Climate Change Adaptation:

Exploring Planning and Response in Three U.S. Cities

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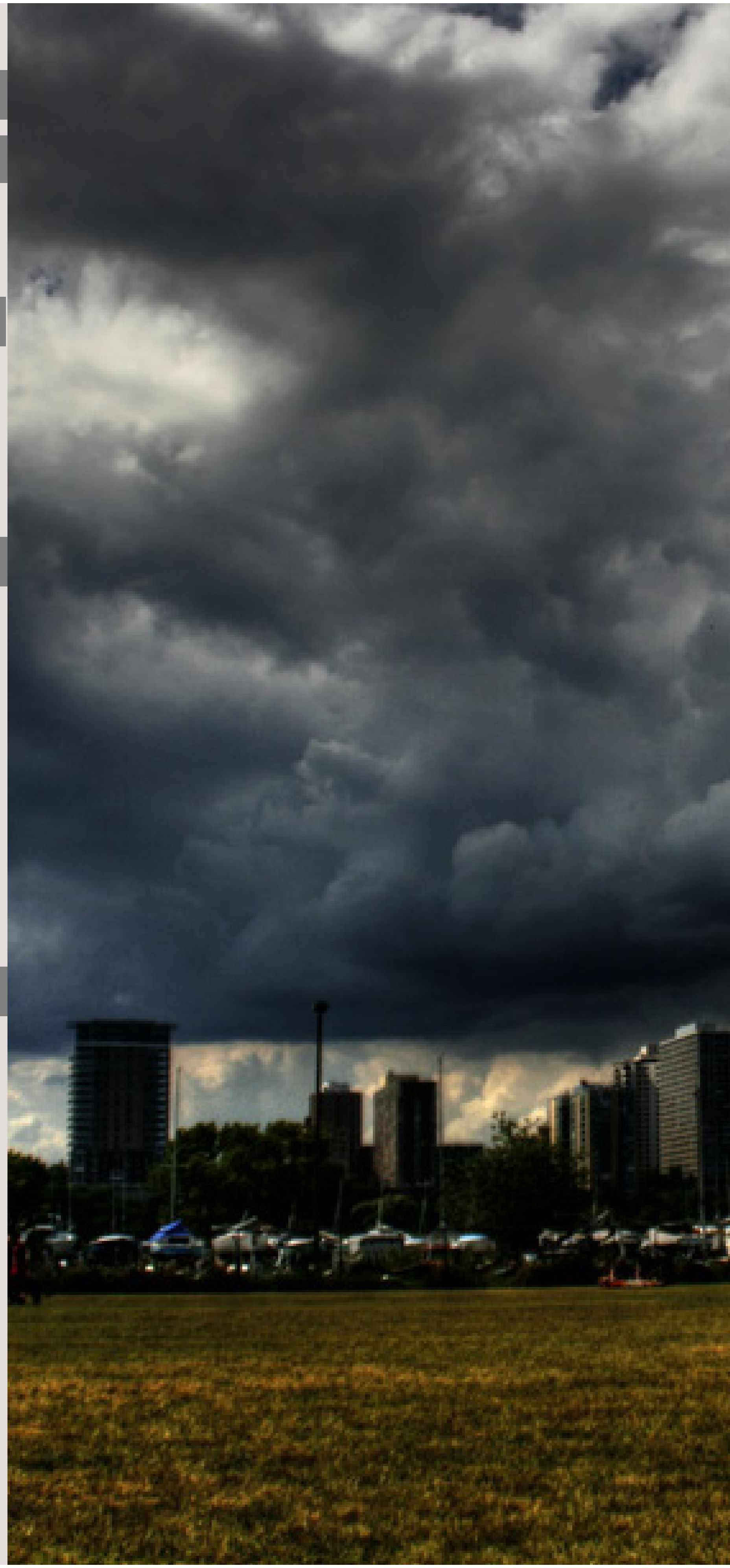

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Executive Summary

There is consensus among the scientific community that anthropogenic activities are driving changes in the global climate and increasing global average temperature. Even if all greenhouse gas-emitting activities were halted immediately, the global community will still experience decades of climate impacts due to the inertia inherent in the global climate system. While climate change mitigation activities are essential to limit future global environment effects, humans face a choice between enduring the worst impacts of climate change, or pursuing adaptation measures which address risks and prepare for the inevitable impacts on physical, social, and natural systems.

Climate Change Adaptation in U.S. Cities

Climate change impacts in the United States vary widely by geographic region. Many major cities have developed climate action plans, however most focus on climate change mitigation, not adaptation. Climate adaptation strategies are not as mature, well understood, or widely used, as mitigation efforts, especially in the United States. However, this trend is gradually shifting as city planners begin integrating adaptation along with existing policies, action plans, and design strategies, to respond to climate change.

Planning and Climate Threats

The Climate Change Adaptation: Exploring Planning and Response in Three U.S. Cities report articulates an iterative and dynamic process that can be used for climate adaptation planning in the U.S. We applied this process to Baltimore, Maryland, Fresno, California, and Milwaukee, Wisconsin in order to analyze the three primary climate threats to U.S. cities:

- Extreme heat, manifested by hotter, dryer summers and droughts
- Extreme storm activity, precipitation events, and flooding
- Sea-level rise and coastal storm surge

We chose each city to highlight at least one of these three risks: the threat of sea-level rise in Baltimore; the threats of extreme precipitation, flooding and lower lake levels in Milwaukee; and the threat of extreme heat and drought in Fresno. However, each city will face multiple threats. The focus of the report is on assessing and responding to the effects of climate change in each city. The main lessons from our report apply to the process and steps of creating a climate change adaptation plan.

Climate Adaptation Planning Process

1) Build a knowledge base about existing climate conditions and likely future regional impacts through a literature review of academic work as well as adaptation plans, site visits, and interviews with local experts. Stakeholder engagement is an important element to include at the outset and maintain throughout the process.

2) Identify major climate impacts, model present and future conditions, pinpoint specific vulnerable populations and neighborhoods, and perform a SWOT (Strength and Weaknesses internal to the city, Opportunities and Threats external to the city) analysis for all sectors of interest to local governments, stakeholders, and planning efforts.

3) Develop adaptation strategies based on the SWOT analysis that address major climate threats and impacts, location and population specific vulnerabilities, and the needs of the city.

4) Identify and reflect on gaps and lessons learned from the process.

5) Repeat the process as necessary to re-evaluate goals, refine recommendations and create new adaptation recommendations; use additional analysis tools to address feasibility concerns and constraints to implementation.

Themes and Sectors for Our Analysis

We found many ways to break down the threats and challenges that a city will face. This report uses a sector-based approach focusing on five distinct sectors (of particular interest for local government planning efforts) and four distinct sub-sectors used to assess crosscutting issues:

Sectors: land use, water, energy, human health, transportation
Sub-sectors: the built environment, the economy, natural systems, social systems

City Specific Analysis and Adaptation Recommendations

Baltimore, Fresno, and Milwaukee were chosen to highlight adaptation planning responses to a distinct set of climate threats. Specific recommendations included in this report are intended to illustrate an iterative process specific to these cities, but applicable to jurisdictions facing similar risks. Research on adaptation strategy processes highlights several important considerations, particularly challenges associated with addressing hazards-based and vulnerability-based approaches, reactive and anticipatory planning, and issues of timeframe and geographic scale. Our recommended adaptation strategy process integrates threat- and sector-based approaches with cross-cutting considerations to respond to the impacts of climate change. This approach results in comprehensive recommendations founded on city- and sector-specific knowledge that address vulnerability and risk.

Baltimore

Baltimore presented an opportunity to explore how to prepare for sea-level rise, storm surge, and increased intensity of extreme storm events such as hurricanes and tropical storms. The main climate risks faced by Baltimore are inundation from sea level rise, high average temperatures, and degraded air quality.

- The Port of Baltimore (which represents over 20 percent of the City's employment base and is a major logistics hub for international freight on the east coast) will experience significant challenges associated with sea-level rise (expensive retrofits, loss of land area) and more frequent storms (damage, service interruptions)
- The City is well resourced with a high median income, and is located within a state which has already demonstrated leadership on climate change adaption and planning
- Coastal infrastructure and developments (including energy generation facilities and water treatment plants) are vulnerable to inundation and damage from sea-level rise and storm surge
- Dense urban development in the city exacerbates the impacts from urban heat island effect
- Predicted temperature increases are likely to result in significantly higher concentrations of ground-level ozone during warm months. Exposure to ozone has negative health impacts and will be most pronounced in those who work outdoors (such as landscaping and construction).

The report identifies *Adaptation Recommendations* for Baltimore that address the threat of sea-level rise, including:

1) Install a land- and water-based coastal buffer

2) Increase resilience of the energy sector

3) Reinforce port infrastructure that will be threatened by sea-level rise

Fresno

Fresno presented an opportunity to explore a city where extreme heat and changes in freshwater availability will directly affect the primary economic sector in the region (agriculture). The main climate risks to Fresno will be extreme heat, reduced snowpack (and reduced freshwater), and flash flooding.

- Agriculture, the primary economic driver for the area, is highly dependent on a moderate and predictable climate. Variability and extreme weather could have a significant impact on local economic development.
- A large portion of the city is covered with hard, impervious surfaces, which leads to an increased threat of flash floods and severe urban heat island effects
- Fresno is located in a state that has a progressive stance on mitigation and adaptation policy geared towards climate change, and will likely receive support from the state for climate action planning
- Low income, agricultural workers will be most heavily impacted be extreme heat and air quality concerns

- Increasing temperatures will bring about an earlier onset of spring snowmelt, resulting in a decrease of water available for irrigation and hydroelectric energy production in summer
- During extended heat events, local electrical distribution capacity may be insufficient to meet supply

The report identifies *Adaptation Recommendations* for Fresno that address the threat of extreme heat, including:

1) Implement afforestation, pocket parks, and green infrastructure

2) Incorporation of light colored and reflective surfaces in infrastructure

3) Install and protect a greenbelt

Milwaukee

Milwaukee presented an opportunity to explore how changes in rain and precipitation patterns, and falling lake levels will impact the Midwest. The main climate risks to Milwaukee are flooding (especially in urban areas), lake level drop, and heat waves.

- Declining tax base and fiscal shortages in the region means that local funding sources for adaptation measures will be extremely limited in the short-term
- Central city (low income) neighborhoods are some of the most at-risk areas in the region for flooding, urban heat island effect, and poor air quality (high levels of ground level ozone)
- Milwaukee has a combined stormwater and sanitary sewer system, which can overflow during extreme precipitation events and cause water borne disease concerns
- Industrial and commercial job centers are disproportionately concentrated in areas of high vulnerability to flooding during extreme rain events
- Lakefront and port properties could require expensive retrofits and more frequent dredging due to lake level drop
- The city of Milwaukee's location at the confluence of three rivers makes it particularly vulnerable to flooding due to predicted increases in extreme precipitation

The report identifies *Adaptation Recommendations* for Milwaukee that address the threat of flooding and extreme precipitation, including:

1) Increase resilience of the energy sector

2) Implement and integrate a comprehensive stormwater management plan

3) Carry out wetland restoration and install a buffer along the rivers and lakeshores

Introduction

The Challenge

The global climate is changing, and these changes are in turn modifying weather patterns throughout the U.S. According to the National Oceanic and Atmospheric Administration (NOAA), the earth's average temperature is warming at a rate of 0.29 degrees Fahrenheit per decade, and the eight warmest years on record have occurred since 2001 (1). Since 1900, total precipitation has increased by 11 percent in the upper Midwest and around 9 percent in the Chesapeake Bay area (2), and has remained relatively unchanged in the San Joaquin Valley (3). Average sea levels rose between 5 and 9 inches worldwide since 1900 (2). In the U.S., changes in temperature, precipitation, and sea and lake levels will affect every city in a unique way.

Many city governments are beginning to use climate action plans to respond to the threats caused by climate change. These plans focus on the reduction of greenhouse gases, the primary driver of climate change. However, experts with the Intergovernmental Panel on Climate Change (IPCC) indicate that the world will experience some degree of climate change no matter how aggressively we reduce our greenhouse gas emissions (4). Despite this and other warnings from the scientific community, very few cities have moved beyond climate change mitigation to specifically address climate change impacts through change adaptation plans that include policies, action plans, and design strategies. This report explores how climate change adaptation planning can be applied in three mid-sized U.S. cities. These cities represent different geographic areas and different climate concerns. This report provides a process for those at the city-planning level interested in designing climate change adaptation plans for their cities.

The Team

This project was completed by an 11 person, interdisciplinary team of graduate students from the Gerald R. Ford School of Public Policy, the School of Natural Resources & Environment, and the Taubman College of Architecture & Urban Planning at the University of Michigan. We come from diverse backgrounds in municipal government, transportation, environmental justice, landscape architecture, sustainable design, urban planning, and public policy. However, we all share common interests in promoting social justice and proactive engagement to help cities prepare for the impacts of climate change. Climate change response is an interconnected endeavor, requiring coordination across almost every area of expertise and profession in city administration. We believe that the diverse makeup of our team emulates the kind of cooperative effort needed to address climate change risks, strategies, and policy decisions at the municipal and regional levels.

Our Process

Shaping a work process for a diverse group of students around the ambitious topic of climate change was a challenge in itself. We began with an intense two-day charette where we shared knowledge and ideas, reviewed literature, brainstormed research topics, chose cities for in-depth investigation, and debated project structure.

Our first major task was to select three cities for our case studies. We performed this process with several criteria and limitations in mind:

- We limited our selection to mid-size cities with a population between 250,000 and 1,000,000 to allow for comparison among the cities, and to focus on slightly smaller cities that were less advanced in their formal climate adaptation planning process.
- We looked for cities with large minority and low-income populations that would provide a useful context for analyzing social justice issues.
- We focused on cities that represented distinct geographic regions and climate zones in the U.S., and presented very different climate change adaptation challenges.
- We excluded cities with strong climate change adaptation plans in process or already in place.

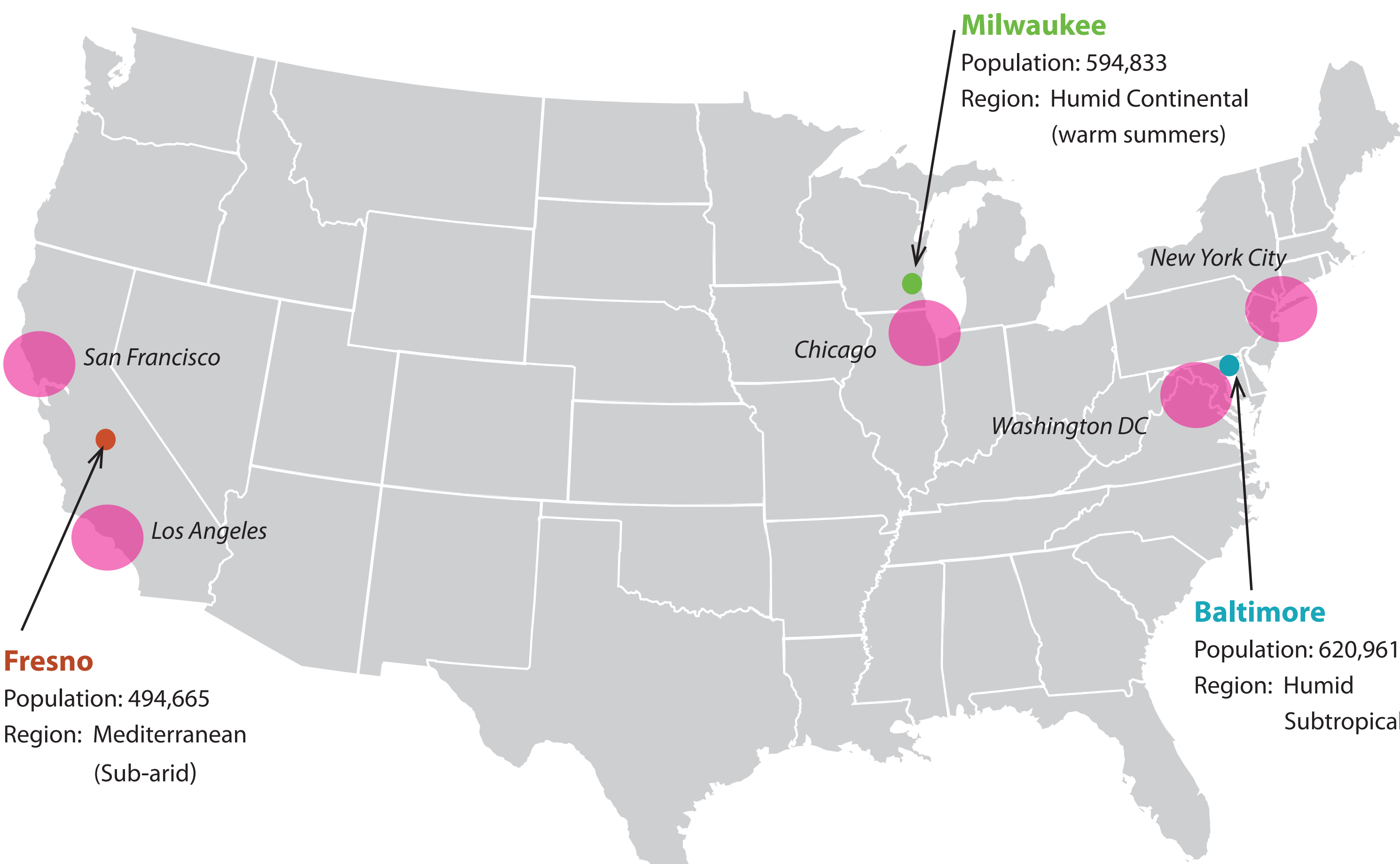

Figure 1: United States Map with location of the three cities selected for our case studies

From this process, we selected the following cities: Baltimore, Maryland; Fresno, California; and Milwaukee, Wisconsin.

We selected Baltimore in order to include a coastal city that will experience significant challenges due to rising sea levels. Baltimore has large minority and low-income populations who tend to live in densely-built central city neighborhoods where higher temperatures are challenging to escape. We chose Fresno because of its arid climate, large agricultural industry, hydroelectric power supply, and location in the water-constrained California Central Valley. Fresno also hosts a large population of migrant workers during harvest season who are likely to be exposed to very severe impacts resulting from increased temperatures. We selected Milwaukee to investigate how climate change might impact Great Lakes cities and explore the myth that the Great Lakes region is relatively immune to the effects of climate change because of its abundant fresh water resources and cold winters. Like many Midwestern cities, Milwaukee has a very high level of racial segregation, declining industries, and problems with blight and abandonment that could exacerbate the challenges associated with climate change.

Figure 2: Baltimore's low-income neighborhoods are more vulnerabile to climate change impacts such as extreme heat and localized flooding

Figure 3: As the growing season extends, migrant workers in and near Fresno will labor in warmer conditions for longer periods of time

Figure 4: Many areas in Milwaukee are suffering from blight and abandonment

Once we selected our cities, we focused on developing an iterative and dynamic analysis structure that would allow us to approach our topic in a systematic way, while still allowing us to revisit topics as we gathered new information.

- **Step One:** Gather peer-reviewed and reputable scientific research on existing climate conditions and the likely future impacts of climate change in our three regions. This step includes a literature review, site visits, and interviews with local experts.
- **Step Two:** Analyze research from step one to explore how climate change is likely to impact each city and supporting systems. This includes identification of major climate change impacts, geographic information systems (GIS) modeling, and a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis for the sectors of interest for local government planning efforts: land use, water, energy, human health, and transportation.
- **Step Three:** Develop adaptation strategies that address major climate change impacts, weaknesses, and threats identified in step two. This step includes best practices research, and selection of policy and design strategies which respond to specific climate change risks.
- **Step Four**: Identify gaps and lessons learned in the analysis performed in the previous steps.
- **Step Five:** The process is repeated as necessary to refine outcomes and take advantage of the learning that occurred during the process.

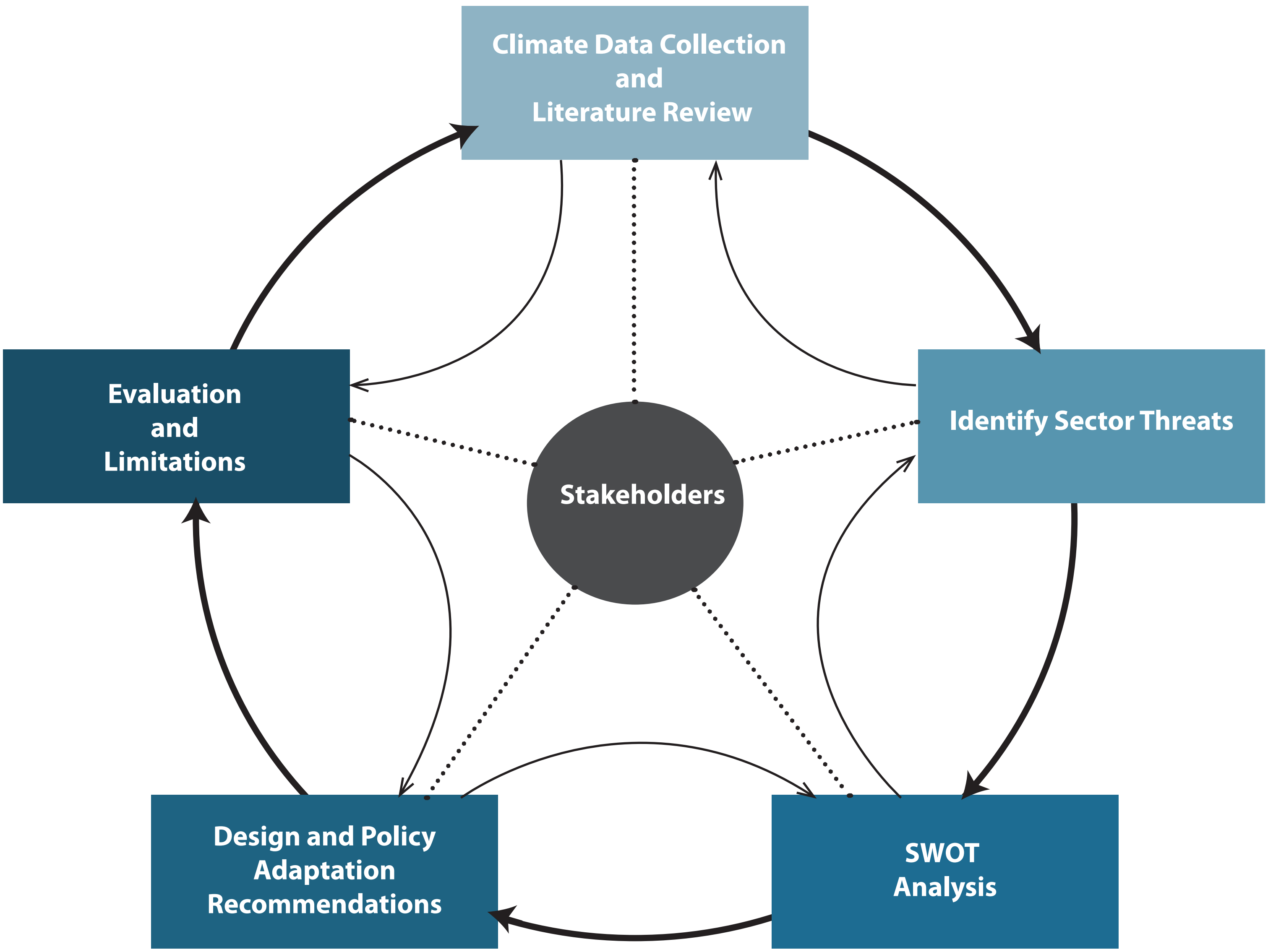

Figure 5: Our proces diagram outlining the steps we took to complete the task

This Report

This report begins with a detailed description of our methodology for climate change adaptation planning in cities. We include examples of state, regional, and non-profit organizations that provide new data and support for climate change adaptation at the city and metro levels.

We move next to a background discussion on climate change data, uncertainty and greenhouse gas emissions scenarios, the limitations of existing global and regional models, and the emergence of new, locally "down-scaled" models that provide data at scales useful for cities.

Then we move to our three case study cities: Baltimore, Fresno, and Milwaukee. We explore each city in-depth using city and regional profiles, climate change predictions, spatial analysis, and a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. We begin by interpreting climate change predictions in the context of impact on local infrastructure, social systems, fiscal health, and natural systems. We present geographic information systems (GIS) analyses that identify vulnerable areas and populations, as well as SWOT analyses that help us interpret future changes in the categories of land use, water, energy, human health, and transportation. We then present potential adaptation strategies and best practices as policy recommendations, action items, and design strategies. Finally, we present a review of our process for addressing climate change adaptation in cities including a gap analysis of the tools and information currently available for professionals working on climate change adaptation at the city level.

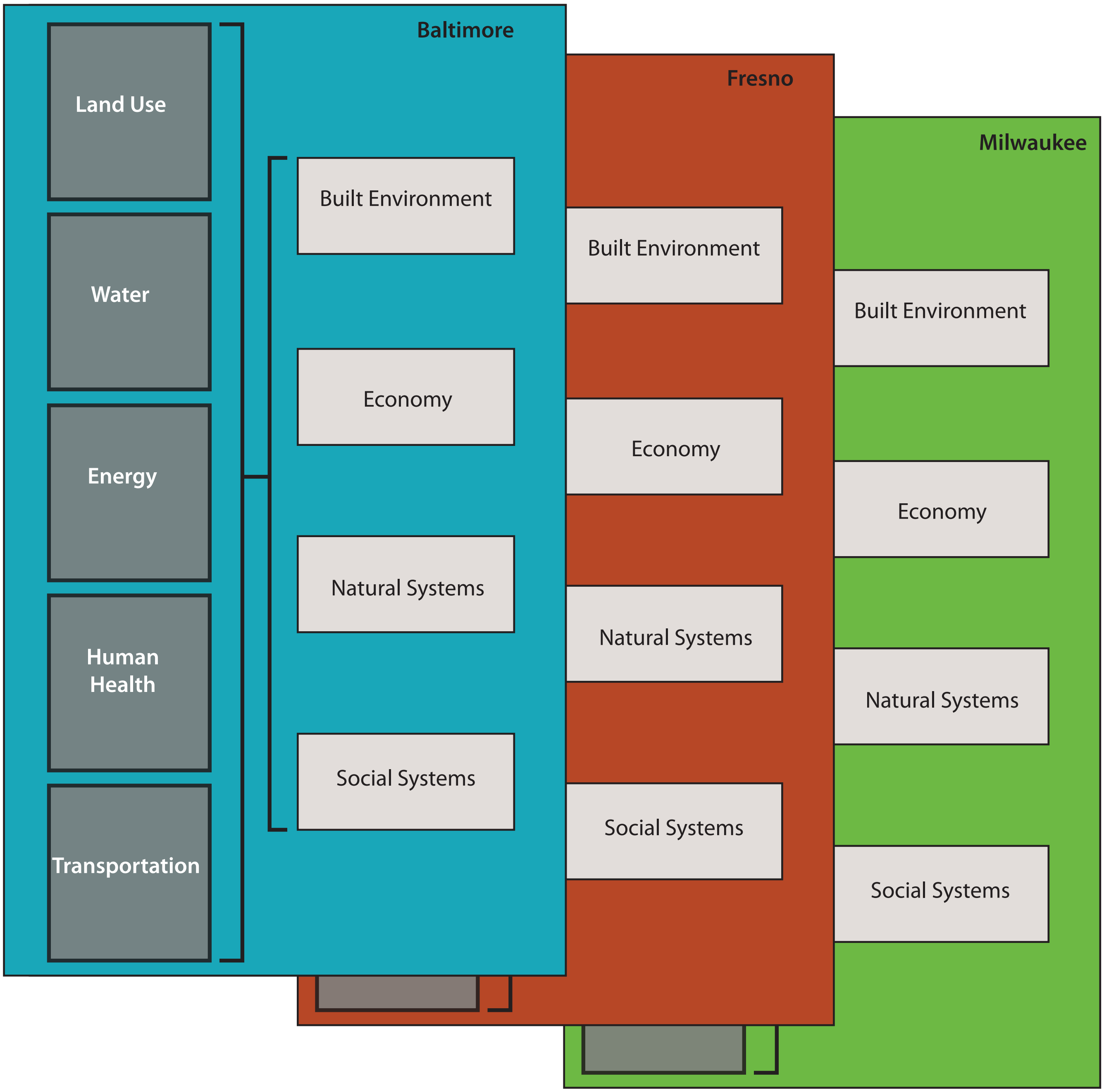

Figure 6: Our methodology for all three cities

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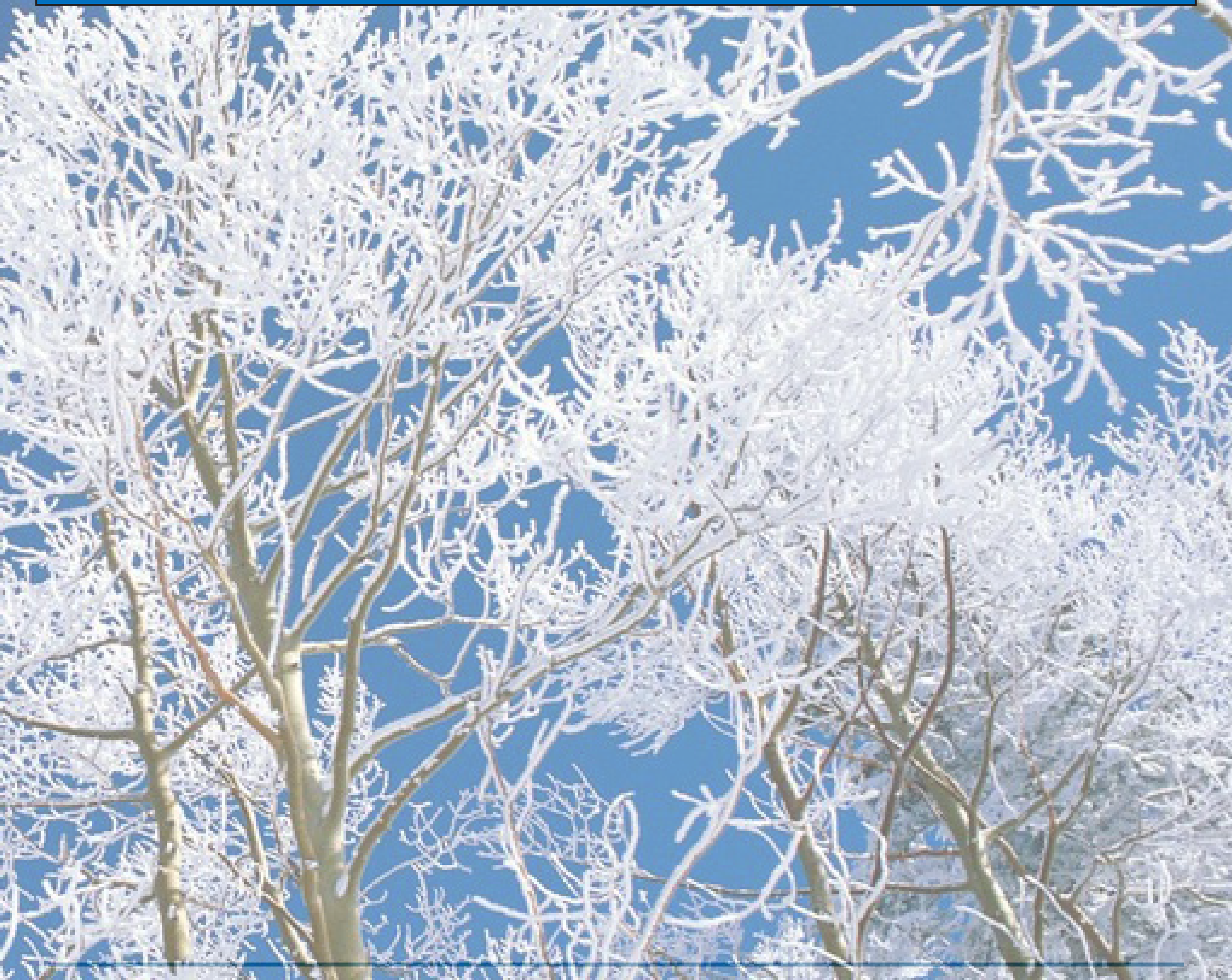
Existing and Future Climate

National Assessment

The United States Global Change Research Program (USGCRP) – formerly known as the U.S. Climate Change Science Program (CCSP) – is the U.S. federal program responsible for coordinating and reporting climate change research in the U.S. Their most recent report: Global Climate Change Impacts in the Unites States (2009) is the most comprehensive resource available for regional-scale climate change impacts. This report, combined with earlier reports from the CCSP, form the basis for our evaluation of local climate change impacts in the cities we studied. These sources used multiple Global Circulation Models (GCM) to predict changes for all regions of the United States. In addition to the USGCRP, we sought out climate impact studies down scaled to the state or regional level and used these (where available) to add greater depth to our understanding of the climate change impacts our cities and regions are likely to experience over the next 100 years.




RENAISSANCE HARBORPLACE HOTEL

Baltimore, Maryland

Baltimore

Current Climate

Baltimore has a humid, sub-tropical climate with consistent precipitation throughout the year, mild winters and hot, humid summers. Baltimore receives an average of 40.8 inches of annual precipitation with all monthly averages falling between 3 and 4 inches. Average temperatures range from 31.8 degrees Fahrenheit in January to 77.0 degrees Fahrenheit in July (1). Changes in precipitation and temperature will be significant in Baltimore, particularly extreme heat events.

Sea Level Rise

Baltimore will be more severely impacted by sea-level rise than any other East Coast city. Threats from sea level rise will be among the most serious impacts Baltimore will face from climate change, with predicted rises between 24 and 48 inches over the course of the current century (2). Combined with more frequent and powerful storms, sea-level rise will result in higher levels of storm surges. As a result, virtually all coastal land will be at higher risks of flooding due to inundation, coastal erosion, and accelerated land subsidence. One study of sea-level rise in the northeastern U.S. found that what is now considered a 100-year flood event will occur at least once every 49 years by century's end, and could occur as frequently as once every two years in some locations (3).

Temperature

Average temperatures in Maryland have increased 2 degrees Fahrenheit since the 1900s, outpacing global average temperature rise. Average temperature will increase by 3 to 6 degrees Fahrenheit (9 degrees in the summer) by century's end, resulting in more severe heat waves (4). There will be an increase in the frequency and intensity of extreme heat events in the Baltimore area, with five to ten more days over 90 degrees Fahrenheit each year by 2050, and between 13 and 63 more days over 90 degrees Fahrenheit by the end of the century.

Precipitation

There will be an overall increase in precipitation across the mid-Atlantic region because of an increase in the presence of moist air due to climate change. Increased flood risk due to an increase in the frequency and severity of intense precipitation is predicted (absolute increase of 20 percent with largest changes occurring in winter months) (18). Rainfall is expected to become more intermittent, and as temperatures warm, evaporation will increase, prolonging droughts in the summer. The frequency and storm tracks of future storms are hard to predict. However, as surface waters warm there is strong evidence that there will be an increase in the number of strong storms striking Baltimore, and with that, an increase in storm surge and rainfall (5). In the early 21st century there will also be an increase in snowfall during the winter months. However, as average temperatures rise, winter precipitation will shift from snowfall to rainfall.

"Baltimore will be more severely impacted by sea-level rise than any other East Coast city."

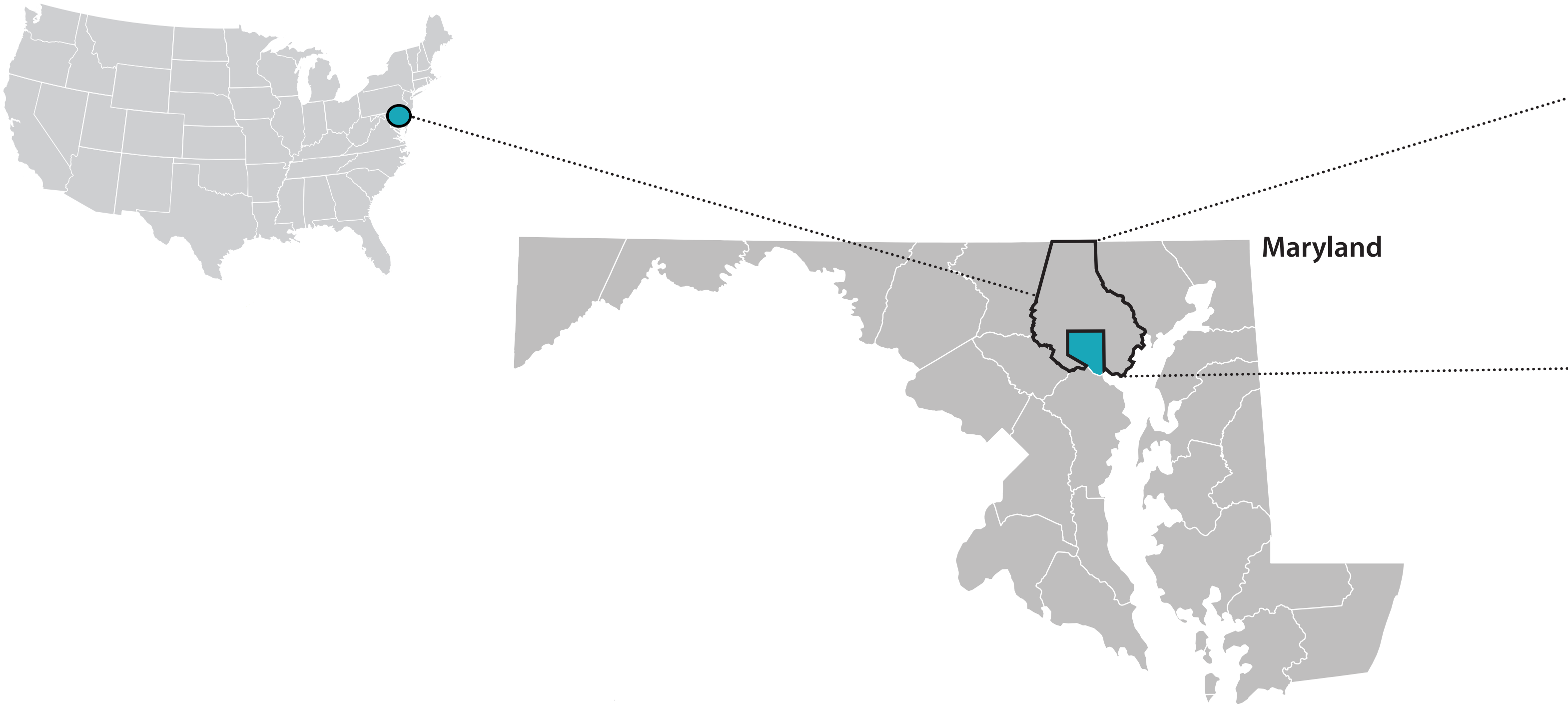


Figure 7: Baltimore County and City Context

	Summary of Projected Climate Changes for the United States Northeast (Ba	
	Climate Variable	General Change Expected
Temperature	Temperature (F)	Increase
	Extreme Heat	Increase of extreme heat days
Precipitation	Extreme Precipitation	Precipitation will come more in brief pulses
	Average Precipitation	Increase
Sea Level	Sea Level	Increase

Table 1: Projected Climate Change for Baltimore

altimore) Adapted from FHWA regional climate matrix and the USGCRP National Climate Assessment	
Change Expected	Projected Change Compared to Recent Changes
(+)1.3 to 3.8 °F for 2010-2029 (+)1.9 to 6.8 °F for 2040-2059 (+)3.0 to 12.5 °F for 2080-2098	Increases compared with observed increase of 1.5 °F between 1993 and 2008 over the 1961-1979 baseline.
Days over 90°F: (+)5 to 10 days for 2010-2040 (+)12 to 29 days for 2040-2070 (+)13 to 63 days for 2070-2100 Days over 100°F: B1 scenario: (+)3 to 9 days A1 scenario: (+)14 to 28 days	Compared to 1 to 2 days over 100 °F over beginning of the century baseline
Maximum precipitation during any five-day period in a year (+)9 to 12% for 2010-2040 (+)8 to 13% for 2040-2070	N/A
(+)2.0 to 8.4% for 2010-2029 (+)3.5 to 13.7% for 2040-2059 (+)6.6 to 21.7% for 2080-2098	These increase can be compared with a increase of 7% between 1993 and 2008 over the 1961-1979 baseline.
Global sea-level rise of 7-79" by the end of the century. No accurate projections because of sensitivity to location	Increase over current level

Fresno, California

Fresno

Current Climate

The regional climate for the Fresno area is heavily dependent on the Pacific Ocean, seasonal westerly winds, and the Sierra Nevada Mountain ranges surrounding the valley. Both the City and the County have a semi-arid climate with warm, dry summers, and cooler, wetter winters. Climate variability is influenced by seasonal fluctuations from weather events like the El Nino Southern Oscillation and the Pacific Decadal Oscillation, both of which impact long-term climate variability (6). Most of the 10.9 inches of annual precipitation falls between the months of October and April with less than 0.1 inches of total rainfall between the months of June and August (1).

Droughts have long been a challenge for the City of Fresno and southern California dating back to the late 1700s and mid-1800s. In the late 1950s and early 1960s prolonged periods of drought led to a 30 percent decrease in local river systems and precipitation (6). This trend was seen again in the late 1980s and early 1990s. As climate change effects continue to grow, the increase of long-term drought conditions will reduce water availability and heavily impact the Fresno economy and its residents.

The City of Fresno has experienced several massive floods since its inception. The first documented flood took place in 1872 when the newly developed Fresno station flooded. The 1880s were a time when major floods continuously devastated the city and much of the downtown was inundated with water. Irrigation began to withdraw water from the area in the late 1800s, yet before an urban storm drainage system was put in place, the downtown experienced numerous floods including a massive flood in downtown Fresno flood in 1925. Massive flooding events continued with the Hammond Avenue flood in 1958 and the Glibert Avenue flood in 1969. The construction of the Fancher Creek reservoir and Big Dry Creek reservoir helped to alleviate flooding in the 1990s (7).

Figure 8: Flooding North of Ventura, Fresno 1969

Figure 9: Flooding in Fresno County on March 23, 1958

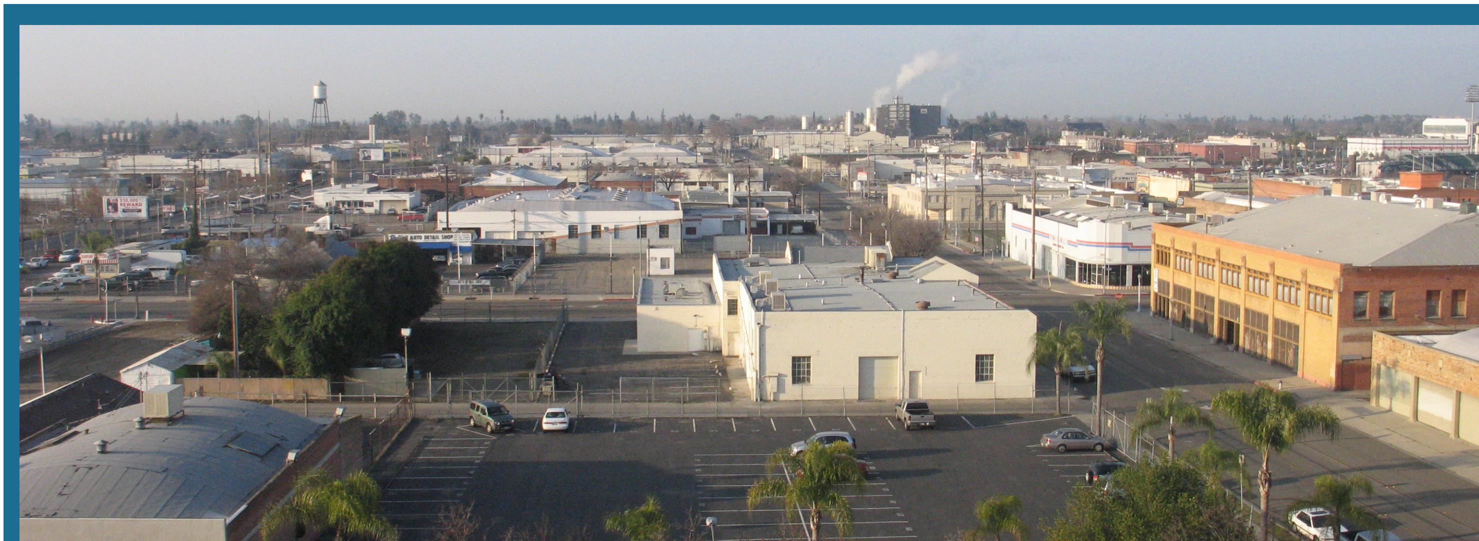


Figure 10: Downtown Fresno

“A large portion of Fresno is covered with surface parking lots, abandoned industrial sites and other impervious surfaces”

Temperature

The most serious impacts Fresno will face resulting from climate change relate to heat and increasing temperatures. Currently, average yearly temperatures range from 45.4 degrees Fahrenheit in December to 81.9 degrees Fahrenheit in July (1). Average high summer temperatures in the San Joaquin Valley reach well into the 90s and historic heat waves have shown temperatures reaching as high as 115 degrees Fahrenheit. Warming will occur across all four seasons, with the largest degree of warming occurring during the summer months. Average daily temperatures are projected to increase between 4 and 5 degrees Fahrenheit by mid-century and between 6 and 10 degrees Fahrenheit by 2100 (8).

Precipitation

Average annual precipitation levels are predicted to remain largely unchanged, with mid-century projections showing a slight increase in total winter precipitation, and a slight decrease in the spring, summer, and fall. However, projections show increases in the proportion of rainfall to snowfall, along with increased intensity of rainstorms. Changes in phase, intensity, and timing of precipitation are projected for precipitation in California's central valley. By mid-century, average strength of precipitation events are projected to increase 15 to 25 percent as compared with current trends.

Paradoxically, the increased frequency of high intensity rain events will not lead to increased fresh water availability. Fresno will experience a higher probability of water shortages and drought because there will be an overall decrease in the number of precipitation events, and higher average temperatures will increase the evaporation rate when it does rain (8). There is a great deal of uncertainty in how climate change will impact the timing, frequency, and intensity of precipitation events. However, patterns are projected to change dramatically. There will be a significant shift in precipitation patterns from snow to rain in the Sierra Nevada Mountains adjacent to Fresno. Early spring snowpack (further exacerbated by higher average spring temperatures) is predicted to decline by 30 to 60 percent by mid-century (9).

Figure 11: Fresno County and City Context

	Summary of Projected Climate Changes for the United States Southwest (	
	Climate Variable	General Change Expected
Temperature	Average Annual Temperature (°F)	Increase
	Average Winter Temperature (°F)	Increase
	Extreme Heat	Increase in number of extreme heat days
Precipitation	Precipitation Annual % Change)	Slight decrease
	Extreme Precipitation	Decrease in number of precipitation events Increase in intensity of precipitation events
	Snowpack	Significant decrease

Table 2: Projected Climate Change for Fresno

Fresno) Adapted from FHWA regional climate matrix and the USGCRP National Climate Assessment	
Change Expected	Projected Change Compared to Recent Changes
(+)1.1 to 4.2 °F for 2010-2029 (+)2.1 to 7.7 °F for 2040-2059 (+)2.8to 13.5 °F for 2080-2098	Increases compared with observed increase of 1.6 °F between 1993 and 2008 over the 1961-1979 baseline.
(+)0.6 to 3.8 °F for 2010-2029 (+)0.8 to 6.2 °F for 2040-2059 (+)1.8 to 11.3 °F for 2080-2098	Increases compared with 1961-1979 baseline
Up to 400% increase in high temperature days per year under high emissions scenario	N/A
(-)8.5 to 8.5% for 2010-2029 (-)13.3 to 12.6% for 2040-2059 (-)26.5 to 19.5% for 2080-2098	N/A
15-25% average increase in intensity of precipitation events by mid century	N/A
Averaged over 2035 to 2064 the amount of water stored as snow in the Sierra Nevadas is projected to decrease by 12 to 42% at all elevations. 60-70% decline in snowpack by mid century	N/A

Milwaukee, Wisconsin

Milwaukee

Current Climate

Milwaukee has a temperate climate with large seasonal variability: summers are typically hot and humid while winters are long and cold. Average monthly temperatures vary widely from 18.9 degrees Fahrenheit in January to 71.9 degrees Fahrenheit in July (1). Average annual precipitation is 32.9 inches with the highest monthly averages of 3.5 inches in April, July, and August (1). In the recent past, Milwaukee and the Midwest region have experienced both severe heat waves and record-breaking floods. Milwaukee is likely to continue to experience significant changes in temperature, precipitation, and lake levels as the regional climate changes over the century.

Temperature

Summer air temperatures in the Milwaukee region are predicted to increase by 3 to 17 degrees Fahrenheit by the end of the century (8). Even more significantly, heat waves are predicted to increase in frequency and severity. Research conducted for the City of Chicago's extensive climate action initiative analyzed various global climate models and "down-scaled" them to the regional level, forecasting increased temperatures and precipitation through 2100 (10). By mid-century, the summers in Wisconsin are expected to feel progressively more like the summers in the southern portion of the U.S. (along the latitude of Missouri or Kansas) (11).

"As temperatures increase and heat waves become more frequent and severe, human health risks due to prolonged heat exposure increase for central city residents"

Figure 12: Children playing in spray from a hydrant

Figure 13: Cooling off on a hot day

Figure 14: River and lake levels fluctuate due to changes in precipitation and often in the form of floods and droughts. The City of Milwaukee documents river and lake level fluctuations and although most fluctuations are 1 to 2 feet in Wisconsin, historical fluctuations over ten feet in height have been recorded.

Winter temperature changes will also have impacts on lakes (both inland and Great Lakes), which will have fewer days of ice cover. As a result, lake levels are predicted to drop by as much as two feet, due to increased evaporation, especially during the winter months (8). Lower lake levels are likely to require more extensive dredging of shipping channels, or else freighters will need to carry less cargo than in years past. Lower lake levels could also have negative consequences for port and recreational vessel infrastructure.

Precipitation

The greatest climate change threats to Milwaukee are related to changing precipitation patterns. Although there is uncertainty over exactly how precipitation will change, it is likely that Milwaukee will see more frequent and more severe rain events than in the 20th century. Average annual precipitation has already increased by 5 to 7 inches per year in the Milwaukee region as compared with a historic mid-20th century baseline (12). Increases in the frequency and intensity of precipitation could result in more frequent and severe flooding of development sited near wetlands and waterways.

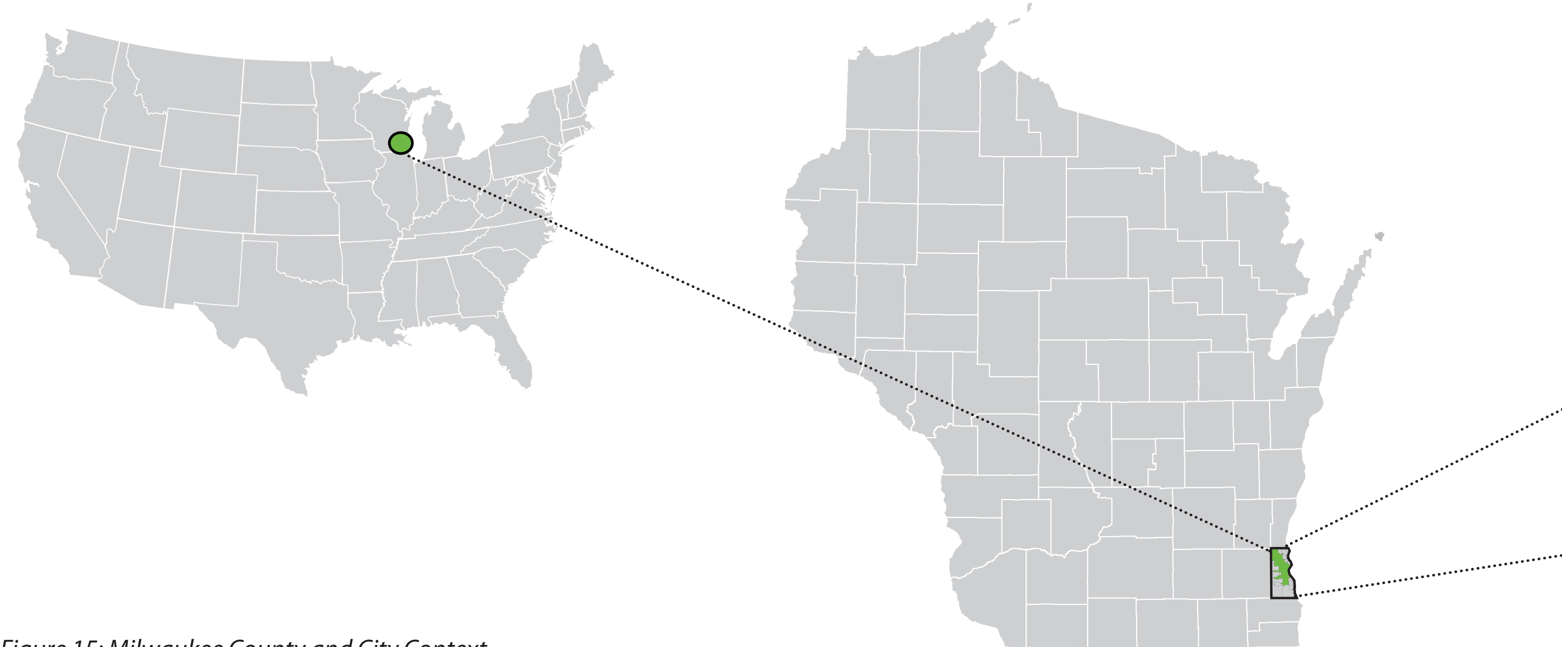


Figure 15: Milwaukee County and City Context

	Summary of Projected Climate Changes for the United States Midwest (Mil	
	Climate Variable	**General Change Expected**
Temperature	Annual Temperature (F)	Increase
	Annual Summer Temperature (F)	Increase
	Annual Winter Temperature (F)	Increase
	Heat Wave Frequency (1995 Chicago/Milwaukee Heat wave)	Increase in frequency and intensity
Precipitation	Extreme Precipitation	Significant increase in heavy rain events
	Average winter precipitation	Increase
	Average summer precipitation	Decrease
Lake Level	Great Lakes average level	Fall

Table 3: Projected Climate Change for Milwaukee

waukee) adapted from FHWA regional climate matrix and the USGCRP National Climate Assessment	
Change Expected	Projected Change Compared to Recent Changes
(+)1.3 to 3.9°F for 2010-2029 (+)1.9 to 7.0°F for 2040-2059 (+)3.0 to 13.8°F for 2080-2098	Compared with increase of 1.4°F between 1993 and 2008 over 1961-1979 baseline.
(+)1.0 to 4.7°F for 2010-2029 (+)1.5 to 8.3°F for 2040-2059 (+)2.7 to 17.5°F for 2080-209	Increases compared with 1961-1979 baseline.
(+)0.6 to 4.9°F for 2010-2029 (+)1.7 to 7.9°F for 2040-2059 (+)3.3 to 13.5°F for 2080-2098	Increases compared with 5-6°F increase observed by 2010 over 1961-1979 baseline. Increases compared with 1961-1979 baseline.
Once per year (higher emissions) 2040-2070 Once in 2 years (lower emission) 3 times per year (higher emissions) 2070-2100	Once in 10 years (lower emissions) Once in 6 years (higher emissions) 2010-2040 Once in 4 years (lower emissions)
By the mid century heavy rains (defined as 2in or more) are projected to increase by approximately 30% in the area	N/A
(+)6 to 7% for 2010-2029 (+)8 to 9% for 2040-2059 (+)10 to 14% for 2080-2098	Compared to 1961 to 1979 baseline
(-) 1% for 2010-2029 (-)1 to (-) 4% for 2040-2059 (-)2 to (-) 9% for 2080-2098	Compared to 1961 to 1979 baseline
(-) 0.2 to (-) 0.3ft Variable by lake (-) 0.7 to (-) 1.7ft Variable by lake (-) 0.6 to (-) 1.9ft Variable by lake	Compared to 2010 level

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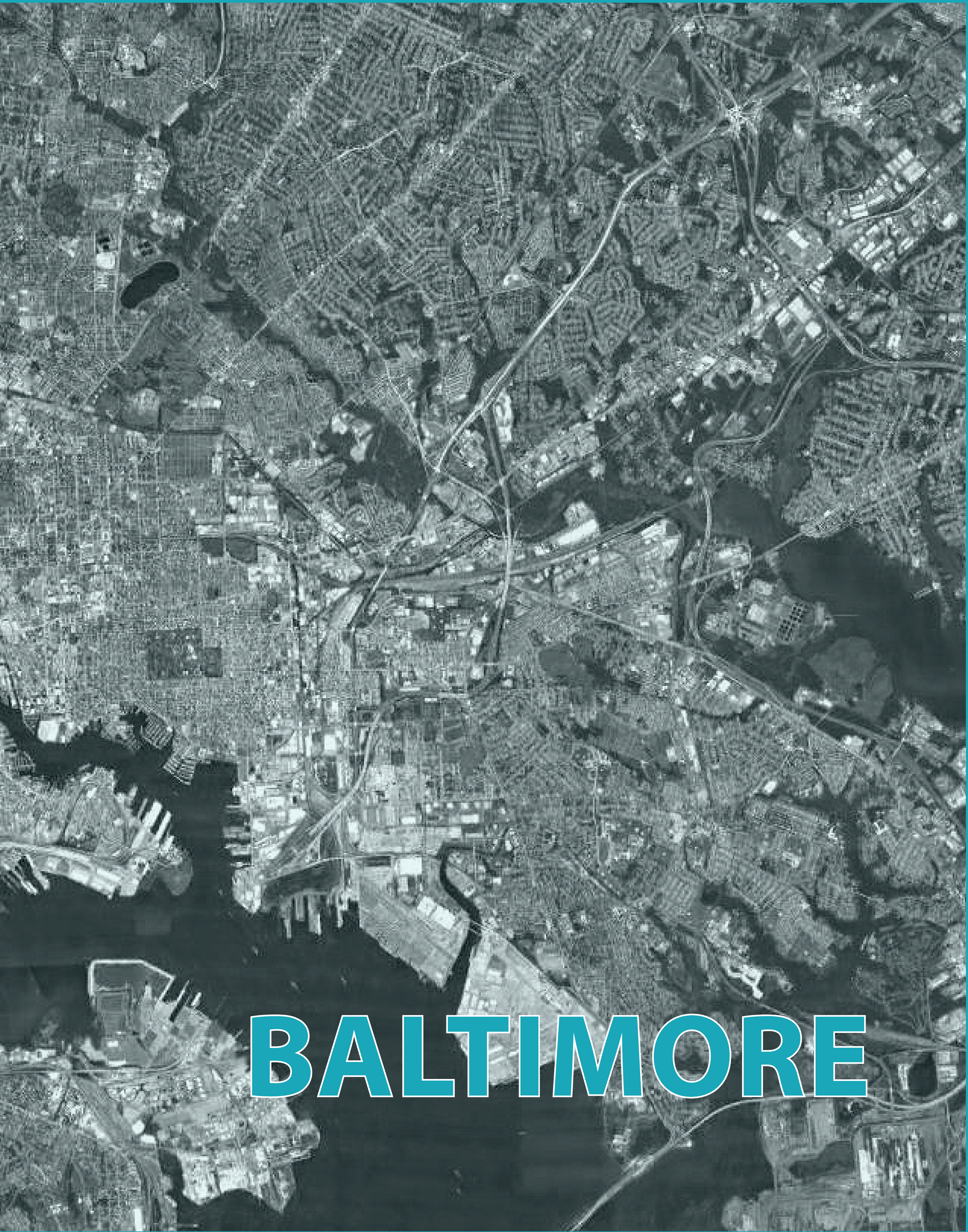
Three Cities

This section provides background research and analysis for the cities of Baltimore, Maryland, Fresno, California, and Milwaukee, Wisconsin necessary for making informed adaptation recommendations. Three primary sections encompass the distinct parts of our planning process: city profile and sector impact analysis, vulnerability analysis, and SWOT analysis.

