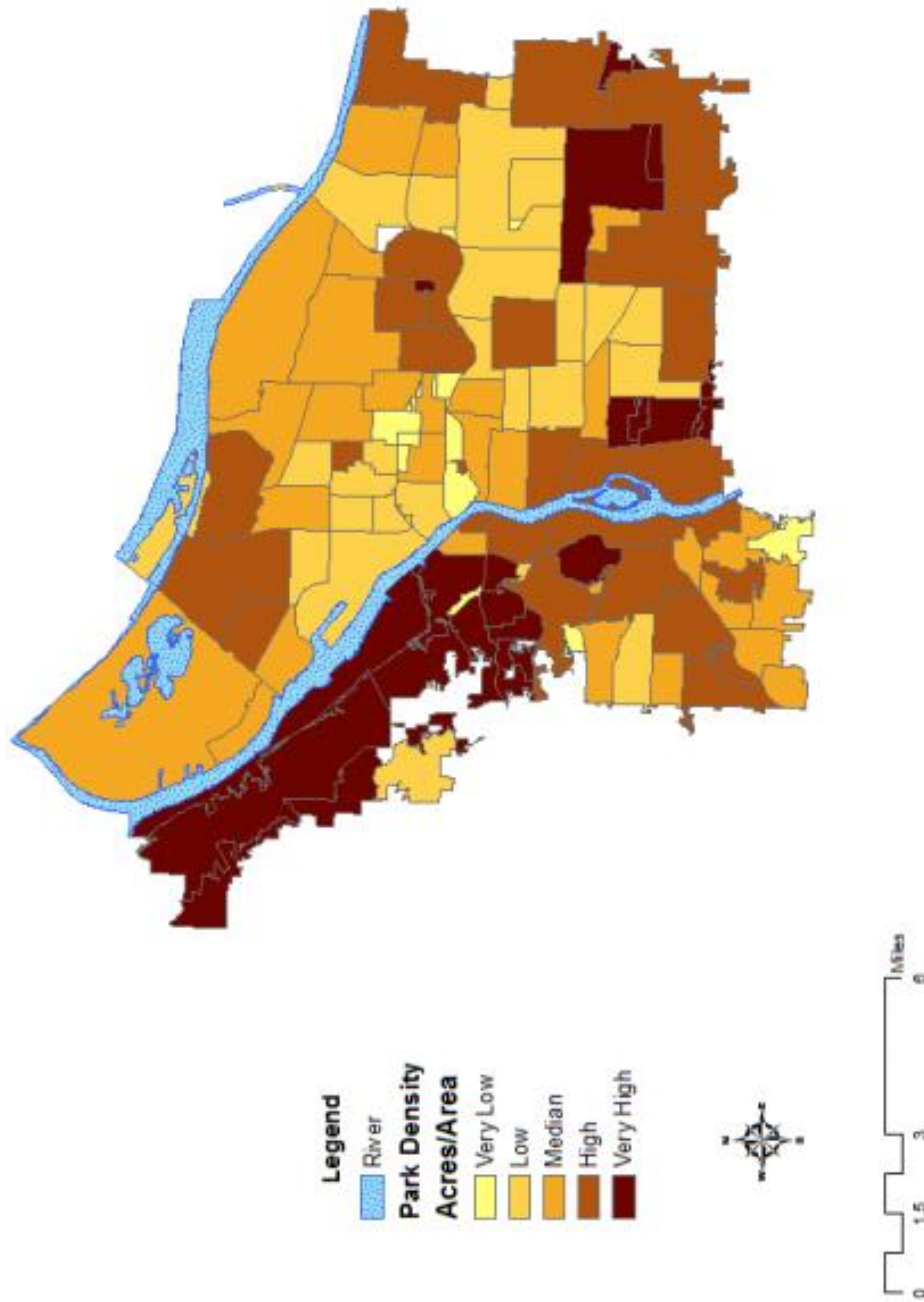
**Figure 3: Heat and Flood Risk.** Urban Heat Island (UHI) data overlaid with flood risk data, where areas of flood risk are identified as (1) included in the FEMA 100-year floodplain or (2) elevation less than 33 feet above sea level. Portland neighborhood outlines are also included. The Urban Heat Island data is shown as a gradient from -0.5F (blue) to 4.6F (red), representing variation from the median regional temperature. The 100-year floodplain is overlaid with a gray outline and all places with an elevation of less than 30 feet (10 meters) are outlined in dark red. Creator credit: Anna Miller and Hunter Wise. Data sources:PortlandMaps.com, Portland Bureau of Planning and Sustainability, PSU Sustaining Urban Places Research Lab.



**Figure 4: Social Vulnerability Index.** Our index of social vulnerability (SoVI) is an aggregate of fifteen vulnerability factors (see Table 1). For each vulnerability factor, only the highest (or lowest) quintile of census tracts was used. (For example the lowest median income tracts were selected, while the highest “non-white” tracts were selected.) These top 15 quintile layers were equally weighted and then added to generate a total vulnerability score of 0-15 per census tract. For analysis, the data was broken into quintiles again: 1-5, least to most vulnerable. Gray areas indicate zero vulnerability. For subsequent data analysis, we identified qQuintile 5 as most relevant. Note: data is not normalized by population or size of tract. Creator credit: Sandy Witte, Maggie Davies and Emily Clark. Data Source: US Census ACS 2015

### *Amenities and Resilience*

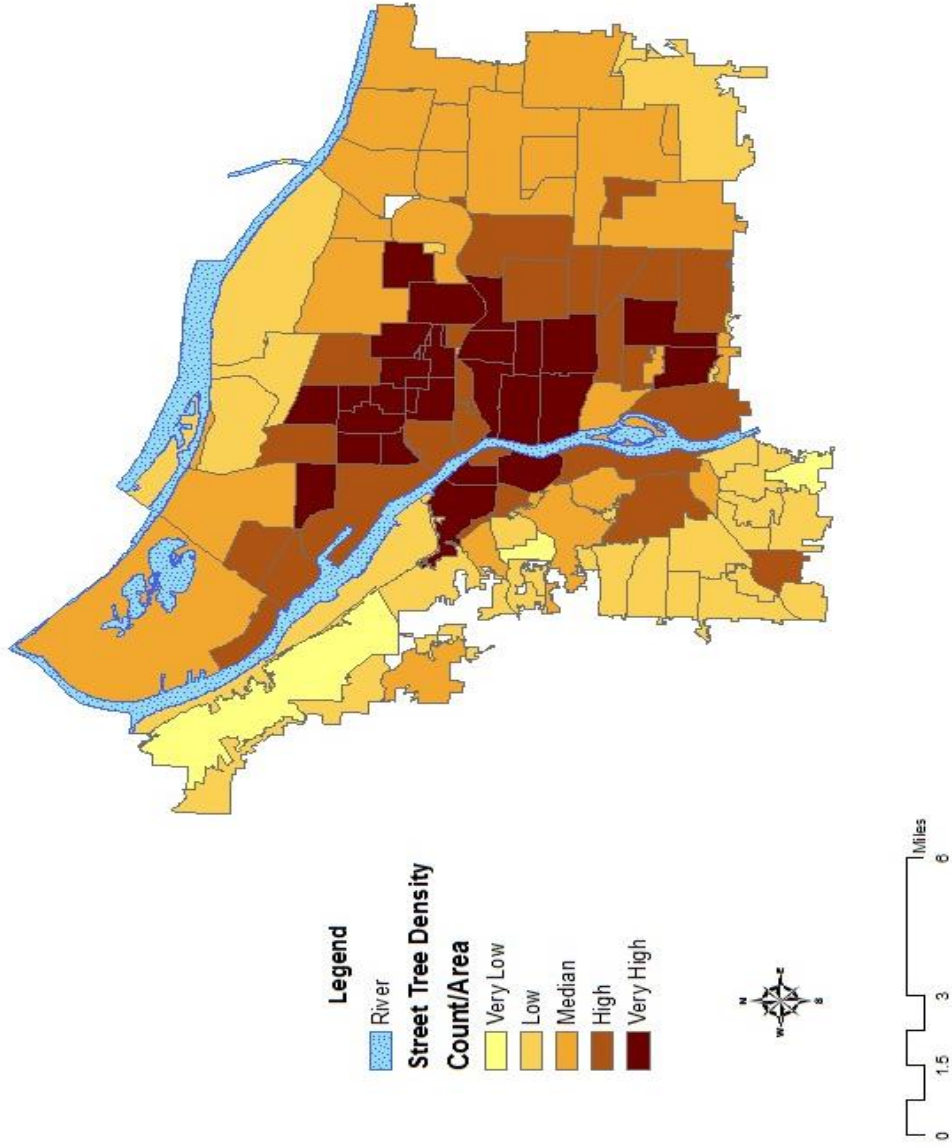
In this section, we map parks, transportation, street trees, and food access. These amenities help vulnerable populations adapt and proceed in the face of growing climate change risks.



**Figure 5: Park Density by Neighborhood.** Sum of acres of park area within each neighborhood was normalized by neighborhood area. Density values were sorted and displayed by quintile. Creator credit: Fiona Marten. Data Source: Portland Parks and Recreation.

### *Park Density by Neighborhood*

Access to parks, which provide heat relief and leisure opportunities, is unevenly distributed throughout the city. Figure 5 shows the density of parks by neighborhood, where density is calculated based on the number of acres of parkland per neighborhood area. As we can see, there are not much parkland in central Southeast. Parks have been shown to help reduce the effects of urban heat, so it is important that people across the city have equal access to parks. In the next section of this report, we will show how parks in the city overlap with vulnerable communities and with the Urban Heat Island effect.

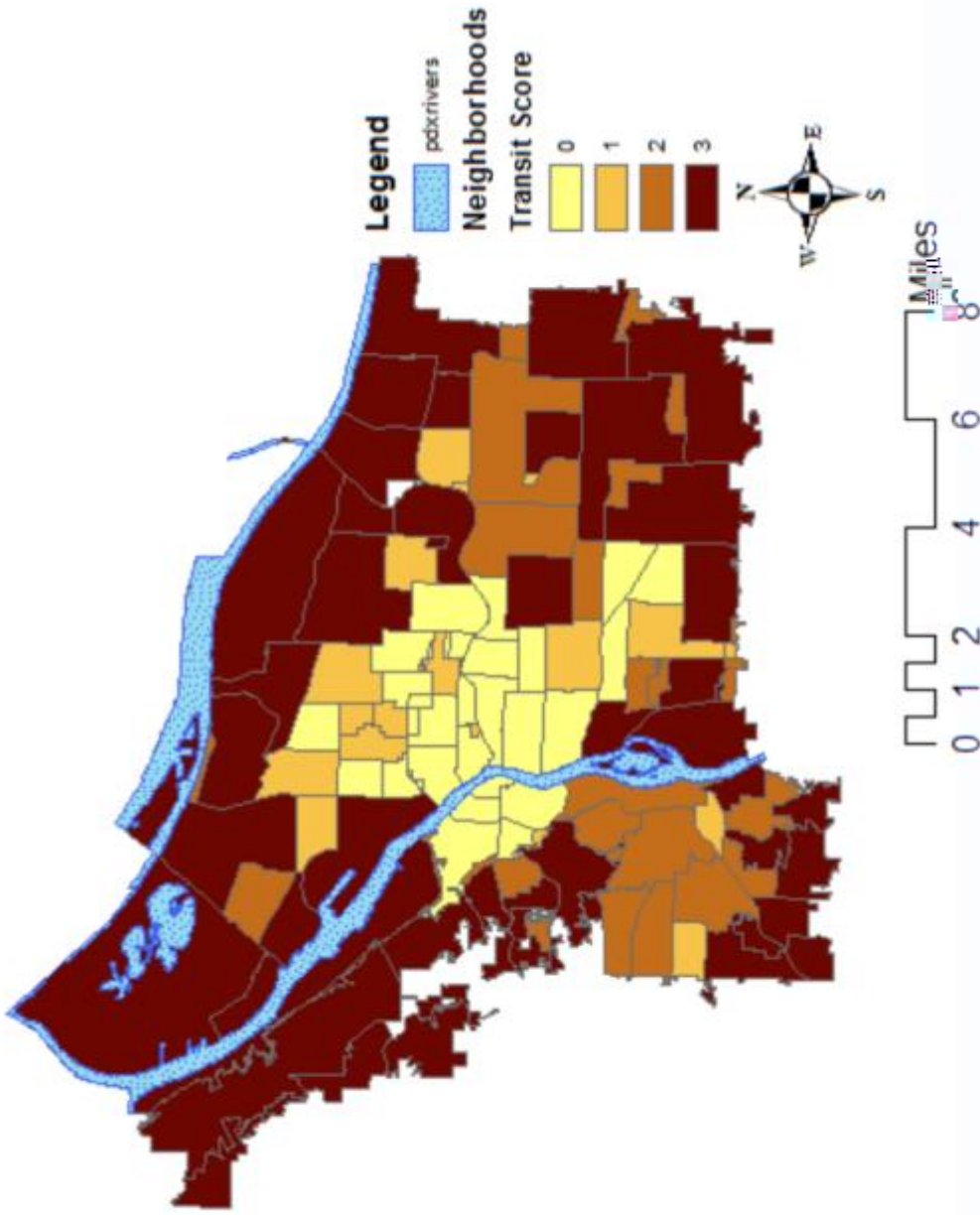


**Figure 6. Street Tree Density by Neighborhood.** The total sum of street trees within each neighborhood was normalized by neighborhood area. Density values were sorted and displayed by quintile. Creator credit: Fiona Marten. Data source: Portland Parks and Recreation.

