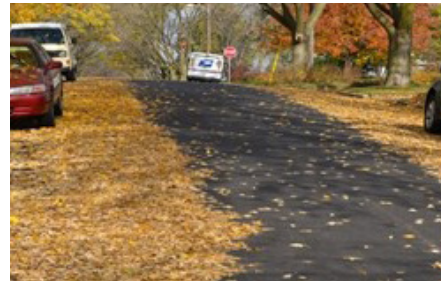PREPARING FOR CLIMATE CHANGE



# CLIMATE CHANGE VULNERABILITY ASSESSMENT FOR STORMWATER

**CITY OF MADISON**

# EXECUTIVE SUMMARY

The climate in Madison is changing, and these changes are causing immediate threats to our citizens, our health, our economy, and our community's overall vitality. We know that over the last several years we have experienced a 2.3°F increase in average annual temperature, with winter experiencing the greatest amount of warming (a 3.4°F increase). Nighttime temperatures are rising, and the number of cold days (< 32°F) are declining. Annual precipitation is changing too: in the last several decades Madison has experienced a 28.1% increase in annual precipitation, with the greatest change happening in winter (43% increase, amounting to roughly an extra 1.6 inches). In addition, we have seen an increase in the frequency and intensity of severe storms, with the City experiencing a 46% increase in the total volume of rainfall in extreme precipitation events (most extreme 1% of storms) annually. These are just some of the changes that have led to serious impacts to our community's infrastructure, economy, social networks, cultural identity, and safety. These impacts are likely to be more extreme as the climate continues to change.

In light of this, the City of Madison has decided to plan for climate change, making sure we are considering what changes are projected to take place in the future and integrating that information into how we, as a City, operate. Guiding this work is a commitment to ensuring the health, safety, and general welfare of all Madison's residents – especially the frontline communities that are already experiencing a disproportionate share of the impacts associated with a changing climate. This Stormwater Vulnerability Assessment is one important component of our City's efforts to create a more equitable and resilient community for all Madison residents – ensuring every resident is prepared for the current and future risks associated with a changing climate.

Within the pages of this report, readers will find more information about how changes in weather and long-term climate have already impacted Madison and details about projected changes in climate relevant to the City. Further, the report provides insights into what those changes might mean in terms of on-the-ground impacts to our stormwater systems, an assessment of Madison's overall stormwater-system vulnerability to these changes, and which segments of the community may be most vulnerable. Finally, this report provides some initial suggestions on what we, as a community, can do to prepare our stormwater system and those it serves for climate-related impacts.

At a high level, we anticipate that climate change will exacerbate or create the following major impacts to stormwater in Madison:

| Type of Event | Impacts | Future Change |
|---|---|---|
| Heavy precipitation | Infrastructure, erosion, disease, transportation, beach closures | Wetter, especially in winter-spring; more heavy rainfalls |
| Drought | Streamflow, lake levels, tree mortality, water usage, food supply | Uncertain but maybe more likely |
| Hot weather | Buckled roads, AC costs, cooling centers, air quality, outside work time | More heat waves and humid conditions with muggy nights |
| Cold weather | Water mains/pipes, heating costs, ice jams, lake ice, health risks | Fewer cold waves eventually but uncertainty in near-term |
| Snowfall | Road plowing and salting, traffic accidents, absenteeism | Less snow overall but possibly in heavier snowfall events |
| Ice | Road salting, traffic and pedestrian accidents | Possibly more ice storms as winter precipitation shifts to liquid |
| Winter melt events | Potholes, road salting, polluted runoff into lakes and streams | Very likely to increase |

| Type of Event | Impacts | Future Change |
|---|---|---|
| Length of growing season | Landscaping, mowing, pest prevalence, suitability of plant species | Very likely to increase |
| Severe storms (hail, tornadoes) | Public safety, infrastructure, property damage | Uncertain |

*Source: Wisconsin Initiative on Climate Change Impacts (WICCI)*

In response to these projected changes and local impacts, the City of Madison has initially identified the following actions:

**Watershed Studies**

The City of Madison Engineering Division launched its Watershed Series in May 2018. During the studies, Engineers will work with eight watershed areas to determine flooding issues and how to design a more resilient stormwater system. This is a continued effort to address areas hardest hit by flooding last summer.  To address these issues, the City is conducting large watershed studies. In 2019 – 2020, the City will focus on the eight watershed studies. These studies will help the City identify existing problems, develop solutions, and prioritize improvements.
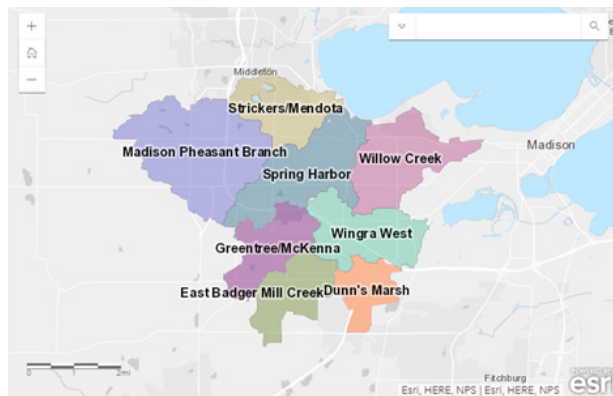


**Flood Mitigation Projects**

The City has constructed a variety of projects over the years to help reduce flooding in neighborhoods and on streets. Additionally, the City does a number of annual, biannual and by each rain event preventative maintenance cleanings to keep stormwater sewers and waterways clear so the infrastructure moves water through the system effectively. Below, find a number of ways the City works to maintain productive stormwater infrastructure.

***Ongoing Storm Sewer Maintenance***

<u>Annual maintenance</u>

- Willow Creek Basin Cleaning: City Engineering has a basin on University Avenue that collects rainwater. In Spring of 2018, Engineering crews removed 305 cubic yards of debris
- Biannual Catch Basin Cleaning: In April and October of every year, City crews clean catch basins in the City. During this clean, on average, crews clean approximately 1,200 structures and clear, on average, 480 tons of debris per season since 2016.
- Priority Grate Cleaning: After and prior to rain events, City crews clear 763 structures of debris. Priority Grates would include anything from inlets to dead ends and big grates.
- Approximately 10 miles of storm sewer built/replaced annually
- Streets Division maintenance by the numbers for 2018:
  - Total miles swept (when sweeping the City multiple times): 39,477

- Total tonnage of debris collected: 4,801.79
- Greenway mowing/debris removal – all the work we do to maintain our system in an attempt to keep the conveyance system clean.

### Current Projects

- McKenna Blvd/Gammon Ln Flood Mitigation Project
- Hawk's Landing Flood Mitigation
- Lower Badger Mill Creek Pond
- Southwest Bike Path/Waite Circle Culvert Reconstruction

## City Development Standards

*These development requirements are currently being updated through the public input process.*

### New Development Requirements for Stormwater Management in the City of Madison

Stormwater management can be broken up into two main categories: water quantity control and water quality control. New development, which we will define as going from farm field to a developed urban condition, has many requirements in both areas. Additionally, at least partially as a result of the intense storms experienced in 2018, Madison is currently in the process of rewriting its stormwater management code to address deficiencies identified during the response to those events.

### Water quantity control

New development is required to match the peak stormwater runoff rate leaving the site to peak predevelopment runoff for varying sized storm events including the 1, 2, 5, 10 and 100 year. This means that a model is used to estimate the rate of discharge from the existing (farmland) site for the above storm events. Then a parallel model is built to show post development conditions and their detention facilities (buildings, parking lots, and ponds that are designed to hold stormwater to reduce the post development runoff rate). The post development model needs to match peak rates to the existing model for the same storm event. Generally, ponds are used to meet this requirement as they act like large bathtubs that fill up and then release the stormwater slowly to make it manageable for downstream facilities.

### Water quality control

- Sediment control: Remove 80% of total suspended solids (sediment) leaving the developed site. This means a model is run to estimate how much sediment will leave the site without treatment, and then devices are designed to trap the sediment and reduce it to 80% of the initial modeling.

- Oil and grease control: Required if the site has a drive through, has over 40 parking spaces, or is a "hot" spot such as a car sales or repair lot.

- Infiltration: Must infiltrate 90 percent of the water that infiltrates during existing conditions. This means you calculate the existing amount of infiltration occurring during an average annual year on the site as farmland and the amount of infiltration that will occur post development with no controls. There is always a drop off from existing to proposed conditions and the amount of infiltration must be 90 percent of the existing amount. This amount is capped at 90 percent by State Statute.

- Thermal control: certain areas of the city (those draining to the Sugar River) are required to complete thermal control to reduce the temperature of the water being discharged off site in an effort to limit temperature increases to a cold-water resource.

*Re-development*

Re-development requires stormwater management practices if the disturbed area exceeds 4000 square feet.

**Watershed Stewardship**

We all play a role in helping improve water quality and flood mitigation in our communities. Watershed Stewardship is one way you can help. From rain gardens, barrels and conservation landscaping, there are a number of ways every resident can help our City.

- Install a Rain Garden
- Modify your Leaf Management Techniques
- Learn about Ripple Effects, Madison Area Stormwater Partnership
  - Madison Area Municipal Stormwater Partnership (MAMSWaP) and Dane County Land & Water Resources Department updates a website named Ripple Effects , which is a resource for anyone in the community who wants to learn more about MAMSWaP and how to reduce and improve stormwater runoff into Dane County lakes, rivers and streams. MAMSWaP is a coalition of Dane County municipalities and organizations working together as part of a permit that requires municipalities to comply with stormwater discharge regulations contained in Wisconsin Administrative Code NR 216. As of 2019, 21 municipalities in central Dane County are on one permit application jointly.
- Share the Impacts of Stormwater Runoff with Neighbors
  - Rain that runs off roofs, land and pavement travels through storm sewers and ditches to our lakes, rivers and streams.
  - Stormwater runoff carries excess nutrients like phosphorus and other pollutants with it, which can fuel algae growth and harm our waters.
  - The way to protect and clean our lakes and streams is to make sure only rain goes into the storm drains and ditches.

*Source: https://www.cityofmadison.com/flooding/city-initiatives*

Implementing these and other actions to effectively and efficiently address our community's climate and socio-economic vulnerabilities will require an "all hands on deck" approach. That is why we invite you to join us as we move forward with creating a more resilient, thriving, and sustainable Madison for all.

# CONTENTS

# 1. WHAT IS A VULNERABILITY ASSESSMENT

As the climate continues to change, communities across the U.S. and the world are asking, "How are these changes already affecting my community?" and "What local impacts might we experience from future changes in climate?" To help answer these questions, communities are using a tool called a vulnerability assessment. A vulnerability assessment helps stakeholders identify:

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,

3. How **sensitive** the various city and community systems are to projected changes in climate, and

4. What **capacity** those systems have to adapt.

**Exposure:** The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2014).

**Sensitivity:** The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC, 2014).

**Impact:** Effects on natural and human systems such as lives, livelihoods, health, ecosystems, economics, societies, cultures, services, and infrastructure (IPCC, 2014).

**Adaptive Capacity:** The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2014).

**Vulnerability:** The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014).

Figure 1 provides a graphical depiction of how exposure, sensitivity, impacts, and adaptive capacity all combine to create vulnerability.



Once completed, the results of a vulnerability assessment can be used to inform the types of actions a community should take to reduce vulnerabilities or seize on potential opportunities.

Currently, most existing vulnerability assessment guidance and tools have either limited or no discussion regarding the important role that a community's social and economic characteristics play in determining local vulnerability. Because of the critical importance social dynamics play in shaping our local community, the City of Madison partnered with fellow Midwestern cities, the Huron River Watershed Council, the Great Lakes Integrated Sciences and Assessments (GLISA), and Headwaters Economics to develop a revised vulnerability assessment template that assesses our community's social, physical, cultural, economic, and environmental vulnerability to climate change. The document you are currently reading is a spinoff of this work, focused explicitly on understanding the vulnerability of Madison's stormwater system to climate change, socio-economic considerations, and local landscape features. We will use this document to help ensure that all our residents are safe, resilient, and thriving both today and in a climate-altered future.

