3. CLIMATE CHANGE IN THE GREAT LAKES REGION AND DAYTON

In the next section we highlight our exposure to historic, current, and projected future changes in weather and climate.

Great Lakes Regional Summary

- Average air temperature in the Great Lakes region has increased by 2.3°F
- Average air temperature is projected to rise 3°F to 6°F by the mid-21st century.
- Total annual precipitation has increased by 14% in the region with significant intra-regional variation.
- The total volume of rain falling in the most extreme 1% of events has increased 35%.
- Total annual precipitation will likely increase in the future, though types of precipitation will vary (i.e., more winter precipitation in the form of rain).

A. Climate Change Profile for the Great Lakes Region

The climate of cities throughout the Great Lakes region is already changing. Rising temperatures are leading to more storm activity in our atmosphere, helping to fuel extreme weather and increased precipitation. While heat, drought, and other changes associated with climate change remain a concern for the future, many areas of the region are already facing challenges associated with more total precipitation and more frequent downpours.

Temperature

Average annual temperatures in the Great Lakes region have increased by 2.3°F since 1951, faster than the global and national rates. Most of this warming has been observed during the late spring and early winter, and in overnight low temperatures. The average temperature for the Great Lakes region is projected to increase in the future (3°F to 6°F by 2050), and many of the northern parts of the region will likely experience the most change. The region is projected to see increases in the number of hot and very hot days by the end of the 21st century, with projections indicating the region will see 17 to 42 more days over 90°F in an average year compared to the late 20th century.

Precipitation

The Great Lakes region has experienced changes in the frequency, amount, and form of precipitation. Total precipitation has increased by 14% since 1951 across the region, though this change varies within the region. Therefore, more local data should be used where available. In addition, heavy precipitation (over 1.25" of rainfall in 24hrs) has increased rapidly throughout the region. The amount of rain falling in the most extreme events (heaviest 1% of storms) has increased by 35% and these events have generally become more frequent since 1951. Much of the region is projected to experience more average annual precipitation with total amounts ranging from an additional 2 to 6 inches per year by the end of the 21st century. In addition, the Great Lakes themselves are projected to contribute more water vapor to the air. This increase in moisture combined with rising temperatures, which are necessary for storm formation, will likely produce more intense storms in the future.

Climate change will likely accelerate in the future.

The observed trends in temperature, precipitation, and seasonality are projected to continue or accelerate into the future. The rate of warming has been fastest during the winter, with some locations experiencing twice the annual warming rate of the Great Lakes region. Temperatures will continue to warm at a pace near or faster than the current rate, and precipitation will likely continue to increase, though variability and multi-year dry periods should still be anticipated. By mid-century, summer and spring temperatures may have greater increases compared to fall and winter.

Preparing for the next normal, not a new normal.

The climate system is dynamic and will continue to change rapidly due to greenhouse gas emissions and inherent feedback systems. The challenges, priorities, and risks of the current or next generation climate will continually change and will affect all sectors. Importantly, climate and weather conditions will not change to a new set of static conditions. This means long-term planning efforts in all departments should regularly evaluate climate and be as flexible and adaptable as possible. Assessing vulnerabilities of a city's assets is a first step toward this goal.

The following table summarizes how various climate risk factors in the Great Lakes region are expected to change in the future. The number and direction of arrows indicate the relative projected trend for mid-century and end of century. A single arrow indicates a projected moderate increase or decrease by mid-century, and two arrows indicate a substantial increase or decrease by end of century.

Table 2: Climate Change in the Great Lakes Region

Risk	By Mid Century	By End of Century	Summary
Convective Weather (Severe Winds, Lightning, Tornadoes, Hail)	**Uncertain***	**Uncertain***	While extreme precipitation has increased in the region, specific severe weather types (e.g., tornadoes and hail) have remained relatively stable over time.
Severe Winter Weather (Ice/Sleet Storms, Snow Storms)	**Uncertain***	↑	Warmer, shorter winters will reduce the length of winter and winter-related impacts. However, some areas may see more ice, sleet, freezing rain, and wet snow with slightly warmer winter temperatures.
Extreme Heat	↑	↑↑	The number of extremely hot days, those over 95°F and 100°F, will likely increase, though not as fast as in areas farther south. Overnight lows have warmed faster than daytime highs, which may lessen opportunities for relief during heat waves.
Extreme Cold	↓	↓↓	The number of extremely cold days (i.e., days below 10°F) have decreased in the region and are projected to decrease even more in the future.
Dam Failures	↑	↑↑	Stronger and more extreme precipitation events coupled with aging dam infrastructure will increase the probability of dam failure, if appropriate measures are not taken.
Flood Hazards	↑	↑↑	Stronger and more extreme precipitation events will be more likely to overwhelm stormwater infrastructure without appropriate adaptation efforts.
Wildfires	**Uncertain***	↑	Summer drought and the number of consecutive dry days may increase in the future, despite more precipitation annually, increasing the risk of wildfires.
Drought	**Uncertain***	↑	Summer drought and the number of consecutive dry days may increase in the future.
Infestation	↑	↑	With shorter winters and longer growing seasons, conditions may become more suitable for invasive species and pests currently found elsewhere and distribute vector-borne illnesses.

**Boxes labeled uncertain reflect either a lack of available data to discern a trend or no apparent trend from existing data.*

The arrows in this table reflect a qualitative assessment made by the project team based on the best available data for the Great Lakes region. While these trends hold true for projections for most of the region, they should not be assumed to hold true for any particular location. Data used to make this assessment is provided by the NOAA Technical Report NESDIS 142-3 and the Third National Climate Assessment.

B. Dayton City Summary

Dayton City Summary

- Average air temperature in Dayton has increased by 0.9°F.
- Average air temperature is projected to rise 3°F to 5°F by the mid-21st century.
- Total annual precipitation has increased by 28.5%.
- The total volume of rainfall in extreme events (heaviest 1% of storms) has increased by 71%.
- Total annual precipitation will likely increase in the future, though types of precipitation will vary (i.e., more winter precipitation in the form of rain).

The following is a summary of historic as well as projected changes in climate specific to Dayton. This information is valuable in helping us understand what changes we have already experienced as well as what changes we anticipate.

Table 3: Historic and Projected Changes in Climate for the City of Dayton

	Historic (1981-2010)	Mid-Century Projections (High Emissions)	End of Century Projections (High Emissions)	Change Mid-century/ End of century	Percent Change* Mid-century/ End of century
Average Temperature	52.2°F	55 to 57°F	57 to 62°F	3 to 5°F / 5 to 10°F	5 to 9% / 9 to 19%
Winter	30.1°F	31 to 34°F	35 to 38°F	1 to 4°F / 5 to 8°F	3 to 13% / 16 to 26%
Spring	51.4°F	53 to 56°F	56 to 62°F	2 to 5°F / 5 to 11°F	3 to 9% / 9 to 21%
Summer	72.7°F	77 to 80°F	82 to 85°F	4 to 7°F / 9 to 12°F	6 to 10% / 13 to 17%
Fall	54.3°F	56 to 60°F	58 to 66°F	2 to 6°F / 4 to 12°F	3 to 10% / 7 to 22%
Average Low Temperature	42.8°F	46 to 48°F	49 to 53°F	3 to 5°F / 6 to 10°F	7 to 12% / 14 to 24%
Average High Temperature	61.6°F	65 to 68°F	67 to 72°F	3 to 6°F / 5 to 10°F	6 to 10% / 9 to 17%
Days/Year Greater than 90°F	10.7 days	32 to 52 days	52 to 86 days	21 to 41 days / 41 to 75 days	199 to 386% / 386 to 704%
Days/Year Greater than 95°F	1.9 days	7 to 19 days	Not Available	5 to 17 days / Not Available	268% to 900% / Not Available
Days/Year Less than 32°F	105.3 days	81 to 84 days	Not Available	-24 to -21 days / Not Available	-23% to -20% / Not Available
Total Annual Precipitation	40.9 in.	37 to 45 in.	37 to 47 in.	-4 to 4 in. / -4 to 6 in.	-10 to 10% / -10 to 15%

Table 3: Historic and Projected Changes in Climate for the City of Dayton					
Winter	8.1 in.	7 to 15 in.	6 to 17 in.	-1 to 7 in. / -2 to 9 in.	-14 to 85% / -26 to 110%
Spring	12.1 in.	9 to 15 in.	10 to 17 in.	-3 to 3 in. / -2 to 5 in.	-26 to 24% / -17 to 40%
Summer	11.2 in.	9 to 13 in.	8 to 13 in.	-2 to 2 in. / -3 to 2 in.	-20 to 16% / -29 to 16%
Fall	9.4 in.	8 to 10 in.	8 to 11 in.	-1 to 1 in. / -1 to 2 in.	-15 to 6% / -15 to 17%
Heavy Precipitation Days	6.1 days (> 1.25")	5.7 to 9.7 days	6.1 to 10.5 days	-0.4 to 3.6 days / 0 to 4.4 days (> 1")	-7 to 59% / 0 to 72%

**Percent change is calculated as the difference between the projected values and the historic average, divided by the observation and multiplied by 100.*

Data provided in this table is described in the "About the Data" section for "GHCN", "CMIP3", and "Dynamically Downscaling for the Midwest and Great Lakes Basin."