### *Street Density by Neighborhood*

Street tree density is highest in Portland's city center, primarily serving Portland's least vulnerable populations. The designation and planning of street trees is a political decision with oversight from the City of Portland and Portland Parks & Recreation. Figure 6 displays the variance of street tree density by neighborhood. Street trees are "any tree planted in the City right-of-way, whether in improved or unimproved right-of-way," as defined by the PP&R Urban Forestry Street Tree Planting Standards. Low levels of street tree density exist within the neighborhoods of Pleasant Valley, Sunderland, and East Columbia. We recognize that the northern neighborhoods have high concentrations of industry and manufacturing, so street tree placement may pose logistical challenges. Much of east Portland contains "low" counts of street tree density by neighborhood, which in periods of high temperature, do not possess high amounts of street trees for heat relief and possibilities for shade. Forest Park, located in the upper left of the figure, is characterized by "Very Low" street tree density count, although this is because the trees within Forest Park cannot be catalogued as "street" trees.

Urban vegetation can indirectly and directly affect local air quality by changing the urban atmospheric environment. Urban trees affect air quality by reducing temperature and other microclimate effects, removing air pollutants from the air, and influencing heat and shade of buildings due to placement near structures. Trees help to provide shade, keeping street and building surfaces cooler, and trees cool the surrounding air through evapotranspiration. Policy recommendations would include focusing tree planting and maintenance in the areas shown by Figure 6 to exhibit "Very Low" and "Low" street tree density counts, in accordance with the guidelines present in the PP&R Urban Forestry Street Tree Planting Standards, with the subsequent benefits of reducing the urban heat island effects of those regions. Another recommendation would be to encourage homeowners to plant street trees near the public areas of their property.

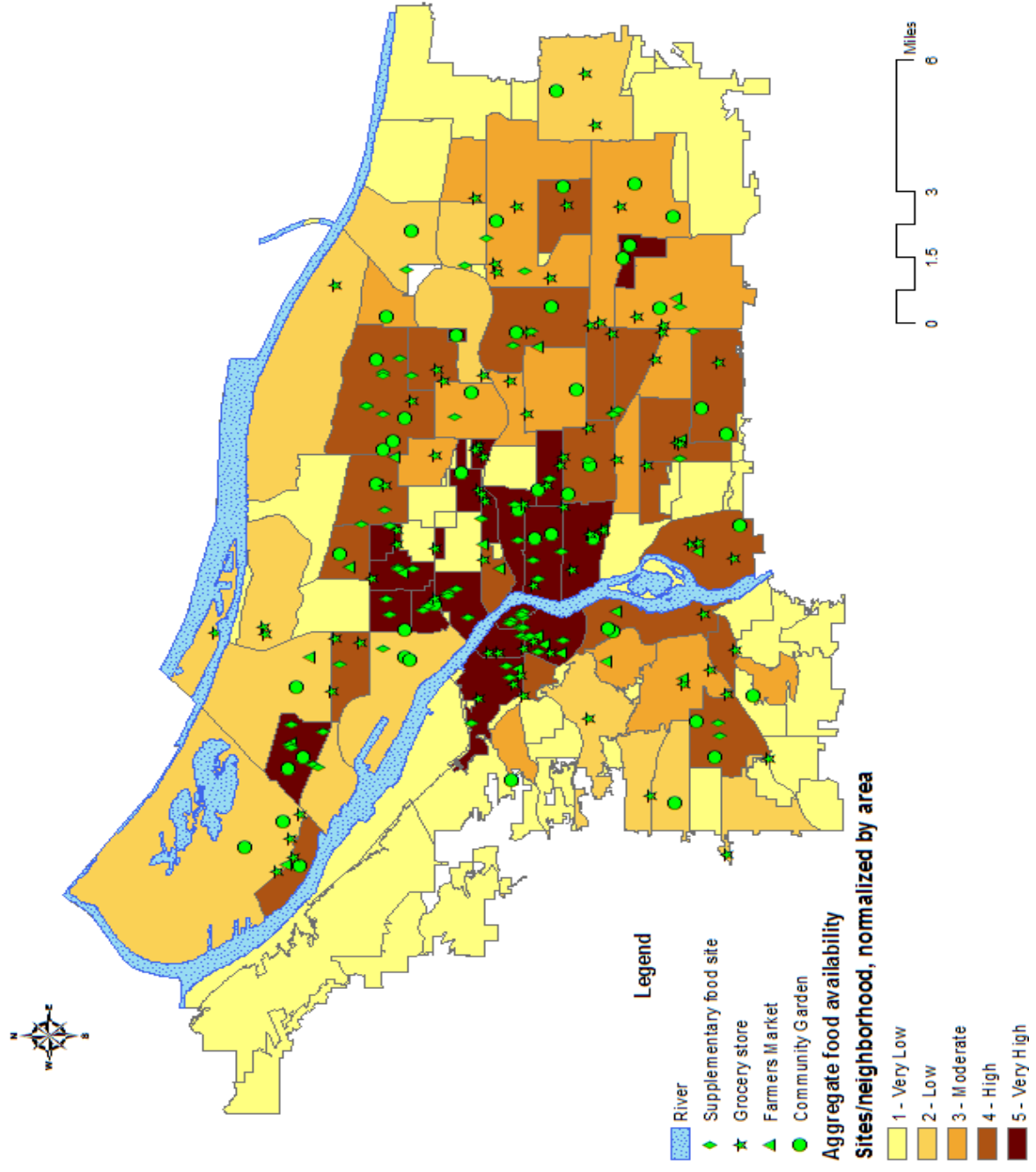


**Figure 7. Transportation Amenity Density by Neighborhood.** Sidewalk density was calculated as the number of sidewalk polygons in a neighborhood. Neighborhoods in the lowest three natural breaks (0-646 segments) were visually confirmed as having few sidewalks and/or low sidewalk connectivity and given a transit score of one. Bike lane density was calculated using the number of bike lanes or streets per neighborhood. Neighborhoods in the lowest three quantiles (0-37 bike lane segments) were given a transit score of one. Bus stop density was calculated using the number of bus stops per neighborhood. Neighborhoods in the lowest three quantiles (0-103 stops) were given a transit score of one. Total transit score was calculated by adding the scores for each transportation mode together to get a composite score for each neighborhood. Neighborhoods with 'complete' non-car transportation systems are indicated with a 0, while neighborhoods lacking adequate transportation systems are indicated with a value of 3. Creator credit: Elaine Kushkowski. Data source: PortlandMaps Open Data.



### *Transportation Amenity Density by Neighborhood*

Neighborhoods which have access to multiple forms of non-car transportation are likely to be more resilient to the effects of extreme heat and flooding. Sidewalks and bike-friendly streets reduces the need for short car trips and encourages use of existing neighborhood amenities. Access to public transportation increases mobility and more importantly ensures that people without personal vehicles can access amenities outside of their neighborhoods. Much of North and East Portland does not have adequate sidewalk coverage, or access to, bike lanes and/or public transportation. This reduces mobility, isolating vulnerable populations, particularly in their ability to access outdoor recreation, food resources, and avoid some of the effects of climate change. Improving the availability of any transportation mode in the areas that have a score of 3 will increase an individual's access to important amenities.



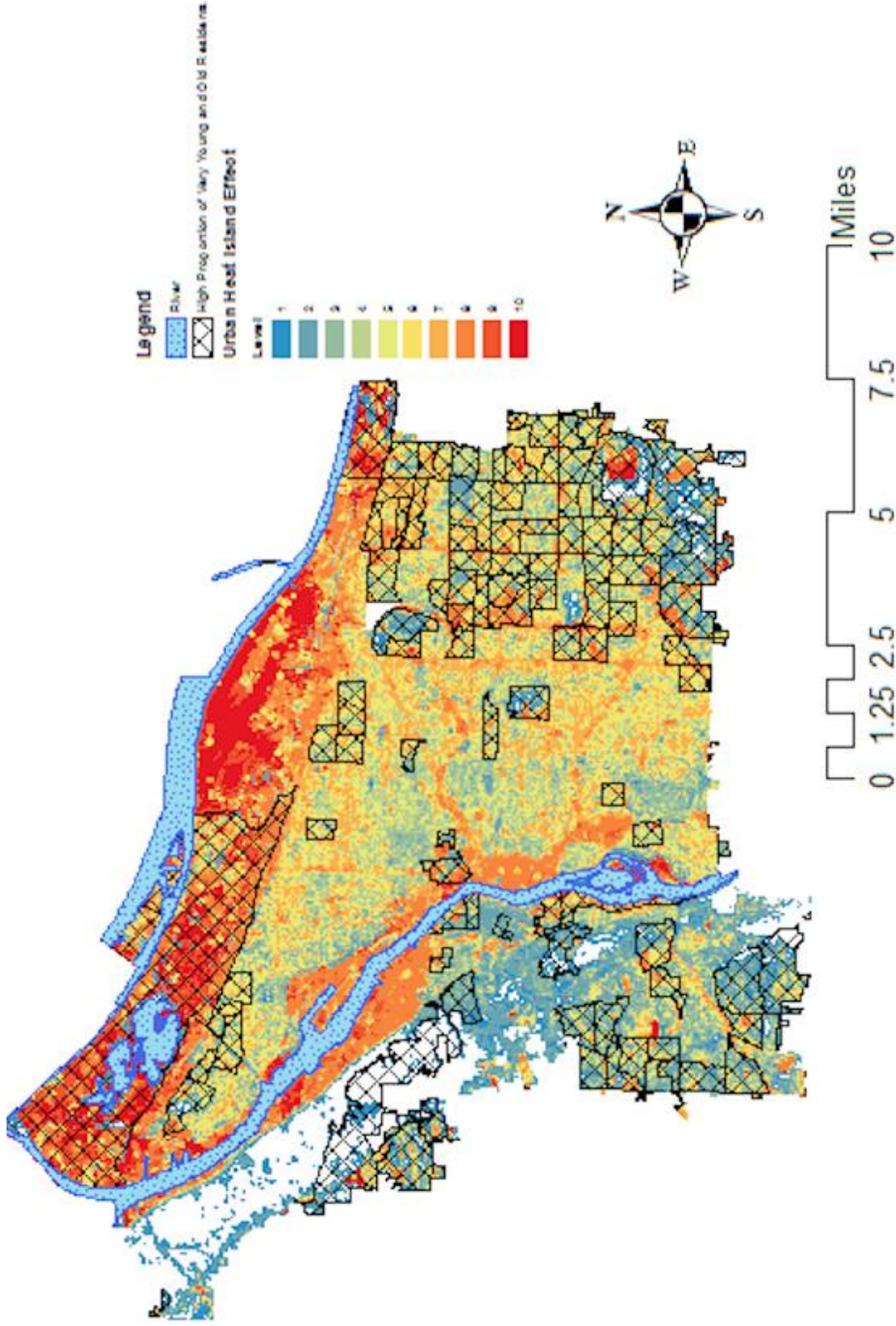
**Figure 8: Food Availability by Neighborhood.** Built by merging four layers representing the types of food access sites studied, each joined to a layer of neighborhood boundaries. Neighborhood food site density rated by quintile, with neighborhoods in the top quintile rated as “Very High” food availability. Creator credit: Anthony Bencivengo. Data source: RILIS Discovery, Regional Equity Atlas, Portland Parks and Recreation, The Gateway Center, Oregon Food Bank, PortlandMaps Open Data.

### *Food Availability by Neighborhood*

Access to food options is an important aspect of community climate resilience. A complex set of factors impact food access, including price and cultural appropriateness. This map shows food availability, reflecting the proximity of food sites to residences. Residents in neighborhoods with lower food site density are less likely to have a source of fresh produce within walkable distance of their home. Figure 8 shows that sites providing access to nutritious food are highly concentrated in areas around downtown Portland, and still reasonably dense in much of East Portland. Of the neighborhoods with low food availability ratings, Forest Park and industrial North Portland have low food demand, while Eastmoreland is not zoned for commercial use but still has easy food access across neighborhood borders.

Grocery stores are most sparse in Northeast and far East Portland, indicating clear disparity in food access across the city. Neighborhoods such as Cully and Madison South are served primarily by community gardens and supplementary food sites, which are not as reliable as grocery stores. Parts of Southwest Portland also have low food availability within walking distance. Many Southwest residents own cars, but their longer travel distances to food sites could pose a threat in the aftermath of an extreme weather event, particularly in regions of Southwest Portland with relatively high landslide risk (City of Portland, 2014).