**Figure 1:** Graphical depiction of the various elements of vulnerability

# 2. SOCIO-ECONOMIC PROFILE OF MADISON

| Table 1: Section Summary[1] | | Age | Income | |
|---|---|---|---|---|
| **Population by age range** | | **Age** | **Income** | |
|  | | 31.3 <br> Median age | $35,802 <br> Per capita income | $65,072 <br> Median household income |

Madison is a unique and diverse city. It is this diversity that makes us great. Madison's residents under the age of 18 are much more diverse than the larger population, suggesting that the City's plans and polices need to be updated to reflect its changing demographics. For example, the number of people aged 60 and over has increased by 54 percent since 2000. However, the large increase in Millennials has driven the City's median age down. Population forecasts indicate that Madison could gain 25% more residents between 2015 and 2040.
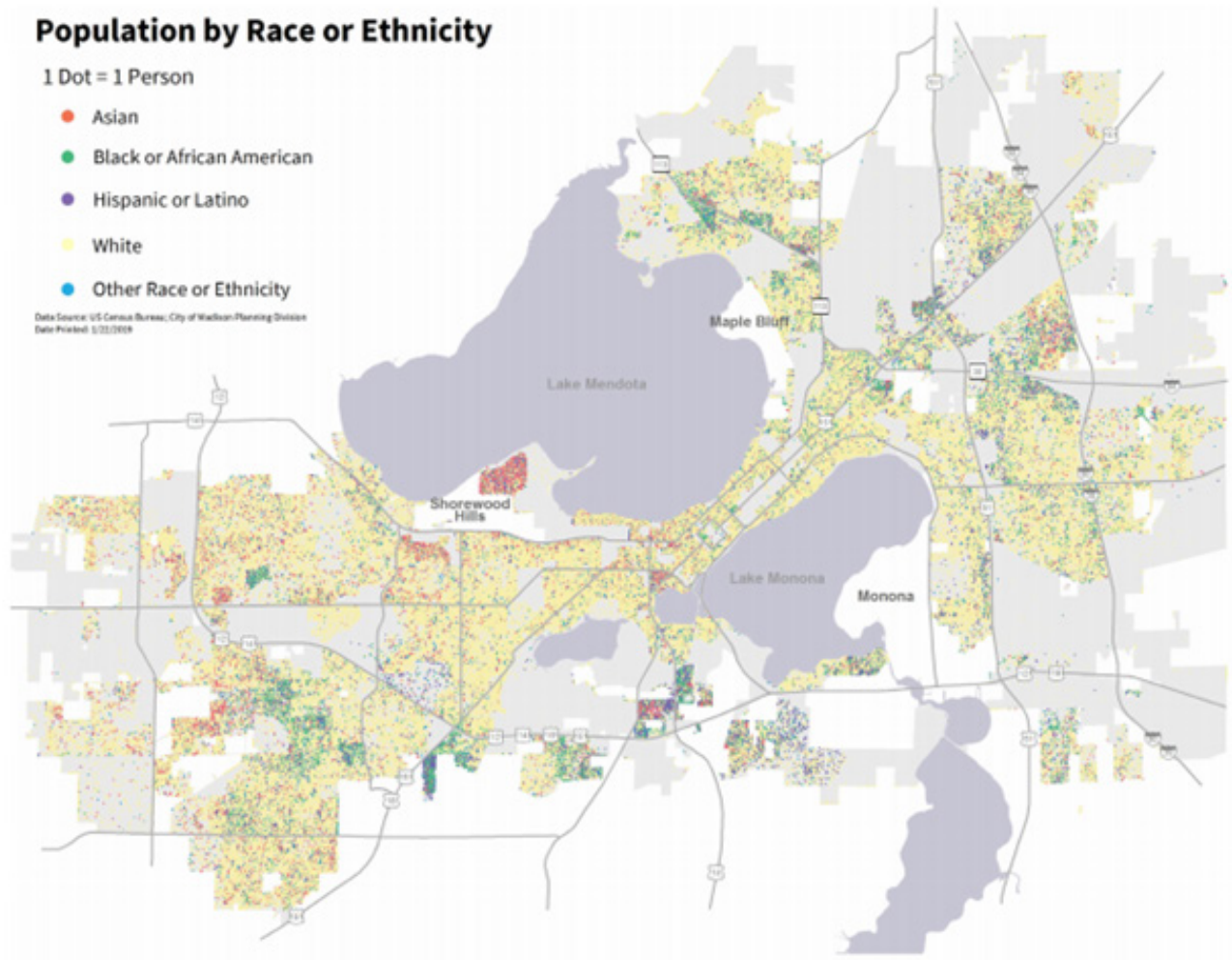


**Figure 2:** Map of Madison showing population residence by race or ethnicity.

This growth and changing demographics highlight the importance of plans that focuses on policies to meet the needs of our future residents.

In order to fully understand how the City of Madison is resilient or vulnerable to climate change, we need to take a deep look at the social characteristics that make up our community. Using the Socio-Economic Data Mapper (Data Mapper) tool from Headwaters Economics, we analyzed ten characteristics that help explain our local vulnerability:

A.   Percent of population over 65

B.   Percent of population under 5

C.   Percent of community in poverty

D.   Percent of population with limited English proficiency

E.   Percent of non-white population

F.   Percent of households receiving public assistance

G.   Percent of households where mortgage is greater than 30% of household income

H.   Percent of disabled

I.   Percent of renters

J.   Percent of population without a high school diploma

## A.  Percent of population over 65

As of 2017, the City of Madison had 248,856 residents, 11.1% (27,564) of which were 65 years or older.  This is lower than the U.S. national average for residents over 65, which is 14.9%. Of this population, approximately 3,964 (1.6%) are 80 years or older. This figure is important because elderly populations are at increased risk of compromised health related to environmental hazards and climate change. In fact, age is the single greatest risk factor related to illness and death from extreme heat[3]  and the elderly are more likely to have pre-existing medical conditions or compromised mobility, which reduces their ability to respond to extreme heat and extreme weather events[4] - which are both likely to become more frequent due to climate change. Finally, the increased likelihood of chronic disease,[5]  combined
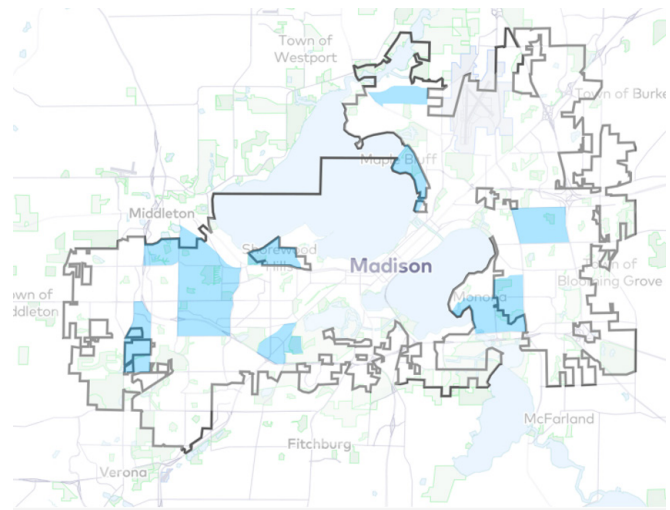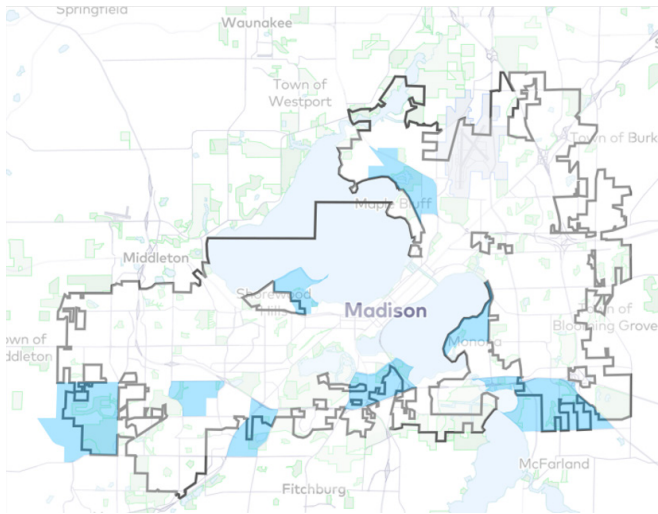


**Figure 3:** Census Tracts in Madison where 15% or more of the population is 65 years of age or older (14.9% is the national average).

with the fact that older adults are more susceptible to air pollution, which is expected to become worse due to climate change, makes them a uniquely vulnerable population.[6]

All of these factors combined mean that the elderly require unique and/or additional services compared to younger residents. As such, understanding our community's age profile helps us determine the appropriate types of services and resources needed to ensure all of Madison's residents are able to survive and thrive in a climate-altered future.

## B.  Percent of population under 5

As of 2017, 5.2% (13,033) of the City of Madison's population was under 5 years of age. This is slightly lower than the national average (6.2%).[7]  Knowing what percentage of our residents are under the age of five and where they reside, is important because children's developing bodies are particularly sensitive to health problems and environmental stresses,[8]  including those associated with climate change. Children also spend more time outside and have faster breathing rates than adults, so they are more at risk for respiratory problems related to things such as ground level ozone, airborne particulates, and allergens:[9] all of which can be exacerbated by climate change. Moreover, because their immune systems are not fully developed, children are more susceptible to infectious diseases,[10] including those that spread during natural disasters.

**Figure 4:** Census Tracts where in Madison where 6% or more of the population is under 5 years of age (6.2% is the national average).

Focusing our efforts on reducing youth vulnerability makes sense for a number of reasons, including the fact that childhood lays the foundation for lifelong health, meaning that poor health during childhood can significantly increase the likelihood of problems throughout adulthood.[11] With the rising cost of health care in the U.S., ensuring that we have a healthy, productive community is pivotal to not only our wellbeing, but also our social structure and our economy.

As we seek to ensure our youth are resilient to climate change, we need to pay particular attention to youth that are living in poverty, as children living in poverty are less likely to receive high-quality health care, meaning that they may be especially sensitive to changes in climate and the ensuing health impacts.[12] Children living in poverty

are also more likely to live in vulnerable areas, including areas that have poor air quality, limited transit options, and homes that are less resilient to changing weather patterns. As we move forward with building community-wide resilience, care must be taken to ensure that children, especially those in poverty, are prioritized.

## C. Percent of community in poverty

As of 2017, 43,568 City of Madison residents were living in poverty; 25,415 were classified as living in deep poverty (meaning they earn less than ½ of the federal poverty level). This represents 18.3% of the City's population that is living in poverty and 10.7% that is living in deep poverty. In addition, data shows that 0.6% of the City's residents (1,530) are both living in poverty and over the age of 65.[13]

The above information focuses on the number of individuals living in poverty. In addition, we also analyzed the number of families living in poverty. As of 2017, 3,996 families (7.9%) in Madison lived in poverty. Of these, 3,067 had at least one child residing in their household, and 2,007 were households with a single mother (4.0% of all households). This rate of family poverty is lower than the national average (10.5% for families in poverty and 4.8% for single mother families in poverty).

Understanding the percent and location of those living in poverty is critical because low income is one of the strongest predictors of compromised health as well as an individual's ability to recover from disasters.[14] Moreover, we know that natural disasters disproportionately impact low-income people because of things such as inadequate housing, social exclusion, a diminished ability to evacuate, lack of property insurance, and more acute emotional
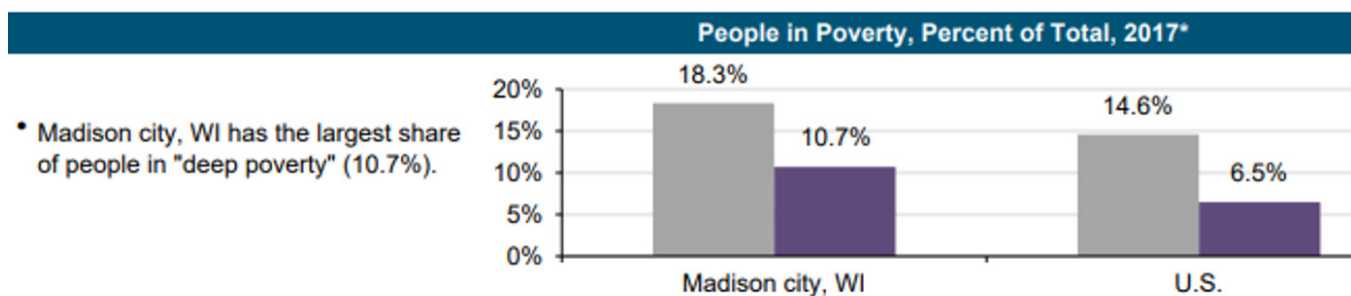


**Figure 5:** Percentage of residents living in poverty. This table was taken from the Populations at Risk Tool created by Headwaters Economics (accessible here).
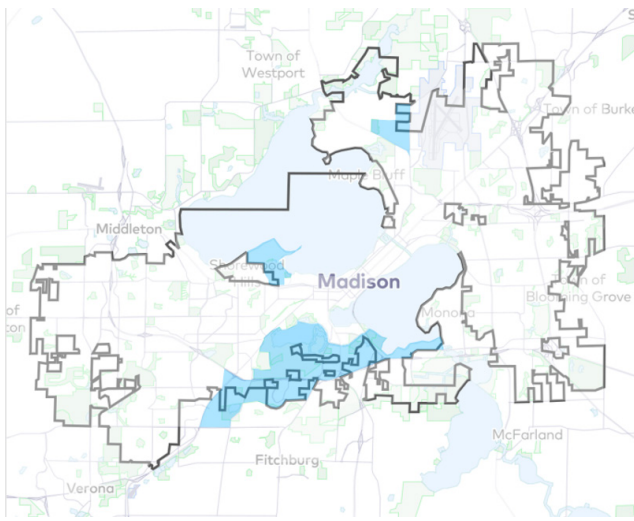
**Figure 6:** Census Tracts in Madison where 11% or more of the families are living in poverty (10.5% is the national average).

stress.[15] In addition, research has shown that low-income people are more likely to be overlooked during the emergency response period following a disaster.[16] Low-income populations are also more likely to live or work in areas with greater exposure to environmental hazards, including working in jobs that require outdoor labor.[17]

Income inequality within a community is also associated with poor health outcomes. Residents in low-income neighborhoods tend to have higher incidences of asthma, depression, diabetes, heart conditions, and emotional stress compared to higher-income neighborhoods.[18] Low-income households also have to make lifestyle compromises in order to make ends meet, such as choosing unhealthy foods, less food, substandard housing, or delayed medical care.[19] Having limited income may also mean that it is simply too expensive to run fans, air conditioners, or heaters to manage indoor living temperatures, not to mention that many low-income residences are located in high crime areas, meaning that residents may feel unsafe opening their windows.[20] Finally, low-income individuals are least likely to have health insurance, which further exacerbates their vulnerability to the negative health impacts associated with climate change such as deteriorating air quality, higher incidences of asthma, and increased allergens.[21]

## D. Percent of population with limited English proficiency

According to the US Census Bureau, in 2017, 2.2% of the Madison community did not speak English well (5,153

people). This is lower than the national average (4.5%).[22] Understanding the percentage and location of people with limited English proficiency is important because many, if not most, aspects of life in the US require basic proficiency in English. For example, knowing about and then accessing emergency services, learning about poverty reduction programs, or accessing health care all necessitate basic English proficiency. Research has found that limited English proficiency can:

- Limit a person's ability to effectively act during emergencies;[23]

- Make it harder to follow directions and interact with agencies, thereby limiting the amount of support available to respond to and recover from disasters of all types;[24]

- Make it harder for people to get higher wage jobs;[25] and

- Result in isolation from other segments of the US population, and social isolation can be a serious health risk.[26]

Because of these factors, it is important that we identify who within our population has limited English proficiency and work with trusted partners to ensure these populations have access to the information, tools, and resources they need to build resilience.

