PLANNING FOR COASTAL AND CLIMATE TRENDS

THE IMPORTANCE OF PLANNING IN COASTAL COMMUNITIES

It is no secret that the Great Lakes are one of the most unique and precious environmental systems in the world. In fact, “the Great Lakes basin contains more than 20% of the world’s surface freshwater supplies and supports a population of more than 30 million people.”¹ Michigan is home to nearly 3,300 miles of Great Lakes shoreline, along with 36,000 miles of rivers and streams, and 11,000 inland lakes.²

Yet in general, riparian land (land adjacent to a water body) throughout Michigan is not adequately protected from development pressures.³ Coastal communities have an especially important role to play in protecting the Great Lakes. In 2001, the Michigan Department of Environmental Quality (DEQ) acknowledged “fragmentation of coastal habitats, loss of agricultural and forest lands, increased impervious surfaces and resulting stormwater runoff, and the increased development in coastal hazard areas, wetlands, and Great Lakes Islands, could be improved through better coastal land-use planning.”⁴

Planning for coastal areas at the local level requires knowledge of both local conditions and state and federal regulations. This chapter aims to address these needs for Emmet County and provide the basis for clear, well-founded recommendations for future land-use planning.

OVERVIEW OF COASTAL DYNAMICS AND THE GREAT LAKES

The Great Lakes function differently than other inland water bodies and tidal oceans. Understanding these dynamics can help Emmet County plan for naturally occurring changes along the shoreline.

Changing Water Levels of the Great Lakes

Great Lakes water level changes result not from the moon’s gravitational pull, but from cyclical changes in rainfall, evaporation, and river and groundwater inflows.⁵ These factors work together to raise and lower the water levels of the Great Lakes in small increments daily,

⁴ Ibid
and larger increments seasonally and over the course of years and decades. Long-term water levels fluctuate by multiple feet.

Figure 1 illustrates the water level of Lake Michigan from 1918 to 2019 (Lake Michigan and Lake Huron are technically considered one lake). However, under certain climate conditions, water levels can dramatically fluctuate over short periods of time. For example, following the extreme winters of 2014 and 2015, water levels in Lake Michigan rose between three to four feet from an all-time low (576 feet) set just a year earlier.

**Figure 1. Lake Michigan-Huron Water Level Changes, 1918 – 2019**

The Great Lakes are in a period of rising lake levels (see Figure 2). Since the early 2000s, water levels had remained low, but historical patterns over the last century indicated that higher water levels were sure to return. In May of 2019, Lake Michigan’s water level rose an astounding 9-inches. Lake Michigan’s water level on June 5, 2019 was 581.61 ft, which was just .19 inches away from the all-time record mark set in 1986.

According to a recent U.S. Army Corps of Engineers summary, based on current conditions, Lake Michigan is expected to continue its seasonal rise and peak in July. From July through September, monthly mean water

---


7 [http://www.lre.usace.army.mil](http://www.lre.usace.army.mil)
levels are forecasted to be less than an inch to 2 inches below the record high water levels, while in October, and November monthly mean levels are forecasted to be 8 to 10 inches below record high levels.8 (see Figure 3).

It is important to note that changes in water levels are not solely responsible for the movement of the shoreline landward and lakeward over time. The velocity and height of waves, erosion of shorelines, and the pace of fluctuating water levels also contribute to coastal dynamics on the Great Lakes.

Wave Energy and Height
The Great Lakes experience high-energy waves and wave setup along the coastline. High-energy waves are high in speed and strong in intensity and are primarily created as fast winds move across the surface of the water for extended distances.9 “Wave setup” is the height of the water as waves reach the shore. High wave setup results as regional storms create high winds on the Great Lakes.10 Powerful and tall waves can quicken the rate of erosion and damage structures near the shoreline.11

In Emmet County, the prevailing winds are predominantly from the west and north.

---

8 http://www.lre.usace.army.mil
11 Ibid.
Erosion
The shorelines of Lake Michigan are mostly made of gravel and sands that easily erode during times of high-energy waves. Coastal erosion can cause flooding and damage infrastructure along bluffs and beaches. Erosion is caused mainly by storms and winds, and is exacerbated when lake levels are high.

Quickly Changing Conditions
The Great Lakes are contained in gradually shifting and tilting basins. This tilting results as the Earth slowly decompresses and rebounds from the immense weight of the glaciers that created the Great Lakes. This shifting causes water levels to change more quickly in some places than others, because the shape of the water basin varies along the coast. This attribute of the Great Lakes makes it difficult to predict the pace of shoreline movement. Therefore, it is safest to plan for great variability and rapid change in water levels.

CLIMATE CHANGE AND THE GREAT LAKES
Powerful waves, erosion, and changing shorelines on the Great Lakes have been well-documented throughout history, and each has implications for planning efforts along the coast. Climate change exacerbates these natural processes and requires preemptive planning in coastal communities. This section will discuss climatologist predictions of increased precipitation and storminess in the Great Lakes region, variable lake water levels, and rising water temperatures. First, it is important to understand the global context of climate disruption.

Global Changes in Climate
Climate and weather are directly related, but not the same thing. Weather refers to the day-to-day conditions in a particular place, like sunny or rainy, hot or cold. Climate refers to the long-term patterns of weather over large areas. When scientists speak of global climate change, they are referring to changes in the generalized, regional patterns of weather over months, years and decades. Climate change is the ongoing change in a region’s general weather characteristics or averages. In the long term, a changing climate will have more substantial effects on the Great Lakes than individual weather events.

Evidence collected over the last century shows a trend toward warmer global temperatures, higher sea levels, and less snow cover in the Northern Hemisphere. Scientists from many fields have observed and documented significant changes in the Earth’s climate. Warming of the climate system is unequivocal and is now expressed in higher air and ocean temperatures, rising sea levels, and melting ice.

---

12 Ibid.
16 Ibid.
18 Ibid.
To help predict what the climate will be in the future, scientists use computer models of the Earth to predict large-scale changes in climate. These General Circulation Models (GCMs) have been improved and verified in recent years, resulting in relatively reliable predictions for climate changes over large regions.\(^\text{19}\) Scientists downscale these techniques to predict climate change for smaller regions.

**Climate Change on the Great Lakes**

The Great Lakes Integrated Sciences and Assessments Program (GLISA) is a consortium of scientists and educators from the University of Michigan and Michigan State University that provides climate models for the Great Lakes region in support of community planning efforts like this Master Plan. Figure 4 illustrates the historical and predicted climate changes from GLISA for the Great Lakes region. According to GLISA, the Great Lakes region experienced a 2.3° Fahrenheit increase in average air temperatures from 1951 to 2017.\(^\text{20}\) An additional increase of 3° to 6° F in average air temperatures is projected by 2050. Although these numbers appear relatively small, they are driving very dramatic changes in Michigan’s climate and greatly impact the Great Lakes.