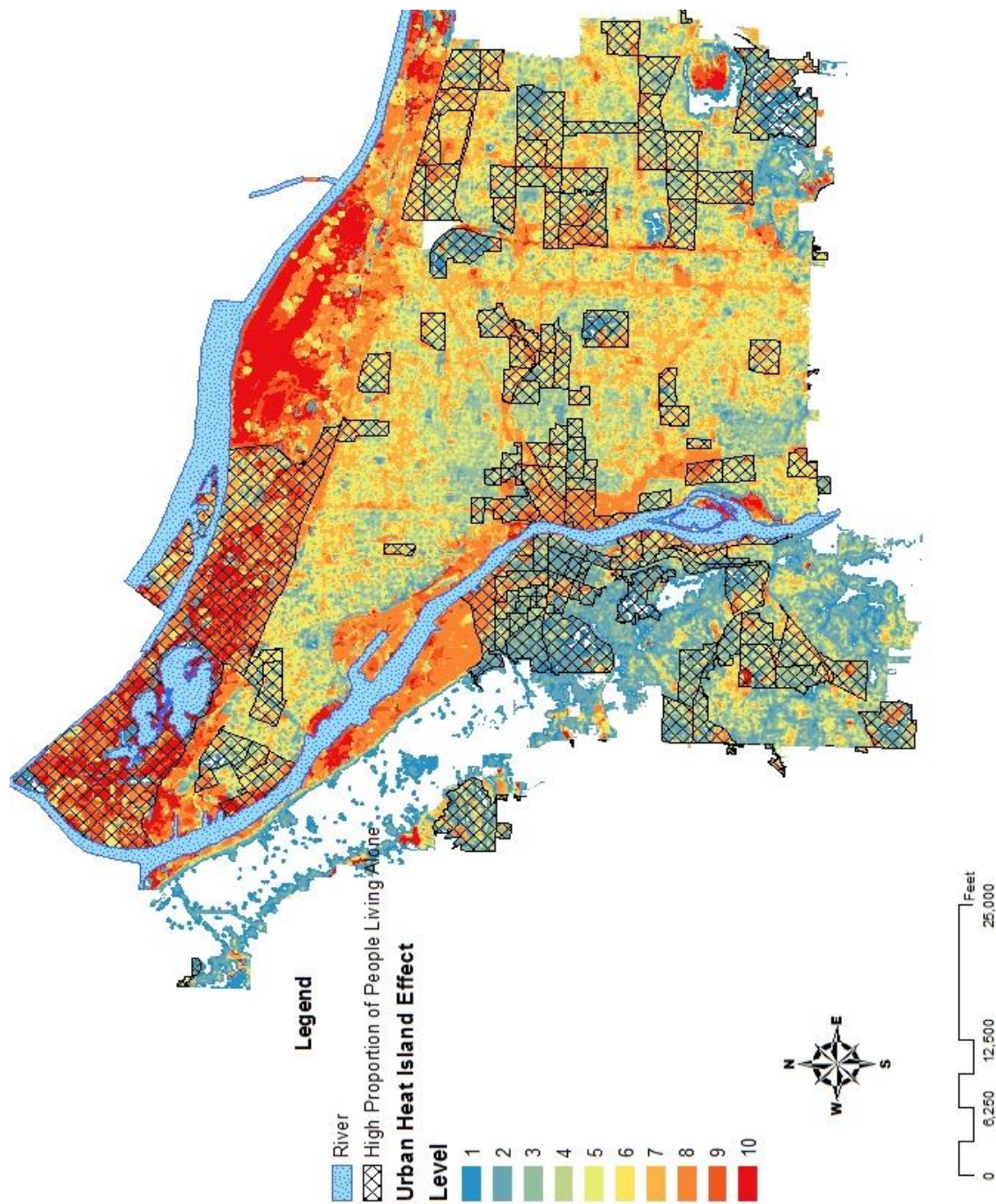
There are a number of ways the City could ameliorate food insecurity. First, new grocery store establishment in underserved areas could be encouraged by replicating tax incentive programs such as the Pennsylvania Fresh Food Financing Initiative and New York City's Healthy Bodega Initiative (USDA, 2009). Second, funding for community garden establishment could be increased. This would be most effective if new community garden sites were implemented on school and park land, with a focus on the food-insecure areas identified in Fig. 8, and then paired with outreach and education campaigns designed to help low-SES communities and communities of color gain maximum benefit from them. Third, funding and outreach for the Produce for People Program could be increased using grants and tax credits to support grassroots food security and sovereignty projects such as Portland Mercado. For post-disaster recommendations, see discussion of Figure 18.



**Figure 9: Urban Heat Island Effects on the Most Socially Vulnerable People.** Highest quintile of proportion of residents over 65 or under 15, overlaid on urban heat island data. The urban heat island data is shown as a gradient from coolest (blue) to warmest (red), relative to the median temperature of the region. Creator credit: Fiona Marten. Data source: US Census ACS 2015, PSU Sustaining Urban Places Research Lab.

### *Urban Heat Island Effects on Most Socially Vulnerable Society*

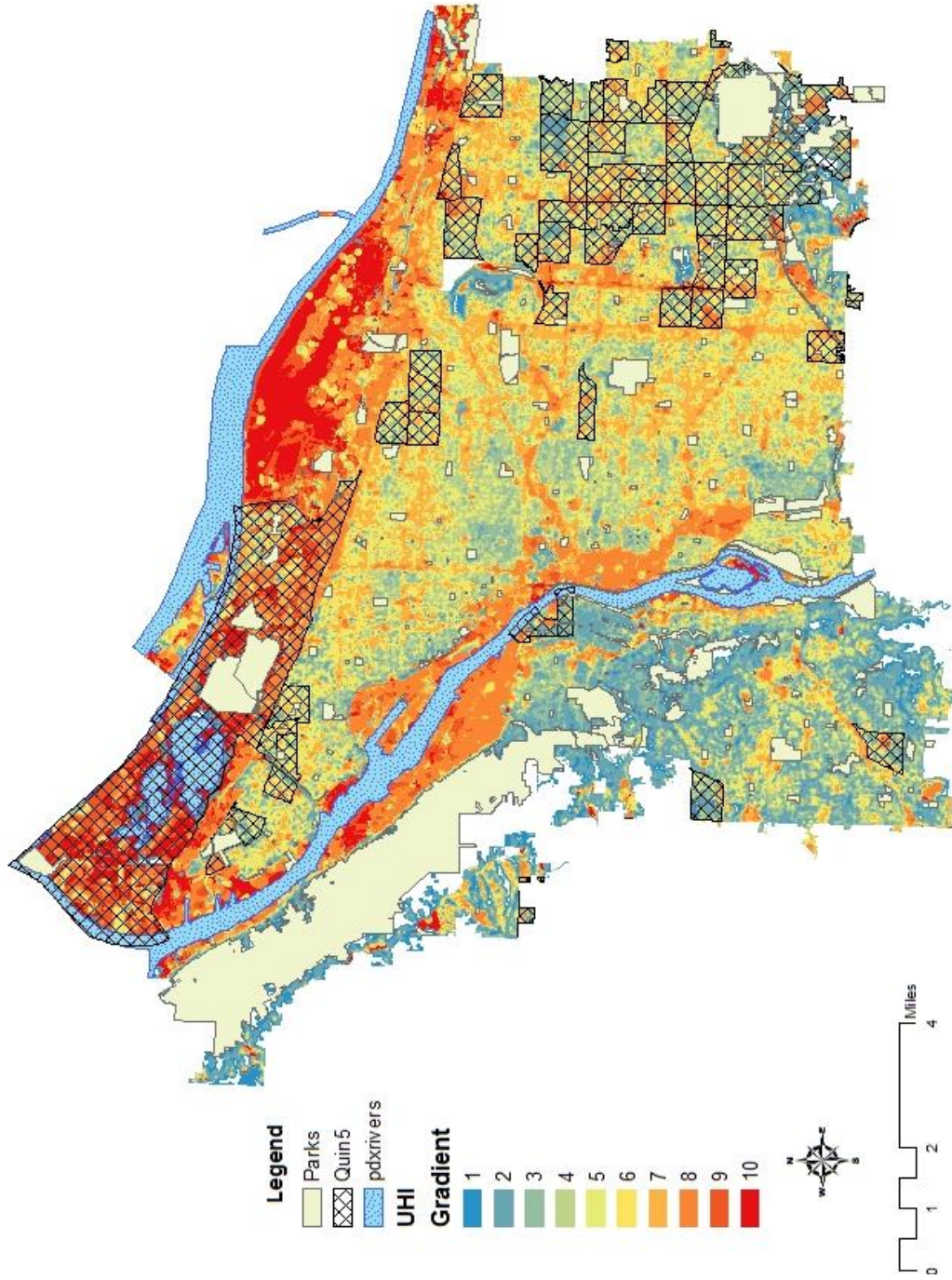
Many of Portland's most vulnerable people live in regions impacted by the urban heat island effect. Figure 9 shows areas of Portland with the greatest population of people over 65 years old or below 15 years old. A qualitative comparison of this map with the overall social vulnerability map (see Fig. 4) showed that they seem to closely correlate. Age is an important factor in determining the capacity of an individual to handle extreme temperatures (Reid et al. 2009) (Vandentorren et al. 2006). Areas which are expected to experience increased heat and have residents of vulnerable ages (under 15 years of age, over 65 years of age) are especially vulnerable to the detrimental health impacts of heat. The areas which fit this profile are communities along the I-205, some small areas of extreme heat in outer east Portland, and some areas along the Columbia River. While any decrease in urban heat island effects will likely improve public health, focusing on these areas will help ensure the greatest reduction in health related heat risks.



**Figure 10: Urban Heat Island Effects in Census Tracts with a High Proportion of People Living Alone.** Census tracts in the highest quintile of proportion of residents who live alone was overlaid on urban heat island effects data. Scores from 1 to 10 represent a difference from median regional temperature, with scores 1 and 2 representing a lower than median average temperature, and 3 through 10 a higher temperature, ranging from 0.9° above for a score of 3 and 4.6° above for a score of 10. Creator credit: Fiona Marten. Data source: PSU Sustaining Urban Places Research Lab, US Census ACS 2015.

### *Urban Heat Island Effect in Census Tract with a High Proportion of People Living Alone*

Many of the regions most impacted by urban heat island have high density of individuals living alone. Individuals living alone do not have immediate household support for emergencies that stem from high temperatures like heat stroke. Figure 14 displays the high proportions of people living alone along with urban heat island effects. Note the effect of considering living alone: this map highlights different areas as high priority compared to the earlier heat island maps. Our overall SoVI indicates that the most vulnerable people live in East or Northeast Portland. The population living alone differs from the population of the old and young because there is a high concentration of single-occupant households concentrated in the urban core. In particular, the neighborhoods of Sullivan's Gulch, Brooklyn, Montavilla, and Pleasant Valley all possess high proportions of people living alone in high heat regions. The city should consider living alone separately from general social vulnerability since living alone establishes different areas of concern. For example, people living alone may need more social services such as an ambulance in case of heat-related illness.

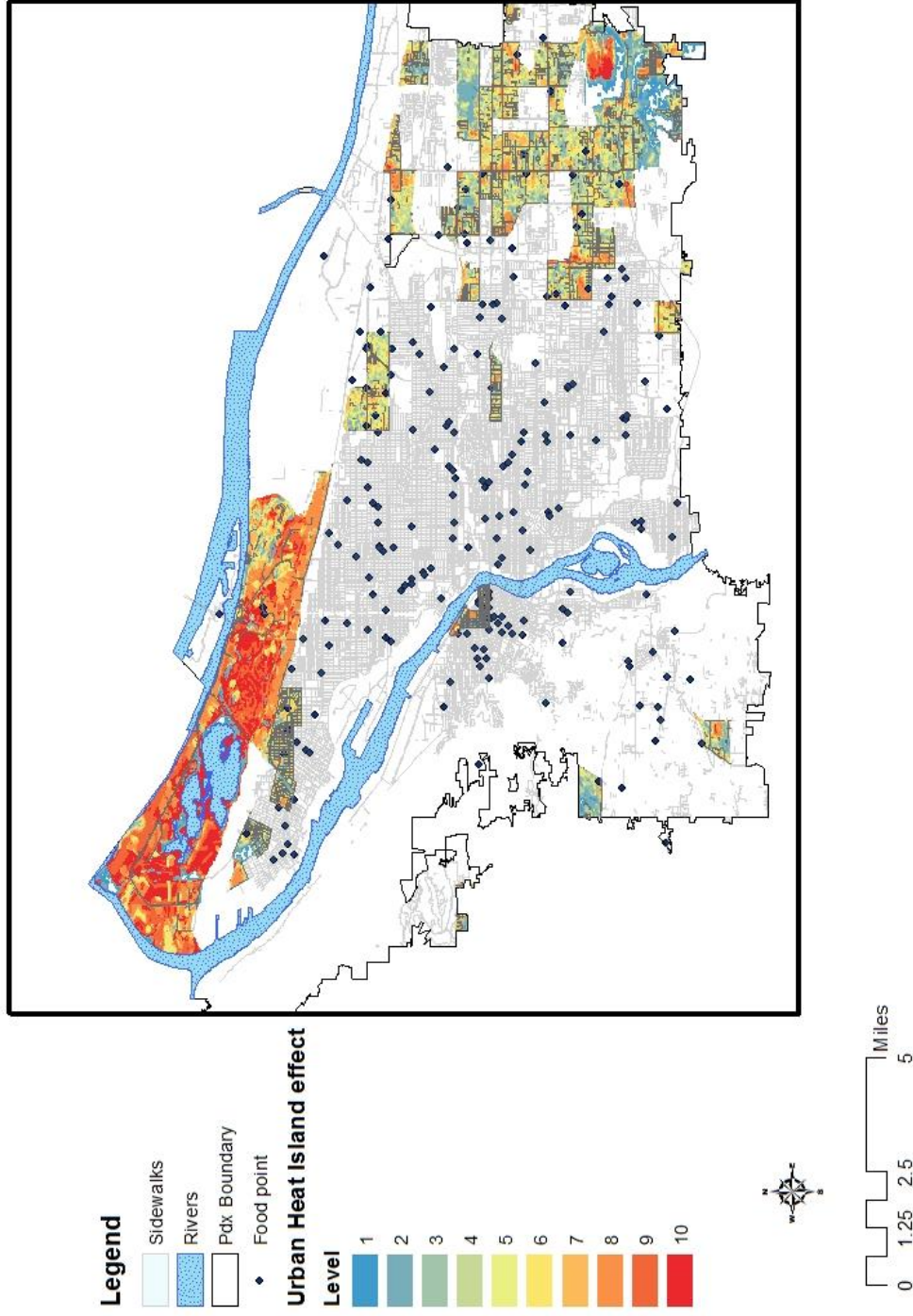


**Figure 11: Urban Heat Island Effects, Park Locations, and Vulnerable Populations.** Portland's most vulnerable quintile and park boundaries were combined with urban heat island effect data. Scores from 1 to 10 represent a difference from median regional temperature, with scores 1 and 2 representing a lower than median average temperature, and 3 through 10 a higher temperature, ranging from 0.9° above for a score of 3 and 4.6° above for a score of 10. Creator credit: Emily Clark, Maggie Davies, Sandy Witte. Data source: Portland Bureau of Transportation, Portland Bureau of Water, PSU Sustaining Urban Places Research Lab, US Census ACS 2015.