Using in-depth research, site visits, and phone interviews, we created city characteristic profiles outlining the impact of climate change on five city sectors: land use, water, energy, human health, and transportation. While these sectors do not incorporate all city services, they will see significant impacts from climate change and are an effective way of organizing the infrastructure and activity within each city. Additionally, categorizing our analysis by these five sectors enables city planners and policy makers who work within each of these areas to easily access research and existing recommendations. This analysis identifies areas of concern within each city and highlights sectors which are more resilient to threats posed by climate change.

Next, using geographic information systems (GIS) software, we determined the location and distribution of vulnerable populations within each city. Using demographic characteristics such as education, poverty, and marital status, we identified the locations of the most disadvantaged and socially vulnerable neighborhoods. We combine this vulnerability analysis with data representing a climate threat unique to each city: sea level rise in Baltimore, urban heat island effect in Fresno, and flood risk in Milwaukee, to pinpoint the overlap between disadvantaged areas and potential climate threats. This allowed us to highlight areas of particular concern.

Finally, using the SWOT tool to integrate climate threats and city sector analysis, we identified the adaptive capacity of each city which later informed our adaptation recommendations. Using this method we analyzed the strengths and weaknesses inherent to city systems and infrastructures, along with the opportunities and threats posed by outside factors. The SWOT analysis identifies cross-cutting issues, highlighting trends within each city which do not fit neatly into one of the five city sectors.



BALTIMORE

Baltimore

Introduction

The City of Baltimore presents an opportunity to explore how communities can prepare for sea-level rise, increasingly heavy storm surges, extreme heat events, and other climate change impacts. The City's vulnerable, low-income population and considerable commercial and residential assets in a dense urban core are at risk. Public and private sector leaders in Baltimore have a history of progressive collaboration on environmental issues, especially involving the Chesapeake Bay, air quality, and land preservation. In the sections that follow, we explore specific risks to Baltimore's Land Use, Water, Energy, Human Health and Transportation sectors. We analyze each sector in terms of how the predicted climate change in Baltimore is likely to disrupt historic patterns. We use geographic information systems (GIS) to visualize how sea level rise might impact vulnerable populations, key infrastructure, and important areas of economic activity. Finally, we conclude our case study by synthesizing these sectors in the form of a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the Baltimore region.

Figure 16: Baltimore Skyline

Climate Change Risks

Tidal-gauge records show a one foot sea level rise in the 20th century along Baltimore's shoreline, and based on the impact of global climate change, sea level rise is expected to accelerate upward by two to four feet before the end of the 21st century (1). Combined with more frequent and stronger storms, this will also result in more severe risks from storm surges. As a result, much of the coastal land will be at higher risks of flooding due to inundation, coastal erosion, and accelerated land subsidence. A study of sea level rise in the northeastern U.S. found that what is now considered a 100-year flood event will occur at least once every 49 years by century's end, and could occur as frequently as once every two years for some locations (2). Other categories in which climate change is likely to create greater risks in the Baltimore regions include:

- Elevated flood risk due to an increase in the frequency and severity of intense precipitation (absolute increase of 20 percent with biggest changes occurring in winter months) (1).
- Higher average temperatures (3 to 6 degrees Fahrenheit), resulting in more severe heat waves (3).
- Degraded air quality due to increased ground-level ozone (50 percent to 300 percent increase in ozone action days by 2100) (4).

Existing Characteristics

The City

Founded in 1729 on a natural harbor, near where the Patapsco River empties into the Chesapeake Bay, the City of Baltimore was one of the most important cities in the American Colonial period. It once served as the de facto national capital, hosting a meeting of the Second Continental Congress in 1776 and 1777. (5) Today, the city's boundaries encompass the most heavily developed area of the State of Maryland, characterized by brownstone row houses, downtown office buildings, multiple university campuses, and one of the nation's busiest seaports. Carved out of the surrounding Baltimore County, the City's borders encompassed 80 square miles of land in 2000 (6). Baltimore City is by far Maryland's most populous municipality and the only city with independent municipal powers on par with county governments. Population has been falling over the last several decades, as has been the case with many older U.S. central cities. In 2009, Baltimore City's population totaled 637,418 residents, down almost one-third from a peak of nearly 950,000 in 1950. However, declines have slowed in recent years, and projections show modest long-term population gains in the city (5) (6).

The City also faces a fiscal crisis as a result of depressed property values, in the wake of the recession of 2009. In fiscal year 2010, the City faced a budget shortfall of $121 million, and made $74 million in cuts. The outlook for 2011 is not any better as housing prices have not increased significantly, and the city budget is over 50 percent reliant on property taxes for revenues. Nevertheless, the city continues to devote significant funding to capital improvement projects, most notably to wastewater systems, which are slated to receive over 60 percent of all capital spending from 2011-2016 (7).

Figure 17 : Shipping docks and staging areas are vulnerable to sea level rise

The Region

The Baltimore region's land use pattern displays the area's rich history, unique natural features, and progressive land use controls. The region encompasses five counties and one city: Baltimore County, Carroll County, Harford County, Howard County, Anne Arundel County, and Baltimore City. Counties are the basic unit of local government in Maryland (as opposed to cities or towns throughout much of the U.S.), making for an unusually centralized governmental structure in the region (8). Some of the counties that surround Baltimore City limit urban development to designated areas, theoretically leaving the majority of the county as agricultural or natural land (9). Development is generally concentrated along major transportation routes (highways and passenger rail), and is more intense in the areas closest to Baltimore City. In stark contrast to Baltimore City, the surrounding region's population has grown dramatically since 1950, as was common in most major U.S. cities. Regional population increased from approximately 1.3 million in 1950 (with over 70 percent in Baltimore City) to over 2.5 million in 2010 (only 25 percent in Baltimore City) (5).

Demographics

Typical of many large metro areas in the U.S., the central city is home to an above average share of racial minorities, persons living in poverty, as well as persons with low educational attainment. In 2000, 30 percent of Baltimore City residents had not graduated from high school, 22 percent lived in poverty and approximately two-thirds were racial minorities (primarily African American). In contrast, the surrounding counties all had at least 85 percent high school graduation rates, no more than 6.5 percent poverty rates, and were no more than one-third racial minority residents (although African American residents are increasingly moving into Baltimore County). Incomes also tend to be lower in Baltimore City ($40,000 median family income) than in the region ($60,000 median family income). All of these demographic trends indicate that the population of Baltimore City is much more likely to be disadvantaged when compared with residents of the surrounding counties (5).

Baltimore City Population	620,961
Baltimore County Population	620,961
Pop. Density/sq. miles	6,745.80
Sq. Miles	92.05
% White	33.1
% Black	63.2
% Asian	2
% Latino/Hispanic	3
% Non Hispanic White	30.9

Table 4: Demographic Information Baltimore


BEST BUY
4

The Economy

The Baltimore region boasts over 1.5 million jobs (10). At one time, these jobs were highly concentrated in Baltimore City. However, as the regional population dispersed regional employment also dispersed. In 2000, Baltimore City had less than 500,000 jobs, about one-third of regional employment. Regional employment is projected to increase slowly over the next few decades, but employment levels in Baltimore City are projected to remain static (5).

The Baltimore region was once a center for flour export, shipbuilding, and manufacturing. In the second half of the 20th century, these industries gave way to service jobs (33 percent in 2000), particularly in health care, education, and technology. The City's close proximity to Washington, D.C. has enabled growth both in direct federal government employment and spin-off employment from consulting and other private-sector business that wish to locate close to the national capitol. In 2000, government employment accounted for over 20 percent of the region's jobs (5).

The geography of the Baltimore region has always been a big part of the region's success and that is still true today. In the 18th century, the combination of the Port and the City's proximity to rich farmland provided the impetus for becoming a large city. Today, the Port remains important; its central location on the eastern seaboard provides economic advantages to users. This proximity allows ocean freight shipments arriving at the port of Baltimore to reach more than half the County's population within a one-day driving distance (11). Therefore, it is not surprising that wholesale retail and trade accounted for 20 percent of the region's jobs in 2000. In 2007, the port of Baltimore created almost $2 billion in economic activity and provided 127,000 jobs (1).

Land Use

History of Development

Baltimore has a long and rich history as a major U.S. city. Baltimore was the second most populous city in the United States in 1830, and a key strategic port during both the War of 1812 and the Civil War. The City underwent multiple development booms and setbacks throughout its long history. Early development tightly focused around the area now known as the Inner Harbor, where the Patapsco River begins to flow into the Chesapeake Bay. The city grew quickly in the early to mid-19th century and established dense neighborhoods typified by narrow, connected row houses. The City of Baltimore, the terminus of the first long-distance railroad in the U.S., firmly established itself as a leading U.S. city and a popular port of entry for immigrants. Baltimore was also an early adopter of the horse-drawn streetcar and later the electric streetcar, which pushed development outward from the Inner Harbor. The city grew through annexation but remained dense and compact (5).

The beginning of the 20th Century brought both ruin and rebirth to the city. On February 7th, 1904, most of downtown Baltimore burned in a great fire. While initially devastating, the fire provided the opportunity to plan a more modern city with comprehensive city services. By 1923, the downtown was redesigned and rebuilt with modern water and sewerage systems, a network of Olmsted designed parks, and a comprehensive zoning ordinance to control future development. These advances came with large increases in development on the northern city limits. The first suburban-style residential developments were built in the 1920s and 1930s. This was accompanied by large industrial development along the coasts and transformative investments in education and the arts (5).

The Great Depression temporarily slowed development in Baltimore, but World War II brought the city back to life with unprecedented manufacturing activity. The post-war boom years brought with them another wave of massive expansion, but this time the development focused on the surrounding counties of the Baltimore Region. Residents left the crowded city in droves for new and spacious suburban developments at the fringe. Private development in the 1950s through 1970s focused on these growing areas outside the central city where lots were larger and neighborhoods were less dense than in the older areas. Meanwhile, the federal government sponsored urban renewal and freeway building projects in Baltimore City, which forever changed the fabric of the city. In recent years, the central city has seen renewed development interest, particularly around the Inner Harbor. A decade of public and private investment here created a space filled with tourist attractions, hotels, and well-designed public spaces. The urban revitalization trend spilled over into some other well-to-do neighborhoods, but some of the poorest neighborhoods have fallen into extreme disrepair; the city had over 15,000 vacant or abandoned homes in 2009 (5).

Suburban counties continued to see explosive growth into the 21st century. Predictions suggest that suburban expansion will continue, with forecasts showing additional population growth near 8 percent from 2010 to 2035. However, due to Maryland's Smart Growth Law and a regional practice of protecting agricultural land, suburban expansion has been guided and somewhat denser in recent years than in many U.S. metro regions (12). A major factor influencing suburban development in the Baltimore region involves its close proximity to the Washington, D.C. metropolitan area. As the both metro areas have expanded, the distance between the Baltimore and the Washington D.C. has narrowed. Today, Baltimore and Washington, D.C. have formed a powerful super-metro area and their leaders are taking steps to make these linkages stronger with improved transportation options between the two metros. In 2000, over 90 percent of Maryland's population resided in the Baltimore-Washington D.C. super-metropolitan area (13).

Natural Features

Located between the Chesapeake Bay and the Appalachian mountains, the Baltimore region is rich in natural features. The city is located on the Patapsco river estuary which feeds into the Chesapeake Bay. Undeveloped coastal areas often consist of tidal wetlands that are heavily vegetated with plant species that can tolerate brackish (salty) water (14). These wetlands create buffer zones along the coasts that provide critical species habitat as well as creating a natural erosion protection system (14). The Chesapeake Bay is the largest estuary in the U.S. The Bay is a unique and sensitive ecosystem with wide seasonal variation in water salinity and temperature (15). The Bay is quite shallow (21 foot average depth) and has experienced significant water quality problems due to nutrient runoff from farms and industrial lands within the watershed (16). Efforts to restore and protect this unique natural environment have been underway for decades and have likely influenced many of the progressive land use policies currently in place (17).

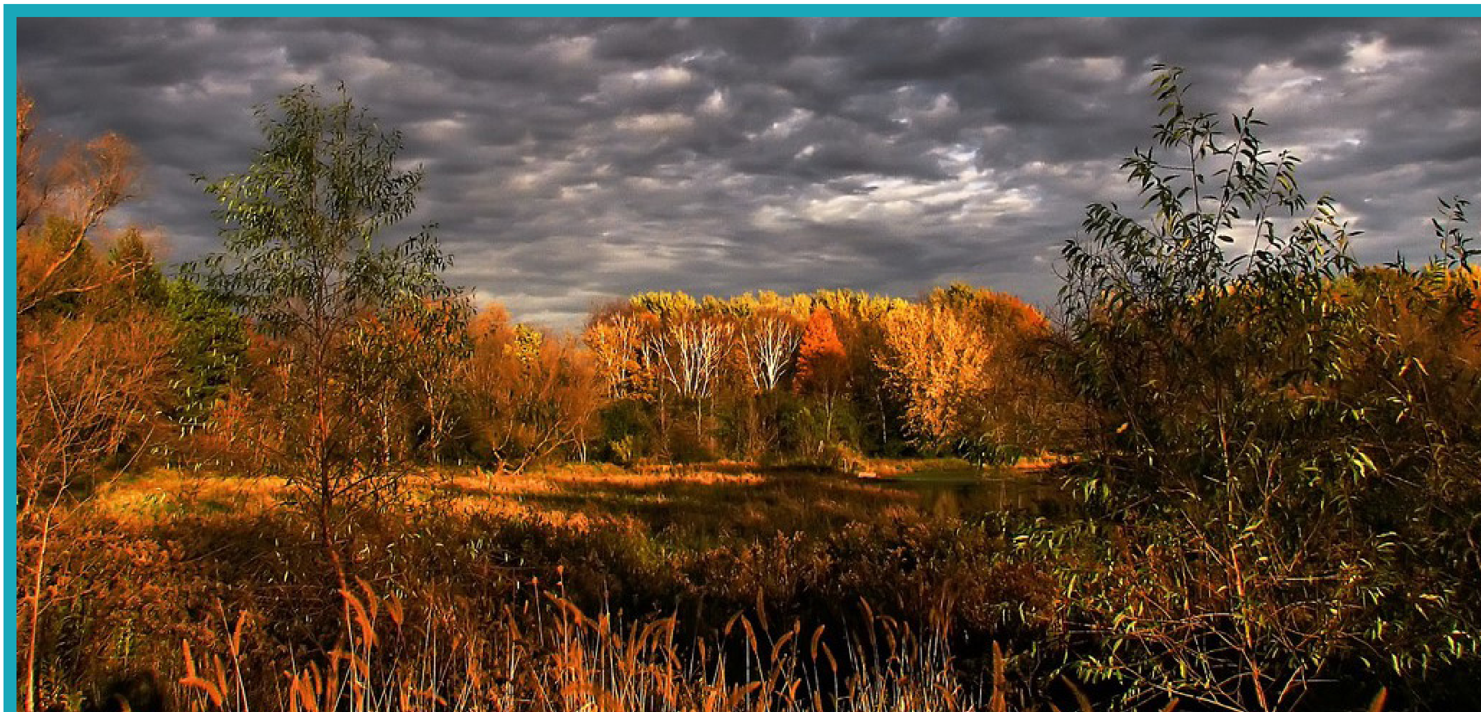


Figure 18: Wetlands that surround Chesapeake Bay are critical coastal erosion buffers and are at risk for inundation as sea-levels rise

Figure 19: Johns Hopkins University and Hospital

Further inland, the Baltimore region is characterized by the gently rolling hills of the Piedmont Plateau (18), where agriculture and forests are the dominant land uses. All of the suburban/rural counties in the Baltimore region have programs to protect farmland and natural landscapes (19). Baltimore County's program is heralded as a national model (12). Between 1980 and 2009, over 55,000 acres of land were preserved through state, county, and private programs. This represents over 21 percent of the total land area in the state (20).

Like many large cities, Baltimore significantly lacks natural areas, particularly in the older, dense neighborhoods. The urban canopy totals 27.4 percent (in contrast to 43 percent hard surfaces and 19 percent grasslands) (21). Many of the most densely populated blocks contain little or no vegetation. The city does have a few large urban parks (6,000 acres in total), including some designed by Frederick Law Olmstead, the legendary landscape architect. However, many areas of the city are predominately hard surfaces, with poor access to parkland, shoreline, or other natural features.

Existing Land Use Pattern

With over 7,000 inhabitants per square mile (6), Baltimore City has an unusually high population density for a mid-sized U.S. city. This is largely due to the city's long history and rapid pace of development in the 19th century. Before the widespread advent of motorized transportation, high densities were the norm in developed areas because everything in the city had to be within walking distance. As a result, older sections of Baltimore City tend to be much denser than newer areas. Many of the most recently developed areas in the surrounding counties are several times less dense (e.g. 1,261 persons per square mile in Baltimore County). In general, residential densities increase as one moves from the edge of the Baltimore region to the center. However, unlike many regions, the Baltimore region has multiple urban centers in the outlying counties with densities two or three times higher than the average suburban density (e.g. Towson) (22).

The City of Baltimore has the most intense and varied development pattern in the region. Industrial land uses related to manufacturing, shipping, energy, and logistics dominate coastal land areas. Residential development is very dense in the core of the city, with many neighborhoods consisting of multi-story attached row houses. These older neighborhoods often lie in close proximity to industrial uses and are more likely to contain neighborhood-serving retail and commercial buildings as well. The Downtown is located at the core of the City, with high-rise offices and many public institutions surrounding the Inner Harbor (the city's primary tourist attraction). The City is also home to multiple universities including the renowned Johns Hopkins University and the University of Maryland, both of which have multiple urban campuses in Baltimore City.

Most of the development in the suburban counties includes single-family detached housing with associated strip malls and shopping centers (19). However, the counties also have significant town centers and employment centers that have been the target areas for rapid development in recent decades. Notably, some of these areas have been developed at higher densities than is common for suburban areas, including not only commercial office buildings, but also a significant share of multi-family residential development. The suburban counties comprise significant areas of protected farmland and natural areas. These protected zones tend to be along streams and rivers, or in the areas that are the most-distant from Baltimore City. Strong land use regulations have been successful at preserving agricultural and natural land uses in recent years, slowing the rate of land being consumed for new suburban development (22).

Local Land Use Regulation

The suburban counties in the Baltimore Region are somewhat unique in the way land uses have been separated. The original development in the outlying counties was rural and agricultural. However, rapid suburban development in the 1940s-1970s consumed a lot of former farmland and natural areas, raising concerns about the damage that unchecked development might cause to the agricultural traditions and natural features in the area. These concerns eventually resulted in counties taking action to preserve these features through large-lot agricultural zoning and by restricting development to designated areas (sometimes called an urban growth boundary or urban/rural demarcation line). These techniques used in tandem are considered a best practice for controlling land-consumptive suburban development (19).

Baltimore City was one of the first areas in the country to adopt a zoning ordinance (1923), and much of the development in the mid-20th century followed the principle of segregated uses (5). However, beginning with natural features preservation and environmental conservation efforts in the 1970s, the region's land use regulation has evolved to be progressive and on the leading edge of the trend toward allowing more mixing of uses and development at higher density (19). These techniques are necessary to allow for growth while preserving land for less intense, rural uses. Because the county is the basic unit of local government for most of the state, land use patterns tend to be slightly more uniform in the Baltimore region than in more fractured regions.

Water

Introduction

The City of Baltimore relies on both surface water resources that are likely to be stressed as a result of climate change. The City's location near the mouths the Gunpowder, Patapsco, and Susquehanna Rivers has historically provided the abundant volumes of fresh water needed to support the City. However, recent drought conditions have illustrated the fragility of the existing supply, resulting in the significant depletion of reservoirs. The predicted reductions in the frequency of precipitation and increases in the frequency of drought will further increase the likelihood of shortages. Equally significant is the threat that rising sea levels and stronger storms pose to coastal wastewater infrastructure and water quality. These facilities already experience periodic flooding and will be significantly threatened as sea levels rise.

Water and Wastewater Infrastructure

Freshwater Supply and Infrastructure

The City of Baltimore's water supply, operated by the Bureau of Water & Wastewater, comes from three reservoirs: the Loch Raven Dam, the Prettyboy Dam, both of which capture water from the Gunpowder River, and the Liberty Dam, which collects water from the North Branch Patapsco River. These reservoirs provide the bulk of the region's fresh water supply but during periods of drought, water is withdrawn from the Susquehanna River from the Conowingo intake using the Deer Creek Pumping Station (23). Approximately 265 million gallons of water per day is processed and supplied to 1.8 million people in the City of Baltimore and metropolitan area. The city operates three water treatment plants including the Montebello Filtration Plant I, Montebello Treatment Plant II, and the Ashburton Filtration Plant. The treatment plants use processes of disinfection, coagulation, sedimentation, filtration, and fluoridation to treat potable water. The Bureau maintains 3,400 miles of water mains in the City and surrounding counties and the operating budget for the Bureau of Water & Wastewater in 2009 exceeded $300 million (23).

Freshwater Supply and Infrastructure

The City of Baltimore uses a separate system for both wastewater and stormwater. The City's Bureau of Water and Wastewater operates two wastewater treatment plants, the Patapsco and Back River, which treat up to 250 million gallons of wastewater per day and serves 1.6 million people in the metropolitan area. The City also maintains 3,100 miles of sanitary mains and 1,000 miles of storm drains which drain by gravity into the Harbor (23).

Natural Water Resources- City and Watershed Level

The four urban watersheds that drain through Baltimore City are sub-watersheds of the Patapsco-Back River Drainage Basin, which in turn is a sub-watershed of the Chesapeake Bay Watershed. The Patapsco River includes 203 miles of stream and its watershed totals 53 square miles which spreads into the northwest portion of the City of Baltimore, within the southwestern portion of Baltimore County. The Patapsco River is a minor river because of its short length; however its last 10 miles are a large tidal estuary inlet of the Chesapeake Bay. The watershed consists of mostly urban land cover (approximately 49 percent) and forest cover (roughly 38 percent) (24). The eastern portion of the Patapsco River watershed is in a highly urbanized area and is subject to extensive urban runoff and other forms of water pollution. The Back River watershed consists of 73 miles of streams located in the City of Baltimore's northeastern quadrant and southeastern portions of Baltimore County - approximately one third of the watershed lies within the City's boundaries. About 70 percent of the Back River watershed is urbanized, much of which predates current stormwater management regulations, thus limited opportunities currently exist for stormwater management controls within this watershed.

Climate Change Impacts on Water

Sea-Level Rise and Flooding

The City of Baltimore has 66.5 miles of shoreline, with a densely populated coast. In recent years sea levels have risen at an average of 3 to 4 milimeters each year, which is twice the global average. Climate models expect these trends to continue and major storm events to increase in severity and frequency (3). Although 3.2 percent of the City of Baltimore's land is within the coastal floodplain, this small area includes many of the City's attractions, industrial areas, as well as residential, commercial and retail land uses. (25) Sea-level rise will impact these resources while projected higher precipitation events will affect river water quality and exacerbate flood risk. The City will also face substantial increases in the extent and frequency of storm surge, coastal flooding, erosion, and property damage (26).

The impacts of sea level rise will increase stress on the urban and developed shorelines where there are pilings, piers, docks and elevated structures. The amount of land available for water-dependent structures and uses may be diminished as land is lost to erosion or becomes inundated or submerged over time. Additionally, sea level rise will increase the vulnerability of existing structures to coastal storm damage. Sewage treatment plants and other public infrastructure may become threatened, and higher water levels may impact sewage and stormwater outflows (27). For example, the Patapsco Wastewater Treatment plant sits less than 7 feet above average sea level and experiences occasional floods. The facility itself is elevated and drains by gravity into the Patapsco River. If Baltimore experiences significant sea-level rise, the treatment plant may flood more frequently or require pumping and additional protection against storms. Streets with associated conduits and utility piping within the existing coastal floodplain will also potentially be affected by sea-level rise (25).

Drought

Baltimore's hot summer conditions are expected to arrive weeks earlier and last later into the fall months. Longer and drier spells during these months will reduce the quantity of water stored in the reservoirs and the amount of water available for human consumption, commercial, and industrial uses. The Baltimore region experienced two severe regional droughts from 1998-1999 and from 2001-2002. This most-recent drought dangerously decreased the water volume to only 49 percent in Baltimore's three reservoirs, and the 1998-1999 drought caused an $800 million loss in crops in the mid-Atlantic region. Because these droughts have so significantly depleted reserves, some water managers predict that the region would need two hurricanes to recharge the water table and fill the rivers (28).

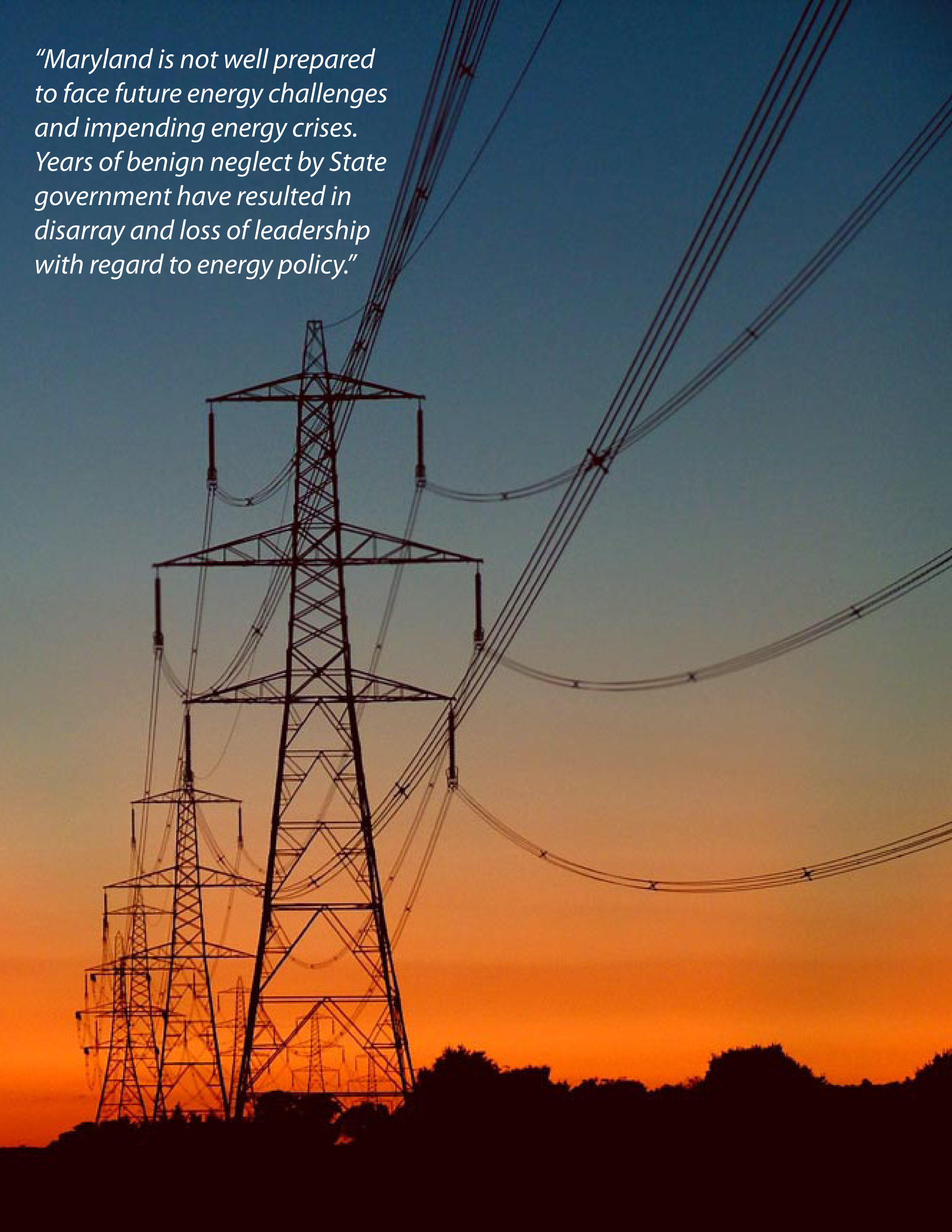
Figure 20: More frequent and intense hurricanes will require a wide range of anticipatory adaptation strategies

Future Threats and Impacts

In September 2003, Hurricane Isabel flooded the City's Inner Harbor, which cost the city $462 million in damages and caused the Baltimore World Trade Center to close for a month. To mitigate future losses due to hurricanes and storm surges, the City of Baltimore must find a solution and strategize for protection from the sea, especially given the threat of sea level rise and larger storm surges. The city also experienced a significant local weather anomaly in February 2010. Baltimore broke seasonal snowfall records as a blizzard entered the East Coast, grounding thousands of flights and closing schools and government offices. 11.9 inches of snow fell in one evening, which set a new annual record of 72.3 inches, surpassing the 62.5 inches record in 1995. In September 2010, downtown Baltimore received nearly 6 inches in one rainstorm event, which combined with high tide, caused the Inner Harbor promenade area to flood. The Baltimore metropolitan area also experienced three sewer overflows during this rain event due to system backup. This flooding caused spillage of 50 gallons per minute of sewage at two locations, and 500 gallons per minute of sewage at another location (29). These events illustrate how disruptive strong storms are to the region and are a good indication of what might be in store for the region under climate change.

*"In February of 2010
11.9 inches of snow fell in
one evening, which set a
new annual record of 72.3 inches."*

"Maryland is not well prepared to face future energy challenges and impending energy crises. Years of benign neglect by State government have resulted in disarray and loss of leadership with regard to energy policy."



Energy

In 2007, Maryland Governor-elect Martin O'Malley's transition team acknowledged the energy challenges faced by all citizens, businesses and other consumers in the state. "Maryland is not well prepared to face future energy challenges and impending energy crises. Years of benign neglect by State government have resulted in disarray and loss of leadership with regard to energy policy (30)." Governor O'Malley's response to this problem included a comprehensive climate change strategy. In the energy sector, innovations thus far are financially justifiable without accounting for reducing the causes or responding to the impacts of climate change. Early strategies have been focused on demand side energy efficiency practices that qualify as both mitigation and adaptation measures. Governor O'Malley took steps early in his term to address energy and climate change, establishing a state commission on climate change, which included a work group on adaptation and response to "develop a Comprehensive Strategy for Reducing Maryland's Climate Change Vulnerability (31)."

Demand

As temperatures rise in the Baltimore area, it is likely that demand for electricity used for cooling will rise. However, Baltimore is investing in energy efficiency projects to reduce future energy demand, and they are leading the way with several innovative projects.

As part of its wide-ranging sustainability initiative, the City of Baltimore accepted the Governor's challenge to reduce energy consumption by 15 percent by 2015. In 2009, the Baltimore Office of Sustainability also issued the following innovation goals:

- Require aggressive energy efficiency standards as part of the Baltimore Green Building Standards
- Increase energy conservation by residents, City government, businesses, and institutions
- Improve the energy efficiency of existing homes and buildings
- Increase renewable energy generation in Baltimore
- Consider efficiency upgrades to homes at point of sale
- Leverage state and federal funds for energy efficiency (32)

In 2009, Baltimore invested $4 million in the aforementioned strategies. The City expects to receive a full return on investment in 5.8 years from reductions in energy bills (33). Congress awarded Baltimore $15.7 million from the American Recovery and Reinvestment Act, passed by Congress in 2009 to weatherize 2,000 homes over three years (33). Also in 2009, the Department of Energy awarded the city $6.37 million to increase the energy efficiency of government buildings and neighborhood facilities (34).

Partnerships with the private sector and foundations have led to creative experiments in energy efficiency in Baltimore. Examples of public-private collaboration include the installation of "Cool Roofs" on 47 residences and 38 building envelope improvement actions, "Project Lightbulb," which retrofitted 1,097 homes in low-income neighborhoods and achieved an annual energy savings of 53 kilowatt hours per house per month. The City also partnered with Baltimore Gas and Electric to provide a suite of energy efficiency programs, from home energy audits to an 80 percent subsidy for efficiency retrofits for small businesses (33).

The Baltimore Community Foundation and the City's Office of Sustainability recruited almost 1,000 active participants in their innovation Baltimore Neighborhood Energy Challenge (35). Targeting eight low-income neighborhoods, the program blends online metrics, interactive mapping applications and distribution of materials with door-to-door, person-to-person organizing. This type of program increases public participation, educates energy consumers, extends the reach of policies, and ultimately increases the resilience of the most vulnerable population in the city.

Supply

Baltimore lies within the PJM electric distribution region, and utilities operating in the state are regulated by the Maryland Public Service Commission. Constellation Energy is the parent company for Baltimore Gas and Electric (BGE), which supplies electricity and natural gas to millions of consumers in Baltimore and eastern Maryland. BGE's electricity generation portfolio includes a mix of coal-fired power plants, oil and natural gas combustion, and a modest array of renewable energy generation, mainly hydroelectric. There are also several petroleum refineries in and around the city, the largest belonging to Chevron – a 75-acre site that includes retention ponds and tanks and is bordered closely by residential homes, wetlands and the Patapsco River. Many of these energy generation facilities are located in coastal areas that may be vulnerable to sea level rise.

Infrastructure and Planning for Change

After almost three years of meetings, the Maryland Commission on Climate Change Adaptation and Response Work Group issued several policy plans in 2010, many of which are applicable to utilities and others in the state's energy sector. As part of this effort, the Maryland Department of Natural Resources is mapping all areas vulnerable to sea-level rise along the Maryland shoreline. This process will create a comprehensive atlas of the State's shoreline that will be easily accessible through an online tool. The Department of Natural Resources will use this inventory and geographic information systems modeling to assess the level of risk for all public and private infrastructures in coastal areas. They will also develop policies which will guide future adaptation actions in response to higher sea levels, guiding decisions on when it is appropriate to invest in protecting key infrastructure, or to retreat, and even abandon existing infrastructure when necessary. These coastline assessments will be a key part of future decisions that involve energy infrastructure in coastal zones, particularly when it comes to the siting of new generation and distribution systems (36).

Figure 21: Sea level rise and increasing severe storm surges will threaten critical infrastructure such as the Gould Street Power Plant, which sits directly on the shoreline

Human Health

Introduction

Baltimore faces a range of human health threats from climate change that will have disparate impacts across the city. The severity of threats from climate change depends not just on the physical impact of the threat itself but the ability of people to adapt and recover. While Baltimore overall has a relatively high median income, there is significant vulnerability in the adaptive capacities of low-income and disadvantaged regions of the city, which exacerbate disparities in health conditions across income levels. In the County Health Rankings, Baltimore ranked last (24th out of 24) among Maryland counties for health outcomes and health factors (37).

The most significant threats to human health from climate change in Baltimore are from heat waves and extreme drought; increased storm intensity and sea level rise (38). The average annual temperature of the region is expected to rise on average 3 degrees to 8 degrees Fahrenheit (9 degrees in the summer) and precipitation is expected to increase about 20 percent (39). Heat stresses will increase the rate of heat illness in Maryland, as temperatures continue to rise and the number of days reaching 100 degrees continues to rise (surpassing 20 days, according to one estimate) (39). As the number of very hot days increases, so will the occurrence of heat waves (38).

There are four main categories of threats and areas of concern for human health in Baltimore

- **Socioeconomic:** The relationship between demographics and the geographic distribution of climate threats that people face in their living and working environments
- **Stress on Water Systems:** Water quality concerns relating to contamination and overdraft of groundwater and impairment of coastal water quality (in the Chesapeake Bay)
- **Stress on Natural systems:** Ecosystem buffers, vector and food-borne diseases spread rates, water-illness transmission, heat intensity and humidity, and winter storm intensity and frequency
- **Stress on Public Health Systems:** Stresses on the services that they provide, on public illness treatment rates, as well as the economic and financial impacts of these stresses

Figure 22: Summer storm impacts children at play

Figure 23: Storm sewer overflow

Figure 24: Standing water collects in a city street

Figure 25: Increased demand on medical personnel

"Baltimore received a D on their Health Disparities Report Card, indicating that there are significant disparities and inequalities in the health of Baltimore residents based on race and socioeconmic status."

Socioeconomic Considerations

Urban Environment

Many of Baltimore's older neighborhoods are home to a very high number of low income and high-risk individuals. Baltimore received a "D" on their *Health Disparities Report Card*, indicating that there are significant disparities and inequalities in the health of Baltimore residents based on race and socioeconomic status (40). This means that there is a large, low-income population vulnerable to current and future health threats from climate change. Baltimore ranks first among east coast cities for the rate of increased mortality once the Minimum Mortality Temperature is exceeded (MMT – the temperatures above which heat-related deaths increase steadily) (38).

The urban heat island effect is expected to be a significant concern in Baltimore as temperatures rise, especially for people of low socioeconomic status (38). Many neighborhoods in central Baltimore are very dense, with a lot of buildings and pavement, and very little vegetation. While air conditioning can reduce the risk of severe heat impacts, the poor and elderly populations in the urban areas of the City are the least likely to have cooling resources (38). It is also important to note that the majority of heat related deaths are predicted to occur at night when the temperature increase is expected to be larger than during the day. This is due to the ability of buildings and paved surfaces to hold onto heat well into the night (38) (41).

Air Quality

Central Maryland has some of the highest rates of asthma and acute respiratory illness in the country (38). Incidents of these ailments are expected to increase in response to environmental stressors from climate change, especially among low income and at-risk populations (38). Ozone formation occurs when high temperatures and high levels of ultra violet (UV) rays catalyze the reaction of ground level pollutants and Volatile Organic Compounds (VOC's) with oxygen, and there is a clear relationship in Baltimore between maximum temperature and ozone concentration (38). Releases of air pollutants and VOC's that form ozone have declined in recent years. However, rising temperatures will likely reverse this trend unless pollutant releases can be reduced at a faster rate (38) (42). Ground-level ozone, a component of smog, can impact human health through irritation of the respiratory system. This reduces lung function, aggravates asthma by increasing sensitivity to allergens, increases susceptibility to respiratory infections, and inflames and damages the lining of the lungs (which can cause chronic obstructive pulmonary disease) (38).

The impacts of ground-level ozone are most pronounced when the air is hot and stagnant, a condition which is exacerbated further by the urban heat island effect (38). Cold fronts help to clean the air, but as climate changes, the number of low pressure systems that bring cold fronts will decrease, and high pressure events characterized by hot stagnant air will persist for longer (38).

Water Systems

Freshwater

The Baltimore region currently draws from groundwater sources for some of its freshwater. While predictions show an overall increase in the amount of precipitation, projected increases will not be sufficient to replace the current overdraft of water supplies (38) (39). The overall impact will be a decrease in the quality and quantity of fresh drinking water. Water quality will also be impaired by increased levels of winter and spring runoff, which elevate the nutrient load into the bay (39). In addition, warmer water temperatures and longer warm seasons result in increased growth of algae and bacteria in the bay, leading to reduced water quality and fish kills (38). If flooding becomes more frequent due to more intense storms, bacteria, pesticides and other unwanted biological organisms and chemical concentrations could increase in drinking water sources (42).

Treatment Plants

There are two wastewater treatment plants in Baltimore, all of which are located along the Chesapeake Bay. One of them has recently experienced flooding and the other is at risk for future extreme flooding events (43). Baltimore does not use a combined sewer overflow (CSO) system, however during extreme precipitation events there have been multiple incidents where system back-ups caused a spillage of sewage at multiple locations throughout the city (43). Harmful runoff also has the potential to damage water and sewage treatment plants, and compromise septic tanks, all of which have the potential to contaminate drinking water supplies (42).

Coastal Water Systems

Baltimore is part of the Chesapeake Bay Watershed, and therefore responsible for managing its polluted storm water runoff. The impact of storm water is particularly acute in the urban environment, because there is a link between the quantity of impervious surfaces within a watershed, and overall water quality of the watershed (44). Once more than 10 percent of the land in the watershed becomes impervious, sediment and chemical pollutants begin to have an impact on water quality (44). As the percentage of impervious surfaces increases, oxygen levels in the stream decrease and stream life are impaired, and even die off once the levels surpass approximately 25 percent (due to high levels of sediment and run-off) (44).

Figure 26: Baltimore wastewater treatment plant, as well as significant petroleum refining infrastructure, face significant risks from sea-level rise and increasing severe storm surges

Natural Systems

Historically, Baltimore has not regularly experienced prolonged periods of cold temperatures (below 40 degrees Fahrenheit), or received large quantities of precipitation in the winter (45). However, with the changing climate, precipitation is predicted to increase during winter. In particular, there will be more intense late-winter storms, and around a 10 percent increase overall in precipitation in the winter and spring (39). Baltimore is not well equipped to respond to extreme storm events, leaving vulnerable populations more isolated and at-risk. During extreme snow events, streets made impassable by snow or ice will isolate populations, and could even delay or inhibit emergency vehicles as they respond to emergency calls.

Vector-born Disease

In Maryland, shifting climate ranges will result in an increased risk of exposure to West Nile Virus (39). However, death from vector-borne disease is relatively low because of public health precautions and available treatments, both of which are capable of adapting to changes in risk level (39). The State of Maryland participates in disease surveillance programs run by the US Department of Agriculture, US Fish and Wildlife Service, and National Wildlife Refuge system to identify and respond to disease outbreaks (46).

Figure 27: Shifting climate ranges will result in an increased risk of exposure to West Nile Virus

Health Systems

Health systems in Baltimore will be stressed by an increased incidence of heat, and precipitation related-illness as a result of climate change. Although there are already several proposed policies and plans that the state has in place to coordinate health systems and responses to the health impacts of climate change, these policies will need to be continually evaluated to identify inefficiencies and unmet needs (47) (46). These policies include:

- Policy CC-11; Evaluate Climate Change Policy Options to Determine Projected Health Risks/ Costs/ Benefits. A commission will be established to review the health risks, costs, and benefits of proposed climate change and energy-related policies and legislation with particular attention to how the legislation will impact vulnerable populations.
- Policy HHSW-1; Health Impact Assessment. The DHMH will conduct a health impact assessment to evaluate the public health impact of projects and policies related to climate change and sea level rise.
- Policy HHSW-2; Interagency Coordination. The DHMH will work to strengthen coordination and management between the different agencies responsible for human health and safety.
- Policy HHSW-9; Vector-borne Surveillance and Control. The DHMH will develop a coordinated plan with other agencies responsible for environmental health issues to assure adequacy of Vector-borne Surveillance and Control Programs.

Transportation

Introduction

Greater precipitation intensity and sea level rise are among the climate change-related impacts that threaten Baltimore's roadways, rail, transit, shipping and air transportation assets. Many of Baltimore's interstate systems and rail lines lie within or near floodplains, and increased frequencies of extreme storm events will impact the operations, maintenance, and construction of these systems. Also, sea-level rise will impact accessibility to Baltimore's port, affecting the Port's billion-dollar industry. Decision makers will need to take action to improve the vulnerability and the longevity of Baltimore's transportation to adjust to flooding and sea-level rise.

Port of Baltimore

The Port of Baltimore is one of only two U.S. eastern seaboard ports whose channel reaches a depth of 50 feet. The Port serves over two-thirds of the population of the United States and is located closer to the Midwest than any other eastern port. Its central location allows cargo to be delivered to one-third of the nation within a day's trip. The Port's attractive location provides over 50,700 jobs, and generates over $3.2 billion in annual economic activity. The Port's activity declined in 2009; however, it still moved 22.3 million tons of freight. (48) The Port significantly contributes to the economies of Baltimore and the State of Maryland (49).

The Francis Scott Key Bridge, the third longest continuous truss bridge in the United States, crosses the Outer Harbor and carries the I-695 route. The Bridge is not a drawbridge, and the fixed height combined with rising sea levels will decrease clearance for ships to pass. Projections show that sea level will rise 2.7 feet by the end of the century (50). This will limit the size of ships that can pass and enter the Port. Dredging the Harbor could help by increasing the depth of the Harbor; however, many environmental issues arise from disturbing settled contaminants.

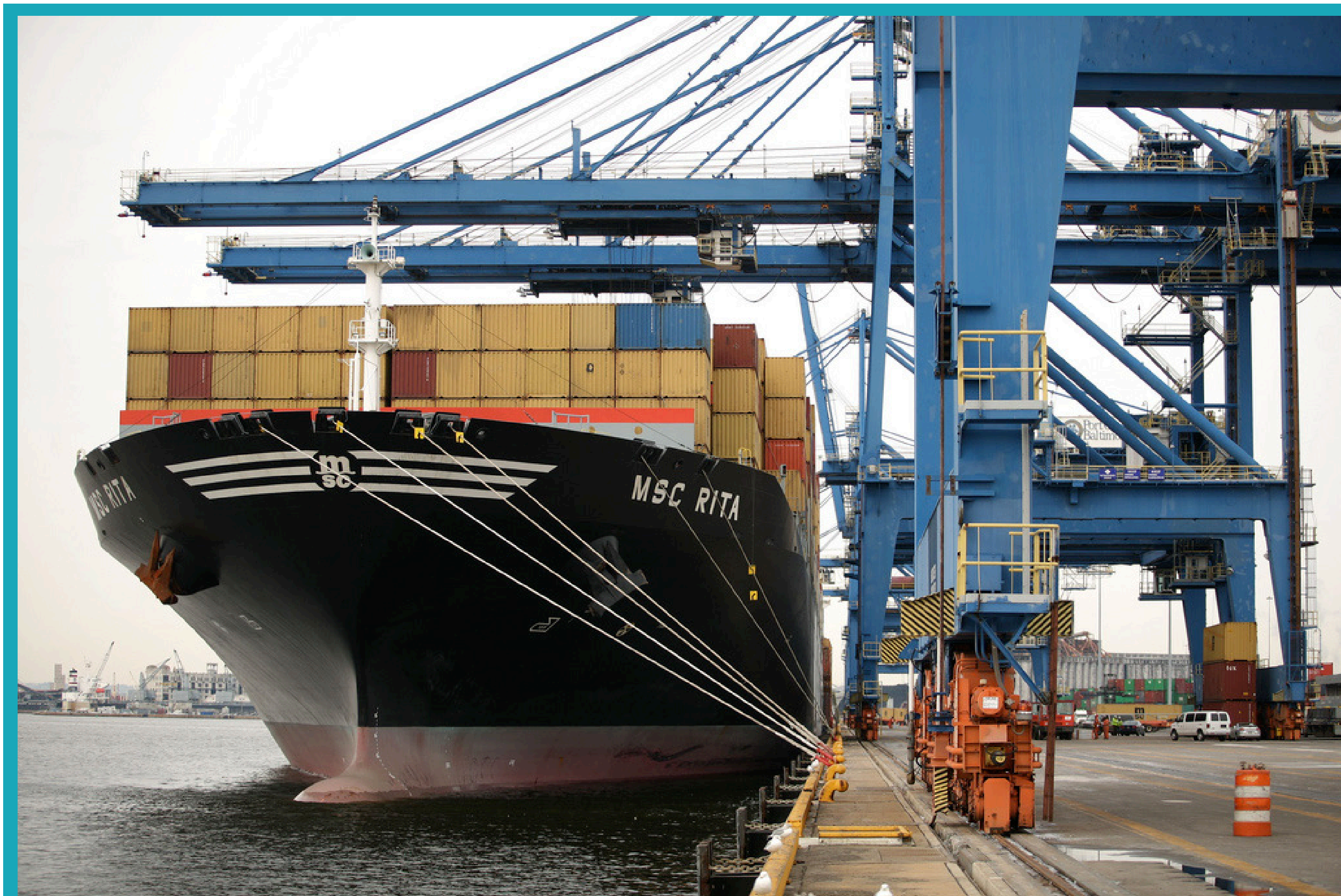


Figure 28: As sea-level rise reduces clearance under the Francis Scott Key Truss Bridge, container ships may need to transport shorter, lighter stacks of cargo, imperiling economic activities at the Port of Baltimore

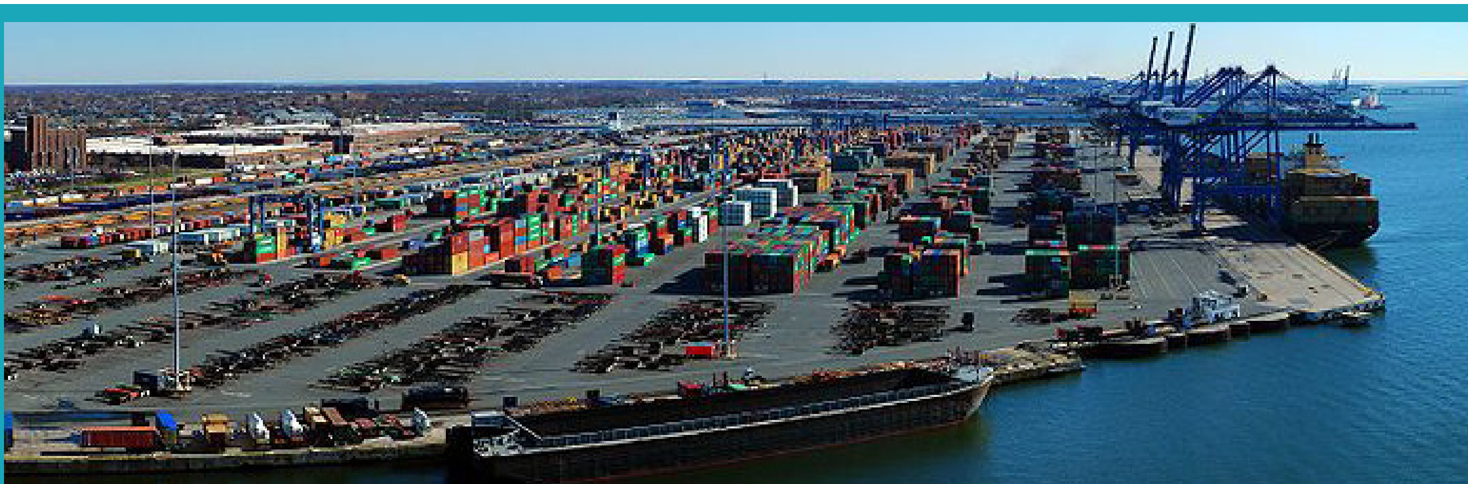


Figure 29: Port of Baltimore container dock

Road Transportation

Baltimore has a radial interstate highway system consisting of eight highways that provide extensive linkages both within the region and to the wider national network. The major highways include I-95, which runs along the southern and eastern edge of Baltimore, I-695, which runs as a loop around the city and I-83, which runs north to south down the center of the city. The rest of the interstates either consist of smaller offshoots of these major highways or highway that lie on the edge of Baltimore County. A few state highways also run throughout Baltimore: US Highway 1, which parallels I-95; US Highway 40, which run west to east; and the Baltimore-Washington Parkway, which connects these two cities.

According to studies, roads are the most vulnerable parts of transportation infrastructure to sea-level rise, Baltimore's biggest climate change threat. Areas of low elevation are the most at risk, and the roads tend to be located below surrounding land, causing drainage and flood concerns (51). The low-lying areas of Baltimore also have the potential to be easily inundated by either extreme precipitation events, such as hurricanes, or by sea level rise. Thus, disruptions in the roadway network of Baltimore due to flooding, storm surge are likely to increase in frequency under climate change conditions. Expected increases in rain and flooding from sea level rise also have the potential to cause increased erosion on the roads, resulting in higher maintenance and a lowered useful life.

Of Baltimore's highways, I-95, I-695, and I-895 are the most vulnerable to sea-level rise and flooding. Parts of I-695, the Baltimore Beltway, lie close to the Chesapeake Bay and associated estuaries, and will likely see the most damage from sea-level rise. I-95 and I-895 may also be affected because their tunnels, the Fort McHenry Tunnel and the Harbor Tunnel, respectively, could flood if rising waters inundate the areas surrounding their entrances. Damage to I-95 would significantly disrupt road traffic in the region, as it is one of the most traveled highways in the United States and a vital economic link between Baltimore and both Washington D.C. and the major metropolises of the northeast U.S. (52).

The road and highway drainage systems that support roadway operation were designed based on historic climate norms. However, as precipitation volumes and frequency of Atlantic storms increase, these systems will be increasingly unable to channel water away from the roadway. This results in flash floods and in turn will affect travelers on limited access highways or in neighborhoods with poor street connectivity. While redundancy (parallel and alternate routes) is built into the regional transportation system, the Baltimore metro area often lacks redundancy, thus increasing the probability of intraregional isolation in the wake of major storms. The City of Baltimore has significant multimodal capacity in the form of public transit systems; however, many of these systems also rely on roadways and will therefore face many of the same challenges as private vehicles. Furthermore, roadway-operating rail systems will be more likely to face service disruptions as a result of flooding because they operate on fixed tracks and are unable to reroute to avoid trouble areas.

Public and Rail Transportation

Baltimore's public transit system consists of a large bus network, three light rail lines, and a metro line. The metro, known as the Metro Subway, opened to the public in 1983, and reached its current length in 1994. Serving over 57,000 people a day, the 15.5 mile-long Metro Subway line has 14 stops going from Johns Hopkins Hospital, located northeast of downtown Baltimore, to the suburb of Owings Mills. The metro contains both underground and aboveground stops. The underground portions consist of the Johns Hopkins Hospital stop and the subsequent seven stations, most of which are in downtown Baltimore. The aboveground stops begin with Owings Mills and the subsequent five stations. Owings Mills, Old Court and Milford Mill stations are above ground and at grade, while Reisterstown Plaza, Rogers Avenue, and West Coldspring stations are above ground and elevated.

While the Metro Subway line avoids most of the City's flood plain, the Shot Tower/Market Place station is located close to the Northwest Branch of the Patapsco River. This area is vulnerable to flooding and could be inundated under extreme sea-level rise scenarios (52). For context we look to New York City, a major east-coast city with an extensive subway system. New York City has several subway stations located in flood-prone areas, which are occasionally flooded by nor'easters (51). In the event of extremely heavy rain or flooding, stations could shut down. Water could flow through street level vents to cause flooding and damage in the underground portion of the line. Also, though many portions of the subway are not located in the floodplains, extreme precipitation may impact the above ground at-grade portions of the line. The entrance to the underground tunnel between West Coldspring and Mondawmin stations is another potential entry point for floodwaters.

The Maryland Transit Administration operates Baltimore's three-line, 33-station light rail network, which is located mostly at-grade and entirely above ground. Baltimore's light rail has fewer daily riders than the Metro Subway, but it serves many important destinations, such as Baltimore Washington International (BWI) Airport, M&T Bank Stadium, Camden Yards, Baltimore Convention Center, Lexington Market, and Penn Station. The light rail system has more stations that lie on or near the city's floodplain than the Metro Subway and the vast majority of these stations serve the aforementioned important destinations, most notably the stadiums and Penn Station, the central rail hub of Baltimore City (52). Light rail is an important form of transportation to Penn Station and BWI Airport, particularly for those without access to private vehicles. The light rail system also provides a redundant way of reaching some of these important destinations in the event of a localized flood on parallel roads. Therefore, disruptions in this service due to flooding or track bed erosion are likely to have significant economic impacts on the functioning of the region.

Figure 30: Maryland Transit Administration metro budd car leaving Millford Mill Station

Heavy Rail

Baltimore serves as an important rail hub for the state of Maryland and the Northeast. The city has two Amtrak stations: Penn Station and BWI Airport. Both regular Amtrak trains and the higher-speed Acela Express, which runs between Boston and Washington, D.C., serve these stations. Two of the three lines of the Maryland Area Rail Commuter (MARC) network also serve the Baltimore area. The MARC Camden Line runs between Washington, D.C.'s Union Station and Baltimore's Camden Station, which is located next to Camden Yards baseball stadium. The MARC Penn Line runs between Washington, D.C.'s Union Station and Perryville, MD, stopping en route at both BWI Airport and Penn Station. MARC operates the fastest commuter trains in the United States, reaching top speeds of 125 miles per hour along the Penn Line.

Both Camden and Penn Stations are located either in or near the city's 100-year floodplain (52). As the frequency of the historic 100-year flood increases, these important hubs are likely to experience service disruptions. Camden Station is outdoors and at-grade, while Penn Station's tracks are below street level but outdoors. In the event of a flood or sea-level rise, the City's heavy rail network would be affected. Rail serves as an important transportation network in the area, especially between Baltimore and Washington, D.C. While the presence of a functional intercity rail system positively contributes to the region's transportation network redundancy, if flooding wipes out parallel roads, it is likely that rails will be inoperable as well (51).

Air Transportation

The Baltimore area is home to two airports: Baltimore-Washington International Thurgood Marshall Airport (BWI) and Martin State Airport. BWI, the area's primary commercial aviation airport, served over 20 million passengers in 2009. The airport is located 10 miles south of the city in the suburb of Linthicum and is accessible by road, light rail, MARC and Amtrak trains.

BWI is distant from the coast and is therefore unlikely to be directly affected by sea-level rise. However, it still may be vulnerable to flooding during extremely heavy precipitation events. To counter the effects of flooding, many airports on the east coast have considered elevating runways in order to avoid water damage on taxiways (51). The Baltimore area also expects to see increased temperatures, which have the potential to cause runway buckling, and both heat and precipitation-related climate impacts will result in more frequent asphalt re-pavement of runways. All of these conditions would likely result in higher maintenance costs and more frequent disruptions.

Martin State Airport, the area's primary civil and military aviation airport, sits nine miles east of the City in the suburb of Middle River. This airport has one asphalt runway and it is accessible by road and by MARC trains. Unlike BWI, Martin State Airport abuts the Chesapeake Bay, thus making it more vulnerable to flooding and the effects of sea-level rise than BWI (52).

Implications

Impacts of climate change will bring about more frequency and intensity of precipitation events as well as a rise in sea level. Transportation serves as an important role in moving people throughout a city. More extreme events may require residents to leave the City before or after a storm event or for emergency vehicles to respond to disaster-type situations. Thus, having a reliable and resilient transportation system is important. Adjusting to the anticipated changes from climate change will impact the long-term transportation costs. Damage incurred by more frequent floodwaters will increase long-term costs if cities do not adjust to these changing climate conditions. Also, since Baltimore's economy relies on the Port, decision makers must adjust to these projected changes to protect the economic vitality of the Port.

Figure 31 : Airport Flooding, as seen here at Chicago's O'Hare Airport, is likely to occur at BWI and disrupt service

Heat Vulnerability Analysis

Introduction

This study identifies the locations that are most vulnerable to climate change in Baltimore, Maryland based on two analyses. First, we calculate a Socioeconomic Disadvantage Status index (SES) to help understand the region's demographic distributions on a census tract level. The second uses terrain topographic data to simulate four scenarios of future sea-level rise: two based on the Intergovernmental Panel on Climate Change (IPCC) climate projection for the State of Maryland, the other two are extreme scenarios for storm-surge-like flooding events.

Methodology

To calculate the Socioeconomic Disadvantage Status Index (SES) for Baltimore, we used a methodology from the Rand Health Center - Center for Population Health and Health Disparities. There are six individual demographic and economic variables included in the integrated index calculation. The six variables are:

1. Percent of adults older than 25 with less than a high school education
2. Percent of males who are unemployed
3. Percent of households with income below the poverty line
4. Percent of households receiving public assistance
5. Percent of households with children that are headed by a female
6. Median household income

All the demographic data for the specific variables were downloaded from the Social Explorer, Census 2000 Summary File 3 (53), and were later joined with the census tract boundaries downloaded from the US Census Bureau, 2009 TIGER/Line Shapefiles (54). The census table sheets from which each variable was calculated are:

1. SF3 T40 Educational Attainment for Population older than 25 years
2. SF3 T74 Employment/Unemployment Status for Civilian Male Population
3. SF3 P92 Poverty Status in 1999 of Household by Household Type by Age of Householder
4. SF3 P64 Public Assistance Income in 1999 for Households
5. SF3 P10 Household Size by Household Type by Presence of Own Children Under 18 Years Old
6. SF3 P53 Median Household Income in 1999 (Dollars)

See Appendix C for a more detailed description of how we calculated this index.