Temperature and Hot/Cold Extremes

Average Temperature

The average air temperature in Dayton has increased by 0.9°F from 1951 to 2017, with the current annual average temperature being 52.2°F. Average seasonal temperatures have also increased, with spring experiencing the greatest increase of 2.2°F. Average temperatures in Dayton are projected to increase 3.0 to 5.0°F by mid-century under a business as usual (i.e., high emissions) scenario, with winter having the greatest increases of 4.0 to 7.0°F.

Hot Days

Days with temperatures at or above 90°F are common with multiple occurrences in most years and no clear increasing or decreasing trend. Many years on record have experienced 2 to 6 consecutive days over 90°F, with events of 7 to 16 consecutive days occurring less frequently. By mid-century (i.e., 2050), models suggest an increase of anywhere from 21 to 41 more days per year over 90°F, and an increase of 41 to 75 more days per year over 90°F by end of century. Models are not able, however, to tell us if those days will be consecutive or not.

Days with high temperatures at or above 95°F are much rarer, with many years seeing at least one occurrence of more than one consecutive day experiencing maximum temperatures over 95°F. By mid-century (i.e., 2050), models suggest an increase of 5 to 17 days over 95°F. However, such hot days will not necessarily occur consecutively.

Heat waves can result from a combination of different drivers including high humidity, daily high temperatures, high nighttime temperatures, stagnant air movement, etc. In the future, models project an increase in the number of days experiencing high temperatures that could lead to additional heat waves, especially since air stagnation events are projected to increase. There is greater certainty that summer nighttime low temperatures will continue to increase, thereby making it more difficult to cool off at night during extended heat events. In addition, any periods of future drought will also contribute to extreme heat.

Cold Days

On average, Dayton experiences 105.3 days per year that fall below freezing (32°F). Historical records show this number has decreased already. The city is projected to experience fewer nights below 32°F, with decreases of 21 to 24 days by mid-century.

Days with temperatures at or below 10°F are very common and have not experienced any clear trends over time. Consecutive days at or below 10°F are also frequent, and typically last for 2 to 5 days with less frequent occurrences lasting 6 to 12 days. In the future, there are projected to be even fewer very cold days, so this type of event will be even rarer.

Precipitation and Flood/Drought Indicators

Average Precipitation

The amount of total annual precipitation in Dayton has increased by 28.5% (9.9") from 1951 to 2017. An increase in precipitation was observed in all four seasons, with the fall seeing the greatest percentage increase of 53.3% (3.8"). Average annual precipitation in Dayton is projected to increase by up to 4 inches by mid-century and by up to 6 inches by the end of the century.

Heavy Precipitation

The frequency and intensity of severe storms has increased historically, with an 85% increase in the number of extreme precipitation events (heaviest 1% of storms) and a 71% increase in the total volume of rainfall during these events between 1981-2010. Dayton is projected to experience an increase of up to 3.6 days of heavy precipitation (days with over 1" of rainfall) per year by mid-century and by up to 4.4 days per year by end of century.

Flooding results when rainfall volumes exceed the capacity of natural and built infrastructure to handle precipitation. Stormwater managers look at several different "design" storms (inches falling over a certain length of time) when designing and managing their systems. These "design" storms are effectively the probability of any given amount of precipitation falling in a set period of time, based on historical experience. Monitoring over time shows that the volumes falling during these "design" storms are increasing. What this means is that the values used to build our existing infrastructure (Bulletin 71 (Huff and Angel, 1992), used data through 1986, and Atlas 14 (NOAA HDSC) added a longer period of data into the 21st century) are dependent on fluctuating estimates of rainfall.

The table below shows precipitation volumes in inches for both Bulletin 71 and Atlas 14 (Bulletin 71/Atlas 14) along with percent change between the two in brackets. This data shows how the "design" storm has changed over time.

In the Great Lakes region, projected changes in seasonal mean precipitation span a range of increases and decreases. In the winter and spring, the region is projected to experience wetter conditions as the global climate warms. By mid-century, some of this precipitation may manifest in the form of increasing snowfall, but projected warmer conditions by end of century suggests such precipitation events will most likely be in the form of rainfall (Wuebbles et al. / USGCRP, 2017).

Precipitation events of more than 2" in a day (i.e., 24-hour period) are projected to increase by up to one day by mid-century and up to about 2 days by end of century. Precipitation events of more than 3" in a day are projected

Table 4: Precipitation Frequencies for the City of Dayton

	1-Yr	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr
1-hr	1.10 in. / 1.11 in. [0.9%]	1.34 in. / 1.34 in. [0%]	1.64 in. / 1.65 in. [0.6%]	1.88 in. / 1.89 in. [0.53%]	2.21 in. / 2.20 in. [0.5%]	2.50 in. / 2.45 in. [-2%]	2.84 in. / 2.69 in. [-5.3%]
12-hr	2.03 in. / 1.93 in. [-4.9%]	2.49 in. / 2.31 in. [-7.2%]	3.04 in. / 2.83 in. [-6.9%]	3.47 in. / 3.25 in. [-6.3%]	4.09 in. / 3.81 in. [-6.8%]	4.63 in. / 4.26 in. [-8.0%]	5.25 in. / 4.72 in. [-10.1%]
24-hr	2.33 in. / 2.26 in. [-3.0%]	2.86 in. / 2.71 in. [-5.2%]	3.49 in. / 3.32 in. [-4.9%]	3.99 in. / 3.80 in. [-4.8%]	4.70 in. / 4.45 in. [-5.3%]	5.32 in. / 4.98 in. [-6.4%]	6.04 in. / 5.51 in. [-8.87%]

This table does not show projections for how the design storm may change in the future due to climate change.

to increase by less than a day by both mid-century and by end of century.

Annual snowfall totals have been variable, with a slight increasing trend in the last 40 years. There has been a slight decreasing trend in days with snowfall (over 0.1" of snowfall in 24 hrs), with varying year-to-year conditions. Warmer temperatures in the future will cause some winter precipitation to transition from snow to rain over time. The projected change in annual snowfall is variable. Annual snowfall is projected to decrease by 2" to 10" by mid-century, with decreases of 7" to 15" by end of century.

Rain Free Periods (3-week events with less than 0.5" of rain)

Drought, defined here as periods of 3 weeks with less than 0.5" of rainfall, has been highly variable year-to-year, with an overall decreasing trend most prominent in summer events. In the future, even though more annual precipitation is projected overall, more is anticipated to fall in shorter, extreme events. Thus, there will be longer periods of time that experience no rainfall, increasing the potential for drought.

In the following chapter we look at local landscape features that influence our exposure and overall vulnerability to climate change in Dayton.

About the Climate Change in the Great Lakes Region and Dayton Data

Coupled Model Intercomparison Project (CMIP) Version 3. The future (mid-century) climate projections for Dayton are based on the Coupled Model Intercomparison Project Version 3 (CMIP3) A2 emissions scenario, representing "business as usual" high emissions scenario. These data were selected because they were used in the Third National Climate Assessment (Melillo et. al., 2014). More information is available at: https://www.wcrp-climate.org/wgcm-cmip

"Dynamical Downscaling for the Midwest and Great Lakes Basin." Future projections are based on the dynamically downscaled data set for the Great Lakes region developed by experts at the University of Wisconsin-Madison. There are a total of six downscaled models that represent how a variety of different variables are projected to change (mid-century, 2040-2059, compared to the recent past, 1980-1999). The ranges are comprised of the lowest and highest values from all six dynamically downscaled data sets. The regional data are available for download at: http://nelson.wisc.edu/ccr/resources/dynamical-downscaling/index.php.

National Oceanic and Atmospheric Administration National Centers for Environmental Information Global Historical Climatology Network Station Observations (GHCN). More information about this station located in Dayton, OH from 1981-2010 is available at: http://glisa.umich.edu/station/W00093815

"National Oceanic and Atmospheric Administration ThreadEx Long-Term Station Extremes for America". ThreadEx is a data set of extreme daily temperature and precipitation values for 270 locations in the United States. For each day of the year at each station, ThreadEx provides the top 3 record high and low daily maximum temperatures, the top 3 record high and low daily minimum temperatures, the top 3 daily precipitation totals, along with the years the records were set for the date (NCAR, 2013). ThreadEx data: http://threadex.rcc-acis.org/

National Oceanic and Atmospheric Administration Hydrometeorological Design Studies Center Atlas 14 Precipitation Frequency Estimates. Data are available at: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

4. LANDSCAPE FEATURES THAT AFFECT DAYTON'S STORMWATER SYSTEM VULNERABILITY

Summary

- Local landscape features such as floodplain location and extent, elevation, slope, landscape cover, and stormwater asset conditions all influence the vulnerability of our stormwater system as well as local flooding potential.
- By combining the aforementioned factors, we were able to generate a holistic assessment of where in Dayton landscape features affect our stormwater systems and our community's vulnerability to flooding. Results showed that that the central area of our city is lower elevation and has greater impervious surface cover.
- Local features influence heat impacts, including: impervious surfaces, urban heat island, and vegetation coverage.
- By combining the aforementioned factors, we were able to generate a holistic assessment of where in Dayton local landscape features may affect our vulnerability to heat. Results showed that high surface temperatures are also concentrated in the center of the city.

