Assessing Health Vulnerability to Climate Change in the Florida Keys

June 2021

SHORELINE CONSERVATION INITIATIVE

International Medical Corps

Assessing Health Vulnerability to Climate Change in the Florida Keys

Prepared for:
International Medical Corps

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Prepared by: Shoreline Conservation Initiative

Stamoulis, K.A., Walker, R., Caster, T., Duncan, B., Boguszewski, V. 2021. Assessing Health Vulnerability to Climate Change in the Florida Keys. Shoreline Conservation Initiative, Haleiwa, HI

Executive Summary

International Medical Corps (IMC) is a nonprofit global humanitarian organization with a mission to improve the quality of life through health interventions and related activities that strengthen underserved communities worldwide. IMC works with communities to strengthen local healthcare systems and promote self-reliance. One of IMC's focus areas is supporting community health resilience, or the ability of a community to withstand, adapt to, and recover from adversity. The resilience of a health system refers to its ability to absorb shocks, and to adapt and respond with the provision of needed services.

IMC worked with Shoreline Conservation Initiative (SCI) to better understand the public health hazards in Monroe County, Florida (Florida Keys) in the face of climate change. To this end, IMC tasked SCI with gathering and synthesizing existing information related to climate change hazards, the health and medical population, medical facilities, and public health risk exposure for the Florida Keys communities. This report provides an overview and summary of the Keys vulnerability to climate change impacts and an assessment of those impacts to the health population and infrastructure. Data on climate change hazards, vulnerabilities, and adaptive capacity (healthcare facilities) by census tracts were combined in a Geographic Information System (GIS) to identify communities that are especially vulnerable to health impacts related to climate hazard exposure. Finally, targeted risk mitigation and resilience strategies for health organizations, facilities and communities are provided.

Due to their unique geography, the Florida Keys are especially vulnerable to tropical storms and hurricanes which are a common threat from June 1–November 30, and can bring high winds, heavy rains, increased wave heights, and storm surge. Severe flooding can occur in areas exposed to the storm surge and/ or heavy rains. The low elevations of the islands also makes them vulnerable to flooding from sea level rise. While primary and secondary health impacts due to flooding are the most severe, high temperatures along with several other climate related hazards also provide increasing risk to public health in the Florida Keys. Vulnerability to these climate hazards varies geographically within the Keys based on various factors.

Social vulnerability in terms of socioeconomic status, household composition and disability, minority status and language, and housing and transportation; and medical vulnerability in terms of medical need, community healthcare access, and health system capability also vary across the Keys creating an uneven capacity for preparedness, response, recovery, and adaptation to climate change hazards. While healthcare facilities are generally prevalent across the Keys, there are rural areas with lower levels of healthcare access.

By combining spatial data on vulnerability to climate change hazards (storm surge, sea level rise, and extreme heat) with social and medical vulnerability, we ranked Florida Keys communities in terms of health vulnerability to climate change. The communities with the highest overall health vulnerability to climate change were more rural communities with a low level of healthcare access including Layton and Duck Key, West Marathon, and Big Pine. These communities are vulnerable to flooding from storm surge and sea level rise as well as social and

medical factors. Conversely, vulnerability to extreme heat is relatively low due to less urbanization. The two communities with the lowest vulnerability to climate change - Mallory Square and Casa Marina - are both located in Key West. Relatively high elevations in Key West make these communities less vulnerable to flooding, though since they are urban areas, vulnerability to extreme heat is of greater concern.

There are a number of strategies that communities and healthcare facilities can use to better prepare for the effects of climate change. Planning and training for emergencies and coordination of the medical community strengthens the ability to maintain services through natural disasters. Strategies that inform communities on how to communicate and coordinate resources are critically important. Many facilities and community members rely on the government or other organizations to provide resources and assistance immediately following an extreme weather event. Coordinated planning and regular drills help to ensure recovery begins quickly and efficiently, and that avoidable secondary hazards do not occur. Physical resilience strategies like flood prevention and utility improvements can mitigate the effects of extreme weather and sea level rise and help reduce interruption of normal operations. Smart development and planning strategies can reduce the impact of flooding, extreme heat, and other climate hazards which are expected to increase in the future.

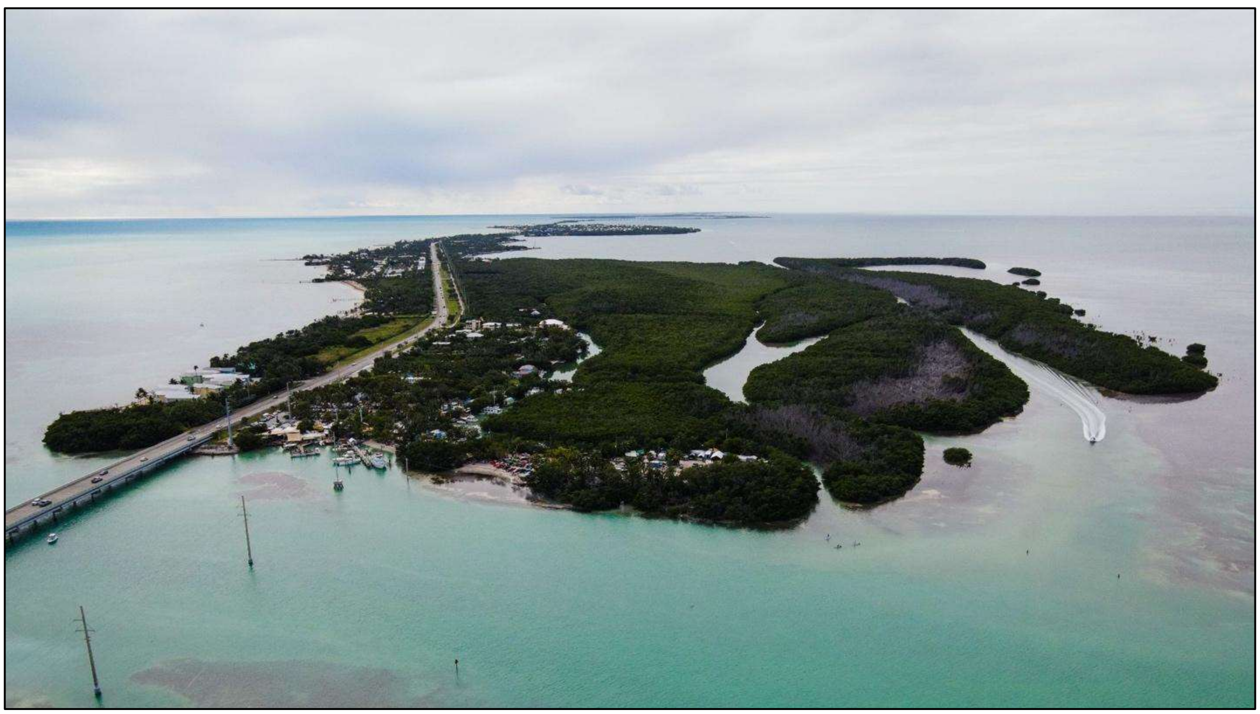

Figure i. Lower Matecumbe Key. Photo: Shoreline Conservation Initiative.