### *Urban Heat Island Effects, Park Locations, and Vulnerable Populations*

Many of Portland's most vulnerable populations live in heat intensive areas. This observation is particularly concerning because these populations may not have access to amenities which would protect them from the heat. In particular, parks are one of the best ways to mitigate the UHI effect because they allow people to physically escape the heat and recuperate. Looking at the overlap of SoVI (crosshatching) with parks (light green), it is apparent that East Portland as well as Cully are characterized by low park access. In addition, the extensive heat island (orange) on the east and west sides of the Willamette has virtually no park space to break up the built landscape. (Note: the downtown heat island is not the subject of this report since we focus on the most vulnerable residents of the city of Portland. However it is important to recognize the lack of parks in the developed areas along the river, where many people are employed, as this also represents a significant health risk on hot days.)



**Figure 12: Vulnerable Populations, Urban Heat Island, Sidewalks and Food Access.** Portland's most vulnerable quintile (paired with urban heat island data) shown with sidewalk data. Food access points are indicated in blue.. Creator credit: Emily Clark, Maggie Davies, Sandy Witte. Data source: Portland Bureau of Transportation, Portland Bureau of Water, PSU Sustaining Urban Places Research Lab, US Census ACS 2015.

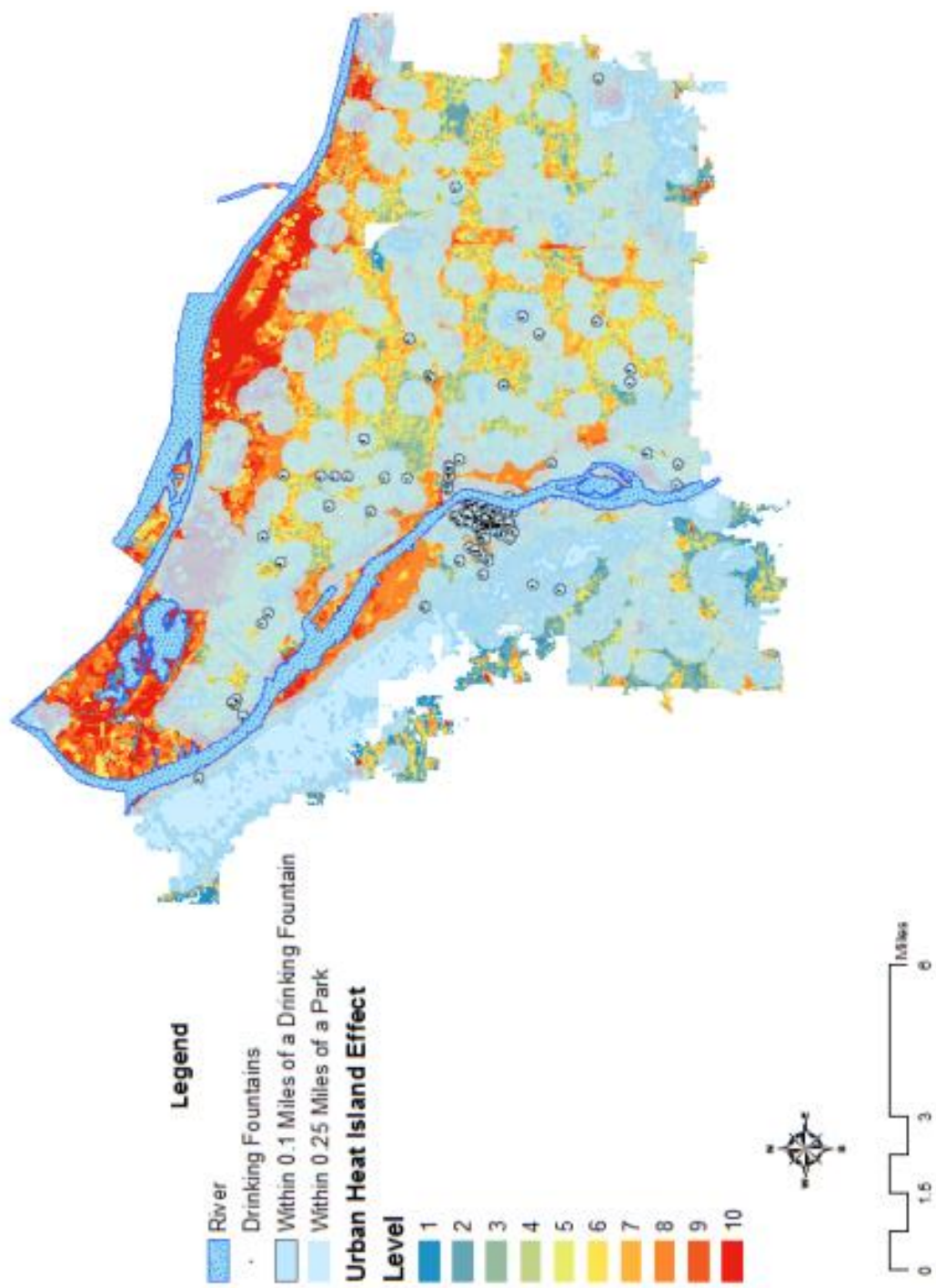
### *Vulnerable Populations, Urban Heat Island, Sidewalks and Food Access*

Not only do many of the city's most vulnerable populations live in regions impacted by the urban heat island effect, but these same regions also correlate with low number of food access points and a lack of complete walking infrastructure to reach food access points. In areas where residents without vehicles have few healthy food options within walking distance, extreme heat events can make reaching the few available sites a difficult and even dangerous task. This is especially true for already vulnerable populations such as people over 65 years old and people with physical mobility limitations.

Figure 12 shows UHI data in areas outside of walking distance of any nutritious produce site. While many of these areas either have negligible UHI effects (west side of Portland) or few residents (industrial areas of north Portland), several pockets of extreme food unavailability are visible. Of particular concern are those areas with high UHI effects, including far Northeast Portland, parts of SE Portland along I-205 (including sections of Powellhurst and Lents), and an area spanning the boundaries between Brooklyn, Sellwood, and Reed. Of these areas of concern, the highest priority should be those in NE and SE Portland, which have a higher percentage of individuals over the age of 65 (see Fig. 12).

All areas of concern identified in Figure 12 have high concentrations of people living alone, which is another vulnerable group. None of the vulnerable groups have easy access to water fountains (see Fig. 13). In addition, many of these regions also have the least access to "improved" sidewalks. This means that the most vulnerable populations have the least access to food within walking distance, and the worst walking conditions as a result of heat and unimproved sidewalks.

We recommend reducing the urban heat island effect by planting street trees and placing public water fountains in identified areas of concern. Additionally, adjust emergency response plans to increase bus frequency, provide shuttles and possibly organize volunteers to deliver important supplies to homes of vulnerable individuals in these areas during an extreme heat event. NE and SE Portland should be prioritized due to their higher proportion of individuals over 65, but heat safety education should also be targeted at the Brooklyn/Sellwood/Reed area of concern. Lastly, we recommend generally improving walking conditions in East Portland (we understand that improvements are already underway here).

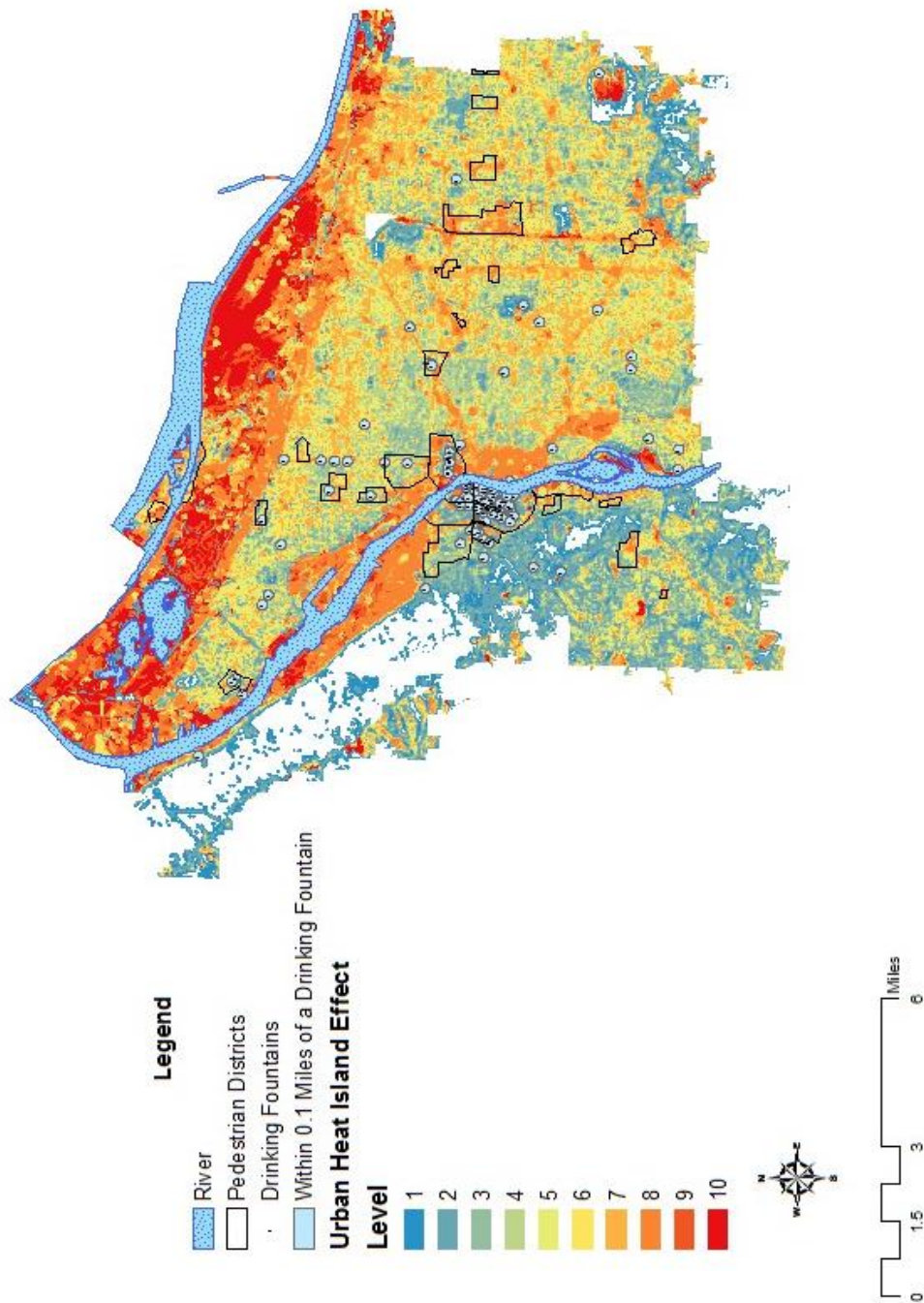


**Figure 13: Urban Heat Island Effects in Areas with Low Park and Drinking Fountain Access.** Buffers of 0.25 miles were created around parks, and buffers of 0.1 miles around water fountains. These layers are shown in addition to urban heat island effect data. Scores from 1 to 10 represent a difference from median regional temperature, with scores 1 and 2 representing a lower than median average temperature, and 3 through 10 a higher temperature, ranging from 0.9° above for a score of 3 and 4.6° above for a score of 10. Creator credit: Fiona Marten. Data source: Portland Bureau of Parks and Recreation, PSU Sustaining Urban Places Research Lab, Portland Water Bureau.

### *Urban Heat Island Effects in Areas with Low Park and Drinking Fountain Access*

Parks and water fountains both perform important functions in helping people cope with heat conditions. Lack of easily accessible parks may exacerbate heat risk to residents. This figure reveals several places where heat could be an issue. Areas along Interstate 205 are exposed to greater heat conditions due to the significant area of asphalt for automobiles, and in many cases lack nearby park access. There are also areas along SE Foster Road where the heat impacts are already high, where water fountains could provide hydration relief for commuters and nearby residents.

Parks function as a space for recreational and leisure activities for both residents of and visitors to Portland. When a park becomes flooded, residents can no longer use the space for heat relief. This puts individuals at risk who lack access to other methods of heat relief during times of high temperatures. The loss of park use increases the pressure on other community spaces to accommodate more individuals who seek a location for relief from the heat.