## E. Percent of non-white population

As of 2017, 21.2% of the population in Madison (52,682) identified as non-white. This is lower than the national
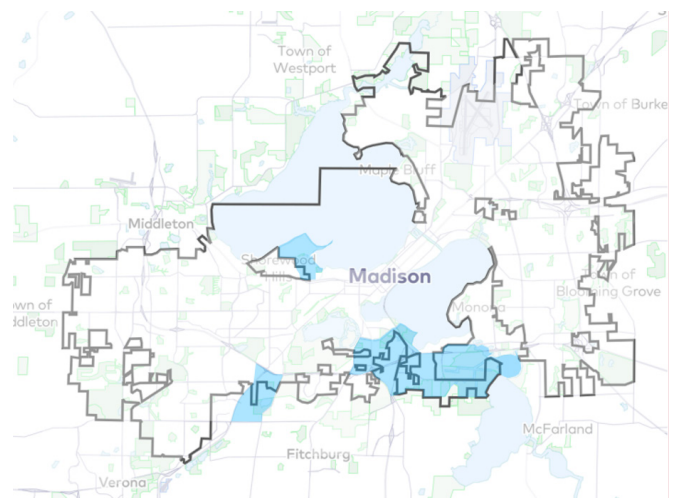


**Figure 7:** Census Tracts in Madison where 5% or more of the population has limited English proficiency (4.5% is the national average).
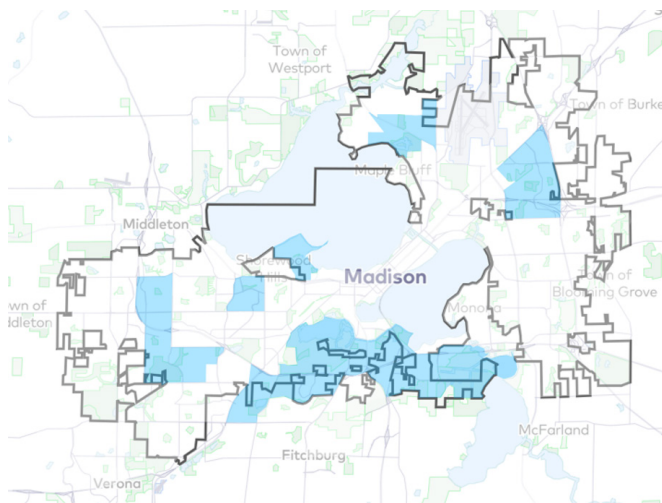
average (27.0%). Of the total population of Madison, 6.5% (16,273) identified as Black or African American, 7.0% (23,063) identified as Hispanic,[27] 0.4% (947) identified as American Indian, and14.3% (35,462) identified as "Other Races".[28]

This information is important because race and ethnicity strongly correlate with disparities in health, exposure to environmental pollution, and vulnerability to natural hazards, including climate-related natural hazards.[29]  More specifically:

- Research consistently finds race-based environmental inequities across many variables, including the tendency for minority populations to live closer to noxious facilities and Superfund sites, and to be exposed to pollution at greater rates than whites.[30]

- Across races, the rates of preventable hospitalizations



**Figure 8:** Census Tracts in Madison where 27% or more of the population identifies as non-white (27% is the national average).

are highest among black and Hispanic populations. Preventable hospital visits often reflect inadequate access to primary care. These types of hospital visits are also costly and inefficient for the health care system.[31]  Relative to other ethnicities and races, Hispanics and Black/African Americans are less likely to have health insurance but rates of uninsured are dropping for both groups.[32]

- Compared to other races, Black/African Americans have higher rates of infant mortality, homicide, heart disease, stroke, and heat-related deaths.[33]

- Hispanics have higher rates of diabetes and asthma, compared to other ethnicities.[34]

- Minority communities often have less access to parks and nutritious food, and are more likely to live in substandard housing, all of which can negatively impact health outcomes.[35]

- Minorities tend to be particularly vulnerable to disasters and extreme heat events. This is due to language differences, housing patterns, variations in the quality of housing, community isolation, and cultural barriers.[36]

- Blacks and Hispanics, two segments of the population that are currently experiencing poorer health outcomes, are an increasing percentage of the U.S. population and our local community.[37]

Given these realities, it is important that the City of Madison ensures that we effectively integrate the needs, perspectives, and lived realities of our population into our efforts to enhance resilience.
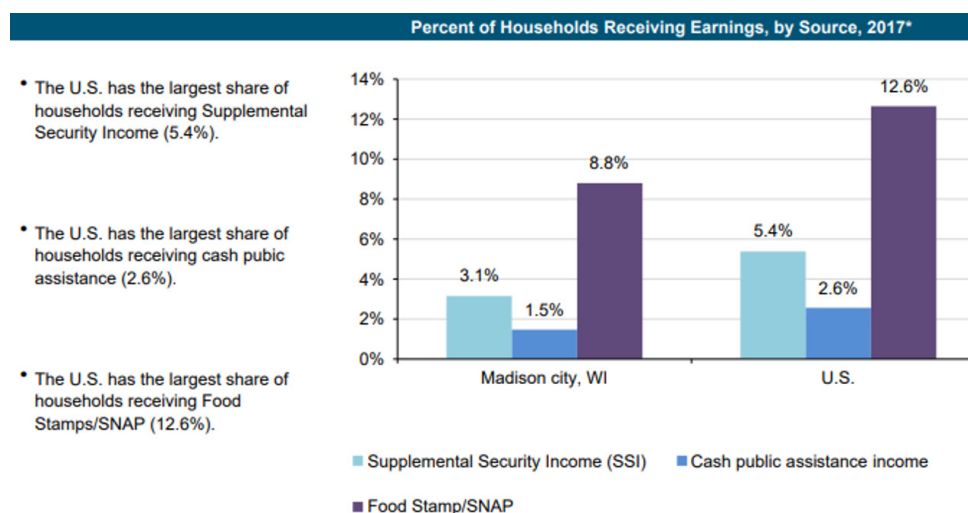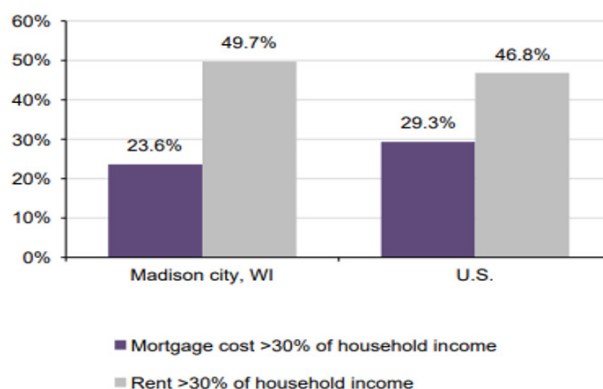


**Figure 9:** Percentage of households in Madison and in the U.S. that receive three types of public assistance.

**Housing Costs as a Percent of Household Income, 2017\***

- The U.S. has the largest share of unaffordable housing for homeowners, with 29.3% spending over 30% of household income on mortgage costs.

- Madison city, WI has the largest share of unaffordable housing for renters, with 49.7% spending over 30% of household income on rental costs.

■ Mortgage cost >30% of household income
■ Rent >30% of household income

**Figure 10:** Comparison of the percentage of households in Madison and the U.S. that spend more than 30% of their income on rental fees or their mortgage.

## F. Percent of households receiving public assistance

As of 2017, 9,494 households within Madison (8.8%) received Food Stamps/SNAP assistance. This rate of Food Stamp/SNAP assistance is lower than the national average, which is 12.6% of all U.S. households.[38] While this isn't the only form of public assistance, we have chosen Food Stamps/SNAP assistance as our indicator of public assistance because it is more widely known than the other types of assistance and, as such, there is a higher likelihood that at-need households are getting this assistance compared to the more obscure forms of public assistance.

Understanding the percentage and location of residents receiving public assistance is important because this information is indicative of households living in poverty or households with insufficient resources. For example, in 2011, families receiving public assistance spent, on average, 77% of their household budget to meet the basic necessities of housing, food, and transportation,[39] leaving little to accommodate other important needs including disaster preparedness, response, and recovery.

## G. Percent of households where mortgage is greater than 30% of household income

As of 2017, 8,731 households (23.6%) in Madison were paying more than the sustainable 30% of household income towards their mortgage and 28,084 households (49.7%) were paying more than the sustainable 30% of household income towards their rent. Rental costs are slightly above the national average and point to a troubling sign regarding the affordability of housing in Madison compared to the income being earned.

The reason this is important is because the federal government considers families with housing costs that exceed 30% of their income to be "housing-cost burdened"[40] and therefore have less disposable income to spend on other necessities such as food, heating/cooling, transportation, healthcare, etc. Research also shows that those households living in affordable housing (those spending less than 30% of household income on housing) are more stable and less likely to move frequently. This can enhance community vitality and cohesion, an important element of creating a more resilient Madison. In addition, this stability is linked to several positive health outcomes in children and young adults, such as improved emotional and behavioral problems, fewer unplanned pregnancies, reduced drug use, and a lower risk for depression.[41]
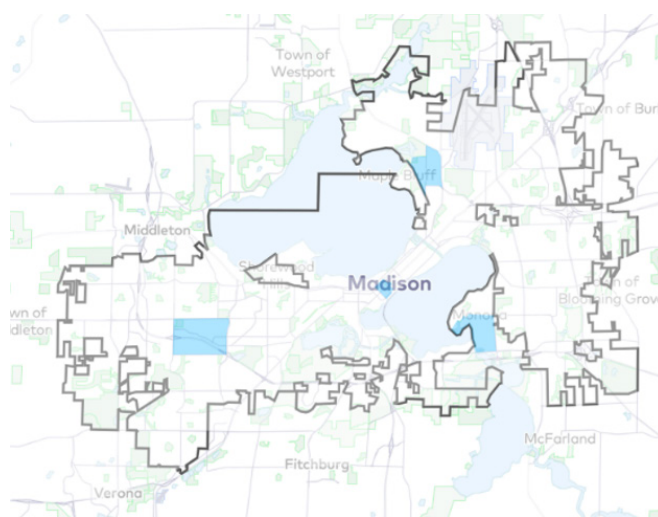


**Figure 11:** Census Tracts in Madison where 13% or more of the population has a disability (12.6% is the national average).
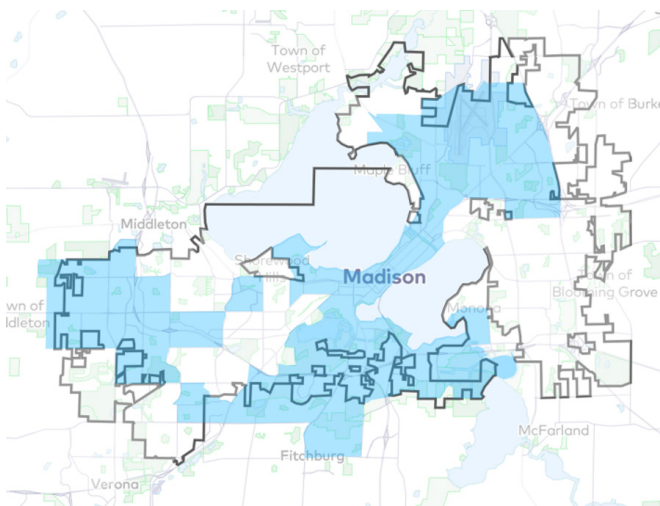
**Figure 12:** Census Tracts in Madison where 36% or more of the housing units were rentals (36.2% is the national average).

As we work to ensure that Madison is building resilience, we must be aware of the needs of all residents, including those with limited economic resources.

## H. Percent of those with disabilities

As of 2017, 20,836 residents of Madison were living with disabilities. This represents 8.4% of our total population; a figure lower than the national average of 12.6%.[42]

People with disabilities are subject to a series of health complications that are often significantly heightened due to environmental conditions. For example, limited mobility and/or being bed ridden raises heat mortality,[43] limited mobility can significantly delay and/or prevent effective evacuation during times of disaster, and extreme weather events can disrupt one's ability to get medical treatment, which can be disastrous for those with compromised health. These are only some of the heightened vulnerabilities faced by people with disabilities. Because of this, Madison is determined to incorporate the needs of

this population in our attempts to create a more resilient community.

## I. Percent of renters

As of 2017, 52.4% of housing units in Madison were rentals; an additional 0.6% were mobile homes.[44] This rate is significantly higher than the national average of 36.2% for rentals, but lower than the national average of 5.7% for mobile home residences.

The median home value in Madison is currently $233,572. This figure represents a decrease in home value of $19,878 based on average home values in 2010.

Understanding what percentage of our population owns a home is important because home ownership contributes to well-being and stability. Home ownership also improves mental health, including increasing self-esteem, creating a heightened sense of control over one's living situation and financial security.[45] On the flip side, the financial stress associated with losing one's home is heightened by people's attachment to place and their neighborhoods.[46]

In terms of renters, studies have repeatedly shown that renters pay a larger proportion of their income in rent. Rental rates have increased over the past 25 years with no sign of abatement.[47] This financial burden is exacerbated by the fact that rental homes are typically not well maintained with conditions such as dampness, mold, and exposure to toxic substances or allergens heightened for those residing in rental units.[48] Because of this, renters may pay even more to heat, cool, or make their rentals more accommodating, further exacerbating the financial impact associated with renting.