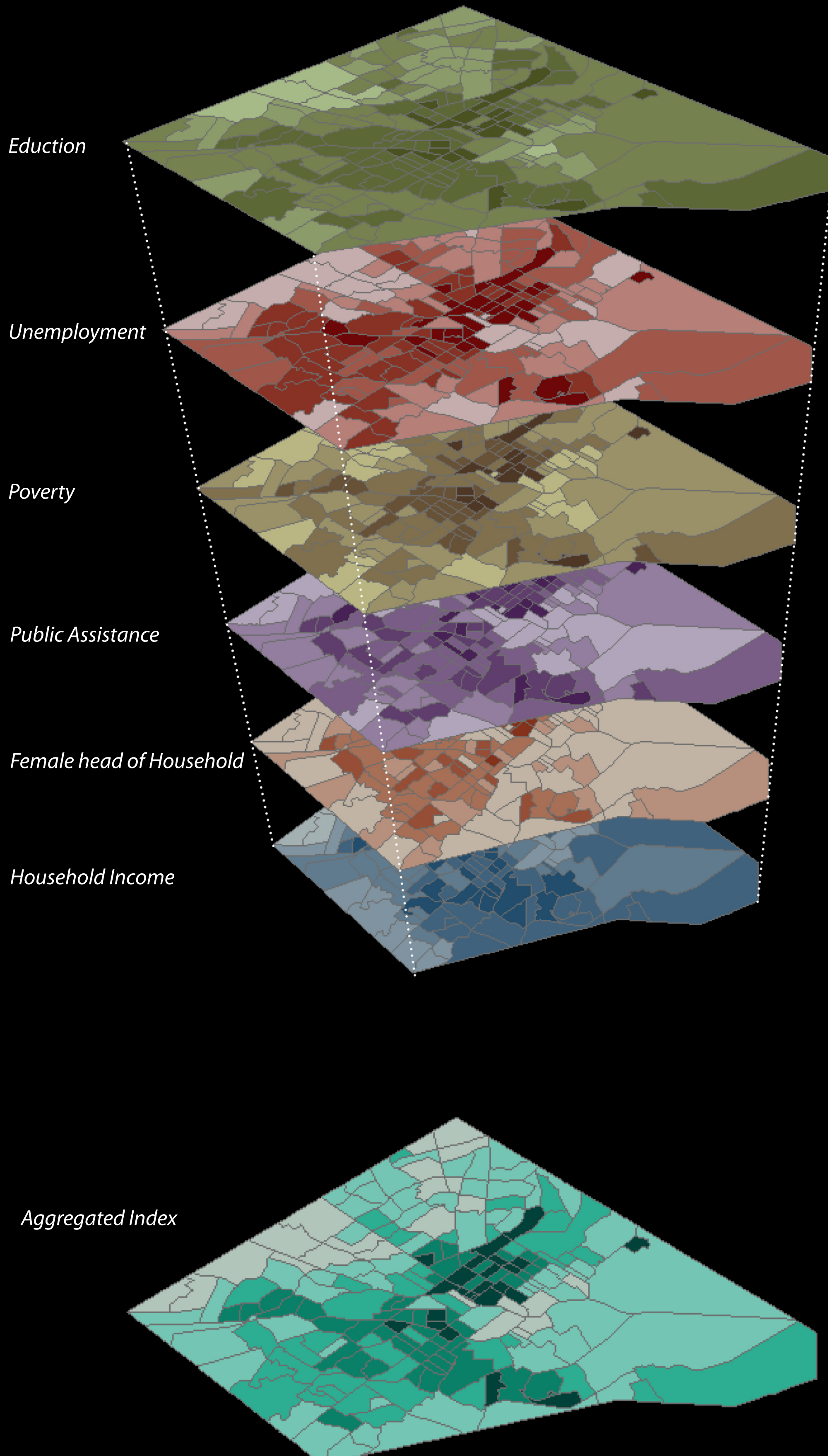
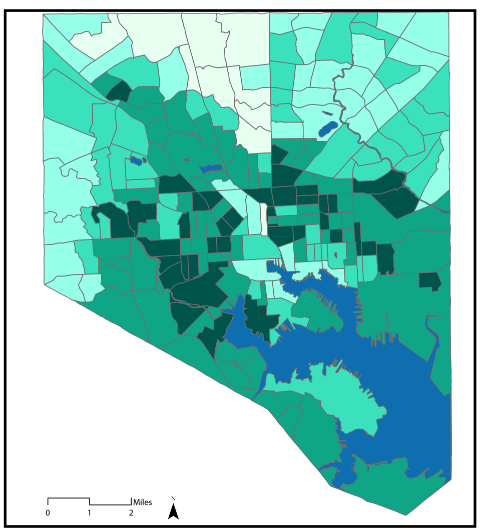


Figure 32: Six individual demographic and economic variable layers were used to generate an index calculation

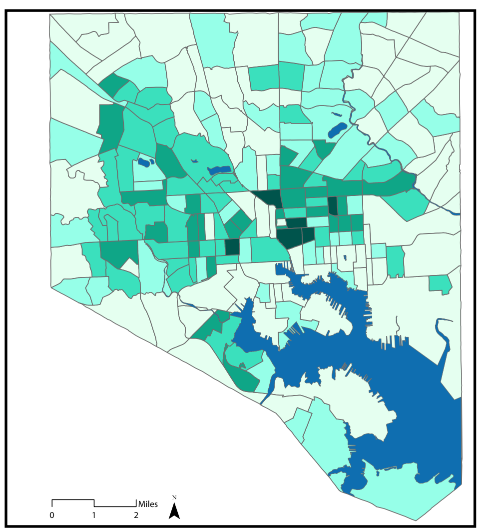
A report of the Adaptation and Response Working Group in the Maryland Commission on Climate Change (MCCC), states that slope is the primary variable controlling the magnitude and range of sea-level rise impacts over time (55 p. 5). Thus, we simulated sea level rise by reclassifying the Digital Elevation Model (DEM) of Baltimore (from the National Elevation Dataset (56)) into 1/3 arc second. Measurement of sea level at any particular location is relative. Relative sea level rise is the sum of global (eustatic) sea level change, plus changes in vertical land movement at a particular location. The MCCC Scientific and Technical Working Group (STWG) determined that Maryland can conservatively expect to experience a relative sea-level rise of 2.7 to 3.4 feet by the end of this century (55 p. 4). As a coastal city, Baltimore is also vulnerable to coastal flood events and inundation from storm waves, the impacts are predicted to become more severe as sea-levels rise. In order to model the impacts of severe coastal inundation, we also created scenarios of five foot and ten foot sea-level rise.



Baltimore Social-Economic Status Index Variables

- 1.89% - 11%
- 11.01% - 24%
- 24.01% - 35%
- 35.01% - 46%
- 46.01% - 100%
- Waterbody

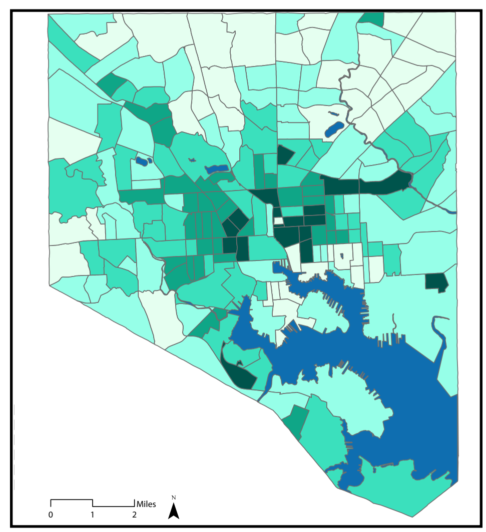
Figure 33: Percent of Adults Older than 25 with Less Than High School



Baltimore Social-Economic Status Index Variables

- 0% - 7%
- 7.01% - 14%
- 14.01% - 22%
- 22.01% - 34%
- 34.01% - 100%
- Waterbody

Figure 34: Percent of Male Unemployed



Baltimore Social-Economic Status Index Variables

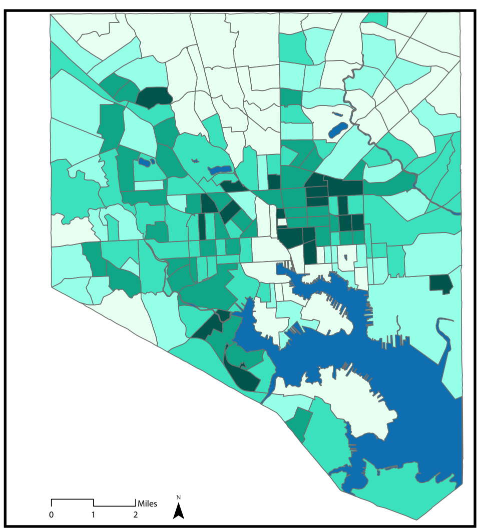
- 0% - 12%
- 12.01% - 19%
- 19.01% - 31%
- 31.01% - 43%
- 43.01% - 100%
- Waterbody

Figure 35: Percent of Household Below Poverty Line

Findings

Vulnerable Population

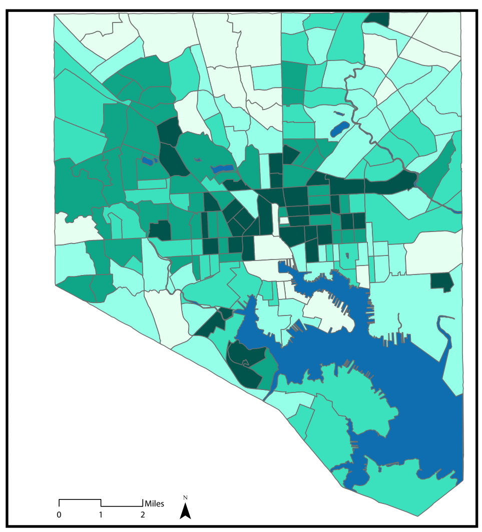
As of 2009, the population of Baltimore was 637,418, with approximately 2.7 million residents in the metropolitan area (57). It is the 21st largest city in the U.S., and characterized by its high proportion of African American population. Wealthier residents tend to live in the northern areas of the City and in suburban areas outside of Baltimore City. The southern, eastern, and western parts of the city generally constitute more deprived socioeconomic residential neighborhoods, which are typically African American. The following six maps show the spatial distribution of each of the six individual socioeconomic variables used to construct the SES index. All of these variables demonstrate that the most socially vulnerable neighborhoods in Baltimore City coincide with the predominately African American neighborhoods that buffer the central business district to the south, east, and west. The northern areas are significantly less vulnerable.



Baltimore Social-Economic Status Index Variables

- 0% - 3%
- 3.01% - 6%
- 6.01% - 11%
- 11.01% - 17%
- 17.01% - 100%
- Waterbody

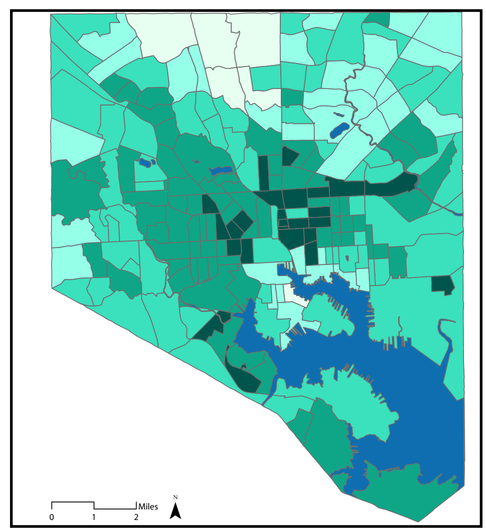
Figure 36: Percent of Household Receiving Public Assistance



Baltimore Social-Economic Status Index Variables

- 0% - 24%
- 24.01% - 42%
- 42.01% - 57%
- 57.01% - 71%
- 71.01% - 100%
- Waterbody

Figure 37: Percent of Household with Child and Headed by a Female



Baltimore Social-Economic Status Index Variable

- 0.00 - 17284.00
- 17284.01 - 27917.00
- 27917.01 - 38500.00
- 38500.01 - 53917.00
- 53917.01 - 101450.00
- Waterbody

Figure 38: Median Household Income

It is also interesting to note that the most socialy vulnerable neighborhoods also tend to have high population densities, as shown in Figure 7.

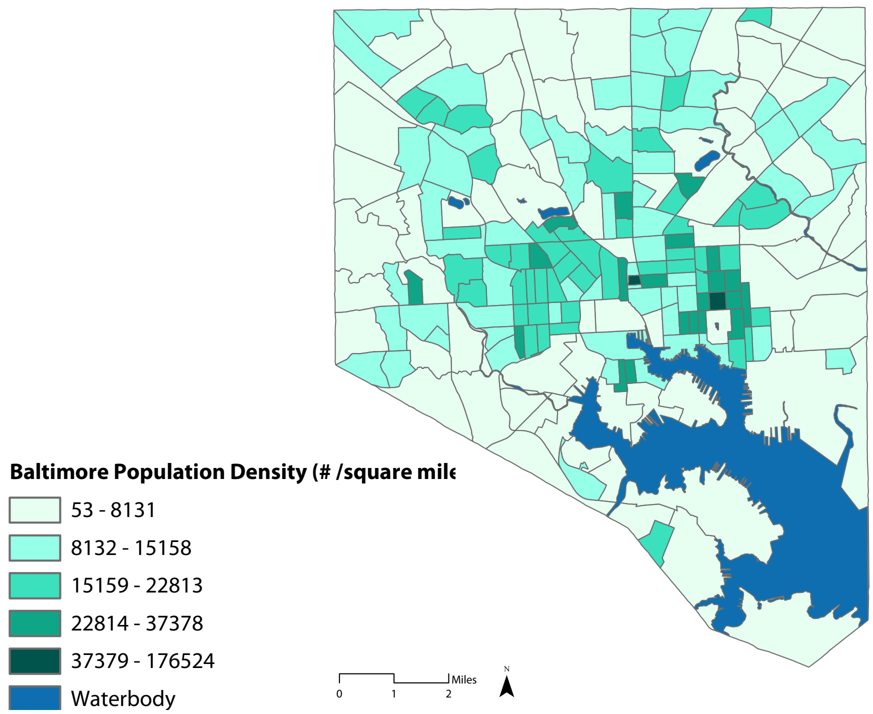


Figure 39 : Population Density

Neighborhoods in the northwest portion of the city have the highest tree cover percentages, with the highest percentage reaching about 60%. On the other hand, census tracts in the southeast have the lowest mean tree cover. As for the mean imperviousness dataset, the central city and its surrounding communities have the highest percent of impervious surface. The area with the smallest proportion of impervious surface is located in the north, coinciding with the high percentage of tree cover in the tree canopy layer.

This map represents the combination of all six socioeconomic variables into a single index, with each variable given equal weight. The SES index is calculated such that higher scores are given to areas of lower socioeconomic vulnerability. The darker colors represent lower scores in the index, showing higher levels of vulnerability. Overall, we see that the additive index reflected the general patterns we observed in each individual variable.

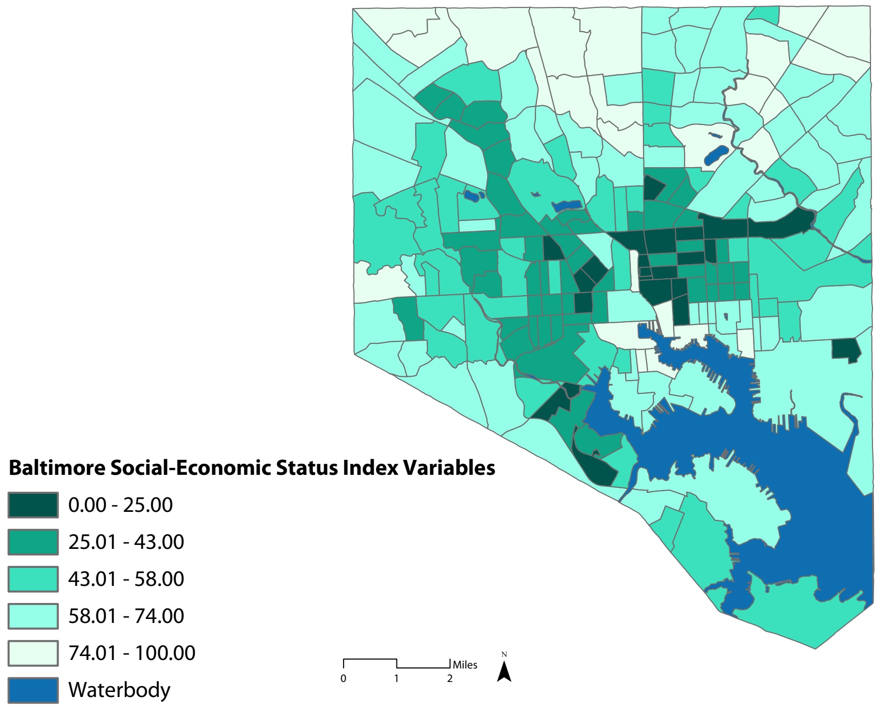


Figure 40 : Integrated RAND Social-Economic Status Index

Sea-Level Rise

Due to its unique geography and geology, the Chesapeake Bay region is considered the third most vulnerable to sea-level rise in the United States, behind Louisiana and southern Florida (55 p. 4). With over 3,000 miles of coastline, Maryland is poised in a very precarious position when it comes to the sea level impacts of climate change. Maryland's coast is particularly vulnerable to both episodic storm events, such as hurricanes and chronic hazards associated with shore erosion, coastal flooding, storm surge, and inundation. These coastal hazards are both driven and exacerbated by climate change and sea-level rise (55 p. 3). Historic tide-gauge records show that sea levels of the Chesapeake Bay have increased by one foot over the past century, at about twice the rate of the global average over the same time period. The state of Maryland is experiencing an increased risk from sea-level rise compared with many other areas due to naturally occurring regional land subsidence.

Sea-level rise can be divided into four parts: shore erosion, coastal flood events, groundwater level rise, and seawater intrusion. Sea-level rise is a causal force which influences the on-going coastal processes that drive erosion, in turn making coastal areas more vulnerable to both chronic erosion and episodic storm events. The expansion of sea water from climate change also increases the height of storm surges, enabling them to extend further inland. As sea-level rises, the groundwater table will increase, and saline water will intrude into fresh water aquifers. Furthermore, two to three feet of additional sea-level rise will result in a dramatic intensification of coastal flood events and pose a significant threat to natural resources and infrastructure in the Baltimore's coastal zone (55 p. 7).

There is not a significant risk to concentrated residential communities from the best-case scenario of a 2.7 foot rise in sea level. The major land cover or land use that will be threatened is coastal industrial infrastructure, natural resources (green space), and coastal wetlands.

In the northwest portion around the Baltimore coastal line, the Fort McHenry Tidal Marsh is likely to be permanently submerged; along with the offshoot south of the Gwynns Falls Trail, on both sides of which are urban planted vegetation. Another area under threat from a 2.7 foot sea-level rise would be costal industrial infrastructure. The properties most likely to be threatened would be the Baltimore port and shipping industry and the container terminals. In the north central portion of the coastal line, the infrastructure of Keystone Ship Berthing Inc., and other nearby industrial berthings would be under high risk. Additionally, more inshore facilities such as the SGS Control Service, Beacon Stevedoring Corporation, are at risk of being submerged from a 2.7 foot sea level rise. Although there probably will not be loss of residential areas, the economic loss and weakened ecosystem services due to the shrunken area of greenspace and coastal wetlands could increase the vulnerability of the city significantly.

The more extreme 3.4 foot sea-level rise scenario does not vary drastically from the 2.7 feet scenario, although there is a larger area submerged, especially in the Inner Harbor downtown area of Baltimore. This marginal difference is mainly due to the resolution of the data used for this study, which is as coarse as 30 by 30 meter. Thus an increase of 0.7 feet of the sea level cannot be obviously seen at this resolution.

However, if sea-level rise reaches 5 or 10 feet during an extreme storm surge, much more land area will be adversely affected, especially greenspaces. For example, along the western side of the coastal water, four large parks, Middle Branch Park, Broening Park, Cherry Hill Park and the Reed Bird Island Park would be inundated under the 5 feet sea-level rise

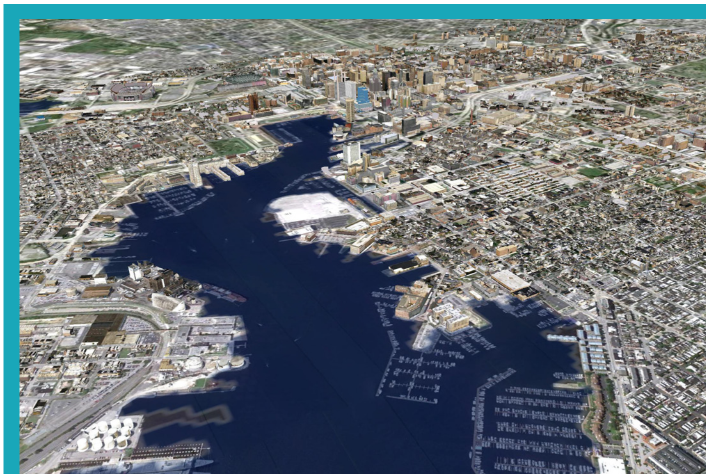


Figure 42: Baltimore Inner Harbor Sea Level Rise 2.7 Feet

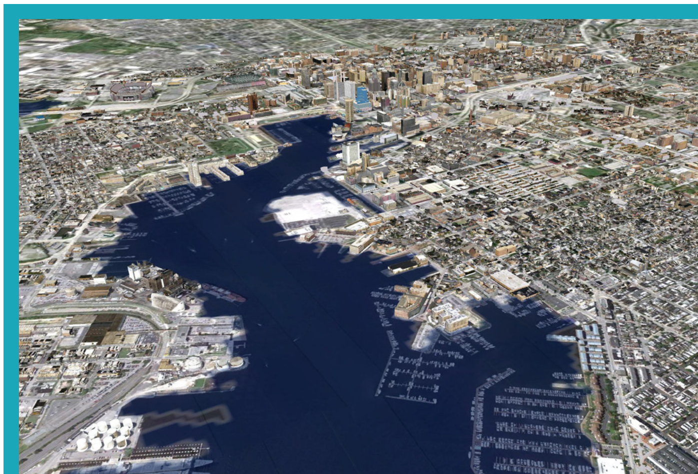


Figure 43: Baltimore Inner Harbor Sea Level Rise 3.4 Feet

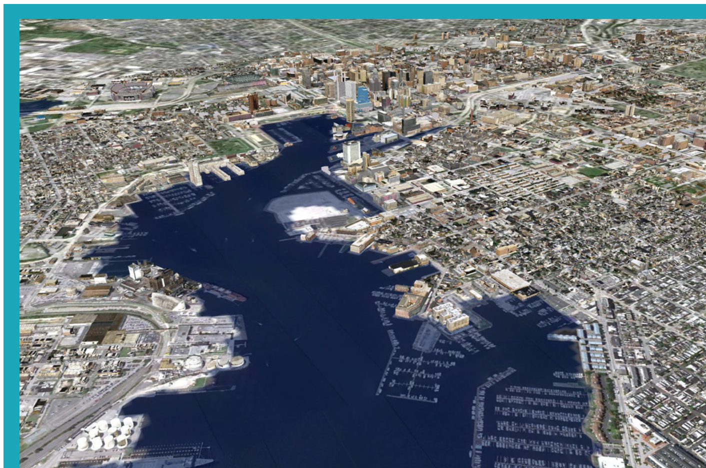


Figure 44: Baltimore Inner Harbor Sea Level Rise 5 Feet

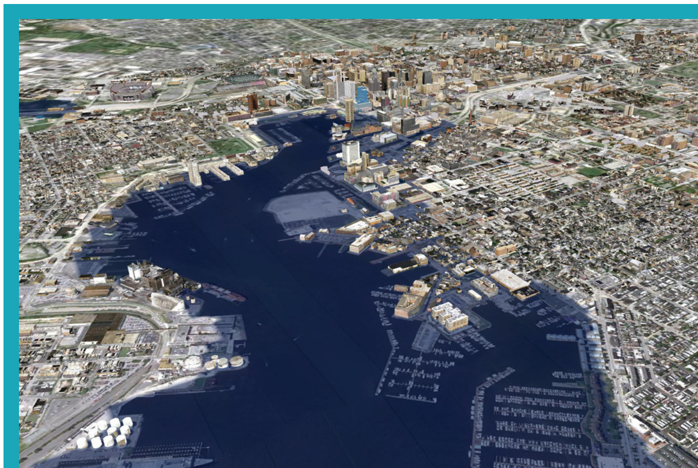


Figure 45: Baltimore Inner Harbor Sea Level Rise 10 Feet

scenario. These natural resource lands provide critical wildlife habitats, have regional significance for migratory birds, sequester large amount of carbon, and generate economic benefits through forestry, fishing, and passive recreation. They play an important role in protecting the shoreline and interior by absorbing the damaging impact of coastal floods, heavy winds, and strong waves, particularly coastal wetlands (55 p. 20). In this respect, they would function exactly as intended. However, there are at least three neighborhoods that would be more vulnerable to climate change if coastal inundation degrades these important greenspaces.

If storm surge were to increase to a height of 10 feet, the two coastal industrial zones on both sides of the water in the southern part of the city would experience severe flooding. For instance, the area of the city where numerous industrial corporations are located, such as the Baltimore Scrap Corporation, Techalloy Co. Inc., Shell Oil Co., Patapsco Waste Water Treatment, Citgo Petroleum Corporation, Cook's Fuel & Energy Service Inc. and Maritime Applied Physics Corporation, would be severely affected. It is easy to imagine the large economic loss as well as the potential of chemical pollution from these companies during flooding events. Furthermore, the City's other coastal industrial zone would also experience severe flooding at the 10 feet of sea-level rise. Properties of the Maryland Transportation Authority, All-State Career School and the Seagirt Marine Terminal, for instance, are likely to be swept by floods during storm surge. The third significant area from the 10 feet sea-level rise expansion would be near the Inner Harbor in downtown Baltimore, where there are many recreational, service facilities, such as the National Aquarium, the Codish Company, US Coast & Geodetic Survey, concert pavilion, and museums. These buildings and infrastructure, along with the inner harbor marina are already at risk under the conservative 2.3 to 3.4 foot scenarios, and the threatened area will be expanded during 10-foot storm surge.

Advantages and Limitations of Spatial Analysis for Climate Adaptation Planning

We assessed six sociodemographic variables so we could better understand the spatial distribution of sociodemographic characteristics in the neighborhoods of Baltimore. We used GIS software to overlay all these related layers together and also used multiple scenarios corresponding to different climate change models to help local decision-makers gather information to analyze more efficiently. It is our intent that city planners using more detailed, locally produced data could replicate this type of analysis to produce projections that will help decision makers plan better to adapt to the effects of climate change.

This study contains some limitations. We expected to find some neighborhoods that are likely to experience flooding due to sea-level rise, and that some of those neighborhoods would contain vulnerable populations. However, the most demographically-disadvantaged populations do not live very close to coastal areas, except for a few census tracts near downtown. After conducting further analysis of the specific features likely to be inundated by sea-level rise, there are not many residential neighborhoods overlaid by our simulated increasing water level. However, the economic loss and damages of coastal industrial infrastructures are likely to be significant especially for the higher sea-level rise scenarios. The second disadvantage of this analysis is that the data used in the simulation is not available at fine scales. As mentioned previously, all the elevation data are downloaded for free from the National Elevation Dataset. The finest resolution available is 30 by 30m Digital Elevation Model. Although 30 meters is an acceptable resolution for regional studies, it is still too course for a local city planning management process. When overlaying the digital elevation model (DEM) with the aerial photographs, which have a resolution of 0.5 to 1 meter, the difference in resolution presents a problem for the analysis. The third point where improvement could be made is the census data used in the first social-economic status analysis. Despite the fact that the index was calculated in 2010, 2000 census data was used because of the unavailability of 2010 data during the study. Also, because the classification of census tract data was the smallest geography available for some variables limiting the geography size to census tract instead of the finer grain census block group. The final weakness of this study is the lack of in-person familiarity with the city, because of the limit of time and resources of the project. It is our intent to provide this study approach to aid local decision-makers in planning for adaptation to future threats from climate change.

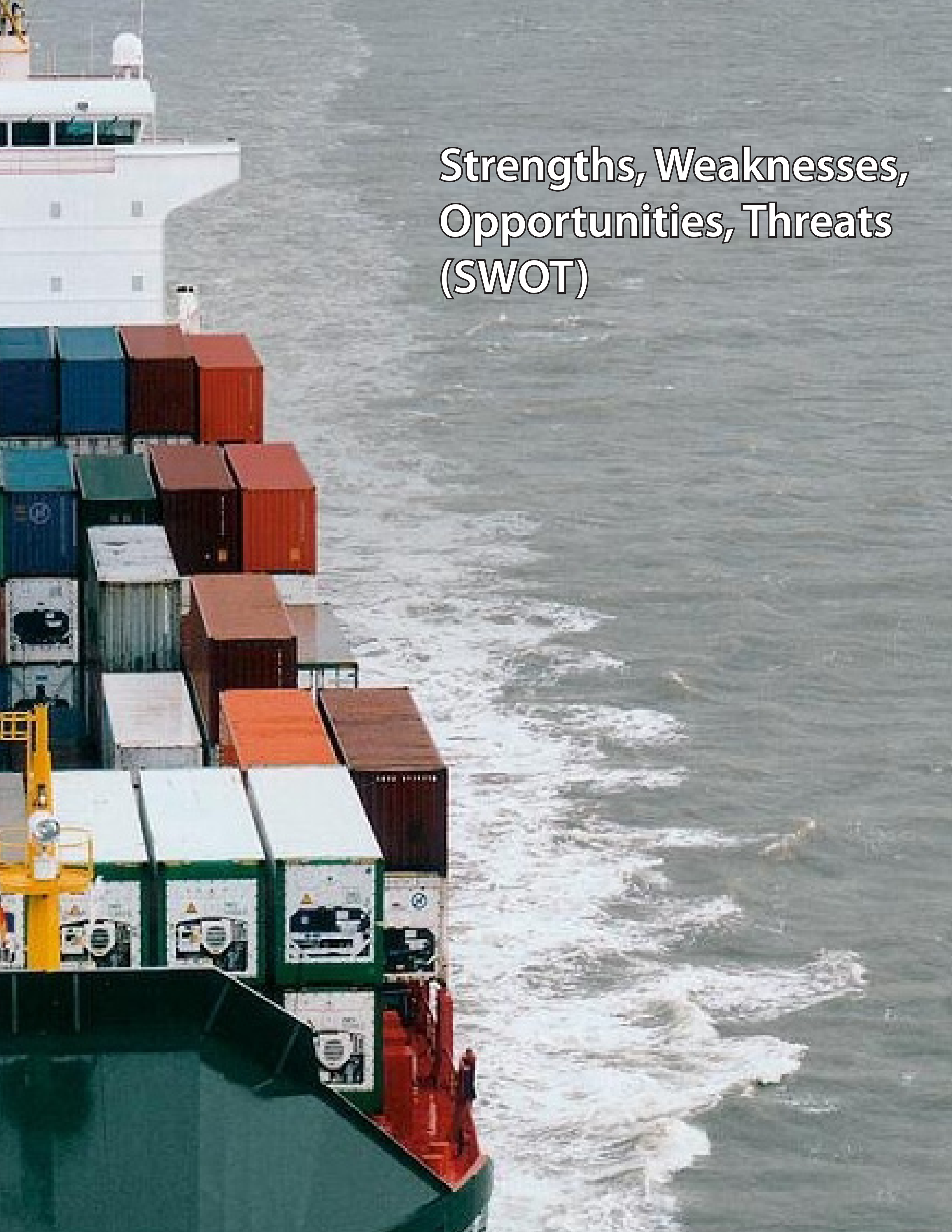
Figure 46: Aerial Baltimore Sea Level Rise

Figure 47: Baltimore Inner Harbor Sea Level Rise

Figure 48: Port of Baltimore Sea Level Rise

Figure 49: Water Treatment Plant Sea Level Rise

Strengths, Weaknesses, Opportunities, Threats (SWOT)



	Strengths	Weaknesses
Land Use	The most at-risk populations (low-income, elderly, minority, or disabled) are generally not located in areas at high risk for flooding due to sea level rise.	There are significant concentrations of low-income and minority residents in central city neighborhoods.
	High share of service, education, and government jobs provides an economic base which is more flexible and less fixed in place, as compared with manufacturing and ocean freight (still important). These industries are less likely to be impacted by climate change than the industrial, manufacturing, and shipping industries.	The central area of Baltimore City has very low tree canopy coverage and an extremely high percentage of impermeable surfaces. Both of these are contributors to the urban heat island effect, which will be further exacerbated by rising temperatures.
	Central city neighborhoods with high population density and mixed land uses will enable residents to meet more of their needs if they become temporarily isolated during storm events.	Freight logistics, industrial infrastructure, and some residential areas are located in areas that are likely to experience significant negative impacts due to rising sea levels and increased storm activity.
	Very strong land preservation programs for forests, wetlands, and agricultural lands at the state level and in most of the outlying counties. These programs enable local governments to control urban growth and limit the environmental impact of new development. These tools will become more important as temperatures and precipitation volumes increase.	The inner harbor area of downtown has been the site of large public and private investments over the last 30 years. Rising sea levels will threaten some of this area, particularly during storm events when storm surge becomes a possibility.
Water	The Waterfront Partnership has teamed with the National Aquarium to create the Healthy Harbor Initiative, a plan to restore Baltimore City's Inner Harbor by improving water quality and installing natural landscapes.	Sewage treatment plants are located along the shoreline and have already experience flooding. These facilities are vulnerable to sea-level rise, and could be damaged during strong storms.
	Baltimore has separate sanitary and stormwater systems and therefore does not face the challenges related to combined sewer overflow that many cities must deal with.	Baltimore City's urban runoff is discharged directly to the Inner Harbor. As the volume of storm precipitations increase, this will result in increased runoff of contaminants and therefore, decreased water quality in the Inner Harbor.

Opportunities	Threats
The national trend of central-city revitalization (migration of middle-class residents into formerly depressed areas) could increase the tax base in areas that are currently highly impoverished. This change could help build local resources for adaptation response in the most at-risk areas.	Highly-developed coastal areas are at significant risk of impacts from rising sea levels and more severe storms (and associated storm surges).
Warmer temperatures and higher CO2 levels will support more annual vegetation growth. Efforts to increase canopy coverage, establish riparian buffers, or re-establish coastal wetlands lost due to sea level rise could show faster benefits.	Urban revitalization efforts may be hampered by increasing temperatures - that will lead to more severe urban heat island effects - and more frequent flooding due to increased severe storms.
	Land use patterns change very slowly. Climate change adaptation strategies that require large shifts in development patterns will take decades to have significant effects.
With proper management, increasing precipitation could be an opportunity to replenish depleted aquifers and to store more fresh water for use during drought periods.	Higher rates of precipitation are likely to increase the amount of pollution carried by runoff into local streams, rivers, lakes.
There are strong connections between public, private, and non-profit actors who are already taking action to address water quality problems in the Chesapeake Bay. This network could be tapped to provide more coordinated climate change adaptation planning and respone mechanisms.	The wastewater treatment system will be stressed by an increase in extreme precipitation events.
There is significant interest in the local academic community related to green infrastructure innovation. Municipalities might have the opportunity to collaborate with researchers on innovate solutions.	Existing dams and water storage infrastructure will be significantly stressed during large storm events, which are predicted to increase.

	Strengths	Weaknesses
Energy	The Maryland Climate Change Commission, established in 2007 and comprised of public, private, research representatives, includes an Adaptation and Impacts working group that has focused on critical infrastructure and advocates for incorporating long term climate risk into existing planning processes.	Baltimore suffers from high electricty prices resulting from high energy grid congestion. This situation is likely to worsen as transmission loss and service disruptions increase as a result of extreme heat and strong storms. In addition, existing generating facilities and transmission infrastructure are aging, further amplifiying the risk of service disruptions, particularly during periods of peak demand.
	Increasing average temperatures will lower demand for natural gas and other heating fuels.	The governance of energy policy within the state and region is fractured. There is no long-term, integrated energy planning, despite the long lead-time associated with energy infrastructure projects, which are capital and planning-intensive.
	Baltimore and the State of Maryland has a political culture that accepts the science behind climate change, and they have demonstrated leadership on energy efficiency and climate-related policy.	Much of the region's commercial and residential building stock is old and not energy efficient, placing a higher than average energy demand on the grid. Furthermore, the oldest and least efficient structures tend to be located in the central city, where many residents do not have the fiscal capacity to invest in improvements.
	Baltimore is located near ample renewable energy sources, especially offshore wind. There are also significant existing energy efficiency and renewable energy programs to build off of, such as the Maryland Smart Grid plan, and a downtown combined heating and cooling district.	Increasing temperatures will reduce transmission/ generation efficiency while simultaneously increasing electricity demand for cooling purposes. These forces are likely to require new infrastructure investments to avoid outages during peak demand periods.
Human Health	Releases of air pollutants and VOC's that react to form ozone have been on the decline in recent decades. This shows that an effective political and policy framework exists to reduce air pollution.	Poor and elderly residents are the most at-risk groups for human health impacts of climate change because they are more likely to have pre-existing health conditions. These residents tend to be concentrated in older, central-city neighborhoods within Baltimore City.
	Maryland's public health system is well-equipped to handle increased threats from pathogenic disease, which are predicted to increase with warmer temperatures and more precipitation.	The existing Health Service Network will be stressed due to a likely increase in the incidence of heat, cold, and precipitation-related illnesses.
	Existing disease surveillance programs in place to control vector-borne diseases: The Maryland Department of Agriculture's Mosquito Control Service, The State of Maryland's arthropod-born disease control program, and the National Wildlife refuge system's mosquito-born disease management policy.	Predicted temperature increases in the Baltimore region are likely to result in significantly higher concentrations of ground-level ozone during warm months. Exposure to ozone has negative health impacts and will be most pronounced in those who work outdoors (such as landscaping and construction workers).
	Maryland has several current/proposed policies to address coordination of health systems and responses including: the Vector-borne Surveillance and Control Program, interagency coordination policies, and Health Impact Assessment.	Baltimore is at high risk for increased heat mortality as temperatures increase: Baltimore is the east coast city with the highest rate of increased mortality at temperatures above the Minimum Mortality Temperature (the temperature above which heat-related deaths increase steadily).
		Baltimore is not well equipped to respond to extreme snow events, making vulnerable populations more isolated and at-risk during extreme snow events. Although somewhat rare in the area, these events are predicted to become more severe when they do occur.

Opportunities	Threats
Energy efficiency programs have the potential to address both mitigation and adaptation in the Greater Baltimore area: Industrial/Commercial energy efficiency strengthens the resilience of the local economy; Residential energy efficiency saves money for residents and helps offset increases in energy demand.	Increasing sea levels will disrupt low lying energy generating facilities and transmission infrastructure, which in Baltimore represents significant existing assets. Existing petroleum and waste-to-energy facilities are also vulnerable to sea level rise.
There is a strong potential to partially meet increased energy demand with renewable resources. Proximity to substantial offshore wind resources on Outer Continental Shelf presents the opportunity to reduce congestion, lower prices, and increase economic activity while increasing the reliability and resilience of Baltimore's energy sector.	Natural gas importation, primarily from the Gulf of Mexico, leaves the Baltimore region vulnerable to disruptions in energy supply and increased price volatility, due to severe storms in the Gulf.
Distributed energy generation could be used to reduce transmission losses by locating generation closer to the point of consumption. This also reduces the need to build expensive new transmission infrastructure, land acquisition costs, and energy waste. This is particularly true for industrial consumers.	
Resilient, clean and distributed energy generation compliments present and future Chesapeake Bay Watershed management plans by reducing pollution.	
Other U.S. cities have developed heat response plans that could be used as models. These plans often include: pro-active preparation, meteorology-based warning systems, rapid and coordinated response during heat waves, and criteria for deactivating response measures.	Increased heavy precipitation events are likely to cause increased rates of septic system failure, leading to groundwater and stream contamination.
New York has already developed a preliminary winter weather response plan that Baltimore could use to develop their own. There are many east coast cities that are in a similar situation as Baltimore with an increase in extreme winter weather events.	Aging of the U.S. population (in particular, the baby boom generation) will result in higher numbers of at-risk persons over time.
	With increase precipitation, runoff from urban area and agriculture will increase the concentration of toxins and pollutants getting into the water supply, and decrease the quality of fresh drinking water
	Warmer temperatures and longer warm seasons allow for the increased growth of algae and bacteria that lead to reduced water quality and increased fish kills

	Strengths	Weaknesses
Transportation	Redundant roadway networks are important for maintaining mobility during flood events. Existing roadway infrastructure in Baltimore has significant redundancy both within the city and in outlying areas. This is especially true along the busy I-95 corridor.	The Francis Scott Key Bridge, which spans the outer Baltimore Harbor, will loose clearance space as sea levels rise. This may restrict the type of vessels that are able to access the port: large container ships and ocean liners will be particularly effected.
	Multi-modal transportation networks provide users with options other than driving, which is important both for mitigation efforts and during extreme events when private transportation systems become less reliable.	The regional transit system does not serve all areas equally. Some areas are auto-dependent, with little transit service available. Others are well served by various transit modes (bus, light rail, and commuter rail).
	Within the Baltimore region, light rail, subway, commuter rail and bus provide transit services, mostly located in the central business district and areas south and northwest of the city.	Although the region has significant transportation network redundancy, all modes of transportation are vulnerable to increased flooding and erosin as a result of more intense precipitation and more frequent strong storms.
	The Baltimore region has strong inter-city transportation links to other cities along the I-95 corridor, especially Washington D.C. Both AMTRAK and MARC provide commuter rail service between the cities in addition to the primary freeway links: I-95 and HWY-295.	
	The Port of Baltimore is a nationally significant seaport with links to multiple freight rail and freeway systems.	
Cross Cutting	Coordination between governments is the norm in the Baltimore region. The small number of autonomous governments implies that working with each other and the State to plan and implement climate change adaptation strategies will be easier than in many places. (all)	Wastewater treatment facilities are located along the shoreline, making them vulnerable to inundation due to sea level rise generally, and particularly to storm surge during Atlantic hurricanes. Flooding of these facilities will result in serious impacts to water quality, ecosystem health, fisheries, and water-borne diseases. (HH, W, LU)
	The State of Maryland is considered a leader on climate change mitigation and adaptation planning: The Maryland Commission on Climate Change provides good state-level leadership for climate change research, as well as adaptation and response efforts. The State's comprehensive strategy for addressing climate change includes key recommendations for policy change, and strategies to adapt to impacts such as sea level, storm, and coastal erosion, and protecting and restoring wetlands.(all)	The dense urban environment of the Baltimore region, typically home to disadvantaged populations, make it vulnerable urban heat island effect. As temperatures increase in the region, this effect will become more severe with serious implications for human health (heat stroke, cardiovascular stress) and energy use (increased cooling days, increased peak energy demand, decreased transmission efficiency). Low tree canopy coverage contributes to these impacts. (E, HH, LU)
	The region is well resourced, with a high median household income, and access to multiple highly-respected universities. While this is not true for all areas (most notably in central Baltimore), on the whole, individuals in the region are well-equipped to respond to the challenges of climate change. (all)	

Opportunities	Threats
Warmer temperatures could extend the shipping season, increasing activity at the Port of Baltimore.	Rail, light rail, subway, and highway tunnels in or near existing floodplains have the potential to be affected by flooding.
The Existing transit network is scalable and could be expanded to increase transportation redundancy in areas that are poorly served.	Due to sea level rise and shoreline change, Port of Baltimore infrastructure might have to be rebuilt to resist encroaching waters and to continue to operate efficiently.
Many other coastal cities will face a range of similar threats related to increased temperature, changing precipitation patterns and sea level rise, including nearby Washington D.C. There are many opportunities to learn and collaborate. (all)	The Port of Baltimore represents over 20% of the City of Baltimore's employment base and is a major logistics hub for international freight on the east coast. This port is likely to experience significant challenges associated with sea level rise (expensive retrofits, loss of land area) and more frequent storms (damage, service interruptions). (LU, T)
Tradition of regional response to water quality issues in the Chesapeake Bay provides a model for regional cooperation in response to environmental problems. Sea level rise and increased runoff due to more frequent extreme precipitation are directly relevant to the existing efforts in the Bay. (all)	Warmer temperatures could result in new invasive insect infestations that damage/kill important tree species. This would have the dual effect of reducing the tree canopy and making heat island effect more severe. (HH, LU)
	Baltimore's transportation energy sector is dependent on commodities that are subject to disruption from climate change. Transportation fuels, especially low carbon blends, are imported from other U.S. states, despite significant existing refining capacity. This makes the Baltimore region vulnerable to disruptions in supply from agriculture-related climate impacts in other regions, and price volatility in both commodities and transportation costs. (T, E, LU)

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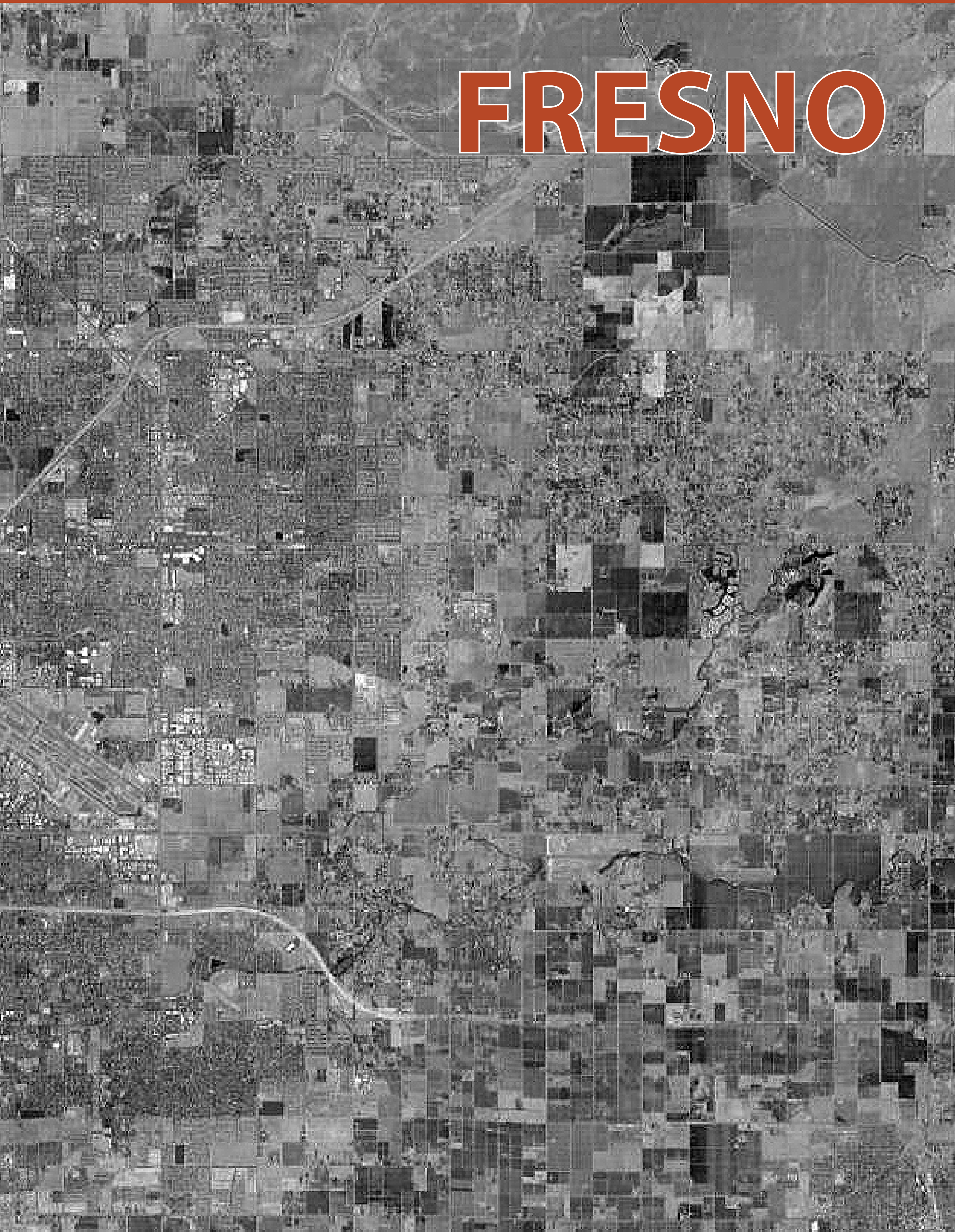
FRESNO



Fresno

Introduction

In examining climate change adaptation in U.S. cities, we wanted to include a city where extreme heat and dwindling fresh water resources will be the primary threats. We chose Fresno because of its location in the water-constrained San Joaquin River Valley, powerful agricultural industry, large number of low-income and minority residents and workers, and because of its reliance on hydroelectric energy generation. In this section, we will revisit the key climate change risks for the Fresno region, followed by a look at the region's existing characteristics and economy. In the sections that follow, we explore five major sectors: land use, water, energy, human health, and transportation. We analyze each sector in terms of how the predicted climate change in Fresno is likely to disrupt historic patterns, resulting in new challenges or opportunities. We use geographic information systems (GIS), to identify vulnerable populations that will be disproportionately impacted by extreme heat, and we conclude our analysis with a systematic look at Strengths, Weaknesses, Opportunities, and Threats (SWOT) for the Fresno region in adapting to climate change.

Climate Change Risks

Rising temperatures, extreme heat, and a reduced availability of fresh water resources are the most significant climate change risks for the Fresno area. Temperatures are predicted to increase between 4 and 5 degrees Fahrenheit by mid-century and between 6 degrees Fahrenheit and 10 degrees Fahrenheit by 2100 (7). Resulting from these changes in temperature trends, there will also be an increase in extreme heat events. Impacts of extreme temperature will be most

Figure 50: Downtown Fresno

severe in urban areas with intense development, large parking lots and little shade. Outdoor workers and low-income families will be hit hardest by these changes because they are the least likely to be able to find safe refuge from the heat. Increased heat events will likely also impact the health of ecosystems in Fresno County and lead to shifts in species and vegetation ranges or possibly even extinctions. This shift will likely lead to changes in insect reproduction and disease resistance. Higher heat and lower precipitations will allow for longer reproduction times and a greater impact on both crops and human health. Furthermore, prolonged dry spells will lead to drier trees, brush and natural grasses which can easily lead to wildfires.

Precipitation patterns will also change, with more winter and spring precipitation coming as rain, rather than snow. This will reduce the snow pack by 30-60 percent in the Sierra Nevada Mountains that feed the San Joaquin River, the major source of fresh water in the region (1). Therefore, it is likely that Fresno will see increased competition for water resources as the century progresses. More intense precipitation events are also likely to negatively impact the City through increased flooding risks. Although Fresno has been preparing and designing storm water management systems for flood events, the region is still unprepared for massive flash flooding. Flooding from increased precipitation may wipe out crops, damage soils, lead to runoff, sewer overflows and increased pollutants in the ground water, as well as disproportionately impact lower income residents. Development in floodplains is typically older lower income housing or mobile home communities, both of which would be heavily impacted by massive flood events.

Existing Characteristics

The City

The City of Fresno is located in the heart of the San Joaquin Valley, 170 miles south of Sacramento and 200 miles north of Los Angeles. The City covers an area of 104 square miles, and since the mid 1990s has experienced a tremendous increase in its population. From 1990 to 2000, the City's population increased from 354,202 to an estimated 500,017, making it the fifth-most populous city in the State of California (66). Population growth is projected to continue into the next few decades with a population of 590,767 anticipated by 2020 (67). This growth trend is evident across all of Fresno County, and population increases of 58 percent are projected within the next 20 years (67). Immigration plays a major factor in the population increase, due to the influx of seasonal agricultural workers during harvest season. As more immigrants migrate to the City, more affluent community members tend to move to the suburbs, resulting in a rapid expansion of the urban area.

Paralleling the increase in population, the physical infrastructure and size of the city has continued to grow. Steady growth brings many economic, social, and educational benefits to the community. However, these benefits also bring new concerns and challenges. For example, as new immigrants move into the older central City, demand for public services increases, while the more affluent residents move outside jurisdictional boundaries. The result is a decline in the City's capacity to support the services that new, low-income migrants often need, an increase in conversion of agricultural and natural land at the urban fringe, and a decline in quality of older neighborhoods in the central city.

Growth patterns have led to a spatial divide between higher and lower income residents within the region. Because more affluent residents tend to cluster together in municipalities with few low-income residents, these neighborhoods can support high-quality services and public amenities, while areas in the city center have been neglected. Today this trend is apparent in the Fulton Mall downtown, which is used primarily by low-income residents. In this area, all the fountains are shut down, and the maintenance of public spaces has been neglected. Some have even called for the City to approve the reopening of the pedestrian mall to automobile traffic (68).

The Region

Metropolitan Fresno is the second largest metropolitan area in the San Joaquin Valley with a population of 1,107,416 people. The County consists of 8,099 square miles, making it one of the most populated counties in the State of California. The Metropolitan area consists of both Fresno and Madera counties in which the City of Fresno makes up the largest portion of the population and largest land area. Similar to the City of Fresno, growth in the Metropolitan Fresno region is expected to increase at a rapid pace through 2025 (67). However, the most recent predictions were made before the economic downturn in 2008. With the poor economic conditions, growth rates in the region have slowed down. Yet, the Fresno region's population continues to increase gradually despite the economic recession (68). The Fresno General Plan for 2025 acknowledges this growth trend and proposes a variety of alternative development strategies to combat potential sprawl in the region. This plan focuses on urban infill, transit oriented development, more efficient land use and improving older neighborhoods, as opposed to a continued emphasis on suburban expansion.

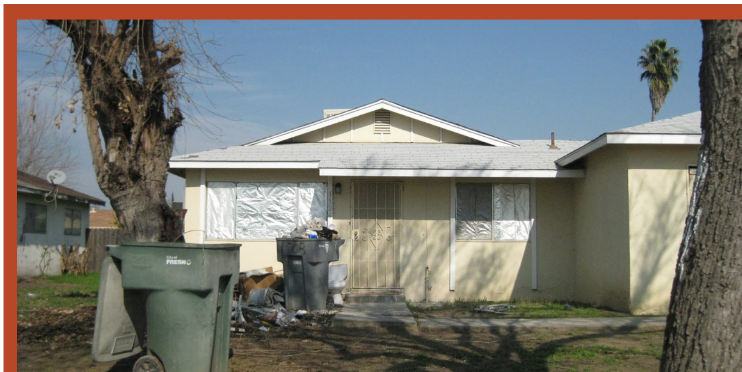


Figure 51: House in Western Fresno

Figure 52: House in Northern Fresno

Demographics

Like most Southern California cities, Fresno has a large Hispanic population that makes up nearly 45 percent of the community. According to the American Community Survey, 33 percent of the population identifies themselves as white while 11 percent identify as Asian and 7.5 percent as Black (66). The region has historically been made up of large populations of immigrants; as of 2000 over 20 percent of Fresno's residents were born in a foreign country (69). According to the 2000 US Census, 40 percent of Fresno's foreign-born residents arrived in the region after 1990, adding substantially to the City's population growth (66).

A large proportion of the city's minority residents are below the poverty level. Within the City of Fresno 19.2 percent of families are below poverty level and 31.7 percent of children are below the poverty level, which is a much higher proportion when compared with other metropolitan areas in the United States (66). Although this is a trend seen throughout many central California cities, Fresno has one of the highest concentrations of poverty in the entire United States with 43.5 percent of poor individuals living in high-poverty neighborhoods in 2000 (70).

Geographically, poverty rates have increased in the south and western portions of the region where most immigrant populations reside. From 1990 to 2000 the greatest increases in poverty concentrations were in downtown and areas directly surrounding downtown Fresno. That trend continues today and most middle and upper-class residents continue to move further away from the city center to the suburbs or the more prosperous City of Clovis. High poverty rates put a large number of Fresno's residents at risk to the impacts of climate change. Additionally, a large number of immigrants make up the seasonal workforce within the Fresno region. Employment opportunities are limited for lower income residents, and the highest proportion of workers without high school diplomas in the region work in agriculture (70). The cyclical situation that occurs with many low-income communities throughout the country is apparent in Fresno, with low quality housing options, low-performing schools and higher crime rates prevalent in low-income areas (71).

2006-2008 American Community Suv.	City of Fresno	Fresno County	United States
Total Population	472,179	895,357	301,237,703
Total Housing Units	164,334	304,156	127,762,925
Average Household Income	$60,677	$62,683	$71,128
Percent of families below the poverty level	19.2%	16.5%	9.6%
Unemployment Rate	8.0%	8.6%	4.1%

Table 5: Fresno Demographic Information

The Economy

Due to its excellent soil quality, Fresno County has the top agricultural production of any county in the United States with over $3.7 billion in sales in 2007 (73). The county produces 60 percent of the world's raisins and 90 percent of the raisins consumed in the United States. Preservation of agricultural land has historically been a high priority for the community, however with increases in the cost of water, energy, fuel and fertilizers, many farmers in the region have been unable to succeed (8). Increased costs of farming along with pressure to sell land for development are both serious threats to the prosperity of agriculture in the Fresno region.

Like most cities in the U.S., Fresno currently suffers from the after-effects of the global economic recession of 2009. A 20 percent decrease in local sales, property, and motor vehicle tax revenues have led to a $30 million operating deficit in fiscal year 2011. Fiscal constraints have drastically reduced funding for some of the most essential city departments for long-term climate change planning, including 60 and 70 percent funding reductions for Fresno's Resource Management and Public Works departments. Sustainability efforts appear to be on-hold for now, as the city tries desperately to maintain basic city services. For a more detailed look at the City of Fresno's budget, see Appendix A.

Agriculture

Due to the increasing growth rate in the City of Fresno, in recent years much of the land near the urban boundary intended for agriculture was converted to accommodate new residential and commercial development. Most agricultural production now occurs within the surrounding Fresno County rather than within the City's borders. According to the 2007 Agricultural Census, Fresno County has 6,081 farms that span over 1,636,224 acres, 1,102,163 acres of which are cropland. The County is the number one agricultural county in the United States and produces over 350 commercial crops (74). Most of the crops produced in the area are heat tolerant crops such as cotton, sorghum, fruits, and vegetables.

The agricultural industry is one of the top employers in Fresno County. It is estimated that over 20 percent of the total population in Fresno are employed in the agricultural industry, and that it contributes over $3.5 billion to the local economy each year (75). Major food processing centers have developed in the area and today there are numerous canning, curing, drying and freezing plants located in the region (75).

Increased temperatures, more frequent flooding, and increased scarcity for water resources are likely to have dramatic impacts on the agricultural industry that the area so heavily depends on. Increases in temperature could have drastic consequences on the inland climate and further warming may exceed heat-tolerance levels for many of the crops and livestock currently farmed in the region. Loss of crops due to heat, drought, and flooding will reverberate throughout the county and effect not only farmers, but their employees, related industries, and the local governments.

Land Use

History of Development

Until the construction of the Central Pacific Railroad through San Joaquin Valley in late 1872, Fresno was mostly uninhabited. When the railroad was constructed, the builders also laid out a small town around the rail station that still exists as the core of the city today. The construction of the railroad is what initially put Fresno on the map and residents of the communities surrounding the San Joaquin River slowly began to migrate to the Fresno area. This was especially true of the City of Millerton where nearly the entire population moved to Fresno after the rail line was developed. Despite this rapid growth, for the first 70 years of the City's existence urban development stayed relatively contained within a small area.