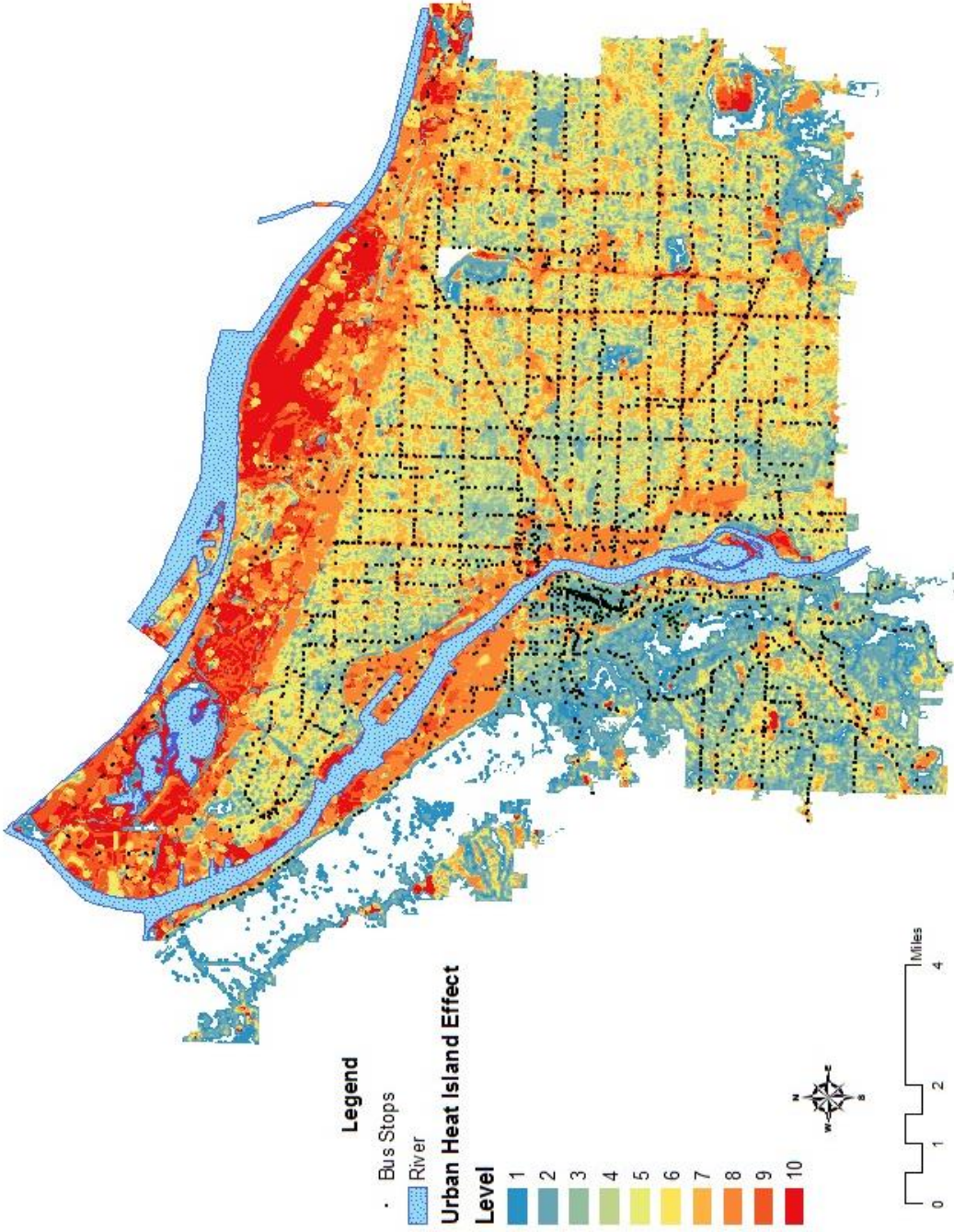


**Figure 14: Pedestrian Districts, Water Fountain Placement, and Urban Heat Island Effects.** Water fountains, along with a 0.1 mile buffer, and pedestrian district outlines were overlaid on urban heat island effect data. Scores from 1 to 10 represent a difference from median regional temperature, with scores 1 and 2 representing a lower than median average temperature, and 3 through 10 a higher temperature, ranging from 0.9\* above for a score of 3 and 4.6\* above for a score of 10. Creator credit: Fiona Marten. Data source: Portland Bureau of Transportation, Portland Bureau of Water, PSU Sustaining Urban Places Research Lab.

### *Pedestrian District, Water Fountain Placement, and Urban Heat Island Effects*

Despite their official designation, many Pedestrian Districts (especially in East Portland) are in high heat regions without drinking fountains. Drinking fountains serve as an alternative to bottled water and accommodating a wide array of constituencies, including children, commuters, runners, unhoused individuals, and tourists. Figure 14 displays the placement of water fountains overlaid over urban heat island effects and shows the regions within Portland that lack water fountain access within 1/10-mile. Several locations on the map highlight the high temperatures that stem from the urban heat island effect that lack adequate water fountain infrastructure. These locations include Northeast Sandy Boulevard, Interstate 205, Southeast 82nd Avenue, and the eastern portions of the Buckman and Hosford-Abernethy neighborhoods along the Willamette. The intense urban heat island effect for NE Sandy Blvd, I-205, and SE 82nd Avenue are in part due to high automobile traffic and low levels of street trees. Policy recommendations for improving water fountain infrastructure include focusing on new water fountain placement along the aforementioned critical areas.

Pedestrian districts are defined by the 1998 Portland Pedestrian Master Plan as “compact walkable areas of intense pedestrian use with a dense mix of land uses and good transit service, where walking is intended to be the primary mode for trips within the district.” In Figure 14, the pedestrian districts that entirely lack water fountains are Hillsdale, Gateway, Ventura Park, Lents, and Macadam. These districts are in need of water fountain infrastructure and are good candidate locations for future fountain placement.

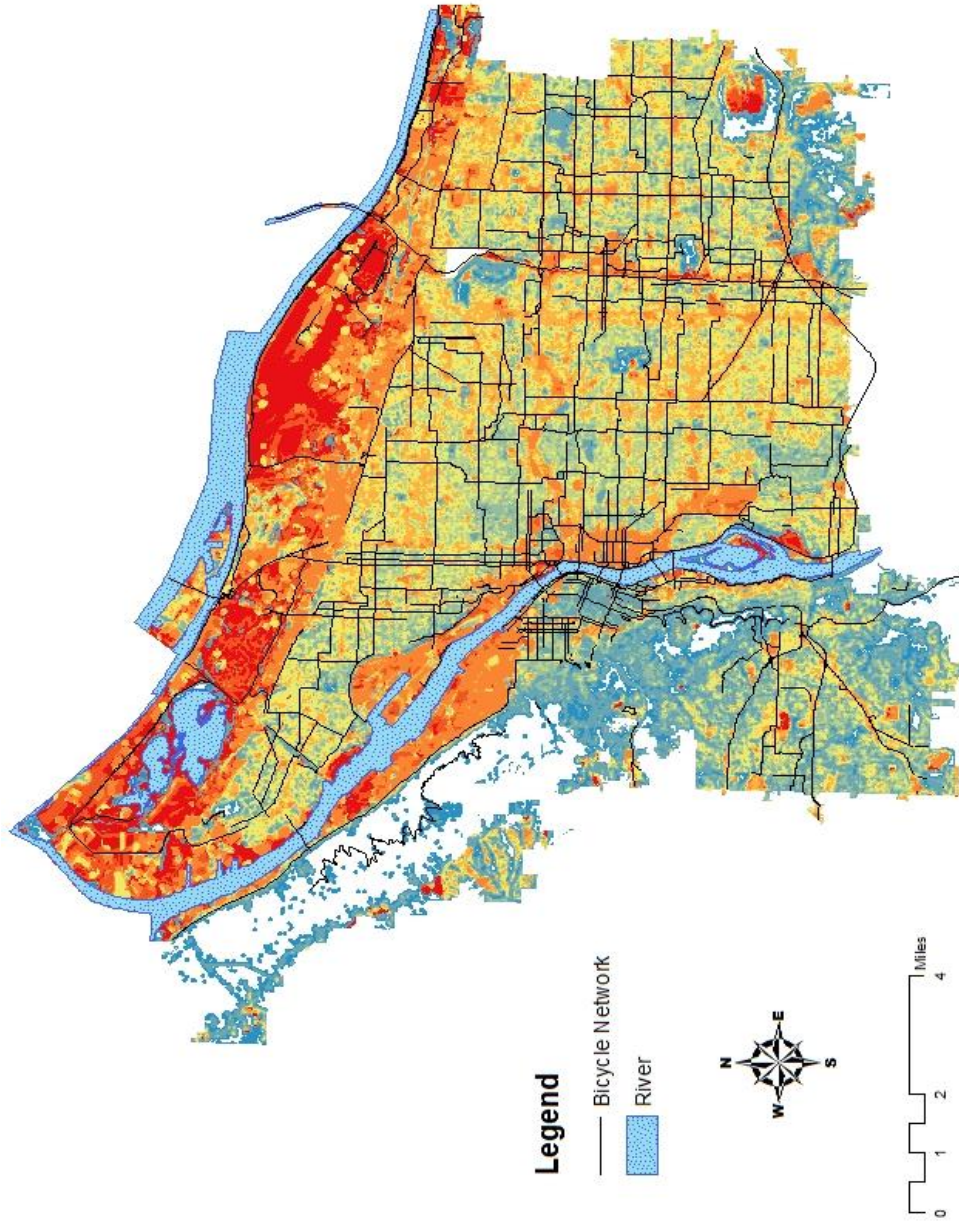


**Figure 15. Bus stops and urban heat islands.** Bus stop data was layered on top of Urban Heat Island (UHI) data. The UHI data is shown as a gradient of coolest (blue) to warmest (red) with the intermediate (yellow/orange), as a deviation from the median temperature of the region (see Figure x for more details). Creator credit: Elaine Kushkowsky. Data source: Portland Bureau of Transportation, PSU Sustaining Urban Places Research Lab.



### *Bus Stops and Urban Heat Islands*

Bus stops are primarily located on arterial streets that are likely to be hotter according to the urban heat index. Vulnerable populations are often reliant on public transportation in order to get to jobs or access other resources outside of their home neighborhood. While waiting for the bus, individuals will be at risk for heat-related illness. To minimize this risk, we suggest construction of shelters in high-heat areas and increasing the density of street trees along routes most affected by urban heat islands.



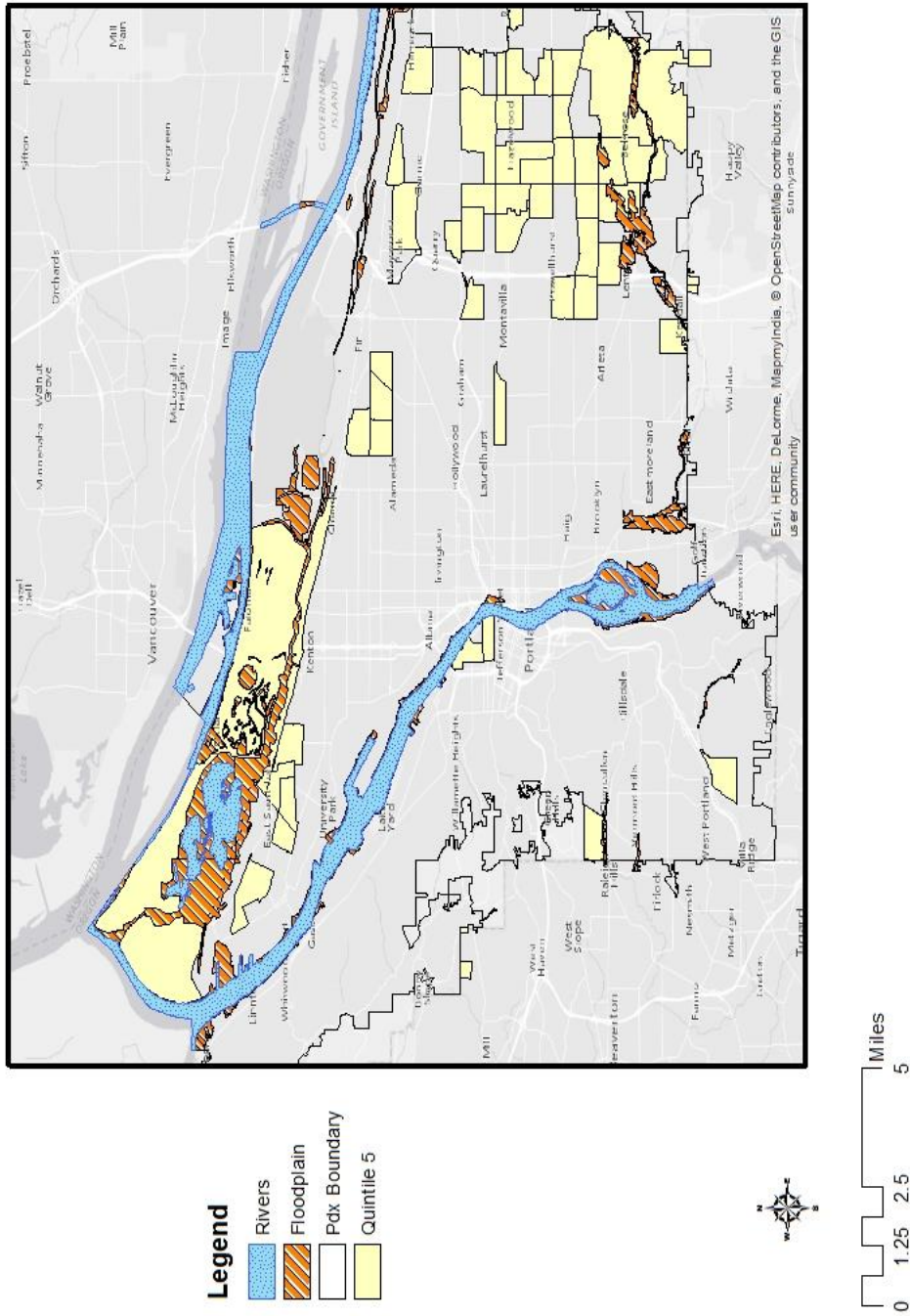
**Figure 16: Urban Heat Island Effects and Portland's Bicycle Network.** Data of the "active" and "planned" bike routes (as opposed to "retired" and "recommended" routes) was layered on top of Urban Heat Island (UHI) data. The UHI data is shown as a gradient of coolest (blue) to warmest (red) with the intermediate (yellow/orange), as a deviation from the median temperature of the region (see Figure x for more details). Creator credit: Fiona Marten. Data source: Portland Bureau of Transportation, PSU Sustaining Urban Places Research Lab.

### *Urban Heat Island Effects and Portland's Bicycle Network*

Many bicycle networks are in high temperature regions, making biking particularly uncomfortable. These data show only the active and planned bike lanes in Portland overlaid on data on urban heat. Neighborhoods along the I-205, in the central eastside, and especially along the Springwater Corridor (a major arterial bike path) are at high risk for heat, therefore inhibiting bike travel. Steps should be taken to help reduce the urban heat island effect on these high travel areas like the Springwater Corridor to encourage biking.