## J. Percent of population without a high school diploma

As of 2017, 7,169 people in Madison did not have a high school diploma (4.6%). This is lower than the national
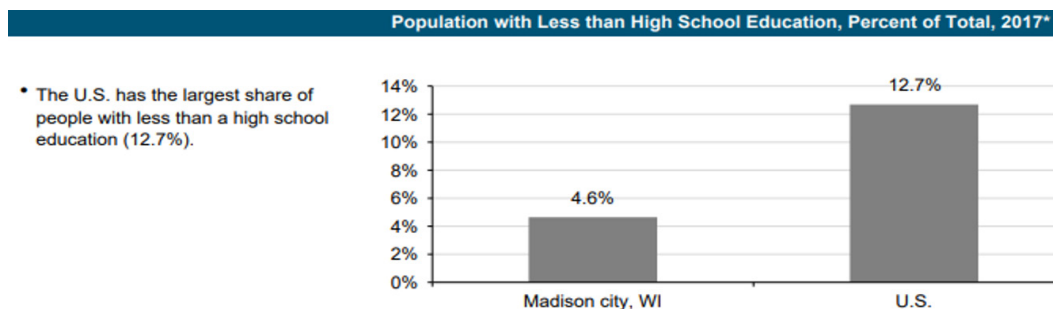


**Figure 13:** Comparison of individuals in Madison and the U.S. that have less than a high school education.

average (12.7%),[49] an important statistic because high school completion is a common proxy for overall socio-economic circumstances. In particular, lack of education is strongly correlated with poverty and poor health. For example:

- People without a high school degree are more than twice as likely to live in inadequate housing compared to those with some college education.[50]

- Thirty-eight percent of Americans without a high school degree do not have health insurance, compared to 10 percent with a college degree.[51]

- The rate of diabetes is much greater for those without a high school degree. Incidence of this disease is more than double the rate of those who have education beyond high school.[52]

- Binge drinking is most severe among those without a high school degree. This demographic group had the highest rate of binge drinking across all measured

categories (such as income, race, ethnicity, or disability status).[53]

## Cumulative Socio-Economic Vulnerability

Combining the findings from each of the previous sections, we were able to create a map denoting some of our most socio-economically vulnerable neighborhoods (Figure 14). This figure identifies all the Census Tracts where the City of Madison has higher than the national average for all of the following variables: percentage of families in poverty; percentage of people with disabilities; percentage of households that rent; percentage of population under the age of five; percentage of population over the age of 65; percentage of population that is non-white; and percentage of population that has difficulty speaking English.

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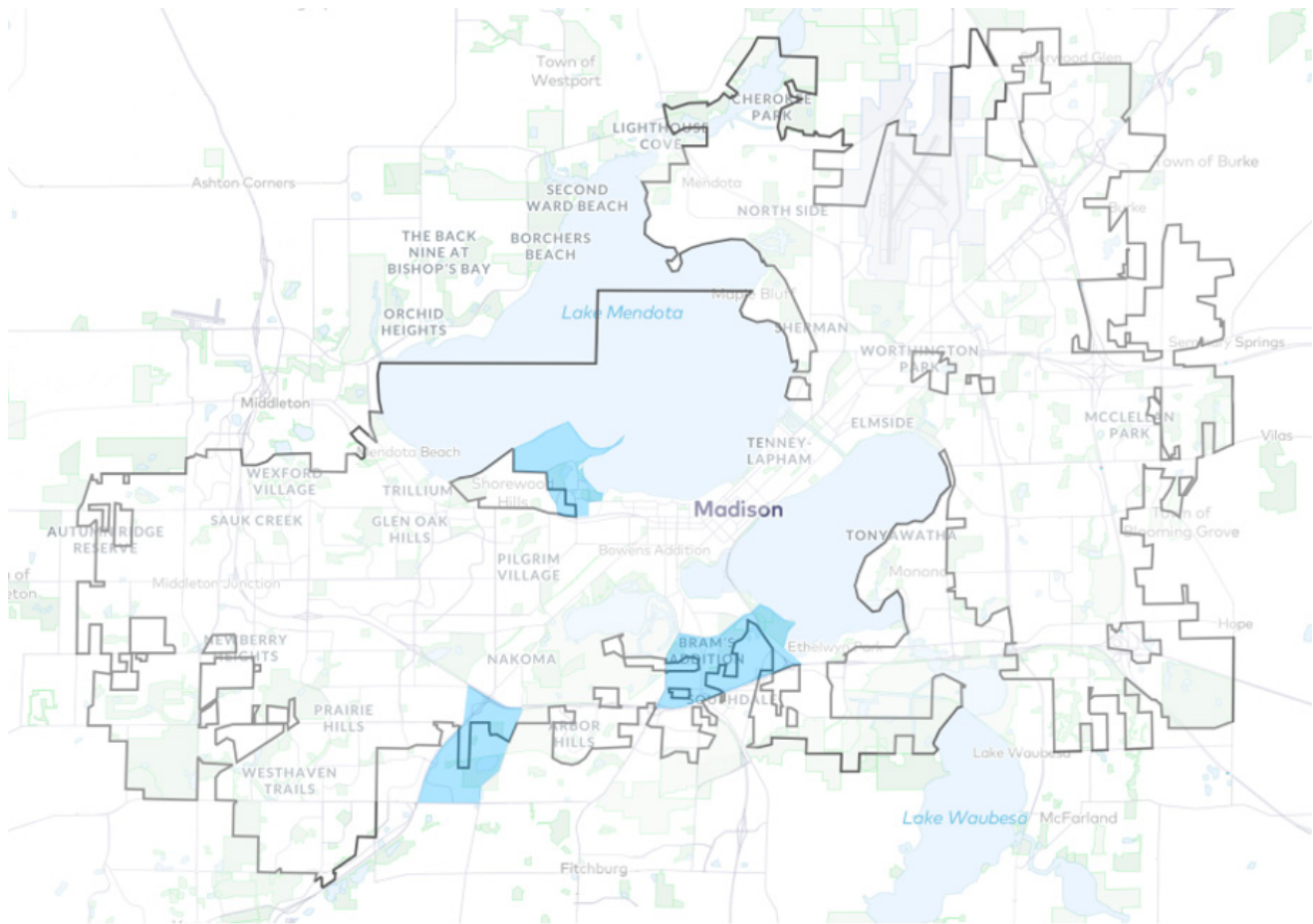


**Figure 14:** Census Tracts within the City of Madison that have the highest overall socioeconomic vulnerability. The map highlights all of the Census Tracts with high averages relative to the rest of the City for: percentage of families in poverty; percentage of people with disabilities; and percentage of population that is non-white.

# 3. CLIMATE CHANGE IN THE GREAT LAKES REGION AND MADISON

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 10ºF) 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. Madison City Summary

### Madison City Summary

- Average air temperature in Madison has increased by 2.3°F.

- Average air temperature is projected to rise 2°F to 6°F by the mid-21st century.

- Total annual precipitation has increased by 28.1%.

- The total volume of rainfall in extreme events (heaviest 1% of storms) has increased by 46%.

- 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 Madison. 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 Madison | | | | | |
|---|---|---|---|---|---|
| | 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 | 46.8°F | 49 to 53°F | 53 to 58°F | 2 to 6°F / 6 to 11°F | 5 to 13% / 13 to 24% |
| Winter | 22°F | 25 to 27°F | 28 to 32°F | 3 to 5°F / 6 to 10°F | 14 to 23% / 27 to 45% |
| Spring | 46.2°F | 48 to 52°F | 51 to 57°F | 2 to 6°F / 5 to 11°F | 4 to 13% / 10 to 23% |
| Summer | 69.5°F | 74 to 77°F | 78 to 83°F | 4 to 7°F / 8 to 13°F | 6 to 11% / 12 to 19% |
| Fall | 49°F | 51 to 55°F | 54 to 61°F | 2 to 6°F / 5 to 12°F | 4 to 12% / 10 to 24% |
| Average Low Temperature | 36.8°F | 40 to 43°F | 44 to 48°F | 3 to 6°F / 7 to 11°F | 9 to 17% / 20 to 30% |
| Average High Temperature | 56.7°F | 59 to 62°F | 61 to 67°F | 2 to 5°F / 4 to 10°F | 4 to 9% / 8 to 18% |
| Days/Year Greater than 90°F | 6.8 days | 20 to 42 days | 41 to 76 days | 13 to 35 days / 34 to 69 days | 194 to 518% / 503 to 1018% |
| Days/Year Greater than 95°F | 1.6 days | 6 to 15 days | Not Available | 4 to 13 days / Not Available | 275% to 838% / Not Available |
| Days/Year Less than 32°F | 144.4 days | 120 to 126 days | Not Available | -24 to -18 days / Not Available | -16% to -13% / Not Available |
| Total Annual Precipitation | 34.5 in. | 34 to 38 in. | 35 to 42 in. | -1 to 3 in. / 0 to 7 in. | -1 to 10% / 1 to 22% |

| Table 3: Historic and Projected Changes in Climate for the City of Madison | | | | | |
|---|---|---|---|---|---|
| Winter | 4.4 in. | 4 to 7 in. | 4 to 7 in. | 0 to 4 in. / 0 to 3 in. | -9 to 59% / -9 to 59% |
| Spring | 9.2 in. | 9 to 11 in. | 9 to 12 in. | 0 to 2 in. / 0 to 3 in. | -2 to 20% / -2 to 30% |
| Summer | 13 in. | 9 to 16 in. | 10 to 15 in. | -4 to 3 in. / -3 to 2 in. | -31 to 23% / -23 to 15% |
| Fall | 7.9 in. | 7 to 8 in. | 8 to 10 in. | -1 to 0 in. / 0 to 2 in. | -11 to 1% / 1to 27% |
| Heavy Precipitation Days | 4.7 days (> 1.25") | 4.5 to 6.1 days | 5.3 to 8.2 days | -0.2 to 1.4 days / 0.6 to 3.5 days (> 1") | -4 to 30% / 13 to 74% |

*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 Madison has increased by 2.3°F from 1951 to 2017, with the current annual average temperature being 46.8°F. Average seasonal temperatures have also increased, with winter experiencing the greatest increase of 3.4°F. Average temperatures in Madison are projected to increase 2.0 to 6.0°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 a slight decreasing trend over time. Many years on record have experienced 2 to 5 consecutive days over 90°F, with events of 5 to 10 consecutive days occurring less frequently. By mid-century (i.e., 2050), models suggest an increase of anywhere from 13 to 35 more days per year over 90˚F, and an increase of 34 to 69 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 have been much rarer, with few occurrences of more than one consecutive day experiencing maximum temperatures

over 95ºF. By mid-century (i.e., 2050), models suggest an increase of 4 to 13 days over 95ºF. 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, Madison experiences 144.4 days per year that fall below freezing (32ºF). Historical records show this number has decreased already. The city is projected to experience fewer nights below 32ºF, with decreases of 18 to 24 days by mid-century.

Days with temperatures at or below 10ºF are very common and have decreased slightly over time. Consecutive days at or below 10ºF are also frequent, and typically last for 2 to 7 days with less frequent occurrences

lasting 8 to 16 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 Madison has increased by 28.1% (8.7") from 1951 to 2017. An increase in precipitation was observed in all four seasons, with the winter seeing the greatest percentage increase of 43% (1.6"). Average annual precipitation in Madison is projected to increase by up to 3 inches by mid-century and by up to 7 inches by the end of the century.

### Heavy Precipitation

The frequency and intensity of severe storms has in creased historically, with a 37% increase in the number of extreme precipitation events (heaviest 1% of storms) and a 46% increase in the total volume of rainfall during these events between 1981-2010. Madison is projected to experience an increase of up to 1.4 days of heavy precipitation (days with over 1" of rainfall) per year by mid-century and by up to 3.5 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 less than one day by mid-century and up to about 1 day by end of century. Precipitation events of more than 3" in a day are projected to increase by less than a day by both mid-century and by

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

## Table 4: Precipitation Frequencies for the City of Madison

|  | 1-Yr | 2-Yr | 5-Yr | 10-Yr | 25-Yr | 50-Yr | 100-Yr |
|---|---|---|---|---|---|---|---|
| 1-hr | 1.06 in. / 1.18 in. [11.3%] | 1.31 in. / 1.37 in. [4.6%] | 1.66 in. / 1.68 in. [1.2%] | 1.97 in. / 1.96 in. [-0.5%] | 2.43 in. / 2.36 in. [-2.9%] | 2.85 in. / 2.69 in. [-5.6%] | 3.32 in. / 3.03 in. [-8.7%] |
| 12-hr | 1.96 in. / 2.17 in. [10.7%] | 2.42 in. / 2.47 in. [2.1%] | 3.07 in. / 3.03 in. [-1.3%] | 3.65 in. / 3.55 in. [-2.7%] | 4.51 in. / 4.34 in. [-3.8%] | 5.27 in. / 5.03 in. [-4.6%] | 6.14 in. / 5.77 in. [-6.0%] |
| 24-hr | 2.25 in. / 2.47 in. [9.8%] | 2.78 in. / 2.82 in. [1.4%] | 3.53 in. / 3.45 in. [-2.3%] | 4.20 in. / 4.03 in. [-4.0%] | 5.18 in. / 4.93 in. [-4.8%] | 6.06 in. / 5.70 in. [-5.9%] | 7.06 in. / 6.54 in. [-7.4%] |

end of century.

Annual snowfall totals have been variable, with no clear increasing or decreasing 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 3" to 9" by mid-century, with decreases of 6" to 17" 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 increasing trend 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 Madison.

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### About the Climate Change in the Great Lakes Region and Madison Data

*Coupled Model Intercomparison Project (CMIP) Version 3.* The future (mid-century) climate projections for Madison 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 Madison, OH from 1981-2010 is available at: http://glisa.umich.edu/station/W00014837

*"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 MADISON'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 Madison landscape features affect our stormwater systems and our community's vulnerability to flooding. Results showed that a steeper slope with more impervious surfaces are more prone to flooding especially if designed before the modern era.