In addition to our socio-economic composition and projected changes in climate, certain features related to the way Dayton is designed and our physical environment make us more or less vulnerable to climate change. This section explores a number of these landscape characteristics or features that affect the vulnerability of our residents and our systems to flooding. We chose to look specifically at our local vulnerability to flooding because this is one of the largest climate impacts we expect to continue experiencing in a climate-altered future.

Landscape Features that Affect Our Stormwater System and Flooding Exposure

Flooding is one of the most common and pervasive climatological impacts to affect the City of Dayton. Every year we experience numerous localized flooding events. These events can cause property damage, road closures, economic disruptions, and other issues. Larger events have far reaching implications for our local economy, transportation systems, and health and safety. Nationally, flood deaths are highest in adults over the age of 50 (although 20-30 years old also have a fairly high vulnerability to flooding-related deaths and injuries).[54] Males are notably more vulnerable to flooding-related deaths, particularly those tied to flash flooding events.[55]

Because of the acute vulnerability we have in Dayton, we want to understand what local landscape features enhance or reduce our local stormwater systems vulnerability as well as our local vulnerability to flooding. The following factors are important elements of understanding these vulnerabilities.

a) Location of Floodplains

b) Elevation

c) Land Cover

d) Stormwater Asset Map

a) Location of Floodplains

Because we know that certain areas of our community are already susceptible to flooding, we used our 100-year and 500-year floodplains as an indicator of future flooding risk. Using data from the Federal Emergency Management Agency (FEMA), we were able to identify areas within Dayton that lie within both the 100 and 500-year floodplains (Figure 13). Land within the 100-year floodplain has a 1% chance of flooding each year. Land within the 500-year floodplain has a 0.2% chance of flooding in any given year. However, we know that climate change is altering these frequencies, making the likelihood of flooding in any given year significantly greater. As such, we thought it important to use both the 100 and the 500-year floodplains as these represent our current and likely future flood risks. In addition to identifying locations vulnerable to flooding, floodplains help us understand where additional demand may be placed on our stormwater system – thereby providing insight into where

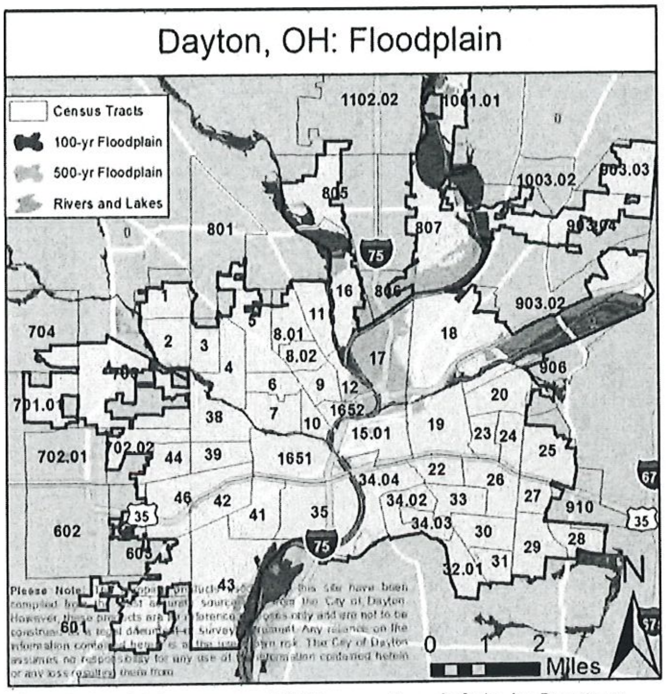

Figure 13: 100-year and 500-year floodplain in Dayton, OH

additional stormwater-related solutions may be needed.

b) Elevation

Understanding the elevation of various areas of our city helps us to understand which areas might be more prone to future flooding and, therefore, where we may have greater stormwater-related challenges. Recognizing that, we used data from the City's GIS office to map the

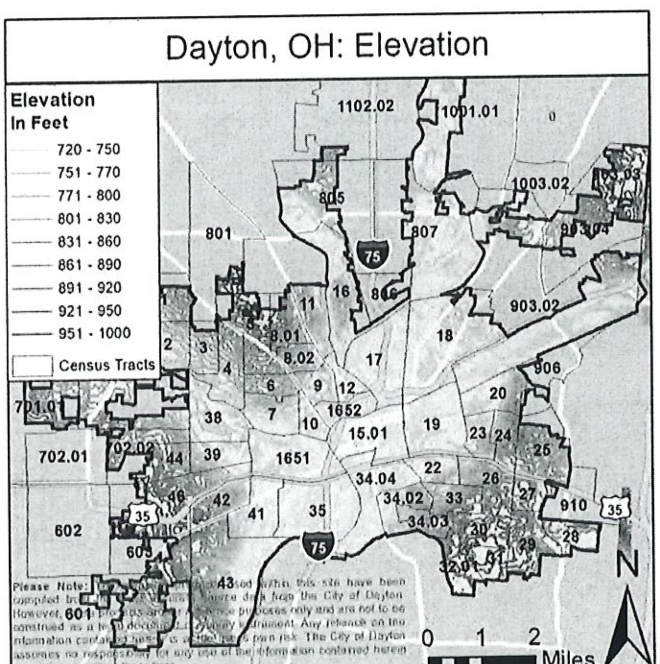

Figure 14: Elevation contours in 10-foot intervals in Dayton, OH.

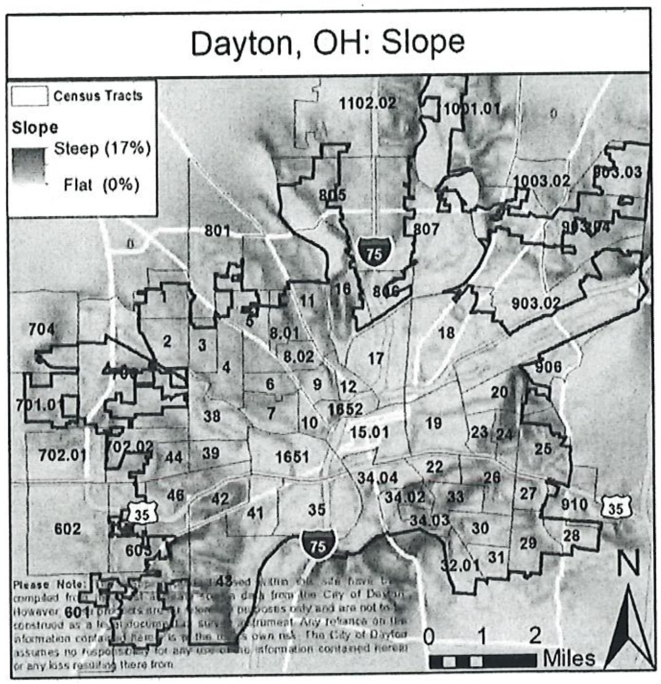

Figure 15: Slope in Dayton, OH

elevation above sea level for the entire city. We used 10-foot contour lines to denote changes in elevation. As shown in Figure 4.2, elevation within city limits ranges from 706-1022 feet (based on the city's 2-ft interval contour data). Elevation within the 100-year flood hazard area ranges from 708-870 feet.

The city's low lying areas (800 feet or less) are predominantly located within/around the central business district or central part of the city as a whole. These areas of lower elevation follow the paths of the Stillwater, Wolf Creek, Mad, and Great Miami rivers. Of these low-lying areas, Census tracts 2, 3, 8.02, 10, 19, 22, 34.04, 35, 41, 43, 44, and 1651 have more than 25% of household that are living in poverty. Of these, tracts 8.02 and 19 have more than 10% uninsured persons. Tracts 16, 903.02 and 906 have more than 20% of their area in the 500-year floodplain.

c) Slope

Slope is the degree of incline or tilt that exists between two points. Understanding slope can help us determine which areas in our community might be particularly susceptible to runoff and erosion from major rain events. Using a Digital Elevation Model raster layer provided by the City's GIS department, we were able to map slope throughout the city.

The City of Dayton's slope range based on percent rise reaches a high value of 16.78%. East and western regions within the city's municipal boundary experience the highest degrees of incline whereas the city's lowest region is relatively unchanged with the exception of Census tracts 9 and 1652. Northridge Estates experiences a change in slope from 0% to 6% with part of the neighborhood boundary being within the 100-year floodplain with the majority being in the 500-year floodplain.