## Flooding, Vulnerabilities, and Impacts

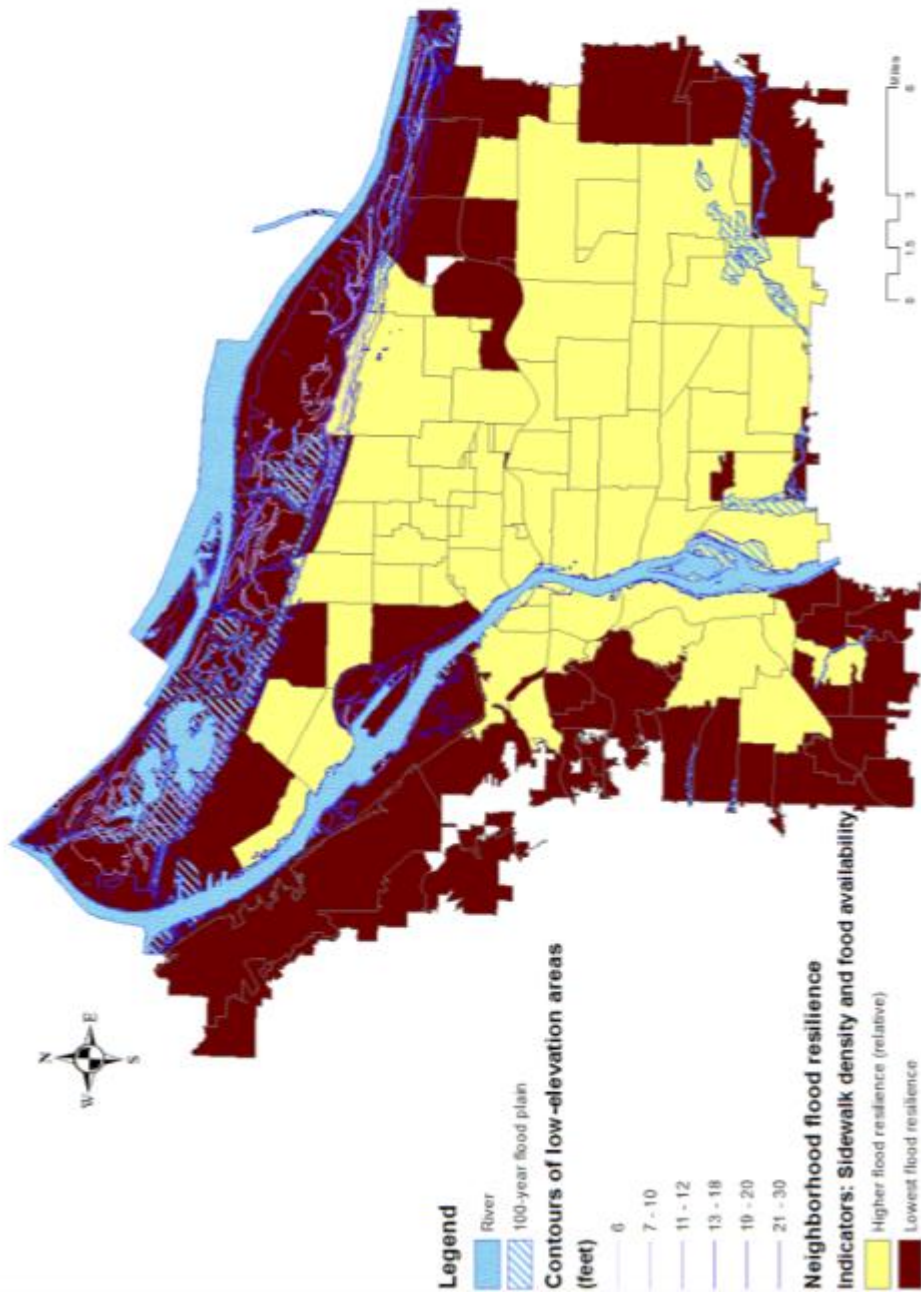
In this final section of maps, we look the risk of flooding in relation to overall social vulnerability and access to food.



**Figure 17: Flood Risk in Census Tracts with Vulnerable Populations.** Display shows 100-year floodplain and proximity to Portland’s most vulnerable populations as determined by our SoVI (“Quintile 5” indicates most vulnerable 20% of population). Creator credit: Sandy Witte, Maggie Davies and Emily Clark. Data source: Portland Bureau of Parks and Recreation, Portland Bureau of Planning and Sustainability, US Census ACS 2015.

### *Flood Risk in Census Tracts with Vulnerable Populations*

Flood risk is strongly dependent on proximity to the hazard, and therefore less associated with social vulnerability. The Johnson Creek floodplain in SE Portland covers much of Eastmoreland, which is one of the wealthiest neighborhoods in Portland. Although many of the most vulnerable populations are not at significant risk of flood hazards, there are a few key vulnerable areas to note. East Portland neighborhoods such as Lents, Pleasant Valley, and Powellhurst-Gilbert are particularly susceptible to flood. Neighborhoods in the lowest quintile already have higher associated impacts, therefore it may be more difficult to evacuate. For this reason, our recommendation to the city is to focus flood preparation in the neighborhoods of Lents, Pleasant Valley, and Powellhurst-Gilbert.

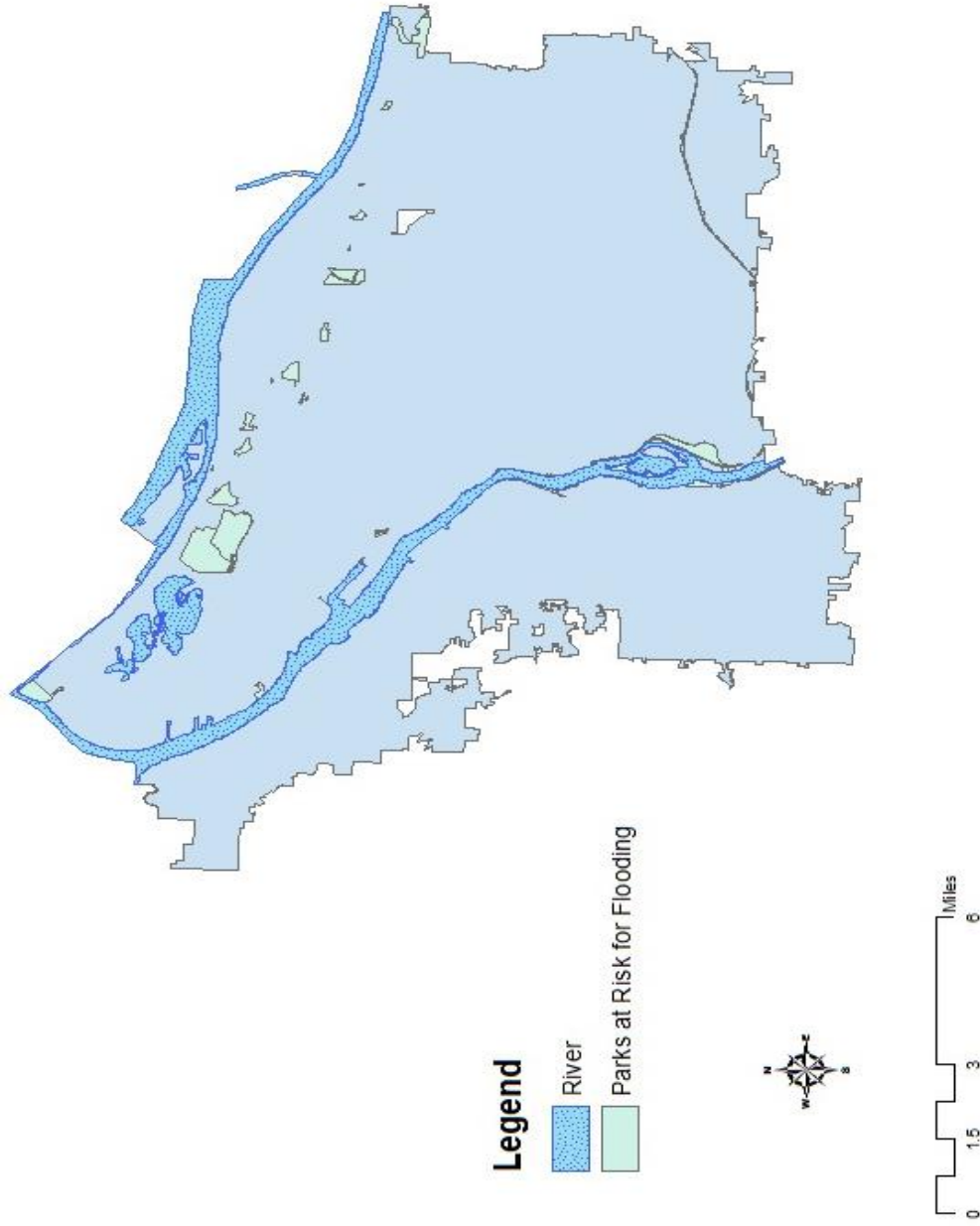


**Figure 18: Flood Impact on Neighborhood Food Access.** Flood hazard zones determined using 100-year floodplain projections, plus areas with elevation under 33 feet (10 meters) above river level (vulnerable to flooding during extreme rainfall). Food access flood vulnerability determined by merging our aggregate food site density layer (see Fig. 8) with a layer joining sidewalk polygon location and size to neighborhood boundaries to calculate sidewalk density per neighborhood, normalized by area. Highlighted neighborhoods are in or below both the 3rd quintile for sidewalk density and the 2nd quintile for food site density. Creator credit: Anthony Bencivengo. Data source: RLIS Discovery, 2007 LiDAR data, PortlandMaps Open Data, Portland Bureau of Planning and Sustainability, Regional Equity Atlas, Portland Parks and Recreation, The Gateway Center, Oregon Food Bank...

### *Flood Impact on Neighborhood Food Access*

North Portland and regions of Southeast Portland are the places where it will be most challenging to access food after a flooding event. In the aftermath of a major flood, neighborhoods where residents lack food access sites within a walkable distance and/or safe routes to reach them will be in urgent need of emergency supply distribution. Neighborhoods without sidewalks are often unsafe for pedestrians during normal weather. Flood conditions with their accompanying mud make walking more difficult, especially for elderly individuals and people with physical handicaps. Figure 18 indicates that a lack of safe pedestrian infrastructure and sparse access to food sites mostly correlate in areas with few people (Forest Park, industrial North Portland) or low vulnerability to flooding (most of Southwest Portland) and in uncommonly small neighborhoods where results are skewed (Reed). There are neighborhoods of concern, however. Southwest Hills and Bridlemile have low food availability and contain portions within the 100-year floodplain, though their flood-vulnerable areas are relatively small and most residents in these neighborhoods own a vehicle. In neighborhoods with high percentages of vulnerable populations (see Figure 4) such as Madison South, Parkrose and Centennial it is consistently difficult to walk to a food site regardless of flood risk. St. Johns combines these difficulties with direct proximity to the 100-year floodplain.

Our recommendations include investing in sidewalk construction for urbanized parts of neighborhoods of concern, with an emphasis on areas with slopes, since paved surfaces in flat, low-elevation areas where rainfall is likely to pool may make these areas more flood-vulnerable. Work to create Neighborhood Emergency Teams (NETs) in Pleasant Valley, Centennial, Wilkes and St. John's, which currently lack them (Portland NET, 2017). In NE Portland, ensure that food banks and other supplementary food sites are prepared to help with emergency supply distribution in the immediate aftermath of a flood.



**Figure 19: Parks at Risk of Flooding.** Displays park areas which lie below 33 feet above sea level. Creator credit: Fiona Marten. Data source: Portland Bureau of Parks and Recreation, Portland Bureau of Planning and Sustainability.



### *Parks at Risk of Flooding*

There are a number of parks in Portland which are susceptible to flood. Within North Portland and in Oaks Bottom, several parks lie in floodplain areas and low-elevation land (defined as less than 33 feet above sea level). We have focused on parks as a resource from urban heat islands, and it is not likely that the parks shown in Figure 19 will flood during high heat days in the summer. Flooding is typical of winter months when Portland receives heavy rain.

However, it merits a note that increased winter flooding may have larger impacts into spring and summer use of parks over time. A flooded park is temporarily unusable and may incur damage to its land, vegetation and facilities. Specific city actions will help mitigate flooding. These include park infrastructure improvements to prevent water collection and improve runoff efficiency. Green infrastructure includes permeable pavements, bioswales, and rain gardens. Since people depend on green spaces for heat relief, park maintenance is relevant (although not the first priority for climate action). Focused mitigation actions will ensure that parks remain in their best condition throughout the year, and provide a way to accommodate increased community needs for heat relief.

## Conclusions

This project builds on Portland’s 2014 Climate Risk and Vulnerabilities Assessment by looking at the spatial distribution of physical risks associated with climate change, alongside the distribution of vulnerable residents, and to amenities which are crucial in helping residents adapt to climate change. It is also a continuation of the goals set out in Portland’s 2014 Climate Change Preparation Strategy, which prioritizes “building response capacity” to risk, using Portland’s Framework for Equity to focus on people that are disproportionately impacted by climate change (City of Portland and Multnomah County, 2014). Our analysis generates specific recommendations for climate equity actions as a first step in addressing these goals. It also helps to illuminate areas for future research as the city moves to increase resilience and adaptive capacity in the most vulnerable communities throughout the city.

This report considered only two of the five climate risks identified by the city: increased incidence of high heat days and increased flooding. The spatial distribution of these risks is unequal throughout the city; some areas are at extreme risk for both flooding and temperature increases while others will likely experience harms from neither. In addition to inequalities in the distribution of physical risks from flooding and heat increases, residents also have unequal abilities to adapt to the harms posed by climate change. The Portland-specific social vulnerability index developed here includes the most common social vulnerability indicators tested in the literature. It aggregates census data regarding socioeconomic status, age, race/ethnicity, gender, family structure, housing tenure, education and social dependence. Using this social vulnerability index, we investigated access to certain urban amenities that also play an important role in helping or hindering residents’ ability to adapt to the harms of climate change. While there are definitely a broad range of amenities to consider in climate adaptation planning, this project focused on transportation, food access, and the distribution of cooling amenities like parks, street trees, and water fountains.

