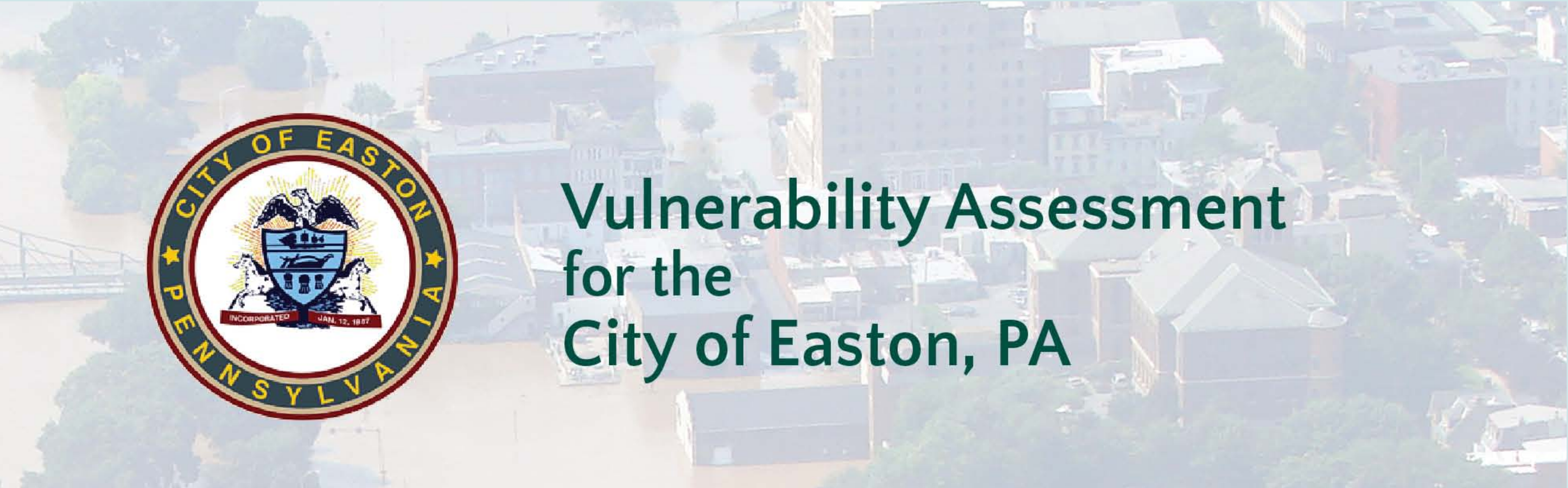
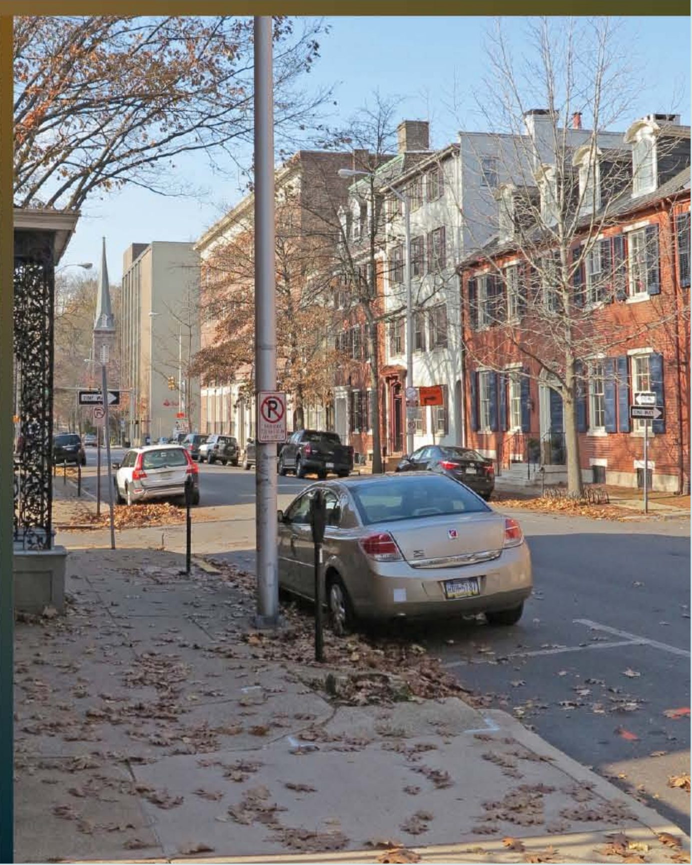


Vulnerability Assessment for the City of Easton, PA

June 2018

Prepared by
Nurture Nature Center for the City of Easton

In fulfillment of the
Global Covenant of Mayors Commitment



Technical Report Purpose

Following the United States' withdrawal from the Paris Climate Accords, cities and towns across the country sought to uphold and commit to these standards at a local and state level. From this goal, the **Global Covenant of Mayors for Climate & Energy (GCM)** was born. Specifically, the GCM is "an international alliance of cities and local governments with a shared long-term vision of promoting and supporting voluntary action to combat climate change and move to a low emission, resilient society." Today, 7,513 cities, representing 699,246,123 people worldwide, have committed to the GCM. The Compact of Mayors is a global coalition of mayors and city officials pledging to reduce local greenhouse gas emissions, enhance resiliency to climate change, and to track their progress transparently (Global Covenant of Mayors for Climate & Energy 2017).

...the GCM [Global Covenant of Mayors for Climate & Energy] is "an international alliance of cities and local governments with a shared long-term vision of promoting and supporting voluntary action to combat climate change and move to a low emission, resilient society."

As part of Easton's commitment to the GCM, this report[1] describes the methods used to develop a vulnerability assessment for the City of Easton, Pennsylvania. Under the adaptation compliance requirements, the GCM stipulates "that participating cities undertake a program of climate change risk and vulnerability assessment and adaptation planning within a three-year period of joining the compact" (Global Covenant of Mayors for Climate & Energy 2017). Subsequently, this report represents a concerted effort to understand, analyze and present Easton's current and projected vulnerability to climate change.

Ultimately, this report represents a piece of Easton's efforts to adapt to and mitigate the effects of climate change and can be used to inform adaptation policies for the city.

Nurture Nature Center (a non-profit organization contracted by the City of Easton) is facilitating Easton's successful participation in the GCM. To this end, this vulnerability assessment represents the work of an interdisciplinary team of students from Lafayette College enrolled in an upper level engineering elective course titled Sustainable Solutions and staff from the Nurture Nature Center. Using Easton's work on the CDP Cities 2017 Information Request as a launching point for this report, flooding and extreme heat events were determined to be the two central threats for Easton — historically, currently, and as projected for the future. Ultimately, this report represents a piece of Easton's efforts to adapt to and mitigate the effects of climate change and can be used to inform adaptation policies for the city.

[1] Structure of this report is modeled from the *Technical Report: Minneapolis Climate Change Vulnerability Assessment*.

Executive Summary

The City of Easton is particularly vulnerable to extreme heat events and flooding. With a changing climate the frequency, intensity and impact of these natural hazards is projected to increase. To assess the vulnerability of the City of Easton, landscape and social vulnerability were analyzed for both extreme heat events and flooding events. Built and non-built environments were considered for landscape vulnerability, and social vulnerability was categorized into specific vulnerable populations. Considering landscape and social vulnerability together suggests that the Downtown area of the City is the most vulnerable and resources and planning should be prioritized accordingly. The West Ward neighborhood is also highly vulnerable due to its social vulnerability and built landscape.

Easton is susceptible to flooding due to its geographic features. Its proximity to the Delaware and Lehigh Rivers and the Bushkill Creek, combined with Easton's expansive areas of low elevation, create a vulnerable natural landscape. Continuous development of impervious surfaces throughout these geographically vulnerable areas adds to the propagation of flood water —thereby creating conditions favorable to damaging flooding. The large percentage of impervious surfaces throughout the City also contributes to the phenomenon known as the urban heat island effect, a principle which causes urban environments to be hotter than their rural counterparts and make them more vulnerable to extreme heat events.

Extreme heat events and flooding challenge the resilience of Easton's infrastructure network. Critical facilities (buildings or organizations that can provide aid) are crucial to supporting city residents. As Easton experiences increasing average and peak temperatures, the probability of electricity demand exceeding capacity increases, which would leave the city at increasing risk of blackouts. Increased heavy precipitation events may strain the City's stormwater infrastructure and increase the risk of flooding. The City of Easton has responded to flood events in the past by creating evacuation plans, raising the working spaces of government buildings, and staggering fire departments to make response efforts more effective. The City still needs to ensure that livable spaces are above the floodplains, that historic districts are protected, and that critical facilities will not be inundated from future storms.

With a changing climate the frequency, intensity and impact of these natural hazards [extreme heat events and flooding] is projected to increase.

An extreme weather event would disproportionately affect certain portions of the population of Easton. These portions of the population have been identified by their ability to respond and adapt to an extreme weather event. The most defining features of vulnerable populations in Easton are physical ability and access to resources. Most of the individuals in vulnerable groups suffer from either a lessened physical ability, whether it be due to age or illness, or lack of access to resources because of financial reasons. The largest vulnerable population in Easton is the elderly, aged 65 and above.

Easton, PA, 2004

Table of Contents

1. Introduction

A climate change vulnerability assessment is an assessment (qualitative and quantitative) to determine the nature, type, consequences and extent of risks posed by climate change. Existing vulnerabilities are evaluated and potential future climate hazards considered in order to assess and understand the potential impacts on residents, operations, health and environment and the degree to which the system is susceptible to adverse climate change effects. Vulnerability is defined by the Global Covenant of Mayors as the "function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." Vulnerability assessments are often broken down by social and landscape vulnerability. Landscape vulnerability represents how the characteristics of the physical environment impacts the city's vulnerability for both built and non-built environments. Social vulnerability represents how the specific demographics of a city influence the relative risk of certain populations to climate change impacts.

This vulnerability assessment focuses on vulnerability in the specific context of flooding and extreme heat events, as these are the two most significant hazards for the City of Easton. Section 2 describes past, present and future conditions of these events. Sections 3 and 4 describe Easton's landscape vulnerability, Section 5 describes Easton's social vulnerability, and Section 6 assesses the impact of these hazards. Section 7 summarizes and outlines critical points of the vulnerability assessment.

Located in Northampton County, Pennsylvania, the City of Easton was founded in the 1750s. The city's location at the confluence of the Delaware and Lehigh Rivers made it a key center of travel, trade and industry in colonial America. The City acted as an important military center during the Revolutionary War and is notable for being one of the first three places where the Declaration of Independence was read. During the Industrial Revolution, its location, once again, played a vital role in the commerce of Lehigh Valley. In fact, "the canals that still exist today connected the coal, iron, and steel industries. With the advent of the railroad, Easton's close proximity to both New York City and Philadelphia served it well in establishing a strong economy" (Easton Main Street Initiative 2018).

Today, Easton is well-known for being the home of the famous Hall of Fame boxer, Larry Holmes, the Crayola Factory and Lafayette College. The city is split up into four sections: Downtown (which contains the Historic District), West Ward, South Side, and College Hill (Figure 1). The total population of Easton is 27,014 people, as of the 2016 American Community Survey. Figure 2 shows the distribution of the population throughout Easton.

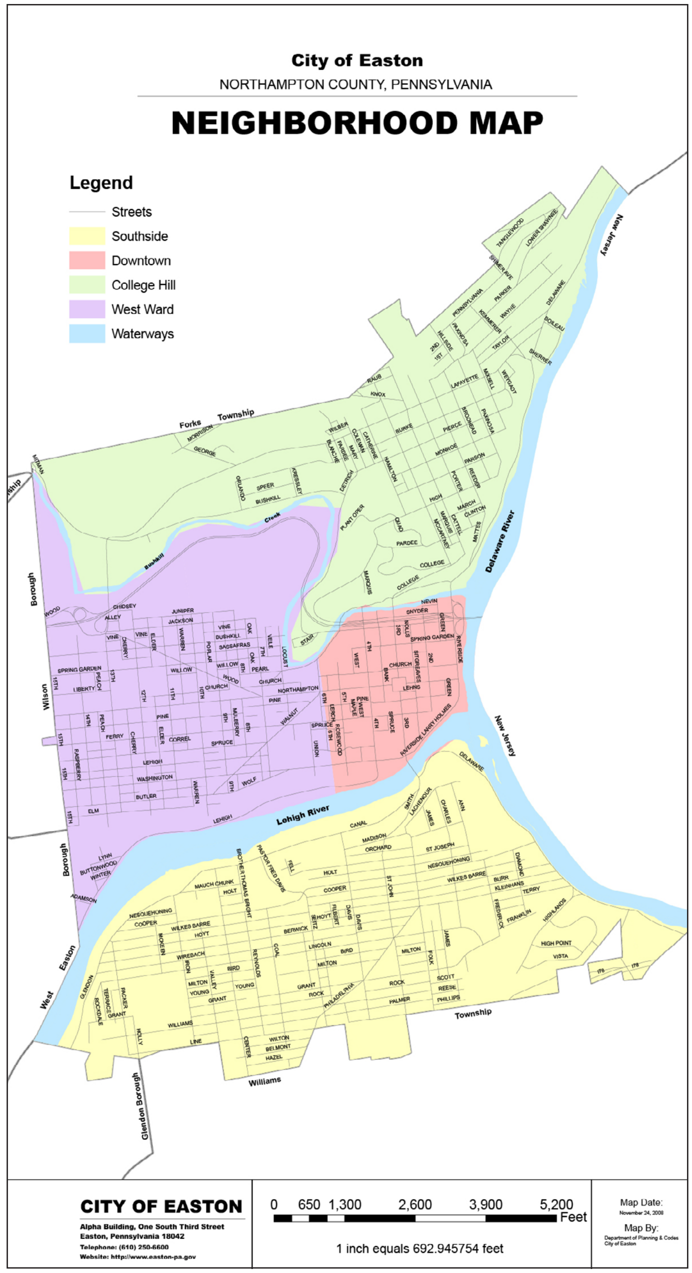


Figure 1. Map of the four neighborhoods in Easton.

Easton is an arts-centered community. Easton's diversity is exhibited in its distinct collection of restaurants, live music events, art galleries, Farmer's Market and various festivals that are held throughout each year. Table 1 shows the distribution of demographics in Easton by race.

Table 1. Demographics of Easton from the 2016 American Community Survey

Race	Number
White	18,054
African American	4,214
American Indian and Alaska Native	494
Asian	877
Hispanic or Latino	6,232

Easton's location and demographics are further analyzed throughout this report with respect to how they contribute to increased vulnerability of the city during extreme heat and flooding events which are changing with climate change.

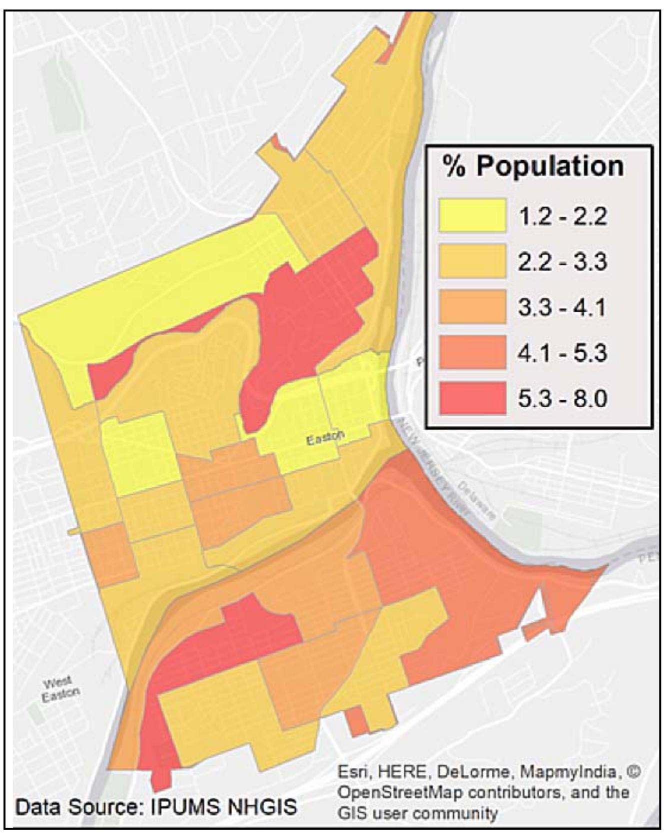


Figure 2. Distribution of population density throughout the City of Easton

Climate change – past, present and future

The global average temperature has been steadily increasing over the past 30 years with the top five warmest years on record (since 1880) all occurring since 2010 (NOAA NCEI 2016). The Intergovernmental Panel on Climate Change (IPCC) Summary for Policy-makers states that this 30-year period has seen the warmest temperatures ever. The IPCC is a scientific, international body under the United Nations that is dedicated to providing the world with an objective view on climate change and the impacts associated with it. They publish a global assessment report of climate change periodically with the last one being finished in 2014. Based on the data from this assessment report, global temperatures have risen 0.85°C over the past century (IPCC 2014). This trend of temperature increase is expected to grow to at least 2°C over the next 20 years based on the current greenhouse gas emissions.

The Intergovernmental Panel on Climate Change (IPCC) Summary for Policymakers states that this 30-year period has seen the warmest temperatures ever.

The IPCC states that there is evidence that indicates a strong, almost linear relationship between cumulative carbon dioxide emissions and projected global temperatures. In order to analyze this relationship, it is necessary to develop different scenarios regarding cumulative carbon dioxide emissions (IPCC 2014). The IPCC Fifth Assessment Report focuses on four main projections for greenhouse gas emissions and their atmospheric concentrations, air pollutant emissions, and land use. These are referred to as representative concentration pathway or RCP's, which "include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high greenhouse gas emissions (RCP8.5)" (IPCC 2014). Scenarios that have no strategies to constrain emissions (termed baseline scenarios) are RCP's ranging from 6-8.5. Essentially, these different pathways provide us with the best and the worst-case scenarios based on different assumptions of greenhouse gas emissions in the near future.

Specifically, in the northeastern United States annual average temperatures have increased by 1.43°F for the period 1986-2016 compared to 1901-1960. The rate of temperature change for Northampton County, PA (1901 to 2014) has been 2 to 2.5°F based on data from the National Oceanic and Atmospheric Administration (NOAA 2016). The average annual temperature for Easton, PA has shown an upward linear trend with a slope of about 0.1 degrees from 1995 to 2017 (Figure 3).

The rate of temperature change for Northampton County, PA (1901 to 2014) has been 2 to 2.5°F...

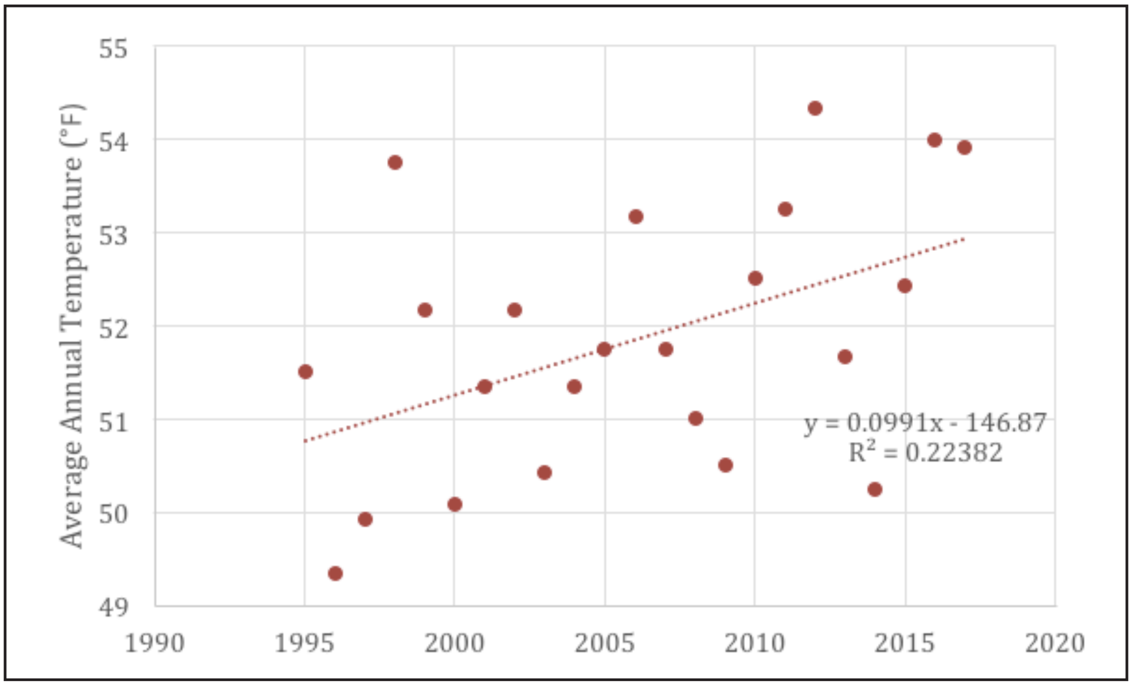


Figure 3. Average annual temperatures for Easton, PA (weatherdatadepot.com)

Extreme temperatures mirror this trend with a high number of heat waves (31 to 60 heatwave warnings by census tract for 2005-2017) for the Easton area. These trends are predicted to continue and intensify with the changing climate. In highly urbanized environments, the urban heat island effect is also a factor in extreme temperatures as increases in concrete/asphalt and reductions in green canopy result in urbanized areas registering a higher temperature than surrounding, vegetated suburban and rural areas.

According to the Fourth National Climate Assessment, which utilized the Intergovernmental Panel on Climate Change's Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios, the annual average temperature across the United States is projected to increase by 2.5°F (RCP 4.5) and 2.9°F (RCP 8.5) by 2021-2050, relative to 1976-2005. For the northeast the change in annual average temperature is 3.98°F (RCP 4.5) and 5.09°F (RCP 8.5) by 2036-2065 and 5.27°F (RCP 4.5) and 9.11°F (RCP 8.5) by 2071-2100 (Vose et al. 2017).

Extreme temperatures are projected to increase more than average and the number of days above 90°F will rise and heat waves will intensify. In the northeast, the warmest day is projected to change by 6.51°F with extreme heat waves (a 5 day 1 in 10-year event) increasing by 12.88°F (Vose et al. 2017). These changes are the difference between the average for 2036-2065 and the average for 1976-2005 under the RCP 8.5 scenario. Very rare extreme events (1 in 20 year) for maximum temperatures are projected to occur annually. These changes translate to about 20-30 more days above 90°F and 20-30 fewer days below freezing in the northeastern parts of the United States by mid-century (RCP 8.5) (Vose et al. 2017).

Figure 4 shows the observed (around 2°F since the beginning of the 20th century) and projected temperature change for a low and high emissions scenario for Pennsylvania. Much of the warming has been in the winter and spring, along with an increase in the number of warm nights (minimum temperature above 70°F) and decrease in number of cold nights (minimum temperature below 0°F) (Frankson et al. 2017). The annual mean temperature change across the state is projected to be 5.9 to 6.3°F (3.3 to 3.5°C) temperature by 2041-2070 relative to 1971-2000 as modeled by the CMIP5, statistically downscaled.

Extreme temperatures are projected to increase more than average and the number of days above 90°F will rise and heat waves will intensify.