Ordinance Misc: Sec. 151.122. - Undeveloped land.

Land subject to flooding, land with excessive slope and land deemed by the Plan Board to be undesirable for development shall not be platted for residential occupancy, nor for such other uses as may involve danger to health, life, or property or to aggravate erosion or flood hazard. The land shall be set aside for compatible uses.

d) Land Cover

Land cover is an important factor affecting flood potential (as well as heat potential). Impervious surfaces and low vegetative covering are indicators of runoff potential. We know that when precipitation falls on impervious surfaces, such as roads, streets, sidewalks, and buildings, it is unable to infiltrate into the soil. Conversely, the greater portion of vegetation cover present, the more precipitation may infiltrate the soil, and thus, the less precipitation moves through the city as run-off. Because of this, the City of Dayton has decided to use impervious surface coverage and vegetation coverage as indicators of local landscape vulnerability to flooding.

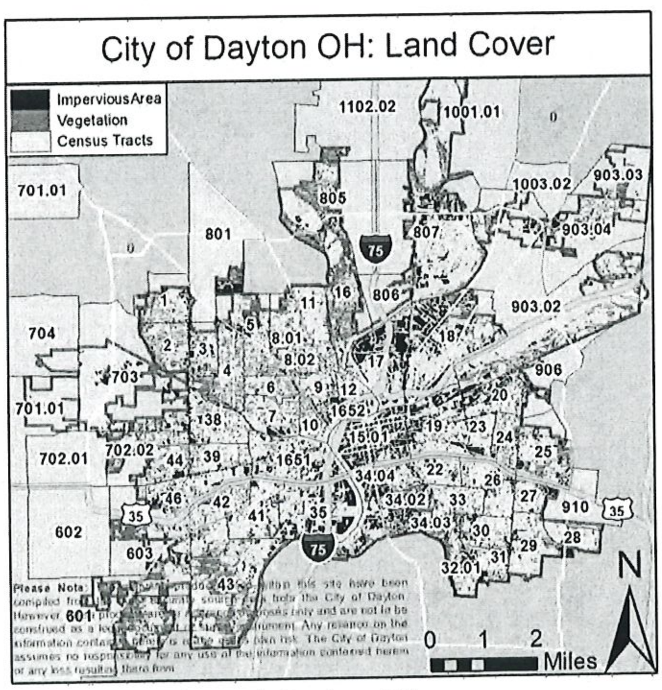

Figure 16: Landcover in Dayton, OH.

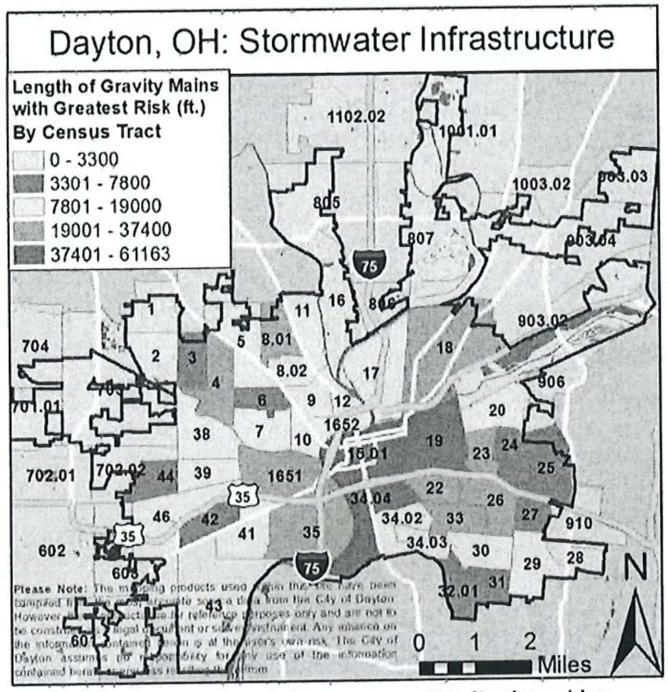

Figure 17: Census tracts in Dayton, OH displayed by the total length in feet of High and Extreme risk gravity mains within each tract.

To determine the location of vegetation and impervious surfaces throughout Dayton we used data from a LIDAR (Light Detection And Ranging) flyover of the city. This remote sensing method allows us to categorize surfaces at relatively small spatial scales.

The following census tracts have a greater area of impervious surface when compared against other types of land cover and have more than 20% of families living in poverty: 3, 12, 18, 19, 20, 22, 23, 34.04, 35, 41, 702.01, and 1651. Census tracts 46, 702.01, 801, 807 and 910 have more impervious surface area than vegetation cover and have an elderly population that is greater than 15% for the respective tracts.

Tract 15.01 has the highest percentage of impervious surface. This tract is representative of the city's central business district and is adjacent to the 100-year floodplain. Population is estimated at 3,482 with a high number of rental properties and low percentage of households living in poverty. Tract 35 has just over 25% impervious surface and less than 5% vegetation cover. In this tract, 78% of residents identified as non-white, and 33% of residents are living in poverty.

e) Stormwater Asset Conditions

The quality (age, condition, capacity) and design of our city's stormwater infrastructure is another important

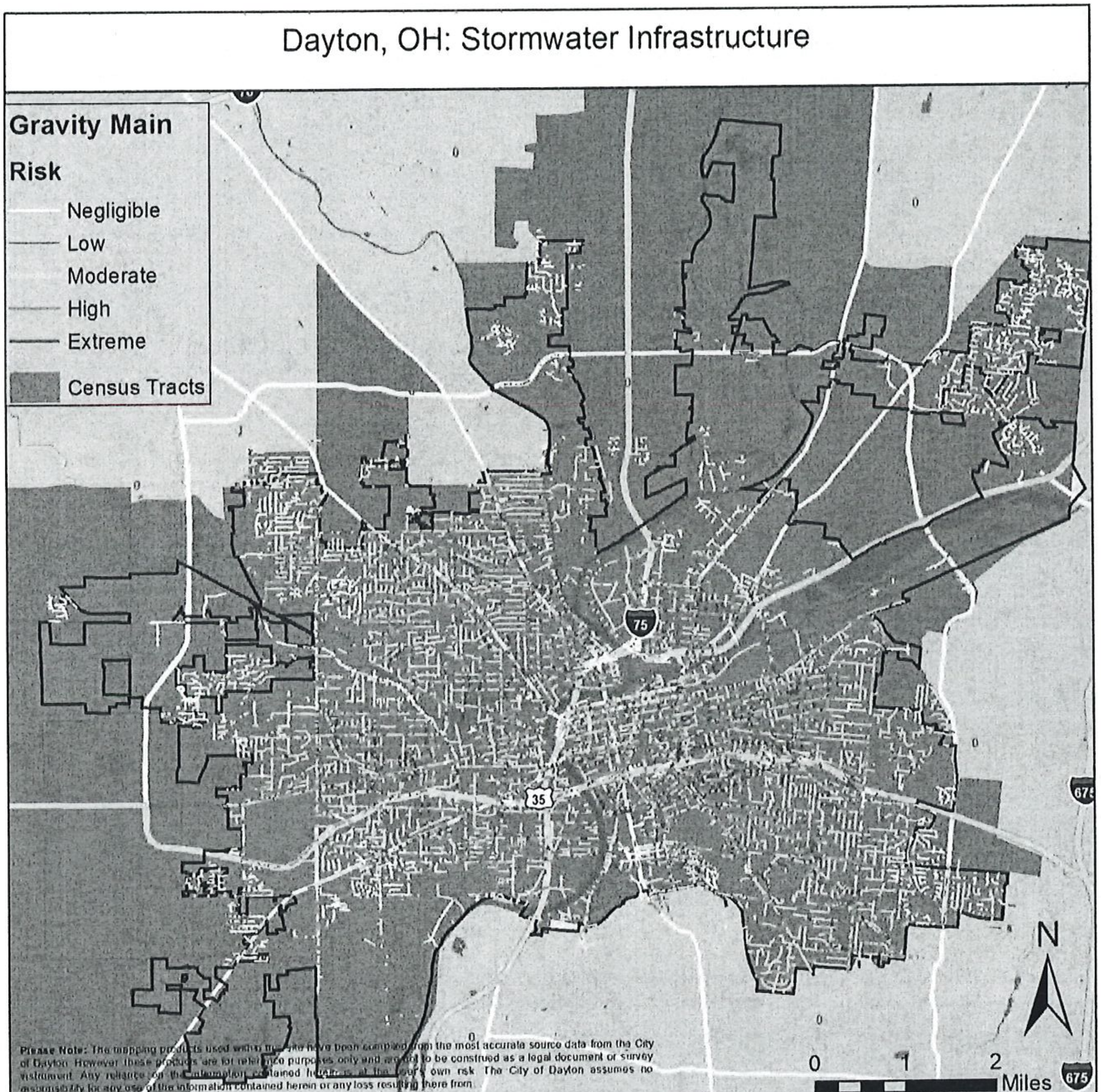

Figure 18: Gravity mains in Dayton, OH. Line colors represent the risk, which takes into account the consequence of failure and likelihood of failure.

element that influences our flooding potential. For the purposes of this landscape assessment, we chose to look at the condition of the various elements of our stormwater system, known as our stormwater asset map. For example, current best practices in our state dictate that all stormwater infrastructure should be built to handle a 10-year storm event. In Dayton, however, we are striving to build all stormwater infrastructure to the current 100-year storm event - since we know the frequency and intensity of storms are changing due to climate change, we want to make sure we are effectively preparing. With that in mind, we conducted an analysis to determine what type of storm events our various stormwater assets can handle as well as the overall condition of our stormwater system.