The National Climate Assessment for 2009 included a number of illustrations to help us understand the extent and character of anticipated climate change impacts.\(^\text{21}\) One of these illustrations, Figure 5, shows Michigan under several emissions scenarios, each leading to changes in Michigan’s climate. Just by maintaining current emission levels, Michigan’s climate will feel more like present-day Arkansas or Oklahoma by the end of the century.\(^\text{22}\)

**Increased Precipitation and Storminess**

There is strong consensus among climate experts that storms greater in number and intensity will occur in the Great Lakes region as a result of climate change.\(^\text{23}\) This is already happening as “the amount of precipitation falling in the heaviest 1% of storms increased by 35% in the Midwest from 1951 to 2017.”\(^\text{24}\) As storms drop more precipitation and generate stronger sustained winds, the Great Lakes will see stronger and higher waves. In addition to direct damage caused by storms, sustained increases in the number of storms and

---

\(^\text{19}\) Intergovernmental Panel on Climate Change (2013). What is a GCM? Web. Access July 2015


\(^\text{22}\) Ibid.


\(^\text{24}\) Ibid.
their intensity can both directly and indirectly pollute waters by overloading sewage and stormwater capabilities. Increases in the intensity of storms also quickens the pace of erosion on Great Lakes shorelines. In fact, the Federal Emergency Management Agency (FEMA) projects approximately 28% of structures within 500 feet of a Great Lake shoreline are susceptible to erosion by 2060.

### Variability of Lake Water Levels

The natural ups and downs in the water levels of Lake Michigan will continue regardless of the impacts of climate change. However, climate change is likely to augment this natural process, resulting in more variable water levels as warmer air temperatures result in fewer days of ice cover and faster evaporation. In other words, lake levels will rise and fall faster and with less predictability than in the past. Fortunately, much of Michigan’s coastal infrastructure was built in previous decades during times of high water levels. However, fast-rising waters can erode shorelines, damage infrastructure, and cause extensive flooding in inland rivers. When lake levels fall, access to infrastructure like docks may be restricted and navigation hazards in shallow waters may be exposed. Low lake levels pose a threat to coastal vegetation and can reduce the pumping efficiency of drinking water intake pipes. Additional ramifications of changing lake levels include a drop in water supply, restricted fish habitats, more invasive

---

30 Ibid.
31 Ibid.
32 Ibid.
Defining Vulnerability in Emmet County

species,34 faster erosion, and an overall decline in beach health.35 Climate change is likely to augment the natural highs and lows of lake levels, causing more variability and a faster rate of change, making each of these potential ramifications both more likely and less predictable.

**Water Temperature**

Climatologists predict there will be fewer days below freezing in Michigan and other Great Lakes states. As temperatures remain warm for a greater part of the year, the winter season will shorten and the lake ice cover that accompanies winter weather will decline. In general, annual average ice cover on the Great Lakes underwent a shift from higher amounts prior to the 1990s to lower amounts in recent decades. However, there remains strong year-to-year variability, and high ice years are still possible.36 Figure 6 illustrates the variability in ice coverage in the Great Lakes between 1973 and 2019.

Lake ice cover allows heat radiation from the sun to be reflected, so when ice declines, the surface water temperature will increase as more heat is absorbed by the water. In the Great Lakes, average summer lake surface temperatures have been increasing faster than the surrounding air temperatures, with Lake Superior surface temperatures increasing by 4.5°F between 1979 and 2006.37

The associated impacts of rising water temperatures include changes to where fish and other aquatic animals can live, increased vulnerability to invasive species, and increased risk of algae blooms.38 Rising water temperatures also enable winds to travel faster across the surface of the lake, increasing the vulnerability of coastal communities to damaging waves as storms and winds increase.39 Lastly, ice cover protects the shoreline during winter storms. With less ice cover, the shoreline is more susceptible to erosion and habitat disruption.

---

34 Ibid.
37 Ibid.
DEFINING VULNERABILITY IN EMMET COUNTY

The effects of climate change have been felt by everyone. With planning and preparation, communities can weather the storms and recover, becoming even better places to live and thrive. Through community-wide planning, resilient communities actively cultivate their abilities to recover from adverse situations and events, working to strengthen and diversify their local economies and communication networks, increase social capital and civic engagement, enhance ecosystem services, improve human health and social systems, and build local adaptive capacity.

Building Community Resilience

As defined by the Urban Sustainability Directors Network, community resilience is the ability of a community to anticipate, accommodate and positively adapt to or thrive amidst changing climate conditions or hazard events and enhance quality of life, reliable systems, economic vitality and conservation of resources for present and future generations. The Rockefeller Foundation emphasizes equity as an important component of resilience, stating that community resilience is the capacity of people — particularly the poor and vulnerable — to survive and thrive no matter what stresses or shocks they encounter. Communities that are resilient are able to learn from adversity and adapt quickly to change. In general, the most important qualities of resilient communities are: (1) Reflective, (2) Flexible, (3) Integrated, (4) Robust, (5) Resourceful, (6) Redundant and (7) Inclusive. The Rockefeller Foundation has identified 12 indicators within these qualities that make for a resilient community (see inset). However, it is important to acknowledge that Emmet County is unique, and not all of these indicators or characteristics may be necessary for the county to be “resilient.”

The Emmet County planning process aims to increase community resilience by fostering civic engagement and improving communication and cooperation between local officials, citizens and neighboring jurisdictions. To improve economic resilience, Emmet County and communities throughout northwest Lower Michigan should work to encourage and support local production of goods and supplies, increasing self-reliance and reducing the flow of funds out of the community. Zoning policies and programs to encourage local investing and entrepreneurship can be helpful in building both employment and production capacity. Local investments, consumption of locally-produced products, and locally-owned businesses all help to diversify the community’s economy, giving it greater resilience.

The following is a vulnerability assessment focused on Emmet County’s coastal communities. This assessment begins with an overview of regional climate trends and predicts societal impacts, then transitions to a detailed assessment of each community’s vulnerabilities to extreme heat and flooding events. Although the assessment is concentrated on these two specific types of events, many of the

According to the Rockefeller Foundation, a Resilient Community often has...

1. Minimal human vulnerability
2. Diverse livelihoods and employment
3. Effective safeguards to human life and health
4. A collective identity and mutual support
5. Comprehensive security and rule of law
6. A sustainable economy
7. Reduced exposure and fragility
8. Effective provision of critical services
9. Reliable mobility and communication
10. Effective leadership and management
11. Empowered stakeholders
12. Integrated development planning
considerations and societal impacts identified would be present in other stresses and shocks within the community (e.g., a winter storm).

In completing the assessment, a variety of factors are considered, such as demographics, environmental conditions, locations of critical facilities and essential services, and the built environment. This assessment informs recommendations for reducing identified community vulnerabilities through policies, programs and projects, which will inevitably lead to a more resilient community.