Observed and Projected Temperature Change

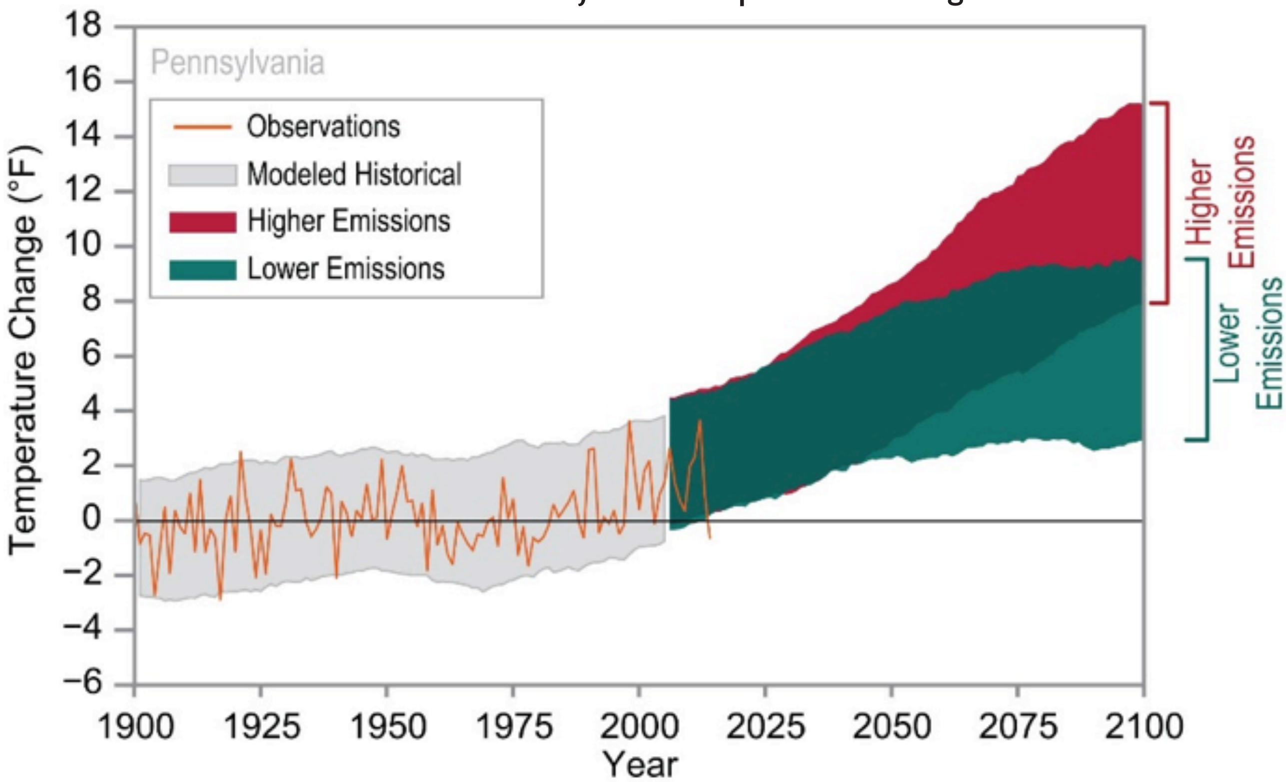


Figure 4. Observed and projected temperature change for Pennsylvania from Frankson et al. 2017

Temperatures are not the only variable changing under climate change. Globally, annual maximum daily precipitation increased 8.5% in the last 110 years with extreme precipitation events increasing (Easterling et al. 2017). With an increase in atmospheric water vapor from a warming climate, the climate will also get wetter in the northeastern United States which results in heavy rainfall events. For Northampton County, the rate of precipitation change has been 5 to 6% from 1901 to 2016 (NOAA 2016). There are also increasing trends in maximum streamflow in the northeast consistent with the increase in observed extreme precipitation (Wehner et al. 2017). The trend of increased frequency and magnitude of heavy precipitation events is expected to continue with the mean annual precipitation change for the eastern half of Pennsylvania projected to be between 10 and 12% increase by 2041-2070 relative to 1971-2000, as modeled with CMIP5 statistically downscaled under the IPCC RCP 8.5 emissions scenario (Shortle et al. 2015). Total annual precipitation projections for 2041-2070 are shown in

Figure 5 with the area including Easton predicted to have the highest amounts of precipitation.

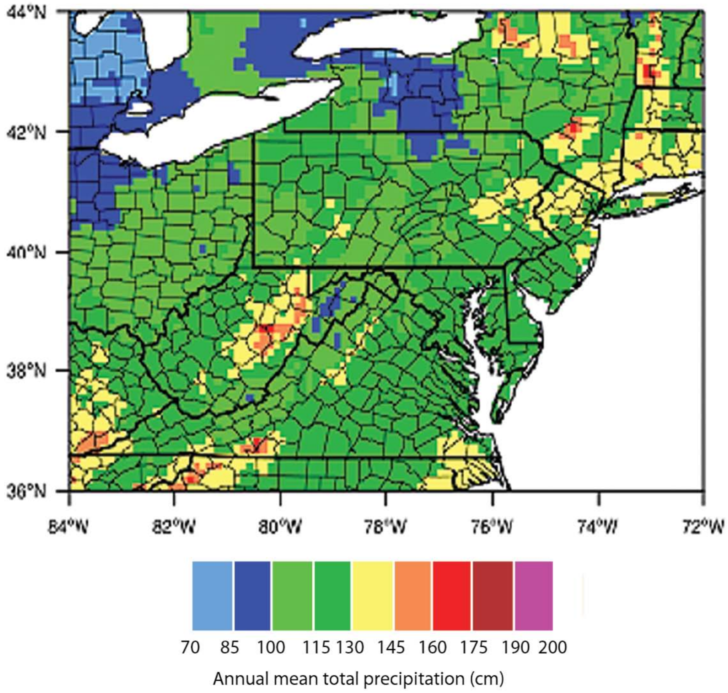


Figure 5. Projections of annual total precipitation for 2041-2070 from the CMIP5 statistically downscaled model under RCP8.5 emissions scenario. From the Pennsylvania Climate Impact Assessment Update 2015

Changes to runoff in the Easton area may increase by 15-20% and even up to 25% (Figure 7). These projections suggest a high probability of an increased risk of flooding in the future especially in the winter and spring months.

Precipitation is expected to increase in all seasons with large increases in winter (14%) and small increases in summer and fall precipitation (Figure 6) and months of above-normal precipitation will increase (Shortle et al. 2015). Since heavy precipitation events can contribute to flooding events, changes to precipitation rates suggest the future potential occurrence of flooding conditions, although this relationship is complex as additional factors including soil moisture and land cover affect flooding occurrence as well. Changes to runoff in the Easton area may increase by 15-20% and even up to 25% (Figure 7). These projections suggest a high probability of an increased risk of flooding in the future especially in the winter and spring months. Consistent with increasing precipitation, the intensity and magnitude of river flooding is also expected to increase.

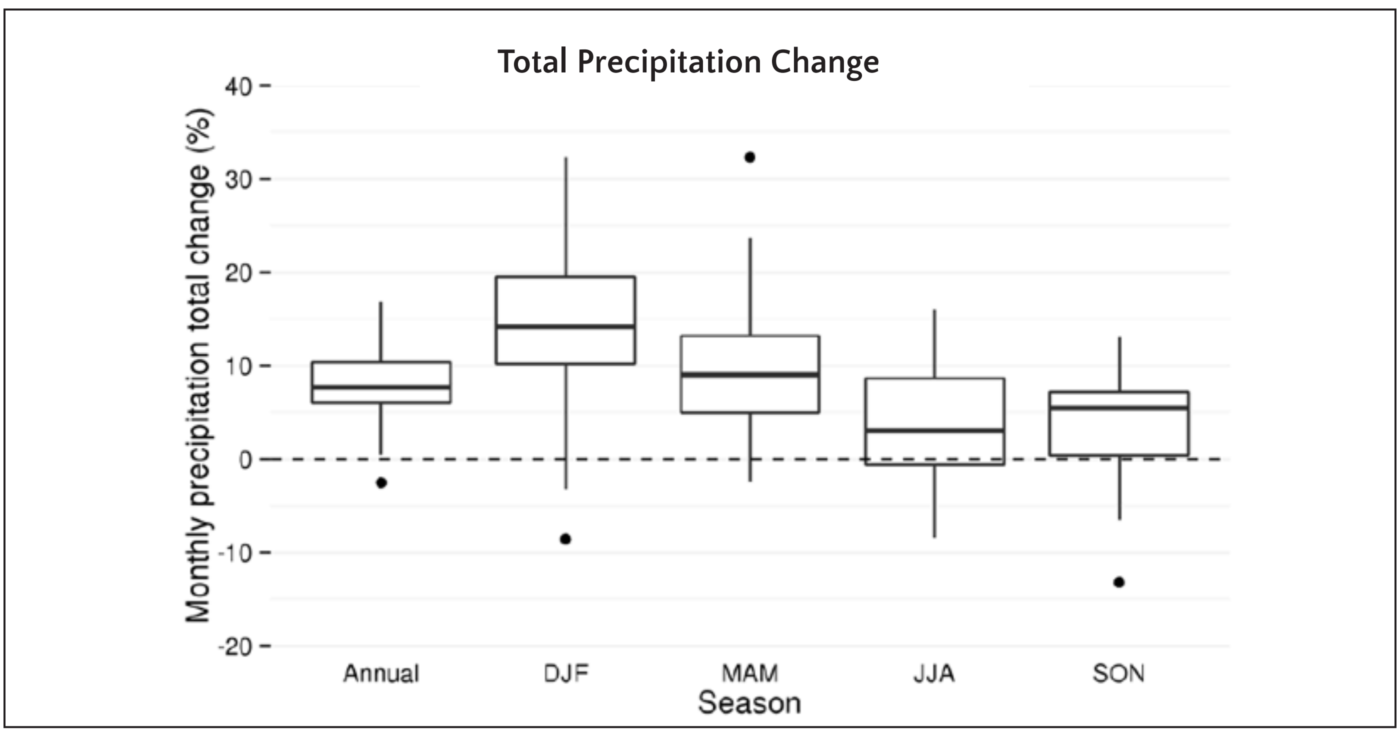


Figure 6. Annual and seasonal precipitation change by 2041-2070 relative to historical from CMIP5 model simulations reported in the PA Climate Impacts Assessment Report Update

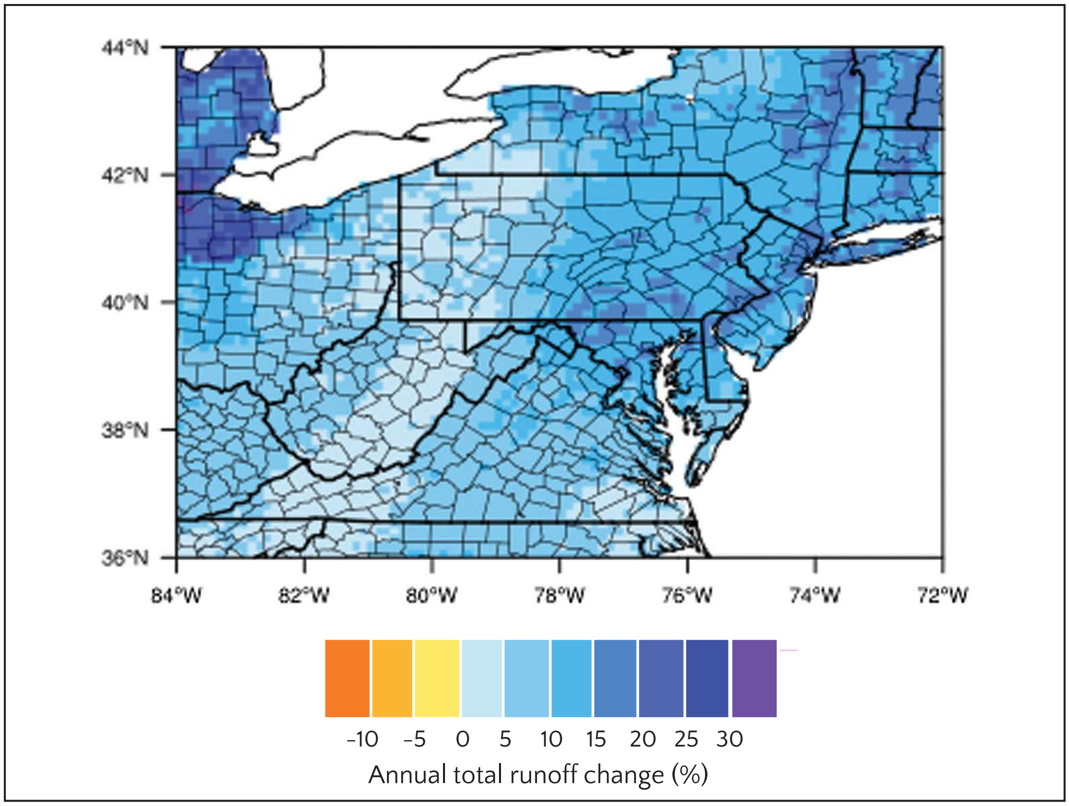


Figure 7. Projected change in annual mean runoff by 2041-2070 compared to 1971-2000 from the CMIP5 statistically downscaled model under the RCP8.5 emissions scenario. From the Pennsylvania Climate Impact Assessment Update 2015.

With this context of past, present and future climate change, the following sections focus specifically on two natural hazards that are most significant for the City of Easton, PA – extreme heat events and flooding.

City of Easton, 2011

2. Past, Present and Future of Extreme Weather Events in Easton

2.1. Extreme Heat Events in Easton

Extreme heat is the leading cause of weather related deaths in the United States, beating out natural disasters such as hurricanes and floods (EPA and CDC 2016). Easton has experienced several heat waves, defined as three or more consecutive days with temperatures above 90°F, between 1997 and 2014. Figure 8 shows historical temperature data from the Lehigh Valley International Airport (ABE)[2], located in Allentown, PA.

Extreme temperatures are not only dangerous during the day but can prevent an area from properly cooling during the evening. This lack of cooling (elevated nighttime temperatures) makes extended heat waves more dangerous.

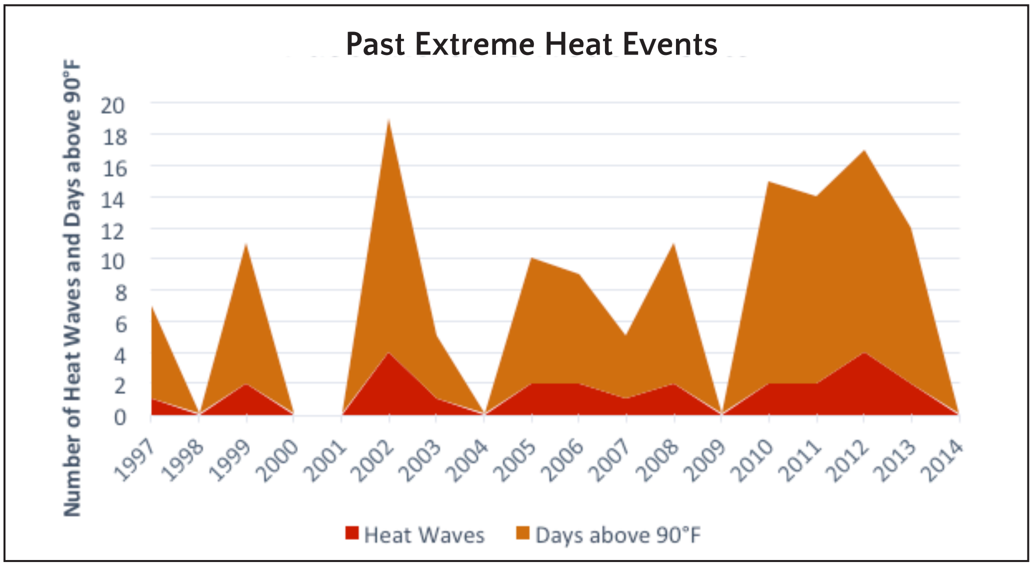


Figure 8. Number of heat waves (red) and days above 90°F (orange) per year as recorded at the Lehigh International Airport Weather Station

The years between 2010 and 2013 had an increase in the number of days with temperatures reaching 90°F and an increase in the frequency of heat waves. The lack of recognizable pattern in the data reflects the variability of heat waves, however, Easton's temperature record suggests summer heat waves are regularly occurring events. From 2015 to 2017, there were three summer heat waves affecting Easton residents, described in Table 2.

Extreme temperatures are not only dangerous during the day but can prevent an area from properly cooling during the evening. This lack of cooling (elevated nighttime temperatures) makes extended heat waves more dangerous. The classification of a heat wave requires three daily consecutive highs above 90°F, but the total number of days above 90°F can indicate a hotter environment as well. There were 7 days above 90°F in 2015, 27 days in 2016, and 2 days in 2017.

Table 2. Recent heat waves affecting Easton from 2015 to 2017.

Heat Wave Year	Start Date	Length (Days)	High Temp.	Low Temp.
2015	August 16th	3	93	91
2016	July 22nd	3	94	91
2016	August 11th	4	95	91

[2]ABE is located about 13 miles from Easton and was used due to the more complete and longer data record compared to more local stations in Easton.

Further, due to the urban heat island (UHI) effect, some areas of Easton may be more at risk than others during extreme heat events. The UHI effect is a phenomenon in urban areas that causes higher air and surface temperatures in cities compared to adjacent rural and suburban environments (Lowe 2016). The UHI effect is mainly due to the landscape qualities of an urban area including increased manmade materials and reduced green spaces. Due to the increased temperatures, high amounts of impervious surfaces, reduced green spaces and tree canopy coverage, urban areas have high energy consumption due to cooling needs. With the changing climate, the UHI effect will become more prevalent in the future and will be a factor in Easton's vulnerability to extreme heat events.

Easton could see an increase of 40 to 50 days with temperatures exceeding 90°F. It is expected that extreme heat events that have been observed every 20 years could happen as often as every two to four years.

To determine how the landscape of Easton makes the city more vulnerable to the UHI effect, historical temperature data of two different weather stations in June, July, and August of 2015, 2016, and 2017 were compared - one weather station located in a more rural setting on Sullivan Trail, and one located at the Nurture Nature Center in downtown Easton. The average temperature in the urban downtown was 2.16° higher than around the suburban Sullivan Trail, while the average low temperature was 3° higher. This data supports the UHI effect in Easton. The annual average temperature of Easton is currently 49.36°F (based on data from 1981-2010) with an observed change of 1.2°F (compared to historical data from 1951-1980). With the effects of climate change, projected changes are expected to range from 2.15°F to 5.91°F (these are based on the difference between current conditions and the projected period 2041-2070). Easton could see an increase of 40 to 50 days with temperatures exceeding 90°F. It is expected that extreme heat events that have been observed every 20 years could happen as often as every two to four years.

The CDC estimates that the duration, severity, and frequency of extreme heat events will increase in the near future as a direct result of climate change (EPA and CDC 2016). Not only will these events last longer, but they will also occur more frequently. The number of days with temperatures over 90°F or more is estimated to increase significantly over the course of the century. The City should be prepared for each day above the extreme heat temperature threshold, with the preparation and attention only increasing with each following consecutive day.

2.2 Flooding Events

FEMA defines a flood as "a general and temporary condition of partial or complete inundation of 2 or more acres of normally dry land area or of 2 or more properties from: overflow of inland or tidal waters; or unusual and rapid accumulation or runoff of surface waters from any source; or mudflow." Easton has a long and arduous past with flooding. With its location between and along both the Delaware River and the Lehigh River, Easton has, is, and will continue to be particularly vulnerable to flooding. These three time periods - the past, present, and future - are critical to understanding Easton's relationship with flooding.

Specifically, since 1841, the Delaware River Basin, of which Easton is a part of, has suffered from thirteen different flood events (Kucz 2007). In Table 3, ten of these flooding events are ranked in terms of their severity, measured by the flood's stage and its flow. The floods did not have one dominant cause, rather they resulted from tropical storm activity, spring rain and spring rain and snowmelt (Kucz 2007). Successive precipitation or storm events led to the largest floods. The lack of a single, isolated variable demonstrates the difficulty of addressing flooding in Easton, as the causes are diverse. Figure 9 shows a plot of this data, combined with information from the National Weather Service, to highlight the increased frequency of flooding in the past 15 years (NWS 2016).

Table 3. Historic quantified flood events of the Delaware River (Kucz 2007).

Rank	Date	Stage (ft)	Flow (cfs)	Cause(s)
1	August 19, 1955	38.85	340000	Hurricane Diane (Aug 18-19) preceded by Hurricane Connie (Aug 11-15)
2	October 10, 1903	35.9	275000	Heavy rains
3	April 4, 2005	34.07	262000	2"-5" Rainfall preceded by abnormal snowpack/snowmelt from a rainfall event on March 28/29, 2005
4	June 29, 2006	33.62	254000	Tropical disturbance with extremely heavy rainfall (3"-10") preceded by June 24-26 heavy rainfall event
5	January 8, 1841	33.3*	250000	Snowmelt and Ice choked floodwaters combined with heavy rains
6	March 19, 1936	32.45	237000	Excessive rain and snowmelt
7	September 19, 2004	30.95	216000	Tropical Storm Ivan preceded by Tropical storm Frances one week earlier
8	January 20, 1996	28.72	187000	Excessive rain and warm temperatures coupled with excessive snowpack/snowmelt/ice jams
9	May 24, 1942	27.5	164000	Severe rainfall
10	April 1, 1940	26.47	154000	Moderate to heavy rainfall combined with moderately heavy snowmelt

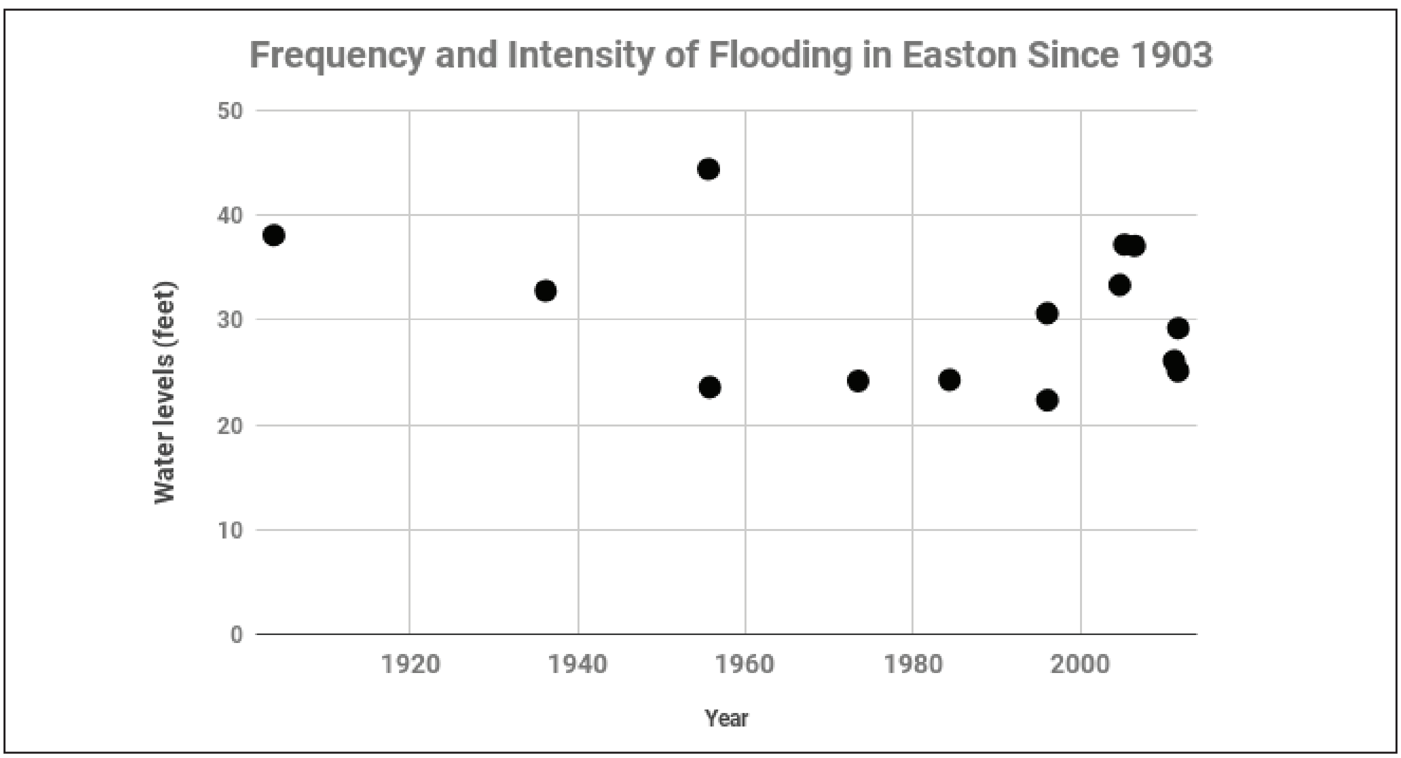


Figure 9. Frequency and intensity of flooding in Easton since 1903.

Six major flood events have occurred in Easton's recent history from 2004 to 2011. Instead of moving chronologically, it will be more useful to assess these six flooding events thematically: tropical activity and spring rain/snowmelt. Tropical activity accounted for the floods in 2004, 2006, and two in 2011, with Tropical Storm Ivan, tropical disturbances, Hurricane Irene and Tropical Storm Lee being the causes, respectively (Kucz 2007). In the case of the 2004 flood, thousands of residents stretching from Easton to Trenton were forced to evacuate their homes and seek shelter from the incoming water. In areas of Easton, the flooding reached to 25 feet above the flood level. In certain areas, the Delaware River received up to six inches of additional rainfall. The severity of this flooding was a result of extreme and heavy rainfall—brought by Hurricane Ivan (Kocieniewski 2004).