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Acknowledgements

Appreciation is owed to the following individuals and organizations that provided information or assistance with this study:

Jean Pierre, VP for Behavioral Health Services, Community Health of South Florida, Inc.(CHI)
Jimmy Bass, Assistant Chief Medical Center, Lower Keys Medical Center
Ashley Matejka, Director of Physician Outreach, Lower Keys Medical Center
Florida Area Health Education Centers
Steve McLearney, Director of Engineering, City of Key West
Marianne Finizio, VP of Community Relations/BD, Community Health of South Florida, Inc.
Peter Wood, VP of Planning and Government Affairs, Community Health of South Florida, Inc.
Kenneth Gould, VP of Logistics and Facilities, Community Health of South Florida, Inc.
Juan Reyes, Risk Management/Compliance/Privacy Officer, Community Health of South Florida
Cyna Wright, Florida Department of Health
Gianna Van Winkle, Florida Association of Community Health Centers
Trevor Rhodes, Program Manager at DC Department of Health
Meaghan Sydlowski, Program Officer, International Medical Corps
Ryann Bresnahan, Research & Learning Specialist, International Medical Corps
Shannon Weiner, Director of Emergency Management, Monroe County
Rhonda Haag, Chief Resilience Officer, Monroe County
Greg Guannel, University of Virgin Islands
Roberto Porro, Coastal Programs Manager, National Disaster Preparedness Training Center
Rebecca Walker, MD, MPH, Associate Professor of Emergency Medicine, Standford University
Colin Bucks, MD, Assistant Professor of Emergency Medicine, Mayo Clinic
Tom Forney, MD, Chief Medical Officer, Wahiawa General Hospital

1. Introduction

A. Climate and health vulnerability assessment

Climate change has been linked to a large range of health impacts (Watts et al. 2021). Identifying communities and places vulnerable to health impacts from climate change can help health organizations and facilities assess, mitigate, and reduce these adverse health impacts. The Climate and Health Program at the Centers for Disease Control and Prevention (CDC) has developed the Building Resilience Against Climate Effects (BRACE) framework to help health professionals prepare for and respond to climate change (Marinucci et al. 2014). The first step of the BRACE framework focuses on anticipating climate hazards and assessing associated health vulnerabilities (Marinucci et al. 2014). The CDC provides guidance on how to assess local health vulnerabilities to climate change hazards in a technical report titled: Assessing Health Vulnerability to Climate Change: A Guide for Health Departments (Manangan et al. 2014). That document provides the following suggested sequence of steps that can be used to assess health vulnerabilities to climate change (adapted from Manangan et al. 2014):

1) Determine the scope of the climate vulnerability assessment.
    a) Identify the area of interest and the projected change in climate exposures.
    b) Identify the health outcome(s) associated with these climate exposures.
2) For these health outcomes, identify the known risk factors (e.g., socioeconomic factors, environmental factors, infrastructure, pre-existing health conditions).
3) Acquire information on health outcomes and associated risk factors at the smallest possible administrative unit in accordance with data privacy regulations and availability.
4) Assess adaptive capacity in terms of the system's (e.g., communities, institutions, public services) ability to reduce hazardous exposure and cope with the health consequences resulting from the exposure.
5) Combine this information in a Geographic Information System (GIS) to identify communities and places that are vulnerable to disease or injury linked to the climate-related exposure.

This report follows and builds upon the above steps suggested by the CDC to conduct an assessment of health vulnerabilities to climate change in the Florida Keys. The geographic scope and context are provided in Section 1B. The relevant climate hazards and projected change in exposures are outlined in Section 1C. The health outcomes associated with these climate exposures are identified in Section 2. Social and medical risk factors (vulnerabilities) contributing to these health outcomes are described in Section 3 along with associated data. Adaptive capacity in terms of health and community infrastructure is described and assessed in Section 4 along with vulnerabilities in these systems. Assembled data on hazards, vulnerabilities, and adaptive capacity (healthcare facilities) is then combined in a Geographic Information System (GIS) to identify communities and places that are vulnerable to health impacts related to climate hazard exposure with results presented in Section 5. Finally, targeted risk mitigation and resilience strategies for health organizations, facilities and communities are described in Section 6.

B. Location, geography and environment

Monroe County encompasses the Florida Keys and is the southernmost county in the United States. Large portions of the county on the Florida mainland are submerged lands associated with Everglades National Park and Big Cypress National Preserve. Less than thirty people reside in the Monroe County portion of the mainland; however, people of both the Seminole and Miccosukee Nations reside in communities nearby. The majority of the County's population lives in the islands of the Florida Keys which consist of an area of about 102 square miles. This report will focus on the communities of the Florida Keys from Key Largo to Key West and any further mention of Monroe County will be in reference to these islands (Figure 1.1).

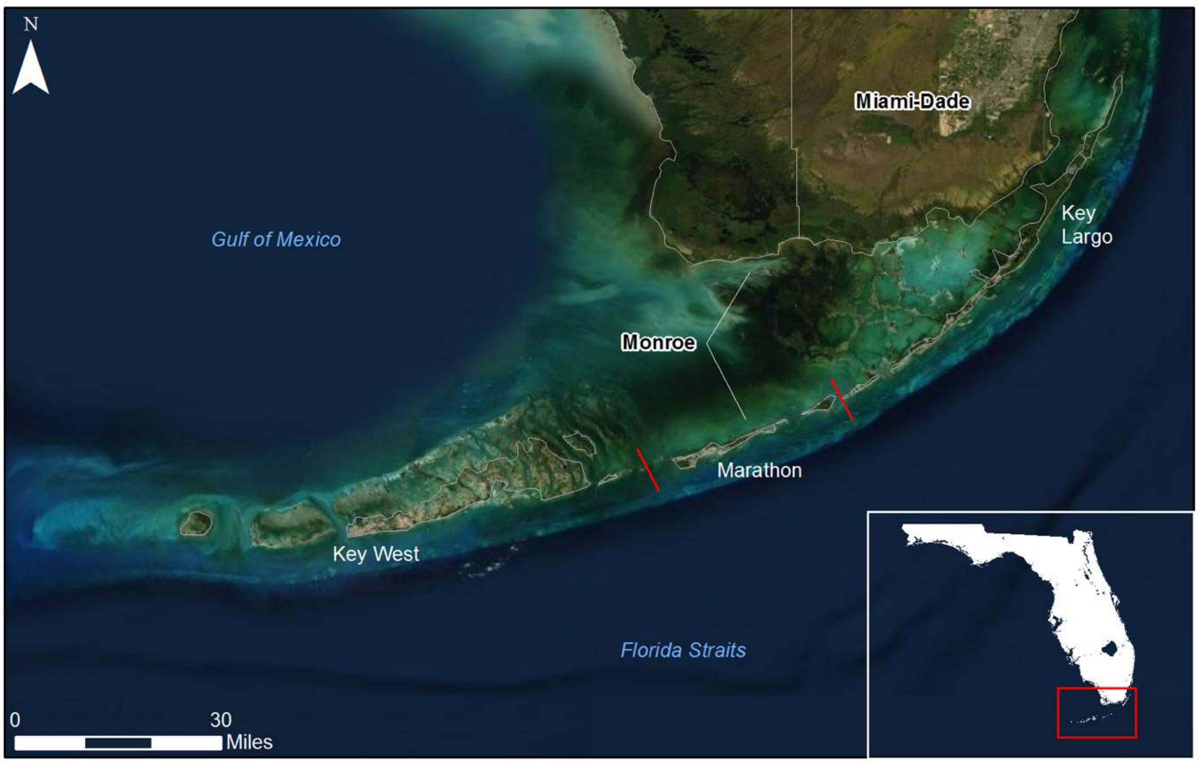


Figure 1.1. Map of the Florida Keys showing county boundaries and divisions (in red) between the Upper, Middle, and Lower Keys.

The Florida Keys make up a chain of about 1,700 low-lying islands more than 220 miles long from the southeast tip of the Florida peninsula to the Dry Tortugas in the Gulf of Mexico. These islands lie along the Florida Straits, dividing the Atlantic Ocean to the east from the Gulf of Mexico to the west and defining the edge of Florida Bay (Figure 1.1). On the Atlantic side of the Keys is the only living coral reef in the continental United States - the third largest barrier reef system in the world. The Upper Keys include the islands from Key Largo to Lower Matecumbe

Key (Islamorada). The northern boundary of the Middle Keys is Craig Island and the southern boundary is the Seven Mile Bridge south of Marathon (Figure 1.2). The Lower Keys have the largest number of islands and extend from Little Duck Key to Key West. The Florida Keys are connected by 112 miles of US Highway 1, extending from Key Largo to Key West.

The islands at each end of the chain are relatively large: Key West is 5.3 square miles with a natural deep-water harbor and the largest population, Key Largo is the largest island at 12.2 square miles. The Keys are rocky islands and sandy beaches are uncommon, though some exist. No point on the Florida Keys is more than four miles from the water. The highest point, Solares Hill in Key West is 16 ft above sea level. The highest elevations of the larger islands are 4-7 feet above sea level. 90% of the landmass of the Florida Keys is at five feet above sea level or less, making them particularly vulnerable to the impacts of sea level rise and storm surge.

Figure 1.2. Seven Mile Bridge south of Marathon representing the southern boundary of the Middle Keys. Photo: Shoreline Conservation Initiative.