**Climate Variability**

Based on the most recent models, the climate of Emmet County will continue to warm, with greater increases in average temperatures during the winter months and at night. There are a variety of weather impacts expected with this change in average temperatures. Some of the potential impacts of climate change in the county are listed below:

- Storms are expected to become more frequent and more severe
- Increases in winter and spring precipitation
- Less precipitation as snow and more as rain
- Less winter ice on lakes
- Extended growing season (earlier spring/later fall)
- More flooding events with risks of erosion
- Increases in frequency and length of severe heat events (heat waves)
- Increased risk of drought, particularly in summer

It is important to note that increased flooding and more intense drought are not mutually exclusive nor contradictory. In the Great Lakes region, scientists are predicting more intense rain events in the fall and winter along with more intense droughts in the summer months.

These changes in climate could have a number of both positive and negative effects in Emmet County. For example, an extended growing season could help support new crops and increase crop yields for area farmers. On the other hand, the highly variable weather conditions — such as severe storms and flooding mixed with summer droughts — present big challenges to farming. Much of the U.S. has been warmer in recent years, and that affects which plants grow best in various regions. The Arbor Day Foundation completed an extensive update of U.S. Hardiness Zones based on data from 5,000 National Climatic Data Center cooperative stations across the continental United States. As illustrated in Figure 7, zones in northwest Lower Michigan are shifting northward. A few decades ago,
Emmet County was solidly in Zone 4; today, Zone 5 plants that once thrived in the southern reaches of the state can now successfully survive in Emmet County.

**Public Health and Climate**

Major health effects of long-term climatic change are predicted for the U.S. Midwest. Already, people in Michigan are experiencing higher rates of skin and eye damage from increased exposure to ultraviolet radiation, increased incidence of respiratory and cardiovascular diseases, and increased incidence of vector-borne and water-borne diseases. Weather conditions and high heat events exacerbate health conditions like allergies, asthma and obesity.

The Michigan Department of Health and Human Services (MDHHS) published the Michigan Climate and Health Adaptation Plan in 2011. The Plan indicates there is an increase in the number of illnesses and deaths as a result of extreme heat events; declining air quality as a result of increased production of ozone and particulate matter from heat and drought events; and adverse changes to water quality and availability following severe weather events.

In the long term, health experts are most concerned with a rising incidence of infectious diseases and outbreaks of new diseases not currently endemic to Michigan; increasing numbers of disease vectors and the appearance of new vectors not currently established in Michigan; and a degradation of food safety, security and supply. For example, blacklegged ticks are one disease vector that has increased in recent years. According to the MDHHS, the first official reported human case of Lyme disease in Michigan was in 1985. Cases have now been reported in both the Upper and Lower Peninsula and are increasing. It is anticipated that the number of cases reported will continue to increase due to public and medical personnel education and expanding tick ranges. Figure 8 illustrates the distribution of the risk for Lyme disease in Michigan, which has increased in recent years.

**Local and Regional Hazards: Severe Weather in Emmet County**

---

The following graphic summarizes a few of the major weather-related events in Emmet County over the past 50 years. Oftentimes, severe weather events result in negative impacts to the local economy and to vulnerable populations in the community.

- **JULY 1957**: An F1 tornado touched down in Emmet County, leaving a 6-mile-long, 33-yard-wide path of destruction. In total, over $25,000 in damage was reported in the tornado’s wake.
- **JANUARY 1995**: Much of northwest Lower Michigan was blanketed in dense fog over a two-day period. The fog caused several traffic accidents, which resulted in four casualties.
- **OCTOBER 1997**: A severe thunderstorm blew across the county, downing numerous trees of various sizes. The U.S. Coast Guard received reports of several waterspouts, and a passing ship measured wind gusts of around 90 knots (104 mph).
- **AUGUST 2001**: All of northwest Lower Michigan experienced an excessive heat event, when temperatures throughout the region stayed in the mid to upper 90s for five consecutive days.
- **NOVEMBER 2003**: A severe wind event brought consistent wind gusts between 55 mph and 70 mph throughout Emmet County. The wind caused $155,000 of property damage, several downed power lines, and significant power outages.

- **APRIL 1993**: Between 2 and 3.2 inches of rain fell on the county over a 12-hour period, causing $5 million in damage.
- **JANUARY 1997**: A severe ice storm blanketed the region in over 3 inches of heavy ice. This ice storm caused widespread power outages and several driving accidents.
- **JUNE 1998**: A severe thunderstorm produced hail up to 2.5 inches in diameter in and around Petoskey. The hail caused $100,000 of property damage and damaged several cars.
- **DECEMBER 2001**: Over a three-day period, 71 inches of snow fell on Emmet County, breaking long-standing records. A State of Emergency was declared by then Governor John Engler and the county requested $59,000 in disaster assistance.
- **AUGUST 2018**: A severe thunderstorm and heavy winds passed through the county, toppling several trees and causing limited power outages and a washout on Atkins Road.
Communities interested in becoming more resilient assess their vulnerabilities and make action plans to reduce their sensitivities and exposures to hazards of all kinds. This Community Vulnerability Assessment has been compiled by the Land Information Access Association to provide a wide variety of useful information aimed at improving climate resilience by reducing human and community vulnerabilities.

**Vulnerability = Exposure + Sensitivity**

A Vulnerability Assessment is designed to identify and help prioritize adaptation strategies in the community planning process. A model that defines vulnerability as “exposure plus sensitivity” is used to complete the assessment. Exposure refers to hazards in the natural or built environment, while sensitivity refers to the degree to which a community or certain segments of a community could be impacted by an event. This concept has been used recently in a variety of studies, such as equity and adaptation assessments conducted by the NAACP, vulnerability and its relationship to adaptation, and hazard-specific vulnerability assessments aimed at measuring exposure, sensitivity, and resilience.

By assessing the potential for exposure to a hazard and the sensitivities of specific populations, maps are generated that identify the community’s areas with relatively greater vulnerability (that is, where exposure and sensitivity overlap). This tool provides direction for community planners and public health workers in reducing risks to human health by understanding where the areas of vulnerability lie and why the vulnerability exists.

For the purposes of this tool, based on the greatest risks in Michigan and most likely predicted climate changes, the vulnerability assessments for Emmet County were limited to extreme heat waves and flooding. However, climate change is predicted to result in increases of other exposures that should also be considered in community planning and development (e.g., high winds, severe winter storms).

Our assessments were based in part on data obtained from the American Community Survey (ACS), a continuing survey program operated by the U.S. Census Bureau. This data includes information on housing, income and education characteristics of the population in geographic areas called “Block Groups,” which contain between 600 and 3,000 individuals. Data from the 2010 Census was also used, including population age and racial composition collected at the Census “Block” level, which is the smallest available geographic area for demographic data.