Similar circumstances surround the flood of 2006. In the summer of 2006, Easton received extreme rainfall for six consecutive days. On the final day, which experienced the heaviest rainfall, the rain no longer infiltrated the area surrounding the Delaware River. With the three floods of 2011, however, the institutional knowledge of Easton's administration had grown and adapted significantly since the flooding in 2004. In conjunction with the decreased severity of these floods and increased preparedness of the City, the impacts of the 2011 floods were markedly less egregious than those less than a decade earlier. Though Easton itself may have become more resilient to flooding, as the intensity and frequency of heavy rainfall events increases as projected under climate change, the risk of severe flooding may increase.

The flood of 2005 was brought on by different conditions: spring rain and snowmelt. Instead of a tropical storm or a hurricane, the area north of the Delaware River became saturated due to long-lasting moist conditions, causing Easton to be particularly vulnerable to a flood event (Kucz 2007). The accumulation of five inches of snow along the Delaware River caused more extreme flooding in the surrounding area and in parts of the Delaware River, this flood was considered a 100-year flood event, or a flood that statistically has a 1-percent chance of occurring in any given year. Two other flooding events listed in Table 3 were also a result of winter snowmelt and spring rain. As a whole, the causal connection between tropical activity and spring rain with flooding may be useful to Easton in understanding its ability to prepare for and mitigate the effects of extreme rainfall.

Six major flood events have occurred in Easton's recent history from 2004 to 2011.

Though the physical damage caused by flooding in Easton has been significant, the economic damage has been equally notable and the increased frequency and intensity of extreme weather events strains the local budget because of necessary repairs and mitigation efforts. The flood in 2004 resulted in expenses that totaled almost $2.5 million. Most of the repairs went to rebuilding the sewage pumping stations and building new second floor offices at the Department of Public Works complex. Though they were costly, the efforts of this rebuild allowed the city to be much better equipped--both in terms of physical responses and institutional knowledge—for future storms. City officials can now be out of the complex within three hours. Subsequently, the repair costs for the floods following the one in 2004 were "minimal" thanks to the rebuild efforts with long-term solutions in mind.

Damage from Hurricane Ivan (2004). Photos courtesy of City of Easton Fire Department

Due to the state of Pennsylvania warming by more than half of a degree Fahrenheit throughout the last century, heavy rainstorms have become more frequent. The average annual precipitation in Pennsylvania has increased from five to ten percent in the last century. Rising temperatures, shifting rainfall patterns, and increasing intensity and frequency of storms are likely to increase the risk of flooding, specifically during the winter and spring months (EPA 2016). Specifically, for Easton, 12–15% more days of extreme precipitation between 2041–2070 are projected. Within this range of percentages, flooding in Easton may also increase between 12–15%. However, just because extreme precipitation events are projected to increase by 15% does not necessarily mean that flooding in Easton will increase by 15%. There are several variables to consider in understanding how 12–15% more days of extreme precipitation impacts flooding in Easton, including storm drainage systems and development in the greater Lehigh Valley. In many ways, the effects of flooding can be drastically alleviated or worsened due to the capacity of storm drainage systems. Easton's drainage system is built for 100-year floods, at minimum, and functions properly from an underground capacity level. Past flooding in Easton demonstrates that the storm drainage system has not been a significant source of destruction from flooding, however, future flooding may still be a concern for Easton, especially as more rain falls in a shorter amount of time. In this way, the storm drainage system could exacerbate flooding and should be considered a source of uncertainty.

Another variable to consider is the city's interaction with the greater Lehigh Valley in its connection to the larger watershed; meaning the surrounding area's development can affect Easton's vulnerability to flooding. As described in the Lehigh Valley Planning Commission's Annual Development Outlook 2017, apartment and warehouse space has more than doubled over the past few years. These figures demonstrate the increased rates of development and industrialization of the Lehigh Valley and suggest similar patterns will be projected for the area's future (Harris 2017). Hidden underneath these figures of growth are figures of disappearance.

Changes in land use in areas surrounding floodplains exacerbates effects of floods due to increased impervious surfaces and runoff.

The county "is losing 2.3 square miles of farmland to development every year" (Kraft 2016). Between the increase in residential and industrial space and the disappearance of farmland, the changing landscape of the collective watershed impacts Easton's flooding.

Changes in land use in areas surrounding floodplains exacerbates effects of floods due to increased impervious surfaces and runoff. For instance, the removal of wetlands led to a direct increase in property damages from flooding in Florida (Brody et al. 2007); removal of forests in developing countries directly increased the severity of flooding (Bradshaw et al. 2007), and the development of the built environment increased damages and costs of flooding in Texas (Brody et al. 2008).

Due to the uncertainty of impacts from surrounding development and the storm drainage system, it is prudent to assume a greater risk of flooding than given by the predicted increase in extreme precipitation. Consequently, this report estimates that by the year 2050, flooding in Easton may increase by 15% or more. This aligns with the 15-20% projected runoff increase by mid-century shown in Figure 7 in Section 1.

In addition, the IPCC report on extreme weather events states that at small urban hydrology scales, increases in rainfall could range from 10 to 60% by 2100 (Revi et al. 2014). With an increase in extreme precipitation events, the 100 and 500-year floodplains may also change. As NOAA notes, "what would be expected to be a 100-year event based on 1950-1979 data, occurs with an average return interval of 60 years when data from the 1978-2007 period are considered" (Department of Commerce 2013).

Photos courtesy of City of Easton Fire Department (2004).

In addition, the IPCC report on extreme weather events states that at small urban hydrology scales, increases in rainfall could range from 10 to 60% by 2100...
With an increase in extreme precipitation events, the 100 and 500-year floodplains may also change.

2.3 Preparedness of the City of Easton

City officials are always intently watching the Delaware River water levels during times of heavy rains. When levels hit about twenty feet, officials are prepared to react, as outlined in the plan, 500 Bushkill Public Works Complex – Flood Evacuation Measures for Personnel and Equipment. The purpose of the document is "to provide general guidelines for flood operations and relocation of personnel and equipment from the public works complex during episodes of flooding" (see Appendix A) In terms of future preparedness toward flooding events, compared to the past, Easton's Public Works maintains the city is resilient when withstanding extreme weather events such as flooding.

However, it is important to note the evacuation plan outlines the steps for Easton's public works complex, the Public Works Director in correspondence with Bureau Supervisors and other departmental heads to implement in order to protect personnel and equipment. This document does not include a preparedness plan for the residents of Easton.

The differences between Easton officials' and Easton residents' preparedness for extreme weather events was reiterated in a hazard and vulnerability assessment meeting with the City's Police and Fire Chiefs and Environmental Advisory Council in April 2018. Fire Chief John Bast discussed the steps Easton's administration takes to provide support to its residents. With not enough people to run shelters during extreme weather events, local churches open during the day if they have power, and the Salvation Army and the Boys and Girls Club of Easton have opened in the past as well. Most places do not have overnight shelters because they are not set up and equipped to handle night responsibilities. During events, transportation services are available for vulnerable populations to bring them to shelters. However, only four people had to be transferred during Superstorm Sandy.

On the City of Easton's website, there is a page titled ***Emergency Alerts*** where people can read and sign up to receive emergency notifications. The system is powered by a program called Nixle. Only about 3,000 out of about 27,000 residents are signed up for these emergency alerts. Communicating about hazards and extreme events is further complicated by the transiency of some of Easton residents with those living in Easton's West Ward moving every four to five months. The homeless population of Easton has also skyrocketed in recent years, now totaling a couple hundred as estimated by the City Police. Getting information to these populations has become increasingly difficult due to their inconsistent living situations.

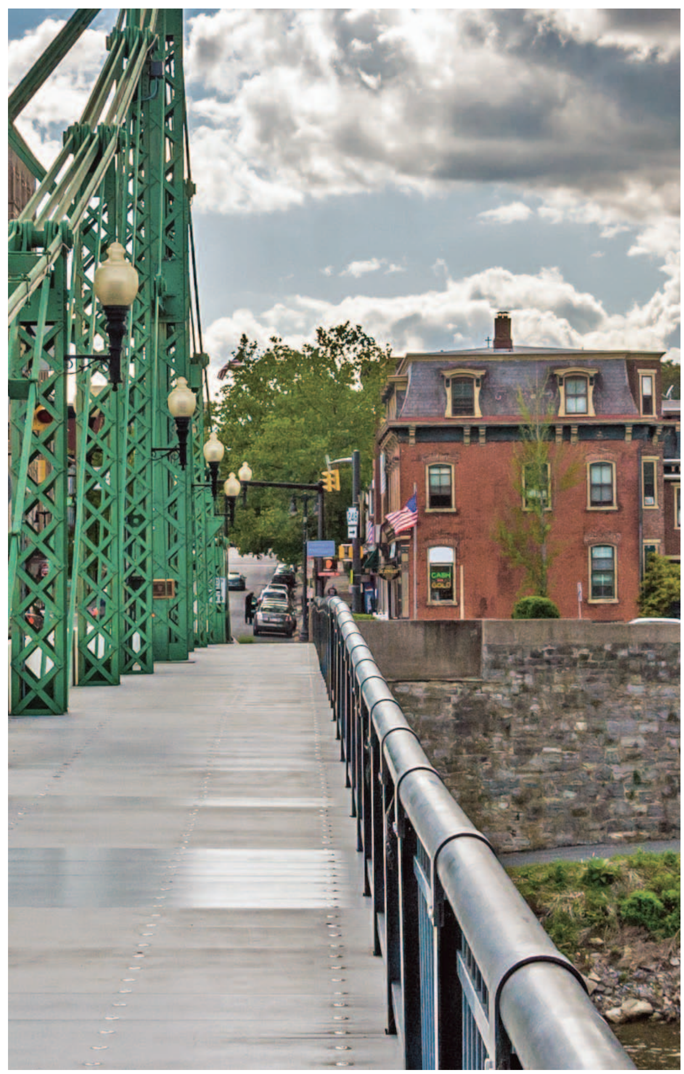
Due to being a small city, the fire department becomes a multipurpose hazards department during extreme events. For example, during Superstorm Sandy, three homes had caught fire at the same time and the department was not equipped to handle all three at once with so many other things going on.

Having only 63 police officers in Easton presents the department with a major disadvantage during times of extreme turmoil. During flooding events, Easton police vehicles are not equipped to hit high waters, which is a major disadvantage for first responders. Due to being a small city, the fire department becomes a multipurpose hazards department during extreme events. For example, during Superstorm Sandy, three homes had caught fire at the same time and the department was not equipped to handle all three at once with so many other things going on. During times like these, the city relies on mutual aid where they call state police for extra forces. Criminal activity and fires are some of the biggest issues that the police and fire department face during times of natural disasters.

It is apparent that while city official infrastructure is able to handle extreme heat and flooding events,

Long-term mitigation efforts prove to be successful and need to be implemented as proactive measures rather than reactionary efforts.

residents lack preparedness. Long-term mitigation efforts prove to be successful and need to be implemented as proactive measures rather than reactionary efforts. The severity of pending environmental changes, improved understanding of mitigation efforts over the last two decades, and changes to the landscape of Easton make the modernization of response to vulnerable groups of critical importance.



3. Landscape Vulnerability: The Natural Environment

3.1. Extreme Heat Events

Impervious surfaces are one of the main contributors to the UHI effect mostly due to low albedo. Albedo determines surface radiation balance - the amount of sunlight and radiation that is either absorbed or reflected by a surface which affects its temperature (Tian et al. 2017). When sunlight is absorbed by surfaces (such as asphalt and other impervious surfaces) and not reflected, it leads to increased air and surface temperatures. Because impervious surfaces have an extremely low albedo, urbanization is a main contributor to the UHI effect (Mohajerani et al. 2017). An urban environment has more buildings and man-made materials such as concrete for sidewalks and asphalt for roads and less green spaces such as parks and gardens compared to a rural or suburban environment. The thermal properties of modern construction materials are very different from natural soil and rock. For example, asphalt concrete has low albedo and high volumetric heat capacity, reaching upwards of 140°F (Mohajerani et al. 2017), absorbing about 90% of the sun's radiation. The West Ward and the Downtown neighborhoods of Easton have the most impervious surfaces and have the most potential for significant UHI effects, increasing their vulnerability to extreme heat events.

Downtown Easton (2017).

Pavements cover about 40% of the urban environment. The percentage of impervious surfaces in each of Easton's 4 major neighborhoods are: 57% in Downtown; 40.4% in West Ward; 36.4% in South Side; and 25.4% in College Hill. The spatial distribution of these surfaces for each Easton neighborhood is shown in Figure 10. Note that the City of Easton just recently (2018) completed an extensive ground level mapping of impervious surfaces to inform a new stormwater management plan but that data is not used here.

The West Ward and the Downtown neighborhoods of Easton have the most impervious surfaces and have the most potential for significant UHI effects, increasing their vulnerability to extreme heat events.

Table 4. Total Area of Impervious Surfaces in Easton neighborhoods.

Neighborhood	Impervious Area	Neighborhood Area Total	% Impervious
West Ward	1,092,782 m2 (270 acres)	2,702,664 m2 (668 acres)	40.4%
Downtown	527,239 m2 (130 acres)	924,260 m2 (228 acres)	57%
South Side	1,323,103 m2 (327 acres)	3,671,539 m2 (907 acres)	36%
College Hill	800,957 m2 (198 acres)	3,151,508 m2 (779 acres)	25.4%

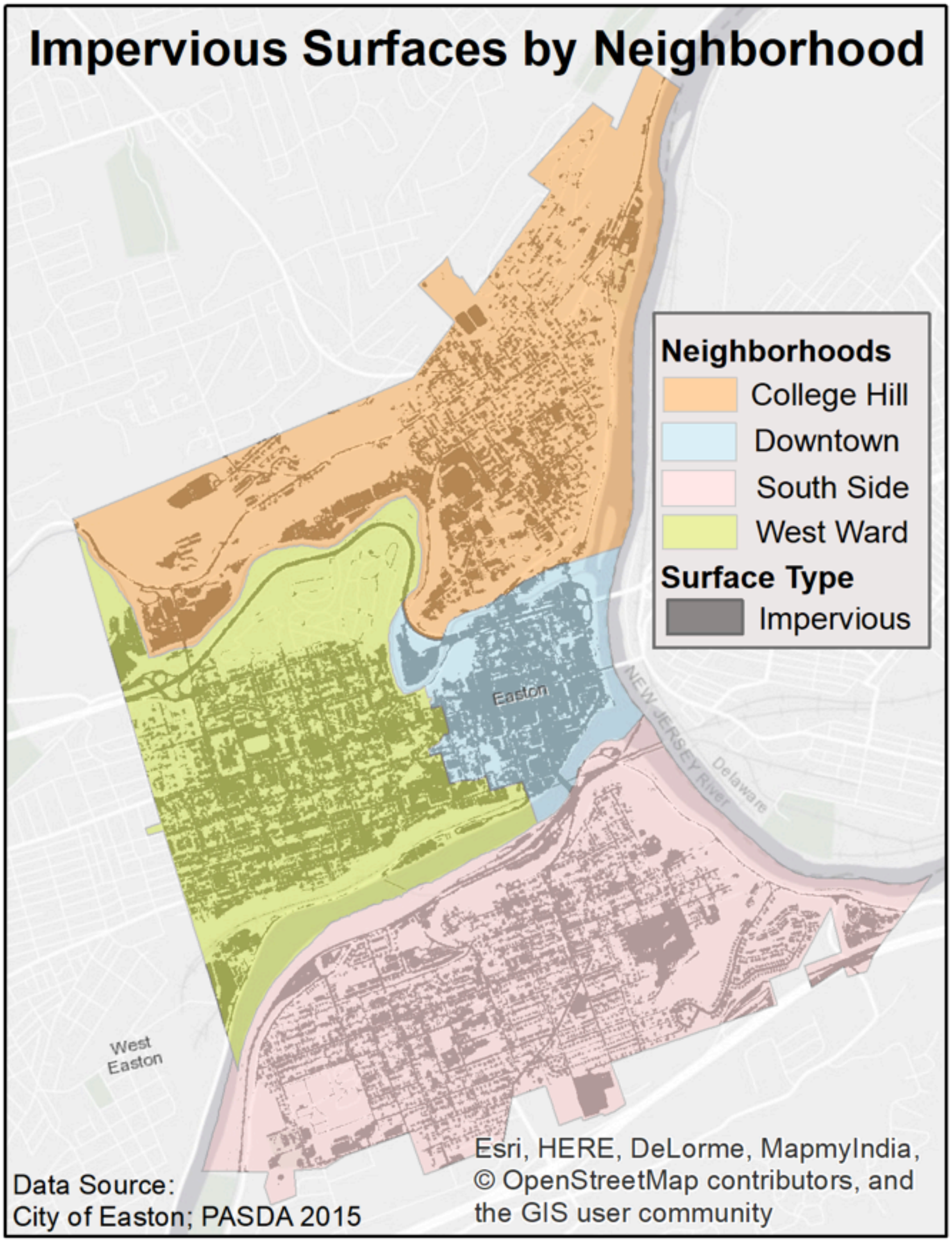


Figure 10. Map of impervious surfaces in Easton, by neighborhood. See Appendix B1.

The main characteristics of Easton's natural landscape are green spaces and tree canopy coverage. These elements increase shade and evapotranspiration, both of which can reduce the UHI effect and decrease vulnerability to extreme heat events. Increasing shade engenders a cooling effect and blocks the sun's light and radiation from being absorbed by impervious surfaces. Parks can play a crucial role in encouraging evapotranspiration, reducing surface temperatures anywhere from 20 to 45°F (EPA 2014). In addition, green spaces result in reduced energy use, improved air quality, reduced pavement maintenance, and improved quality of life. Impervious surfaces and tree canopy intersect in an inversely proportional way; increasing impervious surfaces reduces the amount of green spaces and tree canopy coverage. In the summer, generally 10% to 30% of the sun's energy reaches the surface below the tree with the remainder being absorbed or reflected by the tree itself. Figure 11 shows the amount of tree canopy coverage is lower in West Ward and Downtown compared to South Side and College Hill.

Parks can play a crucial role in encouraging evapotranspiration, reducing surface temperatures anywhere from 20 to 45°F.

Easton currently has a shade tree program - a government program that offers free street facing trees to property owners. Increasing the tree canopy cover is important, but isolated areas of vegetation, such as parks, gardens, yards, and farms are helpful in reducing vulnerability to extreme heat. Parks help the population during extremely hot days, as well planted parks are on average 7.2°F cooler than their urban counterparts (Tan et al. 2016). Considering the zoning district map and the parks map of Easton, the two most vulnerable areas in regard to the natural landscape are the West Ward and Downtown. The West Ward has many small pocket parks, as well as Cottingham stadium, a large park in the middle of the neighborhood. Downtown boasts Scott and Riverside parks, two large parks right on the Delaware river. These parks help reduce the UHI effect,

Photo courtesy of Will Dohe, City of Easton EAC.

but are minimal compared to the mainly concrete and asphalt city blocks.

Increased temperatures during the day and night increase the amount of energy needed to cool residential and commercial areas. Buildings in cities tend to consume more energy and have more CO2 emissions than buildings located in nearby suburban areas. When temperatures go up, the amount of energy use and CO2 emissions increases, causing further future temperature increases. The West Ward and Downtown are the most vulnerable to extreme heat events, as both areas have the most impervious surfaces as well as the least amount of green spaces and tree canopy coverage, resulting in higher energy usage.

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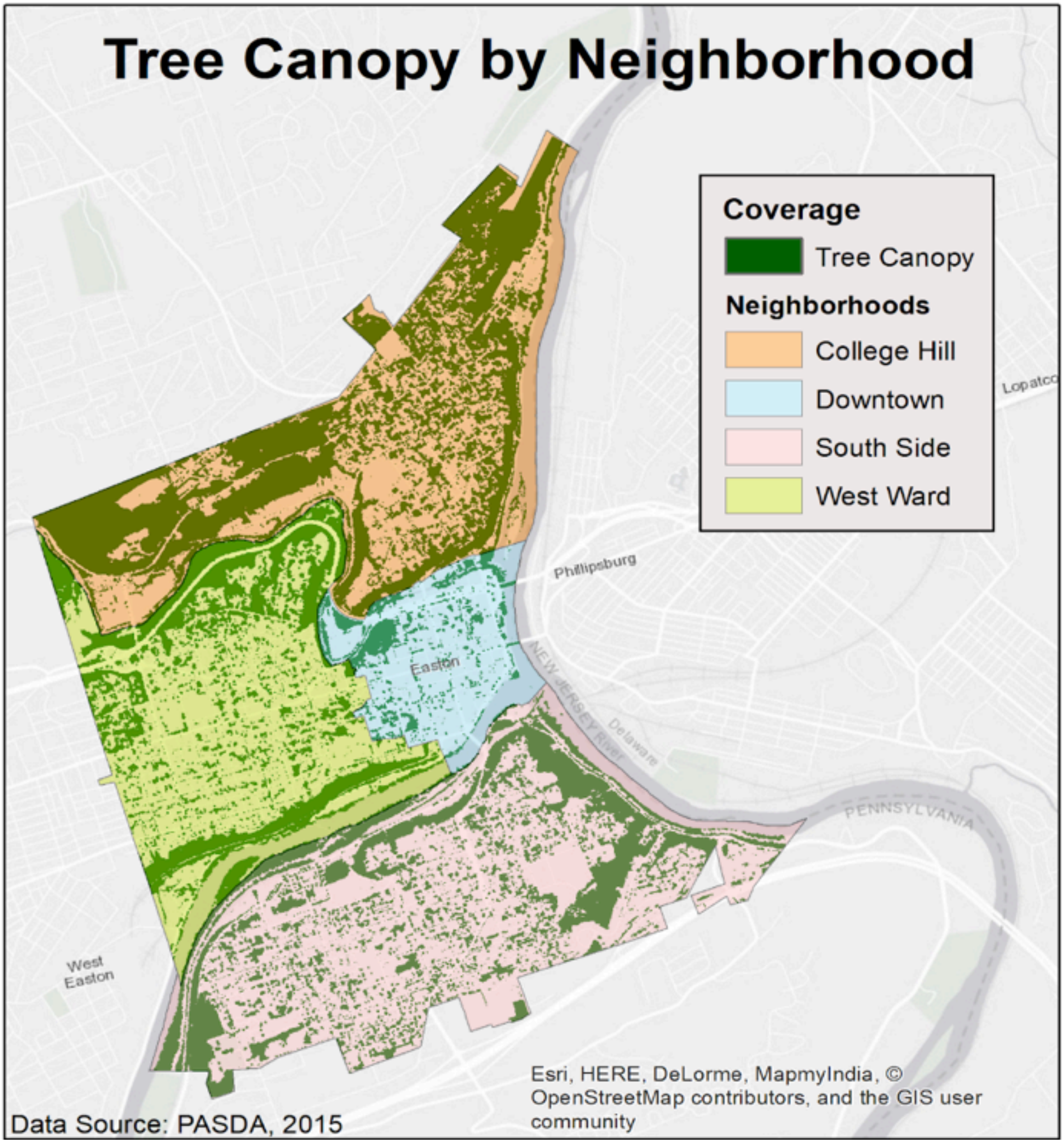

Figure 11. Tree canopy by Neighborhood. See Appendix B2.

3.2. Flooding Events

The physical environment of a city affects its vulnerability to climate change. In considering vulnerability to flooding events, the city's location, floodplains, elevation, slope, and impervious surfaces are important considerations, and Easton's overall location and geography are two of its most vulnerable attributes.

Easton's location along the confluence of the Delaware and Lehigh Rivers is a factor that contributes to extreme flooding, as these two rivers and Bushkill Creek have been subject to flooding in the past. The City of Easton's floodplain is the land along the Delaware River, Lehigh River and Bushkill Creek. FEMA designates floodplains nationwide which are used for zoning and property regulations. As depicted in Figure 12, FEMA has defined two floodplains: a 100-Year floodplain and a 500-Year floodplain. The 100-year floodplain is land that is covered in water during a flood event that has a 1-percent chance of being equaled or exceeded each year. The 500-year floodplain is land that is covered in water during a flood event that has a 0.2-percent chance of being equaled or exceeded each year.