Massive floods made settling in Fresno difficult and the substantial fires of 1882 and 1883 devastated large portions of the western city. Despite these natural disasters, Fresno grew in population and size when irrigation became available through the Fresno Canal and Land Company in 1876. With irrigation, many new immigrants were able to purchase farmland and begin to cultivate crops. The City incorporated in 1885 and drafted its first charter in 1900 as the agriculture industry began to boom. In 1920 the Fresno Irrigation District was formed under the California Irrigation Districts Act as a successor to the Fresno Canal and Land Company. Today the district controls 800 miles of canals and pipelines that provide irrigation to over 150,000 acres of Fresno County land (72).

With the increase in suburban development after World War II, conversion of agricultural land to meet growing population needs increased dramatically, and a great deal of row crop and orchard land was lost to sprawling development patterns. This growth continued into the 1980s, when Fresno was the fastest-growing big city in the United States, with a growth rate of 61.3 percent. Almost all of this growth took the form of new suburban development. Migration away from the city center continued well into the early 2000s as population continued to increase. During this time, large numbers of immigrant families that arrived in the Los Angeles and San Francisco metropolitan areas left these crowded, expensive areas for the lower living costs and open space in Fresno.

Today, although agriculture still plays a prominent role in the economy, most agricultural land in the area is outside of the city limits. The urban and suburban portions of the City have shifted to housing and services like education, government and health care. This shift has lead to the conversion of large amounts of agricultural land (Fresno County lost over 15 percent of its farmland from 2002 to 2007 alone) (2), and disputes between rural and urban communities over resources such as water.

Fresno's first industry was timber production. Virgin timber was harvested and floated down the San Joaquin River to mills in other areas of the Valley. After the Civil War, demand for wool increased and the region shifted from a focus on lumber to sheepherding. Sheepherding lead to an increase in cattle, and in the late 1800s the region became the country's leading cattle producer. The Friant Dam was built by the U.S. Bureau of Reclamation on the upper San Joaquin River in the Sierra Nevada hills and completed in 1944. The dam created the Millerton Lake, which provides water for irrigation to the entire San Joaquin Valley as well as hydroelectricity for a portion of the region. When irrigation reached the Valley, agricultural production soon exploded. The Valley soon became the number one agricultural region in the nation. As with timber, wool, and cattle, agriculture could be slowly phased out as the primary economic driver in the area. Banking and medicine are increasingly becoming primary employers in the region.

Natural Features

The City of Fresno is located in the center of the San Joaquin Valley in the south-central portion of the state of California. The Valley is an extensive area of flat land that lies between the Sierra Nevada range in the east and the Coast range in the west. Elevation within the County ranges from 300 feet in the Valley up to 14,000 feet in the Sierra Nevada Mountains (4). The Sierra Nevada Mountain Range is primarily owned by the U.S. Forest and Park Service and is home to some of the most recognizable U.S. National Parks, including Yosemite, Sequoia, and Kings Canyon.

There are three different land use regions in Fresno County: West Coastal Foothills Region with hot summers and light rain, Central Valley Floor with hot dry summers and humid winters, and the Eastern Sierra Nevada Region with cooler summers and snowy winters. The San Joaquin Valley was a fairly wet place when settlers first arrived in Fresno. The groundwater that flowed north into the Sacramento River delta provided a riparian habitat of freshwater lakes and marshes that supported diverse wildlife. However, the construction of over 1,400 federal and state dams resulted in the draining of the valley as groundwater was diverted for irrigation and human consumption. Today there are very few wet areas in the City of Fresno (less than ½ square mile out of over 100 square miles of total land area within the city) (66).

Figure 53: The San Joaquin Valley extends from Sacramento in the North to the Tehachapi Mountains in the South

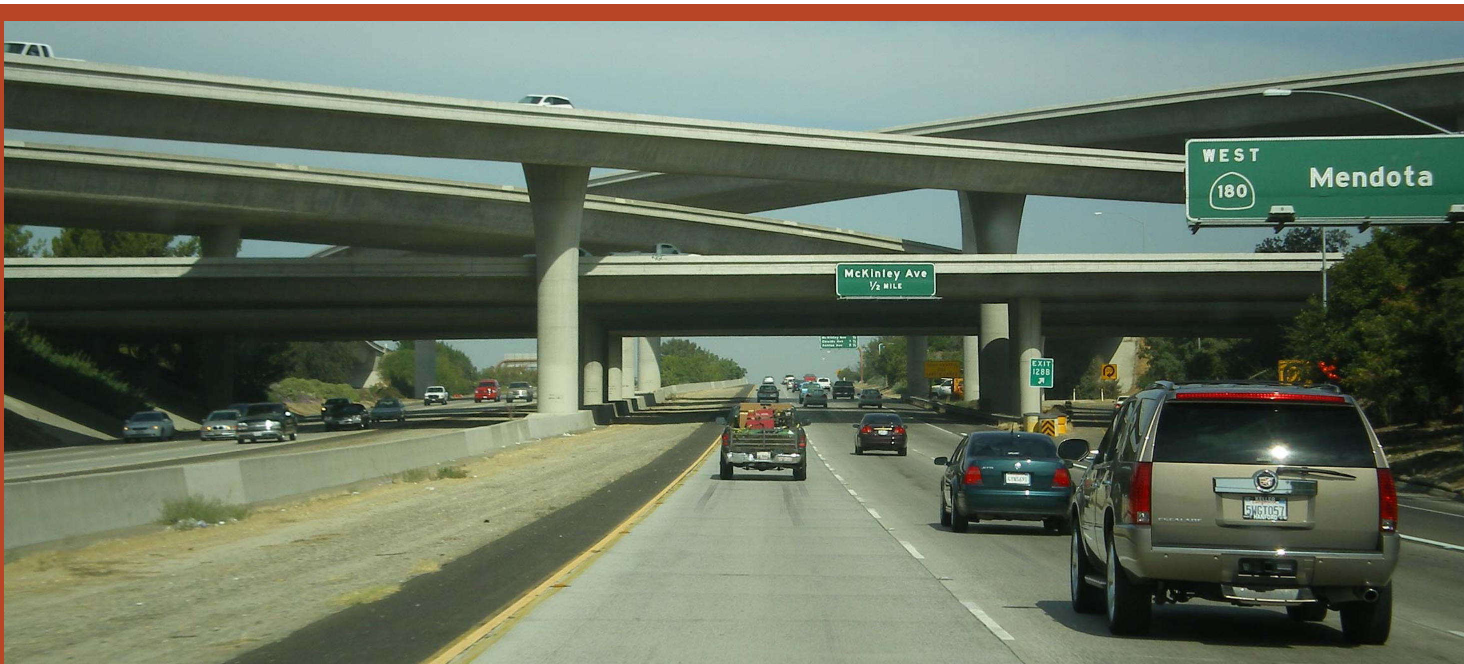


Figure 54: Highways provide quick easy auto transportation and are the spine of Fresno's autocentric transportation system

Figure 55: Wide streets and sprawling strip mall development are characteristic of land use patterns in Fresno

Existing Land Use Pattern

The City of Fresno's land use patterns and zoning are typical of many late 20th century western cities. The aging central business district is surrounded by suburban residential and strip commercial developments, with large lot residential and commercial growth continually pushing the urban area outward. The City's comprehensive plan outlines a much different strategy for development that incorporates mixed uses and urban infill development, while preserving agricultural areas. However, despite the plan for more compact growth, the City continues to approve developments of strip malls and subdivisions in outlying areas (68). Fresno's freeway network is unusually large for a city of its size, and dominates the City's landscape. As a result, the City rarely suffers from traffic congestion. This extensive freeway system enabled the growth patterns seen in the region today, with most new development occurring at the outer edges of the urban area.

Fresno has not moved to implement more efficient growth patterns indicated in their comprehensive plan. Instead, the City is encouraging planned growth at the edge by generating master plans for designated growth areas along the city borders. One such area is called the Southeast Growth Area (SEGA). Here, city planners are focused on pre-planning the site in anticipation of new development, with an agricultural buffer, activity centers, corridor structures, and a potential Bus Rapid Transit stop directly in the center. Meanwhile, these developments continue to pull businesses and residents away from the struggling downtown.

Fresno's city center is mainly abandoned and most residents only visit downtown for an occasional baseball game or large event at the convention center. Currently, downtown spaces consist primarily of struggling stores along major corridors, such as Fulton Mall -- a six-block-long outdoor pedestrian mall. Large industrial lots and surface parking areas divide the downtown from all residential development, and after sunset, the area is deserted.

Local Land Use Regulations

General Plan

There are nine existing Community Plan areas in the City of Fresno that act as guidelines for city development and outline existing conditions within each area. These Community Plans were updated in 1964, 1974 and in 1984, but have not been updated since (67). The City began updating their comprehensive plan every ten years after adopting a Local Planning and Procedures Ordinance in 1987 (67). In accordance with the California State Planning and Zoning Law, the General Plan addresses seven mandatory categories: land use, circulation, housing, conservation, open space, noise, and safety (67). Due to increased demands on infrastructure and public services, the City also included additional considerations such as recreation, energy use, and public services.

Land use decisions and designations made by the City of Fresno are also highly impacted by decisions made in the surrounding counties and cities such as Fresno County, Madera County, and the Cities of Clovis and Sanger. In 1983, the City of Fresno collaborated with the City of Clovis and Fresno County to generate a Joint Planning Resolution, which outlines how all three of the municipalities should work together on urban growth management and land use policy. This agreement, in addition to a 1991 Memorandum of Understanding (MOU), allows the City and County of Fresno to coordinate on land use issues such as spheres of influence, fringe development, land annexation, and policy changes.

The most recently adopted 2025 Fresno General Plan de-emphasizes the traditional paradigm of suburban land use patterns and refocuses on a new urban form for the future. Under this plan, the region would direct much new growth within the boundaries of the City of Fresno, resulting in approximately 61 percent of Fresno County residents living within the proposed Fresno urban boundary by 2025. This plan represents the hope that the anticipated California High Speed Rail (HSR) will pass through downtown Fresno, sparking renewed interest in the aging downtown. The plan also indicates that the City hopes to create a bus rapid transit system (BRT) to connect residents with the high-speed intercity rail, and allow more people who work in areas like San Francisco to reside in Fresno, using the HSR for long-distance commuting.

Within the existing urban boundary, the City of Fresno is made up of nine designated community plan areas, each of which is expected to have a tremendous increase in population within the next 15 years (table of population projection by community areas). The City Planning Department's focus over the last few years has centered on the generation of three major growth areas beyond the existing Fresno urban boundary. Two of those areas are in the Southeast portion of the city and the third area is directly to the north (see map). Although city planners have developed very detailed growth strategies that will help maximize the efficient use of land while accommodating the increase in population, planners are relying heavily on a proposed BRT system to help curb the increase in auto dependency that will accommodate growth in these areas. The city expects to accommodate up to 790,000 people within its boundary by 2025 with 65,000 of those people living in the three designated growth areas (67). Since each growth area is on the outer edge of the city, it remains to be seen if this strategy can curb suburban expansion into natural and agricultural areas.

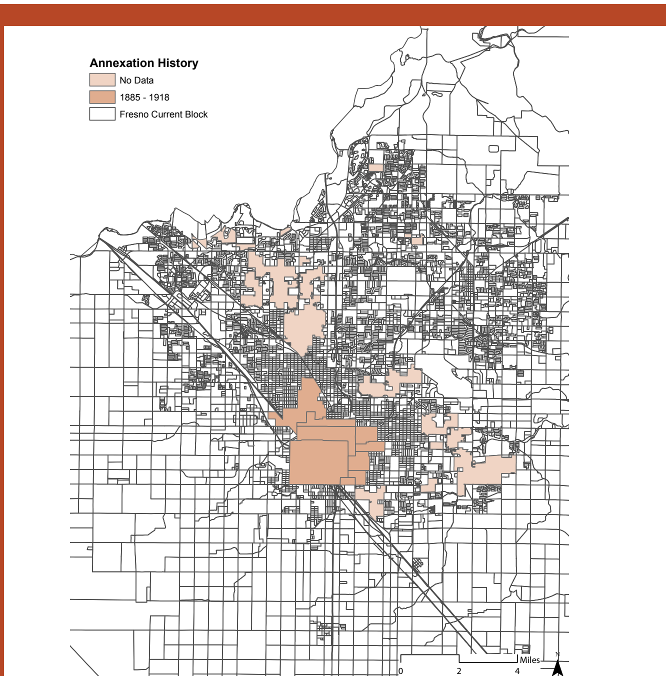


Figure 56: Annexation History 1885-1909

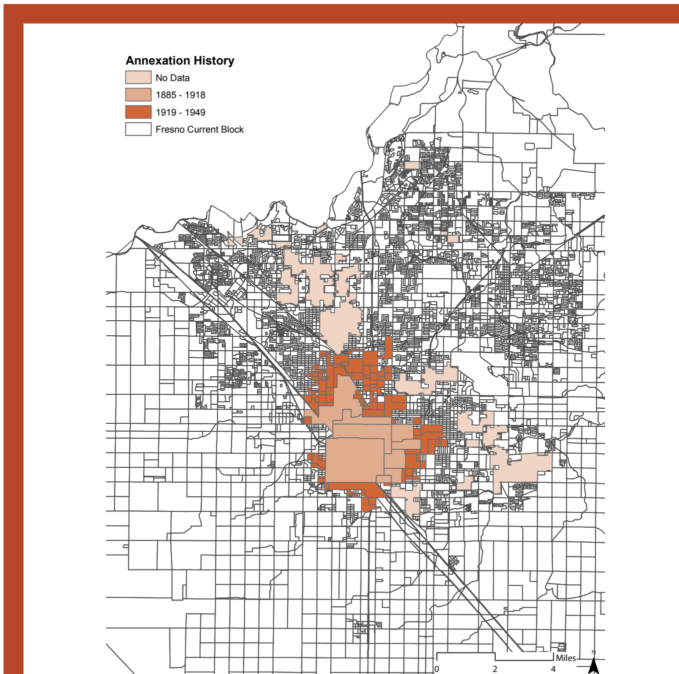


Figure 57: Annexation History 1910-1934

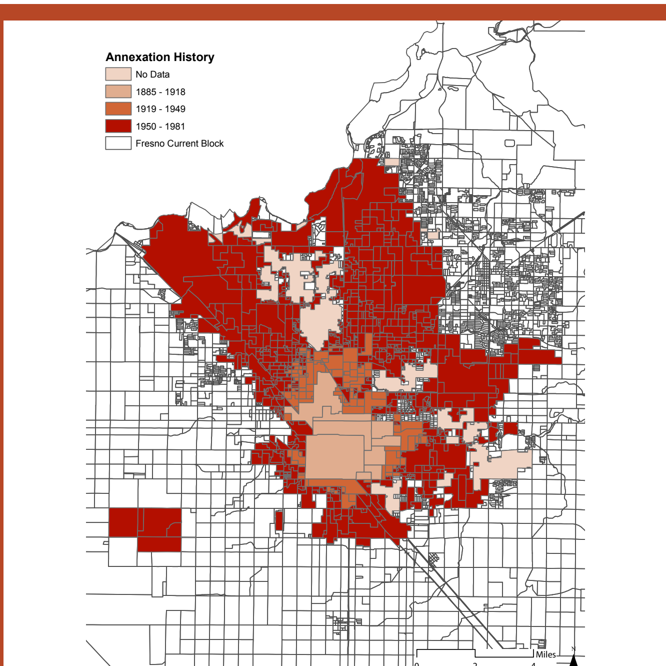


Figure 58: Annexation History 1935-1970

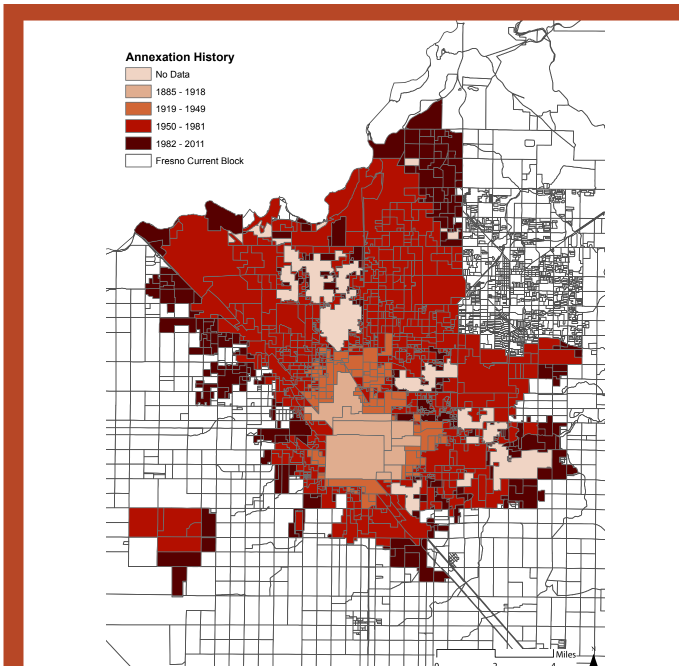


Figure 59: Annexation History 1971-2010

Water

Introduction

Experts project climate change impacts will alter the timing and the intensity of precipitation, which will create increased variation in both periods of drought and flooding to the dry Fresno climate. The increase in temperatures will affect the quantity of water available in rivers, aquifers, and reservoirs throughout the year as winter precipitation begins later and spring snowmelt occurs earlier. As Fresno primarily relies on groundwater and treated surface water for its residents, these changes in the water systems will impact water usage, water management, and water quality for residents in the Fresno area. Increases in drought periods will decrease the amount of water available to use in everyday households as well as the amount available that feeds Fresno's $5 billion agricultural industry (1). While there are real issues of water resource shortages in the future, Fresno residents currently use an average of nearly 300 gallons of water per day, one of the highest in the United States. A rapidly growing population combined with these projected trends will further complicate water issues for the City of Fresno.

Water Infrastructure

Water Resources

The City of Fresno relies mainly on groundwater along with treated surface water to provide for its citizens. Over 250 wells obtain groundwater stored in aquifers to provide about 146 million gallons of water per day for the residents of Fresno. The Fresno Water Division servicing the municipality delivers drinking water to 131,000 residential, commercial, and industrial customers in a 112 square mile area, and in 2008, the Water Division served 502,657 customers. To supplement the groundwater reliance, the Surface Water Treatment Facility (SFTF) receives water from the Enterprise Canal. The Enterprise Canal pulls water from the Sierras that flows into the San Joaquin and King's River, which the SWTF uses to generate about 20 million gallons of water per day. (2)

Fresno's overreliance on groundwater has resulted in aquifers being overdrawn 100 feet – the last 30 feet having occurred in just the past 10 years. Lower water tables not only require additional energy to pump groundwater from deeper in the ground, but the quality of the water may decrease. To prevent overdraft, the City uses its entitlements from the US Bureau of Reclamation and the Fresno Irrigation District to obtain water from Millerton Lake and Pine Flat Dam, respectively, to recharge groundwater aquifers at Leaky Acres. Leaky Acres, the City's 100-acre recharge facility, averages about 14 million gallons of water recharge per day. (16) Currently, the City is looking to improve its infrastructure and to decrease its dependence on groundwater by shifting its focus towards treated surface water, which would be 18 percent more energy efficient (17).

The price of water in Fresno is one of the lowest in the nation. The majority of residents pay a flat rate because water use metering is not required. Unmetered households pay an average of less than $25 per month, while those under a metered system pay anywhere from $0.81 to $1.00 per 1,000 gallons of water. (16) The low cost of water may contribute to the fact that Fresno residents use an average of 300 gallons of water per day per person, one of the highest in the United States. Decision makers are looking to increase prices in order to provide additional sources of funding to improve infrastructure and efficiency (17).

The Fresno Irrigation District (FID) provides the majority of its water to agricultural users and some water is used for groundwater recharge. The FID consists of 245,000 acres and operates over 800 miles of canals and pipelines. Through this, the FID provides about 500,000 acre-feet of water each year for irrigation and recharge. The FID acquires most of its water from the Pine Flat Dam and from the Friant Division. Pine Flat Dam contracts 11.9 percent of its 1,000,000 annual acre-feet of water to the FID and the Friant Division has contracted to sell 135,000 acre-feet per year to the FID. The FID is entitled to 26 percent of the runoff from the King's River, which feeds the Pine Flat Dam. (3)

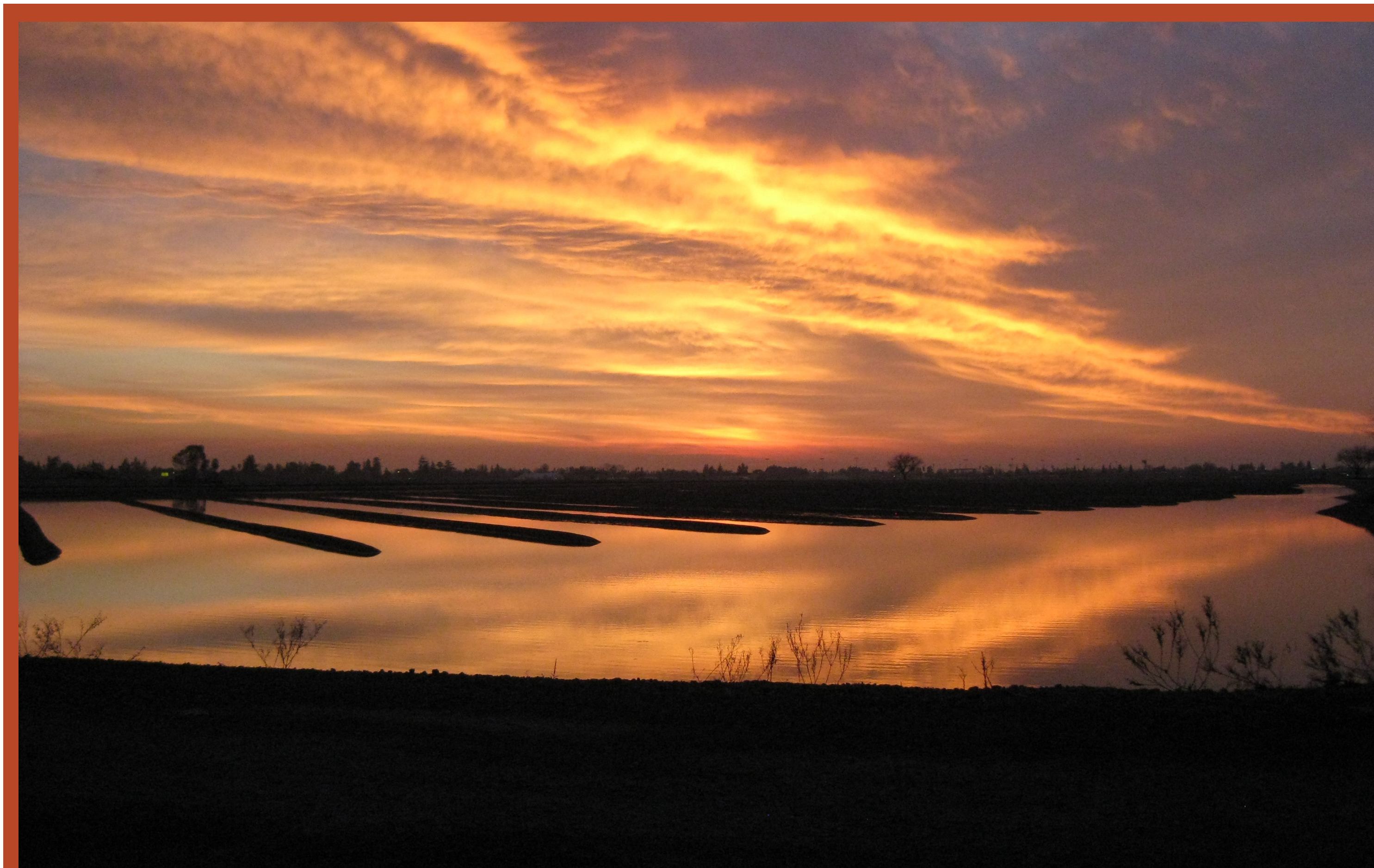


Figure 60: Leaky Acres, Fresno's 100-acre recharge facility, averages about 14 million gallons of water recharge per day

Drainage and Flood Control

Fresno Metropolitan Flood Control District (FMFCD) manages runoff, storm water and wastewater in order to provide drainage and prevent flooding through the use of storm drains, detention and retention ponds, and pumps. The service area covers both urban and rural areas in the central Fresno County area that includes both the City of Fresno and the City of Clovis. This 400 square mile area between the San Joaquin River and the King's River provides 700 miles of pipelines and 152 retention basins. The District captures almost 90 percent of all storm runoff, which enhances water quality and water supply in the area. The District also partners with local agencies to assist in groundwater recharge. During storm events, storm water inlets carry water to the pipelines, which then connect to retention basins. Eighty of the 150 plus retention basins also work as groundwater re-charge facilities, 30 as recreation areas in the dry season, and 10 to aesthetically enhance neighborhoods through landscaping. In regards to flood control, the FMFCD uses three reservoirs and dams, five detention basins, and one re-diversion channel. FMFCD's design is considered one of the best in the country and is internationally renowned for its innovation. In past major storm events, the system in place has effectively prevented flood damage. (4)

Climate Change Impacts on Water

Current Climate Patterns and Projected Changes

Fresno has a semi-arid climate characterized by mild and rainy winters and hot and dry summers. Annual rainfall averages less than 12 inches each year and the majority of the year is sunny. Though average annual rainfall may likely remain the same, climate change will bring about changes in the timing and intensity of precipitation. For Fresno, the increase in temperatures will result in a later onset of winter and an earlier onset of spring. Therefore, more water will be available due to snowmelt from the Sierras earlier in the spring and less water available in the summer months. Due to changes in temperatures at higher elevations along with a reduction in the amount of precipitation falling as snow in the Sierras, snowmelt and early spring storms will result in increased runoff, increasing the probability of flooding. However, this excess water earlier in the year will result in lower quantities of stored water available throughout the year. Dams will be forced to retain lower levels of water in preparation of increased runoff, reducing the overall water stored behind dams available for municipal use (5). Though precipitation mostly falls in the winter and spring periods, when precipitation falls, it will fall with greater intensity. The fluctuations of water levels throughout the year will present many problems affecting not only water resources, but also water use, water quality, and water management.

Precipitation and Flood/Drought Risks

Water Availability

The increase in temperature greatly affects how much water will be available during the year. As temperatures continue to increase, the amount of water in natural systems at different points in the season will greatly affect the availability of water throughout the year. A study of the Sacramento Basin by Gleik using modeling indicates that as temperatures increase, winter runoff will rise and summer runoff will drop. Gleik "found that summer runoff decreased in all scenarios, whereas winter runoff rose in all those scenarios in which precipitation was kept constant or increased. With an increase in temperature of 7 degrees Fahrenheit (4 degrees Celsius) and an increase in precipitation of 20 percent, the winter runoff rose by 75 percent, and the summer runoff decreased by 49 percent (5)."

Snowpack plays an important role in storing precipitation and preventing flooding by slowly releasing this precipitation throughout the year, but climate change will alter this process. A study by Dettinger and Cayan shows that an increased percentage of snowmelt in the mid elevation basins has been occurring earlier in the year, which has led to a decreased percentage in flows in the months from April to July, which can be seen in the runoff index for the San Joaquin River (5). Although little change has occurred in the overall river index, the San Joaquin River has experienced a 19 percent decrease in runoff between the months of April and July (6), meaning that snowmelt and runoff occurred mostly in March. The increased amount of early snowmelt along with changes in precipitation trends in the winter and spring is increasing flooding in the winter and spring months, while leaving the summer and fall drier and with decreased stream flows.

The increasing temperatures causing earlier snowmelt will also impact the amount of snowpack present. As temperatures increase, mountains will retain less snowpack at lower and medium altitude; thus, when precipitation falls at these altitudes, immediate runoff will increase due to increasing temperatures. The decrease in snowpack at these elevations will lead to a lower volume of runoff during spring snowmelt, further decreasing the amount of water available to the city in late spring and summer. (7)

As shown above, shifts in both the timing and phase of precipitation will affect the amount of water available for use by Fresno being stored in snowpack or behind dams. Changes in precipitation in mountainous regions also pose a threat for flood control systems. As storms which normally cause snowfall begin to transition to rain, runoff that would usually be at a moderate flow over a long period of time due to snow melt will come in short more intense events more characteristic of rainfall.

Water Use

Though officials may not need to worry about water shortages in the winter and early spring, they will need to consider the impacts of water shortages later in the year. Fresno only receives about 12 inches of precipitation annually and any further shortages of water in the warmer months could pose a significant threat to city systems, especially to the agricultural industry. Fresno leads California in agricultural production, and California ranks first in agricultural production in the United States. Bouts of very wet or dry conditions have the potential to significantly damage crop production. In times of drought, "agriculture…is likely to suffer reduced crop production, soil losses due to dust storms, and higher water costs" (8). Like the rest of the western United States, California relies on irrigation for the survival of agriculture and a decrease in water availability may devastate the industry and the economic benefits it brings to the region. Though studies show that agricultural water use has declined since 1980, urban water use continues to rise (5). The fact that Fresno residents use about 300 gallons of water per day (compared with the national average of 80 to 100 gallons per day (10)) along with the expected rise in population will continue to affect water issues in Fresno.

The amount of water available not only affects agricultural and urban use, but it also affects the energy sector. Because much of the energy in Fresno is generated from hydroelectric power plants, droughts will negatively affect hydropower electricity generation. This is an issue highlighted by the energy section of this report.

Water Quality

The increase in variability of weather due to climate change in the form of increased periods of dryness, increased precipitation and warmer temperatures will affect the quality of water. With changes in runoff patterns that may lead to increased flooding, drain overflows will increase water contamination problems. (9)

Projected changes will also affect aquatic flora and fauna. The USGCRP explains that "As temperature increases, the ability of water to hold dissolved oxygen declines, and as water becomes anoxic, animal species begin to experience suboptimal conditions" (11). Decreasing stream flows will also have a negative impact on water quality, "decreased flows can exacerbate temperature increases, increasing the concentration of pollutants, increase flushing times, and increase salinity in arid regions. Decreased surface-water volumes can increase sedimentation, concentrate pollutants, and reduce non-point source runoff" (12).

Changes in water levels and precipitation will affect the health of citizens. The human health section of the report will provide more in-depth discussion regarding water quality.

“agriculture…is likely to suffer reduced crop production, soil losses due to dust storms, and higher water costs.”

Water Management

Climate change will impact how water management and water utilities operate. Water utilities operate based on historical data to manage water storage and supply. With the variability and extreme weather events, water utilities will need to adapt their planning and management practices in order to account for increases in variability because historical data will become somewhat obsolete due to deviations from the norm (13). Increases in flood and drought conditions requires water managers to plan effectively for the supply and demand of these waters so that the major dry periods in the summer months will not be left without water. This creates a situation where an increase in the amount of stored water is needed in preparation for drought in the valley, while at the same time dam operators will need to decrease the amount of water behind dams in order to mitigate the effects of runoff and flooding at higher elevations.

Past Events

In the past few years, Fresno has seen short periods of excessive rain as wells as periods of drought. To date, it appears that drought has caused more problems for Fresno than flooding. The most recent drought, which lasted from 2007-2009, affected the agricultural sector as well as the economy. Fresno County proclaimed the area to be in a state of emergency in 2009 due to an unemployment food crisis (14). The lack of water resulted in loss of crops and loss of jobs for farm workers. An estimated 250,000 acres of agriculture was lost in the County during that drought period (15).

Although water management and storage issues are serious problems in Fresno, flooding should not be ignored. It is important to note that though Fresno has not had many problems with flooding in the recent past due to their superior urban flood control system, climate experts project more intense rain events to be a probable impact of climate change. The current storm water and flood control system in Fresno have handled storms thus far, but whether or not the system can handle storms of greater magnitude is unknown. In 1997, a severe storm in the region brought massive rain to the Sierras that caused major flooding and levee failure in the San Joaquin River basin. The storm surged and "peak flows to the San Joaquin River at Friant Dam were estimated at 59,000 cubic feet per second" and damages exceeded $223 million (16). Potential levee failure remains a concern for the area given future climate impacts.

Figure 61: Insuffcent suburban stormwater infrastructure lead to massive flooding in Fresno on January 2nd, 2006

Figure 62: Natural gas is an important part of Fresno's energy portfolio

Energy

Introduction

This analysis of climate change impacts on the energy sector outlines anticipated changes in energy demand, generation, and infrastructure. In particular, this section examines electricity and natural gas consumption, generation, and distribution within the City of Fresno and the surrounding urban areas, with the focus on Pacific Gas and Electric (PG&E), the region's dominant utility company.

Pacific Gas and Electric

PG&E is one of the primary utility providers in the State of California, with a service territory extending from Eureka in the North to Bakersfield in the South. They manage 5.1 million electric and 4.3 million natural gas customers, 159,829 circuit miles of electric transmission and distribution lines, 48,580 miles of natural gas transmission and distribution pipelines, and total generation capacity of 6,870 megawatts (92). PG&E actively evaluates the predicted impacts of climate change on their energy systems.

Climate Impacts on California and Fresno Energy Systems

Climate change will impact the Californian energy systems through increased temperatures, changes in precipitation, and rising sea levels. Increased temperatures will change energy consumption patterns, during both winter and summer months (93). In addition, increasing temperatures will slightly reduce the efficiency of fossil fuel power plants and transmission lines (94). Changing precipitation patterns will impact the reliability of hydroelectric generation, a substantial portion of California's energy profile, as storms become more intense and less frequent. Finally, while sea-level rise is not directly applicable to Fresno, it will impact coastal infrastructure that feeds into the Fresno regional energy network.

Energy Demand

Demand for energy will rise as temperatures increase and extreme heat events become more frequent and intense, due to an increase in demand for cooling, particularly in the summer months (95). This is particularly applicable in California and Fresno given current energy consumption patterns. A study analyzing current energy consumption found "in 2004, 30 percent of California peak electricity demand was attributable to residential and commercial air conditioning use alone" (94). One study predicts that "the number of the 10 percent hottest summer days in Los Angeles will increase from the present 12 days to 28-96 days towards the end of this century" (93). Similar changes are likely to occur in the Fresno region. Therefore, it is important to consider future increases in temperature when modeling future energy capacity, and applying findings to the requisite planning processes.

In 2006, buildings accounted for 72.4 percent of total U.S. energy use (96). Therefore, a review of climate change impacts on building energy use provides a good picture of general demand. Numerous reports outline the anticipated effects of climate change on California building energy use. However, few studies have focused specifically on Fresno or the surrounding area. In lieu of Fresno specific analyses, we use studies of climate impacts on building energy use performed throughout the State and in other southern Californian cities. A recent analysis of Los Angeles projects that cooling demand "will increase by as much as 42 percent in residential buildings and 31 percent in commercial buildings…while heating will go down by 62 percent and 24 percent, respectively towards the end of this century (averaged across four emissions scenarios)" (93). Furthermore, "electricity used for building cooling will increase by more than 50 percent over the next 100 years for certain areas in California under the [IPCC's] worst-case carbon emission scenario" (93). As a result, despite decreases in space heating demand, the net energy use in California will increase by 25 to 28 percent by 2100, and a large portion of demand will shift from natural gas to electricity (93).

Energy Generation

Forecasting California's future energy generation capacity is an essential element in evaluating the impacts of climate change on the energy system. With a growing population, (97) and the anticipated higher per-capita demand for energy (93), we can clearly see that California will require additional capacity. As of 2006, the primary sources for generating electricity in California were natural gas, large hydro, coal, and nuclear energy, with one-fifth of the total volume imported from out-of-state sources (98). At both the state and local level, lawmakers have passed initiatives to establish and implement Renewable Portfolio Standards (RPS). RPS legislation has forced utility providers to focus on developing renewable energy generation sources, which do not include large hydroelectric projects. However, hydroelectricity and nuclear power plants still account for the majority of the energy sources for PG&E and most utility providers in California. As we discuss below, it is unclear if increased future demand can be met through renewable sources.

Figure 63: Thirty percent of electricity in the Fresno Region is used for commercial and residential air conditioning

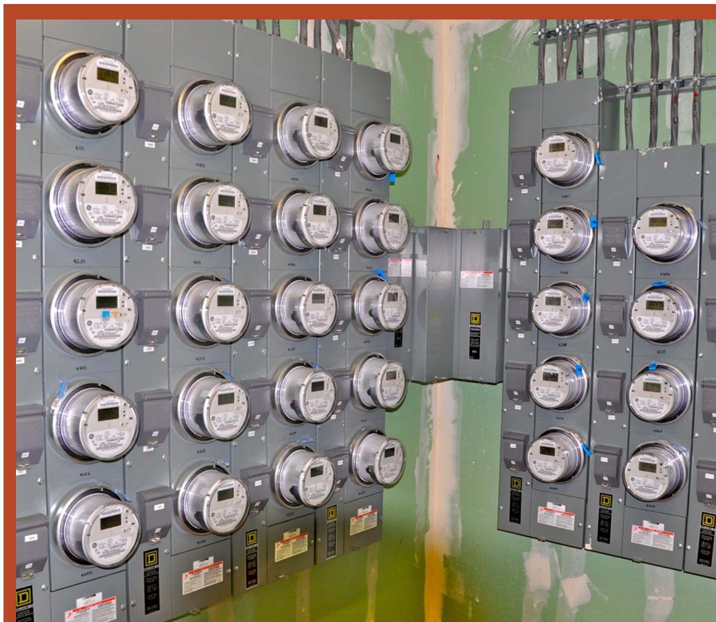
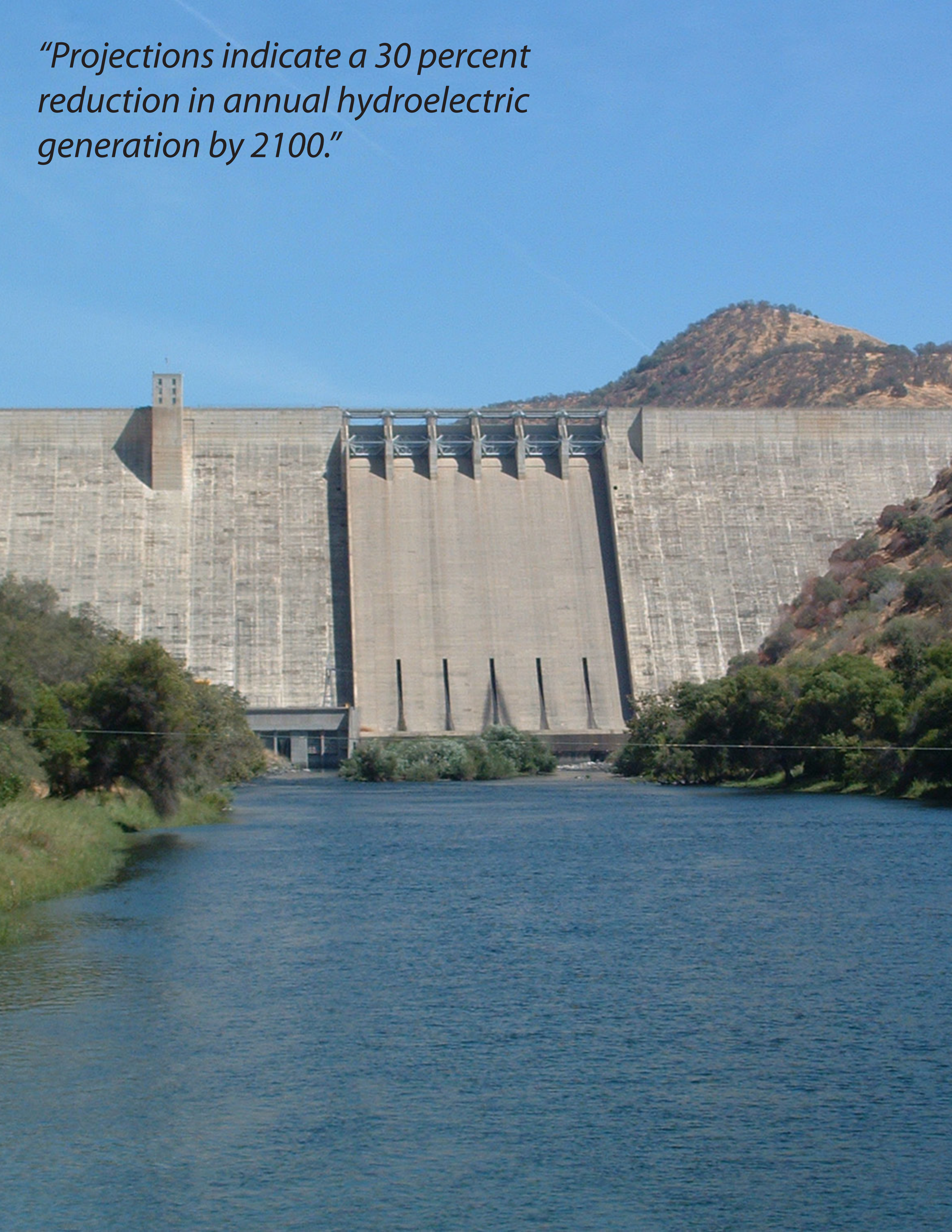


Figure 64: Pacific Gas & Electric Smart Meters

Figure 65: Power generator in California

"Projections indicate a 30 percent reduction in annual hydroelectric generation by 2100."



Hydroelectric Energy Generation

The most vulnerable component of the energy sector in the Fresno region is hydroelectric power generation (98). Hydroelectric plants generate 20 percent of the total electricity produced in the State of California, with additional hydroelectric supply coming from the Pacific Northwest and the Colorado River Basin (98). "Hydropower generation is sensitive to the amount, timing, and geographical pattern of precipitation, as well as temperature" (98). A reduction in the share of precipitation that falls as snow, and an earlier mountain snowmelt will have a distinct impact on hydroelectric generation (94) (98).

While a decrease in overall precipitation is more likely, regional climate models cannot predict with certainty whether or not overall precipitation will increase or decrease in California. Under a scenario with increased precipitation, hydroelectric generation increases substantially. However, a scenario with constant or decreasing precipitation would result in substantial reductions in hydroelectric generation, especially during spring and summer months when demand is highest (94) (98). "A dry high warming climate could result in a 19 percent reduction in hydroelectric generation compared to a 1984-1998 baseline, whereas a wet, high warming climate could increase generation by 5 percent" (94).

Shorter winters and longer summers, when combined with changing precipitation patterns (more precipitation as rain and less as snow) will reduce the mountain snowpack essential to hydroelectric energy production. Therefore, projections indicate a 30 percent reduction in annual hydroelectric generation by 2100 (98). "Hydroelectric facilities most likely to be affected by climate change are the Sacramento, Feather, San Joaquin, and American River systems, which have large hydropower to storage capacity ratios, and changes in projected runoff are large relative to current storage capacity" (94).

Renewable Resource Energy Generation

As of 2009, renewable energy production (which does not include large hydroelectric generation) accounts for approximately 17.7 percent of total electricity production in PG&E's portfolio. This share is predicted to increase to 33 percent by 2020 under Executive Order S-14-08, California's RPS (99). Renewable energy strategies rely heavily on the climate and natural resources for production potential, such as hydrological resources, wind patterns and intensity, and solar radiation (98). Therefore, renewable energy systems are highly vulnerable to impacts from climate change.

Solar Energy Resources

Given the current emphasis on implementing broader photovoltaic solar energy systems and the relatively few studies examining how climate change will impact them, additional research is needed in this area. However, existing literature suggests that climate change may reduce the effectiveness of photovoltaic systems. Climate change has the potential to increase cloudiness due to increased concentrations of carbon dioxide (98) and increase the air temperatures, reducing the electricity output of solar cells (94).

Wind Energy Resources

Wind energy generation is vulnerable to changes in ambient temperatures, humidity, and precipitation (98). The reliability of wind energy generation is directly related to average wind speeds and gustiness (98). Climate predictions indicate increased variability in the location and consistency of wind (98). Additionally, anticipated changes in wind speed are projected to decrease wind power generation by 30 to 40 percent by 2100 (98). A general decrease in wind power generation potential and wind variability will create additional challenges for accurate wind forecasting and the siting of wind farms (98).

Figure 66: Solar Farms in Fresno

Figure 67: Wind Farm Pasadena, CA

Thermoelectric Energy Generation

While recent policy has focused on renewable energy generation, California is still reliant on thermoelectric power generation, with 41 percent of in-state energy generation coming from gas-fired plants and 13 percent from nuclear plants (98). The primary impact of climate change on thermoelectric energy generation will come from changes to the availability and temperature of water for cooling. The efficiency of fossil fuel power plants will decrease with increased air temperatures (94). Additionally, thermoelectric power plants are heavily dependent on water sources for cooling during the energy generation process (98). The reduced reliability of precipitation will substantially affect the ability for thermoelectric plants to supply energy.

Similar to fossil fuel power plants, nuclear energy generation will be negatively impacted by a reduced availability of water for cooling during the production process. Of primary importance is the rising temperature of water, and in particular the rising temperature of ocean water (98). Changes in water temperature will affect the ability of nuclear plants to meet water temperature discharge limits (98).

Energy Infrastructure

Increased temperatures, and increased frequency and size of wildfires will impact the transmission grid and distribution network in the Fresno region (98). Temperature changes can significantly affect the energy transmission and distribution network. These impacts vary when analyzing their effects over the short and long term. In the long term, the effects are relatively small because existing infrastructure has the ability to absorb additional thermal loads due to the relatively slow pace of the anticipated temperature increase. However, in the short term, sudden increases in temperature can have a significant effect on the transmission and distribution system (98). Extreme heat events place additional demand on the energy system, resulting in less reliable and complete delivery of power. As an example, the July 2006 heat wave caused transformers to fail, resulting in a loss of power to over 1.2 million PG&E customers in Northern California (98).

Human Health

Introduction

The effects of climate change will dramatically impact human health issues in Fresno, California. Predicted changes in Fresno include rising temperatures, longer summers, severe droughts, and incidents of heavy rain. These changes are expected to stress existing human health issues in the city and may result in new health issues. Additionally, these changes in climate will place unprecedented pressure on public health systems and services in order to keep city residents healthy.

The public health system will face increased pressure to keep up with changing health issues, requiring significant amounts of funding and resources. The built environment in Fresno is also susceptible to climate impacts and in many cases may contribute to the propagation of certain illnesses. Vulnerable populations in Fresno such as low-income and minority populations and farm workers, live in social conditions that will heighten the propensity for human health problems brought on by climate change impacts. Finally, poorly protected and unmonitored natural systems will lack resilience to health threats such as vector and water-borne disease.

There are four main categories of threats and areas of concern for human health in Fresno:

- **Socioeconomic:** The relationship between demographics, and the geographic distribution of climate threats that people face in their living and working environments.
- **Stress on Water Systems:** Water quality concerns relating to contamination and overdraft of ground and surface water sources, and competition between various water users for scare resources.
- **Stress on Natural systems:** Ecosystem buffers, vector, and food-borne diseases spread rates, water-illness transmission, heat intensity and humidity, and severe storm intensity and frequency.
- **Stress on Public Health Systems:** Stresses on the services that they provide, on public illness treatment rates, as well as the economic and financial impacts of these stresses.

Figure 68: Migrant workers are especially vulnerable to heat

Figure 69: Irrigation sprinklers in San Joaquin Valley

Figure 70: Severe drought conditions

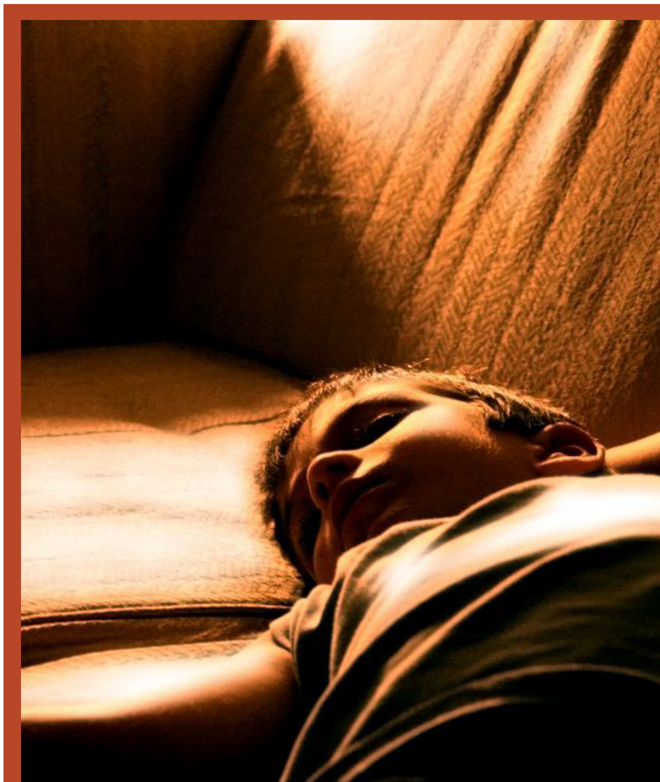


Figure 71: Heat is especially dangerous for children

Figure 72: An area known as "tent city" in Fresno is one of three homeless villages in the City

Figure 73: Passengers wait for the bus on a 100 degree day

Socioeconomic Considerations

According to 1999 census data, more than 26 percent of Fresno residents live below the poverty line, in conditions that leave them vulnerable to climate-related illness. Low-income and minority communities have limited access to cooling mechanisms, most of which depend on the availability of water. Additionally, the large community of farm workers in Fresno will face increasingly dangerous working conditions as temperatures rise.

Farm workers make up one of the lowest income groups in California. As the effects of climate change become more pronounced, record high temperatures and water shortages will exacerbate the already brutal labor conditions. Exposure to extreme temperatures for long periods of time can result in severe dehydration, heat stroke and exhaustion, and even heart attacks. Fresno also has some of the worst air pollution in the United States caused primarily by agricultural practices and vehicles that run on diesel which produce higher amounts of particulate matter than gasoline engines. Because of the low elevation of the city within the San Joaquin Valley, much of the smog and air pollution produced stays trapped between the surrounding mountain ranges, creating additional health concerns. As the growing season extends and working conditions become even hotter, both extreme temperatures and a growing scarcity of drinking water will significantly affect the health of farm workers in and around Fresno. (100)

Public health is threatened by extreme heat events, scarcity of water, and insufficient cooling strategies. In the 2006 California heat wave, 140 deaths were attributed to heat stroke. Of those, 99 percent of cases lived in zip codes where more than 50 percent of residents live below the poverty line (101). Studies suggest that despite high energy costs, functional air conditioners are the most effective strategy to overcome extreme heat (102). However, according to Dr. Edward Moreno of the Fresno County Public Health Department, those high energy costs deter low-income residents from using air conditioners, which ultimately results in serious illness (103). Other factors, such as proximity to neighborhood swimming pools and air-conditioned public buildings will also affect the physical well-being of low-income residents in Fresno.

Contamination of Water Sources

Declining human health, and increases in the spread of illness and disease is directly linked to the way in which climate impacts will affect the built environment of Fresno. Stress on water systems may lead to contamination, and changes in groundwater levels will affect the amount of pesticides present in drinking water.

An area of concern centers on the water systems in Fresno. As the incidence of severe rain events become more frequent and intense, water systems will experience heightened stress. Stress on these systems could result in failures of water and sewage treatment facilities, leading to severe health issues caused by contamination of public water (102). For example, diseases such as cholera and dysentery pose an increased threat if surface water is contaminated (103). A shift to a reliance on bottled water may somewhat offset these concerns. However, low-income residents are unlikely to be able to afford the higher costs of bottled water and in some situations, may not have convenient access to retail outlets (102).

A second area of concern is the agriculture industry's effect on drinking water in and around Fresno. Agriculture fuels the economy of the Central Valley, but it also produces the State's largest amount of water pollution through pesticide runoff (100). Pesticides have long been present in California's drinking water. A study conducted in 1999 concluded that over 100 pesticides were detected in California's drinking water, with the Central Valley bearing the highest levels of contamination (105). The presence of these chemicals in drinking water is associated with increased rates of cancer and other chronic illnesses. Higher pesticide concentrations are likely to occur in surface water, caused by more frequent severe rain events and earlier snowmelt. It is also likely that greater concentrations of pesticides will runoff into groundwater sources. The large percentage of Fresno residents dependent on groundwater will be at risk for contracting illnesses correlated with chemical contamination.

Figure 74: Agricultural runoff of fertilizers, pesticides, and sediment negatively impacts both water and human health

Figure 75: Abandoned warehouses in Fresno collect stagnant water and provdes breeding habitats for mosquitos

Natural System Stressors

Stressed natural systems will exacerbate health-related illnesses in and around Fresno. Lack of vegetation in urban areas amplifies heat, and changes in climate make Fresno susceptible to mosquito vector-borne diseases. Improved city planning to increase the incorporation of vegetation, and expansion of existing vector control programs are necessary to address potential health issues related to Fresno's natural systems.

As temperatures rise and incidents of heavy rain increase, vector-borne diseases will become more prevalent in Fresno. While mosquito vector-borne disease are temperature sensitive, the transmission and maturation of these diseases are to a great extent dependent on other factors, including humidity and rainfall (102). In California, three vector-borne diseases pose a threat to human health: West Nile Virus, Western Equine Encephalitis, and St. Louis Encephalitis (104). Additionally, health professionals are increasingly concerned with the potential spread of Malaria into the Central Valley (103). In this case, creation of vector control programs and disease tracking programs will fall on the Fresno public health system. Without proper tracking and spraying mechanisms in place, vector-borne diseases can create serious health threats.

Trees and vegetation provide an effective way to reduce urban heat islands in the face of climate change. Shade and evapotranspiration can help to decrease temperatures in urban areas by as much as nine degrees Fahrenheit. Heat-related illness will pose increasing concern as temperatures rise, and vegetation is a simple way to mitigate the impact of climate change in Fresno. (106)

Public Health System

The public health system in California is not adequately prepared to cope with the growing demand for health care as a result of climate change impacts. This lack of preparedness will lead to untreated illnesses and the spread of new diseases. In order to keep up with changing health issues in Fresno, public health systems will face pressure to invest significant resources into improved plans and procedures.

The Fresno Public Health System lacks resources in the form of technical expertise, staff with backgrounds in climate science, and funding for programs aimed at climate related illness protection. Additionally, poor coordination between local and state agencies could limit responses in emergency situations. For example, inconsistencies between the City of Fresno and the Fresno County Public Health department exist over heat indicators; the City uses given heat while the health department uses the heat index, resulting in conflict over when to open cooling centers (103). Ultimately, a faulty or under-developed emergency heat plan could lead to the spread of climate-related illness. (104)

The inefficiency of an emergency heat plan during prolonged periods of drought and high temperatures could mean unnecessary heat-related deaths. Without cooling centers in place, vulnerable populations will have few resources available to seek respite from hot temperatures. Equally important are effective heat advisory systems, and education programs on heat-related illness. Public health care providers will face the task of operating these cooling centers, implementing programs for heat advisory and education, and identifying and reaching out to at-risk and low-income populations (103).

"The public health system in California is not adequately prepared to cope with the growing demand for health care as a result of climate change impacts."

Transportation

Introduction

Climate impacts over the next century will affect transportation construction, maintenance, and development in Fresno; along with the way that transportation is planned for and used. This section focuses on climate impacts on the three primary modes of physical transportation infrastructure in the City of Fresno: auto, rail, and air. Transportation infrastructure will be affected primarily by an increase in frequency and intensity of high temperature events and the intensity of precipitation events (1). Climate impacts on the built environment include physical impacts on road, rail, and airport infrastructure because of the limits of design tolerances of all types of infrastructure for both heat and precipitation. Climate impacts on physical infrastructure will also have implications for functions or services relying on physical transportation infrastructure along with city and regional budgets and economies. Because of the type of climate currently seen in the Central Valley along with the projected changes, there are limited direct impacts on physical transportation infrastructure.

Road Transportation

Road infrastructure plays a vital role in the life and economy of the City of Fresno. The major east-west highways in California transport and distribute agriculture from the central valley. Two of these arteries (Highway 152 and 198) lie within 35 miles of Fresno and another (Highway 180) runs through Fresno. Fresno is the hub for several state highways including State Route 99, 168, 41 and 180 (48).These road networks play a crucial role in the economy of California. In 2007, the San Joaquin Valley's (SJV) truck vehicle miles travelled (VMT) accounted for 28 percent of California's total truck VMT providing freight service primarily for shipping produce from farms, the main driver of the Fresno economy. The Fresno urban road infrastructure consists of over 6,000 linear miles of roadway which dramatically exceeds the demand for road infrastructure in the area (48). There is very little, if any congestion within the city; and despite projections for continued large-scale growth in the area, traffic projections show no congestion issues developing in the City of Fresno over the next 25 years (49). Although single-occupancy vehicles dominate urban transportation, the City of Fresno does have a fairly extensive transit service in the form of the Fresno Area Express (FAX). However, because of the size of the transit-dependent population in the area, this service is severely strained (3). The City of Fresno also has a bicycle system specifically designed and implemented by the City's transportation engineer Brian Jones. Almost all major roads in the Fresno/Clovis area have bike lanes included along the shoulder. However, the bike paths are currently severely underused.

Increased occurrence, intensity, and duration of extreme heat events pose a threat to the integrity and lifetime of road transportation infrastructure. Transportation infrastructure is designed to accommodate typical weather patterns and has a limited design tolerance for extreme conditions, including heat-waves (1) (4). An increase of extreme heat in the Fresno region will cause ambient temperatures to more regularly exceed the design tolerances of roads, leading to rutting of pavement, more rapid breakdown of asphalt seal binders, cracking, potholing, and bleeding (5) (6). Bridges are especially vulnerable to extreme heat, making Fresno County's 550 bridges even more susceptible to degradation as a result of extreme heat (4) (48).

Figure 76: Increased occurrence and intensity of extreme heat events pose a threat to the integrity of road transportation infrastructure

Figure 77: Fresno Area Express (FAX) transit service

The increase in the likelihood and magnitude of severe precipitation events will add another threat to road infrastructure in Fresno (7). While the Fresno Metropolitan Flood Control District is a state-of-the-art urban drainage system well suited for dealing with flooding, the system will likely exceed capacity as the intensity and frequency of extreme storm events increase (8). One of the major threats posed by flooding, especially in Fresno-area roads outside the flood control district, is the degradation of road foundations via erosion, subsidence, and flash flood damage. As precipitation events intensify, water flows threatening roads will more regularly exceed the design capacity of the infrastructure, increasing the potential for damage (5). Extreme precipitation events will compound infrastructure damage caused by heat stress, by further decreasing the lifespan of roads, increasing the probability of structural degradation and failure, and increasing the cost to maintain roads in the Fresno area. Currently, Fresno County estimates a $31 million annual shortfall in maintenance and rehabilitation funds, which presents significant issues as these costs will increase as degradation resulting from weather extremes increase (48).

On a county level, flood stopgap measures beyond the flood control district have a limited design tolerance for extreme events including flash flooding (8). As climate changes, flooding will likely surpass these design thresholds, causing more occurrences of infrastructure degradation, which will shorten road life, and increase dangers for motorists and freight transport. In May 2010, Fresno County recognized that much of the flood control facilities in the county are privately owned and do not meet current standards for flood protection (8). Because of insufficient design tolerances in transportation and insufficient flood control facilities throughout the area, transportation infrastructure will have difficulty coping with increased flooding as precipitation trends change.

Rail Transportation

The rail lines in and around the Fresno area are privately owned, as is typical throughout the U.S. The National Rail Passenger Corporation (Amtrak) provides passenger service going north to south through the Central Valley and the Altamont Commuter Express provides service between the San Joaquin Valley and the Bay Area. The primary providers of freight rail transportation are Union Pacific Rail and Burlington Northern Santa Fe Railroad, both privately owned and operated (48).

Similar to roads, the majority of the threats to rail infrastructure fall outside of the City of Fresno. An increase in intensity and longevity of extreme heat events poses a threat to the integrity and service of rail infrastructure in the Fresno area primarily in the form of rail buckling. Rail buckling occurs predominately on isolated hot days during the spring and fall when the range of daily temperatures is largest (5) (1). As temperatures increase to over 95 degrees Fahrenheit, rails begin to warp and railroads generally issue blanket slow-orders to reduce the likelihood of derailment, which pose threats to the safety of the trains and to passenger schedules and freight delivery (5) (9). As extreme heat events become more prevalent and more severe, especially early in the year when temperature fluctuation is the largest, rail infrastructure will face an increased threat from buckling (56).