- 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 Madison local landscape features may affect our vulnerability to heat. Results showed that stormwater utility employees would decrease productivity leading to slower work completion.

In addition to our socio-economic composition and projected changes in climate, certain features related to the way Madison 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 Madison. 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 Madison, 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) Slope

d) Land Cover

e) 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 Madison that lie within both the 100 and 500-year floodplains (Figure 15). 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,

**FEMA Floodplain Zones**
- 100-year floodplains
- 500-year floodplains
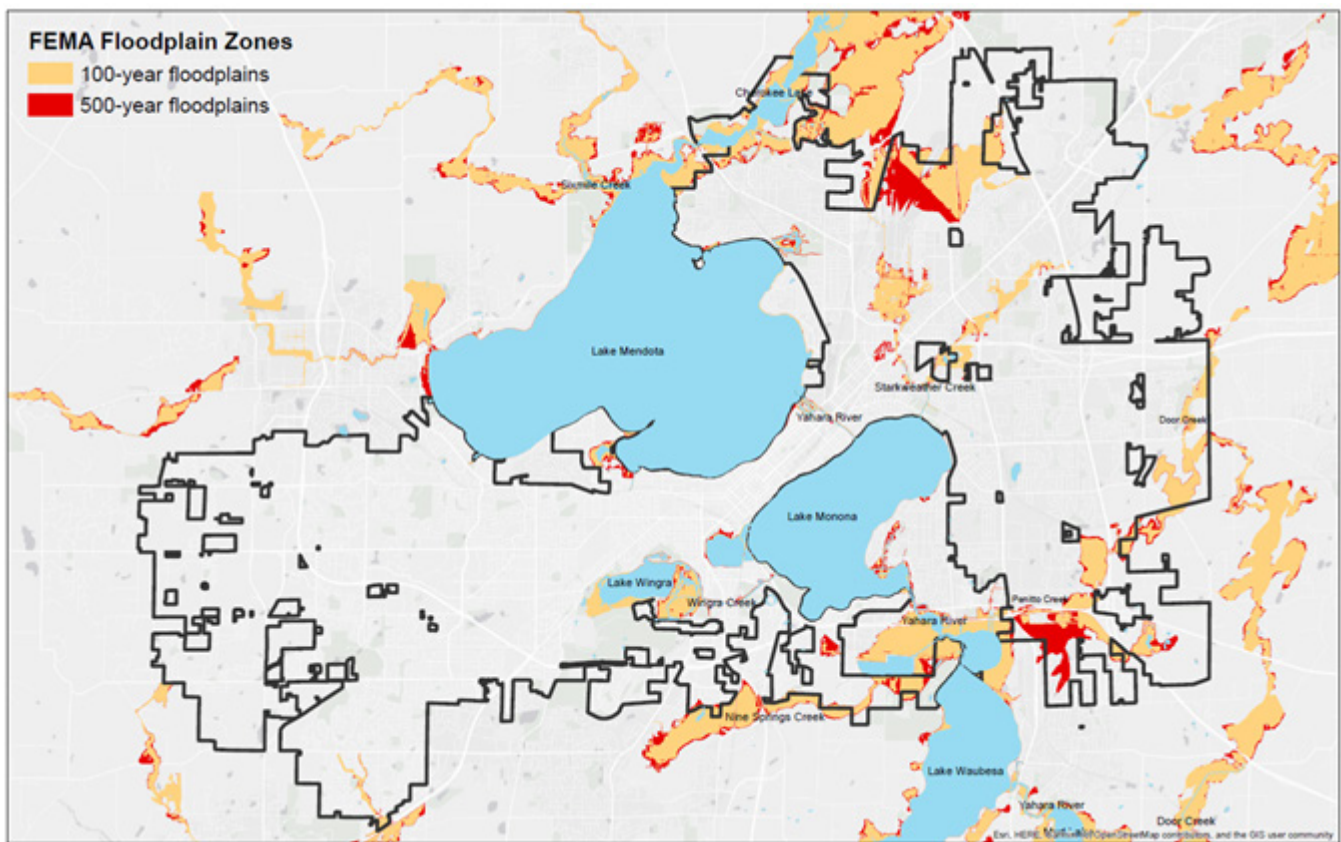
**Figure 15:** Areas in Madison that lie within the 100-year or 500-year floodplains.

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 additional stormwater-related solutions may be needed.

Based on the flood risk denoted in Figure 15, the west side of Madison looks to be of low risk of flooding. However, this is where Madison has experienced repeated flooding. This is where the Watershed studies will aid in determining the actual risk to areas throughout Madison.

**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 elevation above sea level for the entire city. We used 2-foot contour lines to denote changes in elevation. As shown in Figure 16, the isthmus portion of the City of Madison is in a low-lying area and this is where the City

has experienced lake level flooding.

**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. Based on results, we grouped slope into three categories:

      1) Areas with less than 12% slope;

      2) Areas with slope between 12-18%; and

      3) Areas with more than 18% slope.

As shown in Figure 17, slope is not an important feature to consider in the City of Madison.

**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.
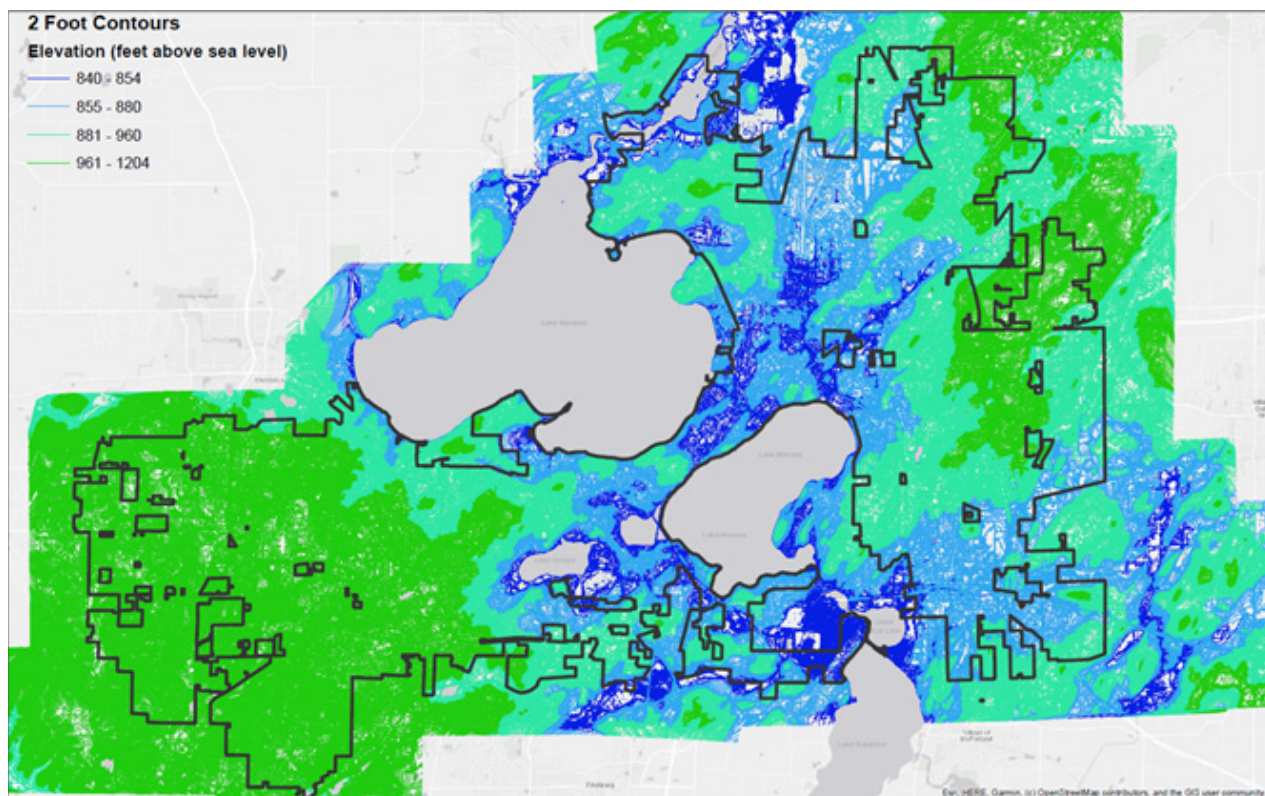
**Figure 16:** Madison elevation map.

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 Madison has decided to use impervious surface coverage and vegetation coverage as indicators of local landscape vulnerability to flooding.

As shown in Figures 18 and 19, the most impervious and least vegetative area encompasses the isthmus which is prone to lake level flooding.
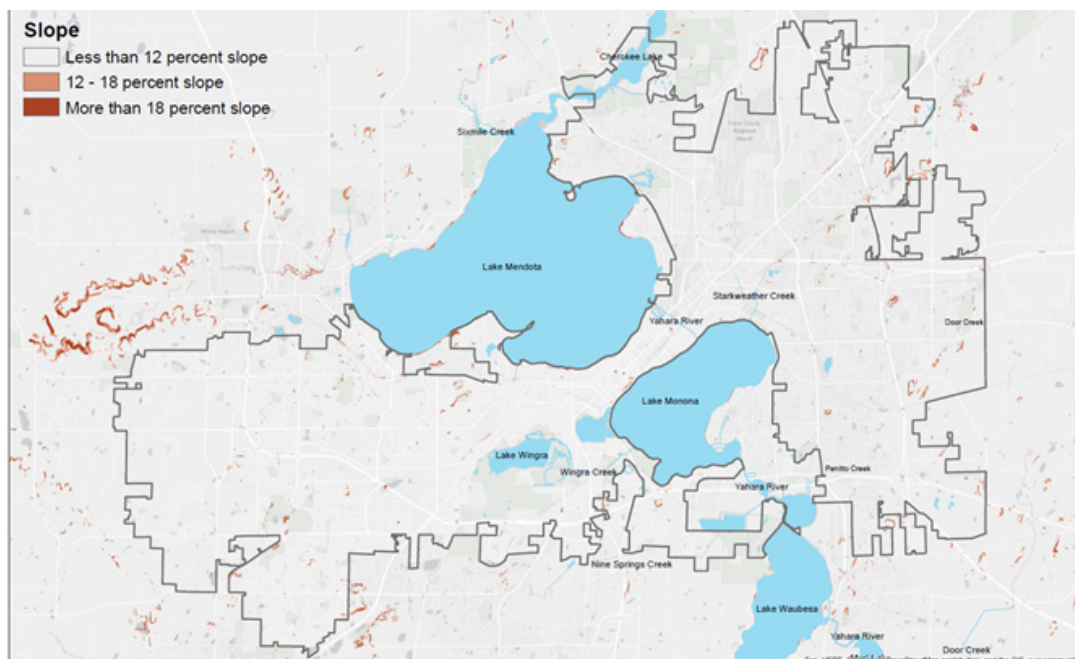


**Figure 17:** Degree of slope across the City of Madison.
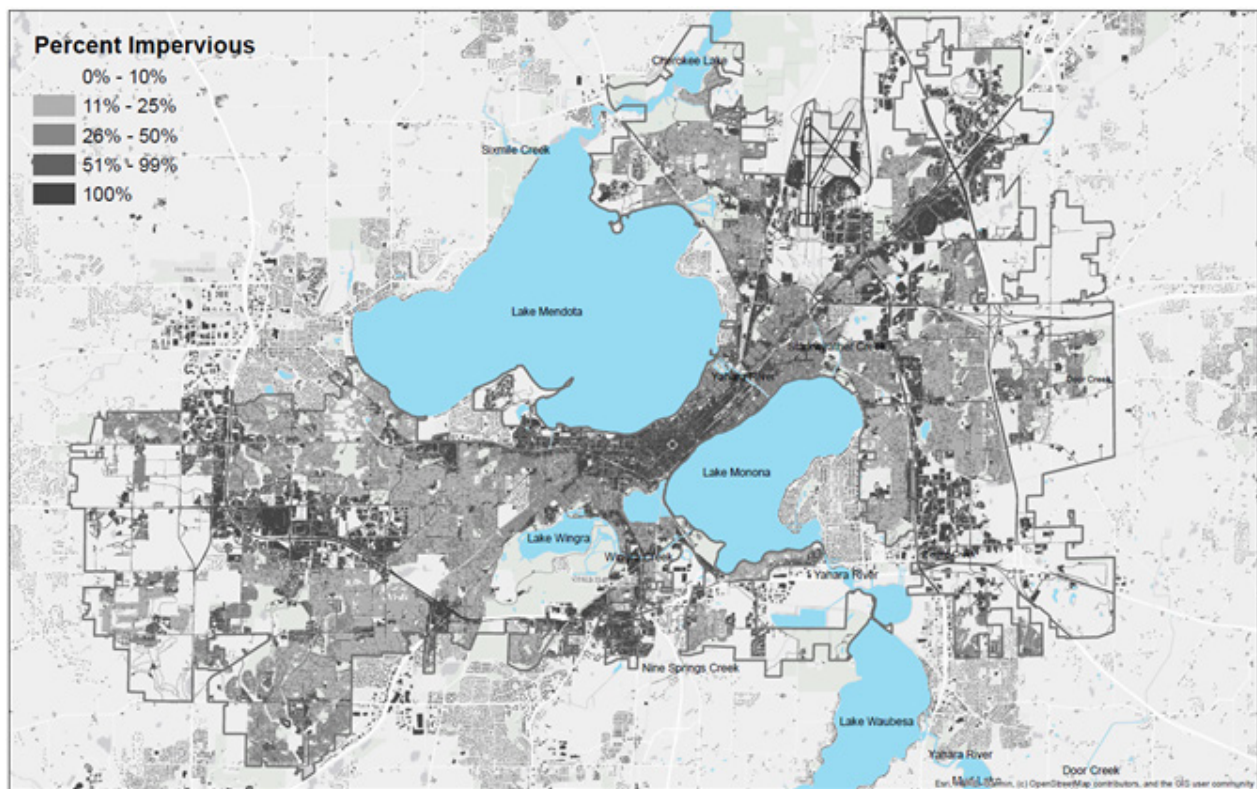
**Figure 18:** Impervious surface coverage in the City of Madison.