---

42 Equity in Building Resilience in Adaptation Planning. National Association for the Advancement of Colored People (NAACP).
Heat Vulnerability

Community vulnerability to heat events varies spatially on local, regional and national scales. In Michigan communities, there are varying degrees of vulnerability to heat based on proximity to the Great Lakes, access to air conditioning, and surrounding environmental factors like tree canopy and impervious surfaces.

Studies have shown that heat-related mortality generally occurs in areas of the community that are warmer, less stable, and are home to more disadvantaged populations. One study found that neighborhoods with the highest temperatures and the least amount of open space and vegetation were also likely to be the most socioeconomically disadvantaged. The same study also found the strongest protective factor for residents was access to air conditioning in the home and in other places, as well as having access to transportation.

A 2012 literature review conducted by researchers at the University of Michigan indicates that children under five and persons over age 65 are highly sensitive to heat events, as are persons living in lower-income Census tracts and minority populations. Living alone, being confined to bed, having a mental illness, not leaving home daily, living on higher floors of multistory buildings, and suffering from alcoholism are additional factors that are associated with increased risk of heat-related mortality.

Many Michigan communities are rural and suburban. There have been limited studies conducted on how heat events impact rural and suburban communities, but one study notes that rural populations may exhibit patterns of vulnerability different from those of urban populations.

Heat Sensitivity Assessment

To create the sensitivity and exposure maps, as well as the resulting vulnerability maps, the project team relied on methodologies developed at the University of Michigan’s Taubman College of Architecture and Urban Planning in a 2012 report.

To conduct the heat sensitivity assessment for coastal communities in Emmet County, the project team used a geographic information system (GIS) for spatial data analyses to show the relative distribution of people most at risk. Five factors have been identified as primary contributors to the sensitivities and risks of people exposed to a heat wave, including: people over 65 years of age; people living alone; people over 25 with less than a high school education; minority populations; and people living below the poverty line. Using U.S. Census data, the project team identified the percentages of people living in each area (by Block Group or Block) for each sensitivity.

---

Defining Vulnerability in Emmet County

People who are older have greater sensitivity to extreme heat events. The technical literature also indicates that older age is associated with higher hospital admission rates in heat waves. In each coastal community, the Percent of Population 65 and Older (Map 1) depicts the relative concentration of older adults in the community by Census Block.

Another sensitivity factor is living alone, which serves as a measure of social isolation. Although living alone is not necessarily a risky thing, people who are socially isolated are at greater risk during an extreme heat event. Isolated people may not be able to recognize symptoms of heat-related illness and take proper action. In this case, the project team used the American Community Survey data for Census Block Groups, broken out into individual Census Blocks for geographic representation (Blocks with no population were not included). Map 2 for each coastal community depicts the concentrations of people living alone.

Literature suggests that minorities are at greater risk during extreme heat events for various reasons, including less reliable access to health care, transportation and other social supports needed to reduce heat exposures.49 Census Blocks were used to map the relative percentages of non-white populations in each coastal community (see Map 3 for each community).

Two socioeconomic factors associated with increased heat-related morbidity and mortality are the percentage of the people living in poverty and percentage of people without a high school diploma. In general, persons living at or below the poverty line have less access to air conditioning or cooling options for their residences. This could limit a person’s access to relief from an extreme heat event. Census Block Groups were used to map the relative percentages of households living below the poverty threshold in Emmet County (please see Map 4 for each coastal community).

Similarly, University of Michigan researchers found studies that demonstrate a direct link between low education attainment and poor health.50 There is also an established correlation between lower educational attainment and income. Based on these findings, Census Block Groups were used to map the relative percent of persons 25 years and older with less than a high school education in Emmet County (see Map 5 for each coastal community).

To complete the heat sensitivity assessment, a cumulative score for all five sensitivity factors for each Census Block was created. In each of the sensitivity factors, the percentages were grouped into five categories (ranging from a very low percentage of people to a relatively high percentage living with the identified sensitivity). The five categorical groupings were generated by the GIS software ArcMap using natural breaks in the data (“groupings”). A ranking of 1 to 5 was assigned to each of the categories, ranging from 1 for the lowest percentage to 5 for the highest. Finally, the team combined the scores within each Census Block. Thus, the most sensitive Census Blocks

Defining Vulnerability in Emmet County

The Sensitivity to Excessive Heat Map (Map 6 for each coastal community) provides a reasonably detailed map of locations where the highest percentages of at-risk residents live. This does not mean these community residents are in immediate danger. Rather, the map provides planning officials a new way of identifying areas where heat waves could present serious problems for a significant number of citizens. These are populations that could be sensitive to extreme heat events.

The Census data used likely double-counts some people, such as in cases where a person is both a minority and over 65; this may overestimate the severity of the sensitivities in some locations. Conversely, the sensitivity analysis may underestimate risk in some areas because it leaves out several key sensitive populations, such as those with preexisting health concerns that denote vulnerability to heat (for example, cardiovascular disease or psychiatric disorders), since such health data is not often available publicly. Emergency managers, hospitals, and community health departments may have additional data available that can be included as the community looks to better understand its sensitive populations. To further improve the analysis, additional variables could be collected through local surveys and observations, such as the degree of social connections among individuals within a community, or materials used in housing.51

Heat Exposure Assessment

When larger communities experience heat waves, air temperatures can vary significantly from place to place both during the day and at night. Some of these differences can be attributed to the varying types of land cover found throughout the community. For example, temperatures can be significantly lower at night in locations with a heavy tree canopy and very little pavement, versus locations with little greenery and lots of pavement.

Impervious surfaces such as paved parking lots, roadways, and buildings absorb large amounts of heat from the air and from sunshine that is then radiated back into the surroundings, and this heat continues to radiate even after the sun has set. Conversely, tree canopy and other vegetation tend to help cool an area through evaporation and transpiration of water, and by providing shade. In places with a high percentage of impervious surface and little tree canopy, the immediate surroundings can be much warmer. Urban areas typically have higher heat indexes (combinations of temperature and humidity) than surrounding suburban or rural areas. This condition has been termed the Urban Heat Island Effect.52

People living in settings with an Urban Heat Island Effect suffer greater exposures to heat over longer periods of time (e.g., warmer nights), making them more vulnerable to health impacts. Studies of the Urban Heat Island Effect (whereby air temperatures in an urban

---


area are 2° to 9° F higher than in a nearby rural area) have shown that the albedo, or reflectivity, of an urban area is one of the most important determinants in reducing the magnitude of the heat island. Increasing the tree canopy cover can also reduce air temperature by 2° to 5° F. Green roofs (vegetative plantings on roofs) may also decrease the Urban Heat Island Effect and decrease stormwater runoff and building energy use. Added benefits from increasing albedo and vegetation include reductions in ground-level ozone pollution and reduced energy costs associated with air conditioning use.