Figure 18 shows the gravity mains that comprise the City of Dayton stormwater system. These gravity mains have been categorized based on composite risk scores, which combines the consequence of failure and likelihood of failure into a single score 1-5 (Negligible-Extreme). We can see that the red and yellow risk (High and Extreme risk) mains are concentrated in the center of the city and risk scores decrease toward the periphery. In Figure 17, we have summarized the gravity main data to show the total

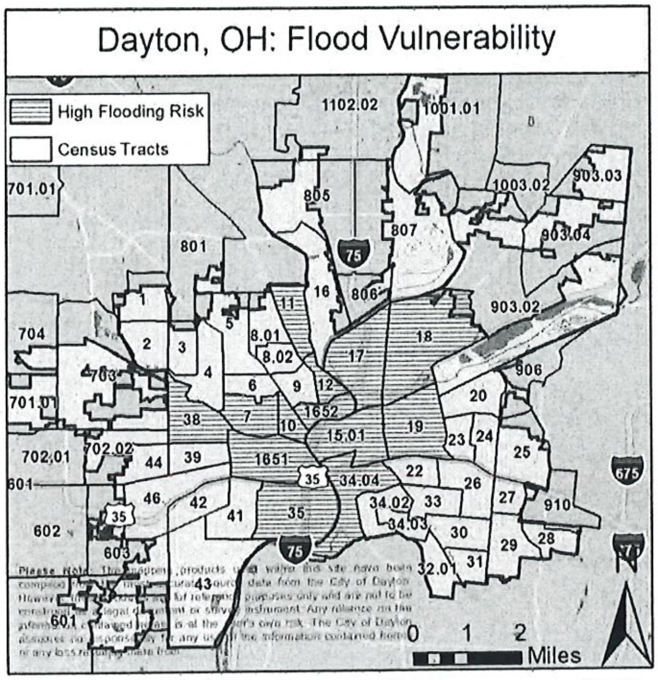

Figure 19: Flood risk in Dayton, OH. These census tracts have greater than 5% of their area within the floodplain (100 and 500-yr), greater than 35% impervious surface, greater than 75% of the area without tree canopy, and greater than 13,000 ft of high or extreme risk gravity mains.

length of gravity mains in each census tract that have risk scores of High and Extreme. This provides an overview of stormwater infrastructure risk and allows us to compare infrastructure risk to other factors that are measured at the census tract level.

Dayton's Stormwater and Flooding Vulnerability Map

By combining the above maps,[55] we are able to identify areas of our community that are particularly sensitive to stormwater-related impacts and flooding (Figure 19).

As can be seen from this map, the areas with the highest risk of flooding are concentrated in the low-lying central area. These census tracts (7, 10, 11, 12, 15.01, 1651, 1652, 17, 18, 19, 34.04, 35, and 38) have greater than 5% of their area within the floodplain (100 and 500-yr), greater than 35% impervious surface, greater than 75% of the area without tree canopy, and greater than 13,000 ft of high or extreme risk gravity mains.

Census tracts where the total length of stormwater gravity mains that have a high risk score (scores between 3 and 5) is greater than the total length of those with low risk scores (between 0 and 2) are as follows: 3, 5, 6, 8.01, 23, 25, 28, 38, 44, 603, 702.02, 903.03, 903.04, 910 & 1652. Of these, tracts 8.01, 28 & 903.04 have average scores that are greater than 3.0. Tract 1652 is comprised of approximately 22% of its total area being impervious surface with the eastern half of the tract being within the 100 and 500-year flood hazard area. Tract 17 has a large amount of impervious surface area (35% of the tract) and is predominantly within the 100 and 500-year flood hazard area. There is little elevation change in this tract. Tract 15.01 has the highest percentage of impervious surface area (40%) and is within the 100 and 500-year flood hazard area.

Landscape Features that Affect Heat and Associated Exposure to our Stormwater System

Extreme heat is the number one weather-related killer in the United States.[56] The majority of people who have traditionally died from heat exposure die in their homes, generally in environments with little or no air conditioning. Extreme heat has the most negative impact on adult populations aged 50+, with men being notably more vulnerable to heat exposure and death than women.

Extreme heat can be exacerbated by local environmental conditions, especially the urban heat island. An urban heat island is a phenomenon whereby urban regions experience warmer temperatures than their rural surroundings.[57] Some of the reasons for the localized urban heat island include: reduced vegetation in urban areas; the materials used to build in urban areas; and urban geometry.

Because of the very real and serious threats posed by extreme heat to Dayton residents, we have chosen to include three local landscape indicators that increase our vulnerability to heat.

a) Vegetation Coverage: Normalized Difference Vegetation Index

b) Impervious Land Cover

c) Urban Heat Island Effect

a) Vegetation Coverage: Normalized Difference Vegetation Index

Many urban areas have a lower percentage of green space, compared to rural regions. Since trees and vegetation provide shade, which helps lower surface temperatures, the lower percentage of green space in urban areas can directly translate into higher temperatures compared to more vegetated rural areas. In addition, trees and other vegetation help reduce air temperatures through a process called evapotranspiration, in which plants release water to the surrounding air, dissipating ambient heat. In urban areas with limited green space, the value of shading and evapotranspiration is limited, particularly when compared to more rural or less developed regions, thereby contributing to elevated urban surface and air temperatures.

Vegetation has been categorized using return values from a LIDAR flyover of the city. As reported in the previous land cover section, the following tracts have less than 5% vegetation coverage: 15.01, 17, 19, 35, 601, 602, 701.01, 702.01, 703, 704, 801, 910, 1003.02, 1101 and 1102.02. The tracts with greater than 20% vegetation coverage are: 2, 4, 6, 8.01, 8.02, 9, 16, 24, 32.01, 34.02, 43 and 702.02.

Areas with lower vegetation coverage, such as tracts 701.01, 704 & 801, have a high (greater than 50%) non-white population and low poverty rates. Tracts 35, 703 & 1651 have a high (greater than 50%) non-white population and poverty rate around 20% or higher. It should also be mentioned that areas with higher vegetation coverage such as tracts 4 & 6 have a high (greater than 50%) minority population though low poverty rate. Tracts 2, 8.01, 8.02, 43 & 702.02 have a high (greater than 50%) minority population and poverty rate around 20% or

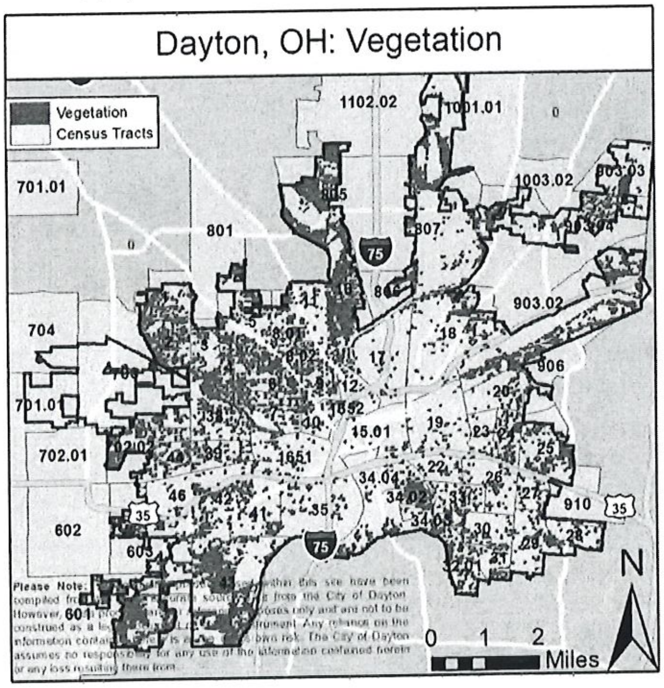

Figure 20: Vegetation cover in Dayton, OH.