Precipitation threats to rail infrastructure closely resemble those to road infrastructure and also lie predominately outside of the city of Fresno because of the robustness of the Fresno Metropolitan Flood Control District. As extreme precipitation events increase, erosion and subsidence will become a larger issue for rail. Heavy precipitation erodes sub-grade, washes away ballast, and weakens the foundation of rail infrastructure (5). Intermodal crossing points such as grade crossings, waterway/railroad trestle intersections are particularly vulnerable to these affects because of the amount of traffic they see beyond rail traffic (56). As erosion, washout, and extreme heat increase, threats to these vulnerable portions of rail infrastructure will increase, as design tolerances become insufficient.

Air Transportation

Though there are eight public use and general aviation airports in the Fresno area, the Primary Commercial Service Hub Airport for the area is the Fresno Yosemite International Airport (FYI), located in the City of Fresno. FYI has a service area that includes six counties: Fresno, Kings, Madera, Mariposa, Merced, and Tulare. In 2008, total passenger movement totaled 1,252,751 passengers at FYI. Though primarily a passenger airport, FYI also serves as a cargo hub (48).

Air transportation has two components: ground infrastructure and air travel. Ground infrastructure is subject to the same types of impacts as road transportation infrastructure. One of the primary threats to ground infrastructure comes from extreme heat. Similar to paved and concrete roads, tarmacs will face more rapid degradation of asphalt seal binders, cracking, potholing, and bleeding of seals (5). Decreased aircraft efficiency adds another concern for air travel that stems from heat. Higher air temperatures reduce air density, which decrease both lift and engine efficiency of aircraft. A National Oceanic and Atmospheric Administration study estimated a summer (June through August) cargo loss of 9 percent in the year 2030 because of increased temperature and atmospheric changes due to climate change for a single Boeing 747 coming out of Phoenix, a city which experiences extreme temperatures similar to Fresno (1). Flooding and the degradation of runway foundations via erosion, subsidence, and flash flood damage pose another major threat (5) (1). Changes to runway conditions can have serious consequences due to the sensitivity of aircraft to runway surfaces; small changes in runway surfaces can have large impacts on the safety of aircraft during takeoff and landing.

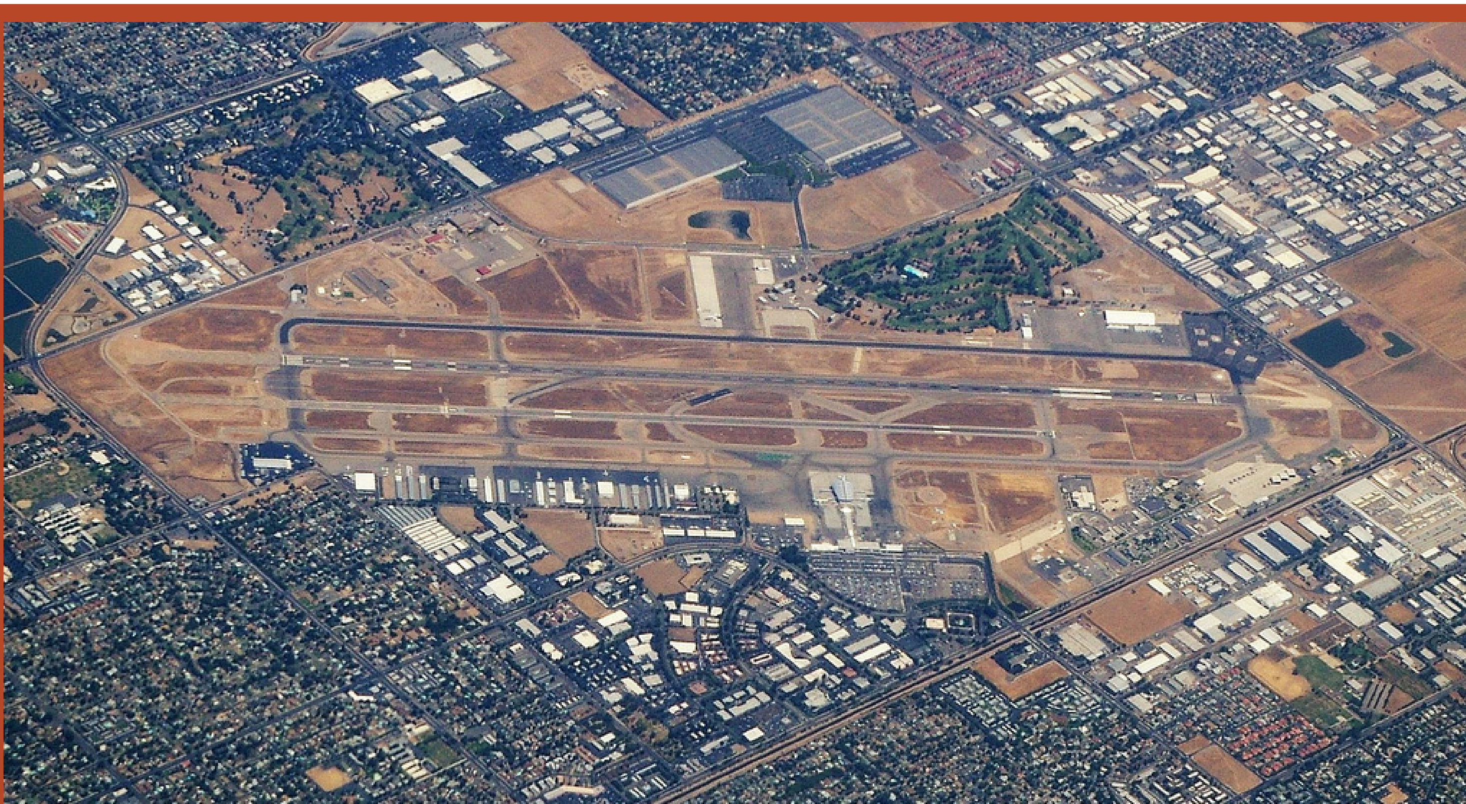


Figure 78: Fresno Yosemite International Airport (FYI)

Implications

Impacts on transportation infrastructure from both heat- and precipitation-related events will create positive feedback loops leading to an increased rate of degradation. Heat degradation from exceeded design tolerances on all types of infrastructure will increase the probability of further damage from precipitation and from regular every day use. This feedback loop not only compromises the integrity of the physical infrastructure, but also threatens the efficiency of the overall system and creates more capital repair costs for city governments and compromises services, which depend on a reliable road infrastructure.

Not only are positive feedback loops formed by the cumulative effects of climate threats, but there are also many secondary impacts to climate impacts on transportation infrastructure. The economy of Fresno is largely dependent on the growth and distribution of agriculture. Fresno's large agricultural industry relies heavily on the road network of Fresno for distribution (48). The County's Regional Transportation Plan (RTP) identifies the number one threat to this freight distribution as being the lack of funds to protect and maintain the $1 billion transportation infrastructure investment that has been made in the region's roadway network (48). The increased wear on transportation infrastructure by extreme weather events brought on by climate change will further add to these issues.

Climate change's impacts on urban road systems will also impact the provision of city services. Climate impacts will heavily affect the Fresno Area Express (FAX), the City's transit service. The FAX is already being pushed beyond its service capabilities due to the high number of transit dependent residents in Fresno. As a result, some riders are left behind at stops because buses are too full. Bus transit services are susceptible to small-scale disruptions in either road conditions or ridership numbers. If flooding or extreme weather compromises road conditions, transit-dependent populations may see further decline in services, which will add to the population's vulnerability. During extreme heat events public buses are often used by low-income residents for cooling, as the buses are air-conditioned. If degraded road conditions trigger schedule delays, chances of heat related sickness increase, as people will be subjected to extremes for longer periods of time.

Heat is the most important factor that will affect the transportation infrastructure in Fresno. Extreme heat will likely reduce the useful life of most transportation infrastructure in the region. However, this is a long-term impact; there are very few imminent dangers to physical infrastructure from heat. Although extreme precipitation events are projected to increase, Fresno's flood control district is state-of-the-art and has great capacity to address urban flooding conditions. Many indirect threats either result from transportation use or contain transportation as a component, such as air pollution, greenhouse gas emissions, and urban heat island effects from concrete and asphalt surfaces.

Figure 79: Extreme heat will likely reduce the useful life of most transportation infrastructure in the region.

Heat Vulnerability Analysis

Introduction

Considering the projected increases in temperature in Fresno, it is important to identify the populations and locations that are most susceptible to extreme heat. This analysis uses GIS and spatial modeling to identify neighborhoods and populations that are highly vulnerable to extreme heat in Fresno County.

Methodology

We used a two-part process to assess heat vulnerability in Fresno. First, we calculated a Neighborhood Socioeconomic Status using census data for six social vulnerability indicators. The Socioeconomic Disadvantage Status (SES) Index we calculated for Fresno was based on a methodology developed by the Rand Health Center – Center for Population Health and Health Disparities. Based on their work, we assigned six variables to create the integrated index:

1. Percent of adults older than 25 with less than a high school education
2. Percent of males who are unemployed
3. Percent of households with income below the poverty line
4. Percent of households receiving public assistance
5. Percent of households with children that are headed by a female
6. Median household income

Next, we overlaid the SES with remote sensing thermal imagery (Landsat TM), and aerial photography to indentify the locations of the hottest neighborhoods. See Appendix C for a more detailed description of the methodology we used to calculate the SES and to identify the most at-risk neighborhoods.

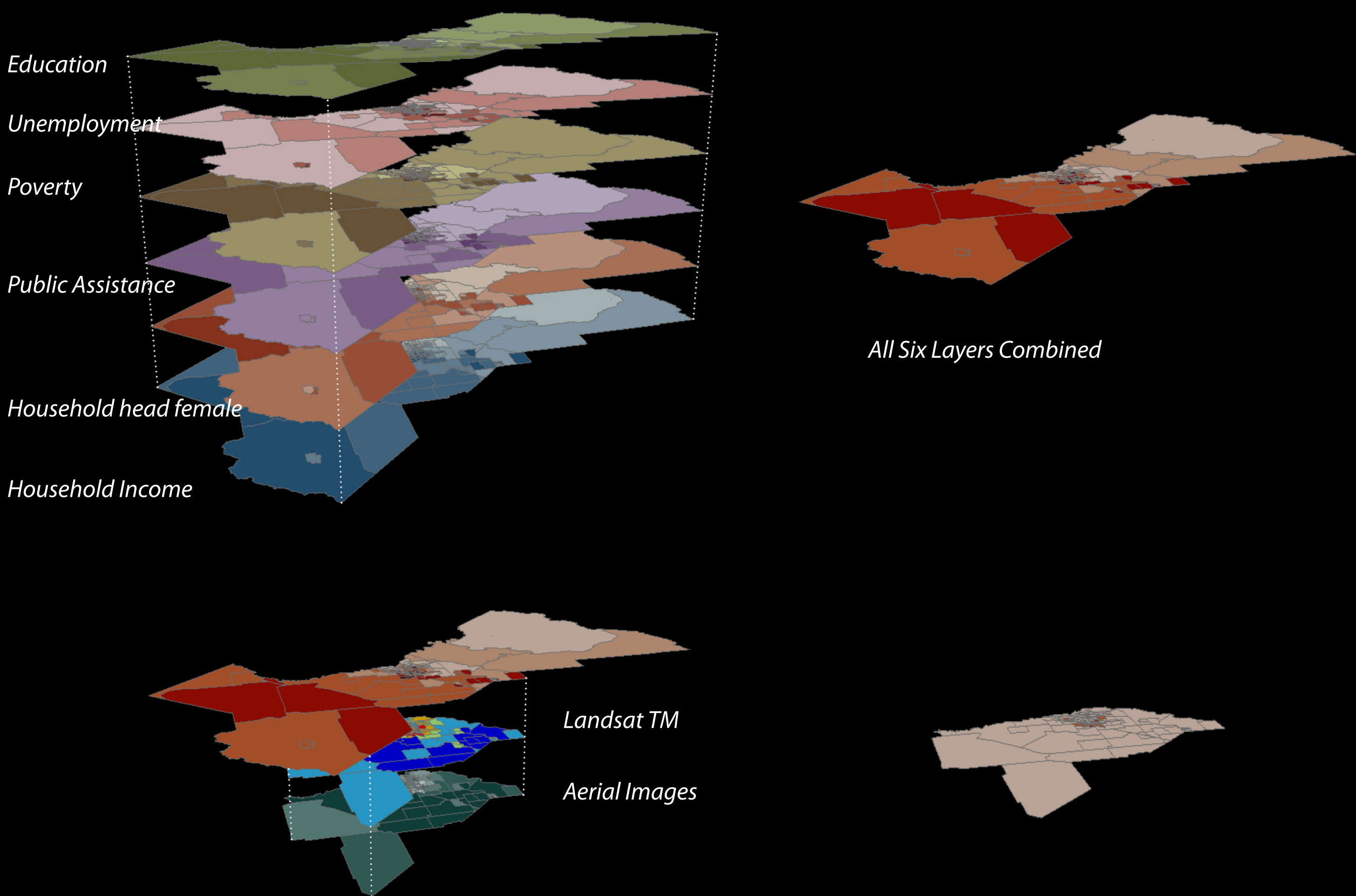


Figure 80: Two-part process to assess heat vulnerability in Fresno, California

Findings

There is overlap between the six socioeconomic variables within Fresno County, indicating areas containing multiple demographic characteristics that indicate social disadvantage. Most of these disadvantaged neighborhoods are located in the urban area, especially the southern part of the City of Fresno. High socioeconomic risk factors mean that these neighborhoods are likely the most vulnerable to climate change because of a relatively low adaptive capacity.

This map represents the combination of all six socioeconomic variables into a single index, with each variable given equal weight. The SES index is calculated such that higher scores are given to areas of lower socio-economic vulnerability. The darker colors represent lower scores in the index, showing higher levels of vulnerability. Overall, we see that the additive index reflected the general patterns we observed in each individual variable. The index identifies the following census tracts as the most vulnerable based on socioeconomic conditions, in Fresno County.

This map shows the socioeconomic index map of the most vulnerable section of Fresno County, overlaid with Landsat TM imagery that shows vegetation.

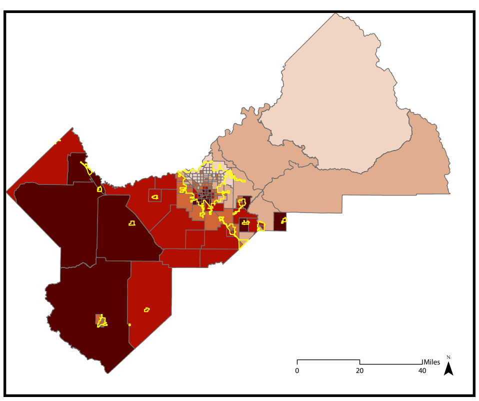


Figure 81: Percent of Adults Older than 25 with Less Than High School Education

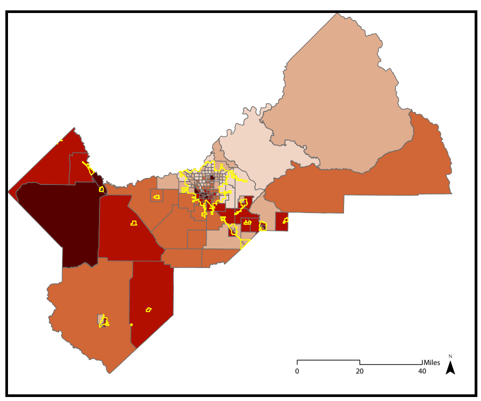


Figure 82: Percent of Male Unemployed

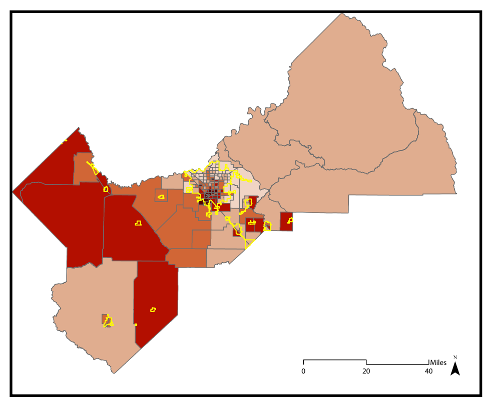


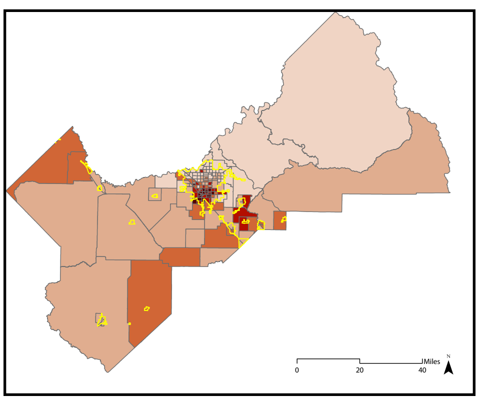
Figure 83: Percent of Household Below Poverty Line

This map shows the most vulnerable section of Fresno County (as determined by the socioeconomic index) overlaid with Landsat TM imagery that shows vegetation. From this overlay we can see the neighborhoods with the lowest mean values, meaning they have the least vegetation and tree coverage, and thus have the least capability to cool the temperature down naturally.

This map indicates the difference in reflectance of heat between neighborhoods varies a lot across the overlaid region. The urban heat island effect is very obvious and can be seen even from the thermal band alone. The light color indicates a higher heat reflection, meaning the temperature is relatively higher than its surroundings.

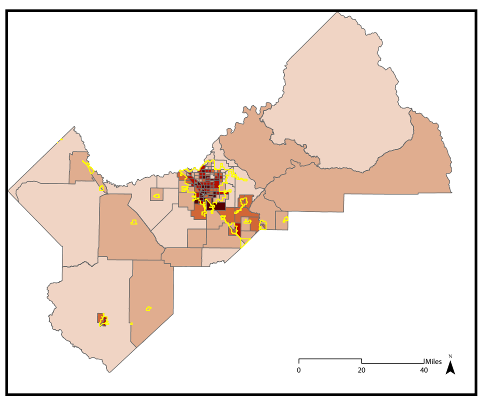
This map combines the NDVI, Landsat Band 6 and SES index together. This image clearly shows that most of the highlighted neighborhoods in the three layers are on both sides of the California State Route 99 in Fresno, in the area surrounded by the Yosemite Freeway, Pearl Harbor Survivors Memorial Highway and Sequoia-Kings Canyon Freeway, in the southwestern part of the Fresno urban area.

By examining the neighborhoods using aerial photography, we find some residential neighborhoods with bare, exposed areas contribute to neighborhood's heat performance and thus increase the risk of the residential communities around them. These neighborhoods also score low in the socioeconomic status index. Therefore, our analysis concludes that these neighborhoods are the most vulnerable to climate change related heat threats in Fresno.



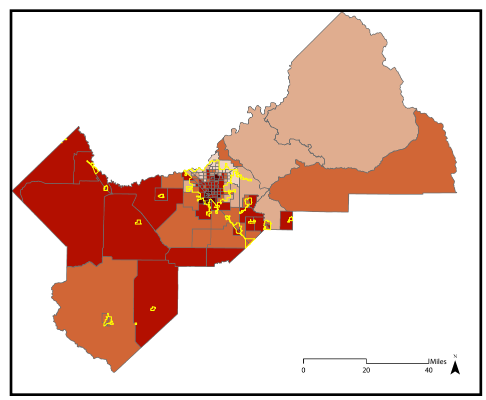
Fresno Social-Economic Status Index Variables
- 0% - 4%
- 4.01% - 8%
- 8.01% - 13%
- 13.01% - 21%
- 21.01% - 100%
- Fresno Urban Area

Figure 84: Percent of Household Receiving Public Assistance



Fresno Social-Economic Status Index Variables
- 0% - 9%
- 9.01% - 18%
- 18.01% - 25%
- 25.01% - 34%
- 34.01% - 100%
- Fresno Urban Area

Figure 85: Percent of Household with Child and Headed by a Female



Fresno Social-Economic Status Index Variables
- 0.00 - 20897.00
- 20897.01 - 32464.00
- 32464.01 - 45268.00
- 45268.01 - 60787.00
- 60787.01 - 98404.00
- Fresno Urban Area

Figure 86: Median Household Income

Advantages and Limitations of Spatial Analysis for Climate Adaptation Planning

The strength of this analysis is the combination of heat vulnerability analysis with socioeconomic disadvantage analysis. We used remote sensing imagery as a scientific resource to locate both the demographic and physical "hotspots" in Fresno. Simply identifying the areas with the highest temperatures around the city is not enough to equip decision makers to take action to adapt to more frequent extreme heat. Decision makers need to know not only where the hottest neighborhoods are, but also where the people with the least ability to adapt to higher temperatures live. This analysis combines data from both aspects and overlays them to show a more complete picture of heat vulnerability in Fresno. This approach could be expanded to include additional variables as more data and resources become available. We intend to show the power of spatial analysis for climate change adaptation planning and encourage planners, scientists, and researchers to adopt these techniques in order to provide actionable information to local decision makers.

There are also some limitations of this analysis. We used remote sensing imagery from the Landsat satellite as the data resource for detecting the neighborhoods with the highest temperatures. The Landsat satellite senses heat based on reflectance of solar radiation. Therefore, the communities with the highest reflectance on the thermal band usually consist of bare concrete structures like a big parking lot, abandoned open land, or warehouse. It does not distinguish between bare land and residential communities, and hence it does not necessarily detect our places of interest: the residential communities. A second limitation of our study is that the census data used for the calculation of the socioeconomic index was from Census 2000. This data is now over ten years old, but it was the most recent census data available for the small geographies (census tracts and block groups) at the time this analysis was conducted. Further updates would be more appropriate as the 2010 census data is released for small geographies.

In general, our reliance on remote sensing data was a limitation. Currently, this data is only available at a large spatial scale. If available, hyper-spatial remote sensing data with less than 1-meter resolution, or hyper-spectral sensors with more divided spectral bands would have enabled us to further analyze the hottest neighborhoods. The remote sensing imagery also does not allow comparison between multiple seasons, or even the same season across multiple years. If this data were available we would have been able to see the trends of physical temperature change, which would be a more powerful scientific indicator of the regional temperature trend due to climate change. While remote sensing data is by far the most cost-effective way to measure hotspots, more fine-grained, place-specific data will need to be collected to enable more robust planning and response in the future.

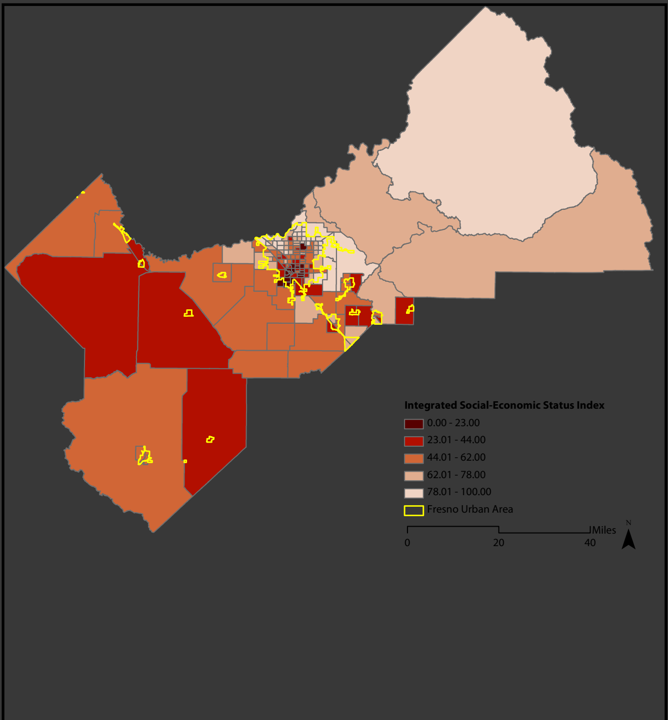


Figure 87: Integrated RAND Social-Economic Status Index

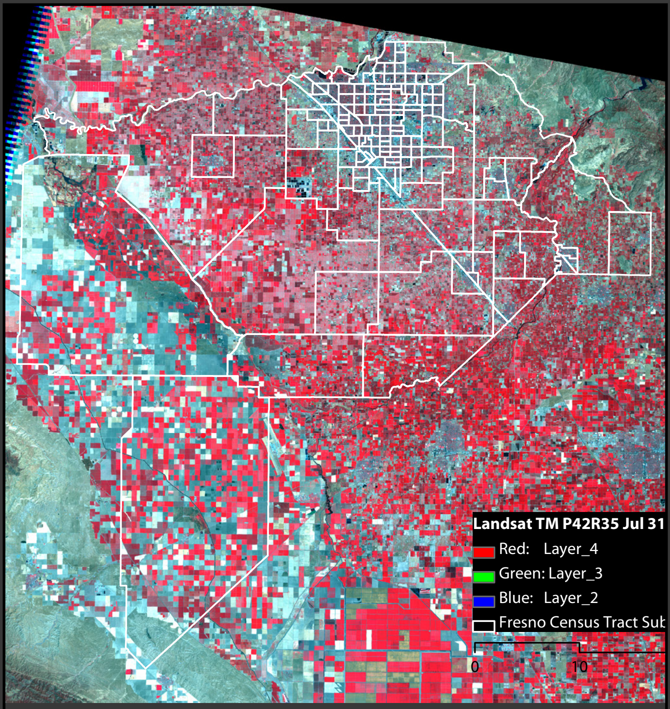


Figure 88: Fresno County subset overlay with landset ETMT

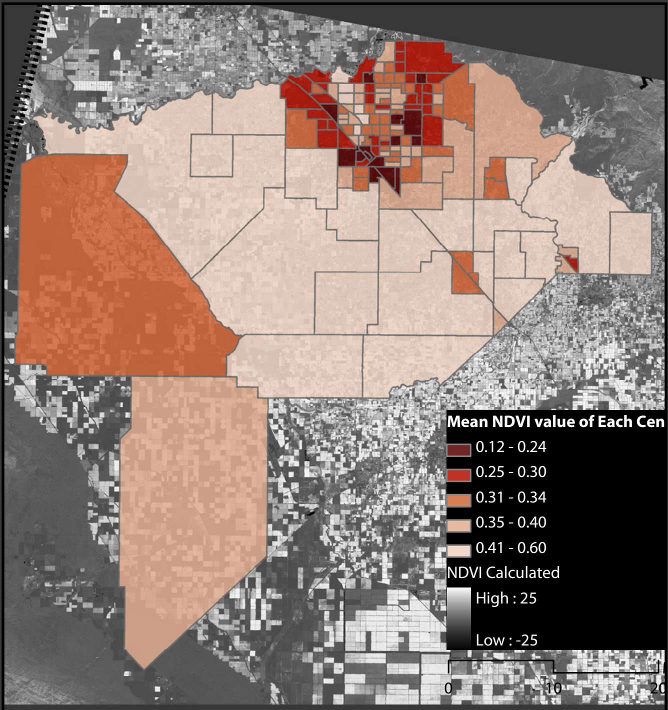


Figure 89: Average Neighborhood NDVI Values

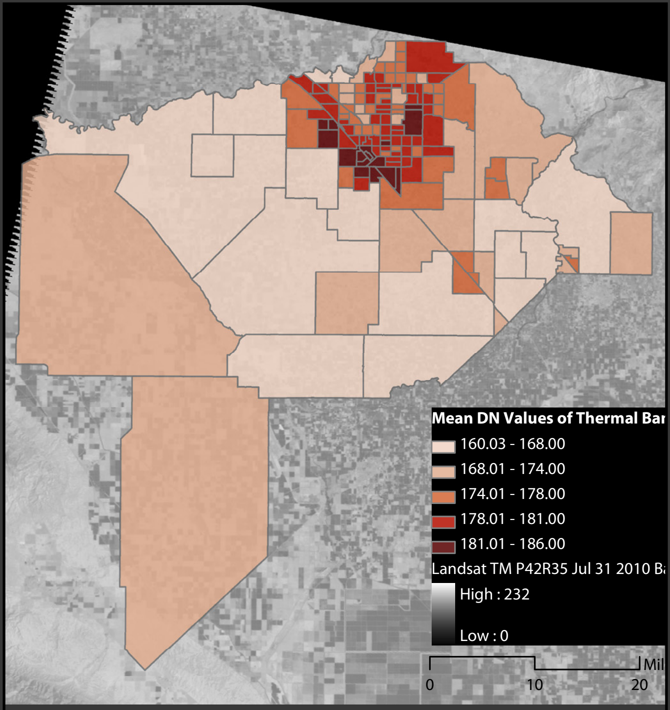


Figure 90: Average DN Values of Landsat TM Thermal Band

Strengths, Weaknesses, Oppor

rtunities, Threats (SWOT)

	Strengths	Weaknesses
Land Use	Fresno is committed to an Urban Growth Boundary and Smart Growth Zones that protect and preserve agricultural land and discourages sprawl.	Greater frequency of extreme storm events will lead to increased flooding and severely impact houses and development located in and around the floodplains and floodways.
	Fresno County's prime agricultural land and food processing plants drive the local economy, thus curbing urban sprawl is aligned with current economic forces.	Higher temperatures for longer periods of time will lead to long periods of drought, increased risk of wild fires, and flash floods, all of which will have significant impacts on public land and personal property
	Fresno's location between popular National Parks maintains consistent and successful tourism industry and access to recreational opportunities.	Increased temperatures and higher nutrient uptake in crops may lead to poor agricultural growing conditions, increased soil salinity, yield reductions, and eventual abandonment of agricultural land.
	Most residents living near the San Joaquin River have higher incomes and likely more of an ability to deal with flash flooding.	Dense development in the old Fresno city center and surrounding neighborhoods make those areas more vulnerable to increasing temperatures and urban heat island effects. These impacts will be more severe in minority communities and areas of lower income housing.
Water	The California Department of Water Resources has begun climate adaptation planning for the water sector in the Fresno region. The Central Valley Flood Protection Plan is an example of this proactive approach.	Fresno residents use an average of about 300 gallons of water per day, one of the highest per capita consumption rates in the nation. This is strongly influenced by Fresno's very low water rates, which are not tied to consumption rates.
	Climate change impacts are incorporated into the California Water Plan Update every five years.	Fresno's primary source of water is groundwater, and the aquifer is currently over drafted by 100 feet, 30 feet of that occurring in the last 10 years.
	Fresno's Water Division has strong organizational capacity and infrastructure to respond to flood events.	The arid nature of Fresno makes it vulnerable to droughts that reduce water availability.
	Fresno sits atop a resilient elastic aquifer, which does not contain fossil water and is very receptive to recharge.	The sprawling nature of development in Fresno has resulted in the need to build extensive water and stormwater infrastructure facilities that serve relatively low-density developments, resulting in high costs per household for service provision.
	Fresno's Water Division is focused on finding alternatives to their current groundwater dependence, and on increasing aquifer recharge, with a goal of zero overdraft by 2025.	

Opportunities	Threats
Higher temperatures may lead to ideal growing conditions for some crops. This may lead to a shift in crops grown in Fresno County, increased crop productivity, and greater yields.	Reduced fresh water supplies will increase the likelihood of political, social, and legal conflict over water supply for municipal, industrial, and agricultural use.
Partnership opportunities exist to utilize resources from cities with similar climate and landscapes, such as Phoenix, and Las Vegas.	Expected new development and infrastructure demands will increase the rate of natural resources exploitation.
The growing agrotourism industry may lead to economic diversity and education opportunities for agricultural workers.	Increased drought, heat waves, and flash flooding in the Fresno area will significantly degrade Fresno's soil quality.
	There could be an increased risk of new and more abundant human pathogens and their host carriers, to which human populations are not adapted or immune, as a result of species distribution shifts that will occur in response to climate shifts.
Excess water in times of flooding can help recharge aquifers if engineers can design better ways to let water infiltrate into the aquifers quickly.	Drought and reductions in water availability will negatively impact domestic and agricultural water usage.
The California Department of Water Resources provides grants to implement Integrated Regional Water Management. Those applying for grants are encouraged to include mitigation and adaptation in their applications.	Increasing temperatures will result in an earlier onset of spring snowmelt, decreasing water availability in the summers.
In 2009, California passed legislation that includes increased regulations and repercussions for groundwater withdrawal and illegal water diversions.	An increased incidence of drought, coupled with rising temperatures, will increase water demand.
The Fresno area water districts plan to improve infrastructure and switch from groundwater to surface water sources, which would be 18% more energy efficient.	Changes in the water quantity will alter the concentration of pollutants and negatively affect water quality.
Fresno is considering water rate increases to finance infrastructure improvements.	New water infrastructure is very costly, and because infrastructure has a long expected useful life, new infrastructure will need to take into account the climate in 50-100 years. This is difficult to do efficiently when future impacts are uncertain.
Flood planning is centralized in California at the State Department of Water Resources. This provides the Fresno area with better access to resources and funding.	In 2010, the California Senate shelved an $11 billion water bond that would have provided new water infrastructure. The bond issue will likely be placed on the ballot in 2012.

	Strengths	Weaknesses
Energy	A majority of PG&E's existing energy production is low-carbon, therefore new policies that require low carbon generation will have little effect on their generation portfolio.	PG&E's energy supply is highly dependent on hydroelectric power (produced internally and purchased from other suppliers). As mountain snowpack and runoff decline, energy generation will decrease, resulting in an increased likelihood of shortages.
	Large renewable energy installations (wind and solar) are located near the City of Fresno, allowing for more flexibility in energy generation. With less dependence on a single fuel source, the region will be less vulnerable to specific climate threats.	Local energy distribution infrastructure may be insufficient to accommodate demand during extended high heat events.
	Existing energy use is relatively high in the Fresno area. Extensive use of air conditioning will result in a smaller percentage increase in energy use, as compared with other areas of the state and country where daily air conditioning use is less common.	State and local budget shortfalls will limit the ability to research and implement innovative energy generation, infrastructure, and efficiency programs that would help adapt to anticipated climate change.
Human Health	The Fresno Public Health Department has programs in place to address vector borne diseases. An ongoing investigation by the health department into West Nile Virus has raised community awareness of the risks of vector-borne disease.	Since 2007 the Fresno Public Health Department is no longer responsible for enforcement of the California Safe Water Drinking Act. The responsibility now falls on the State. This could potentially reduce the effectiveness of the monitoring program.
	The Fresno Public Health Department has a water surveillance program to monitor local water quality.	The large agricultural industry in Fresno attracts large numbers of migrant workers who work long hours in oppressive heat.
	A recent program of the Fresno Public Health Department focused on climate change and human health and featured information on changes to air quality.	High poverty rates, legal work status issues, and high unemployment in the region all generally restrict access to health care and education.
	The City of Fresno's Substandard Housing Program is designed to identify and evaluate substandard housing in Fresno specifically targeting environmental health, sanitation, and safety issues.	Increased CO2 and ozone levels will exacerbate the already poor air quality in Fresno.

Opportunities	Threats
California Assembly Bill 32 (AB32), passed in 2006, requires the California Air Resources Board (CARB) to establish market and regulatory mechanisms to reduce greenhouse gas emissions. Revenue generated could be used to provide funding and technical assistance to understand and adapt to climate change in California.	Energy demand is anticipated to increase substantially as temperatures rise. This increase could overload existing supply and distribution systems causing service outages for the City of Fresno and requiring expensive infrastructure retrofits.
California has been a leader in setting climate change and global warming legislation. California enacted Assembly Bill 1493 in 2002, a standard that requires average new vehicle emissions to be reduced by 30 percent by 2016, which has since been matched by federal regulators.	As high energy consumers, Californian providers routinely purchase electricity from surrounding states during periods of high demand. Projected impacts of climate change throughout the surrounding region may result in a general decline in overall energy production. Thus, external electricity sources will become less reliable.
Detailed reports have been compiled on the climate impacts and associated adaptation strategies for the energy sector in California. Several large institutions are actively studying this issue and producing research that will support adaptation planning and response in California.	Variability in energy prices because of higher temperatures will decrease the efficiency of energy generation, and distribution, and increase demand for electricity.
The energy sector in California and throughout the U.S. has more funding available for research and implementation of strategies than most other sectors.	Climate Change mitigation policies in California favor renewable energy sources which are largely dependent on natural systems and historic climate. Anticipated changes in the climate will increase the risk to these systems. Therefore, conflicts between mitigation and adaptation energy policy may result in higher energy costs. Climate threats will have a significant impact on the ability to provide power to the region. A high reliance on hydroelectric power generation leaves the Fresno region highly vulnerable.
The cities of Fresno and Clovis are currently working together to plan a new rapid bus service. This cooperative model could be used for future projects designed to create a more robust transportation safety net that will enhance mobility during extreme weather events.	A projected increase in heavy trucking traffic which will further exacerbate road infrastructure degradation brought on by extreme heat events.
The State of California is investigating the incidence of vector borne disease including Equine West Nile Virus.	The predicted increased incidence of drought in Fresno may limit access to drinking water, and water for food production.
Mary Nichols, the current Chairman of the California Air Resources Board prioritizes climate change programs, and focuses specifically on air quality issues in the San Joaquin Valley.	Higher temperatures and changes to precipitation patterns may result in new vector diseases, mold spores, and allergens.
Existing health programs could be expanded to include climate change adaptation concerns.	Higher temperatures will result in more dangerous working conditions for migrant farm workers, construction workers, and others who spend time outdoors for long periods.

	Strengths	Weaknesses
Transportation	Heat is only a moderate threat to physical infrastructure because design tolerances account for higher temperatures.	There is a heavy reliance on trucking for freight transportation, making it vulnerable to compromise by infrastructure damage caused by changing conditions.
	Fresno train network provides a travel option for individuals without cars who might need to leave Fresno in the case of extreme flooding or heat.	Over-built surface road infrastructure is a disincentive to the development of alternative modes of transportation in Fresno. The area has few alternative options in the event of infrastructure compromise or failure.
	Fresno is a hub for several major highway corridors. This provides good inward and outward mobility options in the event of extreme flood events.	The bus transit system in Fresno is undercapitalized, leaving riders underserved and limiting mobility in the case of evacuation due extreme weather events. This also compromises the system's ability to serve vulnerable populations which is important in the case of extreme precipitation or extreme heat.
	Robust road drainage system reduces the chance that minor flooding will occur, protecting transportation systems from precipitation events.	Fresno has a large vulnerable population (high poverty, low mobility, migrant population) which puts significant pressure on existing transit infrastructure.
Cross Cutting	Energy suppliers in the Fresno area are used to high energy demands during hot days. This existing capacity will limit the impact of high temperatures on human health in Fresno in the short term. (HH/E)	A high proportion of impervious surfaces in the City of Fresno increases the threats posed by flash floods and urban heat island. (LU/T/W)
	The City's Land Use/Sewage Waste Program of the Public Health Department will encourage new development in targeted areas, slowing sprawl. (LU/HH/W)	Highways are the primary mode for shipping produce from farm to market. More intense storm events will expose the system to increased flooding. (LU/T)
	California State University - Fresno's "The Fresno Climate Project" and the Governor's executive order establishing a Climate Action Team in 2005, has led to significant research and support for climate change mitigation and adaptation efforts in the region. (All)	Fresno has a large immigrant community and low-income population. These populations are likely to experience the most severe impacts of climate change. Lower-income and transit-dependent populations also have limited transportation options in the highly auto-dependent Fresno region, meaning they are less likely to be able to escape extreme heat conditions easily. (T/LU)
	The City of Fresno is working with the Local Government Commission to help develop recommendations for an adaptation strategy in Fresno County. (All)	The area's primary economic driver (agriculture) is highly dependent on a moderate and predictable climate. Variability and extreme weather could have a significant impact on local economic development. (LU/W/E)
		In 2011, a $30 million dollar deficit in the City of Fresno, combined with falling property tax revenues, will reduce financing for adaptation in the short-term. (All)
		Higher temperatures will lead to changes in hydrologic management due to an increased need for irrigation water for agricultural production. Water restrictions may lead to reduced crop yield and lower product quality negatively impacting the local economy. (LU/W/B)
		Regulations significantly impact the amount of surface water available. This has lead to an increase in groundwater extraction which significantly depleted the water level in the city's aquifer. A decrease in rainfall will reduce water availability within the region and lead to competition between agriculture and the local community, along with higher prices. (LU/W)

Opportunities	Threats
California's first highs speed rail corridor will stop in Fresno. This unique service would add to the regions transportation portfolio and provide an alternative to automobile and air travel.	Increase in heat related to climate change will damage roads and runways through cracking, bleeding, potholing, and rutting.
The San Joaquin Valley Regional Transportation Plan calls for expanded Intelligent Transportation Systems which could be used to provide real-time information to travelers about hazards and enhance multi-modal connectivity.	An Increase in land subsidence, washout, and erosion will threaten road, rail, and air infrastructure due to more intense storms and flooding.
Transportation planning in the region takes a progressive approach to integrating land use, transportation, community design and public health in long-range planning. This collaborative approach could be expanded to include climate change adaptation concerns.	The increased incidence of extreme heat will raise the risk of rail buckling, resulting in safety hazards and potential service disruptions.
The cities of Fresno and Clovis are currently working together to plan a new rapid bus service. This cooperative model could be used for future projects designed to create a more robust transportation safety net that will enhance mobility during extreme weather events.	A projected increase in heavy trucking traffic which will further exacerbate road infrastructure degradation brought on by extreme heat events.
The planned development of high speed rail and a transit hub in the city center will support less-sprawling development, and improve transportation options for vulnerable populations. (LU/T)	Fresno has poor air quality due to surrounding agriculture uses, food processing, and automobile emissions. Air quality is predicted to decline further as temperatures increase. (LU/T/HH)
The State of California has a progressive stance on greenhouse gas emissions mitigation, geared towards climate change. Fresno officials may find support for climate adaptation initiatives at the state level. (All)	Maintenance and replacement costs for public infrastructure will increase as the useful life of these structures declines due to more frequent intense heat and storms. (LU, T)
Water collection, capture, and storage can be increased and better managed through infrastructure development and policy intervention. These steps could help the city better deal with anticipated increases in drought and flooding. (W/LU)	High rates of poverty in the city and surrounding area will continue to increase with population growth. An increase in temperatures will disproportionately affect low-income and minority populations living in high-density areas, particularly those who work outdoors. (LU/HH/T)
The current Mayor's emphasis on downtown revitalization could reduce vulnerability of transit-dependent populations and prevent further development of impervious surfaces in outlying areas. (T/LU)	There is currently little Federal policy or financial support at the City, State, or Federal level for climate change adaptation. (All)
The University of California Davis is working on climate change issues in the San Joaquin Valley. This is a possible source of data and partnerships for Fresno on climate change adaption efforts. (All)	Contamination of groundwater systems is likely to occur at precipitation extremes. Drought will contribute to higher concentrations of pesticides entering into groundwater sources, whereas increases in extreme precipitation events may lead to flooding and contamination of groundwater. (LU/W/HH)

Heat Vulnerability Analysis

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MILWAUKEE

Milwaukee

Introduction

The climate challenges and threats we identified in the Milwaukee case study are highly representative of those faced throughout the Midwest. Coastal and arid cities rightfully receive a lot of attention in climate change studies because sea-level rise and increasing global temperatures pose well-documented threats. Our analysis of Milwaukee exemplifies the changes to precipitation and associated flooding that are likely to occur in the Midwest. Milwaukee experienced multiple record-breaking extreme weather events in recent years, including widespread urban flooding and prolonged heat waves. Milwaukee also has a large low-income, minority population that is concentrated in the older urban core. In the sections that follow, we explore five major sectors: land use, water, energy, human health, and transportation. We use these sectors to analyze how the projected climate change in Milwaukee will likely differ from historic climate patterns. Concluding our analysis of Milwaukee, we use geographic information systems (GIS), to identify vulnerable populations and analyze how they may be impacted by future extreme precipitation and flood events.

Climate Change Risks

The intensity of precipitation is likely to increase significantly over the next century in the Milwaukee region. Half of the region's water flows through downtown Milwaukee and into Lake Michigan, and the high percentage of impervious surfaces in the watersheds of the Milwaukee, Kinnikinnick, and Menomonee rivers accelerate the speed and volume of storm water runoff. These rivers have been channelized in the most densely-built areas of Milwaukee, and in many places development extends right up to the river's edge. Recent flood events, such as in July 2010 when over 8 inches of rain fell on parts of the city in a 24-hour period, temporarily closed the airport, opened up sinkholes in city streets, and forced evacuations. These recent events highlight the significant risks associated with urban flooding (1).

Average annual precipitation has already increased by five to seven inches per year as compared with the mid-20th century, and climate predictions indicate that these flooding events will occur more frequently in the future. While precipitation changes will be highly variable and are difficult to predict with accuracy, impervious surfaces and dense developments in close proximity to waterways in the City of Milwaukee suggest that the urban core will experience the most severe impacts of increased extreme precipitation. Low-income and minority populations live almost exclusively within the City; these populations are likely to experience disproportionate negative impacts associated with climate change. Increased temperatures will also be a significant factor in urban Milwaukee. Summer air temperatures are predicted to increase between 3 and 7 degrees Fahrenheit. Higher temperatures will lead to more frequent and severe heat waves, similar to the one in 1995, which resulted in the death of 91 city residents.

Existing Characteristics

The City

Located at the confluence of the Milwaukee, Kinnikinnick, and Menomonee rivers, and along the Lake Michigan shore, Milwaukee is Wisconsin's largest city, both in terms of area and population. Once the 11th most populous city in the United States (1960) with 741,324 residents, Milwaukee's population fell to 596,974 residents by 2000 (an almost 20 percent decline) (2) (3). Population has been stagnant in recent years and population growth forecasts are mixed, ranging from a 64,900 person increase to a 45,700 person decrease in Milwaukee County by 2035 (4). The City encompasses 97 square miles, comprising most of Milwaukee County (2). The City of Milwaukee's urbanized area (a U.S. Census designation of a central city and contiguous surrounding areas with an average of 50,000 persons per square mile) was 487 square miles in 2000, spread across parts of five counties (2).

The Region

The Milwaukee region consists of 2,289 square miles over seven counties in the Southeastern portion of Wisconsin, 28.3 percent of which was urbanized land, encompassing 154 separate local units of government (4). The region's population in 2000 was 1,931,200, including the significant Racine, Kenosha, and Round Lake Beach metropolitan areas (4). While the City of Milwaukee and Milwaukee County have recently experienced stagnant or negative growth, the wider region as a whole has grown. Regional population increased from 1,758,083 persons in 1970 to 1,931,165 persons in 2000, an almost 10 percent increase (4). This trend is likely to continue, with projections ranging from a 3.7 percent increase to a 23.5 percent increase by 2035 (4).

Demographics

Like many Midwestern central cities, Milwaukee is highly segregated by race and economic class. In 2000, the City of Milwaukee had a 50 percent minority population, double the national average of 25 percent (2). Much of this population is concentrated in older neighborhoods to the Northwest of the central city. In contrast, the regional Milwaukee-Racine Consolidated Metropolitan Statistical Area (CMSA) had only a 22 percent minority population and this percentage would be drastically smaller if Milwaukee were excluded (2). A similar disparity exists between the City and region for household income. In 2000, the median household income in the City of Milwaukee was $32,216 as compared to $46,132 (43 percent higher) for the Milwaukee-Racine CMSA, a difference of $13,916 per household (2). Concentrated poverty is a serious problem in the Milwaukee region, but this problem is almost exclusively confined to the central city. In 2000, 95 percent of the region's census tracts with poverty levels above 10 percent were located within the city of Milwaukee (5).

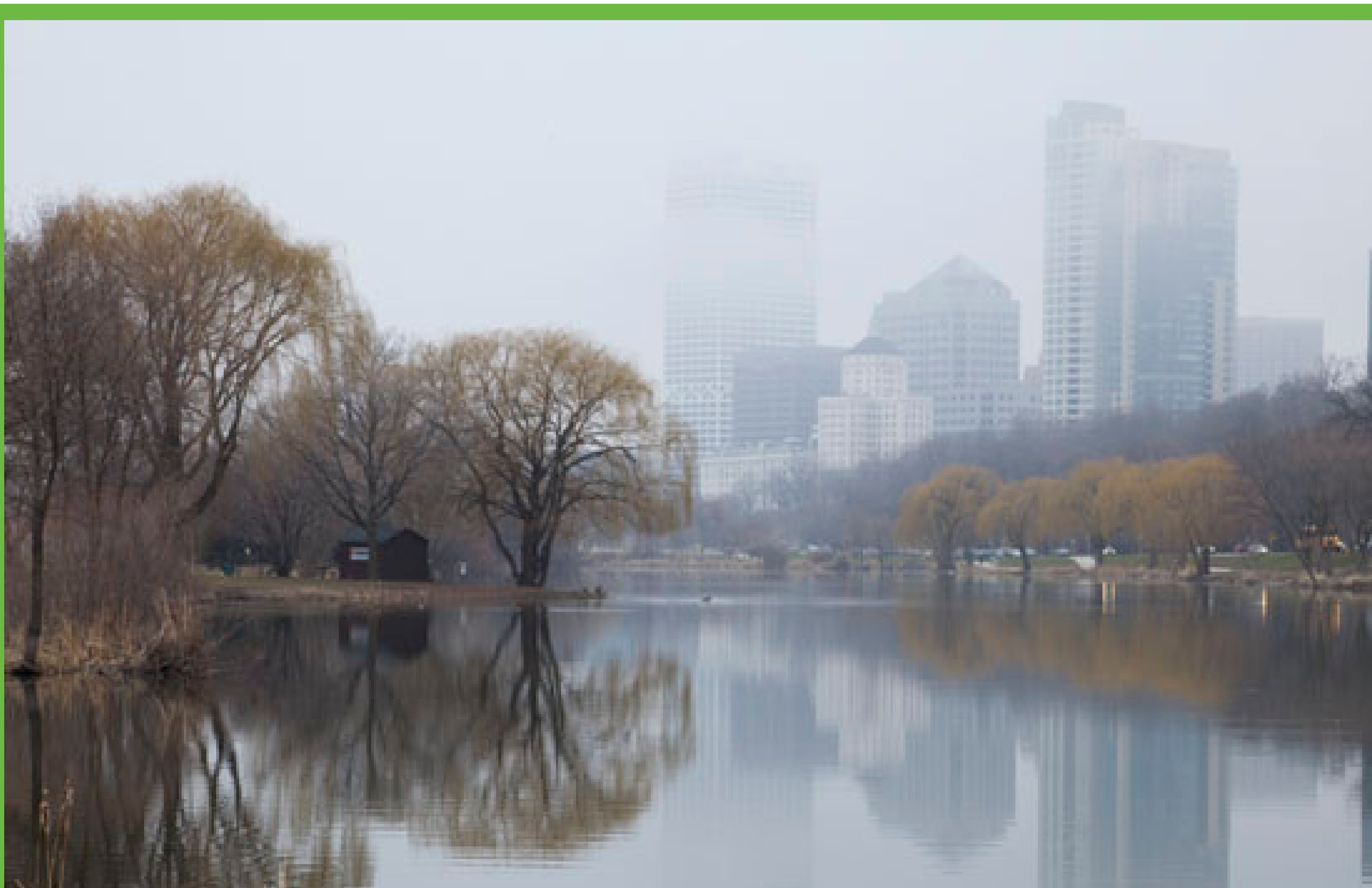

Figure: Downtown Milwaukee as seen from the river

2006-2008 American Community Survey

Milwaukee City Population	594,833
Milwaukee County Population	947,735
Pop. Density/sq. miles	6,138.63
Sq. Miles	96.9
% White	46.8
% Black	38.3
% Asian	3.2
% Latino/Hispanic	15.7
% Non Hispanic White	40.4%

Table 6: Demographic Information Milwaukee


BORDERS

Economy

Milwaukee is the most economically productive city in Wisconsin. The region was home to 1,222,800 jobs in 2000, with over half of these located in Milwaukee County (4). However, Milwaukee's share of regional employment has been falling since the 1950s. Over the last fifty years, the majority of regional job growth has been in the counties surrounding Milwaukee, with Waukesha County leading the way. Waukesha County held over 22 percent of the regions jobs by 2000 and led the region in job growth from 1990-2000, with an increase of 81,100 jobs (a 42.8 percent increase) (4).

The regional economy has historically relied on industrial manufacturing. However, from 1970 to 2000 the regional economy underwent a dramatic shift from manufacturing-based to service-based employment (4). Manufacturing has declined for the past several decades, now representing only 18 percent of regional employment (down from 32 percent in 1970), while jobs in service industries have risen (5). In 2000, retail and service jobs accounted for half of all regional employment (5).

Milwaukee is struggling to recover from the global economic recession of 2009. The City made large cuts to its $1.4 billion budget in 2009 to avoid fiscal insolvency. However, American Recovery and Reinvestment Act funding enabled the city to continue investing in public infrastructure. The City's budget emphasizes the importance of infrastructure in protecting public health, the environment, and the economy. Many of the City's departments focus on sustainable objectives within their budgets, including: 1) increasing energy efficiency and promoting renewable energy, 2) improving surface water quality and decreasing pollutants in runoff, 3) incorporating green infrastructure, 4) updating the flood plan, 5) improving aging infrastructure, and 6) reducing solid waste by 40 percent (6). Furthermore, the City's capital improvement plan calls for more than one-third of all capital investment funding to be spent on environmental projects. Nevertheless, the City will struggle to maintain fiscal solvency without additional cuts. Revenues are falling due to decreasing property tax revenues, and current revenues are primarily devoted to non-discretionary sources. By 2013, non-discretionary spending will approach 75 percent of general fund revenues. For a more detailed look at Milwaukee's budget, see Appendix B.

Land Use

History of Development

To understand the current land use pattern of Milwaukee, it is critical to understand how the city developed. The Milwaukee metropolitan region is typical of many older Midwestern cities. The central city core developed in the early to mid 19th century and grew slowly and densely up until the 20th century (4). During this period, large industrial and port facilities were built along the Milwaukee, Kinnikinnick, and Menomonee rivers, as well as the Lake Michigan Shore. Suburbs served by streetcars appeared in the early 20th century, still relatively close to the core of the City. By the 1940s and 1950s, transportation technology improved and highways were built, the boundaries of the City expanded, and the first ring of suburbs developed. Suburban development at this time was typically much less dense than that of the central city with detached, single-family housing and strictly separated land uses dominating. Population increased dramatically (65 percent increase from 1940 to 1963) and the urbanized area more than doubled, expanding three times faster than population growth. This was also a time of increasing racial and economic segregation. Many middle-class, white residents moved to suburban locations, while less wealthy, predominantly African American residents remained in aging central city neighborhoods (7).

In the 1960s and 1970s, the trend of suburban expansion accelerated. The urbanized area expanded to encompass almost all of Milwaukee County and spilled over into neighboring Waukesha, Ozaukee, and Washington counties, enveloping formerly independent small towns and cities (4). The farther development spread from the central city, the larger and more consumptive the land use patterns were likely to be (7). Population continued to increase, but at a much slower rate (approximately). 7 percent increase from 1963 to 1980) (4). This slowing population growth reduced the expansion of the urbanized area, but the urban still continued at more than six times the rate of population growth (4).

Today, the Milwaukee region has grown to encompass over 579 square miles of urban development (2). Throughout the 1980s and 1990s, suburban expansion continued at increasingly lower densities despite very low population growth (4). Racial and economic polarization has continued and intensified with large areas of concentrated poverty and ethnic minorities isolated in the northwest sector of Milwaukee (2). Most new investments have been in suburban locations far from the aging central city where decay and blight plague many neighborhoods. Population is now evenly split between Milwaukee County, which represents both the central city and many inner-ring suburbs, and outlying counties.

Existing Land Use Pattern

Like most cities, the Milwaukee urban area is primarily residential. The average urban density in the region was 1,289 households per urban square mile in 2000 (4). However, these neighborhoods vary significantly from older neighborhoods in the Milwaukee core with areas of high densities, to large-lot single-family neighborhoods in the suburbs. In general, residential densities fall as a function of distance from the Milwaukee central business district, with the lowest densities at the suburban fringe (2). Residential uses are also strictly separated from other land uses (4). This results from traditional Euclidian zoning practices that prohibit the mixing of land uses (such as residential and commercial). This type of zoning pervades throughout the U.S., and Milwaukee is no exception. Many residential neighborhoods outside the central

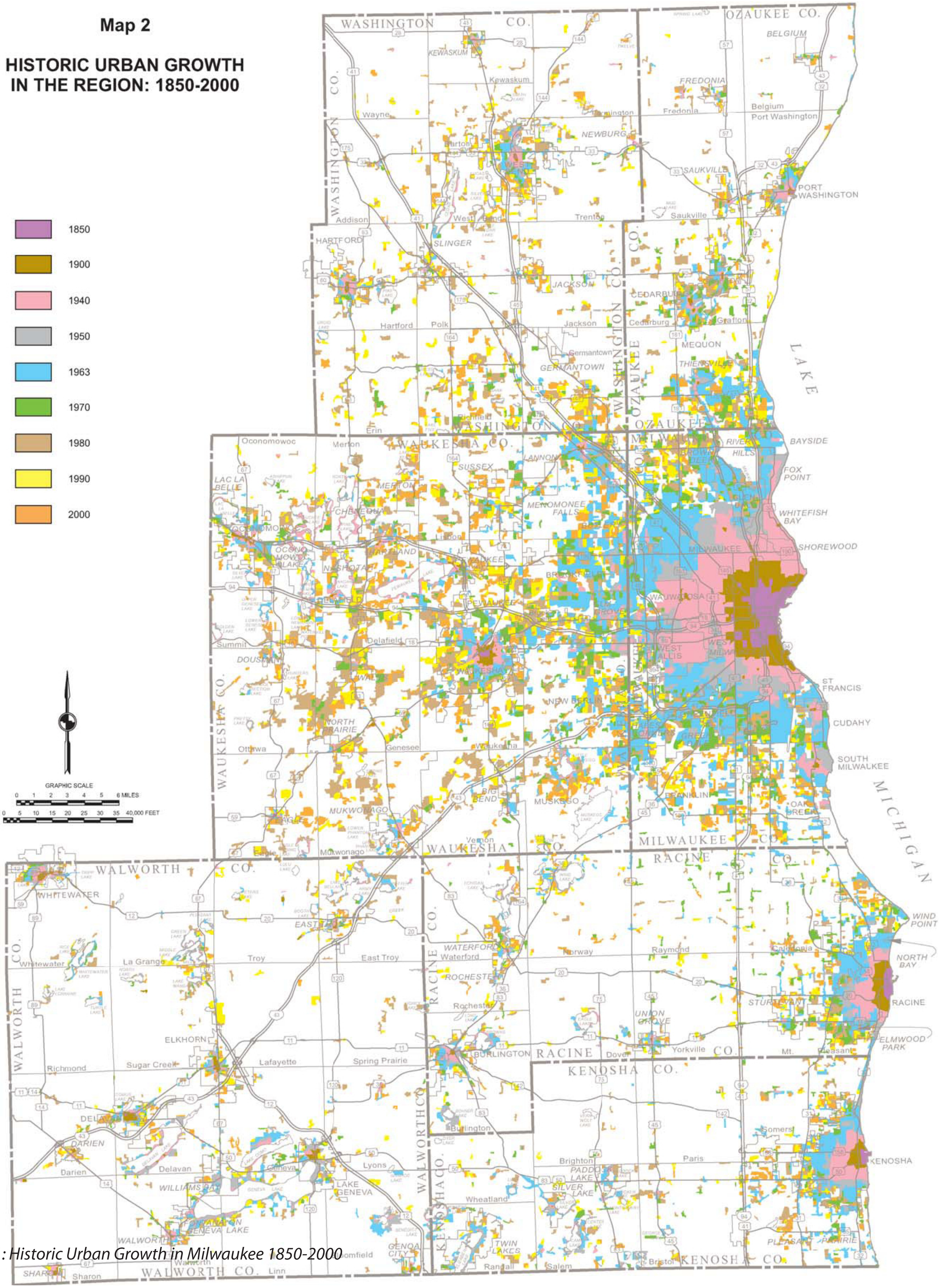

Figure 91: Historic Urban Growth in Milwaukee 1850-2000

business districts rely on the automobile as the primary mode of transportation. However, the 2000 Census showed 75,838 households in the Milwaukee region did not have access to a vehicle. These households are disproportionately located within the City of Milwaukee and are reliant on the region's bus transit systems.