To complete a heat exposure assessment, the project team focused on the Urban Heat Island Effect, and two separate exposure maps were created. The first exposure map depicts the percentage of impervious surfaces within each Census Block, as used in the sensitivity assessment (Map 7 for each coastal community). These percentages are divided into five categories using the GIS software’s natural breaks calculation. Since exposure is lowest in areas with the lowest percentage of impervious surfaces, those scored a 1, with a rating of 5 assigned to areas with the highest percentage of impervious surfaces.

The second exposure factor is percentage of tree canopy. Here, tree canopy is mapped within each Census Block (Map 8 for each coastal community) and scored using a similar five-category process. On Map 8, the highest percentage of tree canopy (and therefore the lowest heat exposure) received a score of 1, and the areas with the least amount of tree canopy received a 5.

The project team combined the results of the two exposure maps to provide a single Excessive Heat Exposure Map (Map 9 for each coastal community), which provides a reliable depiction of where the Urban Heat Island Effect would be most or least intense during a heat wave. Officials in Emmet County can use this map to better assess where new vegetation and tree canopy would be helpful to reduce the heat impact.

Composite Heat Vulnerability Map
The Heat Vulnerability Map is a simple additive combination of the overall sensitivity map and the overall exposures map (see Map 10 for each coastal community). The resulting vulnerability index depicts where concentrations of exposures and sensitive populations create a higher risk for community residents. In general, those areas with a composite score of 22 to 27 (red) have residential populations that may be particularly vulnerable to extreme heat events.

HEAVY RAIN AND FLOODING
Climate scientists say that Emmet County and northwest Lower Michigan can expect more frequent storms of increasing severity in the decades ahead. The total amount of rainfall per year is also likely to increase. However, climate models suggest the precipitation will be more concentrated in the winter, spring and fall seasons, and there will be more localized, intense storms at almost any time of year.

---

The potential for substantially larger rain events raises concerns over harm to human health and damage to buildings and infrastructure.

In assessing vulnerability to flooding, community planners evaluate potential exposures as well as sensitivity. Buildings, roads, bridges, sewer lines and other infrastructure located in a flood zone are exposed to greater risks. Where flowing floodwaters have the greatest energy, structures may be undercut, collapse or move, and soils will erode. Even areas outside of an identified floodplain are subject to flooding from heavy downpours. Where the soils have low permeability and physical drainage is inadequate, water will accumulate and cause ponding during large storm events. Appropriate planning and land-use regulations can help reduce exposures caused by poor site selection. The sensitivity of structures can be modified to reduce risk of damage by applying flood-resistant design standards.

**Exposure to Flooding Hazards**

The Digital Elevation Model Map (Map 11 for each coastal community) offers a useful view of the topography of coastal Emmet County, including the most prominent drainage patterns. On this map, the darkest green colors identify the lowest elevations, while the darkest red colors identify the highest elevations.

**COASTAL HAZARD ANALYSIS**

As part of this master planning process, LIAA and the University of Michigan analyzed shoreline and riverine ecosystem and physical dynamics to help Emmet County manage its shoreline and riverine areas. This chapter presents a brief summary of the team’s framework, results and recommendations.

**Overview of Research Framework**

The Research Framework for this study employs scenario planning to assess environmental and land-use conditions under different climate futures. Scenario planning, in general, identifies driving forces to inform a range of scenarios that are then analyzed and evaluated. In this context, the project team identified natural forces — especially increasing storminess and lake-level fluctuations — that could cause increased problems with flooding. These forces informed the creation of multiple climate futures. Each climate future was tested and evaluated for impacts on the environment and land use in the community.

**Climate Future Definitions**

Rather than presenting a prediction of what the future will bring, each of the following “climate futures” lays out a possible future that might occur. These varying climate futures — all of which are reasonably anticipated possibilities — are arranged from a least impactful to a most impactful condition in terms of the potential for wave damage and flooding hazards they would bring. The following descriptions outline the key assumptions made in defining each of the climate futures as compared to the others. Map 12 for each coastal community shows the estimated land areas that would be affected by waves and flooding under these three climate futures.

**“Lucky” Future:** Under the Lucky Climate Future, Great Lakes water levels will stay relatively low. Although there will be wave and wind
action, major storm events and wave impacts will not encroach on properties landward of current beaches. A Lucky Future projection, indicating the land areas that would be affected by high-energy waves along the shorefront and/or adjacent riverine flooding under these conditions, is shown in green on Map 12.

“Expected” Future: Under the Expected Climate Future, Great Lakes water levels will continue to fluctuate according to long-term decadal patterns, including recent extreme storm events incorporated into the ongoing Great Lakes Coast Flood Study being conducted by the Federal Emergency Management Agency (FEMA). Given those ongoing fluctuations, this Climate Future accounts for periods when Great Lakes still-water elevations are closer to the long-term average. In addition, this Climate Future anticipates the so-called “100-year storm event” (or 1% storm) becoming more like a 20- or 50-year storm event (i.e., an expected storm within the normal community planning time horizon) because of increased storminess. The Expected Future projection is shown in yellow on Map 12.

“Perfect Storm” Future: Under the Perfect Storm Climate Future, Great Lakes water levels will continue to fluctuate according to decadal patterns, consistent with assumptions made for the Expected Future. However, for this Perfect Storm Climate Future, the estimated still-water elevation is set higher than the long-term average and closer to the long-term high (583 feet). In addition, this Climate Future anticipates the occurrence of a so-called “500-year storm event” (or 0.2% storm) occurring within the planning time horizon while lake levels are high. The Perfect Storm Future projection is shown in red on Map 12.

Management: Status Quo
Under the scenario planning algorithm, we assumed that Emmet County and its local jurisdictions would continue to manage land in the same manner they currently employ, in accordance with adopted plans, zoning ordinances and relevant local ordinances. Additional management options could be added at a future date, including using a built-out analysis under the current zoning regulations and build-out analysis using Best Management Practices.

Scenario Planning to Assess Land Use and Environmental Conditions
The three Climate Futures were used to create distinct scenarios, which can then be analyzed for selected conditions as noted above. This array of scenarios represents a range of conditions the county could reasonably encounter in the foreseeable future regarding potential wave and flooding impacts, given changing natural conditions and the development management decisions made in response. For analysis here, each scenario focuses on potential impacts to land use and environmental conditions in the county. Land-use impacts include the acreage, parcels, and structures that would be at risk under different climate futures.
LAND USE RESULTS

Total Acres
Acres of land impacted by flooding progressively increase from the Lucky Climate Future to the Perfect Storm Climate Future. Table 1 shows the total acres of land impacted under each future flood forecast for coastal communities in Emmet County. Mackinaw City data reflects only the portion of the village inside Emmet County.