After the repeat flooding in 2004, 2005, and 2006, the City of Easton decided to regulate to the 500-year standard, instead of the 100-year level minimum federal standard. The city's administration made this decision, because "it was safer and complemented their intentions to open up the river corridor and make it the strong environmental, recreational, and economic draw that the community wanted" (NNC 2012). The 500-year floodplain level standard meant that the City could regulate buildings that were 15 feet to 30 feet higher than with the previous 100-year floodplain regulation (NNC 2012). However, this action was later reversed and the current standard is the 100-year flood level. The City decided to create a more comprehensive code, outlined in Easton's Home Rule Charter, relative to floodplain management in the city. This new addition to floodplain management in Easton encompasses the FEMA designated floodplains in addition to special flood hazard areas (SFHAs), classified in the Flood Insurance Study (FIS), as well as the accompanying Flood Insurance Rate Maps (FIRMs) dated July 16, 2014 (City of Easton 2014).

In addition to its physical location at the confluence of two rivers, Easton's geography both contributes to and exacerbates severe flooding. In particular, elevation change and steep slopes in areas bordering the Delaware River, Lehigh River, and Bushkill Creek contribute significantly to the buildup of flood water in the surrounding areas. With high elevations semi-adjacent to the rivers, the low-lying, flat elevation between the water bodies allows for flood water accumulation (Figure 13). This is exacerbated by the increased amount of impervious surface at the lower elevations which consists of much of Easton's downtown.

Confluence of the Lehigh and Delaware Rivers, Easton, PA

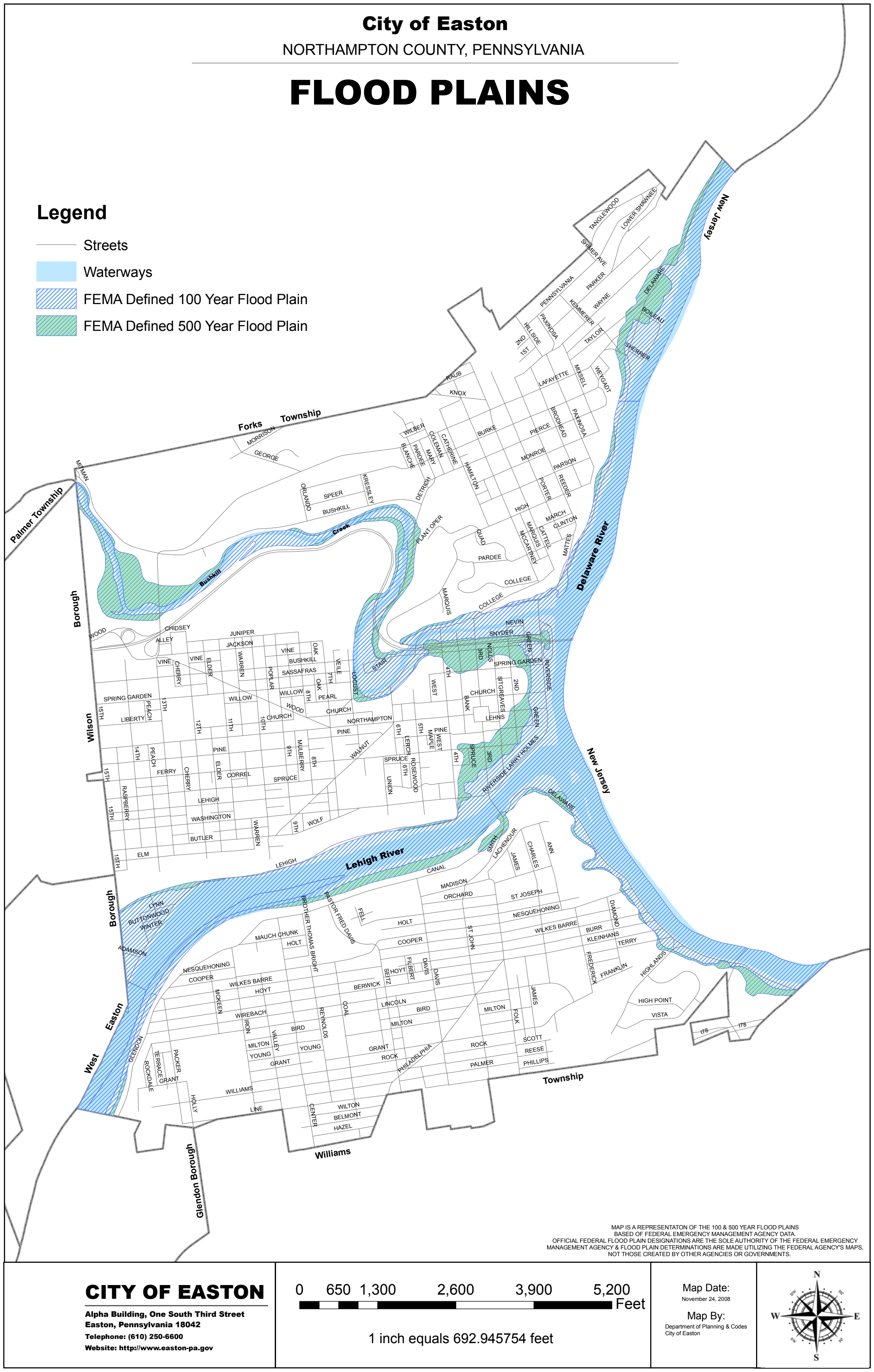

Figure 12. Map of Easton's Floodplains
(Courtesy of the City of Easton)
See Appendix B3 for additional map.

Figure 14 shows how the FEMA designated floodplains intersect with areas of impervious surfaces. While a natural, permeable section of land may absorb excess surface water, paved areas swiftly accumulate flood waters. It is in these low-elevation and predominantly impervious areas that the City sees the most damage on both the built infrastructure and the natural environment. Highlighted areas (green circles) show the areas with high concentrations of impervious surfaces in the floodplain. These low elevations are some of the most vulnerable landscapes in the City of Easton. If the city expands the riparian buffers along its waterways and reduces the amount of impervious surfaces, future flood risk in the urbanized areas near rivers could be limited or minimized.

> *If the city expands the riparian buffers along its waterways and reduces the amount of impervious surfaces, future flood risk in the urbanized areas near the rivers could be limited or minimized.*

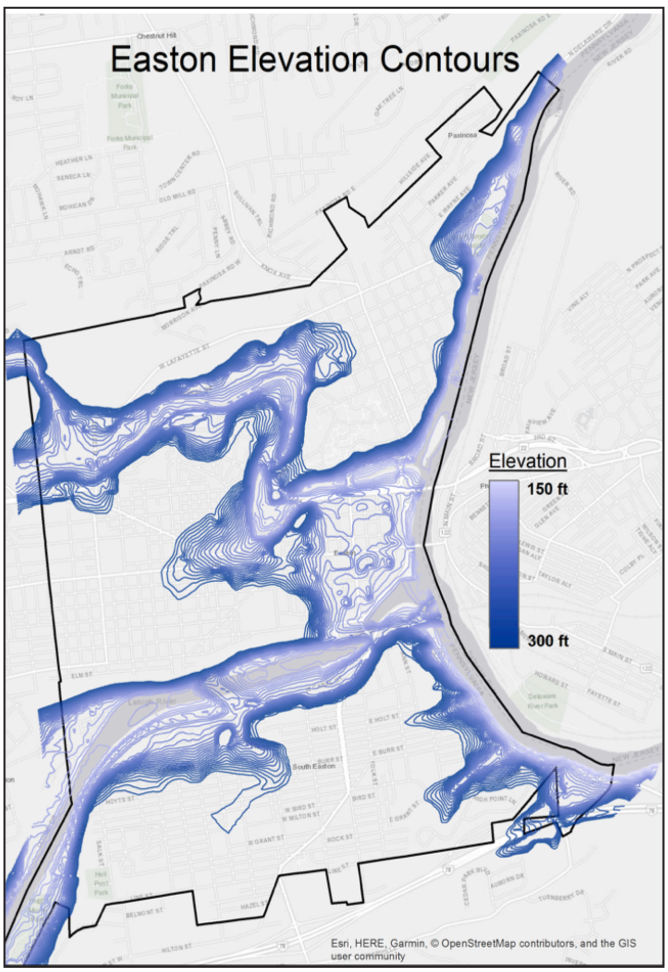

Figure 13. Elevation contours within the City of Easton boundary. *See Appendix B4.*

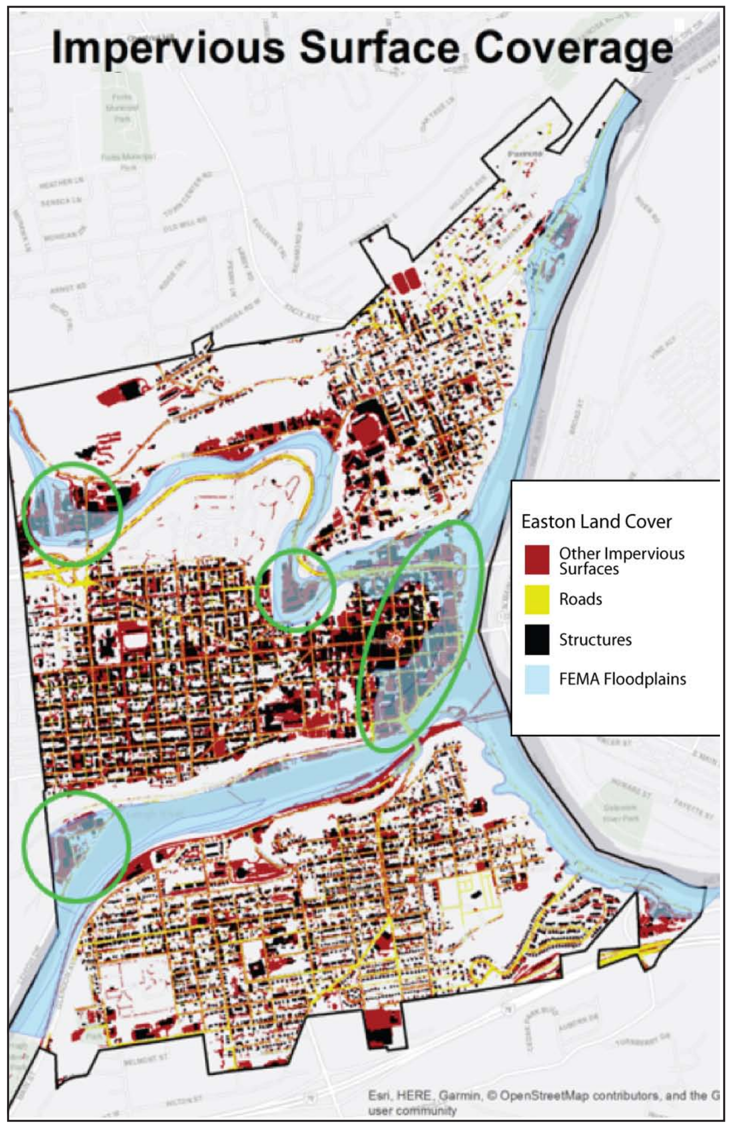

Figure 14. Impervious surfaces throughout the City of Easton with floodplains overlain. Green circles show areas of high vulnerability due to the intersection of impervious surfaces and floodplains. *See Appendix B5.*

4. Landscape Vulnerability: The Built Environment

4.1. Extreme Heat Events

When critical facilities are compromised, Easton's citizens face a greater risk when experiencing extreme weather events. Critical facilities include public services, health facilities, the main roads in which critical facilities can be reached, Easton's Water Authority, and electricity infrastructure. Without resilient infrastructure systems, the Easton community is at a greater risk of finding proper medical treatment. Heat-related diseases such as heat stroke or exhaustion can only be treated through the teamwork of first responders and resources and their timely response.

The most-traveled roads in Easton (Figure 15; Table 5) should receive the highest priority for routine maintenance and repairs to ensure a reliable infrastructure system. In addition, the Philadelphia Ave./St. John St/ Smith Ave corridor is critical for connecting South Side to the rest of Easton. Ordinary maintenance cannot be performed under extreme heat, as working under such conditions is a health risk to workers. The city depends on many of these roads to operate smoothly and without interruption. Built-in redundancies provide the insurance of detours, if any roads are closed due to incomplete maintenance work, and are therefore necessary to mitigate the risk of road closure with no other entry.

Table 5. Most travelled roads per day in Easton by average number of vehicles (PennDOT 2018).

Road	Average Number of Cars	Road Type
Interstate 78	66,500	Interstate Highway
Route 22	35,800	State Highway
Wood Avenue	24,939	Local
N. 13th Street	16,362	Local
Bushkill Drive	15,839	Local
Knox Avenue	14,881	Local
College Avenue	12,242	Local

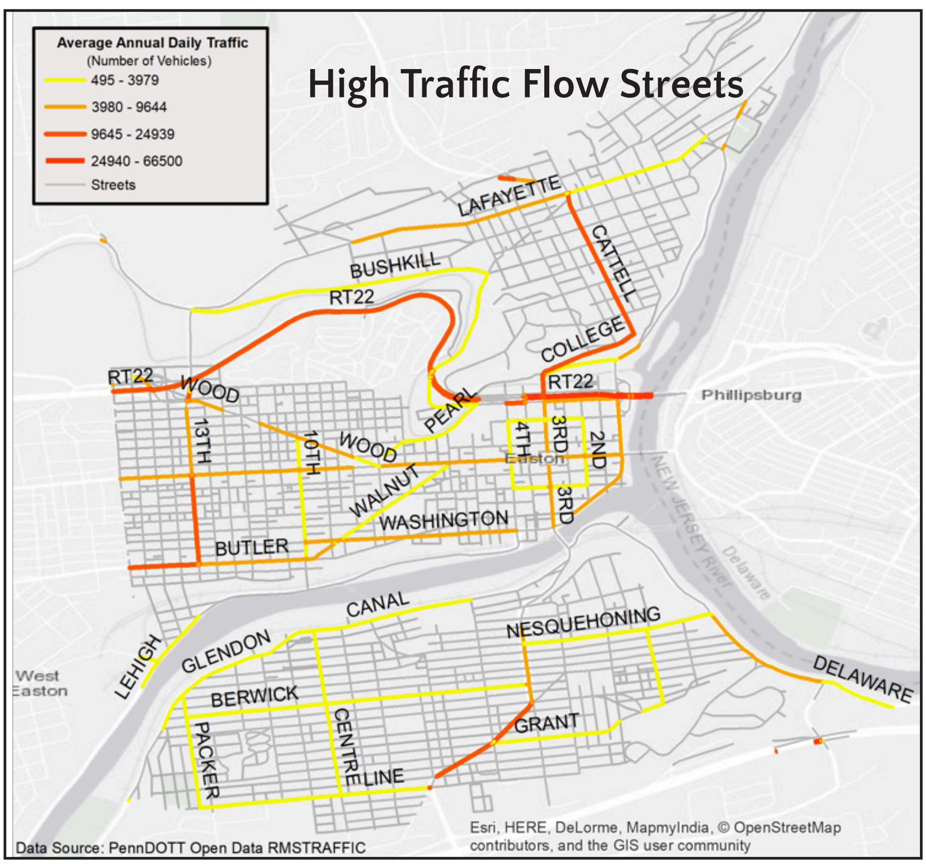

Figure 15. Roads with the most traffic in the City of Easton. See Appendix B6.

Similarly, Easton's bridges are important connections for evacuation, emergency response, and delivery of resources. Both the Northampton Street Bridge and the Phillipsburg Bridge are operated by a joint state coalition between Pennsylvania and New Jersey.

Easton's public transportation is operated by the LANTA (Lehigh and Northampton Transit Authority) Bus Service, which conducts business throughout the Lehigh Valley and is responsible for 10,000 daily work commutes (Fleming 2014), with plans to increase the number of routes in Easton. This suggests a significant fraction of Easton citizens rely on the bus system for mobility.

Water availability is crucial for both hydration and the local sewage system. The Easton Suburban Water Authority is responsible for treating and distributing all of Easton's tap water. Many cities have their water imported from a distant treatment plant, and thus rely on a large reservoir should that water resource be temporarily shut off. Easton utilizes the Delaware River as its water source. While the river is a close, accessible source, in the event of a drought, chemical spill, or similar disaster, the river may be unusable. The Water Authority has 13 tanks and reservoirs, with a total capacity of 24.52 million gallons of water to serve 31,134 customers (Easton Suburban Water Authority 2018). Should an extreme heat event occur, the City of Easton is well-prepared to handle drinking water demand. Having an abundant supply of accessible water is an asset supporting resiliency.

In an extreme heat event or during times of increased temperature, citizens will seek to escape the heat in air-conditioned areas. Citizens affected by heat-induced illnesses will need to seek medical attention somewhere nearby and may need the assistance of critical facilities. Critical facilities are structures or organizations that support the city in the event of a crisis and include hospitals, fire and police stations. These are facilities that provide aid to citizens, and must be able to operate efficiently in the event of a crisis. Easton's critical facilities related to extreme heat events are listed in Table 6.

Critical facilities are structures or organizations that support the city in the event of a crisis and include hospitals, fire and police stations. These are facilities that provide aid to citizens, and must be able to operate efficiently in the event of a crisis.

Table 6. Critical facilities related to managing extreme heat events in the City of Easton.

Healthcare	
Pediatric Medical Center of Lehigh Valley	Easton Hospital Community Care Center
Health Center at Easton	Easton Hospital
Public Services	
Easton Police Department	Easton Suburban Water Authority
Easton Fire Department	
Libraries	
Easton Area Public Library	Earnest Archives and Library
Northampton County Law Library	

These facilities represent Easton's best resources for support during extreme heat events. Libraries provide an air-conditioned environment for public use, and local public services will provide aid as needed.

Easton's electricity is supplied by Metropolitan Edison, a power company supporting parts of eastern Pennsylvania and New Jersey. The company's electricity capacity is not publicly shared, though blackouts due to current energy demand appear to be rare. Likewise, a public record of power outages is not kept, and thus it is unclear how many times power outages have occurred, or if a trend exists. It is common for minor power outages to occur among its two million customers, though these can be attributed to extreme wind or snow damaging equipment rather than a lack of electricity supply.

Blackouts and brownouts are the result of insecure energy infrastructure. While minor power outages may occur due to a small technical malfunction, brownouts and blackouts are a result of electricity demand reaching or exceeding the company's capacity. Unlike minor power outages, blackouts and brownouts affect large masses of citizens, and present a significant threat. As energy demand reaches capacity, power companies mitigate risk by shutting down service to large populations of customers for an hour at a time. In an extreme heat event, air-conditioning units would be cutoff, and an alternative may only exist through a backup generator, which may or may not be available in public buildings. Blackouts are the result of demand exceeding capacity in which all power is shutdown. Due to how electricity is allocated, demand does not need to increase vastly. In one case in Colorado in 1980, electricity demand was only 5.5% higher than usual, but it resulted in rolling blackouts (Adams 2002). In 2003, Metropolitan Edison's parent company, First Energy, was responsible for one of the largest blackouts in the Northeast's history, a result of old power lines, high heat in the summer and out of date equipment. The blackout lasted two days, led to the loss of power for 50 million people, cost $6 billion, and contributed to the death of 11 people (Minkel 2008).

The probability that blackouts and brownouts will occur increases with energy demand. Not only are general year to year increases in demand expected, but demand peaks may get close to, or exceed, capacities as high temperatures increase in frequency and population growth continues. Easton's population has grown marginally over the past several years, increasing by 0.2% per year since 2000 (Population US 2018). The Lehigh Valley has exhibited a similar expansion, growing by 1.2% from 2010 to 2015 (ProximityOne 2018). With population growth, annual energy demand in the United States could be expected to increase by at least 0.4% per year, about 13% between 2017 and 2050 (Global Energy Institute 2018).

With population growth, annual energy demand in the United States could be expected to increase by at least 0.4% per year, about 13% between 2017 and 2050...

Cooling Degree Days (CDDs) is a unit of measure for energy needed to cool a building, and is used to estimate expected energy demand. CDDs measures the number of degrees greater than 65°F in a given day. This baseline was chosen as most thermostats are set to 65°F, and thus energy is used to cool it back down. Conversely, Heating Degree Days (HDDs) is the opposite, representing the value below 65°F, used to estimate the energy demand to heat a building. For days that fluctuate above and below this threshold, fractions of a day are used. As we approach a warmer climate, rising temperatures will lead to increasing CDDs, and decreasing HDDs. The greater the sum of these two values, the more energy is demanded from the power grid. The problem lies at the speed at which each of these values are changing. The number of CDDs are increasing faster than the number of HDDs are decreasing. From 1997 to 2017, Easton saw an increase in CDDs from 582 to 1004 (72.5% increase), while HDDs decreased from 5891 to 4903 (16.8% decrease) (EnergyCAP 2018). At this rate, electricity demand for winter heating will stay constant, while electricity demand in the summer will continue to increase sharply. A predicted increase in electricity demand indicates moving closer to reaching the area's power capacity, threatening the city's current power security.

In the case of blackouts, a full shutdown of power would have a cascading effect on existing infrastructure. While it is unknown how many citizens have backup generators, generators can be expensive and are generally uncommon. A power outage will cut off central air within a home, increasing the likelihood of a heat-related illness. The lack of air conditioning in a home overnight in temperatures over 70 degrees prevents cooling and allows for heat stress to build for the following day (Samenow 2012), making the availability of critical facilities more important. Refrigerators would be cut off as well, counting down the clock for food to stay fresh, and increasing demand for non-perishables.

The lack of air conditioning in a home overnight in temperatures over 70 degrees prevents cooling and allows for heat stress to build for the following day

Depending on whether the City of Easton has backup generators which support infrastructure, traffic lights may also be shut down. While possible to dispatch police officers to temporarily assist in traffic, Easton does not have enough resources to spread the 63 city officers so thinly. Traffic lights shutting down for any extended period of time could be dangerous. Backup generators would also need to support Easton's critical facilities. As sanctuaries to escape extreme heat and to support the ill, these facilities must be able to be open and able to operate in such an event.

Easton businesses would also be greatly affected, depending on the duration of the blackout, due to their reliance on power and technology. However, the restaurant industry, which makes up a large part of Easton's local economy, would be the hardest hit due to food spoilage. Businesses like grocery stores or restaurants that have perishable inventory are the most vulnerable to such events. Further, if resources were available elsewhere, Easton businesses would lose out on potential sales.

4.2. Flooding Events

As a result of the efforts put in place after the floods from 2004, 2005, and 2006 during which around $3 million were given to the city by FEMA for damages and future prevention plans, the City of Easton Department of Public Works is well prepared for a 100-year flood. During the flood of 2004, which caused the most damage due to a lack of preparation, the Public Works complex was damaged heavily and the Sewage Pumping complexes were forced to shut down temporarily. Following the flood of 2006 the city implemented a series of plans to ensure long-term preparedness. City complexes can now be evacuated in around three hours, ensuring that safety workers will no longer be at risk. Additional flood procedures were put in place, such as where to park and how to evacuate certain areas. These evacuation plans go into effect when the Delaware River reaches 20 feet. The city has three different firehouses which are divided by waterways, ensuring fire protection in the case of floods so that fire trucks will always be available. These efforts are the reason why the floods in 2005 and 2006 were worse than their 2004 predecessor yet yielded significantly less damage.

Drains on roads have historically become covered with debris during flood events causing roadways to flood. This debris is a result of the sediment carried from flood water into the city.

However, a greater frequency of extreme weather events may expose new issues. For example, underground sewage treatment lines were built before codes were in place and floodplains were not considered during their construction. Drains on roads have historically become covered with debris during flood events causing roadways to flood. This debris is a result of the sediment carried from flood water into the city. After the last three floods, city plows were needed to clear drains in order to allow the floodwater to be removed. The system was described as "adequate" in spite of the persistent flooding of roadways and clogging of drains. The drain systems have the ability to handle water flow at rates that happen in heavy rain but a future of more rain in a shorter time could worsen roadway flooding.

The most significant indicator that a building is at risk is its location in the floodplain.

Population trends, future construction projects, and industry growth must be considered in assessing infrastructure risk. The overall population of Easton has been relatively stable over the last 15-20 years at a level of 25,000 to 27,000 residents but there has been a recent shift towards the urban core. During the 1980s Easton suffered from a population decline as residents flocked to the suburbs. Easton city officials have the long-term goal of returning Easton's population to around 35,000, the level at which Easton thrived during the 1940s and 1950s which creates construction demands in the future. If floods are not considered during construction plans it could lead to potential damage.