C. Climate change hazards

Flooding and sea level rise

With climate change, the combination of sea level rise, increased precipitation, and more intense hurricanes will result in increased flooding of low-lying homes and infrastructure. Common impacts of flooding include damage to personal property, buildings, and infrastructure; bridge and road closures; service disruptions; and injuries or even fatalities.

Sea level is rising around the globe at increased rates due to the expansion of ocean water from warming and melting of glacial and polar ice caused by climate change. Climate change also influences oceanic processes such as the Florida Current, Gulf Stream and El Nino Southern Oscillation (ENSO), which can influence water levels within the Florida Keys. The 2019 update to the Florida Climate Change Compact's Unified Sea Level Rise Projection for Southeast Florida states that "in the short term, sea level rise is projected to be 10 to 17 inches by 2040 and 21 to 54 inches by 2070 (above the 2000 mean sea level in Key West, Florida). In the long term, sea level rise is projected to be 40 to 136 inches by 2120" (Southeast Florida Regional Climate Change Compact's Sea Level Rise Ad Hoc Work Group 2020).

Sea level rise causes land loss in low-lying coastal areas and exacerbates erosion and flooding as new areas become vulnerable to storm surge, wave action, and higher tides. In Monroe County, there is the added risk of sea level rise causing saltwater intrusion into the Biscayne Aquifer, the county's primary source of drinking water.

Temperature increase

Extreme heat is typically recognized as the condition where temperatures consistently stay ten degrees or more above a region's average high temperature for an extended period. Fatalities can result from extreme temperatures, as they can push the human body beyond its limits (hyperthermia and hypothermia). With climate change, extreme heat can be expected to occur more often and for longer durations. Extreme heat can also cause disruptions to utilities, specifically power outages. When electrically powered cooling systems are disabled, it can rapidly change an uncomfortable situation into an emergency.

Severe weather events

In the case of Monroe County, severe weather events primarily refer to hurricanes. However, the term also applies to any event of severe wind and/or rain that threaten lives, property, and vital infrastructure. Severe wind and rain can present hazards due to the effects of flying debris or downed trees and power lines, and also cause flooding.

Figure 1.3. Hurricane in Monroe County. Photo: https://www.monroecounty-fl.gov/.

Tropical storms and hurricanes are a common threat to Monroe County during hurricane season (June 1–November 30), and can bring high winds, heavy rains, increased wave heights, and storm surge. Devastating flooding can occur in areas exposed to the storm surge and/ or heavy rains. Other impacts include shoreline erosion, and damage to buildings and infrastructure.

In the 1900-2010 time period, Monroe County experienced 15 hurricane strikes, more than any other county in the US (NOAA NHC 2021). The most recent major hurricane to affect the Florida Keys was hurricane Irma in 2017. On September 10, Irma made landfall near Cudjoe Key as a Category 4 hurricane with maximum winds of 115 kt and a minimum pressure of 931 mb. Big Pine Key suffered the worst effects, with maximum observed wind speeds of 104 kt and storm surge reaching 8ft above Mean Higher High Water (MHHW). The localized effects of these types of storms was also on stark display, illustrated by the storm surge observed in Key West, less than 30 miles away, reaching just 2.7ft above MHHW.

Although the frequency of less-severe hurricanes may decrease, climate change is expected to magnify the intensity of more-severe hurricanes (e.g., Category 4 and 5) and also the frequency of these more intense storms is expected to increase. In addition, higher water levels due to sea level rise (SLR) will cause the impacts of waves and storm surge from storms of a similar intensity to worsen over time.

Wildfires and Air pollution

Wildfires are a generally less-severe climate change hazard for Monroe County. While small brush fires have occurred, a majority of vegetation in the County is coastal and semi-aquatic, with a lower vulnerability to fire. Fires located outside of Monroe County have been reported to contribute to air pollution within the Florida Keys. Increasing frequency of fires on the mainland would likely correlate with increased frequency of degraded air quality in Monroe County.

Drought

While less specific to Monroe County, drought has the potential to deplete and degrade the Biscayne aquifer on which Monroe County relies for a vast majority of their fresh water. Periods of drought also have the potential to permanently damage important habitats and ecosystems (Staletovich 2020) that exist within the Everglades National Park and elsewhere within Monroe County. Droughts result in lower water levels and higher risk of fire in the park. Degradation of these ecosystems can cause an array of subsidiary human health effects.

D. Previous and ongoing efforts

Southeast Florida Regional Climate Compact

The Southeast Florida Regional Climate Change Compact is a partnership between Broward, Miami-Dade, Monroe, and Palm Beach counties, to work collaboratively to reduce regional greenhouse gas emissions, implement adaptation strategies, and build climate resilience within their own communities and across the Southeast Florida region. Since its outset in 2009, they have produced resources and guidance on regional collaboration, joint-policies, and infrastructure assessment, while strengthening a network of professionals.

A key product of the Southeast Florida Regional Climate Compact is the Unified Sea Level Rise Projection that was originally released in 2011 and updated periodically. This addresses the recognized need to establish regionally-unified sea level rise planning scenarios in order to ensure consistency in adaptation planning and policy and infrastructure siting and design. The

2019 Projection (Southeast Florida Regional Climate Change Compact's Sea Level Rise Ad Hoc Work Group 2020) is based on sea level rise projections developed by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC 2014) and projections from the National Oceanic and Atmospheric Administration (NOAA) (Sweet et al. 2017). These projections account for regional effects such as vertical land movement and thermal expansion from warming of the Florida Current that produce regional differences in Southeast Florida's rate of sea level rise compared to global projections.

Florida Institute for Health Innovation

In 2014, the Florida Institute for Health Innovation (FIHI) examined the southeast Florida region in a Health Impact Assessment (HIA) of the Regional Climate Compact. This HIA Report examined the four-county region (Broward, Miami-Dade, Monroe, and Palm Beach) as a whole and evaluated each county's unique risk factors and hazards of concern. The HIA was followed by FIHI's Health and Sea Level Rise: Impacts on South Florida (Garces et al. 2016), which supported the adaptation approach developed in the Monroe County Adaptation Guide 2015 for the Health Care Community (Boguszewski 2015). FIHI's team examined factors such as population density, access to recovery resources, finances, and the existing burden of disease in the population as relevant to understanding and reducing risk. The HIA of the Region emphasized the following health risks for Monroe County: respiratory, allergies and airway diseases, foodborne disease and nutrition, mental health, vector-borne and zoonotic Diseases, waterborne diseases.

Florida Department of Health, Monroe County

State population level health data is housed in a number of databases published under an assessment tool at www.FLhealthcharts.com. By an analysis of this data, in combination with other resources, Community Health Assessments are regularly completed by Florida's 67 individual counties. Beginning with the 2013 Community Health Improvement Plan (CHIP), the Florida Department of Health in Monroe County utilized data coordinated into geographically-linked census tract-level combinations to produce nineteen micro-community health assessments within an overarching County-wide Community Health Improvement Plan (CHIP). The 2015 CHIP expanded these assessments and included micro-community health profiles, as well as in-depth perspectives on two of the micro-communities. The 2017 CHIP provided an outline for health improvement for the period of 2018-2020, which in addition to the micro-community health profiles, also contains goals and strategies for four of the micro-communities. Based on the CHIP survey results, of the top five 'Environmental Health and Safety Issues' in Monroe County, 'Climate Change' is ranked second, topped only by Infrastructure/Roadway. In March of 2019 the Florida Department of Health in Monroe County released for publication and community guidance the 2019-2022 Community Health Assessment (CHA). The 2019-2022 CHA reports on the community health and safety priorities of Monroe County's citizens, and lists Monroe County residents' top five Environmental Health and Safety Concerns as infrastructure of roadways, climate change, safety for bicyclists, bike safety, and housing conditions, including indoor air quality, pests, and mold/moisture (FLDOH-Monroe, 2019).

2. Impacts of climate hazards on human health

A. Flooding

Floodwaters and Water Quality Impacts
Flood inundation of homes, cars, and critical infrastructure will continue to be an increasing risk for the Florida Keys. The potential health risks associated with floodwaters mainly concern immediate contact. Flooded waters can contain risks such as down power lines, animal and human waste, dangerous debris, and other contaminants that can lead to severe injuries and infections. Flood water, whether moving or still, can also have serious drowning risks regardless of one's swimming abilities. It is advised to stay out of floodwaters at all possible costs. (CDC, 2019). Floodwaters can also cause potable drinking water issues. Homes and infrastructure can be severed from main water lines, leading to leaks and shut off of water resources. This very incident was seen post Hurricane Irma, when water leaks and shutdowns occurred across the Florida Keys.