Table 1. Total Land Acres Impacted by Flooding

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mackinaw City (Emmet Co.)</td>
<td>13</td>
<td>37</td>
<td>71</td>
</tr>
<tr>
<td>Wawatam Township</td>
<td>177</td>
<td>441</td>
<td>873</td>
</tr>
<tr>
<td>Bliss Township</td>
<td>1486</td>
<td>1927</td>
<td>3058</td>
</tr>
<tr>
<td>Cross Village Township</td>
<td>51</td>
<td>112</td>
<td>245</td>
</tr>
<tr>
<td>Friendship Township</td>
<td>41</td>
<td>55</td>
<td>72</td>
</tr>
<tr>
<td>Readmond Township</td>
<td>49</td>
<td>66</td>
<td>101</td>
</tr>
<tr>
<td>West Traverse Township</td>
<td>66</td>
<td>105</td>
<td>164</td>
</tr>
<tr>
<td>Harbor Springs</td>
<td>25</td>
<td>63</td>
<td>157</td>
</tr>
<tr>
<td>Little Traverse Township</td>
<td>39</td>
<td>68</td>
<td>189</td>
</tr>
<tr>
<td>Bear Creek Township</td>
<td>15</td>
<td>32</td>
<td>97</td>
</tr>
<tr>
<td>Petoskey</td>
<td>87</td>
<td>123</td>
<td>231</td>
</tr>
<tr>
<td>Resort Township</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Parcels
Table 2 shows the total number of parcels (by zoning district) impacted by flooding for each coastal community in which Emmet County is in charge of zoning. Map 12 illustrates the extent of inundation for each Climate Future.
### Table 2. Total Number of Parcels Impacted by Flooding, by Zoning District

<table>
<thead>
<tr>
<th>Wawatam Parcels Impacted</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC B-1 Local Tourist Business District</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>EC B-2 General Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-1 Farm and Forest District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-2 Farm and Forest District</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>EC FR Forest Recreation District</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>EC I-2 General Industrial District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC R-2 General Residential District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC RR Recreational Residential District</td>
<td>202</td>
<td>239</td>
<td>261</td>
</tr>
<tr>
<td>EC SR Scenic Resource District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bliss Parcels Impacted</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC B-1 Local Tourist Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC B-2 General Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-2 Farm and Forest District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FR Forest Recreation District</td>
<td>19</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>EC RR Recreational Residential District</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>EC SR Scenic Resource District</td>
<td>23</td>
<td>23</td>
<td>37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cross Village Parcels Impacted</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC B-1 Local Tourist Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC B-2 General Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-1 Farm and Forest District</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>EC FF-2 Farm and Forest District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FR Forest Recreation District</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>EC R-2 General Residential District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC RR Recreational Residential District</td>
<td>106</td>
<td>136</td>
<td>175</td>
</tr>
<tr>
<td>EC SR Scenic Resource District</td>
<td>58</td>
<td>66</td>
<td>71</td>
</tr>
</tbody>
</table>
### Friendship Parcels Impacted

<table>
<thead>
<tr>
<th>District Description</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC B-1 Local Tourist Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-2 Farm and Forest District</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>EC FR Forest Recreation District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC PUD Planned Unit Development District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC RR Recreational Residential District</td>
<td>48</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>EC SR Scenic Resource District</td>
<td>60</td>
<td>67</td>
<td>69</td>
</tr>
</tbody>
</table>

### Readmond Parcels Impacted

<table>
<thead>
<tr>
<th>District Description</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC B-1 Local Tourist Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC B-2 General Business District</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>EC FR Forest Recreation District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-1 Farm and Forest District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-2 Farm and Forest District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC PT Parking Transition District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC I-1 Light Industrial District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC RR Recreational Residential District</td>
<td>108</td>
<td>138</td>
<td>152</td>
</tr>
<tr>
<td>EC SR Scenic Resource District</td>
<td>23</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

### Bear Creek Parcels Impacted

<table>
<thead>
<tr>
<th>District Description</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC B-1 Local Tourist Business District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC B-2 General Business District</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>EC FF-1 Farm and Forest District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FF-2 Farm and Forest District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC FR Forest Recreation District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC PT Parking Transition District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC PUD Planned Unit Development District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC R-1 One-Family and Two-Family Residential District</td>
<td>14</td>
<td>20</td>
<td>31</td>
</tr>
<tr>
<td>EC R-2 General Residential District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EC RR Recreational Residential District</td>
<td>6</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>EC SR Scenic Resource District</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Structures
Table 3 summarizes the total number of structures impacted under the varying Climate Futures in each coastal community. Mackinaw City data reflects only the portion of the village inside Emmet County.

Table 3. Number of Structures Impacted by Flooding

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Lucky</th>
<th>Expected</th>
<th>Perfect Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mackinaw City (Emmet Co.)</td>
<td>6</td>
<td>92</td>
<td>143</td>
</tr>
<tr>
<td>Wawatam Township</td>
<td>15</td>
<td>70</td>
<td>128</td>
</tr>
<tr>
<td>Bliss Township</td>
<td>0</td>
<td>21</td>
<td>43</td>
</tr>
<tr>
<td>Cross Village Township</td>
<td>0</td>
<td>12</td>
<td>89</td>
</tr>
<tr>
<td>Friendship Township</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Readmond Township</td>
<td>0</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>West Traverse Township</td>
<td>2</td>
<td>23</td>
<td>86</td>
</tr>
<tr>
<td>Harbor Springs</td>
<td>8</td>
<td>51</td>
<td>176</td>
</tr>
<tr>
<td>Little Traverse Township</td>
<td>0</td>
<td>32</td>
<td>103</td>
</tr>
<tr>
<td>Bear Creek Township</td>
<td>0</td>
<td>13</td>
<td>66</td>
</tr>
<tr>
<td>Petoskey</td>
<td>14</td>
<td>63</td>
<td>131</td>
</tr>
<tr>
<td>Resort Township</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
**Critical Dune Areas**

Critical Dune Areas are important assets for Emmet County that, due to their soil composition, may be especially vulnerable to damage from flooding. Currently there are nearly 3,800 acres of dunes in Emmet County. Map 13 identifies Critical Dune Areas in Emmet County for the coastal communities that have dunes.