Communities which lie at the intersection of climate risks, socially vulnerable populations, and low density of urban amenities will have a more difficult time adapting to climate change. Areas with vulnerable populations already have less access to certain amenities such as parks and grocery stores. Amenities which do exist in vulnerable areas will have to cope with more frequent use as people attempt to deal with the effects of climate change. And many urban amenities will themselves be impacted by climate-related problems. This may sound obvious but parks and sidewalks which are at risk for flooding or extreme heat will not provide reliable relief from said heat or flooding. High-risk communities face a three-fold burden as climate hazards increase: more vulnerability, less resilience, and greater stress on limited resources as climate risks take their toll.

Throughout our analyses, several areas of Portland stand out:

- **North Portland along the Columbia River** is at high risk for both increased heat and flooding. This area is primarily industrial, but there are small residential neighborhoods and these fall strongly in the upper quintile for social vulnerability. North Portland is a place where people both live and work, and so the climate change hazards in these neighborhoods will impact a significant population. The neighborhoods along the Columbia also have the lowest density of urban amenities considered in these analyses. *Neighborhoods of particular concern include St. John's, Cully, Sumner, Madison South, Parkrose and Wilkes.*
- **Lents** is a residential neighborhood at risk for increased flooding due to climate change. This area, along with many other neighborhoods east of SE 82nd Avenue, is especially socially vulnerable. Focusing on flood mitigation and helping residents adapt to flooding in this area will be an important part of climate change adaptation planning.
- **The Central Eastside** along the Willamette, especially in and around the Pearl District, faces both increased heat and potential flooding. This area also has a high proportion of residents who live alone, which can make heat stress and heat stroke more dangerous, but does not have a high proportion of other vulnerable characteristics. Finally, while the Central Eastside is well equipped in terms of public transportation and food access, there are few water fountains and parks in the area.
- **Major roads in East Portland** are another site of significant heat risk. Areas surrounding I-205, SE 82nd Avenue, SE Foster Road and NE Sandy Boulevard all experience high levels of the UHI effect. The communities surrounding these major roadways are often some of the most socially vulnerable. Finally, there are significant stretches of these roads where access to cooling amenities such as parks, street trees, and water fountains is slim. The City of Portland should ensure that communities around these major roads have access to amenities which will help them adapt to increasing heat conditions.

The City of Portland plays an important role in helping residents adapt to the dangers of climate change. Some clear recommendations which stem from our work point to the importance of connecting vulnerable communities to the amenities which will help them adapt to the harms posed by climate change. Creating parks and sidewalks, installing water fountains, and increasing transit access into areas of Portland with the most vulnerable residents will help them adapt to climate change. The city should also pay particular attention to the amenities which do exist in areas threatened by heat increases and flooding to ensure that these amenities do not come under additional strain, either from climate risks or increased use. As we move into an increasingly hazardous future, the City of Portland must place creating a more equitable distribution of urban climate resilience-building amenities among its highest priorities.

## Appendix

**Table A1: Hazard data with sources and explanations.**

Concept	Description	Variables	Source
Flood Risk	Areas of Portland that are at high risk for flooding	<ul style="list-style-type: none"><li>· FEMA 100-year floodplain</li><li>· Contour map of land elevation, focusing on under 10 meters below</li></ul>	PortlandMaps.com, data from Portland Bureau of Planning and Sustainability
Heat Risk	Areas of Portland that are at varying risk for increased temperatures	<ul style="list-style-type: none"><li>· Urban heat island map</li></ul>	PSU's Sustaining Urban Places Research Lab

**Table A2: SoVI variables with data sources and explanations.**

Concept	Description	Variables	Source
Socioeconomic status	Access to economic capital makes communities more resilient to loss	<ul style="list-style-type: none"> <li>· Household income* (SE_T083_001)</li> <li>· % Population at or below poverty line* (SE_T113_011)</li> <li>· % Unemployed* (SE_T033_006)</li> <li>· Population density*</li> </ul>	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)
Age	The very young and elderly population are more vulnerable due to decreased mobility and increased pre-existing health risks	<ul style="list-style-type: none"> <li>· % Population &gt;65 (elderly)* (SE_T007B010)</li> <li>· % Population &lt; 10</li> </ul>	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)
Race/ethnicity	Language and cultural barriers can hinder recovery and aid; correlated with low-income; correlated with single-female households; correlated with high-hazard areas	<ul style="list-style-type: none"> <li>% Hispanic</li> <li>% African American (SE_T013_003)</li> <li>% Native American (SE_T013_004)</li> <li>% Asian (SE_T013_005)</li> <li>% non-white (1-SE_T013_002)</li> </ul>	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)
Gender	Women are more vulnerable than men (often must care for family, paid lower wages)	% female (SE_T004_003)	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)
Family structure	Large # of dependents or single heads of household have less capacity to deal with hazards	<ul style="list-style-type: none"> <li>Avg. family size</li> <li>% children in single-parent household (SE_T018_012)</li> <li>% female-head household (SE_T018_015)</li> <li>% live alone (SE_T020_013)</li> </ul>	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)

Housing and Tenure	Mobile homes are easy to destroy. Renters have less home security than homeowners and can lack funds for recovery	<ul style="list-style-type: none"> <li>• % renters (SE_T094_003)</li> </ul>	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)
Education	Linked to socioeconomic status and access to information	% pop. 25 yrs or older with no high school diploma (SE_T152_002)	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)
Social dependence	People depending on social services for survival have low resilience to hazard events	% on Social Security (SE_T078_003)	Sociaexplorer.com, US Census Bureau: American Community Survey (2011-2015)

**Table A3: Impacts amenities with data sources and explanations.**

Concept	Description	Variables	Source
Green spaces	Vegetation helps lower surrounding temperature and provides social benefits	<ul style="list-style-type: none"> <li>· Parks</li> <li>· Street trees</li> </ul>	PortlandMaps.com, data came from Portland Bureau of Parks and Recreation
Public drinking water access	Easy access to water is important in extreme heat	<ul style="list-style-type: none"> <li>· Water fountains</li> </ul>	PortlandMaps.com, data came from Portland Bureau of Water
Food access	Access to affordable nutritious food, especially locally grown produce, builds community resilience and creates social and economic benefits	<ul style="list-style-type: none"> <li>· Grocery stores</li> <li>· Farmers' markets</li> <li>· Community gardens</li> <li>· Supplementary food sites</li> </ul>	Community garden locations from Regional Equity Atlas, updated with info from Portland Parks & Recreation. Other data from PortlandMaps Open Data, with supplementary food site locations updated using info from The Gateway Center and Oregon Food Bank.
Walkability	Access to complete sidewalk networks makes walking a safer and more appealing form of transportation	<ul style="list-style-type: none"> <li>· Sidewalks</li> <li>· Pedestrian Districts</li> </ul>	PortlandMaps.com, data from Portland Bureau of Transportation
Public Transit Info	Public transportation is important for accessing resources outside of one's own neighborhood	<ul style="list-style-type: none"> <li>· Bus stops</li> <li>· Transit stations</li> </ul>	PortlandMaps.com, Metro Data Resource Center and Portland Bureau of Transportation
Bicycle Network	Access to the bicycle network makes biking a more visible and appealing form of transportation	<ul style="list-style-type: none"> <li>· Active and planned bicycle network</li> </ul>	PortlandMaps.com, data from Portland Bureau of Transportation







**Figure 21. The Authors at the Bigelow Wind Farm.** Left to right: Alex “Bird” Loukides, Leo Parker, Anthony Bencivengo, Fiona Marten, Maggie Davies, Anna Miller, Elaine Kushkowski (Not pictured: Emily Clark, Sandy Witte, Hunter Wise) Photo by Chris Koski.

## Bibliography

- Bergstrand, Kelly, Brian Mayer, Babette Brumback, and Yi Zhang. 2015. "Assessing the Relationship Between Social Vulnerability and Community Resilience to Hazards." *Social Indicators Research* 122 (2): 391–409. doi:10.1007/s11205-014-0698-3.
- Bretz, Sarah, Hashem Akbari, and Arthur Rosenfeld. "Practical Issues for Using Solar-Reflective Materials to Mitigate Urban Heat Islands." *Atmospheric Environment* 32, no. 1 (1998): 95–101.
- Buehler, Ralph, and Andrea Hamre. "The Multimodal Majority? Driving, Walking, Cycling, and Public Transportation Use among American Adults." *Transportation; New York* 42, no. 6 (2015): 1081–1101. doi:http://dx.doi.org.proxy.lib.iastate.edu/10.1007/s11116-014-9556-z.
- Burke, Marshall, and David Lobell. "Climate Effects on Food Security: An Overview." In *Climate Change and Food Security*, edited by David Lobell and Marshall Burke, 37:13–30. Dordrecht: Springer Netherlands, 2010. http://www.springerlink.com/index/10.1007/978-90-481-2953-9\_2.
- Checker, Melissa. "Wiped Out by the 'Greenwave': Environmental Gentrification and the Paradoxical Politics of Urban Sustainability." *City & Society* 23, no. 2 (2011): 210–29. doi:10.1111/j.1548-744X.2011.01063.x.
- Chen, Jian, Arleen Hill, and Lensyl Urbano. "A GIS-Based Model for Urban Flood Inundation." *Journal of Hydrology* 373 (2009): 184–92.
- City of Portland. "Climate Change Preparation Strategy: Preparing for Local Impacts in Portland and Multnomah County," 2014. <https://publications.iadb.org/handle/11319/7060>.
- . "Climate Change Preparation Strategy: Risk and Vulnerabilities Assessment." Portland, OR: City of Portland and Multnomah County, 2014. [https://moodle.reed.edu/pluginfile.php/65920/mod\\_resource/content/1/risk-vulnerabilities-assessment-press.pdf](https://moodle.reed.edu/pluginfile.php/65920/mod_resource/content/1/risk-vulnerabilities-assessment-press.pdf).
- . "Climate Action Plan." Portland, OR: City of Portland and Multnomah County, 2015. <https://www.portlandoregon.gov/bps/article/531984>
- . "2035 Comprehensive Plan: Goals and Policies: Transportation." City of Portland, 2016. <https://www.portlandoregon.gov/bps/article/579174>.
- Cradock, Angie L., Philip J. Troped, Billy Fields, Steven J. Melly, Shannon V. Simms, Franz Gimmler, and Marianne Fowler. "Factors Associated with Federal Transportation Funding for Local Pedestrian and Bicycle Programming and Facilities." *Journal of Public Health Policy* 30 (2009): S38–72.
- Cutter, Susan L., Bryan J. Boruff, and W. Lynn Shirley. 2003. "Social Vulnerability to Environmental Hazards." *Social Science Quarterly* 84 (2): 242–61.
- Cutter, Susan L., Christopher T. Emrich, Jennifer J. Webb, and Daniel Morath. 2009. "Social Vulnerability to Climate Variability Hazards: A Review of the Literature." [http://adapt.oxfamamerica.org/resources/Literature\\_Review.pdf](http://adapt.oxfamamerica.org/resources/Literature_Review.pdf).
- Cutter, Susan L., and Christina Finch. 2008. "Temporal and Spatial Changes in Social Vulnerability to Natural Hazards." *Proceedings of the National Academy of Sciences* 105 (7): 2301–6. doi:10.1073/pnas.0710375105.
- "Farmers Markets Matching SNAP." *Partners for a Hunger-Free Oregon*, 2017. <https://oregonhunger.org/farmers-markets-snap>.
- FEMA. "Flood Zones." *Department of Homeland Security FEMA*, 2017. <https://www.fema.gov/flood-zones>.

- Freudenberg, Nicholas, Manuel Pastor, and Barbara Israel. 2011. "Strengthening Community Capacity to Participate in Making Decisions to Reduce Disproportionate Environmental Exposures." *American Journal of Public Health* 101 (Suppl 1): S123–30. doi:10.2105/AJPH.2011.300265.
- Giannakis, Elias, Adriana Bruggeman, Dimitra Poulou, Christos Zoumides, and Marinos Eliades. "Linear Parks along Urban Rivers: Perceptions of Thermal Comfort and Climate Change Adaptation in Cyprus." *Sustainability* 8, no. 10 (2016): 1023. doi:10.3390/su8101023.
- Giles-Corti, Billie, Melissa H. Broomhall, Matthew Knuiiman, Catherine Collins, Kate Douglas, Kevin Ng, Andrea Lange, and Robert J. Donovan. "Increasing Walking: How Important Is Distance To, Attractiveness, and Size of Public Open Space?" *American Journal of Preventive Medicine, Active Living Research*, 28, no. 2, Supplement 2 (2005): 169–76. doi:10.1016/j.amepre.2004.10.018.
- Gittleman, Mara, Carson J. Q. Farmer, Peleg Kremer, and Timon McPhearson. "Estimating Stormwater Runoff for Community Gardens in New York City." *Urban Ecosystems* 20, no. 1 (2017): 129–39. doi:10.1007/s11252-016-0575-8.
- Gregory, Megan M., Timothy W. Leslie, and Laurie E. Drinkwater. "Agroecological and Social Characteristics of New York City Community Gardens: Contributions to Urban Food Security, Ecosystem Services, and Environmental Education." *Urban Ecosystems* 19, no. 2 (2016): 763–94. doi:10.1007/s11252-015-0505-1.
- Guthman, Julie. "'If They Only Knew': The Unbearable Whiteness of Alternative Food." In *Cultivating Food Justice: Race, Class and Sustainability*, edited by Alison Hope Alkon and Julian Agyeman, 263–82. Cambridge, MA: MIT Press, 2011. <http://site.ebrary.com/lib/reed/reader.action?docID=10513544>.
- Haider, Taha. "Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic Heat." *Energy and Buildings* 25, no. 1 (1997): 99–103.
- Hart, Melissa A., and David J. Sailor. "Quantifying the Influence of Land-Use and Surface Characteristics on Spatial Variability in the Urban Heat Island." *Theoretical and Applied Climatology* 95, no. 3–4 (2009): 397–406. doi:10.1007/s00704-008-0017-5.
- Heynen, Nik, Harold A. Perkins, and Parama Roy. "The Political Ecology of Uneven Urban Green Space: The Impact of Political Economy on Race and Ethnicity in Producing Environmental Inequality in Milwaukee." *Urban Affairs Review* 42, no. 1 (2006): 3–25. doi:10.1177/1078087406290729.
- Hofmann, M., and M. O'Mahony. "The Impact of Adverse Weather Conditions on Urban Bus Performance Measures." In *Proceedings. 2005 IEEE Intelligent Transportation Systems, 2005.*, 84–89, 2005. doi:10.1109/ITSC.2005.1520087.
- Hou, Jeffrey, Julie Johnson, and Laura J. Lawson. *Greening Cities, Growing Communities: Learning from Seattle's Urban Community Gardens*. Seattle, WA: University of Washington Press, 2009.
- Ignacio, J. Andres F., Grace T. Cruz, Fernando Nardi, and Sabine Henry. 2015. "Assessing the Effectiveness of a Social Vulnerability Index in Predicting Heterogeneity in the Impacts of Natural Hazards: Case Study of the Tropical Storm Washi Flood in the Philippines." *Vienna Yearbook of Population Research* 13: 91–129.
- Imhoff, Marc L., Ping Zhang, Robert E. Wolfe, and Lahouari Bounoua. "Remote Sensing of the Urban Heat Island Effect across Biomes in the Continental USA." *Remote Sensing of Environment* 114, no. 3 (2010): 504–13. doi:10.1016/j.rse.2009.10.008.
- Irwin, Jennifer D., Victor K. Ng, Timothy J. Rush, Cuong Nguyen, and Meizi He. "Can Food Banks