Standing water which does not recede after a flooding event presents a unique set of hazards. The Key Largo neighborhood of Stillwright Point, like other areas of the County, has witnessed an increase of nuisance flooding events associated with sea level rise and the increasingly higher King Tides, which occur in the absence of precipitation. In 2019, the neighborhood was inundated with saltwater for more than ninety days according to press reports and resident accounts. In 2020, the same area was flooded with seawater for over seventy days (Figure 2.1). Although not all of the streets and adjacent properties were flooded, the saltwater flooding of the only access route (North Blackwater Lane) to the county's single primary road (US Highway 1) left residents stranded and destroyed some residents' vehicles.

Figure 2.1. King Tide flooding in the Stillwright neighborhood of Key Largo in November, 2020. Photo: Emilie Stewart.

Mold and Mildew in Post-Flood Scenarios

Detailed by the Center for Disease Control (CDC), mold and mildew will begin developing within 24-48 hours of home flooding (CDC 2019). Also detailed in the CDC guidelines are the potential health risks involved with mold and mildew in homes. For individuals sensitive to mold, mold exposure can lead to symptoms such as wheezing and red or itchy eyes, with more intense reactions to those with mold allergies or asthma. More severe reactions, such as fever and shortness of breath, may occur in occupational settings such as farmers working around moldy hay (CDC 2019). It is therefore important to monitor impacted facilities and homes for mold growth after flooding has occurred. It is also important to clean and maintain air conditioning units due to increased reliance on indoor, climate-controlled environments with rising outdoor temperatures.

The County and the Municipalities within Monroe County are challenged by an affordable housing crisis. The average age of the housing infrastructure and prolonged exposure to the warm moist climate, as well as the impact of extreme weather events have created challenges for some residents to find mold-free, safe and affordable housing. The County, as well as each Municipality, are developing strategies to address these concerns such as stakeholder input meetings, State collaborative programs, and improved building codes to support resilience.

B. Temperature increase

Heat Related Illness and Death

With historical and modeled data showing a rise in average global temperatures, prolonged heat exposure to high temperatures in association with humidity poses certain health risks to both residents and visitors in the Florida Keys. Heat stroke, exhaustion, dehydration, renal failure, and cramping are specific scenarios where risk can be mitigated by increased public health awareness and planning. Particularly at-risk individuals are within outer age ranges (elderly and young children/infants), as well as those who are unaccustomed to the summer heat waves. Interestingly, public health research also indicates a causal relationship between high heat and both group and intimate partner violence (Levy 2017, Sanz-Barbero et al. 2018).

As scientists predict the future health impact of heat, one metric that has been highlighted by health and environment experts is the heat index. The heat index is a measure of what the temperature feels like to the body, when calculating air temperature and humidity together (National Weather Service: Equation 2014). Figure 2.2 presents the heat index temperature at varying degrees of temperature with relative percent humidity (Dahl et al. 2019).

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112+
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136	
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137		
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137			
55	81	84	86	89	93	97	101	106	112	117	124	130	137				
60	82	84	88	91	95	100	105	110	116	123	129	137					
65	82	85	89	93	98	103	108	114	121	128	136						
70	83	86	90	95	100	105	112	119	126	134							
75	84	88	92	97	103	109	116	124	132								
80	84	89	94	100	106	113	121	129									
85	85	90	96	102	110	117	126	135									
90	86	91	98	105	113	122	131										
95	86	93	100	108	117	127											
100	87	95	103	112	121	132											

80°F–89°F
90°F–99°F
100°F–104°F
105°F+
Off the Charts

Off the Charts
Heat index formula becomes invalid with extreme temperature and humidity combinations that will increasingly result from global warming

Figure 2.2. National Weather Service Heat Index Chart (Dahl et al. 2019).

As humidity and heat rise, so does an individual's core body temperature. Table 2.1 displays the body's response and problematic symptoms corresponding to increasing heat index temperatures. Outdoor workers and high school athletes may be at greater risk of experiencing negative impacts of high heat. According to data from WeatherSTEM, Monroe County conditions exceeded NIOSH's safe limit for very heavy labor (77°F) for at least one hour on 99% of the days from May 1 to Sept. 30, 2018 (Arkush et al. 2018).

Table 2.1. Heat Index degrees with the corresponding health effects (adapted from Dahl et al., 2019).

Heat Index above 90°F	Heat Index above 100°F	Heat Index above 105°F	Heat Index off the charts
Prolonged outdoor activities, such as work and exercise, can lead to heat-related illness.	Children, elderly, pregnant women, and those with underlying conditions become susceptible to heat-related illness.	All population groups are at risk of heat-related illness and prolonged exposure can be fatal.	The precise effects are unknown, but exposure to any individual is hazardous and could be fatal.

In predicting the severity of days with high heat, especially in areas with higher relative humidity such as the Florida Keys, it is essential to know what the future of annual temperatures can bring. Historically, Monroe County experiences about 55 days a year with temperatures exceeding 100 degrees Fahrenheit. Projected future temperatures, with the assumption of implementing rapid mitigation efforts, indicate that Monroe County may be subject to more than 128 days per year where temperatures exceed 100 degrees and higher by late century (after 2070). Table 2.2 shows the historical heat index data for Monroe County, with several future scenarios of days per year the heat index will reach over 90 degrees Fahrenheit (Dahl et al. 2019). It is important to remember that projections are not exact and should be viewed as such.

Table 2.2. Historical and future data for average annual days of high heat in Monroe County (adapted from Dahl et al., 2019).

	Days per year					
		Midcentury		Late century		
Heat Index	Historical	Slow action	No action	Slow action	No action	Rapid action
90°F	161	185	191	191	203	187
100°F	55	128	144	139	171	128
105°F	12	77	104	95	146	78

C. Severe weather events

As global average temperatures rise and our climate changes, the intensity and number of severe weather events are expected to increase. While severe weather covers an array of events, for the purposes of this report as it relates specifically to the Florida Keys, the focus will be on coastal storms. Physical dangers from coastal storms include high winds, flying debris, flooding, large waves, and storm surge.

Figure 2.3. Debris littering a canal in the Florida Keys after hurricane Irma. Photo: https://www.monroecounty-fl.gov/.

The National Weather Service keeps a national ten and thirty-year average of severe weather event fatalities. Over the last ten years, hurricanes have averaged six fatalities per year. This number contrasts with the thirty-year average of 46 fatalities per year. This sharp decline is most likely due to the advancement of weather forecasting and household preparedness. In recent years, the rise of rapid onset coastal storms and hurricanes raises concern. Flooding has accounted for an average of 95 deaths per year over the last ten years and 87 per year over the last thirty-year average. Events of high winds totaled an average of 57 fatalities over the last ten years (NWS 2020). In recent years, a new trend of rapid storm intensification has created difficulties for advanced warnings and evacuations. With less than 48-72 hours warning for evacuation and preparation, the physical dangers of coastal storms can pose greater risks than previous years.

Trauma is among the many long-lasting health impacts of severe weather events in a community and can linger in the population for years following an event. Loss of income, loss of material possessions, sometimes the loss of loved ones, or a home, or simply the psychological awareness of the presence of extreme danger can traumatize individuals in the population during, and following, a severe weather event. There is significant need for the continuity of operations for providers offering mental and behavioral health support and for social services in both the immediate response period following a severe weather event and in the long-term recovery period which ensues. According to data from the Florida Department of Health, in the year following Hurricane Irma, Monroe County's annual suicide count reached a ten-year high (Figure 2.4).