In addition, land use has significantly changed in areas adjacent to Easton, affecting the city indirectly. For example, the area around Bushkill Creek has become more populated in recent decades and the population of Forks Township has more than doubled over the past two decades from 5,969 in 1990 to 15,417 in 2016 according to the U.S. Census. A large amount of stormwater runoff has developed as a result of the population growth in Forks Township. The disappearance of farms also detrimentally affects how well runoff can be retained.

The influence of increasingly severe floods poses a threat to the infrastructure of the City of Easton. Certain buildings and areas of the city are particularly at risk to flood damage due to their location in the city, age, nearby construction changes, standards to pass code, and other potential risks. The most significant indicator that a building is at risk is its location in the floodplain. Critical facilities in the 500-year floodplain include three pumping stations (591 S Delaware Drive, 963 Lehigh Drive, 222 Larry Holmes Drive), a gas station at 158 S 3rd St, Easton Hospital Community Care Center, and the Easton Intermodal Transportation Center.

As of now, city officials believe that city infrastructure is sufficient for handling flooding events. Much of the attention of the city has gone to pre-disaster mitigation efforts focused on response preparedness, and construction and maintenance facilities are in charge of removing sediment.

For the City of Easton, the 100-year floodplain is the standard for infrastructure requirements. In order to meet safety standards, the liveable area for domestic spaces must be above the floodplain. In order to determine if buildings are up to code, the Code Office files information on infrastructure by address. Those liveable spaces which do not meet this requirement are at significant risk from flooding. While there is no available data on buildings not up to current flood codes, there is still extensive information on the buildings lying directly in the floodplain.

Those places with at least a portion of the property in the floodplain are shown in Figure 16. By cross referencing the parcel data for the City of Easton and the individual building footprints, the total possible building loss due to flooding was found to be upwards of $123 million.

The areas most at risk of flooding are properties along Larry Holmes Drive and the Bushkill Creek. The risk associated with flooded liveable spaces is two-fold. The first is immediate damage due to the flux of water, including both personal injury and physical damage to infrastructure and property damage. The second risk is long-term health risks. Much of this is associated with mold and other spores which inhabit spaces with excess water. This could cause damaged spaces to be condemned and require long-term restoration plans.

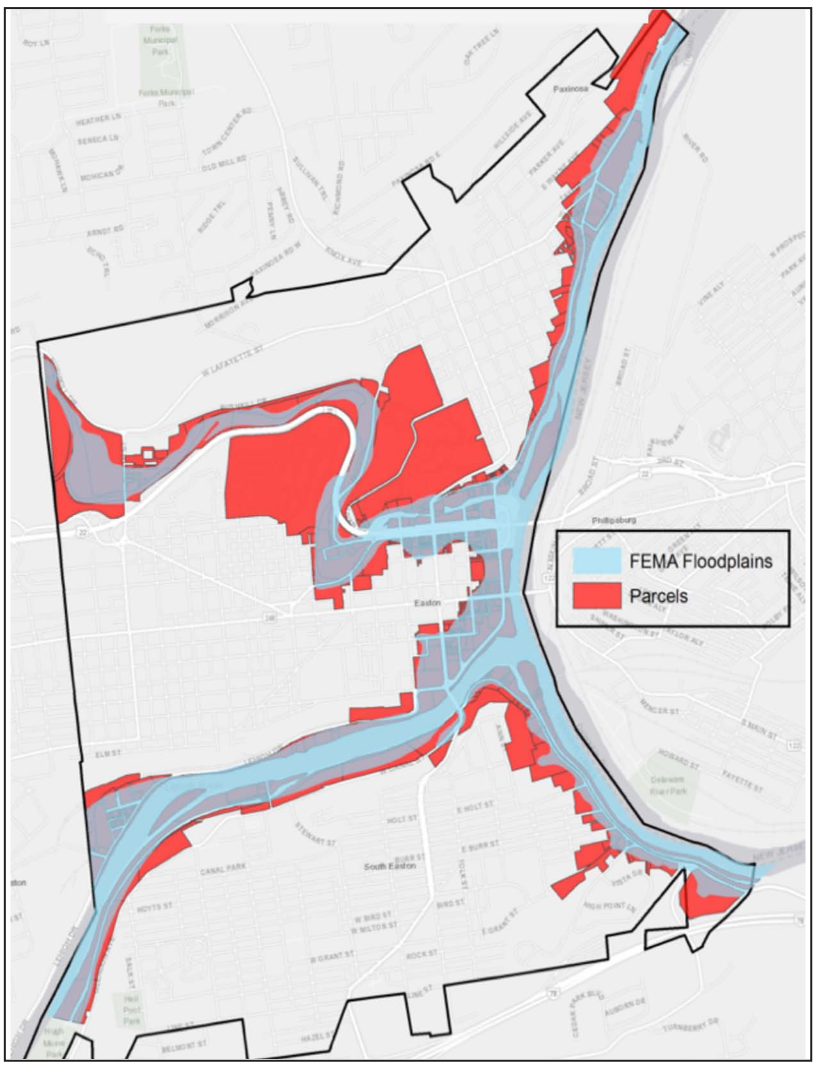

Figure 16. Properties that have portions of their parcel footprint in the floodplain and at possible risk. The building parcels that have a least a portion located in the 500-year floodplain. *See Appendix B7.*

Public service buildings must be available and running in the case of an emergency so that a proper response can be conducted by the city. These services include the Easton Police Department, Easton Suburban Water Authority, and the Easton Fire Department. The latter must act as the response team in the case of emergencies making them particularly valuable in real time. As noted earlier, the location of the three different fire houses was an intentional decision in order to speed up response time and the Easton Police Department was moved to a new building that is no longer within the floodplain. This relocation could enhance the city's ability to act efficiently in case of an emergency.

Public facilities, on the other hand, must be able to respond quickly after an emergency in order to maintain social stability. This includes schools (eight schools, one college), community centers (two), a cemetery, and ten government buildings. A particularly vulnerable group are historical sites in Easton in the floodplain. In order to maintain historical integrity, these sites have special considerations when renovating and do not necessarily need to be elevated above floodplains. Historical sites which could be damaged from pending floods can be seen in the Figure 17.

Industrial and chemical plants create a risk if flood water carries away leaked pollutants. Areas nearby Easton including the Bushkill area, Phillipsburg, and the surrounding Lehigh Valley could lead to damaging pollutants entering floodwater which eventually reaches Easton. This makes it especially important for the City of Easton to work with neighboring municipalities in order to mitigate this risk. In addition, gas stations located in the floodplain risk spilling gasoline and other dangerous chemicals into the surrounding water. Figure 18 depicts flooded gas stations in downtown Easton along Route 611 in September 2004 and April 2005 respectively.

...gas stations located in the floodplain risk spilling gasoline and other dangerous chemicals into the surrounding water.

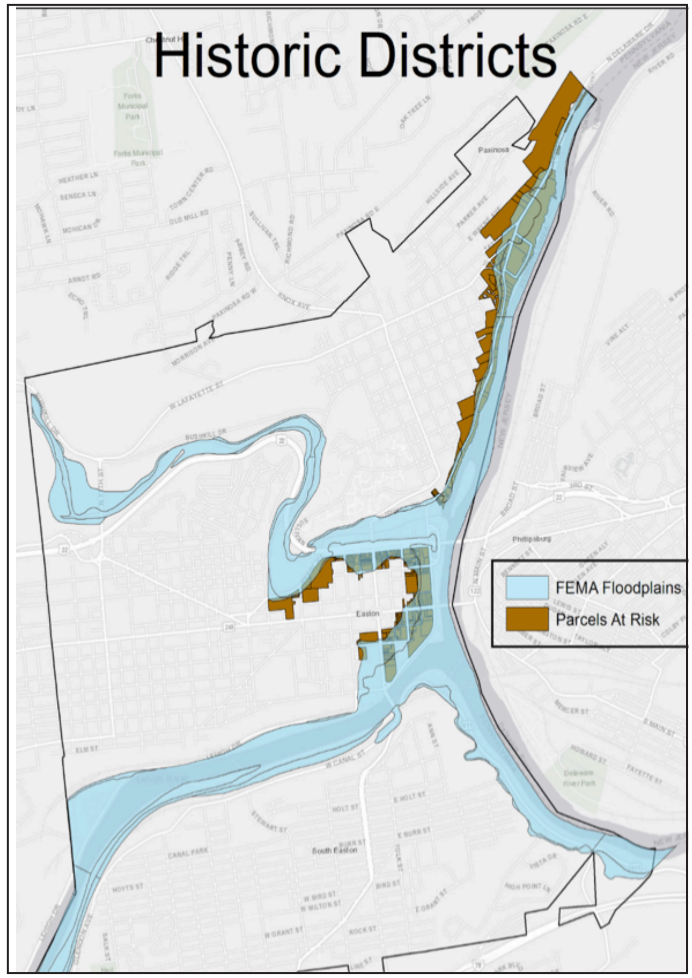

Figure 17. Historic districts at risk due to being in the floodplain. *See Appendix B8*.

Figure 18. September 2004 flood (left) and June 2006 flood (right).

Road segments at risk of flooding were assessed by the Pennsylvania Department of Transportation in an "Extreme Weather Vulnerability Study" (PennDOT 2017) (Figure 19). Larry Holmes Drive in downtown Easton is considered part of the top 1% of high risk roads in the state. But other roads have flooded in the past as well. In 2011, Adamson Street flooded and was unpassable (Andersen 2016). During a moderate flood stage, which is when the Delaware River swells to 26 feet, Larry Holmes Drive, Bushkill Drive, Route 611, and Riverside Street all begin to flood. In the case of a major flood stage when flooding surpasses 30 feet, Northampton Street and North Delaware Drive will flood as well. These floods are more impactful in Downtown Easton where there is high population density and risk of being trapped by flood water (Delaware River Basin Commission 2016). In addition, the Easton Intermodal Transportation Center, which is the center for public transportation out of the city, is located within the floodplain which could impact mass evacuation efforts in emergencies.

Larry Holmes Drive in downtown Easton is considered part of the top 1% of high risk roads in the state.

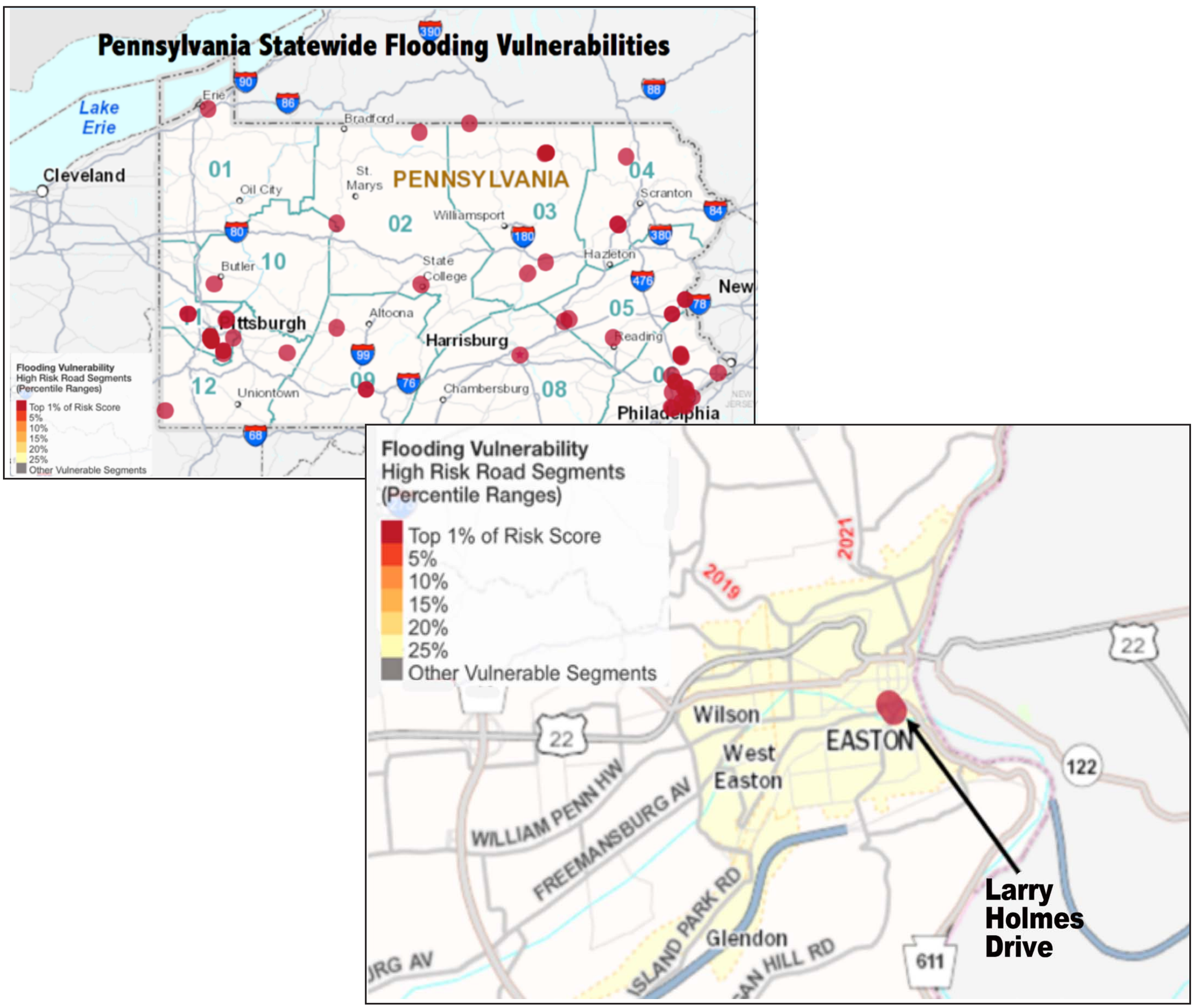

Figure 19. Most vulnerable road infrastructure in Pennsylvania with zoom inset showing Easton

5. Social Vulnerability

The City of Easton has a diverse population. Groups within that population are affected differently by extreme weather events as they have varying abilities to respond and adapt. An extreme weather event would have negative impacts on the citizens of the city in many aspects of their lives, but some portions of the population would be hit exceptionally hard. Transportation could become difficult and electricity scarce if the power grid is overwhelmed by use of air conditioning units during an extreme heat event. Flooding could cause extensive property damage. These effects are discussed in more detail in Sections 3 and 4. This section will focus on how the population of Easton would be affected in response to these systems being impeded by an extreme weather event.

Social vulnerability is defined as the susceptibility of certain social groups to impacts of hazards (City of Boston 2016). An extreme weather event could cause death, injury, and/or disruption of life. The vulnerable populations in Easton have been identified by their ability to respond to an extreme weather event as well as how much they would be affected by such an event.

5.1. Children

According to the American Community Survey of 2012-2016, the City of Easton has around 1,948 children under the age of five which makes up 7.2% of the total population. While older children would also be affected by an extreme weather event, children under the age of five are the most vulnerable to the negative effects of such an event (EPA and CDC 2016). Figure 20 shows where the highest concentrations of children under the age of five reside. These areas are a portion of College Hill, a section of Downtown Easton, and the western portion of South Side.

Children under the age of five are more susceptible to the effects of an extreme heat event. Their bodies cannot handle the same amount of stress that a healthy adult can. Young children are a vulnerable population due to their dependence on parents or caretakers and their limited ability to react to an emergency (Minnesota Climate Change Vulnerability Assessment 2015). Their bodies are also the least developed and therefore the least equipped to handle long exposure to a prolonged heat event (American Academy of Pediatrics 2018). It is estimated that 5,700 more infants could be hospitalized due to rising temperatures by 2050 compared to 1,400 more by 2020 (Perera et al. 2011). There is also the chance of school being cancelled because of an extreme heat event, requiring parents to seek other options for their kids during the day and potentially missing work (City of Boston 2016).

Children face greater vulnerability during flooding events because of their young age and lack of resources. In a flood event, children may face difficulties communicating with others and with emergency response personnel. Further, they are less likely to properly react and follow emergency protocol (City of Boston 2016). Young children may be unable to swim, making flooding situations more dangerous. Children are also vulnerable to the aftereffects of flooding. Recovering from flooding events can take up to months and sometimes years due to trauma from enduring long periods of living with uncertainty (Mort 2016). The situation is worsened by lack of proper shelter, limited access to food or water, or complete upheaval and relocation. After homes have been flooded, moisture can remain in the foundation, drywall, furniture, or other surfaces and lead to mold. Exposure to mold can lead to hay-fever-like symptoms such as stuffy nose, itchy eyes, or sneezing and even asthma attacks.

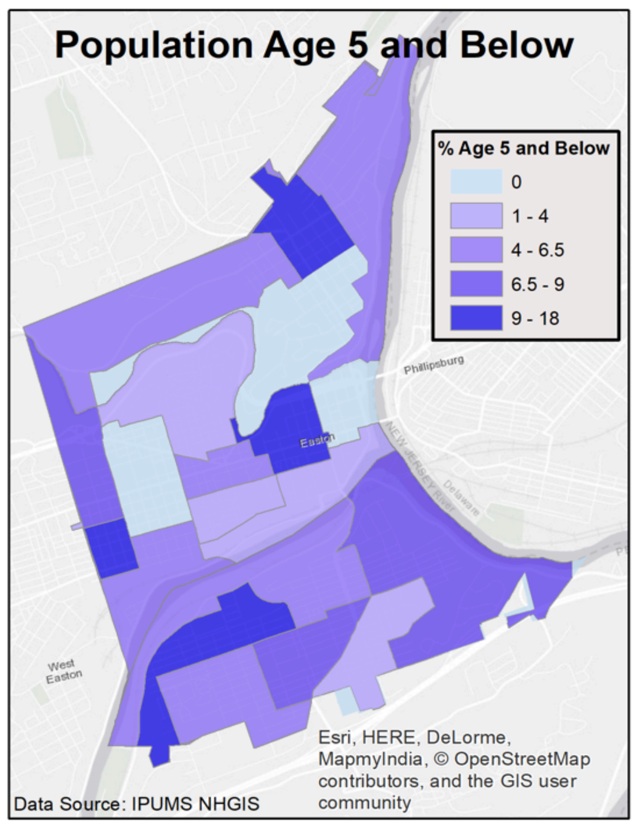

Figure 20. Density and spatial distribution of children (under 18) in the City of Easton. *See Appendix B9.*

5.2. Older Adults (Age 65+)

There are approximately 5,283 individuals over the age of 65 in Easton making up 14% of the total population. The elderly have a higher rate of medical illnesses than other identified groups of the population, frequently experiencing maladies such as cancer, heart disease, and chronic lower respiratory disease which are negatively affected by increased temperatures. The Center for Disease Control estimates that 20% of people 65 years or older have fair or poor health conditions, highlighting their preexisting risk. Figure 21 shows the percentage of the population that is aged 65 or older, and where they are located in Easton. The southern area of the Downtown neighborhood contains the highest percentage of elderly individuals in all of Easton.

Older individuals, with or without chronic illnesses, are more susceptible to experiencing problems like loss of fluids and overheating, which in turn can cause a decrease in blood pressure and elevated heart rates. This is especially problematic for those with heart and circulation issues since it places an additional strain on already weakened systems (British Heart Foundation 2018). Additionally, older individuals also tend to be physically weaker which leaves them more susceptible to fatigue, a symptom of heat exhaustion.

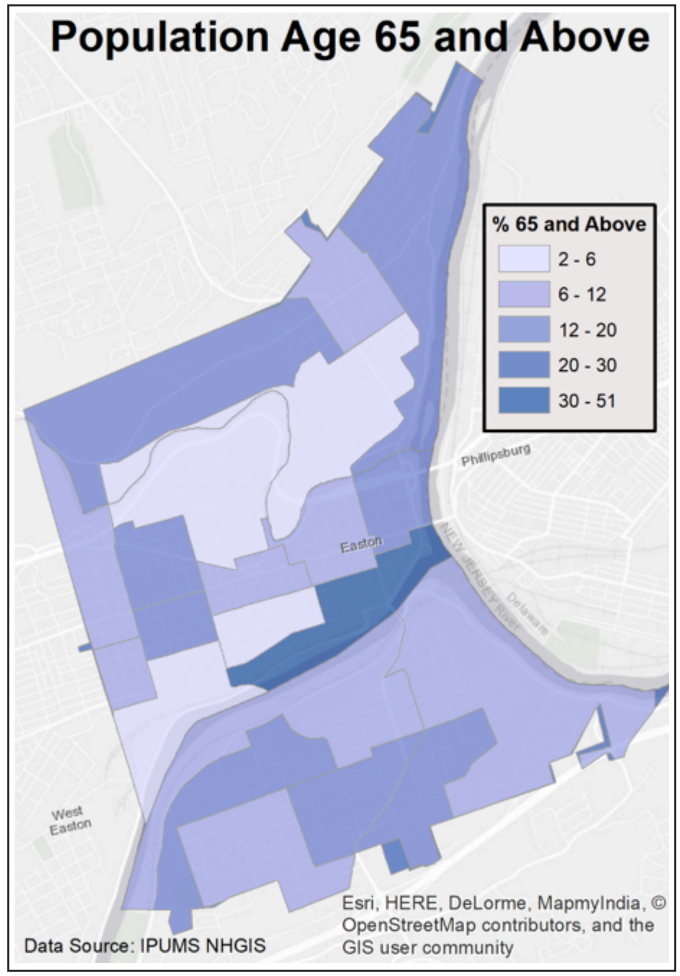

Figure 21. Percentage of population over 65 years old, by block group. *See Appendix B9.*

Older adults tend to be less mobile which increases their vulnerability to an extreme weather event, affecting their timely evacuation (City of Boston 2016). In a study done on the effects of Hurricane Katrina, researchers concluded that the greatest mortality during and immediately after the floods was the elderly (Adams 2011). They primarily attributed this to the lack of evacuation facilities. There are several home health care and assisted living spaces located in Easton, however, the majority of people over the age of 65 reside in their own private homes.

5.3. People Living Alone

The City of Easton has around 3,858 individuals living alone in a household which makes up 35% of the total households. Those areas with the highest density of population living alone are most at risk to due to their inability to get help quickly. Areas such as Downtown Easton, where a majority of homeowners are living alone, and are in close proximity to the river are most vulnerable (Figure 22). West Ward and College Hill neighborhoods also contain a high percentage of individuals living alone, but are deemed less vulnerable as they are farther away from the river.

Anybody living alone is considered more vulnerable to an extreme heat event due to the lack of available assistance from friends or family members. Social networks are important in mitigating health risks from extreme weather events like heat (Klinenberg 2013) and having other people to rely on can decrease the likelihood of injury or harm. During a Chicago heat wave in 1995, portions of the population that lived in close-knit communities had much lower mortality rates compared to surrounding neighborhoods with all other demographics being the same. In the case of Chicago, the benefits of living in one of these close-knit communities was almost equivalent to owning an air conditioner during a heat wave (Klinenberg 2013).

In the case of a flood, being alone and isolated at home could lead to being unnoticed by neighbors or even emergency services. Also, neighbors and neighborhood communities provide another safety net in educating and warning individuals about flooding events. However, people living alone may not be exposed to these public announcements or warnings, increasing their vulnerability. Further, 902 of those living alone are also over the age of 65, compounding their vulnerability and risk to extreme weather events. Older individuals are typically weaker than a healthy adult and if they live alone, there is less chance of help if they were to succumb to an extreme weather-related illness.

5.4. People with Disabilities

According to the American Community Survey of 2012-2016, the City of Easton has around 3,636 citizens with disabilities which makes up 13.4% of the total population. A person with a disability is defined by the CDC as having any, "condition of the body or mind that makes it more difficult for the person with the condition to do certain activities and interact with the world around them" (CDC 2017). In Easton, the Downtown, West Ward, and South Side neighborhoods have the largest percentage of disabled individuals (Figure 23). Specifically, the southern areas of the Downtown and West Ward are the most vulnerable, as they contain the highest percentage of individuals with disabilities in close proximity to the river.

An extreme heat event would affect people with disabilities in numerous ways. Physical and mental disabilities could be negatively impacted under these circumstances as well as other social factors that stem from the disability. For example, people with spinal cord injuries have a decreased ability to sweat as a way to cope with heat. In the case of an extreme heat event, these people would be more susceptible to heat related illnesses, such as heat exhaustion, since their body would not be able to cope with the increased temperature.