- Sustain Nutrient Requirements? A Case Study in Southwestern Ontario.” *Canadian Journal of Public Health / Revue Canadienne de Sante’e Publique* 98, no. 1 (2007): 17–20.
- Jesdale, Bill M., Rachel Morello-Frosch, and Lara Cushing. “The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation.” *Environmental Health Perspectives (Online); Research Triangle Park* 121, no. 7 (2013): 811.
- Jones, Paula, and Rajiv Bhatia. “Supporting Equitable Food Systems Through Food Assistance at Farmers’ Markets.” *American Journal of Public Health* 101, no. 5 (2011): 781–83. doi:10.2105/AJPH.2010.300021.
- Karner, Alex, David M. Hondula, and Jennifer K. Vanos. “Heat Exposure during Non-Motorized Travel: Implications for Transportation Policy under Climate Change.” *Journal of Transport & Health* 2, no. 4 (2015): 451–59. doi:10.1016/j.jth.2015.10.001.
- Kaźmierczak, Aleksandra. “The Contribution of Local Parks to Neighbourhood Social Ties.” *Landscape and Urban Planning, Special Issue: Urban Ecosystem Services*, 109, no. 1 (2013): 31–44. doi:10.1016/j.landurbplan.2012.05.007.
- Kleerekoper, Laura, Marjolein van Esch, and Tadeo Baldiri Salcedo. “How to Make a City Climate-Proof, Addressing the Urban Heat Island Effect.” *Resources, Conservation and Recycling, Climate Proofing Cities*, 64 (2012): 30–38. doi:10.1016/j.resconrec.2011.06.004.
- Kocornik-Mina, Adriana, Thomas McDermott, Guy Michaels, and Ferdinand Rauch. “Flooded Cities.” *CentrePiece*, 2016.
- Lafortezza, Raffaele, Giuseppe Carrus, Giovanni Sanesi, and Clive Davies. “Benefits and Well-Being Perceived by People Visiting Green Spaces in Periods of Heat Stress.” *Urban Forestry & Urban Greening* 8, no. 2 (2009): 97–108. doi:10.1016/j.ufug.2009.02.003.
- League of Women Voters of Portland Education Fund. “How Portland’s Neighborhood Program Works Today.” Portland’s Neighborhood Associations. Portland, OR: The League of Women Voters of Portland Education Fund, 2006. <https://www.portlandoregon.gov/shared/cfm/image.cfm?id=135940>.
- Lee, Richard J., Ipek N. Sener, and S. Nathan Jones. “Understanding the Role of Equity in Active Transportation Planning in the United States.” *Transport Reviews* 37, no. 2 (2017): 211–26. doi:10.1080/01441647.2016.1239660.
- Lowe, Dianne, Kristie L. Ebi, and Bertil Forsberg. “Heatwave Early Warning Systems and Adaptation Advice to Reduce Human Health Consequences of Heatwaves.” *International Journal of Environmental Research and Public Health* 8, no. 12 (2011): 4623–48. doi:10.3390/ijerph8124623.
- Mares, Teresa M., and Devon G. Peña. “Environmental and Food Justice: Toward Local, Slow, and Deep Food Systems.” In *Cultivating Food Justice: Race, Class and Sustainability*, edited by Alison Hope Alkon and Julian Agyeman, 197–220. Cambridge, MA: MIT Press, 2011. <http://site.ebrary.com/lib/reed/reader.action?docID=10513544>.
- Morrow, Betty Hearn. 1999. “Identifying and Mapping Community Vulnerability.” *Disasters* 23 (1): 1–18. doi:10.1111/1467-7717.00102.
- Nankervis, Max. “The Effect of Weather and Climate on Bicycle Commuting.” *Transportation Research Part A: Policy and Practice* 33, no. 6 (1999): 417–31. doi:10.1016/S0965-8564(98)00022-6.
- News Bites US - NYSE. “Allstate and The Allstate Foundation Help Prepare Local Food Banks for Disaster Response Through Renewed Feeding America Partnership.” *News Bites US - NYSE*. July 31, 2014.

- <http://search.proquest.com.proxy.library.reed.edu/docview/1677517572/abstract/2ECC56B676CE4F11PQ/1>.
- NOAA. "NOAA National Weather Service Glossary." .gov. *National Oceanic and Atmospheric Administration*, n.d.
- . "Urban Flooding." *NOAA's National Weather Service Glossary*. National Oceanic and Atmospheric Administration, n.d.
- Norris, Fran H., Betty Pfefferbaum, Susan P. Stevens, Karen F. Wyche, and Rose L. Pfefferbaum. 2008. "Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness." *American Journal of Psychology* 41: 127–50. doi:10.1007/s10464-007-9156-6.
- Ochoa-Rodríguez, Susana, Karl Smith, Maria Aivazoglou, Rui Pina, and Ana Mijic. "Urban Pluvial Flooding and Climate Change: London (UK), Rafina (Greece) and Coimbra (Portugal)." *Grantham Institute: Climate Change and the Environment*, 2017. <https://www.imperial.ac.uk/grantham/our-work/impacts-and-adaptation/ipcc-working-group-ii/water-security-and-flood-risk/urban-flooding/>.
- Office of Neighborhood Involvement. "Office of Neighborhood Involvement FY2014-15 Budget by Program/Subprogram." Portland Office of Neighborhood Involvement, 2014. <https://www.portlandoregon.gov/oni/article/509287>.
- O'Keefe, Phil, Ken Westgate, and Ben Wisner. 1976. "Taking the Naturalness out of Natural Disasters." *Nature* 260 (April): 566–67. doi:DOI: 10.1038/260566a0.
- Oliveira, Sandra, Henrique Andrade, and Teresa Vaz. "The Cooling Effect of Green Spaces as a Contribution to the Mitigation of Urban Heat: A Case Study in Lisbon." *Building and Environment* 46, no. 11 (2011): 2186–94. doi:10.1016/j.buildenv.2011.04.034.
- Önder, Serpil, and Ahmet Akay. "The Roles of Plants in Mitigating the Urban Heat Islands' Negative Effects." *International Journal of Agriculture and Economic Development; Beverly Hills* 2, no. 2 (2014): 18–32.
- Park, Sohyun, Bettylou Sherry, Holly Wethington, and Liping Pan. "Use of Parks or Playgrounds: Reported Access to Drinking Water Fountains among US Adults, 2009." *Journal of Public Health* 34, no. 1 (2012): 65–72. doi:10.1093/pubmed/fdr047.
- Ratick, Samuel J., and Jeffrey P. Osleeb. 2013. "Measuring the Vulnerability of Populations Susceptible to Lead Contamination in the Dominican Republic: Evaluating Composite Index Construction Methods." *GeoJournal* 78 (2): 259–72.
- Reid, Colleen E., Jennifer K. Mann, Ruth Alfasso, Paul B. English, Galatea C. King, Rebecca A. Lincoln, Helene G. Margolis, et al. 2012. "Evaluation of a Heat Vulnerability Index on Abnormally Hot Days: An Environmental Public Health Tracking Study." *Environmental Health Perspectives* 120 (5): 715–20.
- Rosenfeld, Arthur H., Hashem Akbari, Sarah Bretz, David Sailor, and Haider Taha. "Mitigation of Urban Heat Islands- Materials, Utility Programs, Updates." *Journal of Energy Efficiency* 1, no. 1 (1993): 1–20.
- Saelens, Brian E., James F. Sallis, and Lawrence D. Frank. "Environmental Correlates of Walking and Cycling: Findings from the Transportation, Urban Design, and Planning Literatures." *Annals of Behavioral Medicine* 25, no. 2 (2003): 80–91. doi:10.1207/S15324796ABM2502\_03.
- Saelens, Brian E., Anne Vernez Moudon, Bumjoon Kang, Philip M. Hurvitz, and Chuan Zhou. "Relation Between Higher Physical Activity and Public Transit Use." *American Journal of Public Health* 104, no. 5 (2014): 854–60. doi:10.2105/AJPH.2013.301696.

- Schreider, S. Yu, D. I. Smith, and A. J. Jakeman. "Climate Change Impacts on Urban Flooding." *Climatic Change* 47, no. 1–2 (2000): 91–115. doi:10.1023/A:1005621523177.
- Schupp, Justin L. "Cultivating Better Food Access? The Role of Farmers' Markets in the U.S. Local Food Movement." *Rural Sociology*, 2016, n/a – n/a. doi:10.1111/ruso.12124.
- See, Justin C. G., and Emma E. Porio. 2015. "Assessing Social Vulnerability to Flooding in Metro Manila Using Principal Component Analysis." *Philippine Sociological Review* 63: 53–80.
- Sherrieb, Kathleen, Fran H. Norris, and Sandro Galea. 2010. "Measuring Capacities for Community Resilience." *Social Indicators Research* 99 (2): 227–47. doi:10.1007/s11205-010-9576-9.
- Staley, Daniel C. "Urban Forests and Solar Power Generation: Partners in Urban Heat Island Mitigation." *International Journal of Low-Carbon Technologies* 10, no. 1 (2015): 78–86. doi:10.1093/ijlct/ctt058.
- Stamos, Iraklis, Evangelos Mitsakis, and Josep Maria Salanova Grau. "Roadmaps for Adaptation Measures of Transportation to Climate Change." *Transportation Research Record: Journal of the Transportation Research Board* 2532 (2015): 1–12. doi:10.3141/2532-01.
- Svendsen, Erika S., Lindsay K. Campbell, and Heather L. McMillen. "Stories, Shrines, and Symbols: Recognizing Psycho-Social-Spiritual Benefits of Urban Parks and Natural Areas." *Journal of Ethnobiology* 36, no. 4 (2016): 881–907. doi:10.2993/0278-0771-36.4.881.
- Tan, Jianguo, Youfei Zheng, Xu Tang, Changyi Guo, Liping Li, Guixiang Song, Xinrong Zhen, et al. "The Urban Heat Island and Its Impact on Heat Waves and Human Health in Shanghai." *International Journal of Biometeorology* 54, no. 1 (2010): 75–84. doi:10.1007/s00484-009-0256-x.
- Tarasuk, Valerie, Naomi Dachner, Blake Poland, and Stephen Gaetz. "Food Deprivation Is Integral to the 'hand to Mouth' Existence of Homeless Youths in Toronto." *Public Health Nutrition* 12, no. 09 (2009): 1437. doi:10.1017/S1368980008004291.
- Tynon, Joshua W. R. BaurJoanne F. "Urban Nature Parks and Neighborhood Social Health in Portland, Oregon." *Journal of Park and Recreation Administration* 31, no. 4 (2013). [http://search.proquest.com/docview/1780523280?rfr\\_id=info%3Axri%2Fsid%3Aprimo](http://search.proquest.com/docview/1780523280?rfr_id=info%3Axri%2Fsid%3Aprimo).
- USDA. "Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences." Washington, D.C.: USDA Economic Research Service, 2009. [https://www.ers.usda.gov/webdocs/publications/ap036/12716\\_ap036\\_1\\_.pdf](https://www.ers.usda.gov/webdocs/publications/ap036/12716_ap036_1_.pdf).
- Vandentorren, S., P. Bretin, A. Zeghnoun, L. Mandereau-Bruno, A. Croisier, C. Cochet, J. Ribéron, I. Siberan, B. Declercq, and M. Ledrans. 2006. "August 2003 Heat Wave in France: Risk Factors for Death of Elderly People Living at Home." *European Journal of Public Health* 16 (6): 583–91. doi:10.1093/eurpub/ckl063.
- Vitiello, Domenic, Jeane Ann Grisso, K. Leah Whiteside, and Rebecca Fischman. "From Commodity Surplus to Food Justice: Food Banks and Local Agriculture in the United States." *Agriculture and Human Values* 32, no. 3 (2015): 419–30.
- Wall, Thomas A., Warren E. Walker, Vincent A. J. W. Marchau, and Luca Bertolini. "Dynamic Adaptive Approach to Transportation-Infrastructure Planning for Climate Change: San-Francisco-Bay-Area Case Study." *Journal of Infrastructure Systems* 21, no. 4 (n.d.).
- Wolch, Jennifer R., Jason Byrne, and Joshua P. Newell. "Urban Green Space, Public Health, and Environmental Justice: The Challenge of Making Cities 'just Green Enough.'" *Landscape and Urban Planning* 125 (2014): 234–44. doi:10.1016/j.landurbplan.2014.01.017.