**Table 4. Critical Dune Types and Acreage**

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Dune Type</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wawatam Township</td>
<td>Barrier Dunes</td>
<td>189</td>
</tr>
<tr>
<td>Bliss Township</td>
<td>Barrier Dunes</td>
<td>1524</td>
</tr>
<tr>
<td>Bliss Township</td>
<td>Exemplary dune associated plant community</td>
<td>116</td>
</tr>
<tr>
<td>Cross Village Township</td>
<td>Barrier Dunes</td>
<td>1449</td>
</tr>
<tr>
<td>Little Traverse Township</td>
<td>Areas that exhibit dune-like characteristics</td>
<td>103</td>
</tr>
<tr>
<td>Bear Creek Township</td>
<td>Barrier Dunes</td>
<td>410</td>
</tr>
</tbody>
</table>
MAPS - Wawatam Township/Mackinaw City (Emmet Co.)
Map 1
Percent of Population 65 Years and Older (male and female)

- 75.01 - 100.00% (5)
- 40.01 - 75.00% (4)
- 22.23 - 40.00% (3)
- 10.54 - 22.22% (2)
- 3.70 - 10.53% (1)

Map 2
Percent of Households with People Living Alone

- 60.01 - 100.00% (5)
- 50.01 - 80.00% (4)
- 33.34 - 50.00% (3)
- 21.06 - 33.33% (2)
- 8.70 - 21.05% (1)

Lake Michigan
Map 5
Percent of Population 25 years and Older with less than a High School Education

8.40% (5)

Map 6
Relative Sensitivity of Populations to Extreme Heat Events

- 19 - 20 score: (5)
- 17 - 18 score: (4)
- 15 - 18 score: (3)
- 11 - 14 score: (2)
- 10 score: (1)
Defining Vulnerability in Emmet County

Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
Defining Vulnerability in Emmet County

Map 13
Flooding Scenarios and Critical Dunes
MAPS - Bliss Township
Map 1
Percent of Population 65 Years and Older (male and female)

- 50.01 - 85.71% (5)
- 33.34 - 50.00% (4)
- 17.66 - 33.33% (3)
- 6.46 - 17.65% (2)
- 2.78 - 6.45% (1)

Map 2
Percent of Households with People Living Alone

- 50.01 - 72.73% (5)
- 33.34 - 50.00% (4)
- 20.01 - 33.33% (3)
- 12.51 - 20.00% (2)
- 9.09 - 12.50% (1)
Map 3
Percent of Non-white Population

- 30.78 - 50.00% (5)
- 20.60 - 30.77% (4)
- 13.12 - 20.59% (3)
- 7.15 - 13.11% (2)
- 3.80 - 7.14% (1)

Map 4
Percent of Households Living Below the Poverty Threshold

- 15.71 - 17.00% (5)
- 15.70% (4)
Defining Vulnerability in Emmet County

Map 5
Percent of Population 25 years and Older with less than a High School Education

- 8.41 - 14.30% (5)
- 8.40% (4)

Map 6
Relative Sensitivity of Populations to Extreme Heat Events

- Additive score
  - 16 - 20 (5)
  - 16 - 17 (4)
  - 14 - 15 (3)
  - 11 - 13 (2)
  - 8 - 10 (1)
Defining Vulnerability in Emmet County

Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
Map 11
Digital Elevation Model

Map 12
Flooding Scenarios

Legend:
- Green: Lucky Flooding Scenario
- Light Blue: Expected Flooding Scenario
- Red: Perfect Storm Flooding Scenario
- Gray: Building Footprints

Lake Michigan
Map 13
Flooding Scenarios and Critical Dunes

- Lucky Flooding Scenario
- Expected Flooding Scenario
- Perfect Storm Flooding Scenario
- Critical Dunes

Lake Michigan
MAPS - Cross Village Township
Map 1
Percent of Population 65 Years and Older (male and female)

- 50.01 - 100.00% (5)
- 18.76 - 50.00% (4)
- 13.34 - 18.75% (3)
- 8.17 - 13.33% (2)
- 8.16% (1)

Map 2
Percent of Households with People Living Alone

- 71.44 - 100.00% (5)
- 50.01 - 71.43% (4)
- 36.37 - 50.00% (3)
- 25.01 - 36.36% (2)
- 18.18 - 25.00% (1)
Map 3
Percent of Non-white Population

- 54.56 - 100.00% (5)
- 33.34 - 54.55% (4)
- 25.01 - 33.33% (3)
- 7.70 - 25.00% (2)
- 6.67 - 7.69% (1)

Map 4
Percent of Households Living Below the Poverty Threshold

- 10.31 - 15.70% (5)
- 10.21 - 10.30% (4)
- 10.20% (3)
Map 5
Percent of Population 25 years and Older with less than a High School Education

- 8.41 - 8.60% (5)
- 2.71 - 8.40% (4)
- 2.70% (3)

Map 6
Relative Sensitivity of Populations to Extreme Heat Events

- 18 - 20 (5)
- 16 - 17 (4)
- 14 - 15 (3)
- 10 - 13 (2)
- 9 (1)
Defining Vulnerability in Emmet County

Map 7
Percent Impervious Surface Exposure

- 8.58 - 31.86% (5)
- 3.53 - 8.57% (4)
- 0.94 - 3.52% (3)
- 0.29 - 0.93% (2)
- 0.01 - 0.28% (1)

Map 8
Percent Tree Canopy

- 0.05 - 5.71% (5)
- 5.72 - 28.51% (4)
- 28.52 - 40.50% (3)
- 40.51 - 53.25% (2)
- 53.26 - 77.54% (1)
Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
Map 11
Digital Elevation Model

Map 12
Flooding Scenarios

- Lucky Flooding Scenario
- Expected Flooding Scenario
- Perfect Storm Flooding Scenario
- Building Footprints
Map 13
Flooding Scenarios and Critical Dunes

- Lucky Flooding Scenario
- Expected Flooding Scenario
- Perfect Storm Flooding Scenario
- Critical Dunes

Lake Michigan
MAPS - Readmond Township
Defining Vulnerability in Emmet County

Map 1
Percent of Population 65 Years and Older (male and female)

- 70.01 - 100.00% (5)
- 40.01 - 70.00% (4)
- 18.53 - 40.00% (3)
- 9.53 - 18.52% (2)
- 3.57 - 9.52% (1)

Map 2
Percent of Households with People Living Alone

- 75.01 - 100.00% (5)
- 50.01 - 75.00% (4)
- 30.78 - 50.00% (3)
- 20.01 - 30.77% (2)
- 13.33 - 20.00% (1)
Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
MAPS - Friendship Township
Map 5
Percent of Population 25 years and Older with less than a High School Education

- 2.71 - 8.60% (5)
- 1.91 - 2.70% (4)
- 1.90% (3)

Map 6
Relative Sensitivity of Populations to Extreme Heat Events

- Additive score
  - 17 - 18 (5)
  - 15 - 16 (4)
  - 14 (3)
  - 11 - 13 (2)
  - 9 - 10 (1)
Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
MAPS - West Traverse Township
Map 3
Percent of Non-white Population

- 66.68 - 100.00% (5)
- 27.28 - 66.67% (4)
- 11.12 - 27.27% (3)
- 5.89 - 11.11% (2)
- 1.66 - 5.88% (1)

Map 4
Percent of Households Living Below the Poverty Threshold

- 10.51 - 12.30% (5)
- 10.31 - 10.50% (4)
- 6.21 - 10.30% (3)
- 5.91 - 6.20% (2)
- 5.90% (1)
Defining Vulnerability in Emmet County

Map 5
Percent of Population 25 years and Older with less than a High School Education