An extensive grid of roads, rails, and highways connect the region. Most non-residential urban land is located along these important pieces of infrastructure. Commercial uses are primarily located along major roads and near highway exits, with a notable concentration in western Milwaukee County and Eastern Waukesha County (4). Industrial lands are highly concentrated around this infrastructure. In particular, there is a very high concentration of industry around the port, just south of downtown Milwaukee. Most other industrial land uses radiate out from the center along major highways, rail lines, and rivers (4). Milwaukee County is also home to important governmental and institutional land uses. Marquette University's campus occupies 90 acres west of downtown (8) and the University of Wisconsin-Milwaukee's 73 acre main campus is located north of downtown near the Lake Michigan shore (9).

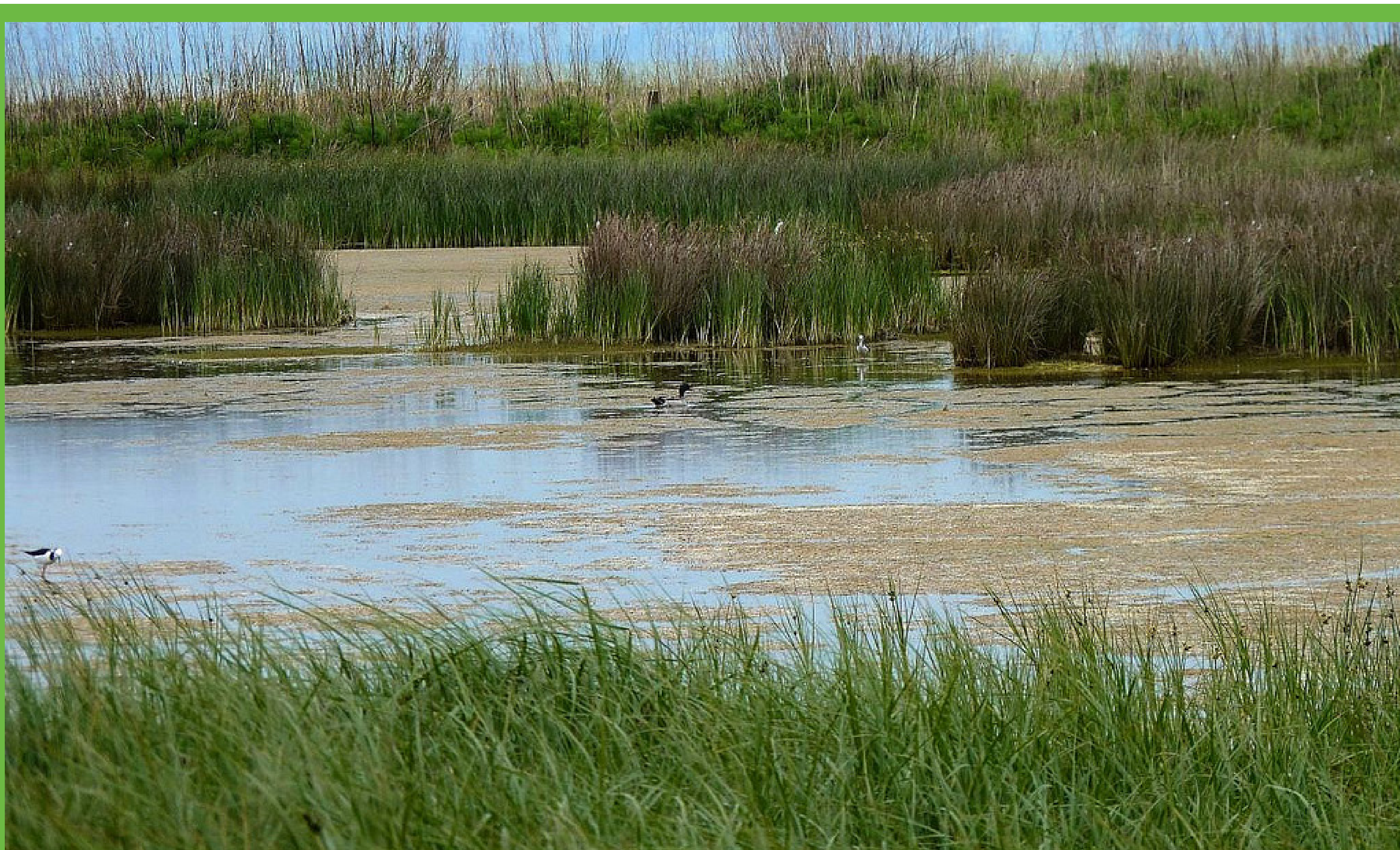

Figure 92: Wetlands play an important role in the natural ecosystem restoration in Milwaukee

Diverse urban land uses are closely packed together in Milwaukee County. Few natural, agricultural, or open spaces remain throughout much of the County, where the population is primarily concentrated (4). This also holds true for the urbanized areas in surrounding counties that border Milwaukee County. As distance from the central city increases, the development pattern is much more likely to be interspersed with agricultural lands, wetlands, lakes, and forested areas (4).

The Milwaukee region has maintained the same acreage of wetlands and forested lands since 1950 (4). The region also designated "primary environmental corridors," often located along rivers and streams, to provide dedicated habitat and facilitate movement of species. These corridors provide important ecosystems services to the region in the form of storm water drainage and water filtration (4). However, almost all of these land uses are located in rural or semi-rural areas with few pockets of natural landscape remaining within the central city. The vast majority of regional environmental corridors have been protected through public ownership, local land use regulation, or state land use regulation (4).

Agricultural land is the most common non-urban land use in the Milwaukee region. 47 percent of the region's land was used for agriculture in 2000 (4). The vast majority of agricultural lands are located outside the highly urbanized counties of Milwaukee and Waukesha. Also, many agricultural lands at the urban fringe are at risk for conversion to urban uses as evidenced by the historic development pattern. From 1950 to 2000, reductions in agricultural lands tracked closely with increases in urbanized lands (4). 22 percent of the region's total farmland was converted to urban uses between 1963 and 2000 (4).

Natural Features

"Milwaukee" derives its name from a Native American phrase meaning "gathering place by the river." The modern city, situated on the western shore of Lake Michigan and at the terminus of three of the State's largest rivers, sits 634 feet above sea level. Unlike other areas of southeastern and south-central Wisconsin, Milwaukee was developed on a low, flat landscape - a result of ancient glacial scouring. Sandstone, dolomite, and shale comprise the bedrock layers below a thick band of clay which itself underlies a shallow and rocky layer of topsoil. Native tree species include sugar maple, basswood, and elm, while areas near Milwaukee include a small oak savannah and a conifer swamp. 41 small lakes lie within Milwaukee County (10). Glacial deposits led to sustained sand, gravel, and limestone extraction in and around the city. Adjacent counties have conducted extensive drainage projects over the past 100 years, leading to a stable regional agricultural sector, though not nearly as productive as other areas of the Midwest (11).

Local Land Use Regulation

The State of Wisconsin is a Home Rule state, which means that the State delegated the majority of land use regulatory powers to the local units of government (12). Each of the Milwaukee region's 154 separate units of local government has broad powers to regulate land use within its borders. These powers vary based on corporate designation (city, village, town, and county). The primary land-use control mechanism is zoning, which sets districts for the use of land and sets restrictions on the height, bulk, and setback of structures. All local units of government in the Milwaukee region have adopted some form of zoning, either independently or by ratifying a county zoning ordinance (4). The State has also mandated that all local governments adopt both floodplain zoning and shoreland zoning ordinances. These ordinances are designed to prevent harmful development in sensitive environmental areas. The floodplain zoning regulations greatly restrict what can be built in the 100-year floodplain (4).

Another kind of important development control in the Milwaukee region are sanitary service districts. Service districts are designated as part of the regional land use planning process coordinated by the South East Wisconsin Regional Planning Commission (SEWRPC) (4). Under State law, municipal water and sewer services cannot be extended to communities outside the designated service districts (4). Recent efforts have focused on conversion of areas originally developed with on-site sewerage disposal (septic) to full, treated sanitary sewer. The unique topography of the area, with abundant depressions due to glacial activity and the proximity to Lake Michigan create significant water drainage challenges that these service districts are designed to help address. Of particular concern is the overflow of combined sanitary sewer and storm water systems during rain events. During heavy rains, these systems discharge untreated wastewater into rivers and streams, eventually flowing into Lake Michigan, a primary source of municipal water for the Milwaukee region and a resource of immeasurable environmental and economic value (4).

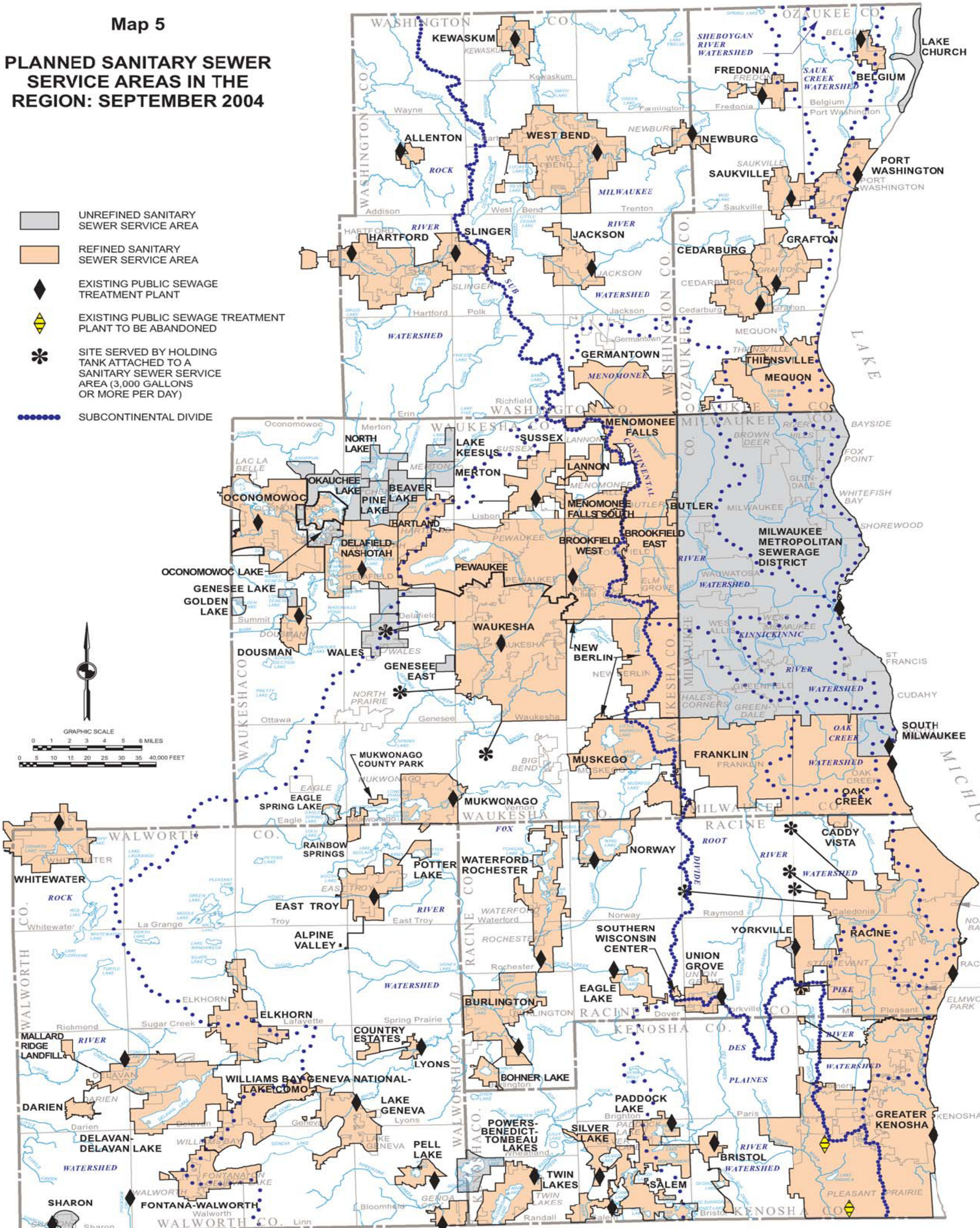

Figure 93: Sanitary Sewer Service Area 2004

Water

Introduction

Fresh water has played a key role in the formation and development of the City of Milwaukee. Before intensive settlement, Milwaukee's three rivers were used for the fur trade (4). By the mid-1800s, farming and mill industries became the main activity along the rivers (4).
As development continued and land uses changed, the health of the water declined in relation to the amount of runoff from agricultural and urban land uses. It is likely that as the climate in Milwaukee changes, extreme precipitation and flood related issues will negatively impact water distribution, waste infrastructure and the natural waterways of Milwaukee in the near future.

Water and Wastewater Infrastructure

Freshwater Supply and Infrastructure

Located on the shore of Lake Michigan, the City of Milwaukee has abundant water resources from the lake, which it treats to provide fresh drinking water for over 800,000 people in 16 communities through the Milwaukee Water Works. Milwaukee Water Works has invested $227 million in treatment and distribution infrastructure for a high quality and reliable water supply. Lake Michigan water is treated using a multiple step process, which includes the use of ozone gas to disinfect, reduce chlorinated disinfection byproducts and remove taste and odor. The processes of coagulation, settling, and filtration are also used to remove additional particles (13).

Sewerage and Stormwater Infrastructure

The Milwaukee Metropolitan Sewerage District, a regional government agency that provides water reclamation and flood management services to over one million people in 28 communities, manages the City of Milwaukee's wastewater. This district spans parts of six watersheds and contains approximately 3,000 miles of pipes (14). Some areas in the district have separate storm and wastewater systems; however, the majority of the City's land area is serviced by a combined sewer overflow system which merges the conveyance of wastewater and stormwater (14).

A recent addition to the wastewater system is the Deep Tunnel System, which is carved out in bedrock 300 feet underground. Approximately 600 million gallons of excess waste and stormwater is stored during heavy rain events to prevent basement backups and sewer overflows. As of 2010, this tunnel system prevented over 70 billion gallons of wastewater from polluting Lake Michigan as the water is treated by a water reclamation facility before it is released into the lake (15).

Climate Change Impacts on Water

Although no single storm and flood event can be attributed directly to climate change, heavy rain events occur more frequently, increasing the likelihood of disastrous floods. Wisconsin's typical flooding scenarios include local stormwater, stream, river, lake, and groundwater flooding, which will all be exacerbated by changing precipitation patterns. Not only has flooding from torrential rain disrupted the City, but lake evaporation has also threatened Lake Michigan's water supply (16). Heavy downpours are expected to lead to more frequent flooding due to the projected pattern of increased precipitation in winter and spring. These changes in Milwaukee and the surrounding region will also affect infrastructure integrity and human health.

Figure 94: Milwaukee Wastewater Treament Plant at night

Precipitation and Flood Risks

Flooding remains a major threat to Milwaukee as the City already experiences weather anomalies and combined sewer overflow issues. Milwaukee is expected to experience increases in the magnitude and frequency of large rainfall events (17). Such flooding events have negative impacts on the economy, built environment, human health, and natural environments.

Climate change and land cover changes will also degrade the natural flood buffering capacities of wetlands and floodplains. More runoff from winter and spring snowmelt events, and summer downpours will cause increased flooding and erosion. Such events could increase pollution in natural water bodies and waterways from urban and agricultural runoff. This often enters the lake untreated and increases stress on water treatment for human consumption and aquatic ecosystems (17).

On July 22, 2010, areas of Milwaukee experienced extremely heavy rain and consequent flooding, which caused a 25-foot sinkhole to open in the street, and engulfed an SUV and a traffic light. There were also reports of areas receiving up to 12 inches of rainfall within a two days. The rainstorm was so severe that the Milwaukee General Mitchell International Airport grounded all flights due to the submerged runway. The excess amount of stormwater prompted flood gates to be opened, which released untreated sewage to enter Lake Michigan (18).

According to data compiled by the Wisconsin Initiative on Climate Change Impacts (WICCI), storm events that deposited two inches of rainfall within 24 hours were nearly five times more likely to occur in the 2000s than in the 1940s (17). Metro Milwaukee Sewerage District and other agencies tasked with flood prevention and stormwater control could face tremendous challenges if storms similar to the July 22, 2010 event, which yielded more than seven inches of rain in some parts of Milwaukee in less than an hour, become more common. Despite the recent completion of the Deep Tunnel System, some scientists worry about its effectiveness. "You can't build a big enough pipe to handle that kind of rainfall," says McLellan, a scientist at UW-Milwaukee's School of Freshwater Sciences and chair of WICCI's Milwaukee workgroup in reference to the July 2010 event (19).

Figure 95: Milwaukee Flood, July 22nd, 2010

Figure 96: Sink hole created by the July 22nd Milwaukee flood

Figure 97: Milwaukee Deep Tunnel System

Evaporation and Lake Michigan Water

Milwaukee is expected to experience longer dry spells between flash, torrential rainfall. Also, warmer temperatures will increase evaporation. Hotter temperatures combined with the loss of moisture will worsen droughts and affect the agriculture industry. The recent eight-year drought that impacted the northern Wisconsin region is an example of the type of future climate impact that Milwaukee can expect (19).

Water levels in rivers, streams, and aquifers will decline due to longer droughts and in turn reduce the area of wetlands and shoreline habitat. This loss of habitat will diminish the ecosystem services which provide flood protection, water quality improvement, shoreline erosion control, and recreational and educational functions. (20)

Changes in the precipitation cycle and seasonal temperatures will also likely result in a drop in Lake Michigan's water levels. Higher temperatures and increasing rates of evaporation in winter will lead to a decline in ice cover causing lake levels to decline. Such an impact will affect shipping, natural ecosystems, recreation and tourism, infrastructure repair and adjustments, and dredging requirements (16). Predicted warmer temperatures are also likely to increase the duration of summer stratification, which can add to the risk of oxygen depletion, and the formation of deep-water "dead zones" for fish and other organisms (21).

With a growing population and ongoing debates over lake water withdrawal, climate change is expected to put pressure on water users throughout the Great Lakes. These pressures will intensify as water shortages develop and pressure for water rights increase in Milwaukee's surrounding cities. Additionally, falling lake levels and warmer water temperatures can accelerate the accumulation of mercury and other contaminants in lake water for human use and the aquatic food chain (21).

Figure 98: Coal train in Milwaukee. Coal-fired power plants are the predominant form of energy generation

Energy

Introduction

In 2006, the State of Wisconsin acknowledged the effects of climate change, but did not reference possible future scenarios, nor explore the impacts that sustained change would have on Wisconsin's energy sector.

> *"Wisconsin climate is showing a warming trend. Winter weather has been warmer than the 30-year normal 15 out of the last 16 years. The summers are also getting warmer, which places a burden on the electrical system through increased cooling for space conditioning and food storage."* (22)

This section examines how climate change is likely to impact energy demand, generation, and infrastructure in the Milwaukee region, with a particular focus on Wisconsin Energy (WE Energy) and Wisconsin Natural Gas, the region's primary electrical and natural gas utilities.

Energy Sector Summary

WE Energy is the electric utility that services customers in Milwaukee and southeastern Wisconsin. Coal makes up the majority of WE Energy's generation portfolio, with additional generation from natural gas and nuclear facilities used during peak periods. There are two coal-fired power plants in the city of Milwaukee. First, the Valley plant has a generation capacity of 272 Megawatts and is located along the Menomonee River, about one mile from Downtown Milwaukee. 23,750 residents, primarily low-income, live within a 1-mile radius of the Valley plant. The city's second, smaller coal power plant is the Milwaukee County Plant, which generates 11 Megawatts. In 2010, WE Energy opened the South Oak Creek Plant on Lake Michigan in the southern suburb of Oak Creek. This new plant is the workhorse of the WE Energy electrical generation portfolio and is capable of generating around 1,200 megawatts of electricity. Both WE Energy and Wisconsin Natural Gas provide residential and commercial natural gas service to the Milwaukee region with overlapping service territories. Western Wisconsin and eastern Lake Michigan both have significant wind resources (greater than 14.5 miles per hour) that can be developed for renewable electricity generation. WE energy operates the Blue Sky Green Field Wind Energy Facility near Lake Winnebago approximately 50 miles from Milwaukee. This facility consists of 88 wind turbines that generate 145 megawatts of electricity.

Energy Demand

The Public Service Commission (PSC) of Wisconsin projects an increase in electricity demand through 2016 in their latest "Strategic Energy Assessment." This report incorporates concerns over climate variability and the impacts of the latest economic recession (23). These increases will come as a result of increased demand for cooling in buildings due to an increase in average temperatures and very hot days. Higher cooling demand will increase peak demands for electricity, which will likely be supplied through natural gas-based generation at the expense of more costly development of renewable energy sources, extending Milwaukee's dependence on imported energy fuel sources. As temperatures and regional population continue to increase, energy demand will continue to grow, with a gradual shift from natural gas for home heating to electricity for cooling.

In 2006, the State of Wisconsin initiated an energy efficiency resource standard for all utilities, establishing an annually increasing schedule of efficiency targets through 2014 (24). The state also instituted a suite of energy policies, including a green power purchasing program, net metering, solar and wind access policies and standards, an energy conservation code, a state building energy code, and a public benefits fund (25). Together these policies are likely to induce significant demand for green power in the Wisconsin.

Energy Generation

The biggest risk to energy generation infrastructure in the Milwaukee region is flooding. As the frequency and intensity of extreme storms increases, the risk for localized, on-site flooding will also increase. It will be more difficult to find suitable sites for new generation infrastructure in the future due to greater concern over water uses, potential lake level drop, and exposure to extreme events.

The efficiency of most power generation infrastructure will also likely decline as temperatures increase. There is a potential for greater variability in wind resources and direct solar radiation, which may negatively impact the investment potential of these clean technologies for the Milwaukee region. Similarly, existing hydropower facilities in the state may become less reliable as winter snowpack decreases and the time between rainstorms increases (even as these events become more severe).

Energy Infrastructure

A new 13- kilovolt electric transmission line is slated for installation in the Milwaukee region in 2014 at a cost of between $33 and $46 million for two miles and the construction of a new substation (23). This is one of eight projects currently before the Public Service Commission (PSC), totaling hundreds of miles of new transmission and associated infrastructure. Even as the Milwaukee region invests in new infrastructure, increased temperatures will decrease the thermodynamic efficiency of these new and costly investments, as well as that of all existing transmission lines. An increase in the occurrence of storms are likely to cause more frequent damage to energy generation and transmission infrastructure.

Figure 99: 272 megawatt coal-fired power plant along the Mennomene River

Human Health

Introduction

There are a variety of human health threats from climate change that need to be considered in formulating a climate change adaptation plan for Milwaukee. Some of the threats are broad and will impact all residents, while other threats will disproportionately harm low-income and minority populations. In a 2010 study, Milwaukee County ranked 71 out of the 72 Wisconsin counties in overall health outcomes (measured by mortality and morbidity) and health factors (measured by health behaviors, clinical care, and socioeconomic, physical and environmental factors (26). While the county ranked poorly in relation to the rest of the state, there are also significant discrepancies in health indicators across the city. Even before future impacts from climate change are taken into account, "widely disparate environmental and socioeconomic contexts mean that not every individual has the same opportunity to initiate or sustain health choices" (27). Changes to Milwaukee's climate will result in even greater challenges for maintaining good health.

When looking at the interplay between climate impacts and human health, the predicted increase in extreme precipitation events and more frequent extreme temperatures will pose the most significant challenges to human health in Milwaukee. According to the U.S. Global Change Research Program's Global Climate Change Impacts in the United States report "During the summer, public health and quality of life, especially in cities, will be negatively affected by increasing heat waves, reduced air quality, and insect and waterborne diseases" (28).

There are four main categories of threats and areas of concern for human health in Milwaukee:

- **Socioeconomic:** The relationship between demographics and the geographic distribution of climate threats that people face in their living and working environments.
- **Stress on Water Systems:** Water quality concerns related to contamination of fresh water sources including surface water contamination from combined sewer overflows and contamination of groundwater sources.
- **Stress on Natural Systems:** Ecosystem buffers, vector and food-borne diseases spread rates, water-illness transmission, heat intensity and humidity, winter storm intensity and frequency.
- **Stress on Public Health Systems:** Stresses on the services provided by public health departments, on public illness treatment rates, as well as the economic and financial impacts of these stresses.

Figure 100: People forced to move from their homes

Figure 101: Rushing river following heavy precipitation event

Figure 102: Ecosystem lake buffer

Figure 103: Scientist examining the leaves for pests

"The effects of heat are most severe in the central areas of large cities, which typically have a high percentage of hard surfaces and low percentages of tree canopy and greenspace."

Socioeconomic Considerations

Urban Heat Island Effect

Increased temperatures will result in more severe urban heat island effects (28) (29). Urban landscapes exacerbate the impacts of increased temperatures because hard materials (concrete and asphalt) absorb solar radiation and become a secondary source of air heating. The urban heat island effect has been associated with increased heat stroke, stress on the cardiovascular system, and stroke (29) (30). Milwaukee and Chicago experienced the devastating effects that extreme heat can have on low-income urban neighborhoods in 1995 when 91 people died of heat-related stressors over ten days of extreme heat. These effects are most severe in the central areas of large cities, which typically have a high percentage of hard surfaces, and low percentages of tree canopy and greenspace. In Milwaukee, the residents of the central areas tend to be low-income and minority residents, putting them at even greater risk. A 2007 study of health disparities in Milwaukee found that those living in the poorest third of the city's zip codes fell significantly behind those in the rest of the city (according to many different measures of health) (27). Nine of the ten poorest zip codes in the city are located in a cluster defined as the "Central City" by the City of Milwaukee's Department of City Development (27).

Air Quality

Pre-existing health conditions, respiratory disorders in particular, are very likely to be exacerbated by warming-induced deterioration in air quality (31). Increased temperatures will increase the dangers posed by ozone and other pollutants in the air; ozone poses the greatest risk to human health in the summer because it forms when air pollutants react with high temperatures and ultraviolet energy from the sun (29) (32). The danger of high ozone concentrations will be longer lasting, because less frequent storms will allow air to stagnate longer (33). Some occupations, particularly those that place people outside in the heat of the day, such as landscaping and construction, can lead to higher ozone exposure (32). Higher temperatures will also exacerbate people's allergies, because as temperatures increase, the growing season will lengthen and the amount of pollen in the air will increase (32).

Water Systems

Combined Sewer and Sanitary Systems

Milwaukee has a combined sanitary and stormwater sewer system that has a history of being overburdened during extreme precipitation events (34). During severe storms these systems cannot treat the high volume of liquid passing through the system, leaving no choice but to discharge directly into the rivers, streams, and lakes, or risk overflows into basements and city streets (34). In 1993, Milwaukee was the site of a Cryptosporidium outbreak, the worst outbreak of a waterborne disease in US history, where 54 people died and over 400,000 cases of gastrointestinal illness were reported (34) (28) (35). This event was linked to contamination of fresh water sources from combined sewer overflows (CSOs). As the climate warms, the Milwaukee region is predicted to experience an increase in extreme precipitation events which will increase the likelihood of overflow events. This will increase the likelihood that fresh water sources will be degraded or contaminated, either from a single isolated event that releases a dangerous pathogen, or the accumulated impact of sewage being released during multiple storms (34).

Figure 104: Milwaukee has a combined sanitary and storm water sewer system which historically has had overflow problems

Natural Systems

Extreme Heat

Milwaukee will experience more days of extreme heat as the climate changes (34) (28). The population in Milwaukee has not historically been regularly exposed to extreme heat events of the same magnitude, or at the same frequency as those experienced in the southern U.S. This makes Milwaukee residents vulnerable when extreme heat events do occur. This is particularly true for low-income (often minority) residents, who are much less likely to have access to air conditioning and live in older homes that were designed to be cooled with natural ventilation. The impacts of heat waves are most severe in areas affected by urban heat island effect, where temperatures remain high at night and do not offer relief from the day's heat (28). The impacts from heat waves are particularly acute among the poor and elderly who are more likely to have pre-existing health conditions, such as diabetes, heart disease, respiratory disease, asthma, or allergies (36) (37). These vulnerable populations are more sensitive to extreme temperatures because their bodies are not able to regulate temperature well (38). Milwaukee's vulnerability to extreme heat was demonstrated in July of 1995, when an extreme heat wave combined with humid air to produce heat index readings in the 120 to 128 range (39). The heat wave lasted for four days and resulted in the direct deaths of 71 people. An additional 72 deaths were indirectly linked to the heat wave (39). Milwaukee can expect events like the July 1995 heat wave to occur more frequently in future years as a result of climate change.

Vector-borne disease dynamics

Ecological change may alter traditional vector-borne disease dynamics, possibly redefining animal hosts, vectors, and disease outcomes at the local and regional scales (40) (36). An increase in precipitation, coupled with a gradual increase in average temperatures in the region, may impact the ecology of the region with implications for human diseases (40). For example, under conditions of high soil saturation, rapid transport of microbial organisms can be enhanced which increases the threat to human health from diseases (36). In addition, the range of many vectors (such as rodents) is likely to extend northward as the precipitation patterns under a warmer climate enhance the vegetation they feed on (28) (31) (41). This expanded range of vector-borne and tick-borne diseases in North American can be modulated by public health measures and other efforts to increase response and coordination (31) (40).

Health Systems

Several agencies in Milwaukee are involved in heat preparedness and response. The City of Milwaukee Health Department, the regional office of the National Weather Service, the Milwaukee County Division of Emergency Management, the Milwaukee County Department on Aging, and a wide array of government and community organizations all work together to explore and implement measures that reduce the public health threat from heat waves. The city has taken lessons from the 1995 heat wave and reviewed research from other cities heat response plans to identify specific actions that, when taken quickly, can help prevent related illness and deaths (42).

The Milwaukee Department of Health (MDH) offers tips on emergency preparedness for extreme heat. MDH's website offers information on air quality, drinking water, and heat health. They have hot weather survival information available, which includes information on wading pools and cooling centers, how heat illness can be affected by medications, how to keep children cool, as well as a general advice hotline.

The City of Milwaukee has also formed a collaborative heat task force to create a coordinated plan of action - the City of Milwaukee Health Department and Milwaukee Health Task Force Plan for Excessive Heat Conditions 2010. This task force issues Heat Health Outlooks, Advisories, Watches and Warnings, performs outreach to at-risk populations, increases coordination between agencies, works with physicians, meteorologists and media to increase the dissemination of information, and continually evaluates the city's response to identify weaknesses and unmet needs (43).

Figure 105: Emergency response vehciles may be unable topovide necessary services due to increases in heavy precipitation events

Transportation

Introduction

This section will discuss the existing transportation systems in the Milwaukee area and the predicted climate change impacts on shipping, road, air, and rail transportation. Increased intense precipitation, lake level drop, and extreme heat will impact not only how people move throughout the city, but will likely require additional costs for the city. These changes in climate will impact the construction, maintenance, and operations of transportation systems in the area. Finally, since the Port of Milwaukee contributes a large amount to the region's economy, responding to these changes will be necessary to maintaining the vitality of the port economy.

Port of Milwaukee

The Port of Milwaukee is an important part of the region's economy. Many commodities go through the port each year including: 1 million pounds of coal, 500,000 tons of cement, and 350,000 tons of goods shipped to and from the Far East and Europe (44). The Port of Milwaukee is important for inland barge shipping as it is the farthest point north accessible to an inland barge shipping. It was strategically built next to two railway lines, the Union Pacific Railroad and the Canadian Pacific Railway, and it has direct interstate highway access to I-794 (45). In addition, the Port of Milwaukee handles passenger travel from the Milwaukee-Muskegon (Michigan) ferry service.

The Port of Milwaukee is located on Lake Michigan, one of the five Great Lakes. Due to the loss of winter ice and increased evaporation, as well as increased erosion, experts anticipate the Great Lakes system to have decreasing water levels in the future. Lake Michigan and Lake Huron are expected to lose the most water— estimated at 4.5 feet between 2002 to 2090 (46). In addition, by 2030, the average monthly lake level of Lake Michigan will be 0.63 feet below the lake's low water datum, making it more difficult for boats to navigate through the channel (46). These figures drastically affect the Port of Milwaukee since it is the northernmost inland barge shipping port. For every inch of water loss, ships must lighten their loads by 270 tons, or 540,000 pounds, which may greatly affect commerce in Milwaukee (47).

As the lakes and navigation channels become shallower, changes must be made to overcome this challenge. Options include using smaller boats that carry less cargo or using existing boats, but require them to carry less cargo than normal. However, if boats carry less cargo, more boats will be needed to make up for the excess cargo, which may potentially pollute the Great Lakes even more. Nonetheless, due to warming temperatures, experts project fewer months in which the lake is frozen, which will likely extend the shipping season (46).

Due to the instability in Great Lake water levels, decision makers will also need to review port design. Considering the impacts of climate change, not only do we expect to see water levels drop due to erosion, but we also expect to see increased storms and flooding (48), and drought from higher temperatures. These factors will make lake levels relatively unpredictable, and changes may be needed to maintain the function and activities of the Port.


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Road Transportation

The City of Milwaukee contains two major interstate highways: I-94 and I-43, which both serve as important transportation systems. The city also contains two minor interstate roads: I-894, a downtown bypass highway for I-94, and I-794, which extends east off I-94 in downtown Milwaukee and goes to the Port of Milwaukee. Roads remain one of the most vulnerable pieces of transportation infrastructure in regards to climate-related impacts. Extreme weather events, whether it is snow, extreme temperatures, or flooding, can affect the highway's infrastructure and traffic flow. Because roads have a lifespan averaging 10 to 20 years, roads take more wear and tear than many other pieces of transportation infrastructure (49).

In the case of Milwaukee, many of the city's highways will be vulnerable to flooding as climate change projections indicate an increase in extreme precipitation events. These extreme precipitation events will make I-43 and I-794, both located within close proximity to Lake Michigan, and I-94, which runs near the city's 100-year floodplain, vulnerable to flooding (50). Since highways serve as an important evacuation route during climate-related emergencies, decision makers should protect the structural integrity of these roadways from flooding.

Milwaukee's public transit network presently consists entirely of buses. At the onset of an extreme precipitation event, transit-reliant populations may experience difficulty in evacuating the city. However, planners are working on an analysis for a new streetcar line within downtown Milwaukee. This new streetcar proposal calls for network extensions throughout the city, which will help diversify evacuation options (51). While streetcars can help improve mobility near Downtown and eventually between neighborhoods and major attractions, the proposed streetcars will be just as vulnerable to flooding as existing buses. Streetcars run on rails and thus are unable to navigate around flooded areas during flood events.

In addition, anticipated warmer temperatures may cause roads in Milwaukee to buckle, making the highways unsafe to be driven on. Since Milwaukee contains an important highway intersection, as well as an important Great Lakes port, the city needs its highways to be as safe and as drivable as possible. To prevent buckling under warmer temperatures, the state will likely need to invest in more durable highway infrastructure in order to maintain a useful life of 10 to 20 years.

Rail Transportation

Milwaukee relies heavily on rail transport for shipping and passenger travel. The Port of Milwaukee is connected to two major railway lines, and the city built a new intermodal train station downtown. Rail transport sees about an average of 1,600 passengers per day in Milwaukee, making it Wisconsin's busiest city for Amtrak. In the past few years, more individuals rely on Amtrak to travel throughout the country, with ridership increasing 6.3 percent from 2009 to 2010. (52)

There have also been recent efforts to build a high-speed passenger rail network from Chicago to Minneapolis via Milwaukee. Although the political process may delay implementation, plans for the high speed rail project are currently not scheduled to be completed. The high-speed rail line would serve as an economic driver, making Milwaukee a more attractive place for meetings and conferences due to its proximity to other Midwestern metropolises.

Climate change impacts will present significant challenges due to the location of Milwaukee's rail infrastructure. Some of the rail lines are in or near floodplains, and intense precipitation could destroy existing railway lines as infrastructure is difficult to adapt. As extreme precipitation events are expected to increase in the future, this has the potential to affect passenger and cargo rail transport. In recent years, the majority of weather-related rail accidents occurred during winter months. However, with an expected increase in winter temperatures and increased precipitation, the annual number of accidents may remain constant (53).

Rail is an important mode of transport for any city. When roads are flooded, under construction, or overcrowded, rail is an important mode of travel for passengers and shipping to get out of the city easily. However, significant investment in the City's rail infrastructure is necessary to increase its resiliency to climate change. The majority of Milwaukee's rail infrastructure is located in floodplains in the City's river valleys. Decision makers need to ensure that rail will be prepared for increased extreme precipitation events to ensure rail access to the City during extreme weather events.

Figure 106: Amtrack provides popular service to Chicago that provides a alternative to driving

Figure 107: Intense storms make air travel unsafe both in the air and on the ground

Figure 108: Transportation infrastructure incurs large costs during extreme precipitation events

Air Transportation

Milwaukee is home to two airports: General Mitchell International Airport and Timmerman Airport. General Mitchell International Airport, located south of downtown, is the city's commercial aviation airport and the largest airport in Wisconsin. A hub for two major commercial airlines, AirTran Airways and Frontier Airlines, the airport handles almost eight million passengers a year with flights throughout the United States, Canada, and Mexico. Mitchell is also home to the General Mitchell Air National Guard Station. The airport has five asphalt and concrete runways, ranging from 4,183 feet to 10,690 feet long. Timmerman Airport, the City's main private aviation airport, is located on the north side of the city. The airport has four runways, two made of asphalt, and the other two made of grass.

Both precipitation and temperature affect aviation. Intense storms make air travel unsafe both in the air and on the ground. Precipitation and climate-related activity, such as freeze-thaw and permafrost degradation has the potential to deteriorate runways. Also, extreme cold and heat can cause runways to buckle (54). In addition, warmer temperatures will reduce the combustion efficiency of planes, thereby requiring either longer runways or lighter loads to safely operate (55). Runways have a life span of about ten years prior to renovation. In Milwaukee, with the potential for warmer weather and increased precipitation, runways at both airports will have to be renovated more often, especially with the threat of freeze thaw damaging runways more often.

Currently, two of Mitchell Airport's runways will be lengthened. The extensions will benefit planes during take off and landing in warmer climates, and the extensions will give pilots more room to handle planes during climate-related emergencies. With the potential for more storms, flight cancellations and delays will likely increase.

Air travel is one of the most impacted modes of transport from extreme climate events. People can drive and trains can operate at slow paces during heavy rain or snow; however, these conditions can cause massive flight delays or cancellations. In July 2010, Mitchell Field closed down during a torrential rainstorm when eight inches of rain fell in two hours.

Implications

Increased intensity of rainfall and extreme heat will affect transportation in Milwaukee. With a recent increase in flooding events, the construction of transportation structures much begin to address stormwater management and the effects of extreme precipitation events. Transportation infrastructure incurs large costs; however, ignoring the projected changes by not incorporating adaptation mechanisms may result in much larger costs in the long run. Not only will improving the adaptability of transportation systems save money over time, but it will also improve the diversity of transportation options to ensure mobility and accessbility during extreme climate events.

Flood Vulnerability Analysis

Introduction

A key technique used to confront threats from climate change, especially extreme events, is to determine where a city's vulnerable populations are located, and how they are situated compared to potential threats. We used GIS to identify the location and distribution of the most vulnerable census block groups within the urbanized area of Milwaukee, Wisconsin, to compare that distribution to the location of Federal Emergency Management Agency (FEMA) flood zones. As highlighted earlier, one of the most significant threats to the Milwaukee area will be an increase in extreme precipitation events, leading to an increase in flooding. To determine the location of areas threatened by large-scale flooding we used FEMA flood zone maps showing a 500 or greater probability flood zone (also known as the 500-year flood zone).

Methodology

The geographic focus of this study is the urbanized area of Milwaukee, as delineated by the 2000 U.S. Census In an attempt to limit the study area to the most urbanized census block groups, the study looks at contiguous census block groups whose centers are located within the Milwaukee urbanized area. The study includes the entire City of Milwaukee, the City of Waukesha and the area between the two. The study area also extends north and south of the city in order to capture contiguous suburban areas.

Vulnerability was determined at a census block level using an index adapted from the Cutter, Brouff, and Shirley method, developed to show county-level social vulnerability to environmental hazards (56). The Social Vulnerability Index (SVI) is an aggregation of five different demographic characteristic indices:

- Age under 18 and over 65 years
- Non-white population
- Female population
- Population density
- Housing value/rent.

Each index is a 0 to 1 decimal value that represents the proportion of the population with the given characteristic living in each block group. The index ranks the proportions in each block group from smallest to largest and also conveys the magnitude of difference between census blocks. The overall SVI was calculated by summing all of the individual demographic vulnerability indices, and it reflects the aggregation of all variables within a census block group.

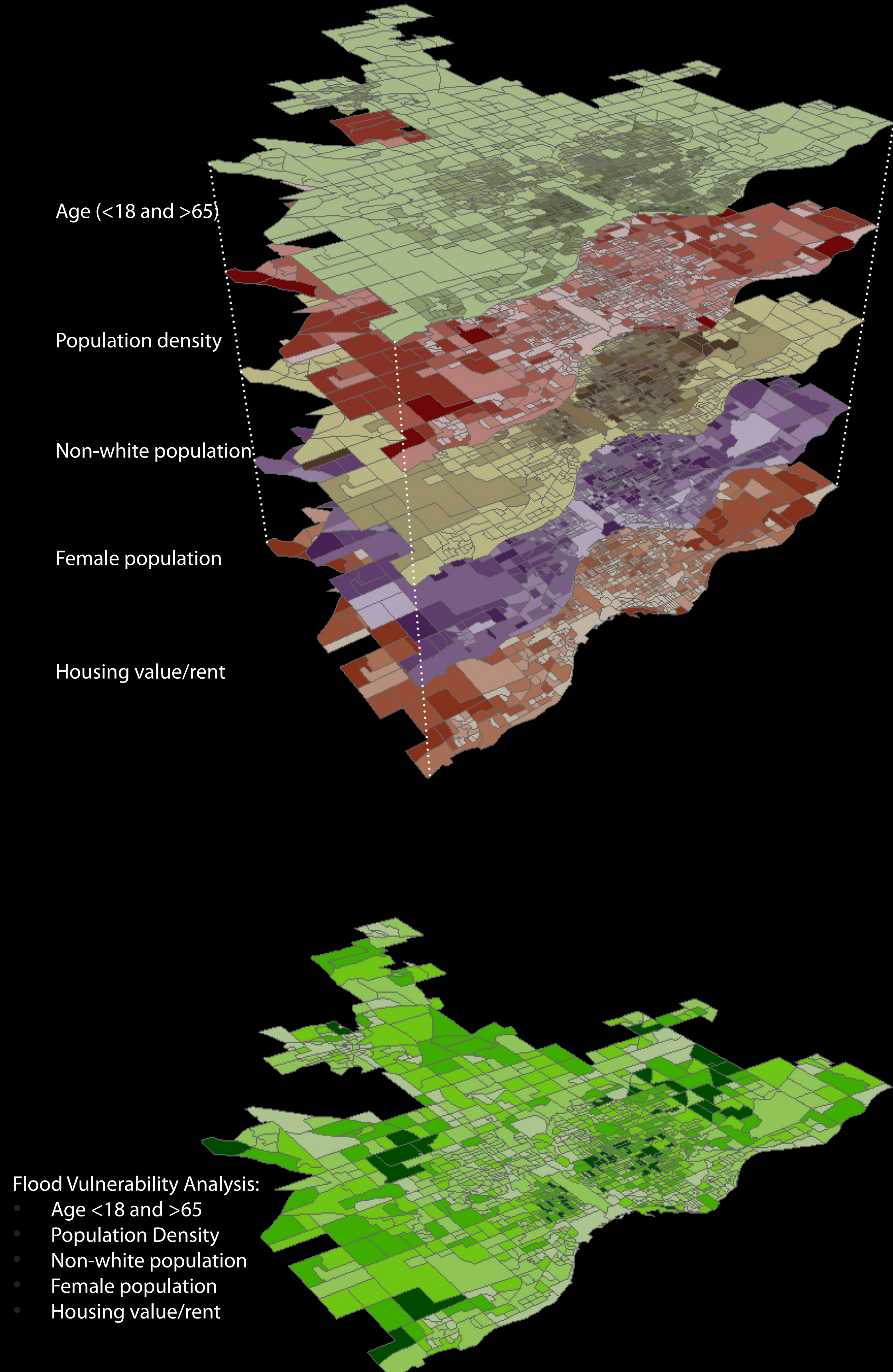

Figure 109: Vulnerability Index generation

Findings

The largest concentrations of vulnerable populations are located in the south central, central, and northern sections of Milwaukee. While a portion of the most vulnerable 15 percent of the urbanized area population lives outside of the city in more rural areas, the majority of the most vulnerable population lives in the central and northern portions of the City of Milwaukee. The census blocks that register highest on the SVI are generally areas with high concentrations of minority and low-income populations.

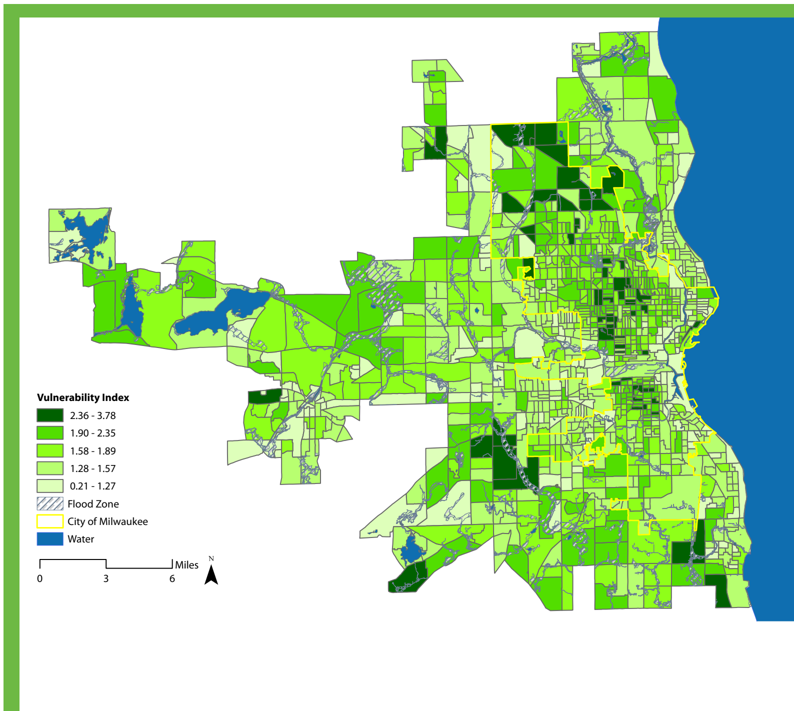

Figure 110 : Distribution of Social Vulnerability and Flood Zones

To assess the potential for these vulnerable populations to be impacted by river flooding, the FEMA flood zone data was overlaid onto the vulnerability index Figure **94**. We performed a correlation analysis to determine the relationship between the SVI and distance to a flood zone. As seen in Figure **95** there is no significant correlation between increasing social vulnerability and proximity to flood zones, if anything there is an inverse relationship. This may be due to higher home values along waterfront property than inland areas, but we did not investigate as the analysis was beyond the scope of this study.

While areas of high social vulnerability generally do not coincide with flood zones, there are some notable cases where there has been documented surface flooding outside of flood zones within areas of high vulnerability. One of the most pointed examples of an interaction between flood hazards and vulnerable population is the area surrounding the 30th Street industrial corridor. This corridor, noted by the red census block groups in Figure **96**, is surrounded by neighborhoods with high vulnerability in the north central portion of Milwaukee. This area has recently experienced surface flooding and sewer overflows following intense rain events (1). Not only is it an area of social vulnerability, but it also is an area that is prone to flooding, despite the fact that it is not in a registered FEMA flood zone. The former Eaton Corp building, located on North 27th Street, was an economic anchor for the troubled neighborhood (which also has problems with crime and drugs). The building was damaged both in the most recent floods of 2010 and in floods several years earlier (57). While Eaton Corp did not cite flooding as the reason they decided to move their headquarters to the suburbs, we can only assume that it was a contributing factor.

Another area of concern is in the central portion of Milwaukee, north of the Kinnikinnick River Figure **97**. During the most recent severe precipitation and flooding event (2010), the Kinnikinnick River delta and the surrounding area experienced significant flooding. The area shown in Figure **98** had problems with sewer overflows into the Kinnikinnick, sinkholes, and severe surface flooding (1). There is also a concentration of highly vulnerable census block groups in this area. One reason for the high vulnerability index in the area is the unusually large proportion of rental housing units where rent is between 25 and 35 percent of household income. These census block groups are also home to a significant minority population, with all census block groups in the area containing about 50 percent minority residents.

While flooding and damage was not limited to areas that rate highly on the SVI, it is important to give special attention to those areas that are socially vulnerable. These populations are likely to have fewer resources available to respond to extreme events brought on by climate change. It is important to identify the most vulnerable areas with at-risk populations and ensure that they these neighborhoods have the proper infrastructure and support to cope and adapt to changing climate and related weather conditions.

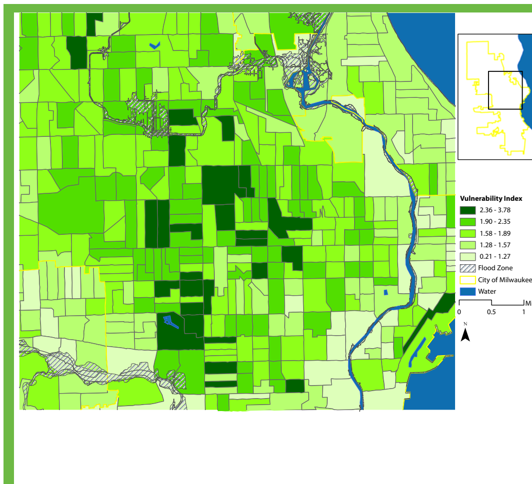

Figure 111: 30th St. Industrial Corridor

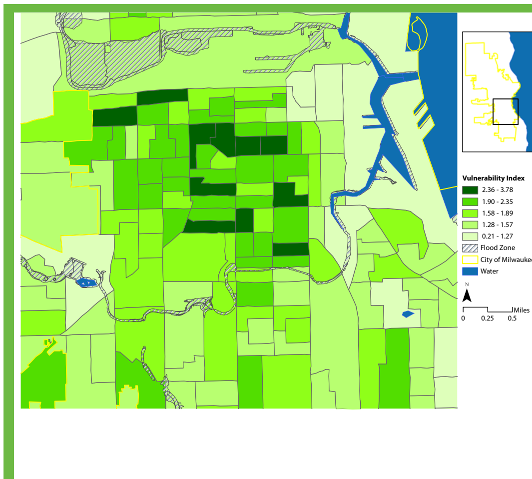

Figure 112: Kinnikinnick River Delta

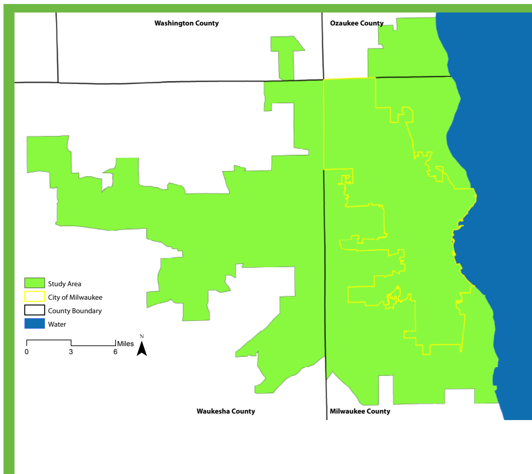

Figure 113: Background Map

Strengths, Weaknesses, Opportunities, Threats (SWOT)

	Strengths	Weaknesses
Land Use	Recent population growth has been primarily in less-dense, suburban areas where flood and heat risks are likely to be lower than in the central city.	High percentages of impervious surfaces in older areas exacerbate flood and heat risks. Relatively little vegetation and wetlands in these areas further exacerbates these risks.
	Residents of lakefront residential property in areas prone to lake level fluctuations are predominately of middle/upper classes. Therefore, the populations who will most directly be exposed to lake level changes have a higher capacity for adapting to changes in lake level.	Industrial and Commercial job centers are disproportionately concentrated in areas of high vulnerability to climate change impacts: Job centers are often located along waterways that are vulnerable to flooding during extreme rain events. Lakefront/port properties could require expensive retrofits and more frequent dredging due to lake level drop.
	The decentralization of development in suburban areas a measure of protection against massive economic loss in the event of severe flooding. Many commercial job centers are located in upstream, suburban areas less prone to flooding during rain events than downstream (central city) locations.	Lake level drop could potentially cause massive destruction of sensitive coastal wetlands, exacerbate erosion and flood risks, reduce habitat, and damage valuable parkland and recreational areas.
	Strong emphasis on the preservation of natural features (Forests, Wetlands, Habitat) at the regional and state level.	Large sections of the region's rivers have been channelized in the city of Milwaukee. This leaves some of the most at-risk areas without significant riparian buffer zones to mitigate the impacts of floods and erosion due to extreme rain events.
Water	Control of municipal water utility (MWW) and waste water district (MMSD) is centralized. Central control enables quick changes in policy.	Municipal water utility officials say they are losing money due to steady decline in customers (population loss) and the increasing costs of production and distribution.
	The waste water district deep tunnel system for controling storm water runoff has significantly reduced annual combine sewer overflows.	The waste water district's Deep Tunnel storage system does not have the ability to hold predicted increases in stormwater volumes.
	Milwaukee Water Council has the stated goal of making the region the world leader in fresh water resources. This goal capitalizes on abundant fresh water resources (something that is likely to be increasingly scarce globally).	The municipal water utility has shown no evidence of an attempt to plan for a changing climate.
	Milwaukee Water Works recently completed first comprehensive carbon and water analysis of a major metropolitan area water cycle.	Rain gardens and biofiltration techniques may not be suitable for the Milwaukee region's soils.
	Drinking water in Milwaukee comes from Lake Michigan, which is viewed as an abundant resource.	

Opportunities	Threats
Economic projections indicate a shift from an industrial and manufacturing to service based economy. Demand for new large manufacturing facilities that create huge stormwater management and heat island issues is likely to be low.	Urban revitalization efforts could be hampered by negative impacts of climate change. Central Milwaukee is at increased risk for flooding and extreme heat as compared with many suburban areas of the region.
National trends point toward a shift in preferences from large lot, suburban housing to more compact, near-suburb or central city housing. New development is likely to be less land-consumptive and be more mixed-use. These trends are likely to slow the rate of land consumption, consequently slowing wetlands loss and enhancing efforts to protect natural features, forests, and agricultural land uses.	Gentrification as a result of urban revitalization could push low-income residents out of their long-time neighborhoods and break apart social support systems that will be needed in times of crisis (e.g. during and immediately after extreme heat and precipitation events).
National urban revitalization trend could increase central city tax base, reduce segregation, and enhance the political base for the most at-risk central city areas.	Land use patterns change very slowly. Climate change adaptation strategies that require large shifts in development patterns will take decades to have significant impacts.
Warmer temperatures could support more annual vegetation growth. Efforts to increase canopy coverage, establish riparian buffers, or re-establish coastal wetlands lost due to lake level drop could show benefits faster.	The city of Milwaukee's location at the confluence of three rivers makes it particularly vulnerable to flooding due to predicted increases in extreme precipitation.
State Natural Resources Board recently approved a rule focused on improving water conservation and water use efficiency statewide. It establishes mandatory water conservation and efficiency measures for certain types of large water withdrawals and promotes voluntary water conservation for all water users statewide.	Wisconsin has no strong legislation requiring the use of "green infrastructure" to reduce need and dependence on traditional underground stormwater management (pipes and tanks).
Wisconsin's existing Safe Drinking Water and Clean Water revolving loan program reserves some funding specifically for "green infrastructure," energy efficiency, and water efficiency projects.	Municipal water infrastructure typically has a long expected useful life. Decisions made today need to anticipate a climate up to 100 years in the future. However, the intensity of climate impacts are not known with certainty.

	Strengths	Weaknesses
Energy	Utilities and regulators have engaged with researchers to understand climate change-related disruptions and impacts. Lessons learned from recent flooding events have increased awareness of need for climate resiliency.	The region's energy supply is dependent on imported fossil fuel sources, undermining the resiliency of the community, exports community wealth, increases pollution, subjecting the city to fossil fuel markets, etc.
	Increasing average temperatures will lower demand for natural gas and other heating fuels.	Electrical transmission infrastructure is aging and likely to need expensive repair/maintenance,/upgrades, partially as a result of increased storm activity.
	Local weather conditions provide potential for the development of renewable energy sources such as solar or offshore wind.	Increasing temperatures will reduce transmission/ generation efficiency and also increase electricity demand for cooling purposes. These forces are likely to necessitate new infrastructure investments. Failure to do so will increase risk of outages during peak demand periods.
Human Health	The city has a collaborative heat task force coordinating the official heat plan among multiple city health and outreach agencies. This task force issues Heat Health Outlooks, Advisories and Watches/ Warnings.	Prevalence of pavement and buildings in the Central City will exacerbate Urban Heat Island effect for central city neighborhoods as temperatures increase.
	The city has a collaborative heat task force coordinating the official heat plan among multiple city health and outreach agencies. This task force issues Heat Health Outlooks, Advisories and Watches/ Warnings.	Low-income and elderly residents are more likely to have existing health conditions that will be exacerbated by climate change impacts and are also less likely to have health insurance.
	The city has experience dealing with catastrophic flooding (flood of record, July of 2010).	This city has a history of water quality problems stemming from combine sewer overflows (Cryptosporidium outbreak, 1993).
		Ground level ozone air pollution is likely to increase.

Opportunities	Threats
Energy efficiency programs address both mitigation and adaptation across all sectors in Greater Milwaukee. Industrial energy efficiency strengthens resilience of the local economy, residential energy efficiency saves money for residents, and both measures help offset any increase in energy demand.	There is the potential for cap-and-trade or other carbon-pricing legislation in near future. This would likely increase the cost of all energy sources in the region, which are almost exclusively carbon-based.
Utility-scale increases in clean energy generation responds to electricity demand increase while contributing to GHG mitigation.	Falling lake levels could disrupt coal delivery to Milwaukee power plants.
Resilient, clean and distributed energy generation reduces transmission losses, reduces need for expensive new transmission infrastructure and land acquisition, and reduces energy waste, particularly in industrial sector.	Climate change impacts in other U.S. regions could drive inter-regional migration and result in fast population growth in the Midwest. Energy systems would need to be scaled up quickly in response, and may not be able to keep up.
The city can start relationships with health networks in surrounding areas taking lessons from peer city's response plans.	The population distribution of vectors including rodents, and other pests are predicted to shift northward as temperatures warm increasing rates of infection and bringing new diseases to the area.
Successfully linking climate change to human health can help build public support for adaptation efforts.	Flooding and lake level drop are likely to result in increased concentrations of toxins in water bodies.
Review current heat plan and previous responses to can help identify inefficiencies and unmet needs.	