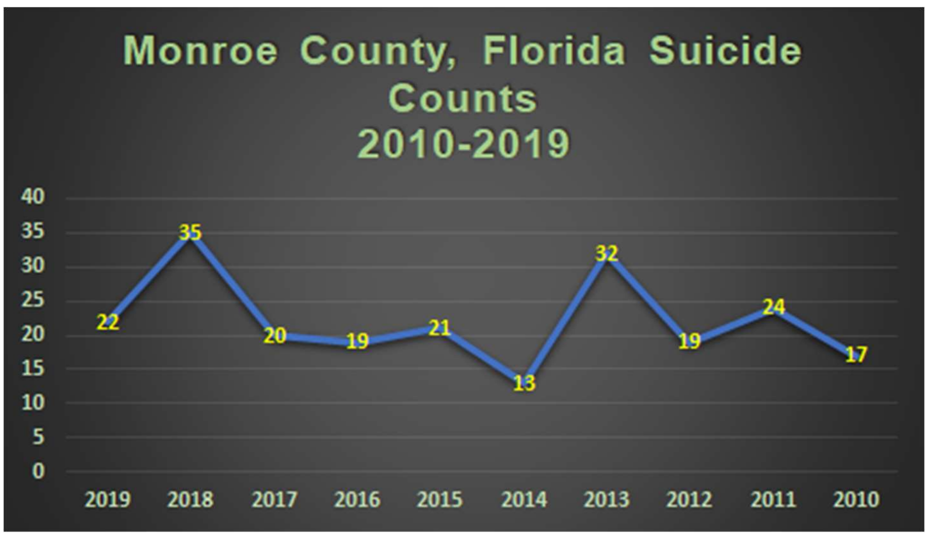


Figure 2.4. Monroe county suicide counts 2010-2019. Florida Department of Health.

D. Wildfires

As temperatures continue to increase in the coming decades with climate change, along with prolonged dry seasons, the number of wildfires and duration of wildfire seasons may also increase. For the last several decades, the United States has averaged between 60,000 and 100,000 wildfires a year (NIFC 2020). As mentioned previously, most of the vegetation in the Florida Keys is coastal or semi-aquatic, creating a reduced risk of wildfires. However, this does not exclude the dangers of wildfires. On March 4th, 2021, a brushfire shut down Card Sound Rd., one of the two entry and exit corridors to the Florida Keys. Besides the immediate risks of property destruction and injury from a fire, occurrences like this create secondary risks such as road closure that can become very problematic during times of evacuation or emergency transportation. Wildfires produce air pollution that can carry miles away from the origin causing respiratory tract irritations and disorders. These include reduced lung function, exacerbations of asthma, heart failure, and premature death. People with predisposed heart and lung conditions are at increased risk from air pollution, as well as children, pregnant women, and the elderly.

E. Air Pollution

Increasing Allergens
Future climate change is expected to exacerbate and prolong pollen and allergy seasons. With increased carbon dioxide emissions contributing to plant growth, both pollen production and allergens in pollen will increase. Additionally, rising temperatures will bring longer pollen and allergy seasons (Reid et al. 2009). Allergens can cause a range of irritations from stuffy nose to itchy eyes; however, the effects can be far more severe for those with asthma. Common symptoms associated with asthma include but are not limited to coughing, wheezing, tightness in the chest, and trouble breathing. Changes to our allergy season will bring heightened health risks for populations that suffer from asthma, especially children. A 2016 study of the school-age population in Monroe County found asthma rates in children comparable to those throughout the United States and demonstrated the highest risk among black students in late elementary and middle school age groups in the Lower Keys and Key West area (Gasana, et. al., 2016).

Changes in Ozone Particulate Matter
Ozone (O3), a highly reactive compound of three parts oxygen in the uppermost layers of Earth’s atmosphere, helps block ultraviolet rays from the sun. Ozone increases in the lower atmosphere when nitrogen oxides and volatile organic compounds become catalyzed by the same ultraviolet rays. Both nitrogen oxides and volatile organic compounds have increased with anthropogenic pollution from sources such as burning fossil fuels, chemical manufacturing, insecticides, and more (Ebi and McGregor 2008). When ozone reaches the lower atmosphere, it poses cardiopulmonary and respiratory complications. Those with asthma, respiratory, and heart conditions are at increased risk when exposed to increased ozone levels. Table 2.3 represents the Environmental Protection Agency’s (EPA) Air Quality Index (AQI). The EPA puts out daily AQI condition levels for areas across the country. The air quality index is measured by parts per billion of ozone and particulate matter.

Table 2.3. Air Quality Index basics for ozone and particle pollution (AirNow 2020).

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for sensitive groups	101 to150	Members of sensitive groups may experience health effects. The general public is likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Healthy warning of emergency conditions: everyone is more likely to be affected.

These same levels of concern have been adopted for modelling future air quality. In the pie charts presented in Figure 2.5, the same coloring for levels of concern is used to represent percent of summer days with the corresponding air quality. On the left are historical conditions for the 1990s, and on the right are future air quality conditions for the 2050s under the IPCC's A2 climate scenario.

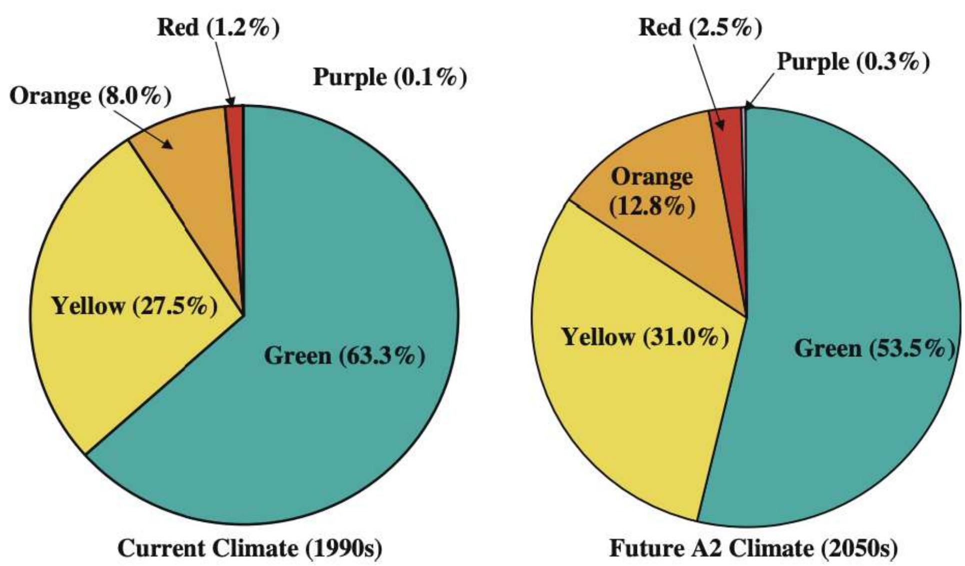


Figure 2.5. Percent of summer days in each ozone air quality index category, on average across the 50 states (Bell et al. 2007).

F. Drought

Drought, lower than average amounts of rain, or the prolonged absence of rains, can have severe adverse health impacts. The effects of drought can be seen over the short or long term and can have community impacts, all the way down to the individual (CDC 2020). As climate change continues to escalate, annual temperatures and dry seasons will continue to increase, leading to higher potential for drought.

The University of Nebraska-Lincoln, in partnership with the United States Department of Agriculture, the National Drought Mitigation Center, the United States Department of Commerce, and the National Oceanic and Atmospheric Administration, produce the United States Drought Monitor (UNL 2021). The United States Drought Monitor produces weekly drought updates for all 50 states with a resolution down to the county level. As of April 2021, the Florida Keys are classified as abnormally dry (Figure 2.6).