### e) Stormwater Asset Conditions

The quality (age, condition, capacity) and design of our city's stormwater infrastructure is another important 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 Madison, however, we are striving to build all stormwater infrastructure to the current 100-year



**Figure 19:** Vegetation coverage in the City of Madison.

**Figure 20:** Stormwater assets in the City of Madison



**Figure 21:** Age of storm pipes in the City of Madison

Climate Change Vulnerability Assessment for Stormwater | City of Madison
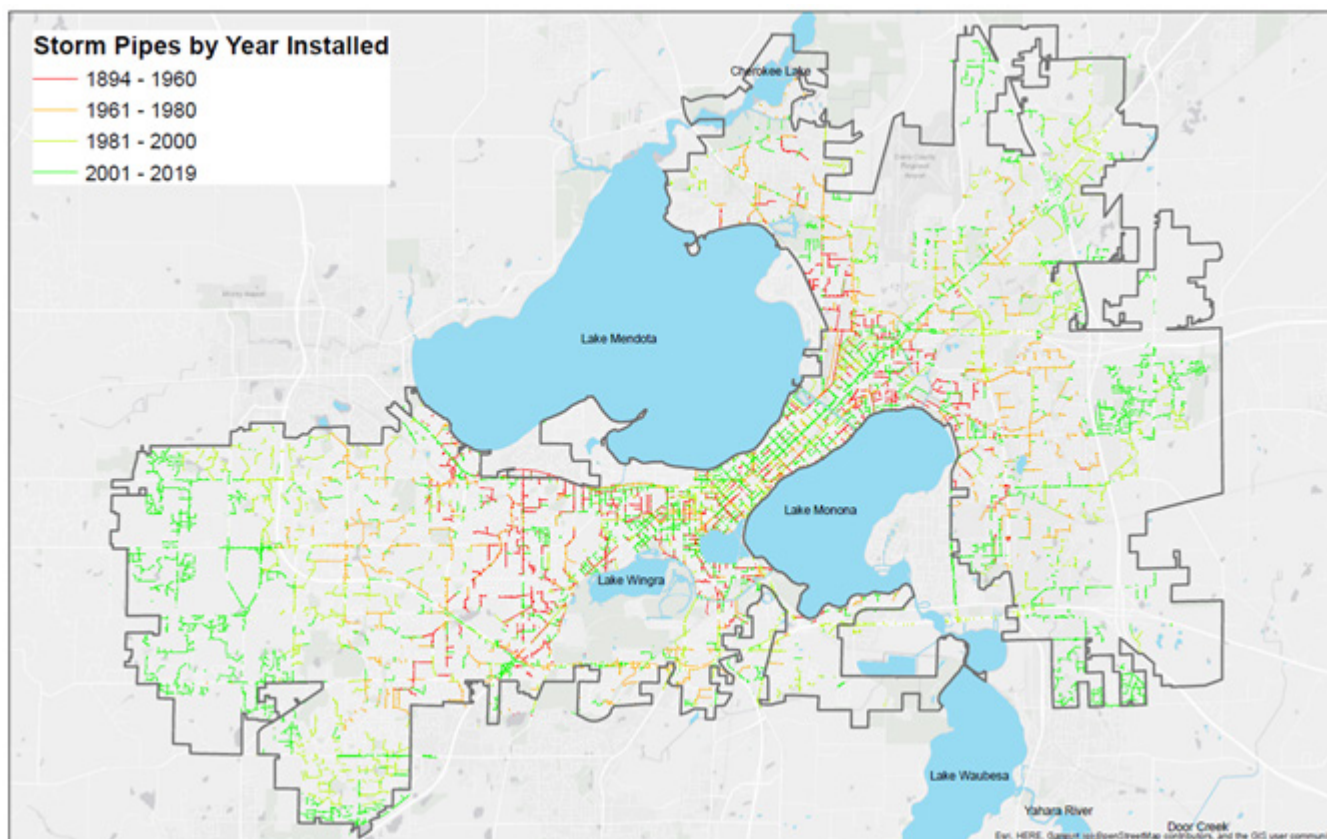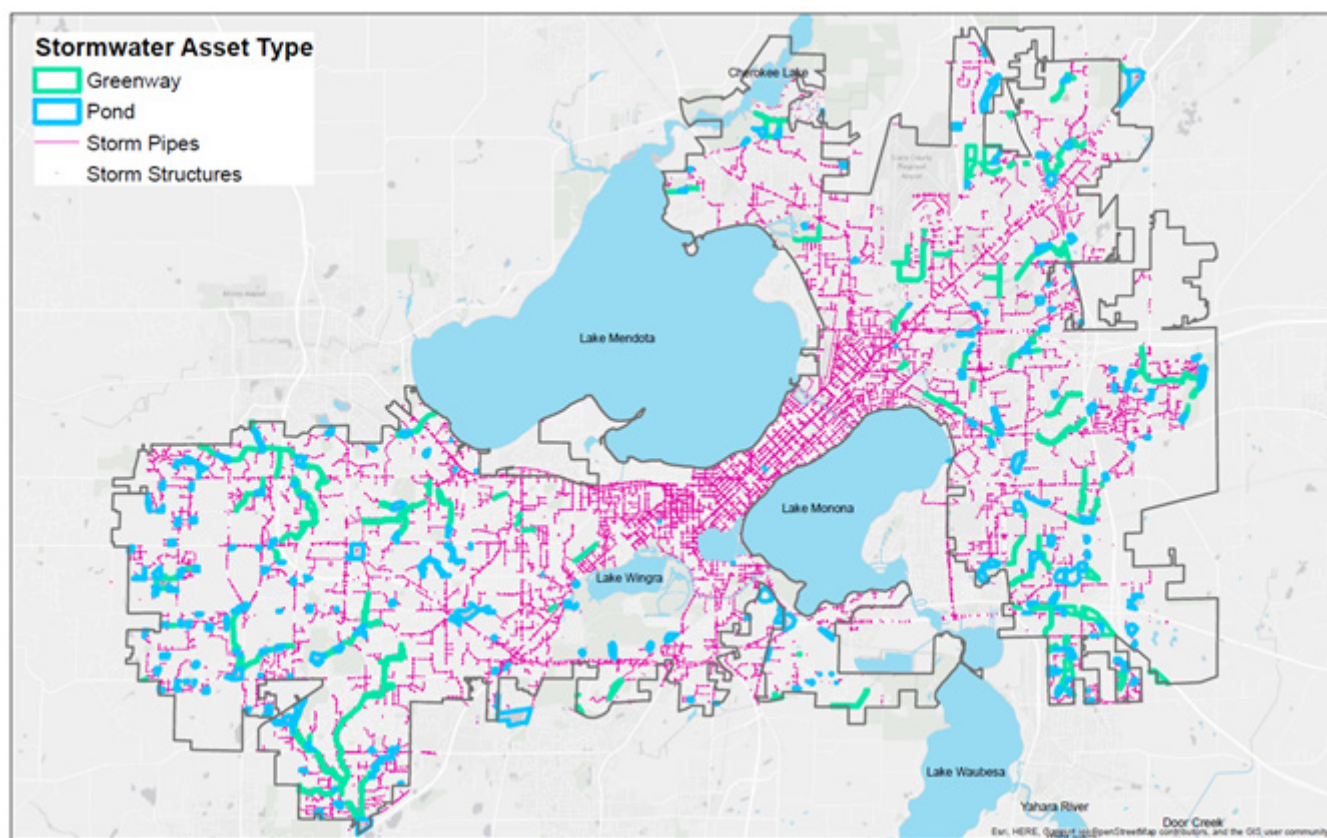
storm event - since we know the frequency and intensity of storms are changing due to climate change, we want to make sure we are effectively preparing. With that in mind, we conducted an analysis to determine what type of storm events our various stormwater assets can handle as well as the overall condition of our stormwater system.

Results (Figure 21) show that the most aged stormwater infrastructure is located on the middle west side which may have contributed to the incidences of flooding.

## 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 Madison 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.

The most urban areas closer to downtown occur on the isthmus which contributes to the reduced vegetation coverage seen in Figure 19.

**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 Madison also mapped the location and percentage of impervious land coverage throughout our community (see Figure 18).

In addition to the greater percentage of impervious surface located in the downtown isthmus region, there are also greater percentages on the east and west side where major retail malls are located along with their large surface parking lots.

**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."[58]  As an example, studies have shown that downtown metropolitan areas can absorb and store twice the amount of heat compared to rural surroundings
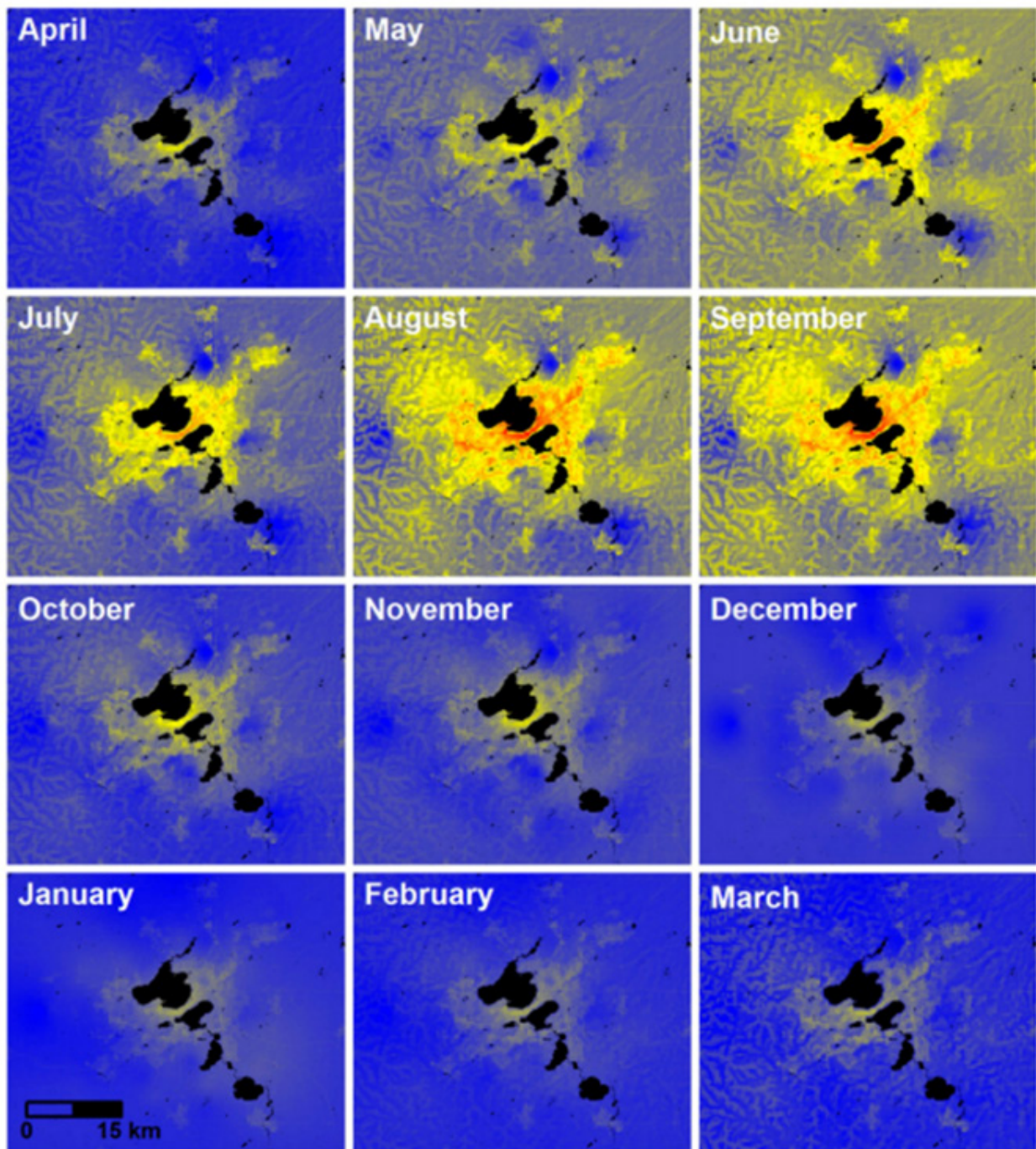
Christopher Kucharik/UW-Madison Water Sustainability and Climate Project

**Figure 22:** Urban heat islands in the City of Madison.

during the daytime.[59]