	Strengths	Weaknesses
Transportation	Existing roadway infrastructure in the city of Milwaukee has significant redundancy to the South and West of the City. Redundant networks are essential to maintaining mobility in the event that infrastructure is out-of-service due to flooding or damage from severe weather events.	The region is highly dependent on personal vehicle travel, and its public transit is basic with limited intercity rail options and no high speed rail.
	Existing rail infrastructure is underutilized and can handle increased traffic volumes, providing an increase in transportation options within the region.	Climate related damage could result in neighborhoods being isolated from the wider region because of roadway inundation.
	The city is a multi-modal transportation hub with service connections to interstate highways, freight rail, intercity passenger rail, inland river barge, and interlake and ocean vessels, providing the city with a wide array of transportation options.	
CROSS CUTTING	Chicago is investing significant resources in planning for climate change adaptation and response. This is a strength for Milwaukee because Chicago and Milwaukee face similar climactic threats. Climate change planning and adaptation efforts being undertaken in Chicago are likely to be highly relevant to efforts in Milwaukee. (all)	The region is divided into a patchwork of local governments with largely independent planning, land use and legislative powers. Serious attempts to plan for climate change adaptation and response will require regional coordination at an unprecedented scale, requiring all of the many local government in the region to work together.
	Older parts of the city and region developed before the advent of modern zoning and strict land-use separation. These older areas still have infrastructure to support mixed-use environments where residents can meet more of their daily needs with short trips, including non-motorized modes. This could be important during times of flooding when transportation links may isolate some neighborhoods. (LU, T)	Power outages on hot days, which will be increasing due to climate change, will pose human health threat. (E, HH)
	Wisconsin Smart Growth Law requires comprehensive land use planning, coordination between different departments (transportation, economic development), and some intergovernmental cooperation on land use issues. This is the type of cooperation that will be necessary to respond to climate change impacts. (all)	Declining tax base and fiscal shortages in the region means that local funding sources for adaptation measures will be extremely limited in the short-term. (all)
	Location on Lake Michigan will moderate temperature increases as compared with areas further removed from the lakes. (all)	Central city neighborhoods are often the most at-risk areas in the region. Central city residents are almost uniformly low-income and minority. (HH, LU, W)
	Educational institutions in the region are actively pursuing climate change adaptation research. (all)	Some of the most densely populated areas of the region are located in high flood-risk areas. (HH, LU, T)
	Regional planners and water resources specialists are working to develop new hydrology models. These updated models will provided a more detailed picture of future flood risk areas, streamflows, etc. (all)	Most local zoning laws are still largely based on separation of uses, require large lots with significant off-street parking. This type of development creates impervious surfaces that contribute to flooding during extreme rain events. High levels of impervious surfaces in close proximity to major waterways have a quick negative effect on water quality and quantity. (LU, W, T)

Opportunities	Threats
A reduction in cold days in winter is likely to reduce roadway snow management costs (salt, plowing), freeing funds that could be used for adaptive responses to other climate impacts.	Lake level drop will require more frequent dredging of shipping channels and decreasing the cargo carrying capacity of ships.
Warmer weather will likely extend the great lakes shipping season due to decreases in lake ice and increasing traffic at the Port of Milwaukee.	Increasing heavy precipitation will increase roadway flooding and accelerate erosion damage to transportation infrastructure.
The majority of transportation funding comes from the federal government, with a much smaller local match (Highway funding has historically been 80% from federal sources).	Current political opposition to transportation infrastructure development (i.e. high speed rail) could delay timely adaptation response.
Many climate change impacts will be similar throughout the Midwest. As research and planning continues, many opportunities to learn and collaborate with others will develop. Of particular value to Milwaukee is the extensive work being undertaken by the City of Chicago. (all)	Increased costs of responding to flooding and other emergencies could further stress already limited resources in the region. (all)
The state has the power to dictate land use regulatory policy to local governments, although this power has seldom been used. This type of coordination may be necessary for some adaptation strategies to be effective and may be required to overcome difficulties imposed by the fractured nature of local governments in the region. (all)	If energy or water infrastructure must be built quickly as a response to population growth, natural systems may suffer. Also, choosing sites for new infrastructure will be more difficult due to developing storm/flooding risks and changing lake levels. (E, LU, W)
Climate change impacts in other U.S. regions are predicted to result in severe water shortages. Abundant fresh water supplies in the Milwaukee region could drive migration to the region, providing increased tax base and jobs. (LU, W)	Political opposition to climate change planning could undermine timely action. High unemployment and stagnant job growth is likely to plague the region in the short-term. Actions on the part of government to address climate change adaptation could be seen as "too expensive" or running contrary to economic development goals. (all)
The State of Wisconsin has strong legislation promoting the preservation and restoration of wetlands.	Warmer temperatures could result in new invasive insect infestations that damage or kill important tree species. This would have the dual effect of reducing the tree canopy and making heat island effect more severe. (HH, LU)
	If more frequent dredging is required in the harbor, it could disturb and re-suspend settled contaminated sediments, causing water quality issues (HH, T, W)

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Adaptation Strategies

Adaptation Strategies

Introduction

This section outlines a general process for developing adaptation strategies and provides specific examples of how to address development, assessment, and implementation of city-level climate adaptation recommendations. The process is based on a review of existing literature and climate adaptation plans. Research on adaptation strategy processes highlights several important considerations, particularly challenges associated with addressing hazards-based and vulnerability-based approaches, reactive and anticipatory planning, and issues of timeframe and geographic scale. Our team used three analysis frames: climate threats, sector effects, and crosscutting issues, when selecting adaptation strategies. Existing climate adaptation plans informed our identification and assessment of specific strategies, summarized in the Overview of Existing Adaptation Planning Strategies and City Specific Adaptation Strategies sections (below). The following analysis provides an overview of existing research on adaptation planning processes, highlights areas of particular interest, offers examples of specific recommendations, and outlines a framework for how cities can respond to anticipated climate change.

Process

Overview of Planned Adaptation to Climate Change

Planned adaptation to climate change often works in two ways, 1) by reducing vulnerability and risk to climate change impacts, and 2) by increasing the adaptive capacity of systems, processes, and infrastructure. Communities currently maintain systems and processes to address a specific range in climate variability, identified as the "coping range". Utilizing a coping range framework demonstrates several important concepts regarding climate change adaptation. In a 2007 report on climate change adaptation, Füssel asserts that challenges occur when climate conditions extend beyond the specified range, resulting in vulnerability and risk. Communities must decide to either increase the coping range, or assume an increased level of climate risk. Decisions to increase the coping range based on observed or predicted events result in adaptation decisions to adjust for future climate conditions. The primary issue pertains to whether an increase in the coping range will allow for an adequate adaptation response to the future climate impacts (1). Therefore, a deliberative adaptation strategy framework should focus on informed and comprehensive responses to anticipated climate impacts.

Hazards- vs. Vulnerability-based Approaches to Climate Impact and Adaptation Assessment

The two primary approaches used in climate change impact and adaptation assessment guidelines are hazards-based and vulnerability-based (1). The hazards-based approach focuses on the impacts of climate change through model-based projections. While this is a common approach used by the Intergovernmental Panel on Climate Change (IPCC) and US Climate Change Science Program (USCCSP), critics highlight a lack of data and projections at relevant spatial scales and the extended timeframe of climate impacts as significant limitations for adaptation policy design (1). Furthermore, integrating non-climatic factors is often insufficient, resulting in adaptation policy recommendations that lack key elements and robustness, specifically consideration of adaptive capacity and social determinants of vulnerability (1).

In contrast, the vulnerability-based approach, like the one used in the United Nations Development Programme-Global Environment Facility (UNDP-GEF) Adaptation Policy Framework, "assesses future climate change in the context of current climate risks" (1). This approach effectively supports inclusion of social and non-climate factors as well as local expertise in the adaptation planning process. The vulnerability-based approach often allows for the development of easily implementable approaches to adaptation that apply to a wide-range of potential climate threats. The location and context-specific nature of the vulnerability assessments and adaptation recommendations reduces their applicability across geographic contexts and can limit collaborative planning.

Integration of the hazards- and vulnerability-based approaches leverages the advantages of each into a single comprehensive approach. Hazards-based approaches focus on long-term decisions and work well in raising awareness given the model driven method (when data and resources are available at the necessary scales). Vulnerability-based approaches integrate non-climate factors, such as socioeconomic status, existing capacity of local systems, and regional governing structure, and also provide a useful process in identifying priority areas for action. An effective adaptation assessment process should begin to integrate the two approaches, resulting in a more comprehensive climate change impact and adaptation assessment process. The process we used for Baltimore, Fresno, and Milwaukee integrates hazards- and vulnerability-based approaches to identify vulnerable populations and high risk locations. This information was used to inform strategies that address this vulnerability and risk (see City Specific Adaptation Strategies).

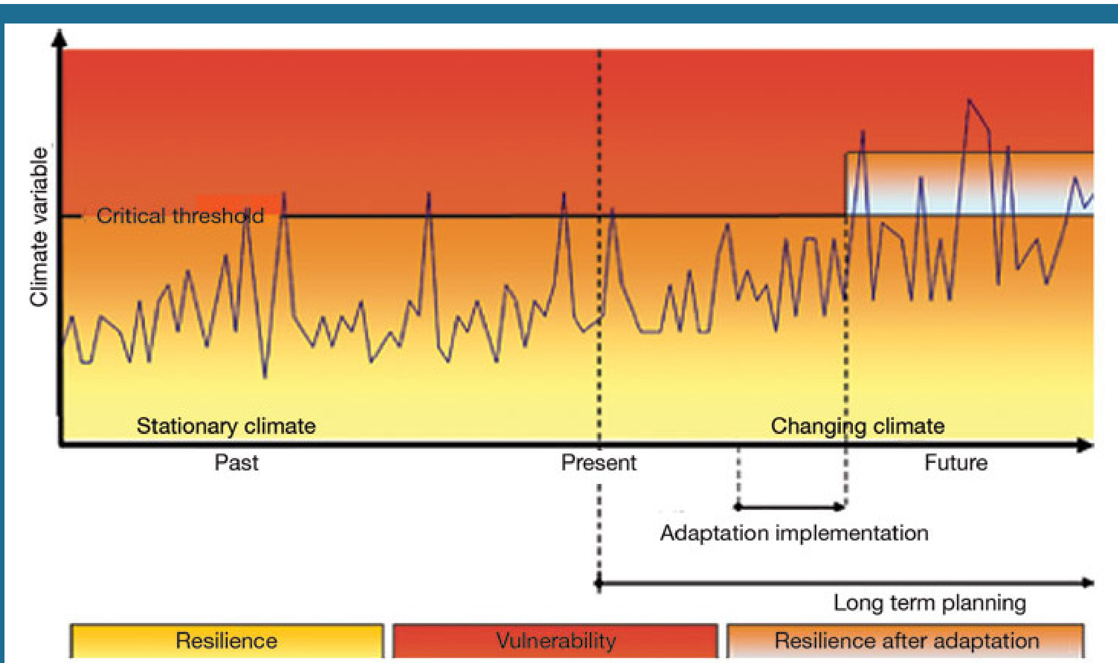


Figure 114: Fussel's Coping Range Diagram

Reactive vs. Anticipatory Adaptation

Climate adaptation strategies fall into two categories: reactive and anticipatory. Reactive adaptation planning is responsive to climate change impacts, allowing processes and systems to adjust as conditions change over time. For instance, new water management systems can be put in place as storm intensity increases, and bridges can be replaced as sea level rises. Reactive adaptation is often prefered to anticipatory planning due to uncertainty over the magnitude, risk, and impact of climate change (2). Similar to adaptation planning, hazards-mitigation is a field "dominated by a reactive approach, and federal funding provided for anticipatory planning is insufficient" (3). However, a reactive adaptation approach has significant drawbacks, including an increase in the magnitude of impacts, a reaction to climate extremes, reduced flexibility in addressing future variability, and higher costs (2).

In contrast, "the goal of anticipatory adaptation measures is to minimize the impact of climate change by reducing vulnerability to its effects, or by enabling reactive adaptation to happen more efficiently" (2). Anticipatory adaptation focuses on implementing processes and procedures that begin addressing potential risk and vulnerability as a result of predicted future climate variability. Anticipatory climate adaptation strategies are prudent to address irreversible or catastrophic impacts when current trends limit the ability to implement adaptive measures later, or when decisions regarding changes to systems or structures have a long lifetime (2). For example, increased expansion of impervious surfaces and stormwater management systems, while practical in addressing short-term precipitation trends, will have a dramatic impact on the long-term management of increasingly intense and frequent precipitation events. While clear advantages result from anticipatory adaptation planning, uncertainty regarding the impacts and timing of climate change are significant impediments (2).

Scale Considerations within Adaptation Strategies

Scale is an important concept to address in developing adaptation strategies, particularly in relation to consideration of cumulative impacts over time and across geographic ranges.

Time Scale Considerations

The two primary time scale factors to consider are 1) the timing of when climate change impacts will occur and 2) the timeframe for the system, process, or element to be developed. In addressing the timing of climate impacts, adaptation planning should consider infrequent but extreme events, as well as incremental climate variability and long-term effects. As a result, adaptation strategies should target both short- and long-term responses to anticipated climate impacts.

In addition to the timing of climate impacts, adaptation strategies should consider the timeframe for replacing existing systems, as well as effects on the implementation of recommendations. As discussed, adaptation strategies are designed to address the effects of climate change on vulnerability and risk, which requires coordinated implementation of processes, systems, and infrastructure in-line with the timing of climate impacts. Time scale is also a primary consideration when determining the effectiveness of defined adaptation strategies. Adaptation recommendations should consider the benefits of implementing a strategy now, utilizing current technology and knowledge, weighed against potential gains that might be realized by waiting for future research and development. This may be particularly applicable to processes and systems with a relatively short useful life or replacement timeframe, which allows for easy implementation of new technologies and information. Finally, from an economic analysis standpoint, the timing of adaptation strategy implementation should consider the value of immediate execution rather than waiting for a point of replacement, or the end of useful life.

Geographic Scale Considerations

Geographic scale is an integral element in developing and implementing adaptation strategies due to variation in climate effects, availability of data and information, resource allocation, and jurisdictional boundaries. While climate science has primarily focused on climate change at the national or global level, "adaptation policies are more closely tied to the local and regional level, since impacts, strategies and benefits are local" (3). Currently, regional climate models are the primary tool used to identify local climate change impacts. However, to enable a more detailed adaptation response, global climate models should be paired with local models (regional, metropolitan, or city) that will integrate useful data on local landform characteristics, land use patterns, land cover, as well as atmospheric and infrastructure systems (3).

Impacts at each scale are of primary importance, as well as the integrated nature of effects between scales. This concept applies to both the negative impacts of climate change, as well as potential benefits of adaptation responses. For example, an urban landscape consisting primarily of impervious surfaces will experience higher levels of sheeting and flooding as precipitation increases in frequency and intensity. In response, a strategy of encouraging detention and infiltration of water at the site level has the benefit of reducing runoff at the neighborhood and city-levels, reducing the need for larger stormwater management systems, and ultimately reducing the risk of flooding at the regional scale. In this way, localized strategies can aggregate to result in regional benefits.

Significant challenges exist in addressing climate change impacts across scales, including limitations on sharing data and resources, and difficulty in organizing collaboration on authoritative structure and response. As such, "the planning process for community-wide climate change adaptations needs to be integrative, strategic, participatory and incorporate [innovative] ways to manage risk" (3). A collaborative approach will address issues of data sharing, information gathering, and will promote capacity building. Establishing a comprehensive strategy will address concerns of authority, as well as encourage innovative strategies. The development and dissemination of sector specific goals and objectives will encourage the awareness and exchange of innovative adaptation strategies. A framework with a broader comprehensive approach and sector specific goals will result in a longer-term vision that is consistent with addressing gradual climate change impacts, and allowing for the short-term implementation of adaptation strategies.

Selecting Adaptation Strategies

Overview

Adaptation strategies can be selected based on their ability to address vulnerability, the viability of their implementation, and their capacity to provide information for future recommendations and decisions. Our adaptation strategy analysis focused on three categories of assessment: threats-based, sector-based, and cross-cutting issue-based.

1. Threat-based adaptation strategies respond to threats associated with anticipated climate changes. Threats-based strategies often stem from a hazards-based approach and result in a broad adaptation focus.

2. Sector-based adaptation strategies address the effects of climate change on a specific city sector. The result is a vulnerability-based approach with sector-focused strategies.

3. Cross-cutting issue-based adaptation strategies "highlight the interdependencies that exist between the inhabitants of the city, its immediate hinterland, and the wider, global, economic and social context" (4). Given the interconnectedness of climate impacts across economic, social, natural, and built environment systems, a focus on adaptation strategies that address cross-cutting effects and benefits is preferred.

Effective adaptation processes often integrate multiple approaches, with each approach providing specific opportunities and challenges. As such, the goal of the adaptation strategy process is to incorporate the three approaches, and to establish a comprehensive, integrated, and collaborative process for addressing climate adaptation planning.

Figure 115: Renewable Energy Installation on a California rooftop

Figure 116: Wetlands are used to capture stormwater and act as a natural buffer against flooding

Comprehensive vs. Sector-Specific Approaches to Adaptation Strategies

Centralized climate adaptation strategies address a broad set of issues, including impacts across sectors, and the interactions between climate threats and opportunities in addressing future change. The primary limitation of centralized planning is that a lack of in-depth local knowledge hinders connections to previous, existing, and future local planning efforts. In contrast, a sector-specific approach has the benefit of focused local expertise and implementation knowledge. Challenges arise when coordinating responses and collaborating on capacity building across sectors. To overcome the limitations of centralized and sector-specific approaches, an overarching comprehensive goal may create an umbrella under which more detailed underlying objectives can exist. A framework focused on generating an overarching strategic plan, and supported by detailed sector-specific goals and targets will enhance the city climate adaptation planning process (5). By engaging multiple stakeholders, including planning organizations (watershed, land use, energy, and infrastructure), research disciplines (physical, biological, and social sciences), political actors, and the public, the adaptation planning process will help identify areas for collaboration, encourage the sharing of knowledge, minimize development and implementation cost, and result in more comprehensive strategies (3).

The primary challenges in organizing a collaborative approach to climate change adaptation are a lack of capacity, authority, and resources to bring multiple stakeholders together. Currently, comprehensive plans are the exception rather than the rule. Thus, "a more common approach is for sector-based departments to identify key threats and related measures," with little emphasis on cross-sector collaboration (5). Given fiscal constraints and political challenges, collaborative and comprehensive adaptation strategies developed using sector-specific knowledge will be essential to meaningfully address the anticipated effects of climate change.

Types of Adaptation Strategies

Climate adaptation strategies are typically categorized as technological, behavioral, financial, institutional, or informational (3).

Technological adaptation strategies typically focus on physical improvements or responses to climate impacts. These strategies can take the form of physical structures, such as levees, cooling centers, or stormwater infrastructure, as well as replacement of man-made infrastructure with natural systems. Technological strategies are often popular recommendations due to extensive expertise applicable to climate adaptation. Technological adaptation strategies provide significant opportunities to address anticipated climate impacts, however they can be expensive and result in limited flexibility over time.

Behavioral adaptation strategies educate the public, businesses, governments, and industrial communities about potential changes in use or processes. Behavioral adaptation strategies have been highly popular because they also raise awareness among the public (4). In addition to generating support for adaptation planning through education, behavioral strategies provide low-cost and short-term solutions to anticipated climate impacts.

Financial adaptation strategies are increasingly important due to challenges in fiscal planning at the municipal level. These strategies arise in the form of incentives, tax structures, financial planning, and adjustments to insurance related programs. Financial adaptation strategies reduce barriers to implementation of additional strategies, incorporate systematic responses to economic changes, and minimize financial risks associated with anticipated climate change.

Institutional adaptation strategies coordinate information and build capacity to address climate change. Institutional capacity building is essential to managing collaborative planning processes, implementing recommendations (both physical and process oriented), and monitoring the effectiveness of adaptation responses over time. Institutional structure and coordinating capacity are especially important to the integration of climate change impacts into existing planning and decision-making (4). As such, focusing on capacity building and coordination of information will be useful for the short-term implementation of strategies, as well as for the long-term growth of local adaptive capacity.

Informational adaptation strategies are important for building knowledge to address future climate variability. Uncertainty is a significant barrier in addressing climate change impacts. Uncertainty stems from a lack of consistent past climate data across regions, questions regarding societal decisions over time, and climate model error. Building knowledge through more extensive monitoring of current climate patterns, by integrating urban indicators with climate projections, and researching effects on various sectors and urban scales will result in better informed adaptation strategies over time.

While adaptation strategies typically focus on one of the five identified categories, there are often cross-cutting issues associated with successful development, implementation, and monitoring. A technological strategy requires a wealth of information to adequately develop a response, the institutional and financial capacity to implement, and public education and acceptance to ensure long-term support. Given the complexity in addressing anticipated climate change impacts, it is important to identify short-term, achievable objectives that when successfully applied, result in longer-term responses to vulnerability and resiliency. As such, it is essential to outline city-specific measures of effectiveness and feasibility when developing adaptation strategies.

Assessing Adaptation Strategies

Overview

Several methods exist to assess the efficacy, viability, and priority of adaptation strategies. Conventional assessment methods rely on cost-benefit analysis, cost-effectiveness, or multi-criteria evaluation (3). As an example, an economic evaluation method discussed in the Organization for Economic Cooperation and Development (OECD) report, *The Economics of Climate Change Impacts and Policy Benefits at City Scale: A Conceptual Framework*, incorporates downscaling socioeconomic scenarios as well as climate predictions (3). While numerous methods and frameworks assess adaptation strategies, there are several common elements among all methods. First, and of primary importance, climate change will result in effects across sectors and industries. As such, the methods for assessing adaptation strategies, and therefore efficacy in building resiliency to identified vulnerabilities, must account for a variety of issues. In addition to standard elements within conventional assessment methods, criteria for assessing climate adaptation strategies should include interdependencies, distributional impacts, and the extent of public participation (3). An excellent example of an adaptation strategies assessment framework is laid out in the Victoria Climate Change in the Western Port Region adaptation plan.

Victoria Assessment Criteria Example

The screening criteria used in the *Victoria Climate Change in the Western Port Region* (VCCWPR) adaptation plan provides a valuable framework for assessing adaptation strategy priorities. Rather than focusing on the criteria as a simple yes or no answer, VCCWPR created a graduated scale that allows for strategies to be cross-compared by simple rankings. While specific strategies may rank low on community acceptance, higher scores in effectiveness and flexibility may prioritize implementation. As an example, the use of coastal buffers may require displacing existing uses and residents to allow for restoration. While significant public controversy will result, coastal buffers provide an effective and flexible long-term response to the effects of sea-level rise. As such, the assessment process may highlight coastal buffers as a strategy in addressing the anticipated climate impacts of sea-level rise and storm surge.

Victoria Assessment Criteria:

a. *Effectiveness:* policy or measure expands knowledge, builds adaptive capacity, or implements processes or technology that result in reductions in vulnerability and risk.

b. *Immediacy:* policy or measure that either results in short-term benefits, or requires short-term implementation to increase efficacy and achievement of long-term benefits.

c. *Financial viability:* policy or measure is not cost prohibitive, or is able to be reasonably covered under budgetary allocations, with increased revenue, through cost-sharing, either across sectors or levels of government.

d. *Political feasibility:* policy or measure is within the scope of control and responsibility of the government body, is acceptable to and encouraged by government staff, and does not conflict with existing policies or responsibilities.

e. *Community acceptance:* policy or measure is accepted by a significant proportion of the local body and does not infringe upon the stated rights of residents or businesses.

f. *Flexibility:* policy or measure is consistent with the underlying purpose of adaptation, in that it is flexible to future information regarding climate change and allows for incremental change over time as capacity and knowledge increases.

g. *Concurrent effects:* policy or measure avoids negative environmental, social, and economic consequences, focusing on win-win outcomes by promoting additional environmental, social, and economic benefits in addition to addressing climate change risk.

Existing Adaptation Planning Strategies

The following table of existing strategies provides a summary of recommended responses outlined in city adaptation plans and peer-reviewed literature.

Please see the next page for the Table of Existing Adaptation Planning Strategies (refer to Appendix D for the complete list of reviewed strategies).

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Implementation of a "Green Grid" for East London	Heat Precipitation Flooding	Creation of a network of interlinked, multi-purpose open spaces, support citizen access to openspace, help store water, and cool the vicinity.	Land use Water Energy Human Health Transportation	Physical	London Adaptation Plan (2010)
Flood Storage Areas	Flooding Precipitation Sea-level rise	Designing areas to manage flood impacts minimizes the effect on more vulnerable land uses. Storage areas should be focused in existing or future open space.	Land use Water	Physical	London Adaptation Plan (2010)
Implement a coordinated network of information technology solutions to assist in wildfire response	Drought Heat	Encourages information sharing and coordinated response to wildfires	Human Health Water Land Use Transportation	Process	Climate Change in the Western Port Region (Victoria 2008)
Perform detailed coastal modeling to identify areas most vulnerable to sea-level rise, storm surge, and inundation	Sea-level rise	Coastal modeling will help focus adaptation efforts on areas most vulnerable to future climate impacts and encourage efficient allocation of time and resources	Transportation Land use Human Health Energy Water	Knowledge	Climate Change in the Western Port Region (Victoria 2008)
Collaborate with local health department and organizations to perform a city-specific assessment of the impacts and opportunities of climate change on health services	Heat Precipitation Flooding Sea-level rise Storm surge Wildfire	A collaborative effort in identifying and addressing potential heat vulnerability will increase efficiency in addressing impacts and coordinating a response	Human Health	Process Knowledge	London Adaptation Plan (2010)
Local passive cooling demonstration project of how to retrofit a social housing development to reduce risk of overheating	Heat	Demonstrating the costs and benefits of passive cooling techniques will educate the building industry, government agencies, and the public, and increase incorporation into standard building practice	Energy Human Health Land Use	Physical Behavioral	London Adaptation Plan (2010)
Create a climate change and insurance commission to evaluate the insurance ramifications of climate change risks.	Flooding Precipitation Heat Storm surge	Insurance programs have the ability to provide significant incentives in adapting to climate change. Analysis of existing insurance programs and processes will highlight areas for improvement and collaboration	Land use Human Health Water	Process	Maryland Climate Change Commission Policy Recommend (2010)
Enhance ecosystem services through habitat restoration	Heat Precipitation Flooding	Ecosystem services of habitat restoration and increased greenspace reduce flood risk, offset the effects of urban heat island, reduce energy demand, and support biodiversity	Land use Water Energy Human Health Transportation	Physical	London Adaptation Plan (2010)

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Integrate sea level rise and flood-recurrence interval projections into all relevant agency programs and regulatory, permitting, planning, and funding decisions.	Sea-level rise	Integrating climate impacts into existing processes and programs will provide short-term benefits of raising awareness and long-term benefits of more comprehensive sector adaptation planning	Land use Water Energy Human Health Transportation	Process	New York State Climate Action Plan (New York 2010)
Assess energy distribution infrastructure and update as necessary to ensure resiliency to climate change	Heat Precipitation	The current energy infrastructure is vulnerable to climate impacts of heat and flooding. Updating infrastructure capacity will increase the resiliency of the energy system to climate impacts.	Energy	Knowledge Physical	London Adaptation Plan (2010)
Adjust building codes and develop design guidelines to increase thermal efficiency and reduce demand for mechanical cooling	Heat	Updating building codes will require minimum thermal efficiency standards, and can address both the effects on energy and human health from heat events	Land use Energy Human Health	Physical Process	London Adaptation Plan (2010)
Encourage implementation of new green roofs	Heat Precipitation	Green roofs operate in a similar manner to increased greenspace, however they have the ability to increase the thermal efficiency of buildings	Land use Energy	Physical Process	London Adaptation Plan (2010)
Increase reservoir capacity	Drought	Increased water storage through reservoir expansion, while useful in capturing large volumes of rainfall and streamflow runoff, is expensive and requires vast areas of land.	Water Land use	Physical	London Adaptation Plan (2010)
Reduce the loss of water through better leakage management	Drought	Water leakage amounts to a significant portion of the total water supply, in London estimated at up to 25 percent, which if captured could increase the resilience of the water supply system in meeting increased demand.	Water	Physical Process	London Adaptation Plan (2010)
Enhance existing education and outreach activities, employing multilingual approaches and appropriate media to increase awareness of the public health consequences of heat	Heat	Education of the public is an important element of any climate adaptation plan. Community input often provides information on the benefits of comprehensive adaptation planning and encouraging adjustment in behavior in support of adaptation efforts.	Human Health	Process Behavioral	New York State Climate Action Plan (New York 2010)

Adaptation Planning, Processes, and Strategies Case Studies

California Water Plan Case Study

Overview

Water issues affect multiple stakeholders, so the California State-led Water Plan provides a comprehensive and collaborative framework in addressing a variety of climate change related water issues. Projected increases in flooding and drought have spurred California leaders in responding to anticipated future risk and damage prevention. The State Plan encourages various entities to work together to provide greater efficiency and preparedness for an uncertain future.

Background

The California Water plan provides a framework for water managers, lawmakers, and the public to make decisions concerning the future of water in California. The plan includes water supply and demand data, as well as evaluations of existing water management programs and proposed alternative assessments of the State's water needs. The plan also highlights the State's primary water issues, which guide decision-makers in their endeavors (6). While the Department of Water Resources is responsible for leading the California Water Plan process, including a required update every five years, the recent update was completed using a diverse, statewide perspective covering a variety of issues and visions (7).

Figure 117: Proper management of water is essential to the quality of life in California

The Plan

The report is divided into five volumes: Strategic Plan, Resource Management Strategies, Regional Reports, Reference Guide, and Technical Guide. The Strategic Plan lays out the mission, vision, goals, objectives, current water conditions and challenges, and future uncertainties. The Resource Management Strategies provide a plan to meet the objectives. The Regional Reports show supply and demand trends for the twelve different regions over the last few years, water use projections, and potential scenarios. The Reference Guide lists all the sources used in developing the plan, and the Technical Guide documents the process of creating the plan through a web portal. (7)

The California Water Plan emphasizes greater statewide and regional collaboration in addressing continued population growth and reduced water supplies by providing greater efficiency (7). Changes in snowpack, snowmelt, and temperatures have drawn increased attention to the impacts of climate change and the need for the water sector to include associated threats in their planning processes. The 2005 Plan Update incorporated climate change effects, specifically addressing issues of longer periods of drought and increased flood events, aging infrastructure, and declining ecosystems (8).

To emphasize the significance of climate change impacts and sustainability, the 2009 Plan Update extensively expanded the incorporation of climate change within the plan. The 2009 Plan Update stresses the urgency, primarily due to climate change impacts, of addressing state water issues (7). The plan incorporates climate change impacts within all applicable volumes by focusing on the uncertainty associated with climate change impacts, and the strategies take into account possible climate change scenarios. Additionally, the regional reports contain sections that address climate change and the need to adapt to these changes (9). Thus, rather than delegating responsibility to each locality, the State Plan analyzes the data, identifies issues, and outlines actions necessary in responding to water sector climate threats. In this way, the California Water Plan is an example of a centralized adaptation plan.

Integrative Regional Water Management

The California Water Plan encourages greater collaboration in establishing a regional approach to water management through the State's Integrative Regional Water Management (IRWM) program. The IRWM "is a collaborative effort to manage all aspects of water resources in a region…and attempts to address the issues and differing perspectives of all the entities involved through mutually beneficial solutions"(10). By coming together, these regions will be able to bring improved quality, quantity, and reliability in their water resources, and regions will work towards self-sufficiency in providing water for the region. In 2002 and 2006, the state passed three different propositions that provide funding for projects consistent with IRWM goals. Through this program, entities can come together and apply for IRWM grants that fund planning processes, implementation mechanisms, and stormwater management. (10)

Key Findings

Laying out concerns, challenges, and issues related to the water sector through a statewide plan allows for greater access to information.

With a statewide plan addressing water issues, many smaller entities do not need to allocate time and resources on climate threat research and analysis. Instead, decision-makers can focus on responding to climate change impacts.

Encouraging regional thinking in tackling climate change impacts related to waters result in greater efficiency.

A regional approach allows for a system-wide or watershed analysis. Since water systems operate beyond municipal and district boundaries, assessing problems and solutions at the regional scale allows multiple entities to invest in a single planning process.

Providing grant opportunities encourages collaboration in dealing with water systems.

Since collaboration intends to create dynamic solutions in addressing water issues, providing the funding opportunities pushes stakeholders to work together.

Promoting collaboration among all stakeholders in the development of a plan ensures that both the majority and minority voices are heard.

By including a variety of stakeholders in the decision-making process, a more comprehensive outcome may result with a variety of factors considered.

Figure 118: Rendering of a proposed pocket park in Fresno

The Toronto Green Standard Case Study

Overview

The City of Toronto continues to lead the way in municipal climate change adaptation planning. The Toronto Green Standard (TGS) provides an example of adaptation strategies incorporated within building standards. The TGS was adopted in 2009 as an important element within Toronto's broader Climate Change Action Plan and Sustainable Energy Strategy, which aims to cut Toronto's greenhouse gas emissions 80 percent by 2050 (11). The TGS consists of a two-tiered set of performance measurements for sustainable building design and development. The standard focuses on five sectors: air quality, greenhouse gas emissions and energy efficiency, water quality and efficiency, solid waste, and ecology. The TGS applies to three types of development: low-rise, non-residential, low-rise residential, and mid-high rise (for any use). (12)

How TGS Works

In TGS's two-tiered system, Tier 1 outlines required building measures, while Tier 2 consists of additional voluntary building measures. As such, all new planning applications and site plan approvals must meet all the requirements of the TGS Tier 1 program. To support the increased environmental benefits in the optional Tier 2 measures, developers qualify for a 20 percent refund of municipal development charges (12). The TGS system outlines a series of specifications, definitions, and potential strategies to fulfill the required and voluntary measures. Examples of strategies include using green roofs, greening impervious surfaces, planting drought-tolerant native species, using high albedo asphalt, and integrating bioswales or vegetative filter strips in the development project. The Toronto Green Standard is an example of a sector-based approach to mitigation and adaptation of climate change impacts. (12)

Key Findings

Standards are transferable across municipalities.

Since most cities require site plan review, updating building regulations can help new construction projects adapt to an uncertain climate.

Similar standards can address a variety of issues linked to climate change.

Municipalities can target many different environmental concerns by changing the building codes. Requirements involving building materials, landscaping, and pervious surfaces can reduce the impacts of climate change.

Incentives are needed to induce developers to adopt innovative practices.

Incentives are needed to overcome the additional costs of innovative environmental practices. When incentives are provided, developers are more likely to consider implementing more environmentally beneficial elements.

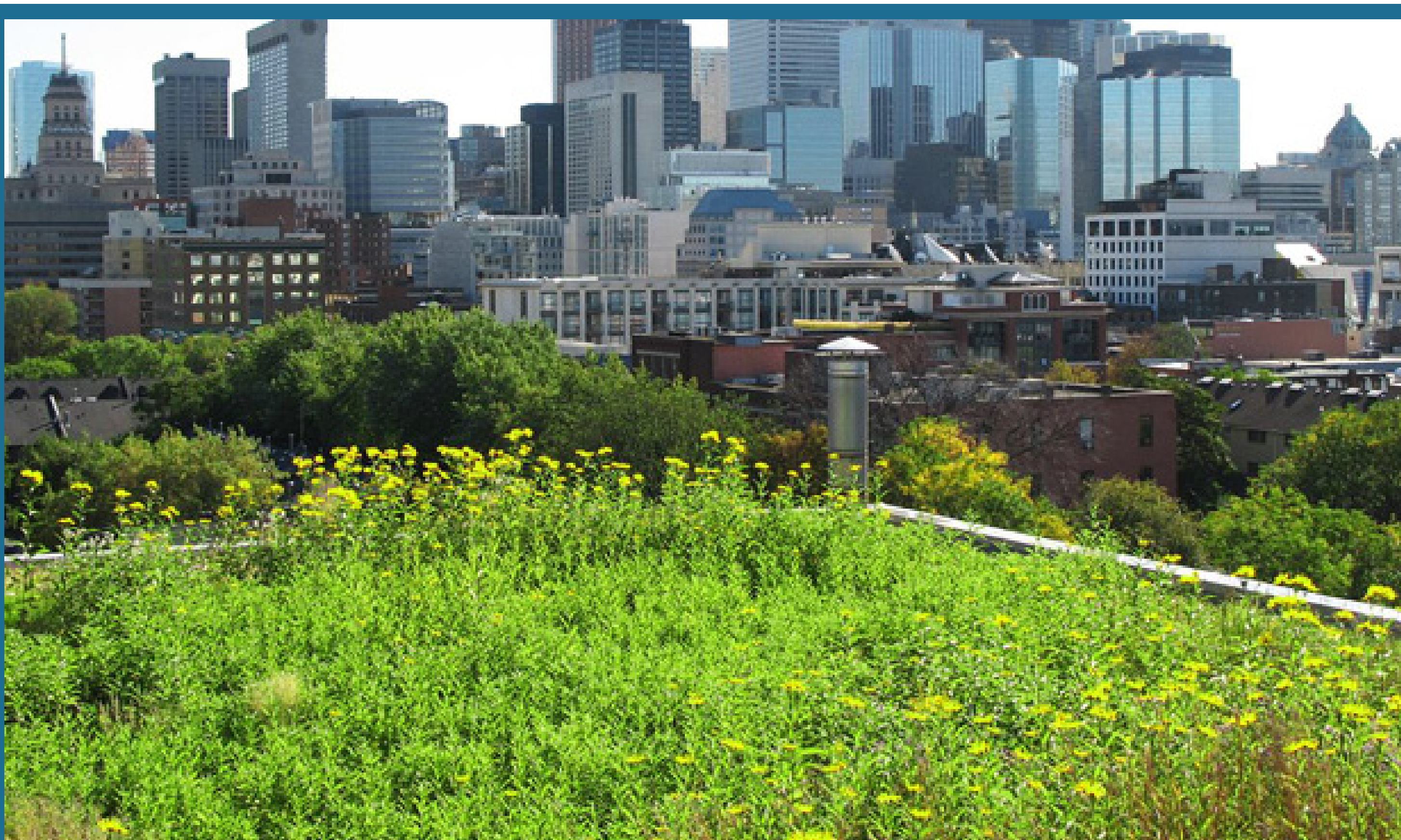


Figure 119: Greenroof exemplifies Toronto Green Standard

City-Specific Adaptation Strategies

Overview

This section provides example adaptation strategies for each of the three case study cities we analyzed in the previous section (Baltimore, Fresno, and Milwaukee). We use each city to highlight a specific climate threat, and then provide examples of appropriate responses that address capacity building and coordination.

The adaptation strategies framework we used begins by identifying the primary threats as identified in national climate change assessments, downscaled regional modes, and recent extreme weather events. Our process begins with a broad goal that addresses the primary climate threats and associated effects (economics, social, natural and built environment). Next, we develop a comprehensive set of strategies and a series of sector-specific objectives that support the broad goal. These objectives are organized into the following categories: capacity building, knowledge base, process, behavioral, and physical.

Due to our limited local expertise, the purpose of this section is to provide a set of examples on the process of developing adaptation strategies. For each city, our adaptation recommendations focus exclusively on one specific threat. For Baltimore, we focus on seal-level rise, for Fresno we focus on extreme heat, and for Milwaukee we focus on stormwater runoff and flooding.

Baltimore Adaptation Recommendations

Overview

The primary climate threats facing Baltimore are increasing temperatures and an increasing frequency and intensity of extreme heat events, increasing intensity and frequency of precipitation events, and sea-level rise (with corresponding more severe storm surge). For a detailed outline of the climate threats and associated threats on the built environment, please reference (climate threats table for Baltimore).

Baltimore Recommendation One

Goal: Minimize disruption in, and damage to, coastal development and infrastructure from sea-level rise and storm surge.

Strategy: Establish a water and land based coastal buffer to provide passive protection to coastal areas.

Sectors Impacted:

- Water – reduces the risk of overflow and inundation of water treatment facilities; vegetative buffers and wetlands filter run-off going into the Bay
- Land use – reduces risk and damage to businesses and developments near the coast from storms and storm surge.
- Energy – reduces risk of damage to low-lying energy generation facilities
- Transportation – reduces dependence on, and use of, transportation infrastructure along the shoreline; reduces risk of damage to the port as an economic hub

Description: Create a land and water-based coastal buffer between the ocean and development in the city, that combines natural and built components to minimize infrastructure damage to businesses and developments resulting from storms, storm surge and sea-level rise. Focusing first on areas at high risk from sea-level rise and storm surge, existing businesses should be encouraged to relocate all non-essential activities and facilities. Relocation assistance in the form of incentives, tax rebates, and direct compensation should be provided to compensate land owners for the value of the properties they vacate. This will minimize damage to businesses and facilities that do not need to be located on or near the port to operate. Non-essential new developments or major repairs and renovations to existing facilities (including major repairs to buildings damaged by storm activity) should not be allowed within the coastal buffer. This option would minimize the financial burden of disaster recovery placed on the city, through a disincentive policy that places responsibility for any damages that occur to non-essential businesses from storm surge and sea-level rise squarely on owners who refuse to relocate outside of the buffer.

Capacity Building:

Knowledge Base:

- Map and model coastal shoreline, sea-level rise, and future storm track and intensity projections, to determine the coastal areas that are vulnerable to sea-level rise and storm surge.
- Inventory and classify all businesses and infrastructure along the coast with the aim of identifying:
    - Facilities most vulnerable to damage
    - Non-essential business and activities
    - Essential business and activities
    - Road and transportation infrastructure which will no longer be needed in the coastal buffer
- Identify which incentive system is most appropriate to encourage relocation, and de-incentivize operating in at risk locations
- Analyze future capacity and upgrading needs for water treatment plants to avoid overflow during storms, and minimize overflow from storm surge, and energy generation facilities to minimize damage
- Research which plant species are native to the area and are best suited to provide buffering services, such as filtering toxins from stormwater runoff

Process:

- Establish a planning team with members of the local government, business leaders who will be impacted by the implementation of a coastal buffer, and natural science experts (likely from local universities)
- Develop a framework to divest financial responsibility for non-essential commercial coastal damage from the city and place it on impacted businesses
- Develop a relocation incentive/compensation/tax break program and outline program funding sources
- Encourage collaboration between local government departments which are responsible for different aspects of the policy (e.g. transportation, environment, planning and zoning)

Behavioral:

- Reach out to all businesses that are located within the buffer
    - Engage them in the design of the program
    - Educate them on the purpose of the program, the short and long term costs and benefits
    - Reach out to the public and educate them on the value and need for a coastal buffer, as a way to increase pressure on businesses to embrace the concept

Physical:

- Move companies out of the coastal buffer
- Allow construction of new facilities within the buffer only when no existing building outside the coastal buffer meets a company's needs
- Tear down or move buildings which are located within the coastal buffer
- Remove roads and transportation infrastructure which is no longer needed in the coastal buffer
- Install vegetative landscaping with native plants in the coastal buffer to establish a coastal nourishment zone
- Expand installation of floating wetlands
- Construct flood walls, levees, and additional flood prevention infrastructure

Figure 120: Rendering of a proposed floating wetland barrier in Baltimore's Inner Harbor

Baltimore Recommendation Two

Goal: Increase resilience of energy system to disruptions in energy generation, supply shocks, and price volatility caused by storm activity and sea-level rise

Strategy: Transition away from coastal electricity generation facilities, increase energy generation capacity at inland facilities, and encourage technologies that are not dependent on fuels that come in through the Port

Sectors Impacted:

- Energy – reduces disruptions to supply of primary fuels (petroleum, natural gas) that come in through the Port; reduces disruptions to low lying electricity generation facilities resulting from sea-level rise or storm surge; proactive action minimizes costs (relative to reactive action costs)
- Human Health – minimizes impacts on human health and well-being from brownouts and blackouts
- Land Use – reduces risks to new electricity generation facilities by requiring that they locate further inland, away from the coast

Description: Conduct a comprehensive assessment of the energy profile of the region to minimize the potential for supply disruptions, price volatility and energy shortages. Many electricity generation facilities are located in areas vulnerable to storm surge inundation, or displacement by sea-level rise. Identification of vulnerable facilities will allow time to reduce dependence on, and phase out the use of, vulnerable facilities. New electricity generation facilities take a significant amount of time to be permitted and constructed; therefore, a significant amount of lead-time is needed to minimize disruptions in supply. Additionally, existing electricity generation facilities depend on primary energy sources, often imported through the Port of Baltimore. Extreme weather events can disrupt the supply of petroleum and natural gas, and drive up energy prices. A shift in focus to renewable energy sources would decrease volatility and disruption in the supply of primary energy sources, while reducing greenhouse gas emissions from energy production.

Capacity Building:

Knowledge Base:

- Map and model coastal shoreline and sea-level rise, and future storm track and intensity projections, to determine the vulnerability of every energy generation facility in Baltimore to:
    - Sea-level rise
    - Storm surge
    - Extreme storm activity such as wind and rain

- Analyze capacity of vulnerable generation sites
- Identify existing, non-vulnerable generation facilities which can increase generation capacity:
    - with existing infrastructure
    - through expansion
- Project growth in future energy demand
- Evaluate the feasibility and potential for renewable and alternative energy production in Baltimore
- Encourage energy efficiency measures to decrease overall energy demand

Process:

- Establish a planning or working group between city government, the public utility commission, customers and electricity suppliers in the region
- Create a program and allocate funds to begin the process of phasing out and eventually shutting down the most vulnerable facilities; reinforce vulnerable, but lower priority sites to maximize the life of the facility
- Ban the construction of new generation facilities in vulnerable areas

Behavioral:

- Increase public awareness about the benefits of decreasing energy use
- Increase public awareness of the short and long term cost and benefits of switching away from traditional energy sources
- Engage companies and utilities about the short and long term costs of remaining in vulnerable locations, compared with the costs of relocating, or shifting activity to non-threatened facilities

Physical:

- Expand capacity at non-threatened generation facilities to accommodate the demand currently being served by vulnerable facilities
- Build new generation facilities in non-coastal zones
- Build renewable energy infrastructure such as solar array farms and wind farms to replace currently threatened energy generation facilities

Baltimore Recommendation Three

Goals: Maintain port access and protect port infrastructure from sea-level rise and storm surge

Strategy: Reinforce threatened port infrastructure and develop a plan to address decreased bridge clearance from sea-level rise

Sectors Impacted:

- Energy –minimizes disruptions to natural gas and petroleum supplies brought in through the Port of Baltimore
- Land Use – reduces damage to port infrastructure
- Transportation – minimizes disruptions in the importation and distribution of goods that come in through the Port; could eventually disrupt traffic over and under the Francis Scott Key Bridge

Description: Port and bridge infrastructure were built to the historical optimal level relative to sea-levels. Rebuilding the Port would take relatively little time compared to the time scale associated with sea-level rise, however as the rate of sea-level rise accelerates the Port will have to be rebuilt faster and more frequently. Reinforcing the existing port infrastructure to withstand the predicted increase in frequency and intensity of hurricanes, extreme weather events, and storm surges, will decrease the costs of periodic repairs and minimize service and supply disruptions. Rebuilding the Port to be more robust will decrease reactive repair costs and minimize supply disruptions. Developing a plan to address the decrease in bridge clearance will minimize disruptions to supply, by engaging shipping and receiving businesses in determining an appropriate solution, and providing adequate upfront information for future supply management.

Capacity Building:

Knowledge Base:

- Map and model the timescale of sea-level rise impacts to identify:
  - Areas of the Port shoreline and port infrastructure which will be most vulnerable to sea-level rise and storm surge
  - Impact on bridge clearance
- Identify funding sources to pay for Port rebuilding and reinforcement work
- Identify which import products will be most impacted by threats to specific areas in the port, as well as bridge clearance
- Analyze the short and long term financial implications of disruptions to port activity, and proactive planning and action
- Evaluate transportation contingencies for I-695 in the event that the Francis Key Scott bridge must be rebuilt to increase clearance

Process:

- Establish a Port stakeholder group with city officials, Port businesses and companies, and natural scientists to address shoreline concerns related to sea-level rise
- Develop a program to incentivize the cooperation and collaboration of import companies that will be most affected by sea-level rise
- Encourage collaboration between port authorities and companies which will face bridge clearance issues, to avoid a loss of port business resulting from business switching to a different port

Behavior:

- Provide educational materials to port companies and authorities on the threats from sea-level rise and storm surge
- Educate the public on the possibility of supply disruptions to decrease system shocks if weather does disrupt port activities

Physical:

- Reinforce existing port buildings
- Rebuild port infrastructure as needed to maintain efficient opperations
- Construct flood walls, levees, and additional flood prevention infrastructure
- Increase the clearance and height of the bridge, as needed

Figure 121: Innovative sea barriers to protect against storm surge and sea level rise

Fresno Adaptation Recommendations

Overview

The primary climate threats facing Fresno are: increasing temperatures, an increasing frequency and intensity of extreme heat events, decreasing snowpack and associated reliability of stream flow runoff patterns, increasing variability of precipitation events, characterized by more intense events and longer periods of drought. For a detailed outline of the climate threats and associated effects on the built environment, please reference the climate threats table for Fresno.

Fresno Recommendation One

Goal: Mitigate the impacts of rising temperatures and extreme precipitation events associated with climate change

Strategy: Implement afforestation, pocket parks, and green infrastructure in urban and residential areas

Sectors Impacted:

- Water – provides more permeable surfaces and reduces the impacts of flooding
- Land use – increases ecosystem services
- Human health – reduces the risk of heat related illness, improves urban air quality, and decreases propagation of vector-borne diseases
- Energy – reduces energy consumption for cooling during peak hours and heat waves

Description: Strategic planting of trees, shrubs and other natural vegetation in residential and urban areas can help address the anticipated increases in heat, and impacts related to increases in frequency and intensity of precipitation. Afforestation, pocket parks, and green infrastructure address urban heat threats by providing increased shade, supporting evapotranspiration, and reducing the extent of low-albedo impervious surfaces. Additionally, these strategies help reduce the intensity of stormwater runoff by infiltrating water onsite, thereby minimizing flooding risk and watershed impacts. Finally, urban afforestation, pocket parks, and green infrastructure reduce the risk of vector-borne diseases by decreasing areas of standing water, which serve as a breeding ground for mosquitoes.

Capacity Building:

Knowledge Base:

- Conduct extensive city mapping to inventory and identify priority areas for implementation of green infrastructure, afforestation and pocket parks, with a focus on:
    - Vulnerable populations
    - Greenspace
    - Hardscapes
    - Zoning
- Identify limitations that zoning ordinances will place on efforts to expand greenspaces, as well as opportunities that zoning might provide to expand greenspaces
- Research native species and appropriate landscaping in the context of anticipated climate impacts to determine which species will perform the intended functions of flood prevention and shading
- Identify existing programs and incentives, gaps, and collaborative opportunities for expanding green infrastructure and natural vegetation

Process:

- Establish a collaborative planning process between the departments of parks and recreation, public utilities, public works, and development and resource management to integrate afforestation and pocket parks
- Encourage collaboration and participation of city departments, local non-profit organizations, community groups, and the private sector in planning the program
- Develop an incentive program to encourage participation across the community (public and private sectors) in increasing afforestation and green infrastructure.
- Establish a set of green infrastructure and tree planting guidelines

Behavioral:

- Organize a public awareness campaign to highlight the benefits of landscaping on energy efficiency, water retention, summer cooling, and human health
- Engage communities for participation in:
    - Community plantings
    - Design competitions
    - Tree protection programs
    - Incorporation of garden plots into parks

Physical:

- Plant trees throughout the City
- Integrate pocket parks into existing landscapes
- Integrate green infrastructure and tree planting guidelines into the construction of public infrastructure and works projects
- Transition existing hardscapes to greenspace and pocket parks during replacement and maintenance
- Remove under-utilized impervious surfaces and replace with native vegetation

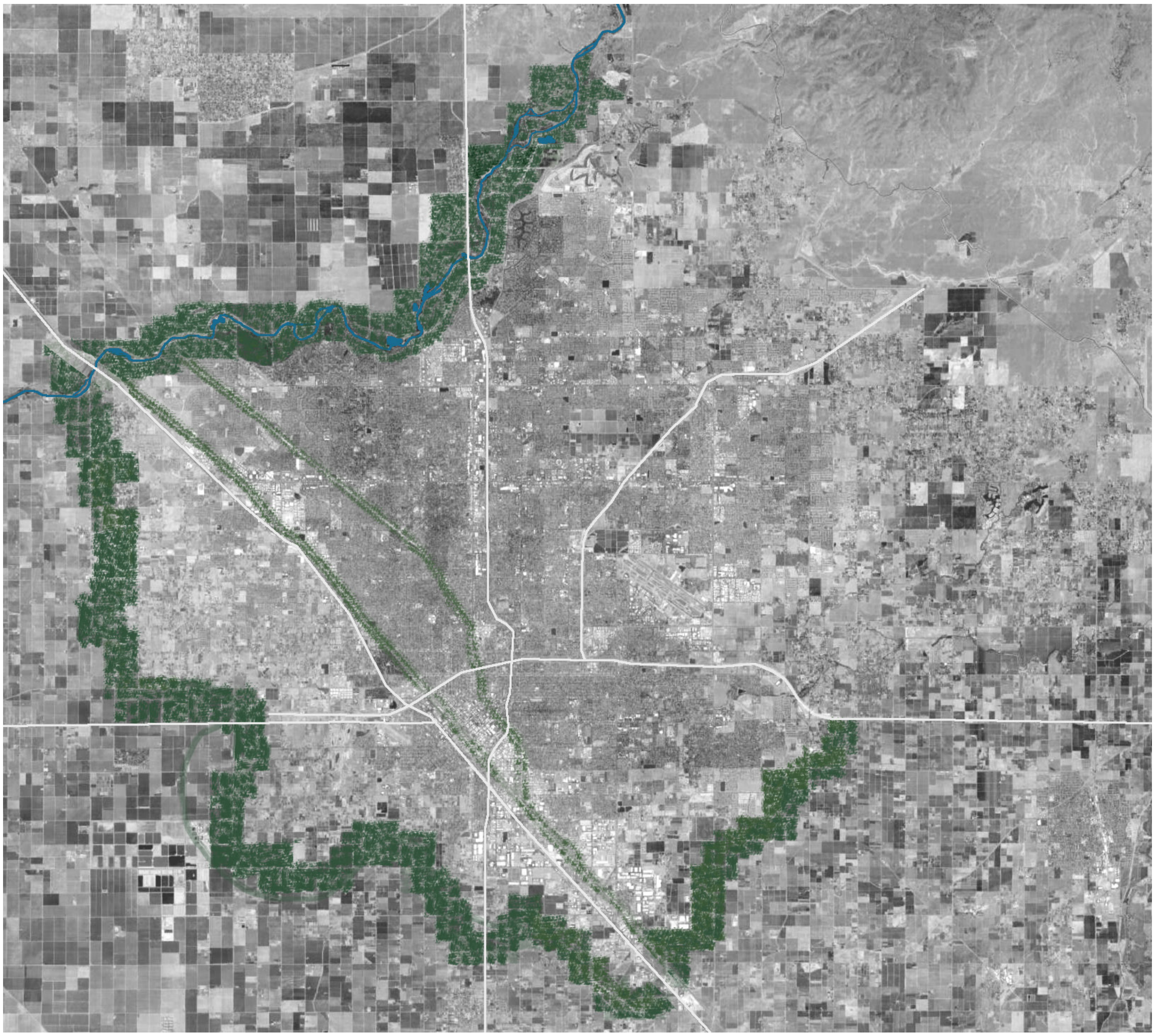


Figure 122: Rendering of a proposed greenbelt surrounding Fresno

Fresno Recommendation Two

Goal: Reduce the impact of extreme heat and the corresponding urban heat island effect

Strategy: Incorporation of high-albedo surfaces into building construction and maintenance, and existing transportation infrastructure

Sectors Impacted:

- Energy – reduces energy consumption for cooling during peak hours and heat waves
- Human Health – reduces the risk of heat related illness and mortality during heat waves, especially in residential areas
- Transportation – utilizes existing infrastructure as a way to mitigate the effects of urban heat island
- Land use – increases the albedo of surfaces and buildings

Description: Dark colored pavement and building materials exacerbate urban heat island effect. These dark surfaces absorb heat causing the city to reach higher temperatures during the day and to retain heat well after temperatures drop in the evening. Incorporating light colored and reflective materials, such as white paint and white concrete, in building construction and maintenance can help reduce urban heat island effect. A paper supported by the California Institute for Energy Efficiency reported that high-albedo roofs can reduce heat gain by up to 10 percent and dramatically decrease energy use for cooling (13). These effects are particularly valuable in low-income residential areas where high-energy costs deter air conditioning use during extremely hot periods. Additionally, utilizing high-albedo materials on large surfaces such as roads and parking lots can help to cool vast urban areas (14).

Capacity Building:

Knowledge Base:

- Utilize remote sensing and thermal imaging to map surface temperatures throughout the City, identify hot-spots, and rank priority areas for implementation
- Evaluate the performance of high-albedo options relative to conventional options and trade-offs in performance or durability
- Research construction materials to determine which low-albedo roofing materials, paving materials, and building materials are best suited to Fresno's climate and weather

- Research existing funding sources at the state and federal level to implement the high-albedo program in the form of:
    - Grants
    - Tax credits
    - Incentive programs
- Use Cost-Benefit Analysis to determine the financial feasibility of implementing this strategy

Process:

- Collaborate across city departments to incorporate this strategy on all city owned property
- Develop programs and tax breaks that incentivize both businesses and residents to employ this strategy as a money saving opportunity
- Create an ordinance that requires all new buildings and transportation spaces to utilize high-albedo surface materials*(provided that the high-albedo alternatives do not demonstrate major reductions in performance or durability)

Behavior:

- Educate the public about the new incentive program
- Provide educational materials (pamphlets, educational workshops, websites) to home and business owners identifying how they will directly benefit from the program
- Engage the community in public projects to re-paint surfaces using high-albedo colors

*Physical**:

- Use reflective surfaces when replacing roofing on buildings, especially in hot-spot areas
- Incorporate reflective surfaces when resurfacing existing transportation areas, including roads, parking lots, bike paths, and sidewalks
- Use high-albedo materials in all new construction

**Green surfaces, including green alleys and low-impact development techniques, help reduce urban heat island effects and should be included as a potential alternative within building and surface materials requirements. While green roofs also reduce urban heat island effects, implementation in Fresno may lead to increased risk of fire danger due to the arid climate.*

Fresno Recommendation Three

Goal: Develop a natural barrier to protect against predicted climate impacts

Strategy: Establish a greenbelt that provides a buffer between existing urbanized areas and surrounding natural and agricultural spaces

Sectors Impacted:

- Water – increases the areas of permeable surface, protects against flooding, and aids in recharging the aquifer
- Land use – increases ecosystem services, and protects farmland and open spaces
- Human health – reduces the risk of heat related illness and improves urban air quality

Description: A greenbelt or natural buffer between the urban city limits and agricultural areas will serve to recharge the aquifer, provide increased areas of pervious surface, bolster ecosystem services, provide environmental education opportunities, and protect farmland and open spaces outside of the city. Countries and cities around the world use greenbelts as a strategy to adapt to climate change. In England, greenbelts around cities provide natural areas which support evapotranspiration and contribute to cooling wetlands which protect against flooding, and water retention which aids in times of drought (15).

Capacity Building:

Knowledge building:

- Map and inventory all land features, with a special focus on border and transitional regions between agricultural and urban areas
- Research native species to identify the optimal species and vegetative composition for a green buffer
- Research spatial limitations to identify the optimal size and land use for the Fresno buffer
- Inventory land outside of current city limits that will be impacted by the greenbelt to create profiles of ownership and land use

Process:

- Establish a purchase of development rights program requiring collaboration between the City, County, and State governments. The program will:
    - Create funding legislation for the greenbelt
    - Establish a board to run the program

    - Develop high-valued areas outside of the city that will make surrounding areas less attractive to develop and unofficially expand the range of the greenbelt without requiring the purchase of all land in the belt
- Establish coordination between the central City government and the City Council to develop an advisory committee
- Encourage collaboration between the City government and local environmental non-profits and land trusts with expertise on conservation and land preservation

Behavioral:

- Use the greenbelt to create educational programs for schools, summer camps, community and youth groups, and other environmental groups establish coordination between the central city government and the City Council to develop an advisory committee
- Educate the public about the benefits of the greenbelt and use the programs as an opportunity to increase stakeholder engagement in green projects across the City
- Develop a pilot greenbelt as an example project which other cities can replicate

Physical:

- Begin development and maintenance of land in the greenbelt
    - Clear land of any built structures
    - Decontaminate and clean polluted sites
    - Re-vegetate land with desired vegetation and native species

Milwaukee Adaptation Recommendations

Overview

The primary climate threats facing Milwaukee are increasing temperatures, increasing frequency and intensity of extreme heat events, increasing intensity and frequency of precipitation events, and gradually declining lake levels. For a detailed outline of the climate threats and associated effects on the built environment, please reference climate threats table for Milwaukee.