People with disabilities also tend to have much higher rates of poverty which adds to their vulnerability. The most pressing challenge for a disabled person living in poverty during an extreme heat event would be access air conditioning and transportation (Ghenis 2015). They may lack the income to purchase an air conditioner or have it running constantly during a prolonged heat wave. Mobility also becomes an issue if they need to evacuate in the case of an emergency. People with physical disabilities may find it hard to access public transportation during a flooding or extreme heat event and if they are

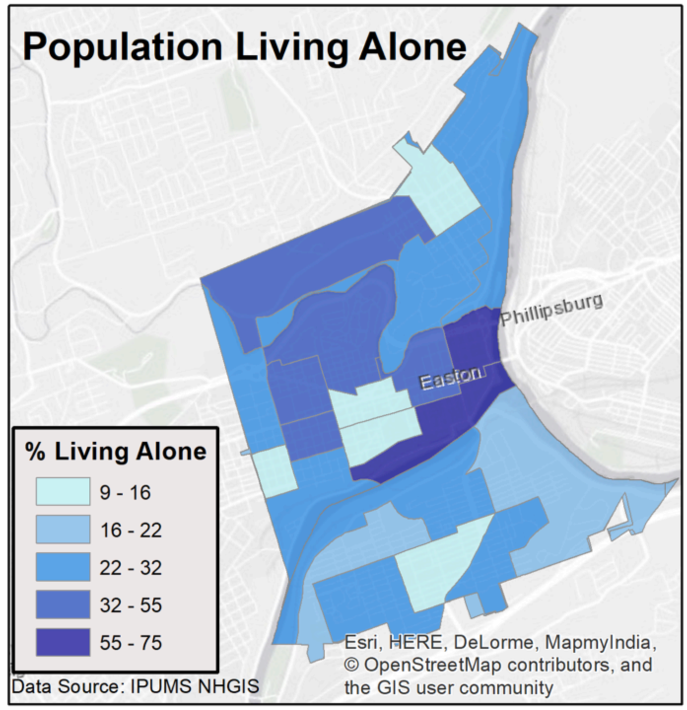

Figure 22. Percentage of people living alone, by block group. *See Appendix B9.*

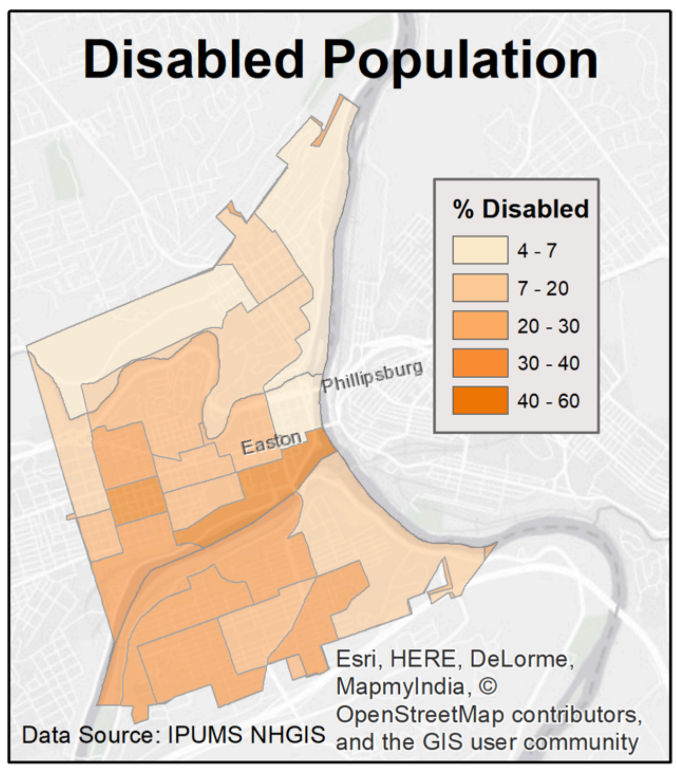

Figure 23. Percentage of population that is disabled, by block group. *See Appendix B9.*

living in poverty, they may not have access to a personal vehicle. Further, individuals with disabilities can find it difficult to prepare and react to a disaster (City of Boston 2016). Research conducted during the 2011 Japan earthquake and tsunami found that the mortality rate of individuals with disabilities was twice that of the rest of the population (Fujii 2012). Similar to young children, people with disabilities may require external assistance that may be limited during a disaster.

Poverty is often associated with poor quality housing, more limited ability to prepare in advance for impending hazards, greater dependence on outside assistance, and subsequently increased difficulty in recovering from a natural weather event...

5.5. Poverty

Based on 2016 population estimates, roughly 4,470 individuals or 18.9% of Easton's population are below the poverty line. This is higher than the average for Pennsylvania which was 13.2% in 2016. Downtown, West Ward, and South Side neighborhoods all contain high percentages of households that earn below $30,000 (Figure 24). In addition, there is a large percentage of households in the southern areas of the Downtown and West Ward, and northern areas of the South Side that earn less than $30,000 and are in close proximity to the river.

A subsection of the poverty vulnerable population is the homeless. They are considered living in extreme poverty due to lack of a steady income and self-owned shelter and are especially vulnerable to weather conditions (Romaszko et al. 2017). Between the months of January and September in 2017, a system set up by homelessness advocates identified 1,380 individuals living in Easton, Bethlehem, and Allentown (Tatu 2017) and the Easton police are aware of hundreds of homeless individuals. Some of these individuals occupy areas near the banks of the Lehigh and Delaware Rivers. Their makeshift homes and lack of technology exacerbate their vulnerability and risk to extreme weather events such as flooding.

Those living below or around the poverty line are considered a vulnerable population due to their lack of access to resources such as having air conditioning or car. Lack of expendable income means that an emergency places more stress on an already precarious financial situation. Even if someone owns an air conditioner, operating it constantly during a prolonged heat event could be outside of their budget. This population also tends to be less mobile due to lack of access to reliable transportation on top of having less supplies for an extended stay in the case of a prolonged extreme event. Poverty is often associated with poor quality housing, more limited ability to prepare in advance for impending hazards, greater dependence on outside assistance, and subsequently increased difficulty in recovering from a natural weather event (City of Minneapolis 2015). During natural disasters, individuals afflicted by poverty have also been found to face higher mortality rates (Wisner et al. 1994). Residents without televisions, computers, or mobile smart phones may face challenges receiving news about hazards or emergencies and homeowners may struggle to afford insurance that will cover flood damage (City of Boston 2016). Having little to no income can make evacuating very difficult, as individuals will have to resort to public transportation which could be impeded in the case of a flood. If unable to evacuate, residents may be vulnerable staying at home without the proper supplies and preparation.

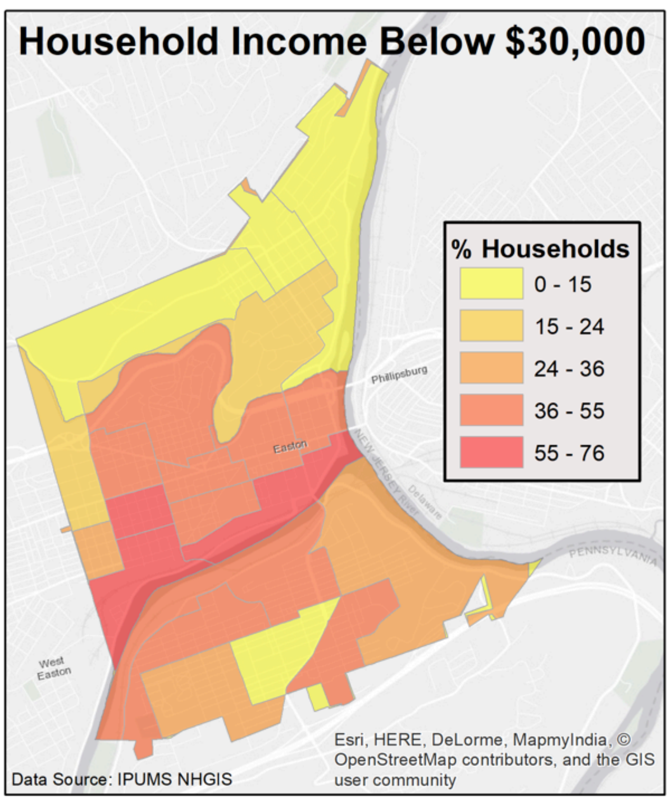

Figure 24. Percentage of households in poverty, by block group. *See Appendix B9.*

5.6. Renters

Renters are considered a vulnerable population in Easton due to their lack of permanent housing. They are less tied down to their location and typically are made up of other socially vulnerable populations such as those living with a low income (Burby 2003). Renters typically spend less time in one location making them unaware of information regarding an emergency in their city, along with less exposure to public information on preparedness, and less familiarity with local risks and protocol. They may also lack social networks which is a powerful tool for vulnerable populations in the event of a natural hazard. Renters would also suffer more heavily from damages due to lack of insurance - compared with 95% of homeowners, only 41% of renters owned insurance for their place of residence (Insurance Information Institute 2016) - and may have more trouble rebuilding or repairing their homes after an extreme weather event. Only a fraction of renters had insurance during Hurricane Harvey. Many of the renters with flooded basements, ruined furniture, and damaged walls had to dig deep into their wallets to compensate for these damages (Condon 2017).

Previous studies on past natural disasters have shown that renters are disproportionately affected. In a study done on the recovery of Hurricane Katrina, researchers concluded that "disasters tend to disproportionately damage rental and low-income housing" (Fussell 2015). There is less financial incentive for both renters and owners of rental property to fund mitigation measures to increase resiliency to disasters compared to homeowners. According to the 2010 census, the City of Easton had 1,334 renter occupied housing units out of 10,162 total housing units (13.1%). There is a significant number (over 50%) of renter occupied housing in Downtown and portions of the West Ward.

Previous studies on past natural disasters have shown that renters are disproportionately affected.

5.7. Aggregated Social Vulnerability Map

Independently, each category of Easton's social vulnerability provides critical insight into the location and vulnerability of certain populations, but a more comprehensive view of social vulnerability in the city can be ascertained by aggregating this information by block group. The resulting social vulnerability map (Figure 25) includes all five vulnerable populations- children, people with disabilities, people living alone, low income, and the elderly- weighted equally, and populations could count twice. For example, if a block group has high levels of children and poverty, it would be counted twice as 'vulnerable'. This methodology emphasizes which locations in Easton need the most help and priority during an extreme weather event. It should be noted that this map does not account for the population inside each of the block group, meaning that the darker colors represent higher numbers of people within the identified vulnerable categories rather than a higher percentage of that block group being identified as vulnerable. In addition, results may be skewed depending on certain facilities contained in the block groups. For example, there may be elder care facilities located in one of the block groups. The social vulnerability map is meant to give a generalized look at where people in the City of Easton are vulnerable. Further explanation of Easton's vulnerabilities, including how the social vulnerability relates to flooding, is discussed in Section 7.

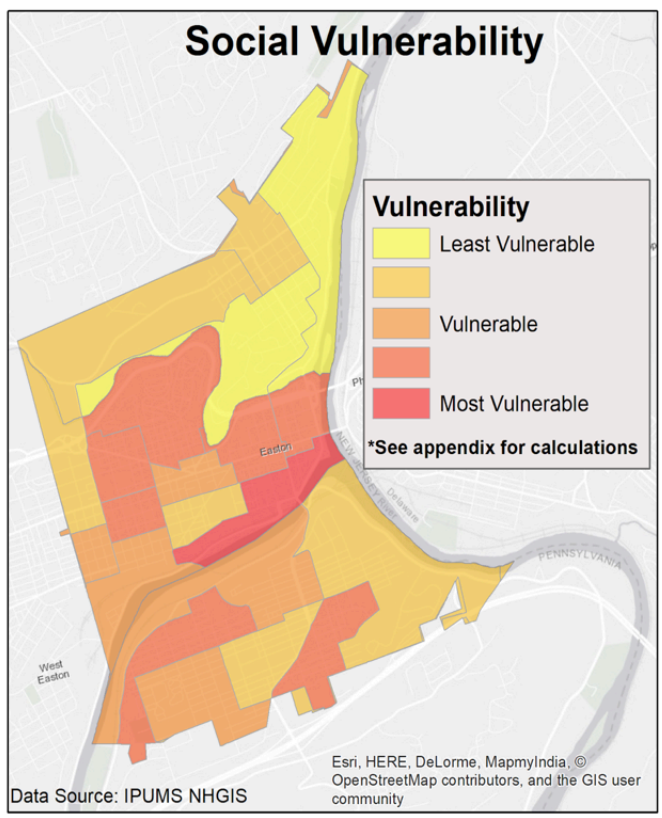

Figure 25. Spatial distribution of social vulnerability for the City of Easton based on aggregation of five vulnerable populations. *See Appendix B10.*

An additional source of information, the Social Vulnerability Index (SVI) for Northampton County provides a comparable view of social vulnerability. The SVI was created to analyze the entire United States and factors in 14 different areas including poverty, lack of vehicle access, and crowded housing (ATSDR 2014). It is divided into quartiles, and parts of Easton exists within the top two quartiles, suggesting that it is among the most socially vulnerable areas in the United States (Figure 26). In comparison Figure 25 breaks Easton into even smaller groups, analyzing block groups instead of census tracts so it provides more detailed information and can assist in formulating policy, allocating city funds, and determining areas needing the most assistance.

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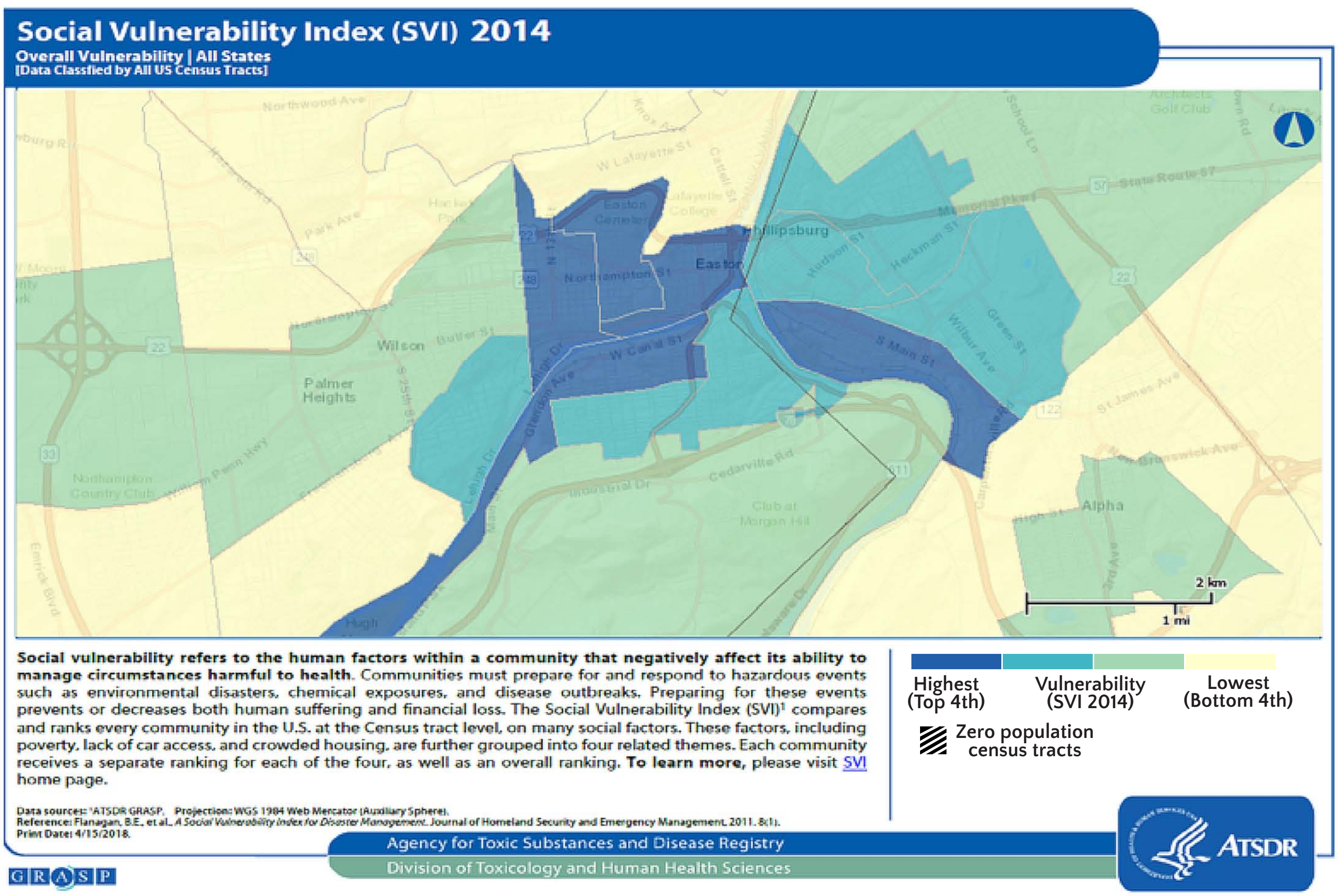

Figure 26. Social Vulnerability Index from ATSDR showing Easton in comparison to all areas of the United States.

6. Extreme Weather Events Effects on Human Health and Wildlife

6.1. Human Health

Air Quality & Urban Smog

Air quality degradation is among the most noticeable of effects from an extreme heat event. Poor air quality in both developed and developing areas compromises the health of about one-half of the world's urban population (Elsom 2014). This occurs when high temperatures persist, which, when combined with air pollution from car and power plant emissions, creates ground-level ozone referred to as "urban smog" (Perera 2011). The creation of ground level ozone, or urban smog, occurs as nitrogen oxide (NO3) and volatile organic compounds (VOCs), hydrocarbons that contain carcinogenic substances (Elsom 2014), chemically react in the presence of heat and sunlight. Exacerbated by the urban heat island effect and higher-than-usual evening temperatures, this process can severely degrade air quality, especially in urban areas when emissions from cars, factories, and power plants are combined with extreme heat, creating hazardous breathing conditions.

Deteriorating air quality in Easton contributes to public health degradation and puts a strain on the health care economy. By 2020, it is estimated that the continental US could spend $5.4 billion on health impacts associated with ozone increase due to an estimated 2.8 million more occurrences of symptoms related to overheating. This includes a host of health problems not limited to asthma, heat exhaustion, and worsening of chronic illness (Perera 2011), to which vulnerable populations are most susceptible (Section 5).

From 1996-2013, Northampton County (including Easton) surpassed the recommended ozone level and received an "F" grade for ozone quality (American Lung Association 2018). As of 2013 ozone levels have decreased, and as of April 18, 2018, air quality was deemed to be "good" (Airnow 2018). However, with population growth and increased development of warehouses and truck traffic, air quality still remains a concern. The population growth and emissions in the entire Lehigh Valley can and will impact Easton. In recent years, likely tied with revitalization in Easton, Bethlehem, and Allentown, the Lehigh Valley is becoming an increasingly desirable place to work and live with a forecasted population growth of nearly 1 million residents by 2040, from a current ~830,000. Easton alone is expected to grow by about 20% in the next 20 years, which equates to about 5,000 more residents (Tauber 2017). More people means more traffic and emissions - Route 22 and I-78 alone saw 89,000 cars per day in 2014 (Falsone 2017), and now reaches over 100,000 today. This is mostly a result of residents commuting between towns in the Lehigh Valley and to and from nearby cities like New York and Philadelphia.

Easton alone is expected to grow by about 20% in the next 20 years, which equates to about 5,000 more residents.

Food Supply

Although a comprehensive analysis of the effects of extreme heat on food supply goes beyond the scope of this initial vulnerability assessment, it is important to acknowledge this concern. Months of highest occurrence of extreme heat events and the primary growing season often coincide which can present problems for specific crops. Heat sensitive plants, like lettuce, parsley, and cabbage, can suffer and scorch, tomato, squash, and pepper plants can blister, and crop yields can dramatically decrease. Heat can also stress livestock, decreasing milk production from cows. Additionally, heat can scorch tree leaves, damaging tree canopy in green spaces, the importance of which is discussed in Section 3.

Delaware River at Easton, 2006.

Flooding Events

Beyond the immediate physical impacts, flooding can cause long term physical effects and psychological impacts. Long term physical and economic impacts most significantly come from the product of lingering dampness: mold. Victims of Hurricane Katrina experienced upper respiratory tract infections, coughs, and asthma due to indoor dampness (Solomon et al. 2006). Many people suffered from long-term health effects from the respiratory hazard, and buildings underwent extensive treatment, increasing the time of recovery and costs of flooding.

A city prepared to deal with both the short term and the long term, and the visible and the invisible impacts of flooding will be better equipped to recover and remain resilient in the case of flooding.

Flooding can also cause long-term mental health issues for those who experience flooding. For instance, flooding in England and Wales left constituents with symptoms indicative of long term mental health issues with 59% of those who experienced flooding reported physical health effects and 60% reported psychological effects (Tunstall et al. 2006). A city prepared to deal with both the short term and the long term, and the visible and the invisible impacts of flooding will be better equipped to recover and remain resilient in the case of flooding.

6.2. Wildlife

Prolonged heat events cause degradation to plant, mammal, and fish populations, due to changes in available food, reproductive behavior, and water quality. The daily activity and growth rates of species tend to slow during heat waves. Mammals particularly will reduce activity in order to sustain high energy levels (Parmesan et al. 2000). In aquatic habitats, warming waters subject to multiple 90+ degree days and warmer-than-usual nights can cause increased fish deaths and compromised water quality due to increased algae growth. Smaller ecosystems, such as rivers and creeks, lose substantial amounts of water during heat events. Changes in water levels can permanently change how animal and plant populations live along river banks. Easton's wildlife is particularly vulnerable to extreme heat events - the Delaware and the Lehigh rivers and the Bushkill Creek all have considerable fish populations at risk.

For much wildlife, such as vegetation, flooding can be beneficial to the ecosystem. Plants along rivers tend to benefit from this natural ecological process that ensures biological productivity. However, the flooding of a riverbank can both carry nutrients and pollutants to surrounding areas. If there happens to be a chemical leak near the floodplains, those pollutants can be spread across an area and cause damage for a period of time much longer than the actual flood event. These pollutants can affect the drinking water for mammals living nearby. While the particular wildlife inhabiting the banks of the Delaware River is not at an immediate risk, it is important to understand the potential ecological changes floodwaters may induce in the future.

7. Critical Points

The key features of vulnerable populations are physical ability and access to resources. For instance, the elderly tend to be less mobile, while those living in poverty may not have the financial resources to respond to flooding damage or to purchase air conditioning for their homes. Both the characteristics and location of the vulnerabilities identified in this assessment should be considered for planning and preparation as climate change affects the frequency, intensity, and duration of extreme heat events and flooding in Easton.

> *...Downtown and West Ward are the two most vulnerable areas within the city.*

Analysis of the intersection of landscape and social vulnerabilities suggests that Downtown and West Ward are the two most vulnerable areas within the city. The Downtown area, located north of the Lehigh River and west of the Delaware River, is the most vulnerable in terms of flooding, landscape vulnerability, and social vulnerability. The Downtown area is also highly vulnerable to extreme heat events due to its high percentage of impervious surfaces, low tree canopy coverage, and large portions of vulnerable populations (elderly and living alone). The highest traffic roads in Easton are located in Downtown as well and are key points of access for resources and evacuation.

While the West Ward is not considered a vulnerable area with respect to flood events due to its location outside the FEMA 500-year floodplain, it is considered vulnerable to extreme heat events based on having a high percentage of impervious surfaces and low percentage of tree canopies. An extreme heat event would impact this area significantly more than other areas of the city due to the large portion of vulnerable populations (poverty and renters) not being suited to deal with prolonged heat exposure.

8. Conclusion

Easton's overall vulnerability to climate change and extreme weather events, particularly for flooding and extreme heat event hazards, assessed in the context of landscape and social vulnerability provides critical information on where and how to prioritize preparedness and adaptation efforts. The increasing frequency of extreme heat events can be attributed to the changing climate, the increase of manmade surfaces, and the reduction of the natural landscape, leaving the built infrastructure at greater risk of power outages. Easton's natural geography is its greatest vulnerability under a changing climate with increased risk of flooding due to the potential for heavy rainfall, which may directly affect critical infrastructure within the city. Some of the most vulnerable populations within the City of Easton are those living in poverty, the elderly, and people with disabilities - populations who will be greatly affected by projected changes to extreme heat and flooding events under climate change.