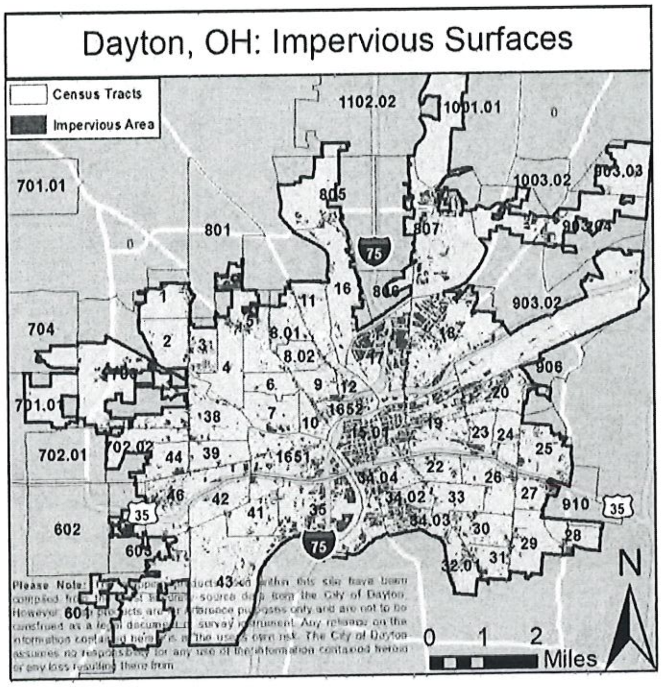

Figure 21: Impervious Surfaces in Dayton, OH.

higher.

b) Impervious Land Cover

In contrast to vegetated areas, we know that impervious surfaces, surfaces made from materials that do not absorb precipitation (e.g., asphalt, concrete, brick), are extremely effective at trapping heat. Given this, the City of Dayton also mapped the location and percentage of impervious land coverage throughout our community (Figure 21).

The majority of Census tracts with less than 5% impervious surface coverage are predominantly areas where there are less than 20% of families living in poverty. There are several tracts which contradict correlation between low impervious surface areas and affluence. Tracts 42, 43, 702.1, 702.2 & 805 all have more than 20% of families that are living below the poverty line. Tracts 702.1 & 702.2 also have more than a 50% minority population.

Census tracts 15.01, 17, 18, 19, 20, 34.02, 34.03, 34.04, 35 & 1652 have impervious surface area that covers more than 20% of total area occupied by each tract. Of these, tracts 18, 19, 20, 34.04 & 35 have more than 20% of their residents living in poverty. Tract 35 has 78% minority residents and 33% or residents living in poverty.

Zoning varies throughout Census tracts. Zoning districts within these areas which occupy the most acreage within the tract's boundary are shown in Table 5.

Table 5: Most Prominant Zoning District by Census Tract	
Census Tract	**Most Predominant Zoning District**
15.01	B-4
17	I-3
18	I-1
19	I-2
20	I-3
34.02	R-7
34.03	R-7
34.04	OR-2
35	I-3
1652	I-3

Of the above, these districts also contain the highest percentage of impervious surface with the exception of tract 34.04, which has the most impervious surface in zone I-2; tract 35, which has the most impervious surface in zone B-2; and tract 1652, which has the most impervious surface in zone R-6.

Based on analysis of impervious areas and how they relate to the city's zoning designation, areas zoned R-7, R-4, B-2, I-1, I-2 & I-3 have the highest concentration of impervious surface area.

c) Urban Heat Island Effect

Most urban areas consist of roads, roofs, buildings, and other materials that, traditionally, have low solar reflectance and high heat capacity. Solar reflectance (also known as albedo) is the percentage of solar energy reflected by a surface. Darker surfaces, which tend to abound in urban areas, have lower solar reflectance values compared to lighter surfaces meaning that they reflect less and absorb more of the sun's energy. This absorbed heat increases surface temperatures and contributes to the formation of urban heat islands. According to the US EPA, "another important property of building material that influences heat island development is a material's heat capacity, which refers to its ability to store heat. Many building materials frequently used in urban areas, such as steel and stone, have high heat capacities. As a result, cities are typically more effective at storing the sun's energy as heat within their infrastructure."[57] As an example, studies have shown that downtown metropolitan areas can absorb and store twice the amount of heat compared to rural surroundings during the daytime.[58]

The city's land surface temperate map was created using Landsat 8 image, specifically USGS Product ID LC08_L1TP_020032_20190612_20190612_01_RT, file date 2019-06-12. The TIF imagery files were processed using raster math to create a land surface temperature raster that shows degrees Fahrenheit for the City of Dayton. The resulting file was clipped to the city's municipal boundary.

There is a correlation between impervious surfaces and areas of high land surface temperature. The city's downtown and industrial centers have higher concentrations of impervious surfaces. Conversely, areas which contain more vegetation coverage are at the lower end of the land surface temperature spectrum.

The southeast portion of the city (as defined by those areas south of the Mad River and east of the Great Miami), tract 35 and the section of tract 801 within city limits are subject to a generally higher land surface temperature than those areas west of the Great Miami River. Census tracts 17 and 18 which are northeast of the confluence of the Great Miami and Mad River systems also show higher land surface temperature values. Areas east of the Great

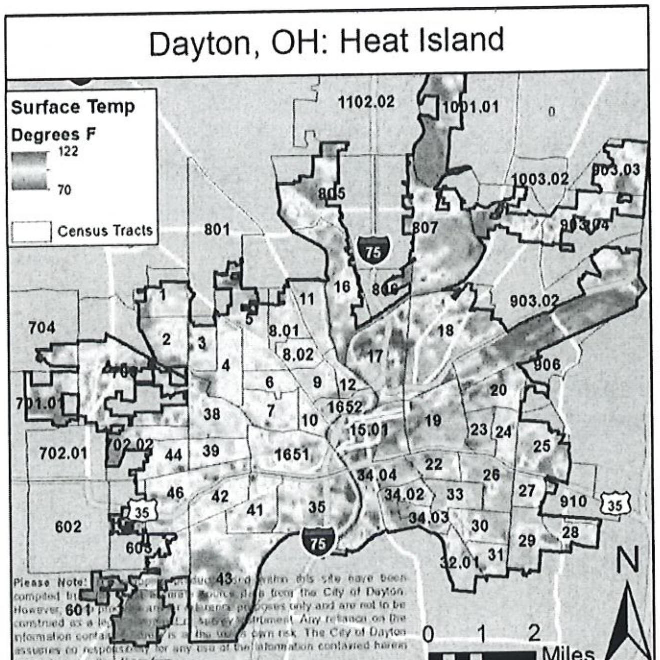

Figure 22: Land surface temperature in degrees Fahrenheit in Dayton, OH.

Miami River also have more impervious surface coverage than those west of the Great Miami.

d. Other Factors That Influence Stormwater Vulnerability and Local Vulnerability to Flooding

In addition to the factors discussed above, there are a series of local environmental conditions that can affect vulnerability to flooding and other climate-related impacts. For example, factors such as the number and location of impaired water bodies, the location of hazardous waste sites, the current condition of drinking water (especially data related to contaminants), and the location of solid waste sites and generators are all important factors that can influence neighborhood-level vulnerability to extreme events.

Urban gardens and parks (displayed in Figure 23) are some ways to increase the amount of green space that helps keep our city cooler and allows diversion of runoff.

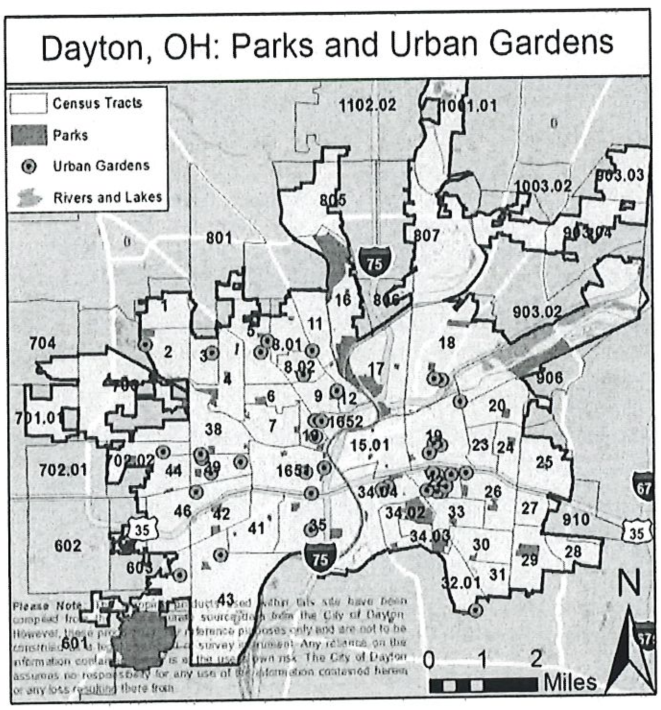

Figure 23: Parks and Urban Gardens in Dayton, OH.