Milwaukee Recommendation One

Goal: Increase the resilience of Milwaukee's energy sector to disruptions in energy generation, supply shocks, and price volatility caused by flooding

Strategy: Create an integrated energy plan that focuses on bolstering the robustness of energy infrastructure, diversifying the regions energy profile through renewable energy generation, and decreasing energy usage

Sectors Impacted:

- Water – reduces degradation in water quality from air pollution produced during fossil fuel generation; reduces energy sector demand for water; reduces potential for spills or accidental releases of oil or natural gas into water bodies
- Land use – reduces the need for ecologically intrusive electric transmission lines and new generation facilities; increases the distribution of small renewable energy projects across the landscape
- Human health – increases reliability of (and decreases likelihood of disruptions to) electric generation relied on to meet cooling demands
- Energy – reduces energy consumption for cooling during peak hours and heat waves by reducing long distance transmission losses

Description: Integrated energy planning will bring energy consumers together with energy producers to address gaps and vulnerabilities in the current energy system, strengthen the energy infrastructure, and identify strategies to align incentives across producers and consumers to encourage an increase in renewable energy generation and increased energy efficiency. The majority of Milwaukee's electricity currently comes from coal, with additional capacity provided by natural gas and nuclear facilities located throughout the state. The greatest threat to Milwaukee's energy infrastructure is from flooding, as the frequency and intensity of storms increase. In the long term, flooding, extreme storms and water-use concerns will decrease the number of sites suitable for new energy generation facilities. Diversification of the energy profile with renewable energy resources will distribute increased demand and reduce the risk of disruptions in energy supply.

Capacity Building:

Knowledge Base:

- Map and model changes in lake levels and flood risk to determine the vulnerability of existing energy generation facilities
- Inventory current energy supply and demand by energy source
- Determine remaining useful life of existing generation facilities
- Project future energy demand in the metro region
- Identify existing incentives to encourage energy efficiency
- Evaluate the feasibility and potential for renewable and alternative energy production in Milwaukee

Process:

- Establish a working group with the local utility commission, the city government, energy suppliers and local consumers
- Encourage collaboration between energy suppliers, urban planners, and the zoning commission to identify low risk sites for future energy generation facilities, and to coordinate the expansion of renewable energy projects
- Phase-out old and vulnerable facilities and decrease reliance on energy generated elsewhere in the state
- Develop a program to encourage decreased energy use among residents, and to remove perverse incentives that deter utilities from energy efficiency

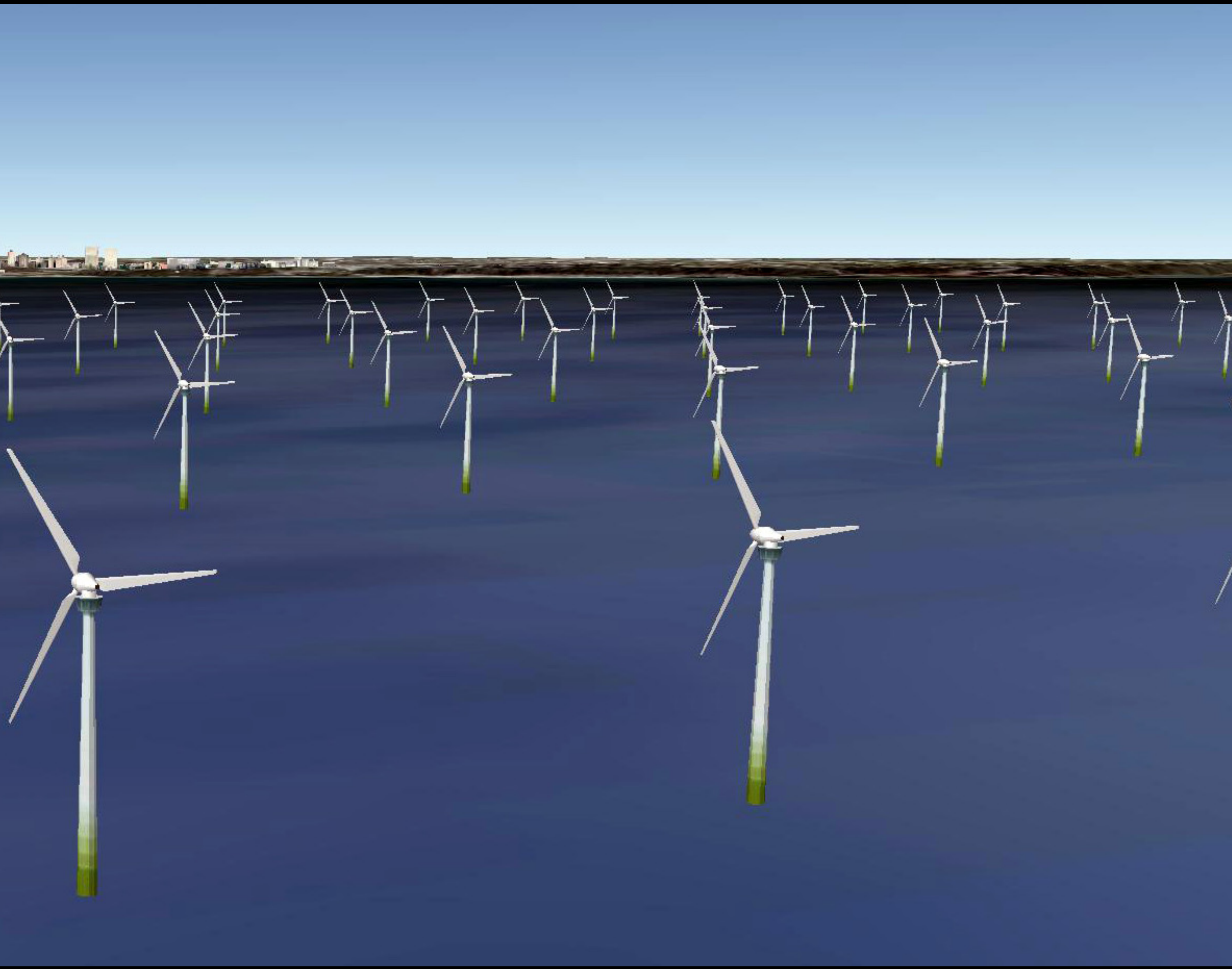
Behavioral:

- Run a public awareness campaign to encourage energy efficiency
- Engage people in a dialog about the potential for small and large scale renewable energy production in the region
- Educate the energy generation companies about the risks that floods pose to their facilities so they can plan and reinforce infrastructure as they see fit

Physical:

- Reinforce the physical infrastructure of energy generation facilities
- Build new sites and transmission capacity as needed; tear down old and high risk facilities
- Build renewable energy projects in optimal locations

Figure 123: Rendering of a proposed floating wind turbine farm in Lake Michigan, 3 miles off the coast of the City of Milwaukee



Milwaukee Recommendation Two

Goal: Increase resilience of Milwaukee stormwater infrastructure to more frequent and intense precipitation and flooding

Strategy: Create an integrated stormwater management plan

Sectors Impacted:

- Water – reduces the threat of localized flooding; reduces the possibility of drinking water contamination; protects the health of aquatic life and riparian habitat
- Land use – controls erosion, and reduces risk of property loss from flood damage
- Human health – reduces the risk of future outbreaks of water-borne diseases; reduces physical safety risks posed by flooding; benefits public health through the expansion of permeable green spaces
- Energy – reduced risk to critical energy infrastructure through decreased flood risk

Description: Integrated stormwater management planning combines 50- to 100-year precipitation projections, based on robust climatology data that includes potential climate change impacts and inventories. These methods project both supply and demand side volume over the same period. The planning process accounts for opportunities and threats across spatial (from a small lot to an entire watershed) and temporal scales, based on existing infrastructure and technology. Stormwater management is a significant concern because the City sits at the confluence of three rivers, on land that used to be a marsh. Significant flooding threats have resulted from the replacement of the natural surface with impermeable urban infrastructure, however flooding and erosion can be controlled through a series of ponds, hard drainage structures, and the development and enforcement of policies to encourage property owners to consider water management before they begin development is approved.

Capacity Building:

Knowledge Base:

- Identify populations and properties vulnerable to flooding
- Update hydrological models and flood maps to reflect predicted increase in precipitation
- Inventory age and capacity of existing stormwater infrastructure, and create a prioritized timeline for repairs, considering available financial resources
- Identify the full range of stormwater management practices available, such as increasing the area of permeable surfaces (green spaces)

Process:

- Encourage collaboration between city officials, emergency responders and local community action groups to increase the robustness of emergency preparedness
- Encourage individual actions, such as installing rain barrels, setting up retention ponds, and planning native species
- Establish a working group with city planners and representatives from the storm water management district, and representatives from the community to develop a collaborative management plan
- Develop a policy to deter residential or commercial development in areas vulnerable to increased flood risk
- Enhance local ordinances to require property owners to consider stormwater management as they develop their land

Behavioral:

- Educate the public about the risks from flooding and stormwater runoff, and the individual actions that they can take to help manage stormwater
- Engage individuals and businesses to encourage design and construction practices that decrease vulnerability to flooding
- Involve the public in small scale projects to expand permeable spaces
- Encourage compact and low impact development in the watershed

Physical:

- Replace or retrofit aging stromwater runoff infrastructure
- Reduce impervious surfaces through the use of permeable pavement, and by targeting large vacant industrial sites for environmental remediation and ecological restoration
- Carry out erosion prevention and management activities
- Build street-side gardens and green space that collect water and debris, and enhance neighborhood beautification

Figure 124: Rendering of a proposed riverside park and wetland in downtown Milwaukee


THE IRON HORSE HOTEL


THE IRON HORSE HOTEL

Milwaukee Recommendation Three

Goal: Protect fresh water supplies from contaminated and polluted runoff

Strategy: Implement wetland restoration techniques and create a buffer along the river and lake shores

Sectors Impacted:

- Water – reduces the risk of water contamination and degradation
- Human Health – reduces the risk of waterborne diseases
- Land use – protects ecosystems and wildlife from contamination and polluted water

Description: Wetlands and buffers provide significant benefits through natural processing and mitigation of pollution entering the regional watershed from stormwater runoff. Pollution runoff and contamination from combined sewer overflow is projected to rise as the frequency and intensity of precipitation events increase. Strategic implementation of wetlands and buffers will reduce future strain on existing stormwater infrastructure and provide resiliency in addressing health and flooding impacts. In addition to reducing vulnerability, wetlands and natural buffers offer additional greenspace and recreational opportunities.

Capacity Building:

Knowledge Base:

- Generate a stormwater runoff map to identify the most sensitive areas to contamination and pollution runoff
- Identify and map targeted areas to implement natural buffers and wetlands
- Review case studies of natural systems restoration to highlight lessons learned, allowing for the development of more effective and cost-efficient strategies
- Identify businesses and current developments in prime restoration areas that will be impacted or displaced by wetland restoration or buffers

Process:

- Establish a collaborative stakeholder group consisting of local water, land use, transportation, and health organizations to inform a policy and plan of action
- Engage local non-profit and community groups supportive of water quality, ecosystem services, and habitat restoration in planning and implementation processes
- Work with local researchers to define an optimal set of plants and habitat essential to natural management of pollution and contaminants

Behavioral:

- Provide a broad public education campaign using pamphlets, signage, and design competitions
- Educate and engage the public through community input and charrette processes on the benefits and costs of river and lake restoration projects
- Encourage natural science and ecosystem services education in local educational programs
- Inform private landowners of the value and benefits associated with wetland restoration and buffers

Physical:

- Initiate a wetland restoration demonstration project to highlight benefits, costs, and analyze associated processes
- Include restoration and buffer strategies in proposed government projects, including new parks, infrastructure improvements, and maintenance of public space
- Implement a large wetland restoration project as a public amenity, and to address flood risk in essential urban areas
- Develop a natural science and environmental education center within a restored wetland area

Figure 125: Ecosystem services are an important strategy in revitalizing urban areas

Primary Resources for Adaptation Planning

IPCC

The Intergovernmental Panel on Climate Change (IPCC) is a multinational scientific body created by the World Meteorological Organization and the United Nations Environment Programme. The IPCC consists of three working groups: Working Group I focuses on climate science, Working Group II specifically explores climate impacts, adaptation and vulnerability, and Working Group III addresses mitigation efforts. The global assessment reports produced by Working Group II are an important resource for adaptation planning efforts. The fourth adaptation report, published in 2007, examines current adaptation practices, adaptive capacity, and strategies for enhancing adaptation. Working Group II will release their next adaptation report in 2014. The work of the IPCC provides a global context and perspective on climate change adaptation which is valuable at any level of planning. (16)

UNFCCC

The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty that aims to address the causes of climate change and develop strategies to cope with inevitable climate impacts. The UNFCCC secretariat supports institutions involved in the climate change process, including the Conference of Parties, out of which have come binding agreements like the Kyoto Protocol. While the UNFCCC adaptation arm focuses on developing countries, their published reports such as *Action on the Ground* and *Adaptation Assessment, Planning, and Practice* provided useful information for any government addressing climate change adaptation. Additionally, the UNFCCC adaptation strategies database offers extensive case study examples of city-level adaptation projects. (17)

C40

The Climate Leadership Group (C40) is a group of 40 cities (with many other partnering cities) on six continents that work together to mitigate climate change and associated impacts. The organization offers best practice case studies on eight aspects of urban life, which provide strong examples of steps taken by cities around the world to combat the impact of climate change. Areas of focus include: buildings, energy, lighting, ports, renewables, transport, waste, and water. While C40 focuses primarily on mitigation, they provide various forms of assistance to local governments, which may be helpful in initiating adaptation programs. (18)

ICLEI- Local Governments for Sustainability

The International Council for Local Environmental Initiatives (ICLEI) is a council of over 1,000 local governments worldwide. Their programs and projects promote participatory, long-term, strategic planning processes that address local sustainability while protecting global common goods. Their climate program is divided into mitigation, adaptation, and advocacy groups, and is carried out at regional levels around the world. ICLEI provides resources to aid local governments in initiating adaptation programs and increasing adaptive capacity. This local-level focus makes ICLEI a useful resource for city planning departments embarking on climate change adaptation projects. (19)

USGCRP

Established in 1989, the U.S. Global Change Research Program (USGCRP) is a partnership of 13 U.S. federal government agencies, which coordinate and integrate research on global environmental changes and their implications for society. Specifically, their research focuses on adaptation science, strategic planning, and climate modeling. Their 2010 recommendations for a national adaptation strategy urge federal agencies to promote adaptation in agency planning and to make scientific information about climate change impacts accessible to public and private decision makers. Furthermore, the USGCRP 2010 report recommends that the federal government strengthen existing efforts to help developing countries reduce their vulnerability to climate change and build strong partnerships to support state, local, and tribal adaptation. The USGCRP serves as a useful resource in examining adaptation planning due to their broad approach to setting national-level climate adaptation goals. (20)

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Gaps Analysis and Lessons Learned

Introduction

Based on a thorough review of literature and adaptation planning efforts, and through interaction with local stakeholders, our team identified a series of gaps in current knowledge, as well as important lessons applicable to future adaptation planning efforts. The relative lack of existing in-depth city adaptation plans presented several research and methodological challenges. Additionally, we discovered promising avenues of research and analysis that we were unable to pursue due to time, resource, and access constraints. This section summarizes some of the key gaps we found in climate adaptation knowledge and research, as well as limitations in our project adaptation planning process. Finally, we identified important lessons learned through our research and analysis, which will assist others working on climate adaptation and response planning or research.

Knowledge Research and Gaps

Existing scientific research on climate change impacts primarily focuses on macro-scale changes that are difficult to connect to adaptation strategies. Climate projections for average changes in temperature, precipitation, storms, and other impacts provide planners with a predicted direction and a relative magnitude of change. However, providing climate adaptation planners with data on future extreme events will allow for more robust vulnerability analysis.

The quality and availability of climate prediction data varies significantly by geographic region. Most climate models study highly populated regions, often with a disproportionate focus on coastal areas. Some forward-thinking regions have devoted significant research to developing "downscaled", region-specific models, rather than relying on global circulation models. However, many jurisdictions have limited resources to conduct region-specific "downscaling" of climate models, which leads to dramatic differences in the quality of data available across cities. This mismatch suggests a need for greater collaboration between climate scientists, governments, and climate adaptation planners to produce a methodology that will result in consistent data for all regions.

Existing U.S. climate adaptation plans often focus on process oriented, rather than actionable, strategies. Our examination of leading plans from around the world revealed that the final recommendations of many reports focus on knowledge gathering, research, and process development, with few contextual or city-specific implementation plans. While knowledge building and city-level processes are important, climate adaptation strategies should begin to incorporate outcome-oriented strategies. Specific attention should be applied to action and implementation, particularly concerning decisions that have long-term consequences. The framework provided in the climate adaptation strategy section attempts to address this gap by outlining capacity building objectives that result in achieving the broader strategy goal. We hope these can serve as meaningful frameworks for adaptation recommendations in subsequent plans.

Limitations of Our Process

As researchers studying climate change in distant cities, we were unable to deeply engage the local population in our process. To integrate local knowledge into the project planning process we worked with local climate experts, government officials, and regional planners in Baltimore, Fresno, and Milwaukee. We also performed site visits to learn more about local issues and to study the regional landscape. However, an ideal planning process would involve broader engagement of the various stakeholders, including the city sectors, local businesses, regional research institutions, and the residents of each city. Local and regional stakeholders have significant knowledge about how the climate has changed over time and the effects of change on the local population. This information can compliment regional climate models and is an integral component in assessing vulnerability and risk.

We approached this project from a planning perspective, focusing on socially vulnerable populations and risks to critical systems in cities. Our analysis is future-oriented, intending to provide guidance for long-term actions that will increase the adaptive capacity and resiliency of cities. However, there are several other approaches and strategies for adaptation planning which could provide a valuable perspective. Examples include:

- Framing vulnerability and risk as primarily an emergency response and preparedness issue
- Quantitative valuation, using cost-benefit analysis for prioritization of adaptation strategies, with an emphasis on short-term benefits
- Analysis of existing and emerging technologies for adaptation
- Infrastructure vulnerability analysis to determine where extreme events are likely to cause significant damage
- Hydrological modeling based on predicted climate changes
- A focus on inducing human behavior changes to reduce climate risks
- Political and fiscal feasibility analysis of adaptation recommendations
- Producing city-specific climate models using statistical "downscaling", rather than a relying on global circulation models
- Legal analysis of existing local, state and federal laws for compatibility with adaptation recommendations
- Suggestions for model ordinances, building codes, and other regulations which support best practices
- In-depth ecological impact assessments, including a stronger emphasis on aquatic ecosystems
- Economic impact analysis of changes in stocks of natural resources, and agricultural productivity

Lessons Learned

There is a need for stronger collaboration with climate scientists in the adaptation planning process. Our initial process intended to create original, city-specific climate change models for each case study city. However, we quickly realized these models are highly complex and beyond our project scope. Instead, our analysis relies on national and regional assessments performed using global circulation models. The global scale of climate predictions has a distinct impact on the ability for researchers to perform city- and neighborhood-scale analysis. Moving forward, social and environmental studies would benefit from city- and region-specific climate models, which would allow for better assessment of local vulnerability.

Uncertainty is inherent to the climate change adaptation process. Many adaptation planning documents reflect a reluctance to pursue actionable strategies in the face of uncertain climate projections. Uncertainty is inherent in climate modeling, environmental and social analyses, and human behavior. While an emphasis has been placed on reducing model error, a defined human response to increasing global greenhouse gas emissions is necessary to ensure greater certainty in the projected impacts of climate change. As a result, professionals should assume uncertainty cannot be eliminated when engaging in adaptation planning.

Climate change adaptation plans tend to focus on research and modeling, often at the expense of action-oriented planning. Given the extensive uncertainty inherent to climate adaptation planning, the tendency is to reduce uncertainty through extensive research and modeling. We observed an emphasis on climate impact modeling and assessment in several planning documents we reviewed from around the world. Similar to other planning documents our report also focused on existing conditions and climate change impacts. As a result, many reports provide few recommendations and adaptation strategies linked to this research. A stronger action-oriented focus is needed in climate adaptation plans to achieve meaningful results.

Final Thoughts

Climate change impacts vary widely across the United States. In response, cities are developing climate action plans to reduce their impact on the environment. While progress is being made regarding mitigation policy, there is a significant gap in the integration of meaningful, locally focused, proactive climate adaptation efforts into city planning processes. By following our process of evaluating city and sector threats, synthesizing and prioritizing adaptation strategies, and repeating this process as needed to fill in gaps, cities can develop the capacity to preemptively respond to climate threats while simultaneously improving the lives of their citizens.

The development and implementation of a climate adaptation plan requires short-term capital investment. However, the long-term societal benefits of implementing adaptive strategies can outweigh initial capital costs. Initial costs of proactive planning can be estimated and planned for, however the future costs of inaction are highly uncertain and often go beyond financial impacts to include loss of human life, significant damage to infrastructure, and severe disruptions to city operations.

Integrating climate adaptation planning into general planning practices will better prepare cities for uncertainty regardless of the severity of future climate impacts. Extreme weather events will pose a threat to city systems, even if their frequency does not increase. Social inequity will continue to impact vulnerable populations if their needs are not considered and provided for by social programs. Ecosystem and environmental health will be threatened by growth in human impact and population, especially at the urban and regional levels.

Integrated climate adaptation planning incorporates social and ecological contexts across temporal and geographic scales. Local needs are evaluated in relation to their interactions with regional and global factors. Long term environmental health is pursued with responsiveness to short term constraints. Humans are inherently connected with the environment and ecosystems. The actions of planners, policy makers, natural scientists, designers, and local stakeholders shape the urban systems and ecosystems that surround them. We are not all regional experts; however we are stakeholders in our global environment. This report is our contribution to the body of knowledge on climate adaptation planning in the U.S.

Appendix A

Glossary

100-year flood – a flood with a 1 percent probability of occurring in any single year

Adaptive capacity – the ability of institutions, systems, and individuals to adjust to the potential damage of climate change

Albedo – the proportion of light or radiation reflected by a surface back into space

Brownfield – a former industrial or commercial site where future use is affected by real or perceived environmental contamination

Capacity building – the process of developing technical skills and institutional capability to enable communities to effectively address the causes and results of climate change

Climate – the weather conditions prevailing in an area in general or over an extended period of time

Climate change – a change in global climate patterns that is largely attributed to increased levels of carbon dioxide produced by the use of fossil fuels

Climate change adaptation – initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects

Climate change mitigation – measures designed to decrease the intensity of greenhouse gas emissions that have the potential to affect climate change

Climate modeling – the process of using quantitative methods to simulate interactions of the atmosphere, oceans, land surface, and ice in order to predict future climate patterns and/or future climate dynamics

Coastal buffer – an area along a coastline that is legally protected in order to preserve marine ecology and ecosystems by preventing construction

Combined sewer overflow – the discharge of stormwater and domestic waste that results when sewer capacity is exceeded during heavy storms. The resulting volume of rainwater and sanitary wastewater exceeds the system's capacity and sewage is forced to overflow into area streams and rivers

Constructed wetland – a structure built with natural materials that possess functions of natural wetlands for the purpose of improving the quality of stormwater runoff

Contaminant – A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful effects to humans or the environment

Coping range – the range of variability of a climate variable whose consequences or outputs can be measured in terms of tolerable levels of harm or risk

Downscaling – in regards to climate modeling, downscaling is the process of taking the output from a General Circulation Model (GCM) and applying the data to smaller geographic units for a Regional Climate Model (RCM)

Economic development – a program, group of policies, and/or activity that seeks to improve the well-being and quality of life for a neighborhood or community

Floodplain – a low area of land that is adjacent to a body of water that is subject to flooding; these areas are delineated based on units of 100-year flooding events

Fossil fuel – a nonrenewable, carbon-based, natural fuel, such as coal or gas

Flushing time – the time required to remove a contaminant from a harbor or estuary

General Circulation Model (GCM) – a global, three-dimensional computer model of the climate system, which can be used to simulate the effects of climate change

Geographic Information Systems (GIS) – a computer program that captures, stores, analyzes, manages, and presents pieces of geographically linked data

Green infrastructure – a network of natural and constructed pieces of infrastructure that support native species, maintain natural ecological processes, sustain air and water resources, and contribute to general health and quality of life

Heat wave – a prolonged period of excessively hot weather, often accompanied by high levels of humidity

Impervious surface – impenetrable surfaces, such as stone, asphalt, and concrete, that are used to construct pavements, including parking lots, roads, sidewalks, and buildings

Land use planning – Land use planning is the term used for a branch of public policy which encompasses various disciplines which seek to order and regulate the use of land in an efficient and ethical way, thus preventing land use conflicts

Pocket park – a small park, often built on vacant land parcels in urban settings, which provides green and sitting space

Policy – a set of principles intended to govern actions and behavior

Redundant Transportation Network – A network that provides multiple routes for destinations throughout a city

Regional Circulation Model (RCM) – a model that is similar to a GCM but on a smaller, regional scale

Remote sensing – is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing devices not in intimate contact with the object such as by way of aircraft, spacecraft, satellite, buoy, or ship

Sociodemographic – pertaining to social and demographic factors, such as age, race, and gender

Spatial modeling – analytical procedures applied with GIS which include three categories: geometric models, coincidence models, and adjacency models. All three model categories support operations on geographic data objects such as points, lines, polygons, tins, and grids, and functions are organized in a sequence of steps to derive the desired information for analysis

Stakeholder – a person or organization with direct stakes in an organization or specific decision

Sustainability – an attempt to provide the best outcomes for human and natural environments in the present and future

Urban heat island effect – Warmer air temperatures in cities compared to the surrounding countryside. Cities replace natural land with pavement, sidewalks, and buildings, and as such heat is absorbed and collected causing it to be hotter than in areas where vegetation serves as a natural coolant

Urban planning – the process of creating the future physical arrangement, condition, and activities of a community

Vector borne disease – an infection that is usually transmitted by insects, most notably by mosquitoes and ticks

Vulnerability – the state of being susceptible to climate change impacts based on inherent qualities or characteristics of a location or population

Watershed – an area of land that separates waters flowing into streams, basins, or rivers; an area drained by a body of water

Wetland – a lowland area consisting of marshes and swamps

Wind farm – a group of wind turbines that generate electricity for an area

Appendix B: Budget

Introduction

Due to the recession of the late 2000s, many cities nationwide including Baltimore, Fresno and Milwaukee, are struggling with their finances. Many of the items that we propose in our adaptation section will be a major undertaking, especially given the current economic situation. In order to provide a financial perspective for climate change adaptation we found it beneficial to analyze Baltimore, Fresno, and Milwaukee's most recent budgets and capital improvement plans, and determine whether these three cities have the fiscal capacity to implement climate change adaptation strategies today. However, it is important to remember that economic conditions can change rapidly, thus the current fiscal capacity is not the only indicator for a city's future ability to fund climate change adaption measures.

Baltimore

Baltimore's present-day financial situation is similar to that of many other American cities affected by the recent recession. For the first time since the city's fiscal year (FY) 2005, the City's operating budget declined from the previous year. The city cut $73 million in spending and faces a budget shortfall of $121 million. The budget shortfall includes $54 million in revenue shortfall from FY 2010 due to declining budget tax receipts and highway user revenue, along with a $67 million increase in the costs of maintaining current services, including pensions and retiree care. (1)

Baltimore City's total budget for FY 2011 is $2.936 billion. Of that figure, $2.262 billion is set aside for the operating budget, which is 1.3% lower than the FY 2010 operating budget of $2.291 million. The remaining $673 million, approximately 23% of the total budget, is set aside for the city's capital budget, which in FY 2011 is 3.5% higher than FY 2010's capital budget of $534 million. 47% of the city's total budget has been allocated to the city's general fund. The city's wastewater and water utilities will receive fairly large shares of total capital spending in FY 2011 at 6.1% and 4.6% respectively (1). To finance the $1.383 billion general fund, Baltimore City relies very heavily on property tax. 55.4% of general fund revenues will come from property taxes. The city's 3.2% income tax is the second largest revenue generator, contributing 17.6% of all general fund revenues. (1)

In the first year of the 2011-16 Capital Improvement Plan, the city plans to invest heavily in transportation and water infrastructure. 85.7% of the capital budget going towards wastewater (60.2%), transportation (13.3%), and water (12.2%) (1). Planned wastewater improvements include numerous sewer rehabilitation programs, nutrient removal programs, and sewer replacement projects. The transportation improvements include bridge repairs, highway improvements, and new pedestrian infrastructure development. Planned water improvements include water recycling programs and reservoir improvements (2).

44% of the capital budget is financed by state grants, while 17.5% comes from revenue bonds, and 12.7% from federal grants (1). As we have highlighted, transportation and water are two of the biggest issues in regards to climate change adaptation that Baltimore is facing. Baltimore is spending its capital budget wisely and appears to be capable of accomplishing the goals laid out in the capital improvement plan.

Fresno

Fresno, like many municipalities across California and the country, is grappling with a loss of tax revenue caused by the deep recession of 2008-2010. Fresno entered 2011 with a $30.6 million deficit resulting from a 20% decrease in revenue over the past two years. Fresno relies primarily on a sales tax, property tax, and a motor vehicle license fee for its operating revenue. The FY 2011 budget includes $953 million in total spending (3).

Budget cuts are causing the city to draw down emergency reserve funding to fund basic services, creating a challenging funding environment for adaptation projects in Fresno. These challenges are illustrated best by the recent deterioration of the Fresno Parks and Recreation Department, which was funding reduced by a third since 2009 (4). With 50% less staff in the department, residents can see the grass growing too high, and the pools closed for long periods in the summer. This has lead to political unrest and leadership turnover. The Parks Director resigned when the Assistant Director was laid off, leaving no program management in place at the department. This type of management turnover takes a toll, not only on short term, day-to-day operations, but compromises the organization's ability to do the kind of long term, complex, and participatory planning required for climate change adaptation.

Offices that are critical to adaptation planning are enduring the greatest budget reductions. Public Works, whose budget was reduced 71.55% from last year, includes the city's engineering services and capital project management divisions. The Development and Resource Management Department's budget was also reduced by 63.81%, negatively impacting the Offices of Sustainability; Planning and Land Use Management; Building and Safety Inspection; Development Review; and Code Enforcement (3). Due to these budget cuts there have been a significant reduction in the city's sustainability initiative: "Sustainable Fresno." The initiative's website has a blog and calendar, suggesting that it recognizes the importance of public participation. However, the blog and calendar contain no content, indicating a lack of staff and resources to carry out even basic outreach (5).

Fresno's Capital Improvement Plans are drafted in 5-year increments. The FY 2011-2015 plan outlines $906.5 million in proposed capital spending. The vast majority of projects outlined in the plan are utilities and public works projects (80% of planned capital spending) (3). This implies a focus on building new infrastructure to accommodate new development. This may also reflect preparation for Fresno's participation in the California High Speed Rail Authority's initiative, including the possibility for the location of a regional train maintenance facility that Fresno estimates would deliver a $1 billion annual economic boost to the local economy. (6)

Milwaukee

Milwaukee, like many other cities in the United States, is working hard to recover from the financial crisis of 2008-2010. Due to major operating budget cuts last year, Milwaukee has more fiscal stability, but the City is still working hard to achieve fiscal sustainability. Improved stability allowed for a slight increase in the city's overall budget in FY 2011. However, the majority of the increase covers rising health care costs, not expanded city services. Milwaukee's total FY 2011 budget is $1.47 billion (an increase from $1.44 billion in FY 2010), with the general fund budget constituting $590 million (an increase of 4% from the FY 2010 budget of $567 million). The City's capital improvements plan totals $254.2 million, $117 million of which is transferred from the city general fund. The rest of the capital improvements plan is funded from grants and special revenue funds. (7)

To improve the city's immediate fiscal future, Milwaukee took several steps that included the reduction of $31M in operating budget expenses in order to meet 2011 budget obligations. Milwaukee made strong investments in 2009 to the Employee Retirement System funds, which prevented additional debt to meet future obligations. In addition, the city utilized the American Recovery and Reinvestment Act to obtain tens of millions of dollars of funding for core infrastructure improvements. Despite recent improvements, Milwaukee faces significant fiscal stability challenges, which are related to prior commitments to which they are legal bound, and other commitments, which they have no control over. (7)

One of the barriers to achieving fiscal sustainability in Milwaukee is the large percentage of the city's $247 million tax levy required to be allocated towards non-discretionary expenses. In 2010, 65% were allocated towards non-discretionary expenses and by 2013 this is expected to rise to 76%. This will greatly inhibit future budget flexibility. (7)

The Milwaukee budget emphasizes the importance of infrastructure, in protecting the public health and the environment, and to stimulating the economy. The budget commits $8.8 million to a major renovation of the city's sewer system. This money will be used to fix parts of the system that experience sewage backup. In addition, many of the city's departments focus on sustainable objectives in their budget requests. Some of the departmental objectives and strategies listed in the budget documents include increasing energy efficiency and promoting renewable energy, improving surface water quality and decreasing pollutants in runoff, incorporating green infrastructure, updating the flood plan, improving aging infrastructure, and reducing solid waste by 40%. (7)

Milwaukee's current capital improvement plan covers 2009 to 2014. The plan focuses on surface transportation, environment, health and public safety, economic development, culture and recreation, and general government sectors. Environmental projects are slated to receive the most funding, totaling more than one-third of the 2009-2014 capital improvements budget. These environmental projects will work on reducing pollution, protecting human health, and maintain cleanliness through improvements to sanitation, forestry, and the sewer and water systems. The second largest area of funding is surface transportation, which involves improvements to streets, alleys, bridges, and parking structures. A smaller portion (3.6%) of capital funds will support health and public safety projects, including facility improvements and equipment replacement. The aforementioned objectives and strategies show that Milwaukee is attempting to be pro-active about improving their infrastructure and other public works, and suggest that they are supporting departments that will be important to climate change adaptation planning efforts. (8)

Appendix C: Vulnerability Methods

Introduction

As Baltimore, Fresno, and Milwaukee prepare for the forthcoming impacts of climate change, certain areas of these cities are going to be more impacted than others. We calculated socioeconomic indices based on previously conducted studies in order to determine the most vulnerable populations in regards to sea level rise in Baltimore, urban heat island effect in Fresno, and flooding in Milwaukee. This appendix discusses our methodology for the vulnerability mapping sections for each city.

Baltimore

To calculate the Socioeconomic Disadvantage Status Index (SES) for Baltimore, we used a methodology from the Rand Health Center - Center for Population Health and Health Disparities. There are six individual demographic and economic variables included in the integrated index calculation. The six variables are:

1. Percent of adults older than age 25 with less than a high school education
2. Percent of males who are unemployed
3. Percent of households with income below the poverty line
4. Percent of households receiving public assistance
5. Percent of households with children that are headed by a female
6. Median household income

All the demographic data for the specific variables were downloaded from the Social Explorer, Census 2000 Summary File 3 (59), and were later joined with the census tract boundaries downloaded from the US Census Bureau, 2009 TIGER/Line Shapefiles (60). The census table sheets from which each variable was calculated are:

1. SF3 T40 Educational Attainment for Population older than 25 years
2. SF3 T74 Employment/Unemployment Status for Civilian Male Population
3. SF3 P92 Poverty Status in 1999 of Household by Household Type by Age of Householder
4. SF3 P64 Public Assistance Income in 1999 for Households
5. SF3 P10 Household Size by Household Type by Presence of Own Children Under 18 Years Old
6. SF3 P53 Median Household Income in 1999 (Dollars)

Discussion of Variables: Baltimore and Fresno

Some populations are more vulnerable to climate change impacts because they do not have the resources to cope with extreme events. Common demographic characteristics of these types of population are poverty and low income, age, lower educational attainment, race, linguistic isolation, university students, and female-headed households (122 pp. 242-261). This section includes a description of the variables used by both the Baltimore and Fresno vulnerability analysis as each of the variables applies to the Fresno area. These traits are common among large portions of Fresno's population, but are unevenly distributed across the county. Over the long term, the impact of both climate change and he decreasing availability of vital natural resources (such as clean air to breathe and water to drink) will continue to disproportionately burden these populations because they have a lower ability to respond and cope with such changes (123). A detailed spatial distribution of each variable in Fresno County is presented as below:

The first variable, percentage of population older than 25 with less than a high school education, which studies have indicated as a proxy of lower capacity to adapt to extreme events, has a high value in the five rural western tracts and in several neighborhoods to the south of the urban core. In some studies, lower educational attainment correlates with lower adaptive capacity to deal with extreme events. Possible connections between education and the ability to deal with disasters and change include lower wage- and salary-earning capacity, and thus lower income; a lower capacity to obtain and understand emergency preparedness and response information, lack of access to health care, and various types of insurance (e.g., fire, flood, and health insurance), some degree of disenfranchisement from society, and so on. People with less education require a higher level of attention and assistance from public agencies than those with greater resources of their own (124).

High unemployment rates and income inequality are persistent and growing problems in urban areas. Part of the reason for high poverty in the county is the high proportion of low-wage workers. For example, agricultural production often depends on seasonal, low-wage workers who work during the growing season and collect unemployment during the off-season (124).

Lower income often correlates with lower access to the resources necessary to prepare for or evacuate during an emergency, or to take the actions required to adapt to changing conditions (e.g., insulating one's house, elevating one's house above a given flood elevation) (124).

The percentage of households receiving public assistance variable shows a similar pattern to that of the percentage of households below the poverty line variable. As we might expect, many neighborhoods with a high percentage of households below the poverty line also have a high percentage of households receiving public assistance.

Women can have a more difficult time during recovery than men, often due to sector-specific employment, lower wages, and family care responsibilities. This variable represents the incidence of single-mother-headed households, one of the most at-risk social groups.

The growing disparity between income brackets has the potential to create social friction and isolation of social groups from each other, undermining the sense of community and mutual support that is needed to meet the challenges posed by changes in climate. Extreme poverty and low levels of wealth undermine the ability of families and communities to act proactively, and causes dependence on outside sources of governmental aid when disasters strike. Thus, low income is one of the most important indicators of limited adaptive capacity, and can be addressed through special needs-related programs or by creating opportunities for low income populations to make a better living (124). Although not a component of our index, housing ownership also tends to be a factor in adaptive capacity. It indicates how much control an occupant has over their living conditions For example, ownership dictates if an individual has the option to make structural adjustments to their home for flood protection or insulation from heat, or whether they are able to modify vegetation surrounding the house (124).

The following process was used to calculate determine vulnerability within the county of Fresno (118):

1. Compute Annual Fresno Means and Standard Deviations

    a) Using the census tract data, the mean and standard deviation were calculated across all tracts, creating a Fresno mean and standard deviation

2. Calculate Z-scores and Un-normalized measures

    a) For each census tract, a z-score was derived for each variable by subtracting from it the US mean and dividing that number by the U.S. standard deviation for each variable. The un-normalized index was calculated by taking the z-score for the median household income variable and subtracting from it the z-scores for each of the other five variables. Thus, for census tract j, the un-normalized index UNINDX(j) = Z6-Z1-Z2-Z3-Z4-Z5. If any of the six selected census measures had a missing value, the un-normalized index was also classified by a missing value.

3. Compute the Normalized Measures

    a) Using the maximum and minimum value of UNINDX, the index measures were rescaled such that the values would fall between 0 and 100.

Milwaukee: Social Vulnerability Index Method

All of the demographic data used for this study was downloaded from the census website. The following census data tables from the SF3 dataset were used:

1. P3 Population
2. P6 Race
3. P8 Sex by age
4. H1 Housing units
5. H 70 Median gross rent as a percentage of household income
6. H 85 Median value for all owner occupied housing units

Discussion of Variables: Milwaukee

Race and Ethnicity

Differences in race and ethnicity increase language and cultural barriers that affect access to post-disaster funding and residential locations in high hazard areas.
Sources: Pulido (2000), Peacock, Morrow, and Gladwin (1997, 2000), Bolin with Stanford (1998), and Bolin (1993) as cited by Boruff, Cutter, and Shirley (2003).

Gender (Female)

Women can have a more difficult time during recovery than men, often due to sector-specific employment, lower wages, and family care responsibilities.
Sources: Blaikie et al. (1994), Enarson and Morrow (1998), Enarson and Scanlon (1999), Morrow and Phillips (1999), Fothergill (1996), Peacock, Morrow, and Gladwin (1997, 2000), Hewitt (1997), and Cutter (1996) as cited by Boruff, Cutter, and Shirley (2003).

Age

Extreme of the age spectrum affect the movement out of harm's way. Parents lose time and money caring for children when daycare facilities are affected; elderly may have mobility constraints or mobility concerns increasing the burden of care and lack of resilience.
Sources: Cutter, Mitchell, and Scott (2000), O'Brien and Mileti (1992), Hewitt (1997), and Ngo (2001) as cited by Boruff, Cutter, and Shirley (2003).

Value

Addresses as areas ability to absorb losses and enhance resilience to hazard impacts. Wealth enables communities to absorb and recover from losses more quickly do to insurance, social safety nets, and entitlement programs.
Sources: Cutter, Mitchell, and Scott (2000), Burton, Kates, and White (1993), Blaikie et al. (1994), Peacock, Morrow, and Gladwin (1997, 2000), Hewitt (1997), Puente (1999), and Platt (1999), Heinz Center for Science, Economics, and the Environment (2000), and Marrow (1999) as cited by Boruff, Cutter, and Shirley (2003).

Density

The original method called for the use of housing units as a proxy for a storm event to cause damage to the largest amount of property in the smallest area. However, when working with small geographies such as census tracts there may be a small number of housing units despite the fact that there is a large population present. Thus population density was a better proxy of this measure for small geographies.

Social Vulnerability Index Calculation

The vulnerability index for female, non-white, under 18 and over 65 population, and population density was calculated using the following method. First the percentage (X) of each variable that falls within each census block group was calculated where (a) is the number of individuals in a census block group and (b) is the total number of individuals in the study area.

For example, if a census block group has a female population of 500 (a) of a total female population of 10,000 (b) within the study area the X value is calculated as 500/10000. The social vulnerability (SV) for each variable is then determined by dividing each the X value by the X value of the census block group with the largest X value or Xmax.

This provides a 0-1 value for each characteristic where 0 is the lowest vulnerability where none of that population characteristic occurs in the census block group and 1 is the census block group that has the maximum number of that population characteristic in the study area. The census block group with 500 females has an X value of 0.05. The highest female population of any census block group is 600 with an X value of 0.06. Thus the 0-1 vulnerability index for female population in that census block group is 0.05/0.06 or 0.83. This value not only orders each census block from containing the smallest amount of each variable to the most of each variable, but also shows the magnitude of difference between each census block (4).

The housing value/rent vulnerability consists of an aggregation of both housing value and median rent as a proportion of income and is then weighted by the proportion of rental and owner occupied units in each census block group. The rent vulnerability index is calculated using the same formula as the other variables, however the housing value is calculated differently. First the difference between the study area median housing value (c) is calculated and is subtracted from the census block group median housing value (d)

$$A = c-d$$

The absolute value of A is taken to find the difference between the block group's median value and the study area's median value. The block group whose value has the largest difference from the median is then added to every block groups median value to create the B value.

The B value for each census block group is then divided by the largest B value in the study area to give the 0-1 vulnerability index value.

In order to correctly weight the housing value and the median rent proportion correctly, the percentage of both renter and owner occupied units.

The both the housing value and rent vulnerability indices are multiplied by their respective R and H values to reflect the proportion of the housing stock in each census block group. The SV for each of the variables is then added to create the overall social vulnerability index for the entire study area.

To assess the potential for these vulnerable populations to be impacted by river flooding FEMA flood zone data were overlaid onto the vulnerability index. For this analysis all flood ways under 500 years were used in order to assess the maximum effect a flood could have in any flood zone within the city. While areas of dense social vulnerability generally do not coincide with flood zones in Milwaukee, there are some notable cases where there has been documented surface flooding outside of flood zones within areas of high vulnerability which were discussed within the document.

Baltimore Climate Threat Analysis

A report of the Adaptation and Response Working Group of the Maryland Commission on Climate Change (MCCC), states that slope is the primary variable controlling the magnitude and range of sea-level rise impacts over time (6 p. 5). Thus, we simulated sea level rise by reclassifying the Digital Elevation Model (DEM) of Baltimore (from the National Elevation Dataset (7)) into 1/3 arc second. Measurement of sea level at any particular location is relative. Relative sea level rise is the sum of global (eustatic) sea level change, plus changes in vertical land movement at a particular location. The MCCC Scientific and Technical Working Group (STWG) determined that Maryland can conservatively expect to experience a relative sea-level rise of 2.7 to 3.4 feet by the end of this century (6 p. 4). As a coastal city, Baltimore is also vulnerable to coastal flood events and inundation from storm surges. These and the impact are predicted to become more severe as sea-levels rise. In order to model the impacts of severe coastal inundation, we also created scenarios of 5 foot and 10 foot sea-level rise.

Fresno Climate Threat Analysis

We used the Normalized Difference Vegetation Index (NDVI) from a Landsat TM imagery band 3, band 4, as well as used the thermal band (band 6) as a supplemental layer to assess the heat "hotspots" in Fresno. The NDVI is a normalized index related to the amount of vegetation and distinguishes between soil or water and vegetation based on mathematical combination of spectral bands to accentuate the spectral properties of green plants (8). For Landsat imageries, NDVI is usually calculated as (NIR-Red)/ (NIR +Red), NIR is the near infrared band, which is Band 4 in Landsat TM, and Red is Band 3. High NDVI pixel values usually mean green vegetation, whereas negative or near zero values mean water, rock or bare soil (8). The Landsat TM scene was downloaded from the Earth Resources Observation and Science Center (EROS), US Geological Survey (USGS). The imagery was taken on July 31st, 2010, path 42 row 35. An atmospheric correction was conducted for both the near-infrared and the visible bands, using the Chavez (1996) COST method to remove the influence of path radiance to arrive at standardized and calibrated actual Earth surface reflectance (9). However, this method doesn't apply to the thermal band because it was left uncorrected and can only be used as a supplemental layer to help identify the "hotspot". The zonal statistics from Spatial Analyst Toolbox in was used to compute the mean NDVI values for each census tract, and the mean Digital Number (DN) values of each tract in the thermal band layer, to assess the average vegetation coverage and relative summer temperature level in the county's neighborhoods. Finally, the demographics, the Landsat images were overlaid with aerial photographs from the online base map services provided by the ESRI Maps and Data group (10) to assess Fresno's vulnerability to extreme heat threats.

Appendix D: Adaptation

Figure 126: Green Roof in Vancouver, Canada

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Develop or update Water Resource Management Plans	Drought	Water Resource Management Plans identify projected supply and demand of water, thus helping outline methods of providing sufficient water given climate impacts	Water	Process	London Adaptation Plan (2010)
Improving water efficiency	Drought	Water efficiency can be promoted through water metering, higher water efficiency standards for new development, retrofitting of existing homes, and education of the public over consumer behavior	Water Energy	Process Physical Behavioral	London Adaptation Plan (2010)
Approved use of reclaimed water for non-potable uses	Drought	A significant amount of wastewater is currently under utilized; encouraging use of reclaimed water reduces pressure on water supply	Water Human Health	Process Physical	London Adaptation Plan (2010)
Reduce the loss of water through better leakage management	Drought	Water leakage amounts to a significant portion of the total water supply, estimates in London state up to 25 percent, which if captured increase the resilience of the water supply system in meeting increased demand	Water	Process	London Adaptation Plan (2010)
Increase reservoir capacity	Drought	Increased water storage through reservoir expansion, while useful in capturing large volumes of rainfall and runoff, is expensive and requires vast areas of land	Water Land Use	Physical	London Adaptation Plan (2010)
Maintenance of defensible space around structure	Drought Wildfire	Utilizing basic maintenance and natural landscaping, property owners can establish a barrier to the risk of wildfires	Land Use Water	Physical	Bedsworth (2008) Preparing California for a Changing Climate
Establish an Integrated Fire Management Plan (IFMP)	Drought Heat	An IFMP encourages collaboration between agencies, ensures consistency of fire management practices and standards, and helps establish adequate funding	Human Health Water Land Use Transportation	Process	Climate Change in the Western Port Region (Victoria 2008)
Increase surface water storage system	Drought Flooding	A surface water storage system will help ensure access to freshwater supplies during extended droughts and help manage increased stormwater	Water Human Health Land Use	Physical	Adapting California's Water Management (2008)
Implement a coordinated network of information technology solutions to assist wildfire response	Drought Heat	Encourages information sharing and the coordination of responses to wildfires	Human Health Water Land Use Transportation	Process	Climate Change in the Western Port Region (Victoria 2008)

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Support R&D of agricultural adaptation strategies that simultaneously manage on-farm GHG emissions and adaptation concerns	Drought Heat Precipitation	Research initiatives are essential to the long run development and implementation of informed and responsive adaptation strategies	Land Use Water Energy Human Health	Knowledge Process	New York State Climate Action Plan (New York 2010)
Regional flood risk appraisal	Flooding	Identification of regional structures and systems at risk of flood damage useful in developing recommendations to improve resilience	Land Use Water	Knowledge	London Adaptation Plan (2010)
Flood Response Strategic Plan	Flooding	Ensure a coordinated response among departments and services in protecting life and wellbeing, as well as reducing damage to environment and property	Land Use Water Transportation	Process	London Adaptation Plan (2010)
Implementing extreme weather warning services (flood, heat, storm surge, etc.)	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Advanced warning allows for planning and preparation of the public and vulnerable populations. Incorporation of new technologies, including text messages, emails, or phone messages, provide broader communication	Energy Human Health Land Use Transportation Water	Process	London Adaptation Plan (2010)
Collaborate with local health department and organizations to perform a city-specific assessment of the impacts and opportunities of climate change on health services	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	A collaborative effort in identifying potential heat vulnerability will increase efficiency in addressing impacts and coordinating a response	Human Health Transportation	Process	London Adaptation Plan (2010)
Implementation of a "Green Grid" for East London	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Creation of a network of interlinked, multi-purpose open spaces, support citizen access to openspace, help store water, and cool the vicinity	Energy Human Health Land Use Transportation Water	Physical	London Adaptation Plan (2010)
Collaborate with the insurance sector on establishing building regulations requiring incorporation of climate resilient elements when structures are rebuilt or renovated	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	The insurance sector has the ability to provide distinct incentives to incorporate adaptation	Land Use Water Energy	Process Knowledge	London Adaptation Plan (2010)

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Assess energy distribution infrastructure and update as necessary to ensure resiliency to climate change	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	The current energy infrastructure is vulnerable to climate impacts of heat and flooding. Updating infrastructure capacity will increase the resiliency of the energy system to climate impacts	Energy	Process	London Adaptation Plan (2010)
Community education programs to inform the public and relevant agencies about climate risk and vulnerability to coastal zones, infrastructure, buildings, human health, and surrounding ecosystems	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Community education is an essential element of comprehensive adaptation planning strategies. Adjusting individual behavior can provide significant returns in addressing climate impacts	Energy Human Health Land Use Transportation Water	Behavior Process	Climate Change in the Western Port Region (Victoria 2008)
Develop an interagency mechanism to regularly evaluate climate change science, set research priorities, coordinate regulatory and funding actions, and assess progress	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	A collaborative approach to assessing climate impacts and identifying appropriate responses results in a comprehensive response to climate change	Energy Human Health Land Use Transportation Water	Knowledge Process	New York State Climate Action Plan (New York 2010)
Determine how existing telecommunications technology and social networking systems can be better integrated into early warning and evacuation systems	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Telecommunications has become a primary system to the functioning of urban societies. Considerations should focus on how technology should be protected and integrated into adaptation responses	Energy Human Health Land Use Transportation Water	Knowledge	New York State Climate Action Plan (New York 2010)
Increase the resilience of communities by providing additional support for responsible development concepts, such as smart growth, compact development, and green infrastructure	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Responsible development concepts support adaptation by limiting the effects of stormwater runoff and urban heat island effects, as well as the reducing release of GHG emissions	Energy Human Health Land Use Transportation Water	Process Physical	New York State Climate Action Plan (New York 2010)

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Agencies and authorities, including municipalities, with jurisdiction over communication infrastructure, should prepare detailed inventories of telecommunications facilities, networks, and corridors	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Given our reliance on telecommunication systems, assessment of communication infrastructure is essential to a comprehensive adaptation plan	Energy Human Health Land Use Transportation Water	Process	New York State Climate Action Plan (New York 2010)
Direct funding to adaptation of critical transportation routes used for emergency preparedness and response at greatest risk from climate impacts	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Addressing emergency preparedness is important in responding to extreme climate events and limiting the magnitude of the impacts	Transportation Human Health	Process	New York State Climate Action Plan (New York 2010)
Create a climate change and insurance commission to evaluate the insurance ramifications of climate change risks, and develop a plan in response	Flooding Heat Precipitation Sea-level rise Storm surge Wildfire	Insurance programs have the ability to provide significant incentives in adapting to climate change. Analysis of existing insurance programs and processes will highlight areas for improvement and collaboration	Energy Human Health Land Use Transportation Water	Process Knowledge	Maryland Climate Change Commission Policy (2010)
Integrate climate change projections into flood and surface water management plans	Flooding Precipitation	Updating existing flood and stormwater management plans allows for more accurate information regarding future impacts, as well as potential opportunities for collaboration with bordering jurisdictions	Water Land Use	Knowledge Process	London Adaptation Plan (2010); Climate Change in the Western Port Region (Victoria 2008)
Flood Storage Areas	Flooding Sea-level rise Precipitation	Designing areas to deliberately manage flood impacts minimizes the impact on more vulnerable land uses. Identifying storage areas should focus on existing or future planned open space	Water Land Use	Physical	London Adaptation Plan (2010)
Undertake a feasibility study, including implementation of a network of weather stations	Heat	Better monitoring results in 1) better data to refine climate projections, 2) provides a warning system for extreme heat events, and 3) identifies the most heat vulnerable neighborhoods	Energy Human Health Land Use Transportation Water	Knowledge Process	London Adaptation Plan (2010)

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Adjust building codes and develop design guidelines to increase thermal efficiency and reduce demand for mechanical cooling	Heat	Updating building codes to set a higher minimum thermal efficiency standard can address effects on both energy demand and human health from heat events	Land Use Energy Human Health	Physical Process	London Adaptation Plan (2010)
Local passive cooling demonstration project of how to retrofit a social housing development to reduce risk of overheating	Heat	Demonstrating the costs and benefits of passive cooling techniques will educate the building industry, government agencies, and the public, and help incorporate the techniques into standard building practice	Land Use Energy Human Health	Physical Behavioral	London Adaptation Plan (2010)
Review of existing emergency response plans (flood or other) to establish an appropriate response to heatwaves	Heat	Using existing response plans as examples will promote efficiency in outlining new emergency response plans for extreme heat events	Energy Human Health Land Use Transportation Water	Knowledge Process	London Adaptation Plan (2010); Climate Change in the Western Port Region (Victoria 2008)
Require air conditioning and passive cooling techniques (white roofs, operable windows, etc.) in all public transit modes	Heat	Heat can have a significant impact on individuals within various public transit modes, increasing the impact on vulnerable populations	Human Health Transportation	Physical	London Adaptation Plan (2010)
Assess the adequacy of existing heat-warning systems and expand the capacity of existing cooling-center programs	Heat	Assessment of existing systems, and updating as necessary, is important not only at the onset of adaptation planning, but continuously over time	Human Health	Knowledge Process	New York State Climate Action Plan (New York 2010)
Enhance existing education and outreach activities, employing multilingual approaches and appropriate media to increase awareness of the public health consequences of heat	Heat	Education of the public is an important element of any climate adaptation plan. Community input often provides information on the benefits of comprehensive adaptation planning and encouraging adjustment in behavior in support of adaptation efforts	Human Health	Behavioral	New York State Climate Action Plan (New York 2010)
Increase greenspace, vegetation, and tree cover	Heat Precipitation	Increased greenspace reduces the amount of impervious surface, thus reducing the effects of urban heat island effects and stormwater runoff	Land Use	Physical	London Adaptation Plan (2010)

Adaptation Strategy	Climate Threat(s)	Benefits	Sector(s) Impacted	Strategy Category	Resources
Encourage implementation of new green roofs	Heat Precipitation	Green roofs operate in a similar manner to increased greenspace, with an added benefit of increasing the thermal efficiency of buildings	Land Use Energy	Physical	London Adaptation Plan (2010)
Enahance ecosystem services through habitat restoration	Precipitation Heat Flooding	Ecosystem services of habitat restoration and increased greenspace reduce flood risk, offset the effects of urban heat island, reduce energy demand, and support biodiversity	Energy Human Health Land Use Transportation Water	Physical	London Adaptation Plan (2010)
Beaches and foreshore areas should be rated and prioritized for protection	Sea-level rise	Prioritizing areas for protection will allow for the efficient allocation of time and resources to the most vulnerable locations	Energy Human Health Land Use Transportation Water	Knowledge Process	Climate Change in the Western Port Region (Victoria 2008)
Perform detailed coastal modeling to identify areas most vulnerable to sea-level rise, storm surge, and inundation	Sea-level rise	Modeling of vulnerable areas is a fundamental tool essential in prioritizing adapation responses	Energy Human Health Land Use Transportation Water	Knowledge	Climate Change in the Western Port Region (Victoria 2008)
Integrate sea level rise and flood-recurrence interval projections into all relevant agency programs and regulatory, permitting, planning, and funding decisions	Sea-level rise	Integration of climate projections into current and future planning efforts will allow for sector-specific organizations to begin addressing climate change impacts	Land Use Water Human Health	Process Knowledge	New York State Climate Action Plan (New York 2010)
Implementation of barriers to protect against high water levels	Sea-level rise Flood	Infrastructure in the form of physical barriers can provide additional protection in vulnerable areas to the effects of sea-level rise, storm surge, and flooding	Land Use Water Transportation	Physical	Climate Change in the Western Port Region (Victoria 2008)
Require stricter coastal building and zoning codes	Storm surge Sea-level rise	Bulding code should be updated to account for climate impacts of wind, storm surge, and sea-level rise, particularly in hurricane and extreme wind prone coastal areas	Land Use	Physical	Hurricane Ike: Nature's Force vs. Structural Strength (2009)

Photo Citations

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	Figure 7 – Baltimore county and city context	Kristin Baja
	Table 1 – projected climate change for Baltimore	Generated and designed by Peter Sotherland and Kristin Baja
Fresno	Sierra Nevada	Tragerwaterreport files
	Fig 8 - Flood 1969	Fresno Metropolitan Flood Control District
	Fig 9 - Flood 1958	Fresno Metropolitan Flood Control District
	Fig10 – Dowtown Fresno Surface parking Fresno	Kristin Baja (Feb, 2011)
	Lightning	Newnaturewallpaper.com
	Figure 11 – Fresno County and City Contect	Krisitn Baja
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Milwaukee	Lake Michigan sunrise	Jbdeham (flickr)

	Figure 12: Heatwave with hydrant	Liz Kasameyer (flickr)
	Figure 13: Heatwave Milwaukee	Photoblogstateman.com
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	Figures 33-41: Vulnerability GIS maps	Kailai Zhang
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	Figure 42-45: Sea level rise maps	Kailai Zhang, Lani Leuthvilay
	Figure 46-49: Sea level rise	Kailai Zhang, Lani Leuthvilay
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