- 3.91 - 8.60% (5)
- 1.91 - 3.90% (4)
- 1.21 - 1.90% (3)
- 1.11 - 1.20% (2)
- 1.10% (1)

Map 6
Relative Sensitivity of Populations to Extreme Heat Events

- Additive score
- 18 - 21 (5)
- 15 - 17 (4)
- 12 - 14 (3)
- 9 - 11 (2)
- 5 - 8 (1)
Map 7  
Percent Impervious Surface Exposure

Map 8  
Percent Tree Canopy

Lake Michigan
Defining Vulnerability in Emmet County

Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
Defining Vulnerability in Emmet County

Map 11
Digital Elevation Model

Map 12
Flooding Scenarios

- Lucky Flooding Scenario
- Expected Flooding Scenario
- Perfect Storm Flooding Scenario
- Building Footprints
MAPS - Little Traverse Township
Map 1
Percent of Population 65 Years and Older (male and female)

Map 2
Percent of Households with People Living Alone
Defining Vulnerability in Emmet County

Map 3
Percent of Non-white Population

Map 4
Percent of Households Living Below the Poverty Threshold
Map 5
Percent of Population 25 years and Older with less than a High School Education

Map 6
Relative Sensitivity of Populations to Extreme Heat Events
Defining Vulnerability in Emmet County

Map 7
Percent Impervious Surface Exposure

Map 8
Percent Tree Canopy
Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
Defining Vulnerability in Emmet County

Map 11
Digital Elevation Model

Map 12
Flooding Scenarios
MAPS - Harbor Springs
Defining Vulnerability in Emmet County

Map 1
Percent of Population 65 Years and Older (male and female)

- 61.55 - 100.00% (5)
- 41.68 - 61.54% (4)
- 28.58 - 41.67% (3)
- 14.30 - 28.57% (2)
- 3.33 - 14.29% (1)

Map 2
Percent of Households with People Living Alone

- 75.01 - 100.00% (5)
- 57.15 - 75.00% (4)
- 42.12 - 57.14% (3)
- 20.58 - 42.11% (2)
- 14.29 - 28.57% (1)
Map 3
Percent of Non-white Population

- 31.26 - 55.56% (5)
- 22.23 - 31.25% (4)
- 14.30 - 22.22% (3)
- 7.70 - 14.29% (2)
- 2.54 - 7.69% (1)

Map 4
Percent of Households Living Below the Poverty Threshold

- 10.51 - 12.30% (5)
- 6.21 - 10.50% (4)
- 5.81 - 6.20% (3)
- 5.00% (2)
Map 5
Percent of Population 25 years and Older with less than a High School Education

1.51 - 3.90% (5)
1.21 - 1.50% (4)
1.11 - 1.20% (3)
1.10% (2)

Map 6
Relative Sensitivity of Populations to Extreme Heat Events

additive score
re-score
18 - 21 (5)
15 - 18 (4)
12 - 14 (3)
8 - 11 (2)
6 - 7 (1)
Map 7
Percent Impervious Surface Exposure

- 69.67 - 85.00% (5)
- 52.99 - 69.66% (4)
- 35.70 - 52.98% (3)
- 16.65 - 35.69% (2)
- 1.00 - 18.64% (1)

Map 8
Percent Tree Canopy

- 1.47 - 6.62% (1)
- 6.63 - 21.60% (2)
- 21.61 - 30.34% (3)
- 30.35 - 36.66% (4)
- 36.87 - 79.87% (5)
Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
Map 11
Digital Elevation Model

Map 12
Flooding Scenarios

- Lucky Flooding Scenario
- Expected Flooding Scenario
- Perfect Storm Flooding Scenario
- Building Footprints

Lake Michigan
MAPS - Bear Creek Township
Defining Vulnerability in Emmet County

Map 5
Percent of Population 25 years and Older with less than a High School Education

Map 6
Relative Sensitivity of Populations to Extreme Heat Events
Defining Vulnerability in Emmet County

Map 9
Relative Environmental Exposure to Extreme Heat Events

- Total score
- 9 - 10 (5)
- 7 - 8 (4)
- 5 - 6 (3)
- 4 (2)
- 2 - 3 (1)

Map 10
Population Vulnerable to Extreme Heat Events

- Total score
- 9 - 10
- 7 - 8
- 5 - 6
- 4
- 2 - 3
Defining Vulnerability in Emmet County

Map 11
Digital Elevation Model

Map 12
Flooding Scenarios

- High: 1,300 ft
- Low: 576 ft

Legend:
- Lucky Flooding Scenario
- Expected Flooding Scenario
- Perfect Storm Flooding Scenario
- Building Footprints
MAPS - Petoskey
Defining Vulnerability in Emmet County

Map 1
Percent of Population 65 Years and Older (male and female)

Map 2
Percent of Households with People Living Alone

Legend:
- 57.15 - 100.00% (6)
- 33.34 - 57.14% (4)
- 20.01 - 33.33% (3)
- 9.89 - 20.00% (2)
- 1.49 - 9.68% (1)
Defining Vulnerability in Emmet County

Emmet County Master Plan

Map 3
Percent of Non-white Population

Map 4
Percent of Households Living Below the Poverty Threshold

- 34.79 - 100.00% (5)
- 23.09 - 34.78% (4)
- 12.78 - 23.00% (3)
- 6.29 - 12.77% (2)
- 1.69 - 6.28% (1)

- 12.61 - 18.70% (5)
- 11.61 - 12.60% (4)
- 7.51 - 11.60% (3)
- 5.61 - 7.50% (2)
- 5.60% (1)
Map 5
Percent of Population 25 years and Older with less than a High School Education

Map 6
Relative Sensitivity of Populations to Extreme Heat Events

Legend:
- 5.61 - 6.20% (5)
- 4.11 - 5.60% (4)
- 3.81 - 4.10% (3)
- 3.01 - 3.80% (2)
- 3.00% (1)

Legend:
- 16 - 22 (5)
- 13 - 15 (4)
- 10 - 12 (3)
- 7 - 9 (2)
- 4 - 6 (1)
Defining Vulnerability in Emmet County

Map 9
Relative Environmental Exposure to Extreme Heat Events

Map 10
Population Vulnerable to Extreme Heat Events
MAPS - Resort Township
Map 1
Percent of Population 65 Years and Older (male and female)

Map 2
Percent of Households with People Living Alone
Map 5
Percent of Population 25 years and Older with less than a High School Education

Map 6
Relative Sensitivity of Populations to Extreme Heat Events
Map 7
Percent Impervious Surface Exposure

Map 8
Percent Tree Canopy
Defining Vulnerability in Emmet County

Map 11
Digital Elevation Model

Map 12
Flooding Scenarios

- Lucky Flooding Scenario
- Expected Flooding Scenario
- Perfect Storm Flooding Scenario
- Building Footprints