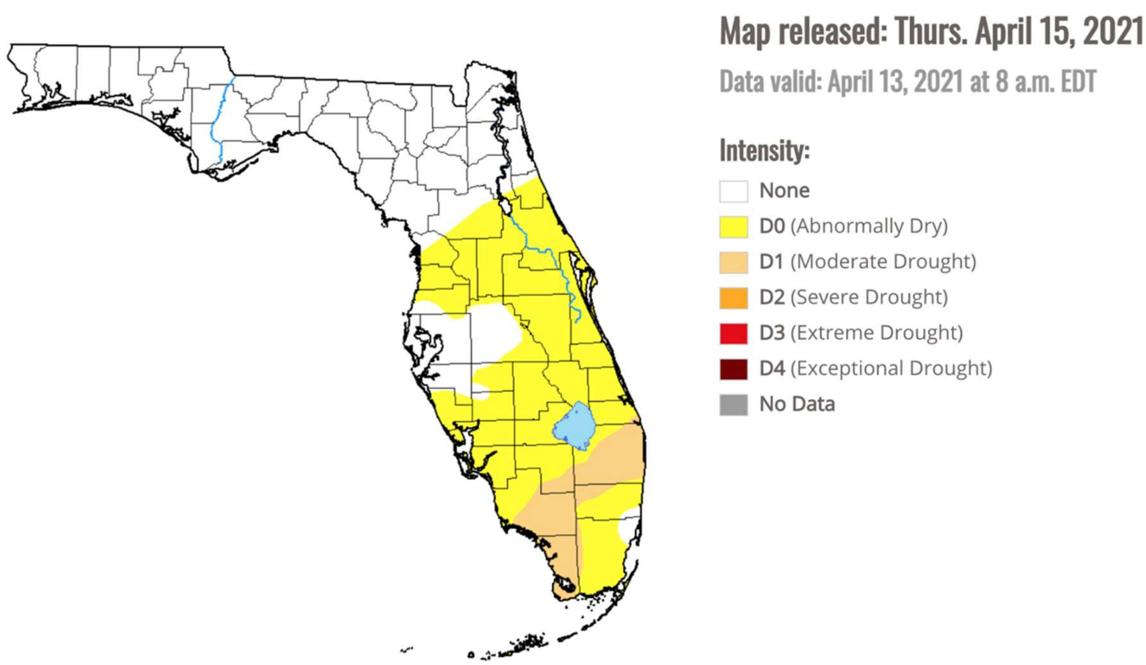


Figure 2.6. Map of drought conditions across the state of Florida, April 2021 (UNL 2021).

The Center for Disease Control has outlined general impacts that can occur during times of drought. Drought can lead to shortages of drinking water and a decline in drinking water quality. Drought contributes to an increased risk of wildfires leading to poor air quality. Reduced availability of potable water can lead to lowered hygiene and sanitation. Finally, drought contributes to decreases in food and nutrients and rises in vector-borne illnesses (CDC 2020). Table 2.3 shows the United States Drought Monitor's definition of potential risks associated with different degrees of drought intensity that correlate to the preceding image.

Table 2.4. Potential impacts across different severity of drought (UNL 2021).

Category	Impact
D0	Small brush fires increase
	Increased landscape irrigation is needed; voluntary water conservation is requested
D1	Burn bans are possible
	Trees and bushes begin browning
	Water supply decreases
D2	Pasture is drying, hay yields are low
	Large increase of wildfire abundance; fire danger is elevated; burn bans are implemented
	Lawns and landscapes go dormant
	Bears and snakes change food and water habitats
	Air and water quality are poor; water salinity is high; river and lake levels are low
D3	Fire danger is extreme; fire restrictions increase
	Saltwater species replace freshwater species; sea intrusion
	Nesting bird populations grow with increased nesting area; mosquitoes increase
	Fish kills occur; toxic algae blooms appear
	Ground water declines; Lake Okeechobee is extremely low
D4	Ground water declines rapidly
	Large municipalities use alternative water sources, borrow water

The Florida Keys receives all of its potable waters from the Biscayne aquifer which is unconfined and highly susceptible to fluctuations in precipitation (USGS 1990). Drought is not an immediate concern for the Florida Keys but should be monitored as annual temperatures continue to increase.

G. Secondary Hazards

Secondary climate change hazards are second order impacts related to direct climate change hazards and likewise are expected to increase under climate change. These hazards and associated impacts are the result of one or more effects of climate change and include vector-borne illness, vibriosis, harmful algal blooms, and mental health.

Mental Health

The devastation, traumas, and hardships of extreme climate events can lead to severe mental health impacts. These impacts can include stress, anxiety, depression, and post-traumatic stress disorders. In some cases, the effects are mild and can be overcome with time, with lasting psychological disorders in others (Dodgen et al. 2016). Figure 2.6 below illustrates the common personal and community health impacts after experiencing severe climate impacts.

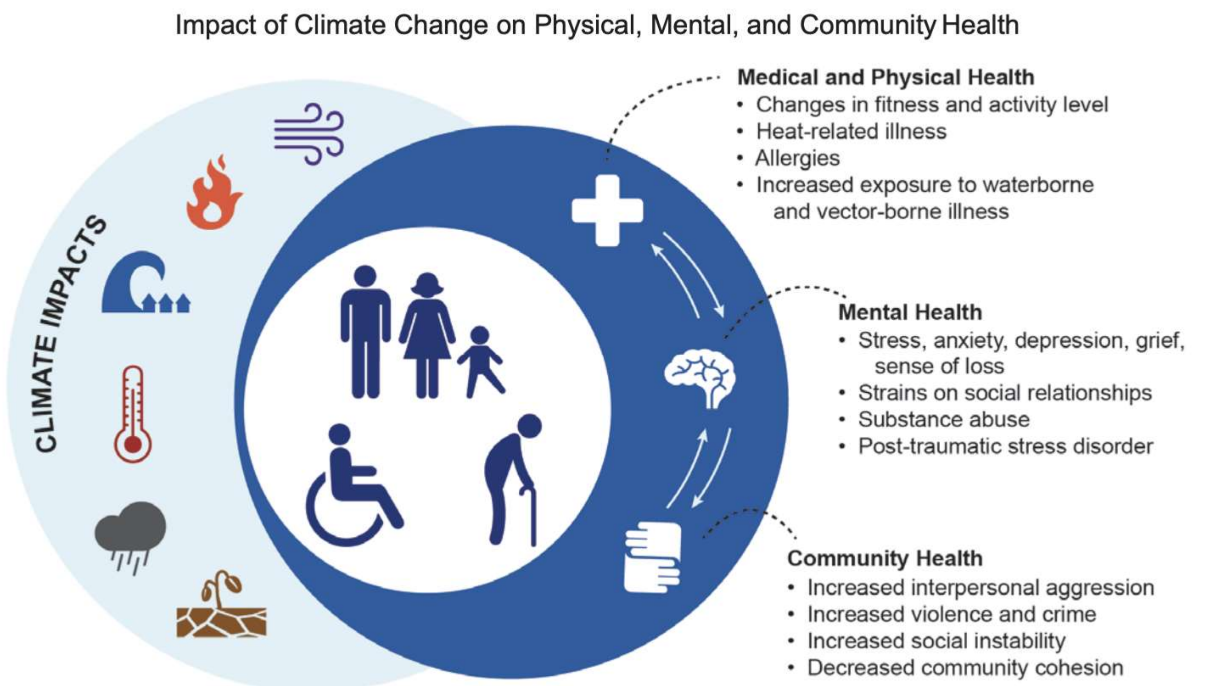


Figure 2.7. Impact of Climate Change on Physical, Mental, and Community Health (APA, 2017).

One study examined post-traumatic stress and depression among children after a severe hurricane, and the results show a clear and significant impact on mental health and well-being (Self-Brown et al. 2012). Impacts of mental health from climate events can disproportionately affect different groups of individuals as well. Women, children, elderly, those with pre-existing mental health conditions, first responders, and economically-challenged are at higher risk (Dodgen et al. 2016). Due to the remote location and low density of mental health services, organizations such as Community Health of South Florida, Inc. offer remote tele-health services. As the impacts of climate change increase and more events are endured, services like tele-health will be crucial for personal and community health.

Vector-Borne Illness

According to the Florida Keys Mosquito Control District, the Florida Keys host a variety of mosquito species including the Black Salt Marsh Mosquito (Aedes taeniorhynchus), *Aedes aegypti,* and the Southern House Mosquito (Culex quinquefasciatus) (Florida Keys Mosquito Control District 2019). The *Aedes aegypti* (Aedes mosquito) has been identified as a potential and future health hazard for the Florida Keys. The Aedes mosquito is a known vector of diseases such as dengue fever, chikungunya, Zika fever, Mayaro and yellow fever viruses, and other disease agents. Figure 2.7 represents the CDC's estimated potential range of the Aedes mosquito population.