Using information from the UW-Madison Water Sustainability and Climate Project59 we were able to determine the local urban heat island effect throughout the City of Madison.
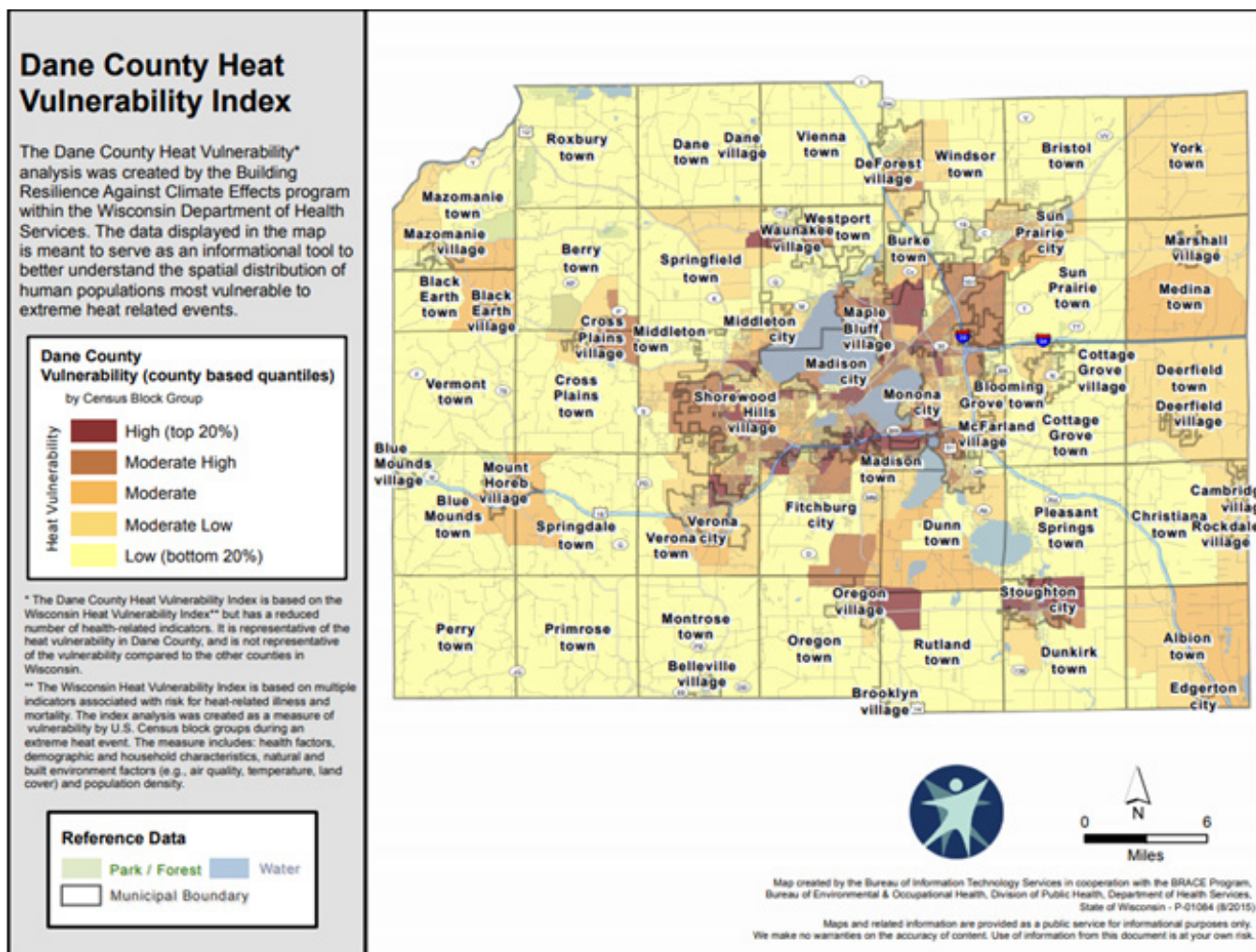
Figure 22 shows Madison's urban heat island. The Urban Heat Island maps show a warmer area throughout the downtown region in the isthmus of the City of Madison that is especially pronounced between June and September.

## Madison's Heat Vulnerability Map

Using methodology developed by the San Francisco

**Figure 23:** City of Madison heat vulnerability map. Source: https://www.dhs.wisconsin.gov/publications/p01084-dane.pdf

Department of Public Health, the Wisconsin Building Resilience Against Climate Effects (BRACE) staff conducted a geo-spatial analysis of heat-related vulnerability in both Wisconsin as a whole and the greater Madison urban area, with assistance from the Wisconsin Department of Health Services (DHS) Bureau of Information Technology Services. We used this information to identify the specific areas of our community that are particularly sensitive to heat (Figure 23.

As can be seen from this map, neighborhood areas along US 12, frequently referred to by locals as the Beltline, are seen as having a higher heat vulnerability as well as areas outside of the urban center.

## 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 FEMA 100-Year and 500-Year Floodplains do not adequately represent the landscape in Madison that has experienced repeated flooding.  We also see that that the more built out and more dense landscape in the urban

# 5. MADISON'S VULNERABILITY ASSESSMENT RESULTS

Using the information outlined in the previous sections, the City of Madison 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. As such, to undertake our vulnerability assessment we engaged in the following nine steps.

## Step 1: Define Scope of Assessment

For the purpose of Madison's vulnerability assessment, we chose to focus on our entire stormwater system. The remainder of this section provides a short description of the City's stormwater system and the various components evaluated as part of our vulnerability assessment.

| Table 5: Elements Included in the System-Wide Stormwater Vulnerability Assessment | |
| --- | --- |
| **Stormwater System Element** | **Type of System** |
| Street – curb gutter | Built System |
| Inlets | Built System |
| Outflows | Built System |
| Conveyance – pipes | Built System |
| Conveyance - swales | Natural System |
| Underground storage | Built System |
| Above ground storage (wetlands) | Natural System |
| Street trees | Natural System |
| Small green infrastructure | Natural System |
| Large green infrastructure | Natural System |
| Treatment swirl | Built System |
| Residential street trees in floodplain | Natural System |
| Commercial street trees in floodplain | Built System |

| Table 5: Elements Included in the System-Wide Stormwater Vulnerability Assessment | |
|---|---|
| Employees – public works | Social Systems and Vulnerable Populations |
| General public | Social Systems and Vulnerable Populations |
| Vulnerable populations | Social Systems and Vulnerable Populations |
| Budget | Government Services |
| Receiving water ecology | Natural System |
| Creek | Natural System |
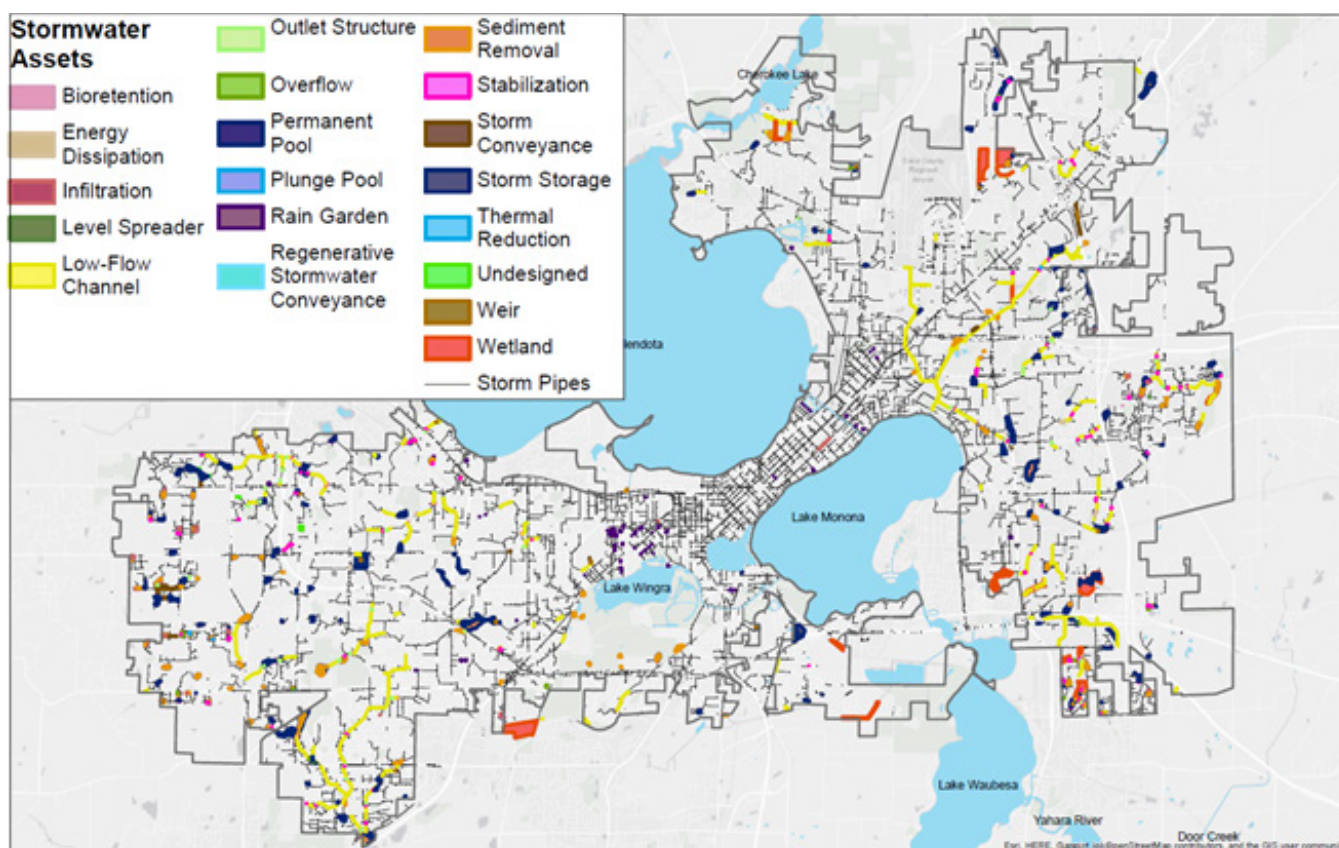


**Figure 24:** City of Madison Stormwater Assets

| Table 6: Specific Project: Storm Drain Replacement |
|---|
| Storm drain design and specifications |
| Surrounding neighborhoods |
| Retirement community |
| Affordable housing site in the vicinity of the project |

**Table 7** provides a sample of the systems and system elements evaluated as part of the City of Madison's stormwater system vulnerability assessment process.

| Table 7: Scope of Vulnerability Assesments | | | | |
|---|---|---|---|---|
| **Ref#** | **City** | **System** | **System Component** | **Geographical Distribution System Component (Census Tract, if applicable)** |
| 1 | Madison | Stormwater | Hard System - Pipes & Structures | All_Madison vs. All_Madison |
| 2 | Madison | Stormwater | Soft Systems - Greenways, ponds, & other green infrastructure | All_Madison vs. All_Madison |
| 3 | Madison | Stormwater | Stormwater Utilities Employees | All_Madison vs. All_Madison |
| 4 | Madison | Stormwater | Social Systems - Engagement with flood-prone watersheds | All_Madison vs. All_Madison |

## Step 2: Socio-Economic Analysis

The second step of our assessment focused on compiling and analyzing socio-economic information, at the pertinent geographical scale, for the various elements evaluated as part of our stormwater-system vulnerability assessment.

To do this, we built upon the data outlined in Chapter 2 to more deeply understand who could be affected by each of the elements evaluated in our vulnerability assessment.

Guiding this section were two key questions:

1. How will socio-economic vulnerability influence the elements being evaluated in our vulnerability assessment?

2. How will the elements (i.e., the thing being evaluated as part of our vulnerability assessment) impact (i.e., help or hinder) socio-economic vulnerability?

**Table 8** below demonstrates the results from this step of our assessment for a subset of our system.

| Table 8: Socio-Economic Analysis | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Project Details** | | **Socio-Economic Vulnerability** | | | | | | | | | | | |
| System Component | Geographical Distribution of System Component (Census Tract, if applicable) | % of Population Over 65 | % of Population Under 5 | % of Community in Poverty | % of Population with Limited English Proficiency | % of Non-White Population | % of Households Receiving Food Stamps/ SNAP | % of Households Where Mortgage is >30% of HH Income | % Disabled | % of Renters | % of Population Without a High School Diploma | How Will Socio-Economic Vulnerability Influence This System Component? | How Will This System Component Impact (e.g., help or hinder) Socio-Economic Vulnerability? |
| Hard System - Pipes & Structures | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | City-wide goal regardless of socio-economic vulnerability | This system component will help community wide. |
| | vs. | | | | | | | | | | | | |
| | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | | |
| Soft Systems - Greenways, ponds, & other green infrastructure | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | Implementation will be different than Hard Systems. There will be renters versus owners which will make harder to Implement especially in certain socio-economic vulnerable populations: high renters, high poverty, low English proficiency | Just as likely to help regardless of socio-economic vulnerability. Issue is that it will be more difficult to implement which is tied to rentals, limited educational attainment and limited English proficiency |
| | vs. | | | | | | | | | | | | |
| | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | | |
| Stormwater Utilities Employees | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | Current HR policies & procedures cover employees | N/A. |
| | vs. | | | | | | | | | | | | |
| | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | | |
| Social Systems - Engagement with flood prone watersheds | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | It will be more challenging to get socio-economic vulnerable populations to get involved and engaged. | The impacts of engagement will be based on which socio-economic vulnerability group |
| | vs. | | | | | | | | | | | | |
| | All_Madison | 11.1 | 5.2 | 18.3 | 2.2 | 21.2 | 8.8 | 23.6 | 8.4 | 52.4 | 4.6 | | |

## Step 3: Exposure Analysis

The third step in our assessment was the compilation and analysis of pertinent climate change information to understand how the various elements being evaluated as part of our stormwater vulnerability assessment could be or already are exposed and impacted by a changing climate.

The intent of this step is to understand responses to two key questions:

1. How will projected changes in climate influence the elements being evaluated as part of our stormwater vulnerability assessment?

2. How will the elements (i.e., the thing being evaluated as part of our stormwater vulnerability assessment) impact (i.e., help or hinder) projected changes in climate?