By assessing the physical and social vulnerability of the City of Easton related to two main hazards, flooding and extreme heat events, both currently and in the future under a changing climate (warmer and wetter), this report determines that climate change will influence the future of Easton's residents and landscape. The City should continue its efforts to prepare for the extreme weather events and prioritize resources and planning to those areas deemed most vulnerable, particularly the Downtown area.

> *...climate change will influence the future of Easton's residents and landscape. The City should continue its efforts to prepare for the extreme weather events and prioritize resources and planning to those areas deemed most vulnerable, particularly the Downtown area.*

9. Limitations and other considerations

This assessment focused on just two natural hazards that have affected Easton and are projected to increase under climate change. There are other hazards that may have significant impacts on the City such as heavy snowstorms and hurricanes. Snowstorms that bring lots of heavy snow may temporarily increase in the future due to the weakening of the Arctic jet stream that allows cold Arctic air to dip farther south into Pennsylvania. When this happens in late winter it can intersect with warmer, moisture laden air masses from the south and create favorable conditions for heavy snow. As the climate continues to warm, there will be less chance for snow to accumulate, however. Heavy snowstorms can disrupt travel, create hazardous driving conditions, and result in power outages and property damage. Extratropical storms/hurricanes can bring tremendous rain and wind which may result in flooding, power outages, hazardous driving conditions, and property damage. With a warmer atmosphere that holds more moisture, these storms have the potential to bring a significant amount of rain.

10. Acknowledgements

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12. Appendix

Appendix A.

500 Bushkill Public Works Complex – Flood Evacuation Measures for Personnel and Equipment

City of Easton
Department of Public Works

Standard Operating Procedure # : DPW-1
Last Revision Date: June 2016
Prepared By: David Hopkins, Director

TITLE:
500 Bushkill Public Works Complex – Flood Evacuation Measures for Personnel and Equipment

PURPOSE:
To provide general guidelines for flood operations and relocation of personnel and equipment from the public works complex during episodes of flooding

PROCEDURE:

When weather forecasts predict conditions that could possibly lead to flood stage water levels and/or possible flooding at the public works complex (i.e. snowmelt, heavy precipitation, etc.), the Public Works Director in consultation with Bureau Supervisors and other departmental heads will implement this operating procedure to protect personnel and equipment and provide for general guidelines for flood operations.

1) During weather forecasts that predict possible flooding, all supervisors are to be on-call and available to come to work. Exceptions will be made in extreme cases where people are absolutely unavailable.
2) The City's trash hauler is to be placed on notice immediately that volume limits for curbside removal of trash in potential affected areas are to be waived and that arrangement are to be made to provide adequate vehicles and equipment to remove household flood spoils.
3) As much in advance as possible, supervisors are to compile a list of employees who will be available to come to work, along with their contact information, should an evacuation of the complex be necessary. This list should remain accessible at all times
4) Decisions regarding the degree of evacuation will need to be made based upon specific conditions at the time due to the fact that all storms are different and can lead to varied results. If conditions are calling for flooding that is estimated to be minor in nature with only slightly elevated water levels above flood stage, vehicles and equipment will be moved to the higher ground of the 500 complex on the northern side. Any materials that could become damaged are to be stored in trucks or elevated to second floor levels. The Bushkill Creek and the Rivers

are to be monitored on a constant basis by Highway personnel throughout the event.

5) If conditions are calling for flooding that is estimated to be of major concern with significant elevation of water levels above flood stage, specifically conditions calling for **flood stage elevation of 28' or above for the Delaware River**, of the following locations will be used for storage of equipment:

 HIGHWAY – all vehicles and equipment will be moved to the Lafayette College Electrical sub-station located on Bushkill Drive. Overflow may be parked on Dietrich Road or other suitable location

 PARKS – bandstand should be moved to Pine Street along north curb – be careful of Met-Ed manhole in street.

 MAINTENANCE – vehicles and equipment should be moved to Parking Garage, 3rd Street Lots, and/or other suitable location

 MOTORS – vehicles and equipment should be moved to Pine Street Parking Garage, 3rd Street Lots, and/or other suitable location

 ELECTRIC – vehicles and equipment should be moved to Parking Garage, 3rd Street Lots, and/or other suitable location

 RECYCLING CENTER – the City's Trash Hauler is to be notified by the Highway Department to haul roll-off bins off-site to 4th and Washington until notice is given to return. Cardboard Compactor power unit is to be removed and stored in a safe, dry place by the City Electrician. The Attendant Shed is to be moved by forklift to higher ground off of Sullivan Trail. Gates are to be locked to prevent migration of any materials that may float.

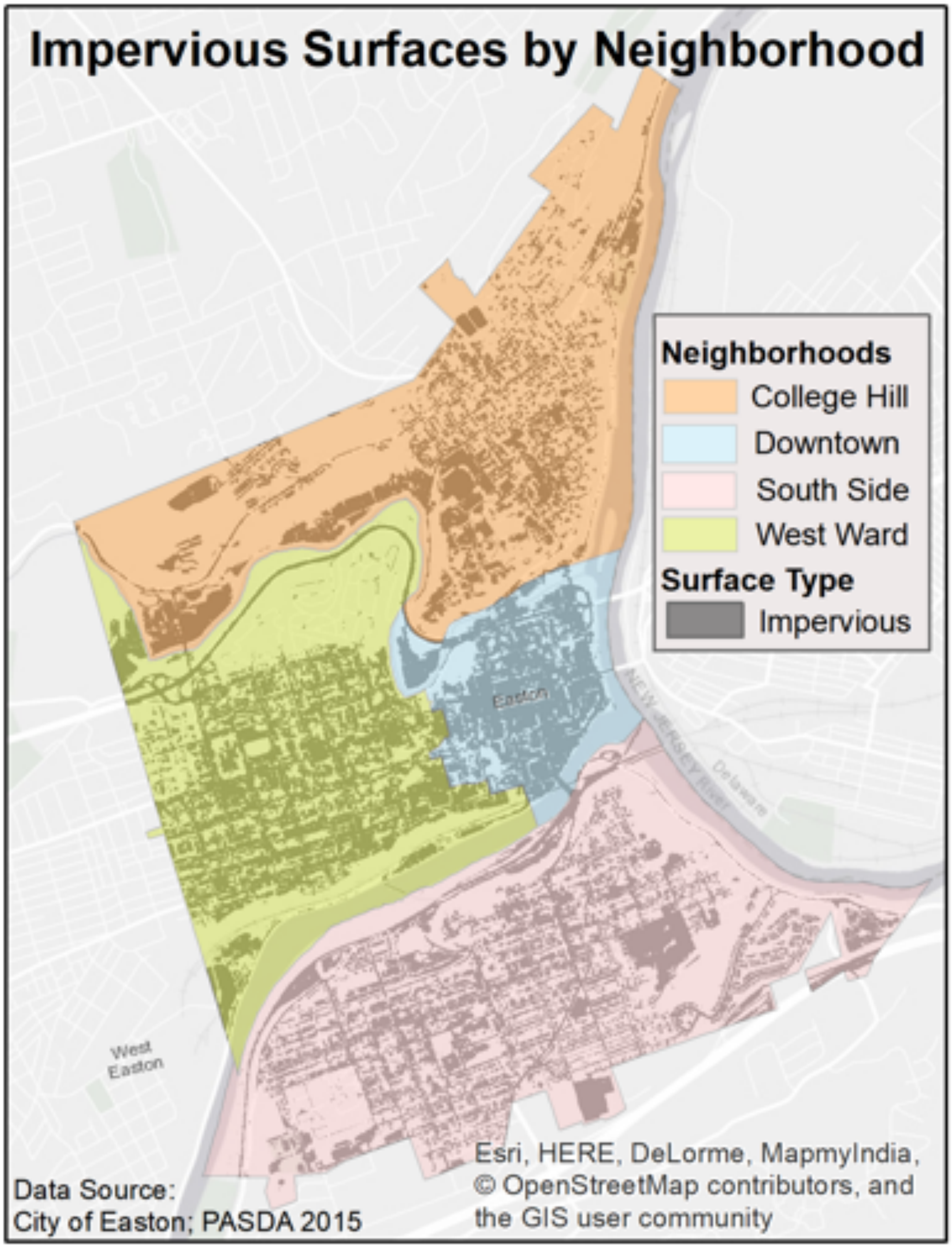
6) All small equipment and materials (spare parts, concrete, etc) are to be relocated to a second floor location or to be removed to higher ground along with the equipment. Computers, electronic equipment, and files may be stored on the 3rd floor of City Hall or in another acceptable location as determined by the supervisor.
7) During periods where the work site is inaccessible due to water levels, employees will continue to report to work as usual during normal business hours or as assigned by the supervisor on weekends, holidays or after hours to the following muster locations:
8) When flood waters recede, cleanup efforts will begin as conditions dictate in order to resume normal operations as quickly as possible so that we can begin servicing the community in the shortest possible timeframe

Appendix B.
Map Methods

This appendix explains the methodology behind the creation of the maps that were highlighted throughout the text. It is focused on giving readers a more in-depth look at how the maps were created, along with the reasoning behind the creation of the maps. This section includes instructions on how data was handled, along with a brief explanation of the datasets used. These instructions are intended for novice users of GIS (Geographic Information Systems).

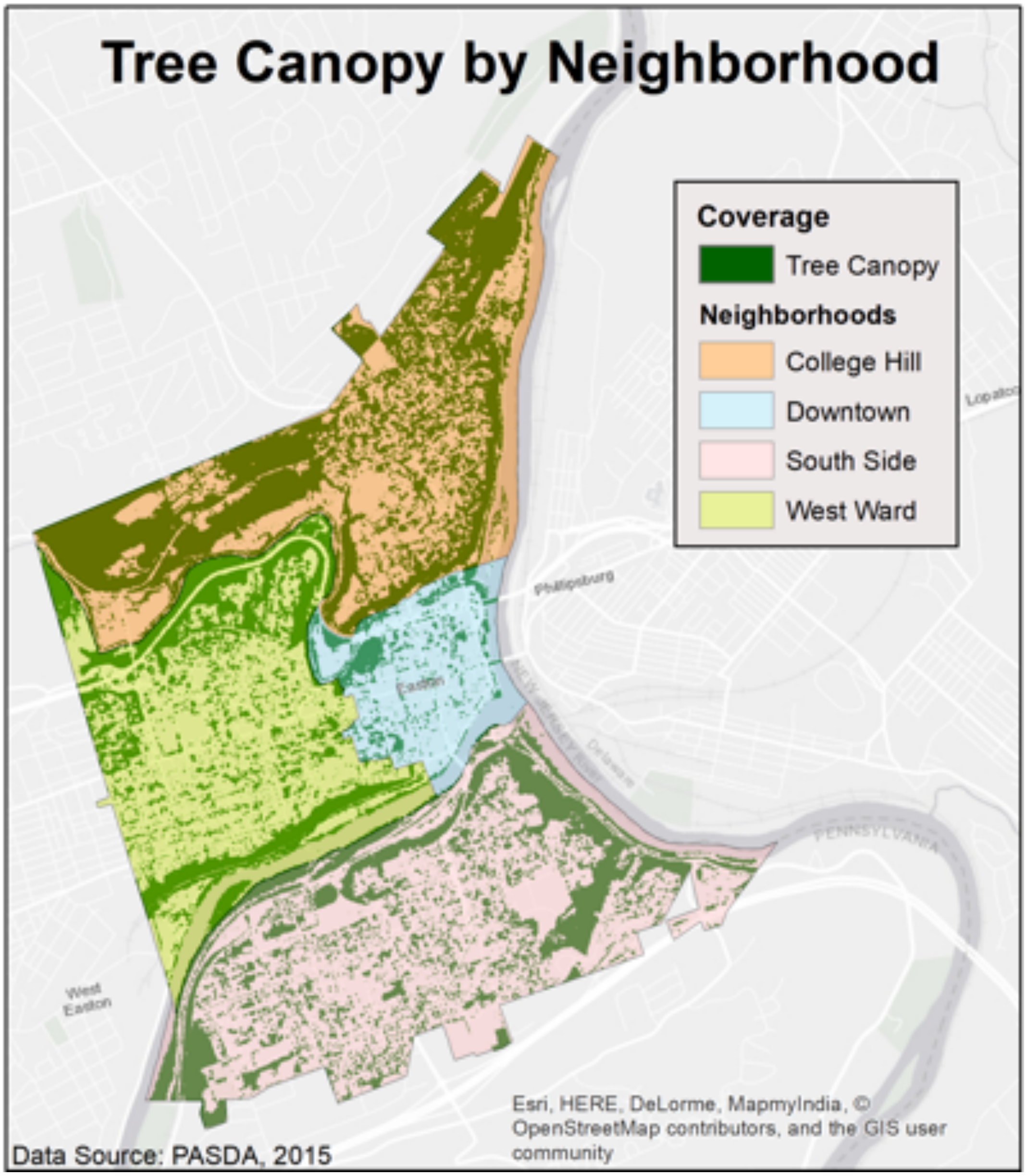
The maps explained in this appendix were made with ArcGIS, specifically, ArcMap- a software developed by Esri to not only create maps, but also analyze them according to specific characteristics (i.e. similar population density, location, land use, etc.). It is important to know that ArcMap has a set of tools that accomplish a wide array of tasks. Throughout the appendix several of the tools used will be referenced with the assumption that readers will be able to use and enable the tools on their own. If there are more specific questions on how to use ArcGIS or Esri products please refer to Esri's website, with several tutorials and guidelines.

Appendix B1.
Impervious surfaces by neighborhood in Easton



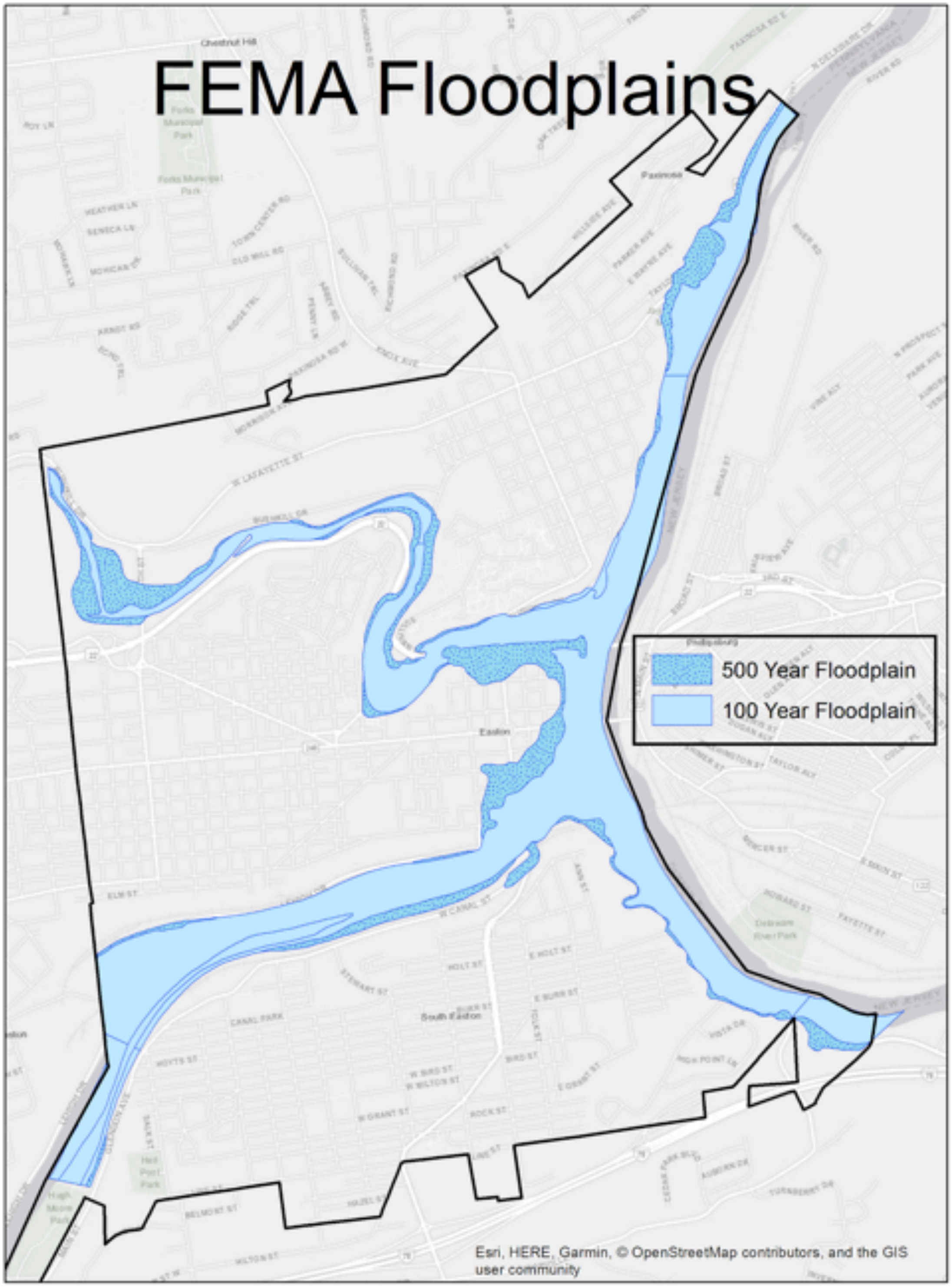
Data Sources: IPUMS NHGIS
This map was created using Pennsylvania PASDA data and a shapefile from the City of Easton. This map was also used to make the analysis of impervious surfaces by neighborhood found in Section 3.1 of this report. The total area that is covered by impervious surfaces was divided by the total area of each neighborhood to find the percentage of tree canopy cover. We counted roads, structures and barren areas as impervious surfaces.

Appendix B2.
Tree canopy coverage by neighborhood in Easton



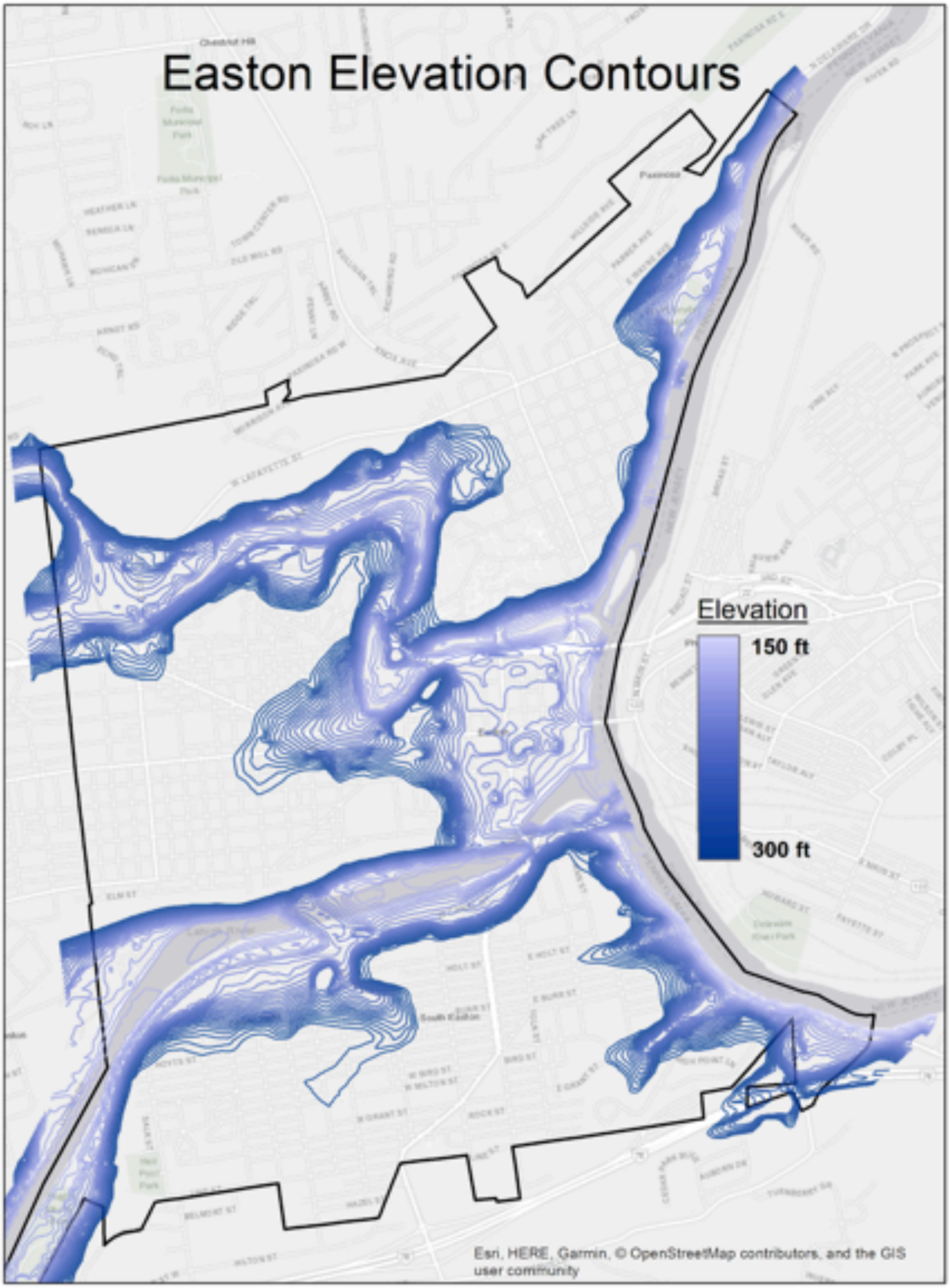
Data Source: City of Easton; PASDA
The map was created by overlaying Easton's neighborhoods and tree coverage.
The neighborhood shapefile is from the City of Easton and tree canopy was downloaded from the PASDA website (http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=3170).
This map was also used to make the analysis of tree coverage by neighborhood.
The total area of the tree canopy was divided by the total area of each neighborhood to find the percentage of tree canopy cover.

Appendix B3.
FEMA Designated Floodplains in Easton



Data Source: Federal Emergency Management Agency (FEMA)
This map contains both the 100 and 500 year FEMA designated floodplains for the City of Easton, PA. The map is centered around a shapefile with the outline of Easton's borders. FEMA designated floodplain shapefiles were added to a basemap of Easton to provide a reference point.

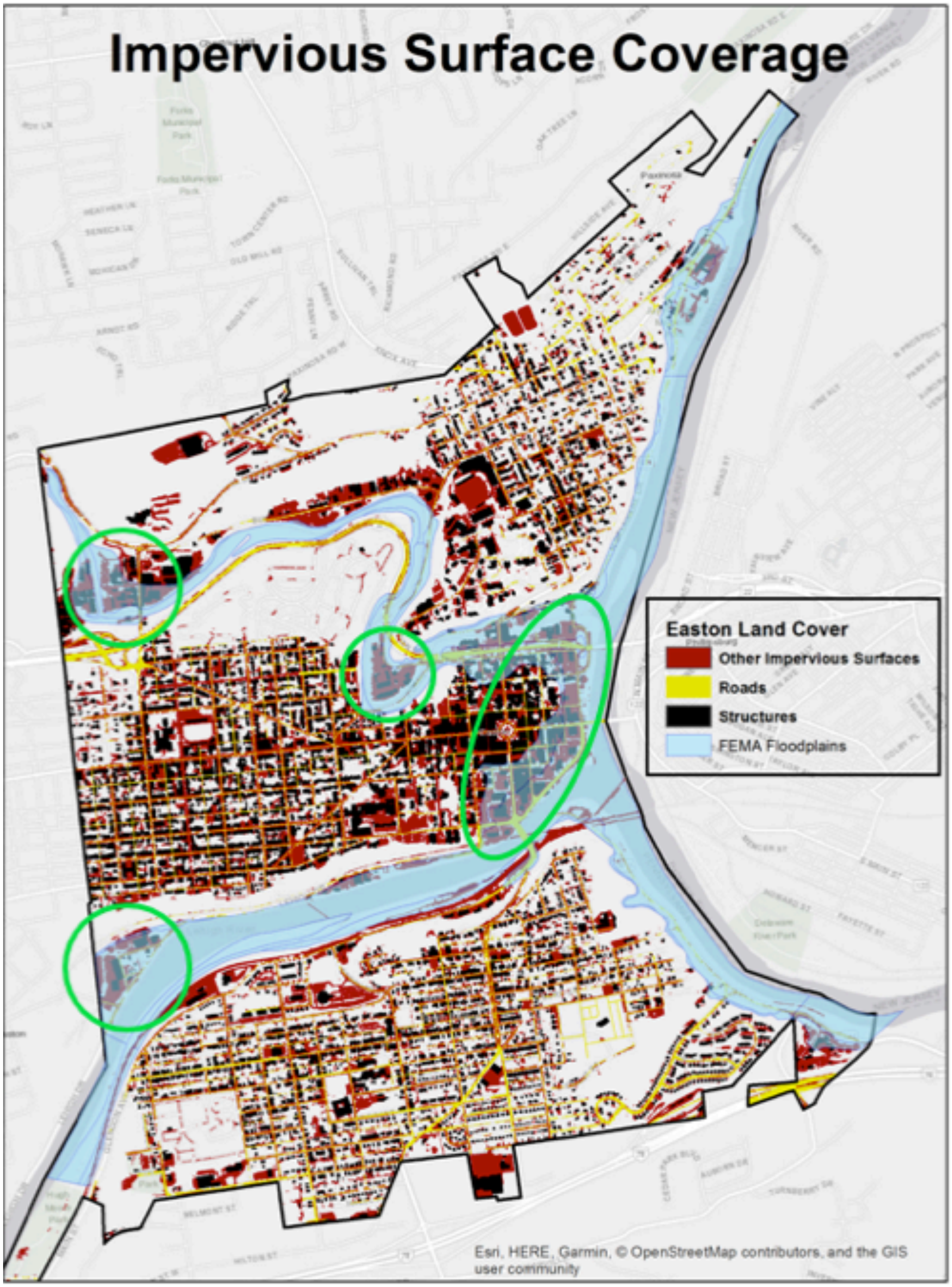
Appendix B4.
Relative Elevation & Slope Contours in Easton, PA



Data Source: City of Easton, PA
This map depicts the range of elevation and slope throughout Easton.