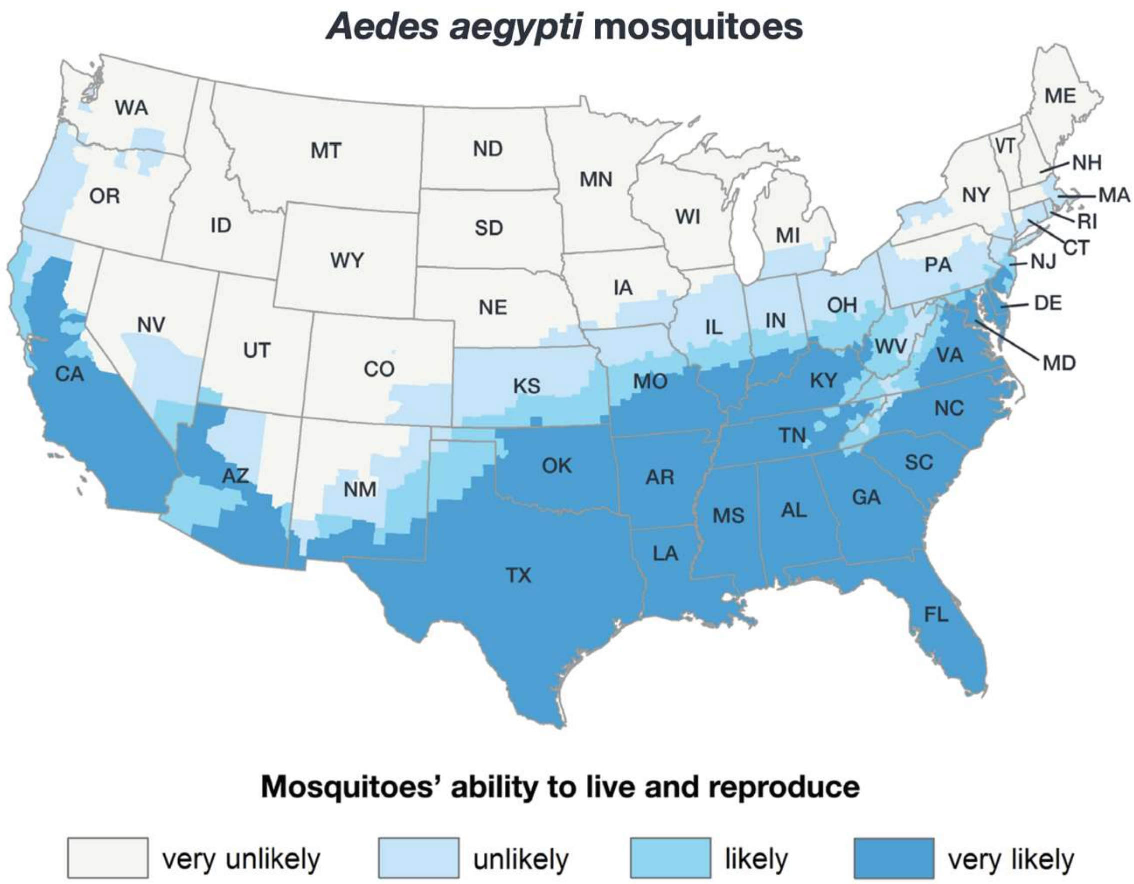


Figure 2.8. Map of *Aedes aegypti* mosquito sustainable habitat area (CDC, 2019).

Noted in previous sections, with the onset of future climate change there may be an increase of flooding and standing water in and around populated areas. Transient or flooded waters are the ideal breeding habitat for the Aedes mosquito. Future modeling shows an increased risk for the population and habitat of the Aedes mosquito (Kraemer et al. 2019).

In August of 2020, the Florida Department of Health confirmed 47 cases of Dengue Fever in Key Largo, with continued testing in the area. The Florida Keys Mosquito Control District employs three methods of mosquito control in their operations, “Source Reduction, Larval Control and Adult Control.” These mitigation strategies and the work done by the Mosquito Control District will be of increasing importance as future climate change onsets in the Florida Keys.

Harmful algal blooms

Harmful algal blooms (HABs) are described by the International Panel on Climate Change as proliferations of phytoplankton and macroalgae that have negative effects on marine environments and associated biota (IPCC 2014). Illness from HABs can be contracted through direct or secondary contact such as swimming, digesting water containing HABs, consumption of contaminated fish and shellfish, and breathing harmful toxins in the surrounding air. (Bindoff et al. 2019)

The Florida Department of Environmental Protection documented one algal bloom incidence within the Florida Keys in 2019. A recent report in Marine Pollution Bulletin links sea level rise, increased precipitation and other climate change factors to increased risk of fecal contamination of near shore waters and beaches in the Florida Keys (Barreras et al. 2019). While the occurrence of algal bloom events is low in the Florida Keys, conditions should continue to be monitored and the public aware of the risks that can occur from such events.

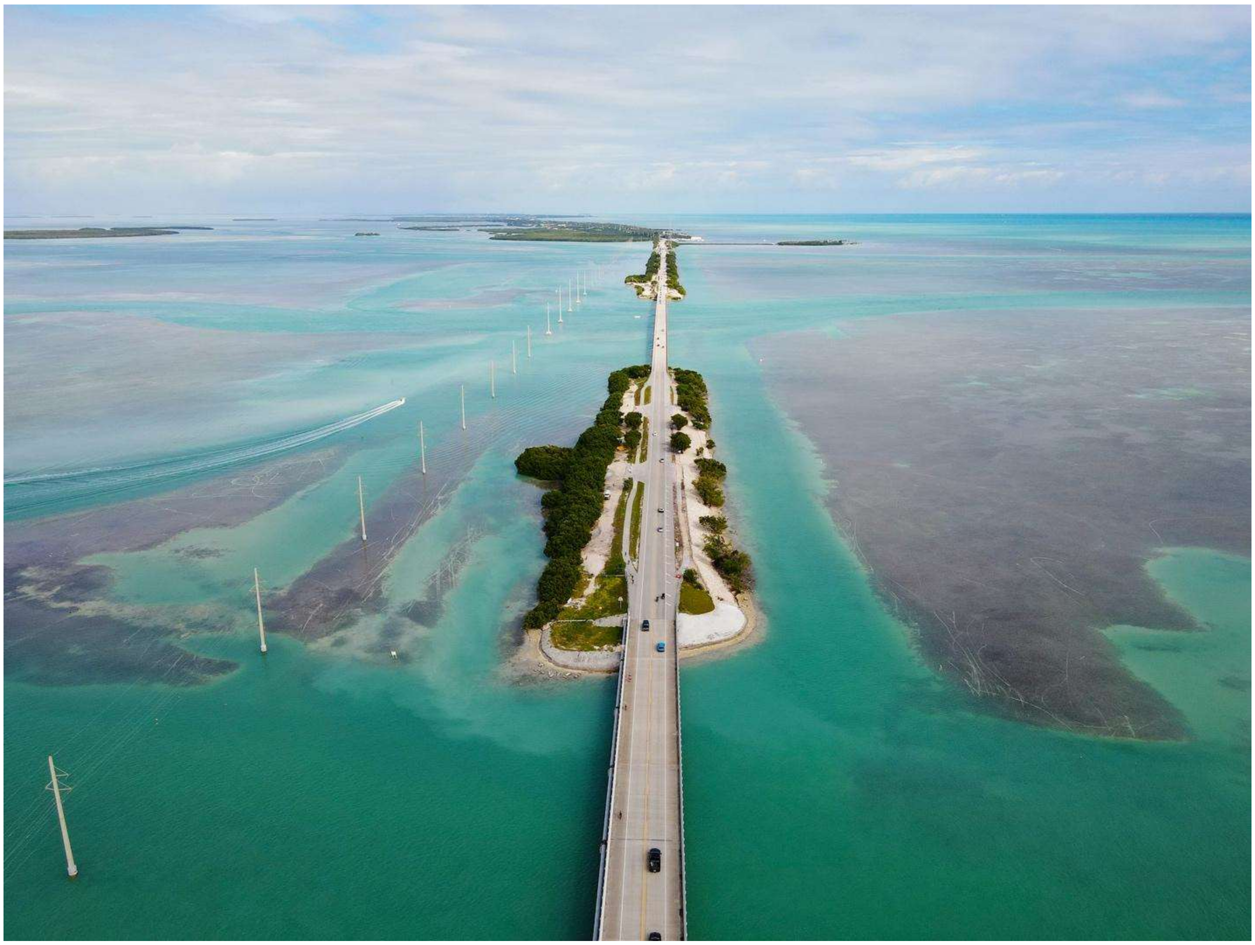


Figure 2.9. Overseas Highway One. Photo: Shoreline Conservation Initiative.