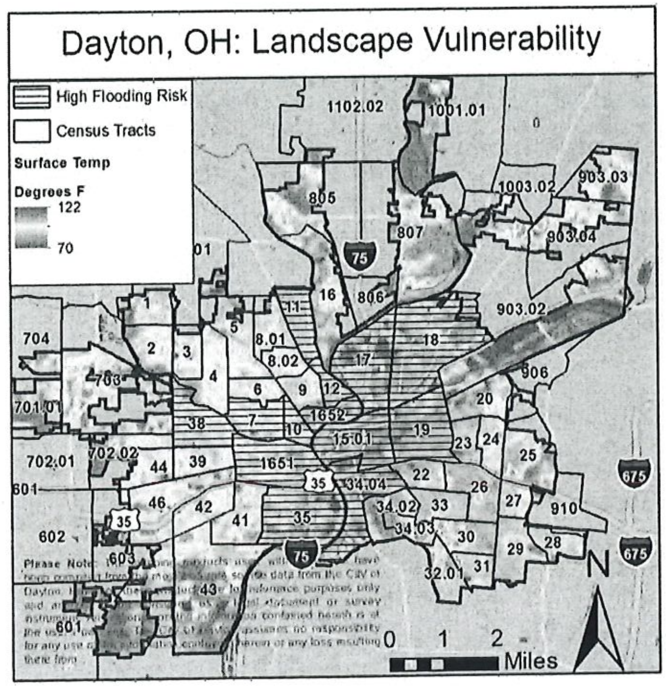

Figure 24: Landscape vulnerability in Dayton, OH. This map combines the urban heat island data and the areas of high flooding risk to display where the population is likely to be most exposed to the hazards of climate change.

Looking at our parks map, we can see that some of the surface temperature hotspots in tracts 15.10, 19, and 18 correspond to areas with fewer parks and vegetation.

Summary of Landscape Vulnerability

The results in this section shed light on some of the local characteristics that can reduce or increase our community's vulnerability to flooding and extreme heat. Based on the cumulative results from this section, we know that the areas with highest flood risk tend to be the areas with greatest heat risk. This means that exposure to climate related hardships will be focused on the tracts at the greatest risk for both flooding and heat. Notable exceptions are tracts 7, 10, 38, and the west side of 1651, which all have high flood risk and lower heat risk.

In the next section we use all the previous information to complete our vulnerability assessment.

5. DAYTON'S VULNERABILITY ASSESSMENT RESULTS

Using the information outlined in the previous sections, the City of Dayton completed a vulnerability assessment of our stormwater system. A vulnerability assessment helps determine the extent to which our city and its major elements are susceptible to harm from climate change. Our vulnerability assessment helps us understand:

1. What changes in climate are projected to happen and what those changes could mean in terms of local **impacts**,
2. The level of **exposure** the community has to potential changes and impacts,
3. How **sensitive** the various city and community systems are to projected changes in climate, and
4. What **capacity** those systems have to adapt.

As previously identified, this vulnerability assessment is specific to the City's stormwater systems.

Table 6: Elements Included in a System-Wide Stormwater Vulnerability Assessment

Stormwater System Element	Type of System
Conveyance system	Built System
Street Trees	Built System / Natural System
Impervious Surfaces	Built System
Geothermal Heating and Cooling	Built System
Regional Disaster Response	Built System / Social System
Sourcewater Protection	Built System / Natural System
City Employees	Social Systems and Vulnerable Populations
Levees	Built System
Green Infrastructure	Built System

Sensitivity

Sensitivity is the degree to which a system and its constituent parts (e.g., built, natural, human) can be or are affected by changes in climate conditions or specific climate impacts. For example, a building built in the 500-year floodplain with flood-proofing measures is much less sensitive to a flood than one in the 100-year floodplain with no flood-proofing measures.

To determine how sensitive each of our stormwater elements were, we answered three questions:

1. What, if any, existing stresses affect this element?
2. How might demand for this element change given expected impacts from climate change?
3. What, if any, limiting factors does this element have that make it more sensitive?

We answered these questions for each of the Elements included in the scope of our assessment. The responses to these three questions were used to assign a sensitivity score for each element. We used the qualitative evaluation criteria provided in Figure 25 to assign sensitivity scores.

Figure 25: Sensitivity Levels	
S0	Element will not be affected by the climate-related impact
S1	Element will be minimally affected by the climate-related impact
S2	Element will be somewhat affected by the climate-related impact
S3	Element will be largely affected by the climate-related impact
S4	Element will be greatly affected by the climate-related impact

Adaptive Capacity

Adaptive capacity is a measure of the ability of an element (e.g., institutions, humans, infrastructure, species) to adjust to potential damage, to take advantage of opportunities, or to cope with consequences. Some of the most important factors influencing the adaptive capacity of an element are access to and control over natural, social, physical, and financial resources. This includes things such as knowledge (or access to knowledge), good health, financial resources, ability to migrate (e.g., resources, space, lack of competition), redundant systems, access to social safety nets, and overall social connectivity.

To determine the adaptive capacity of each of the elements evaluated in our stormwater system vulnerability assessment, we answered five questions:

1. Does the element currently have what it will need to adapt to the impacts identified?
2. Can the element accommodate projected climate impacts with minimum disruption or costs?
3. If not, what does the element need to help it adapt to the identified impacts?
4. What is needed in order to help the element adapt to the identified impacts?
5. Is the element already stressed in ways that will limit its ability to accommodate identified impacts?

Responses to these questions were then used to assess how adaptive each of the elements evaluated were to projected changes in climate. We used the qualitative evaluation criteria provided in Figure 26 to assign these adaptive capacity scores.

Figure 26: Adaptive Capacity Levels	
AC0	Element is not able to accommodate or adjust to projected changes in climate
AC1	Element is minimally able to accommodate or adjust to projected changes in climate
AC2	Element is somewhat able to accommodate or adjust to projected changes in climate
AC3	Element is mostly able to accommodate or adjust to projected changes in climate
AC4	Element is able to accommodate or adjust to projected changes in climate in a beneficial way

Vulnerability

The final step in our vulnerability assessment was combining the sensitivity and adaptive capacity scores into a vulnerability score. Using Figure 27 below, we were able to determine which elements within our stormwater system were the most vulnerable (red) and which were the least vulnerable (green).

Element Summaries

Below we have included a summary for each element that was analyzed in our assessment:

Conveyance System

The stormwater conveyance system is our primary concern relating to stormwater management. We have a good understanding of where stormwater pipes are older and run under businesses and houses, which can help us prioritize funds for replacement. However, more actual assessments of pipe condition should be conducted to further prevent failures. In some areas, there are streams that have been piped underground, which increases the risk of flooding in those drainage areas. Peak capacity must be considered in the design and prioritization processes due to the predictions of significant increases in heavy precipitation events. Current conveyance pipes might be undersized to deal with future changes in climate and extreme rain events. The stormwater conveyance system was assigned a sensitivity score of 3 because it will be largely impacted by these effects of climate change.

Due to the high cost of replacing underground

		Sensitivity: Low to High				
		S0	S1	S2	S3	S4
Adaptive Capacity: High to Low	AC4	Green Infrastructure		City Employees	Street Trees	
	AC3			Impervious Surfaces; Sourcewater Protection	Disaster Response	Geothermal
	AC2					
	AC1				Conveyance System	
	AC0		Levees			Stormwater Pipes

Figure 27: Stormwater system elements displayed by their sensitivity and adaptive capacity. Red corresponds to high vulnerability and green corresponds to low vulnerability.

infrastructure, it is important to focus on monitoring efforts that will help allocate funds most efficiently. These cost restrictions have led us to assign an adaptive capacity score of 1 to the stormwater conveyance system, because it will be minimally able to adapt to climate change with current funding. Also, the areas we have identified with high socio-economic vulnerability may have limited ability to pay higher rates, which slows infrastructure improvements. Given the high percentage of low income and renter populations in Dayton, this is of particular concern. We must seek policy solutions to promote equitable distribution of resources.

Street Trees and Impervious Surfaces

Climate change can potentially have a negative impact on the urban forest and increase stress on trees, which would result in increased urban heat island effect and potentially greater runoff. Less prosperous parts of the city currently have less tree canopy coverage. Reaching into the neighborhoods to encourage planting efforts has historically been hard, so future work to encourage more planting will require unique engagement techniques. Lack of tree canopy negatively impacts certain neighborhoods more so than others, making them more susceptible to climate-related impacts.

Efforts to decrease impervious surfaces can help reduce runoff and alleviate the heat island effect. However, this will also reduce some of the revenue that is used for maintenance of the stormwater conveyance system.

Geothermal Heating and Cooling

Geothermal provides a great opportunity for businesses to implement an environmentally friendly and cost-effective means of heating and cooling. This method uses groundwater to pre-heat or cool air going into the heating or cooling system, saving energy. However, the prevalence of open-loop systems creates a challenge in the reduction of capacity of the City's stormwater system, as these constantly drain into storm sewers. As temperatures rise, more geothermal water is likely to be discharged. More water pumped during high intensity rainfall events increases the likelihood of flooding. We may look into ways for some of the cost savings to be dedicated to bolstering the stormwater infrastructure or there may be solutions that involve limiting these systems when there are heavy rain events or incentivizing the design of closed-loop systems.