**Table 9** below demonstrates the results from this step of our assessment for a subset of the stormwater system.

| | Project Details | | | Climate Vulnerability | | | |
|---|---|---|---|---|---|---|---|
| Ref # | City | System | System Component | Variable of Interest | Sub-Variables of Interest | How Will Projected Changes in Climate Influence This System Component? | How Will This System Component Impact (e.g., help or hinder) Projected Changes? |
| 1 | Madison | Stormwater | Hard System - Pipes & Structures | Precipitation | Total Annual Precip | More system overflows as a result of the increased intensity cellular activity. System will no longer function as designed. 10 year, only 8 year. - Because the annual precipitation is up, lake level & groundwater also up. Isthmus drainage not operating optimally due to higher backwater, residential problems. | No impacts |
| | | | | Precipitation | Winter Avg Precip | | |
| | | | | Precipitation | Spring Avg Precip | | |
| | | | | Precipitation | Summer Avg Precip | | |
| | | | | Precipitation | Heavy Precipitation Days(>1.25") | | |
| 2 | Madison | Stormwater | Soft Systems - Greenways, ponds, & other green infrastructure | Temperature | Summer Avg Temp | Plant species selection changes in greenways & ponds. Also a challenge to maintain due to saturation & controlled burns. Natural selection causes shifts to non-native plant species. More erosion due to larger rain events. | More growth but not necessarily the plants you want. Example of Reed Canary vs. Blue Stem Grass: Reed Canary doesn't include offer pollinator / habitat characteristics. |
| | | | | Temperature | Days/Year Greater Than 90F | | |
| | | | | Precipitation | Summer Avg Precip | | |
| | | | | Precipitation | Spring Avg Precip | | |
| | | | | Precipitation | Heavy Precipitation Days(>1.25") | | |
| 3 | Madison | Stormwater | Stormwater Utilities Employees | Temperature | Days/Year Greater Than 90F | High heat slows crews down, more rest periods will be needed. More rain slows down work efforts as they cannot work in wet systems. | Self reinforcing - slow down of work loss of time for needed repairs for impacts of climate change |
| | | | | Precipitation | Summer Avg Precip | | |
| 4 | Madison | Stormwater | Social Systems - Engagement with flood prone watersheds | Precipitation | Heavy Precipitation Days(>1.25") | Increase in phone calls incoming as well as public information outreach which crowds out other existing work | No impacts |

## Step 4: Landscape Analysis: Flooding

The fourth step in our vulnerability assessment focused on compiling and analyzing pertinent information needed to understand how the various elements in our stormwater system already are exposed to flooding. To do this, we collected information, to the extent available, regarding elevation; whether or not the system was in the floodplain; slope; percent impervious land cover; and the storm event capacity and condition of infrastructure in the region. Where possible, we used data on the census tract level. When not available, we used citywide data.

Once data was compiled we used two questions to guide our assessment of each stormwater element's vulnerability to flooding:

1. How do local landscape features influence the element's vulnerability to flooding?
2. How will each element exacerbate or reduce landscape vulnerability to flooding?

**Table 10** below demonstrates the results from this step of our assessment:

| Landscape Vulnerability: Flooding | | | | | | | |
|---|---|---|---|---|---|---|---|
| System Component | Geographical Distribution of System Component (Census Tract, if applicable) | Landscape Variables That Could Affect Your Community's Local Vulnerability to Flooding | | | | How Do Local Landscape Features Influence This System Component's Vulnerability to Flooding? | How Does This System Component Exacerbate or Reduce Landscape Vulnerability to Flooding? |
| Hard System - Pipes & Structures | All_Madison | Elevation | In Floodplain (Y/N) | Slope (e.g., less than 12%; between 12-18%; over 18%) | Percent Impervious Land Cover | Storm Event Capacity of Infrastructure (e.g. 10-yr event; 20-yr event) | In areas where there are steeper slopes in addition to more impervious surfaces will be more prone to flood, especially if the hard systems were designed in the pre-modern era. | Systems designed using methods prior to modern era are more vulnerable to increased high-intensity rain events |
| Soft Systems - Greenways, ponds, & other green infrastructure | All_Madison | Elevation | In Floodplain (Y/N) | Slope (e.g., less than 12%; between 12-18%; over 18%) | Percent Impervious Land Cover | Storm Event Capacity of Infrastructure (e.g. 10-yr event; 20-yr event) | Erosion & instability of the soft systems as well as an increase of the high rates of flow | Soft systems will require more frequent maintenance |
| Stormwater Utilities Employees | All_Madison | Elevation | In Floodplain (Y/N) | Slope (e.g., less than 12%; between 12-18%; over 18%) | Percent Impervious Land Cover | Storm Event Capacity of Infrastructure (e.g. 10-yr event; 20-yr event) | It will be challenging to work in a changing system conditions. Employees will experience more calls than historic trend | Employees will not able to do other work |
| Social Systems - Engagement with flood prone watersheds | All_Madison | Elevation | In Floodplain (Y/N) | Slope (e.g., less than 12%; between 12-18%; over 18%) | Percent Impervious Land Cover | Storm Event Capacity of Infrastructure (e.g. 10-yr event; 20-yr event) | There will be a greater need for education & outreach while also adapting to the changing conditions | Engagement and outreach doesn't happen fast enough while also not wide-ranging enough. This can cause mis-information to spread in the interim. |

## Step 5: Cumulative Impacts

The fifth step in our analysis combined the information and analysis done in steps 2-4 to gather a holistic sense for the different ways each element evaluated as part of our stormwater system vulnerability assessment was impacted by socio-economic considerations, changes in climate, and local landscape features. Once we had combined all of this information, we then asked the following question:

1. How will the element affect socio-economic, climate, and landscape features?
2. How will socio-economic, climate, and landscape features affect the element?

**Table 11** below demonstrates the results from this step of our assessment.

| Project Description | | | | Cumulative Impacts |
|---|---|---|---|---|
| Ref # | City | System | System Component | Based On All Analysis Completed So Far, Summarize How This System Component: 1) Will Be Affected By and 2) Will Affect Socio-Economic, Climate, and Landscape Features. |
| 1 | Madison | Stormwater | Hard System - Pipes & Structures | 1) The Hard System will be further stressed, especially those designed over 120+ years ago. The Hard Systems have varying degrees of success and do not function well currently and will function less well with more rain & more intense rain events.<br><br>2) Repairs to the Hard System are extremely expensive. For example: 2 retrofits cost approximately $6m and it impacts approximately 100 people (population = 250k total). Also, challenging to fund. This leads to the following questions: when do we not protect infrastructure & deconstruct. How do we rank projects on cost / benefit analysis. How does the Racial Equity Social Justice Initiative come into play. And how do we assess property valuations. |
| 2 | Madison | Stormwater | Soft Systems - Greenways, ponds, & other green infrastructure | 1) Soft Systems will be further stressed, especially those designed over 120+ years ago. The Soft Systems have varying degrees of success and do not function well currently and will function less well with more rain & more intense rain events<br><br>2) Repairs to the Soft Systems are extremely expensive. For example: 2 Green Infrastructure projects cost approximately $6m and will impact approximately 100 people (population = 250k total). Also, challenging to fund. Similar Questions to Hard Systems: When do we not protect infrastructure & tear down. How do we rank projects on cost / benefit analysis. How does the Racial Equity Social Justice Initiative come into play. And how do we assess property valuations. When looking at retrofits in parkland, how to assess the tradeoffs for various socioeconomic & stakeholder groups |
| 3 | Madison | Stormwater | Stormwater Utilities Employees | We will need more employees for more repairs, more staff will require more funding in the budget (regardless of whether it is done in house vs. contracted out). |
| 4 | Madison | Stormwater | Social Systems - Engagement with flood prone watersheds | The Flood Prone Watersheds are affected more often which will cause property values to be lowered, question on how to sell a less valuable house. Wisconsin is a disclosure state. It will take more staff work and effort. And the budget process means that solutions will be more long term. Projects deemed to be high cost with a low number of impacted people will most likely not be prioritized |

# Step 6: Sensitivity Assessment

The sixth step of our assessment focused on the sensitivity of each element evaluated in the stormwater system to the impacts identified in the previous step. 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 impacts identified in Step 5?

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 17 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 |

Results from this analysis found that we do not have a particularly high sensitivity (scores of S3-S4) for our elements. Rather, all four elements were assigned a score of moderate sensitivity (S2) or those likely to have limited sensitivity to climate-related impacts (S0-S1).

**Table 12** below demonstrates the results from this step of our assessment for a subset of the stormwater system.

| | Project Description | | | Sensitivity Assessment | | | |
|---|---|---|---|---|---|---|---|
| Ref # | City | System | System Component | What, If Any Existing Stresses Affect This System Component? | How Might Demand For This System Component Change Given Cumulative Impacts Identified? | What, If Any, Limiting Factors Does This System Component Have? (e.g., think about how projected impacts might influence the System Component's operational thresholds) | How Sensitive is This System Component to Projected Changes in Climate? (e.g., Sensitivity Score) |
| 1 | Madison | Stormwater | Hard System - Pipes & Structures | Infrastructure is more than 100 years old which means it is less able to react to stress. | This will increase non-uniformity and more so in the older portion of town, where pipes are more stressed | Flooding and failures will happen | S2 - System will be somewhat affected by the climate-related impact |
| 2 | Madison | Stormwater | Soft Systems - Greenways, ponds, & other green infrastructure | Not all are in good existing condition | It will make it harder on greenways where maintenance will become more difficult. This leads to a positive feedback loop which will expand areas which need repair | Organic systems can only adapt slowly | S2 - System will be somewhat affected by the climate-related impact |
| 3 | Madison | Stormwater | Stormwater Utilities Employees | We already are stretched thin | Need for crews will increase which will lead to further stressing | Budget for staffing | S1 - System will be minimally affected by the climate-related impact |
| 4 | Madison | Stormwater | Social Systems - Engagement with flood prone watersheds | Inequality & Housing Disparities | The more flooding will require more outreach which will need more staff time | Budget for staffing | S1 - System will be minimally affected by the climate-related impact |

## Step 7: Adaptive Capacity Assessment

The seventh step of our assessment focused on the adaptive capacity of each element to the impacts identified in the previous step. 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 each of the elements evaluated in our stormwater system vulnerability assessment have, 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 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 21 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 |

Results from this analysis found that we have a particularly low adaptive capacity (scores of AC0-AC1) for our Hard Systems.  However, we have a high adaptive capacity to climate related impacts (AC3-AC4) for the remaining elements.

**Table 13** below demonstrates the results from the adaptive capacity assessment.

| | Project Description | | | Adaptive Capacity Assessment | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ref # | City | System | System Component | Does the System Component Have What it Will Need to Adapt to the Identified Cumulative Impacts? | What Does the System Component Need to Help it Adapt to the Identified Cumulative Impacts? | What Would You Need in order to Provide What the System Component Needs to Adapt to the Identified Cumulative Impacts? | Can the System Component Accommodate Projected Identified Cumulative Impacts at Minimum Disruption or Costs? | Is the Project or System Component Already Stressed in Ways that Will Limit its Ability to Accommodate Identified Cumulative Impacts? | How Adaptive is the System Component to Projected Identified Cumulative Impacts? (i.e., adaptive capacity score) |
| 1 | Madison | Stormwater | Hard System - Pipes & Structures | Budgets are very tight. We have the knowledge but not the resources. | Staff time and budget for resources | We will need to assess reconstruction and construction projects based on watershed modeling | No | Yes | AC1 - System is minimally able to accommodate or adjust to projected changes in climate |
| 2 | Madison | Stormwater | Soft Systems - Greenways, ponds, & other green infrastructure | Partially, plants will shift over time to ones better suited, or dominant speicies will take over | Budget & replanting, shifting species through human intervention | Staff time and budget for resources | Partially | Marginally | AC3 - System is mostly able to accommodate or adjust to projected changes in climate |
| 3 | Madison | Stormwater | Stormwater Utilities Employees | Mostly | Will require different equipment as well as working different hours | Changes in policy | Yes | No | AC4 - System is able to accommodate or adjust to projected changes in climate in a beneficial way |
| 4 | Madison | Stormwater | Social Systems - Engagement with flood prone watersheds | This will require more public meetings which will require more staff time including overtime | More time allocated to additional staff | More time allocated to additional staff | Yes | Yes | AC3 - System is mostly able to accommodate or adjust to projected changes in climate |

## Step 8: Calculating Vulnerability

The final step in our vulnerability assessment was combining the sensitivity and adaptive capacity scores into a vulnerability score. Using Figure 23 below, we were able to determine which elements within our stormwater system were the most vulnerable (red) and which were the least vulnerable (green).

Figure 27 shows the results for our citywide vulnerability assessment.

This stormwater system vulnerability assessment found that the City of Madison stormwater hard systems were the least able to adapt and the most sensitive to climate change impacts. This finding aligns with the landscape feature of the age of the hard system pipes that need replacing and repairs. It also speaks to the changing flood map landscape for which hard systems designed in the last century will not be adequate for future storm events.

A positive finding from the vulnerability assessment is that stormwater utilities employees have a high propensity to adapt and are the least sensitive to climate change impacts. This is in part to existing robust HR policies and a general work culture that is supportive and responsive to staff needs.

| | | Sensitivity: Low to High | | | | |
|---|---|---|---|---|---|---|
| | | S0 | S1 | S2 | S3 | S4 |
| Adaptive Capacity: High to Low | AC4 | | Stormwater Employees | | | |
| | AC3 | | Social Systems | Soft Systems | | |
| | AC2 | | | | | |
| | AC1 | | | Hard Systems | | |
| | AC0 | | | | | |

**Figure 27**. Results for our citywide vulnerability assessment.

# 6. NEXT STEPS

This document represents an important step in building resilience to climate change in Madison. 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:

- Prioritizing Hard Systems for repairs and upgrades based on watershed data

- Increasing outreach for Soft System implementation on private property

- Engaging stormwater utility employees on staffing needs

- Gearing Public Information Meetings towards greater and more diverse outreach methods

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 Madison, 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, including Climate Resilience Planning partnership with the Wisconsin Initiative on Climate Change Impacts (WICCI).

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 Madison. 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 Madison. It's time to get to work!

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