Appendix B5.

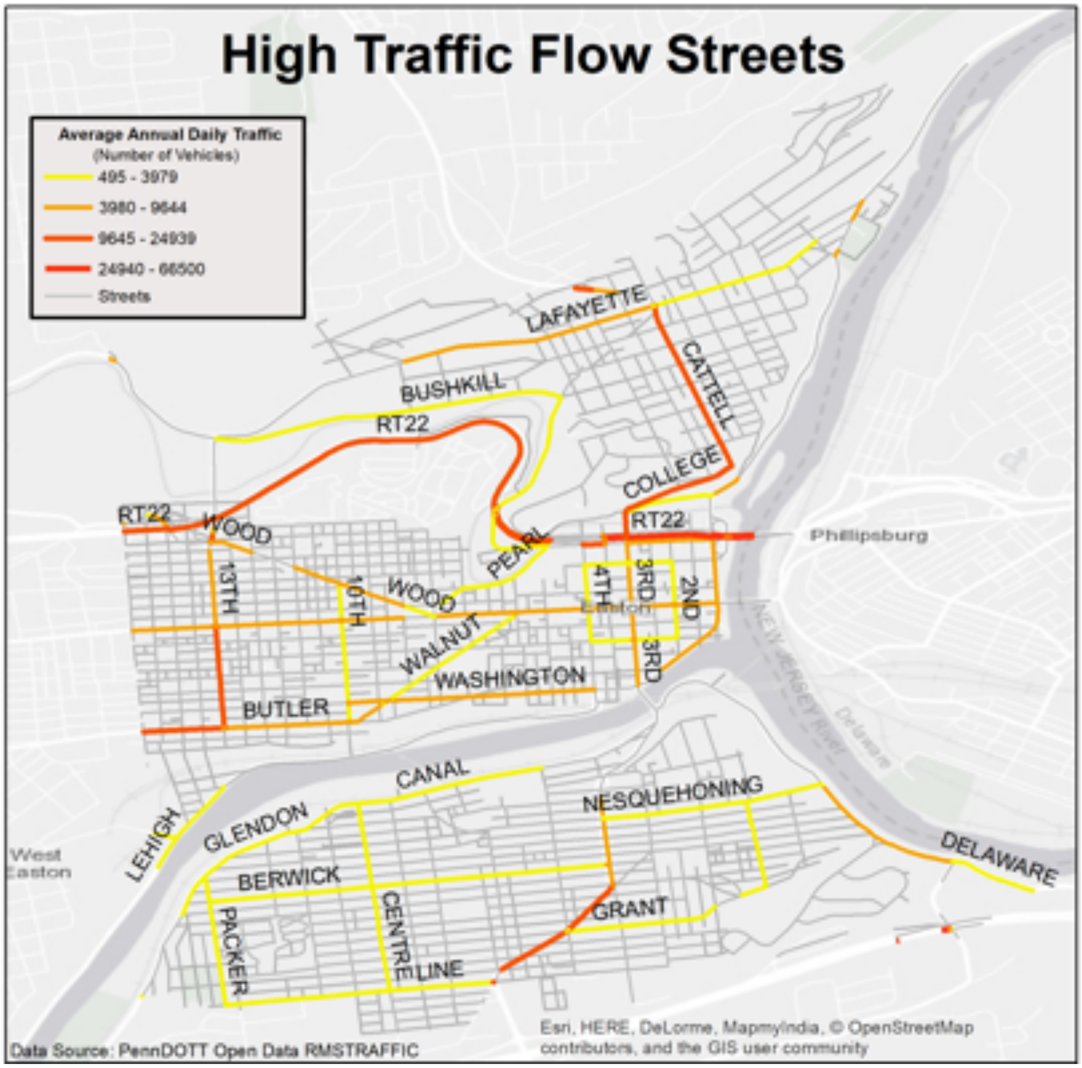
Impervious Surface Coverage in Easton, PA



Data Source: City of Easton, PA; FEMA

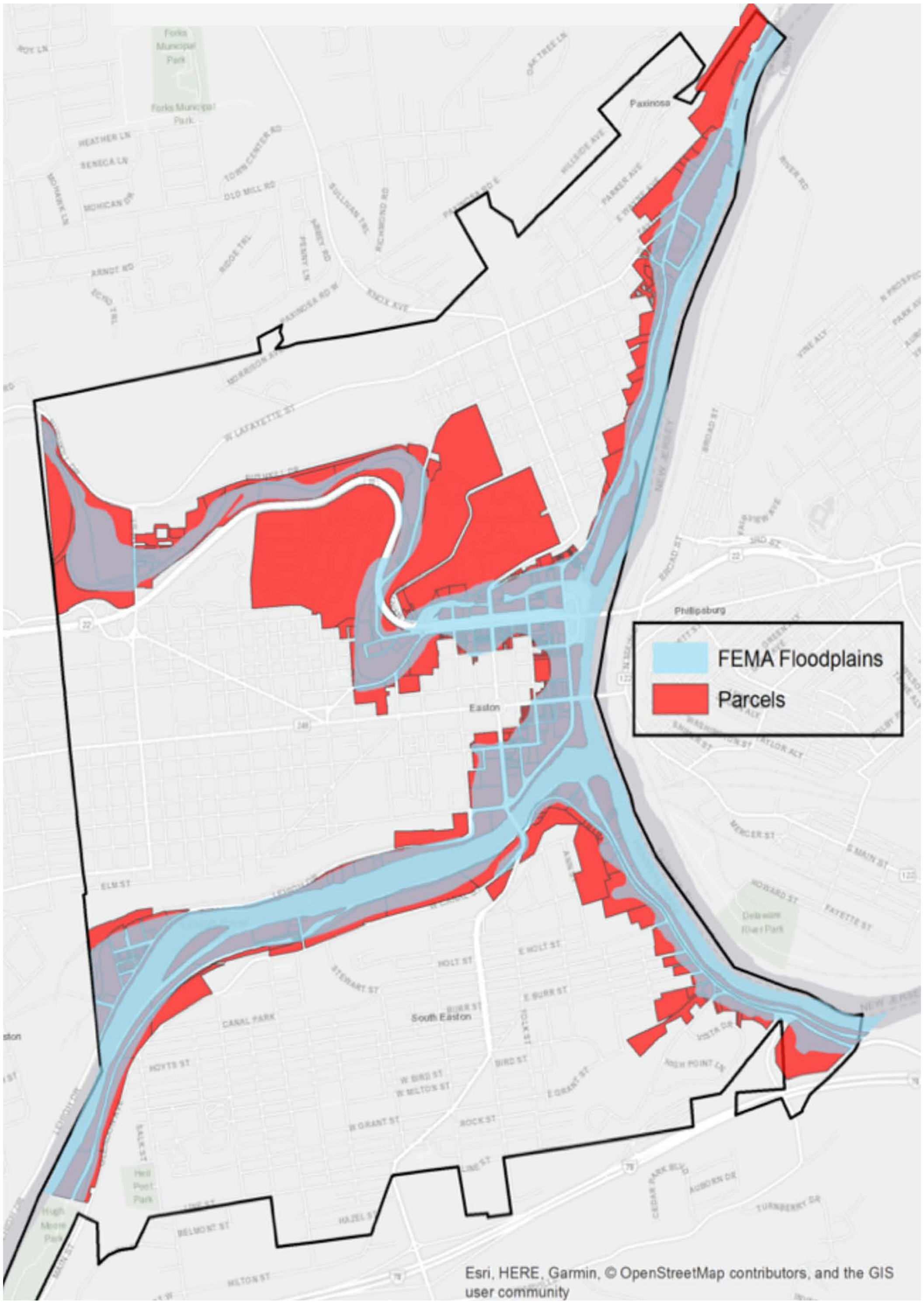
This map depicts the variety and concentration of impervious surfaces throughout Easton, PA. The dataset was narrowed down from all land use surfaces (Tree canopy, water, watersheds, roads, structure, other impervious surfaces, and tree canopy covering water) to solely roads, structures, and other impervious surfaces and the FEMA designated floodplains were added to see the correlation between flooding and impervious surfaces.

Appendix B6.
High Traffic Flow in Easton



Data Source: City of Easton; PennDOT
Two data sets were used for this map: 1) the streets (and their names) for all of Easton and 2) roads most traveled in Easton taken from PennDOT Open Data RM and is labeled as RMSTRAFFIC. RMSTRAFFIC was buffered to create thicker lines and joined to the street dataset so properties of both datasets were combined in one table and divided by jenks.
The specific dataset for the RMSTRAFFIC data set is https://data-pennshare.opendata.arcgis.com/datasets/rmstraffic-traffic-volumes?geometry=-75.241%2C40.687%2C-75.186%2C40.698&selectedAttribute=CUR_AADT.

Appendix B7.
Parcels with Portions of the Property Vulnerable to Flooding in Easton, PA

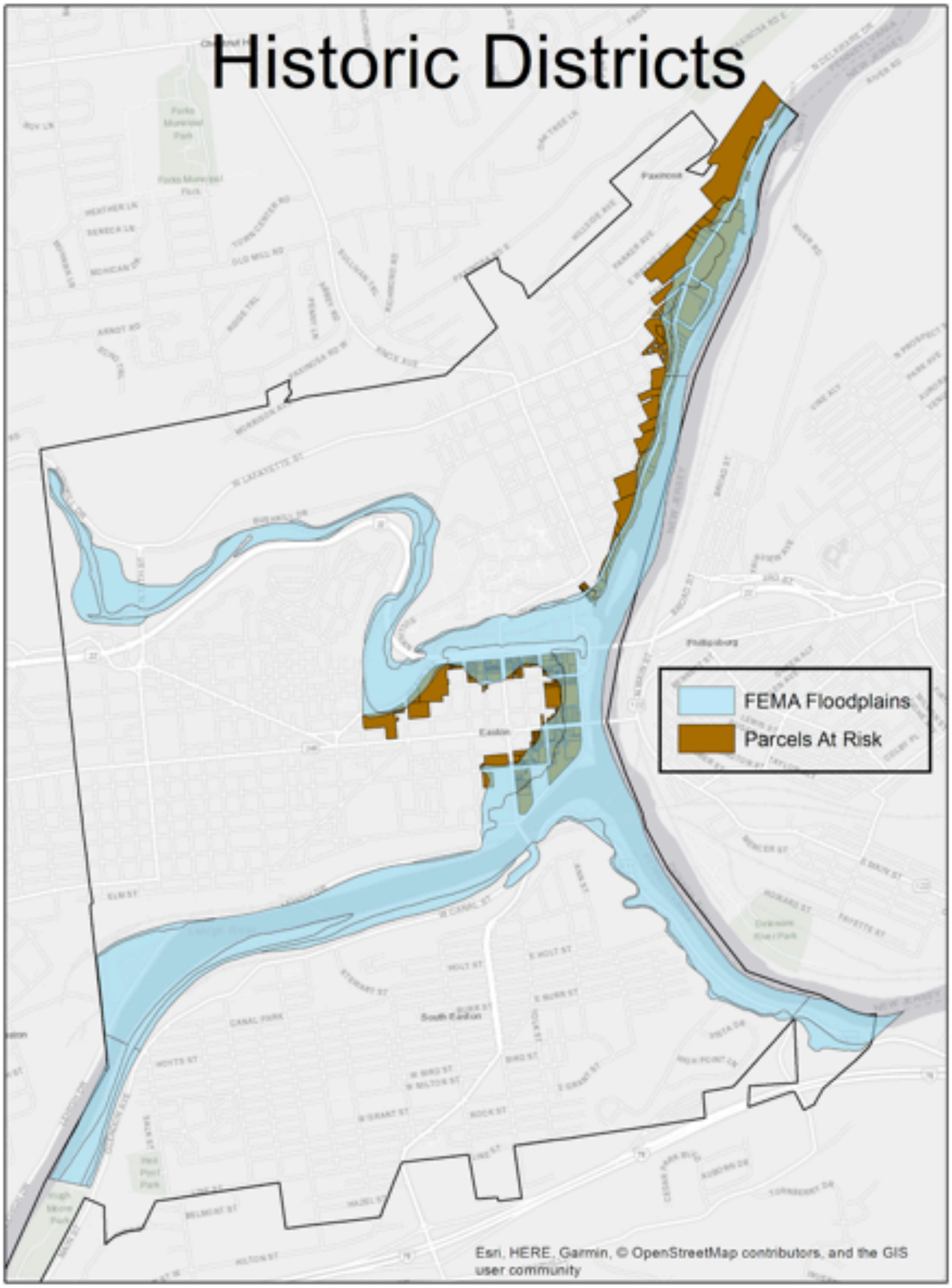


Data Source: City of Easton, PA; FEMA

This map depicts the parcels with portions of their area vulnerable to flooding in the City of Easton. A shapefile containing the building footprints in Easton was cross referenced with data regarding their respective land parcels. After doing so, the most vulnerable parcels were isolated and highlighted by cross referencing the floodplains with the building parcels. Finally, parcel data was extrapolated in order to determine specific addresses and building values directly affected in the floodplains.

Appendix B8.

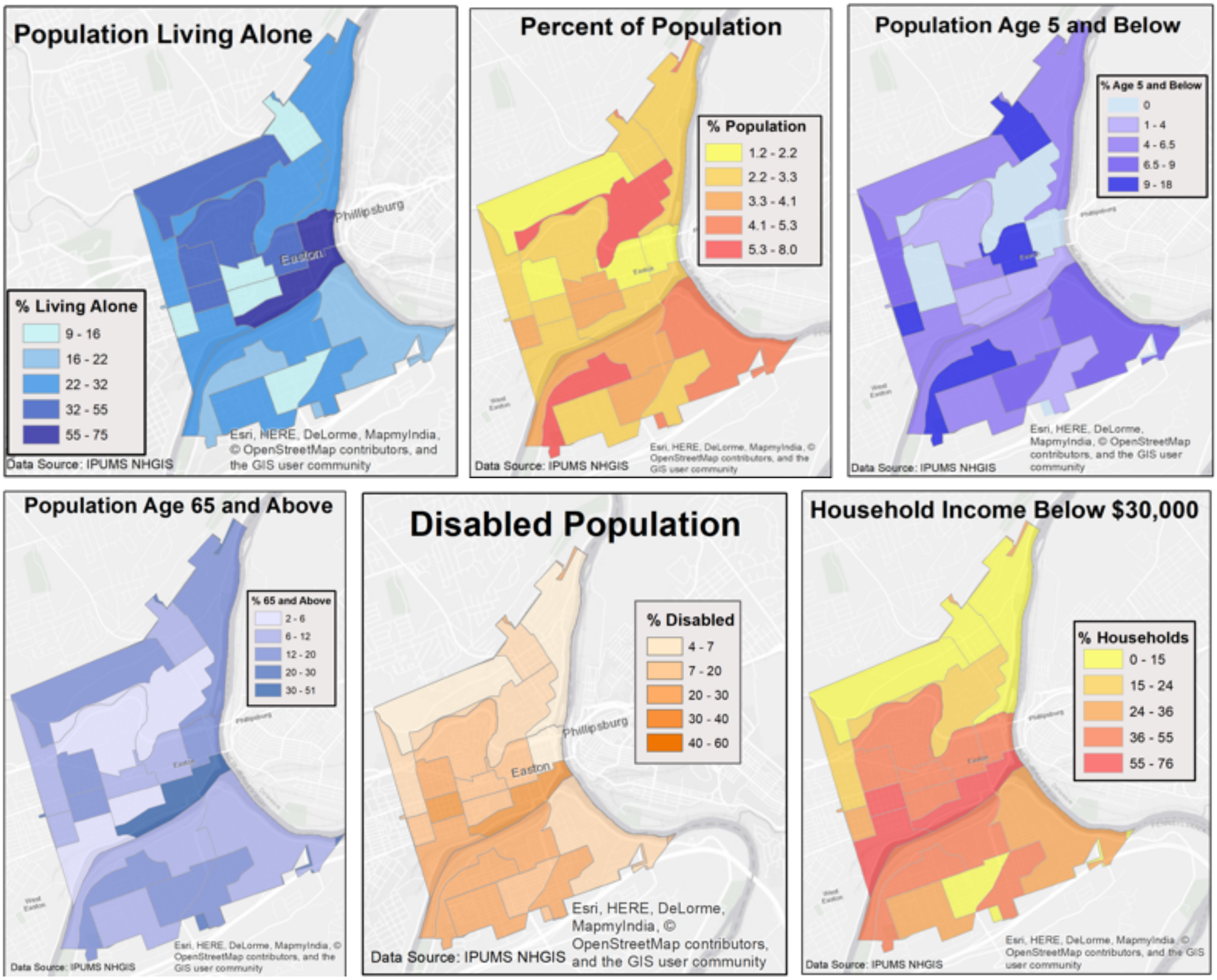
Historic District & Relative Property Parcels Vulnerable to Flooding in Easton, PA



Data Source: City of Easton, PA; FEMA
This map depicts the buildings vulnerable to flooding in the City of Easton, specific to the two designated historic districts. A shapefile containing the building footprints in Easton was cross referenced with data regarding their respective land parcels in the historic districts of Easton. After doing so, the most vulnerable parcels were isolated and highlighted by cross referencing the floodplains with the building parcels. In turn the building addresses and respective values were analyzed to determine their vulnerability to flooding.

Appendix B9.

Population and Social Vulnerability



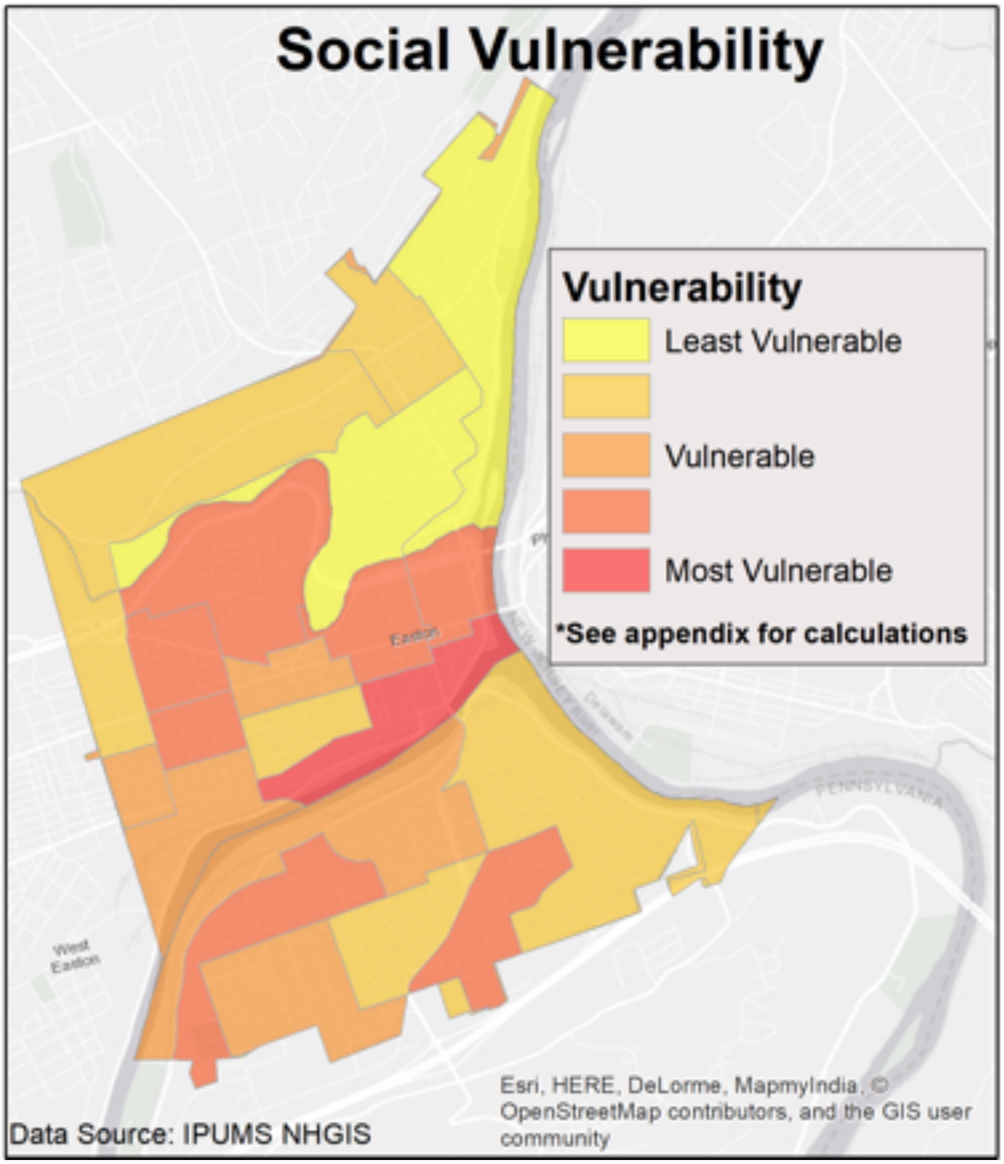
Data Sources: IPUMS NHGIS

This appendix covers the following maps:

1. Age 5 and Below- Percentage of children in the block group
2. Age 65 and Above- Percentage of elderly in the block group
3. Disabilities- Percentage of disabled in the block group
4. Household Income Below $30,000- Percentage of households earning less than $30,000 a year in the block group
5. Living Alone- Percentage of households living alone in the block group
6. Percent of Population- Percentage of population in the block group.

These maps were all made similarly and are explained in one appendix section. The neighborhood shapefile is from the City of Easton and the data set is from IMPUS NHGIS. IMPUS NHGIS uses survey data and reorganizes them to make it easy to use. Specifically, block group data from the American Community Survey 2012-2016 for Pennsylvania was used. The specific data for each individual map was downloaded and clipped using the boundaries the City of Easton. Afterwards, all the columns for the datasets were copied into a master database .csv file. The total count of the vulnerable population was divided by the universe (i.e. households, individuals, etc.) to find the percentage. These percentages were used to create all the maps mentioned above. The percentages were classified by following a two-step process. First, they were divided by jenks, then rounded to the closest integer. For transparency, these divisions are inclusive of the upper limit.

Appendix B10.
Index created by compiling vulnerable populations in Easton



Data Source: IPUMS NHGIS
This map was created by adding the layers of vulnerable populations: children under age 5, the elderly, disabled, poor and the population living alone. These layers are shown individually in the maps of these populations in Section 5. They were all weighted equally in terms of impact. Some populations may have been counted twice (i.e. someone can be elderly and living alone). It is also important to note that these are divided into block groups using the American Community Survey 2012-2016. As such, they are large areas that can be furthered divided by independently studying each block group for particularly vulnerable populations. Furthermore, the five values (from least vulnerable to most vulnerable) were classified by jenks. Then, the values were rounded to the closest integer. The upper limits are inclusive.