Regional Disaster Response

As the probability of heavy rain events increases, we must consider how we can effectively respond to more flooding emergencies. Consolidating the lessons learned from previous emergency response can help prepare for future emergencies. Also, the hotter temperatures associated with climate change will make it more difficult for responders to work long shifts in an emergency, especially around the hot spots of our urban heat island.

Sourcewater Protection

Drinking water in Dayton comes from the Great Miami Buried Valley Aquifer, which represent the sole source of water for over 400,000 people in the Dayton area. With changes in climate, the aquifer volume should not be at risk, but quality may be. The increase in flood risk from storms will lead to a greater groundwater contamination risk because these floods may affect chemical storage areas around the well fields. Any water source problems will likely have more impact on vulnerable communities. Through years of diligent work, Sourcewater Protection Program has been a successful example of innovative water resource management, including 6 regional governmental partners and a variety of creative enforcement and incentive tools. We must continue this work and implement new ways to monitor groundwater contamination risks.

City Employees

Our employees are the most important part of our organization. We will share in the negative impacts of climate change, but also have a great ability to help mitigate impacts for ourselves and our community. In prevention and disaster response, it is the effectiveness of our employees that will lessen the negative impacts to our community. With greater stress on our infrastructure, it will be important to ensure we have enough employees to handle the increased workload. An emphasis on educating and empowering our employees to succeed on the job as well as be role models in the community will serve our city well in the long term.

Levees

Our levee system is quite strong and will likely be more than enough to prevent flooding from higher river levels. However, the city has expanded since these levees were constructed, so it may be useful to ensure that newer developments are equally protected by our levees. Because levees tend to be open space with vegetation, there is potential to use them to mitigate heat island effects, but the changing climate may influence what types of vegetation are most effective to plant.

Green Infrastructure

Green infrastructure can be a cost effective way to alleviate some impacts of climate change. Green infrastructure is a broad term for techniques that dissipate the impact of rainwater by replicating natural areas and capturing water. We can make use of downspout disconnection, in which the rooftop drainage pipes are diverted to permeable areas, water storage, or bioswales. Bioswales are linear features that use vegetation to slow down moving water and allow it to filter and infiltrate into the ground rather than flowing into storm sewers. These, and many other methods, can be woven into development plans with fairly low cost and can help soften the impact on our stormwater systems as we see more frequent heavy rains.

While green infrastructure is not a complete solution, studies have shown that the combination of green infrastructure with traditional stormwater infrastructure can be very cost effective.[59] Many of these methods have additional benefits such as providing more vegetation to mitigate the heat island effect and a more aesthetically

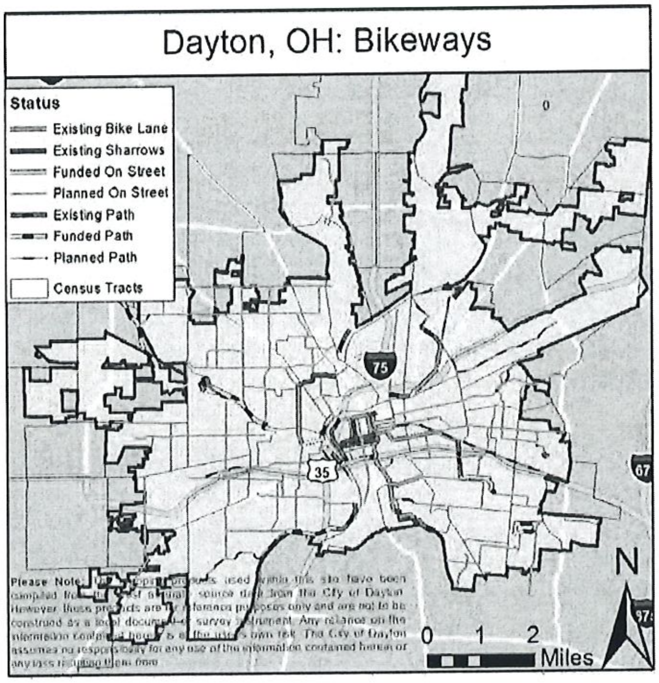

Figure 28: Bikeways of Dayton, OH. Existing bikeways are displayed in green, planned are displayed in blue, and funded bikeways are displayed in yellow. Black dashes indicate the bikeways as a designated bike path, as opposed to a shared lane or bike lane on a roadway.

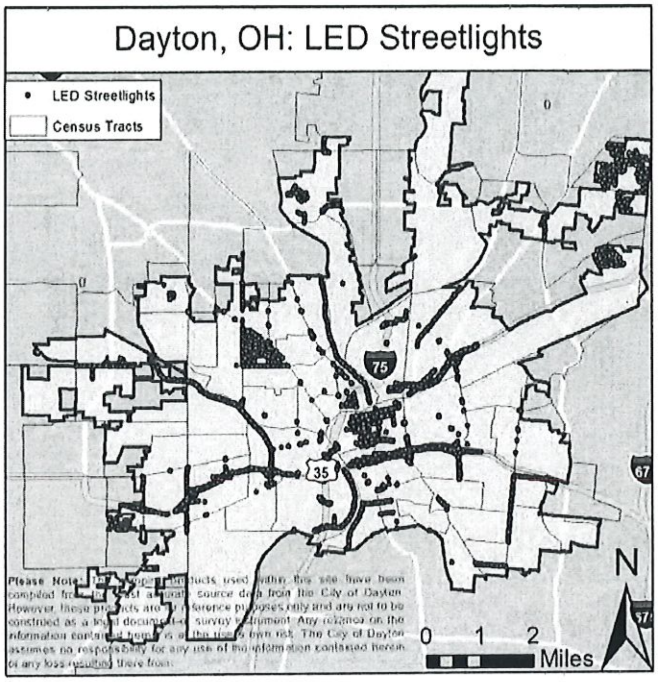

Figure 29: LED streetlights in Dayton, OH.

pleasing environment. Our city certainly has room to grow into these methods and better record existing green infrastructure.

Other Mitigation Actions

Actions that will help reduce the carbon footprint of our city are great steps in the right direction of sustainability. Emphasizing the use of bikes instead of gas-powered vehicles is one way to reduce greenhouse gas emissions. Also, designated bike paths can also act as corridors of green space that can help reduce runoff and the urban heat island effect. Figure 28 shows the bikeways in Dayton; including those that are funded and planned as well as existing bikeways.

Using LED streetlights instead of incandescent or halogen bulbs reduces the energy used to keep our roads safe. Figure 29 shows locations that already use LED streetlights.

6. NEXT STEPS

This document represents an important step in building resilience to climate change in Dayton. To truly prepare, however, we need to implement actions that will reduce our local vulnerability and enhance our resilience. Through the course of this stormwater system vulnerability assessment, we identified a handful of initial actions that can lay the foundation for longer-term adaptation planning and action. These actions include:

- Increasing capacity and monitoring stormwater conveyance infrastructure.
- Emphasizing the use of green infrastructure practices.
- Managing tradeoffs between open-loop geothermal heating/cooling and stormwater infrastructure capacity.
- Continue monitoring our levee system and protecting our sourcewater from contamination.
- Ensure equitable implementation of solutions.

These, however, are just initial actions. We know far more thought and planning are needed to design a cohesive strategy for enhancing local resilience to climate change. In our quest to create a more resilient Dayton, we are prepared to immediately undertake the following actions:

1. Present this vulnerability assessment to City Council and seek formal adoption.
2. Initiate a formal adaptation planning process that includes a diversity of community stakeholders.
3. Align our vulnerability reduction efforts with our community's multi-hazard mitigation planning and disaster risk reduction efforts.
4. Align our vulnerability reduction efforts with other relevant community planning and action initiatives.
5. Annually report on progress implementing the strategies identified in this plan and others related to reducing local vulnerability.
6. Every 5 years, revise this assessment based on new information (e.g., changes to climate science) and any relevant changes to community priorities. As part of this review process, include metrics that denote how our community's overall vulnerability to climate change has evolved. This may take the form of revising our community's landscape vulnerability as well as our socio-economic vulnerability to see if there have been notable changes. We may also identify, through public input processes, a number of other key metrics we'd like to track to measure reductions in vulnerability. To the fullest extent possible, we will regularly track and report on these metrics so that we can demonstrate how our community's vulnerability is changing.
7. Begin and/or enhance collaboration with peer communities in the region in order to foster greater regional resilience towards climate change and natural disasters.
8. Share successes and lessons learned with our peers to help foster greater resilience not only in our community but also in the region, across the state, and throughout the nation.

Conclusion

Preparing for climate change is a process, not an outcome. This plan represents an important step in that process for the City of Dayton. Our success in preparing for climate change will depend on whether the strategies identified in this plan and those developed through a formal adaptation planning process are implemented, and whether an iterative process is established to frequently revisit this plan and all the other plans and programs used to manage the way we live, work, play, and operate in our city. We, as a City, are committed to working with all residents, business, and interested stakeholders to make sure we build a thriving, sustainable, and resilient Dayton. It's time to get to work!

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Acknowledgements

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