3. Population risk factors

A. Population overview

According to the US Census Bureau, the average residential population of Monroe County for the period of 2015-19 was 75,798 persons. From 1970 to 2019, the Florida Department of Health reports a near 40% increase in Monroe County's population. To control the rate of growth in the County and ensure that development did not outpace the resources of the island chain too quickly, and to ensure safe evacuation for residents during disasters, the Rate of Growth Ordinance (ROGO) was developed. The ROGO controls development density through the numbers of building allocations allowed within the County, by community.

Monroe County comprises three concentrated population areas: the Upper Keys, the Middle Keys, and the Lower Keys. Within these areas, the population and built-environment centers are Key Largo (Upper Keys), Marathon (Middle Keys), Big Pine Key (Lower Keys), and Key West. The land mass and populations are partitioned between the incorporated municipalities and the unincorporated areas of Monroe County. Key West, Marathon, Islamorada, and portions of Key Largo are incorporated tax entities for the purposes of assessment and service provision. The remaining communities are the jurisdiction of the County government. All entities work collaboratively to support the public health of visitors and residents through partnerships such as the County Commissioner's Health Services Advisory Board (HSAB).

Public transportation is available from Key West to Marathon with local and express services throughout the day. Services connect riders from Marathon to the mainland through a private firm which stops in the Upper Keys. This service links to Miami-Dade public transportation services in Florida City, just north of the Keys. Many residents and public officials seek to expand public transportation services along US 1 to reduce traffic on the primary transportation artery, increase accessibility for the local workforce, and to promote reduction of greenhouse gas emissions.

Table 3.1. Census tract 5-year (2014-2018) population estimates. Tracts are ordered from north to south.

Tract	Name	Population
9702	North Key Largo and Ocean Beach	1,060
9703	Sexton and Lake Surprise	2,282
9704	Pennecamp Park Area	3,779
9705	Rock Harbor	2,185
9706	South Key Largo	1,708
9707	Tavernier	2,852
9708	East Islamorada	4,303
9709	West Islamorada	1,578
9710.01	Key Colony Beach	1,117
9710.02	Layton and Duck Key	1,509
9711	Marathon Shores	3,770
9712	Central Marathon	2,350
9713	West Marathon	1,579
9714.01	Big Pine South	3,236
9714.02	Big Pine North	1,692
9715.01	Cudjoe Key	2,030
9715.02	Summerland, Ramrod, and the Torches	3,064
9716	Sugarloaf	2,150
9717	Big Coppitt	3,345
9718	Stock Island and Key Haven	5,634
9719	New Town East	6,402
9720	Key West Airport Area	3,556
9721	New Town West	4,788
9722	Truman Avenue Area	3,361
9723	Mallory Square	2,697
9724	Bahama Village	2,430
9725	Casa Marina	1,088
9726	Old Town Key West	763

Upper Keys

The Upper Keys stretch between Key Largo in the north to Islamorada in the south and encompass eight census tracts (Figure 3.1). The Upper Keys residential population is approximately 18,500 persons between mile markers 126 and 74. The most populous census tract is East Islamorada followed by Pennecamp Park Area in Key Largo (Table 3.1). The census tract with the lowest population is North Key Largo and Ocean Beach. The Upper Keys boasts some of the highest elevations in the County. As the northernmost area of the County, residents confront intense visitor traffic along the primary transportation artery, US Highway 1, which connects the County to the mainland of Florida and is maintained by the State of Florida. This area is closest to the mainland of Florida and also experiences a strong influx of daily workers from Miami-Dade. This transient workforce does not reside in the Keys and may be more likely to use health provider services nearer to their residences, except for emergency and work-related health concerns. The College of the Florida Keys, formerly a community college and now offering four-year accredited degrees, is currently constructing a campus in the Upper Keys.

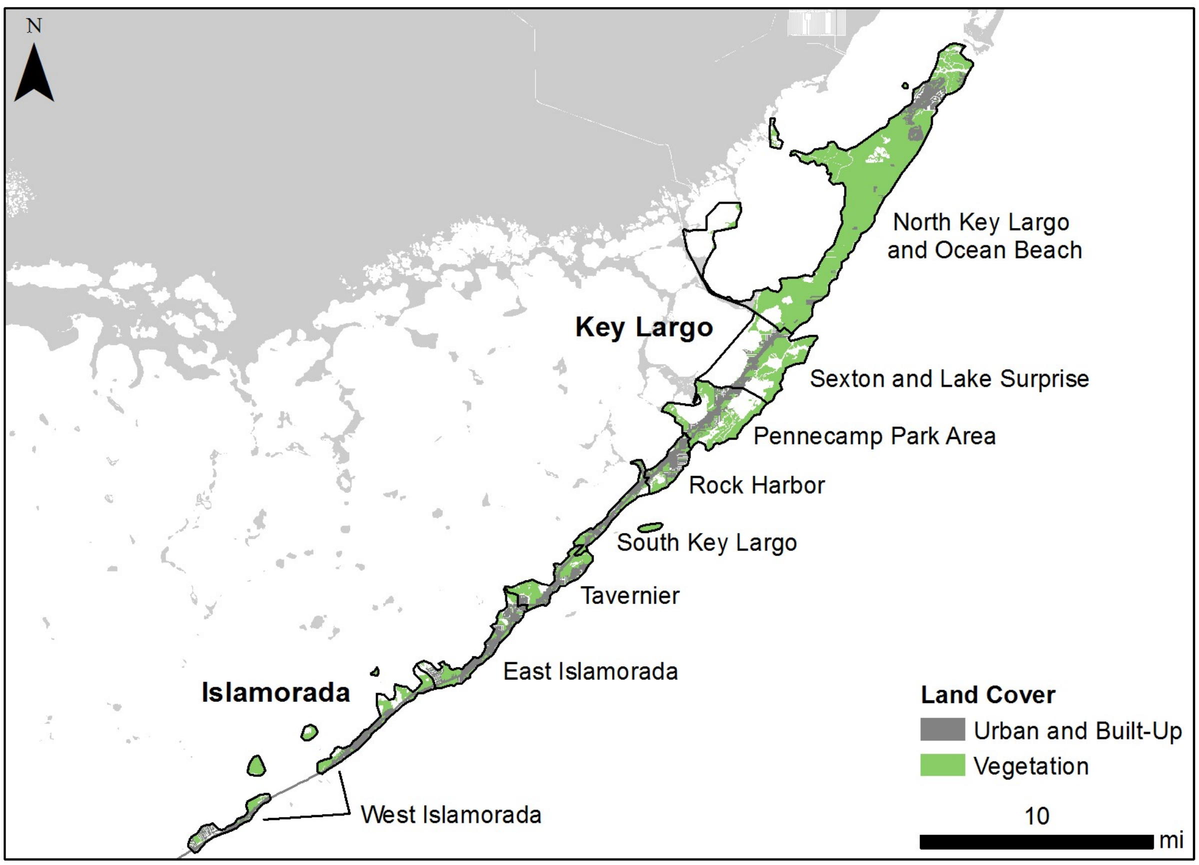


Figure 3.1. Census tracts in the Upper Keys showing vegetated and built land cover.

Figure 3.2. Key Largo coastline near Rodriguez Key. Photo: Shoreline Conservation Initiative.

Middle Keys

The Middle Keys range from Layton to Marathon (mile marker 74 to 48) and are home to approximately 12,000 persons in five census-tracts (Figure 3.3). The highest population resides in Marathon Shores and the least populated census tract is Layton and Duck Key (Table 3.1). Middle Keys residents also contend with pedestrian safety and traffic issues along US 1. Homelessness is among priority community health concerns in the Marathon community. Limited and scarce tree canopy in the Middle Keys can make outdoor work in periods of high heat hazardous, limit outdoor mobility for persons with existing chronic diseases, and increase exposure to cancer-promoting ultraviolet sun rays. Mental and substance abuse services, as well as affordability of care, were noted as priority concerns in the 2015 FLDOH, West Marathon Micro-Community Health Profile (FLDOH 2015). There are homeless camps in the City of Marathon, as well as live aboard boating communities. The City of Marathon and the Middle Keys are also home to several aging mobile home parks and as a traditional fishing community has historically experienced cyclical poverty. The Marathon Highschool is used as a campus for the College of the Florida Keys.

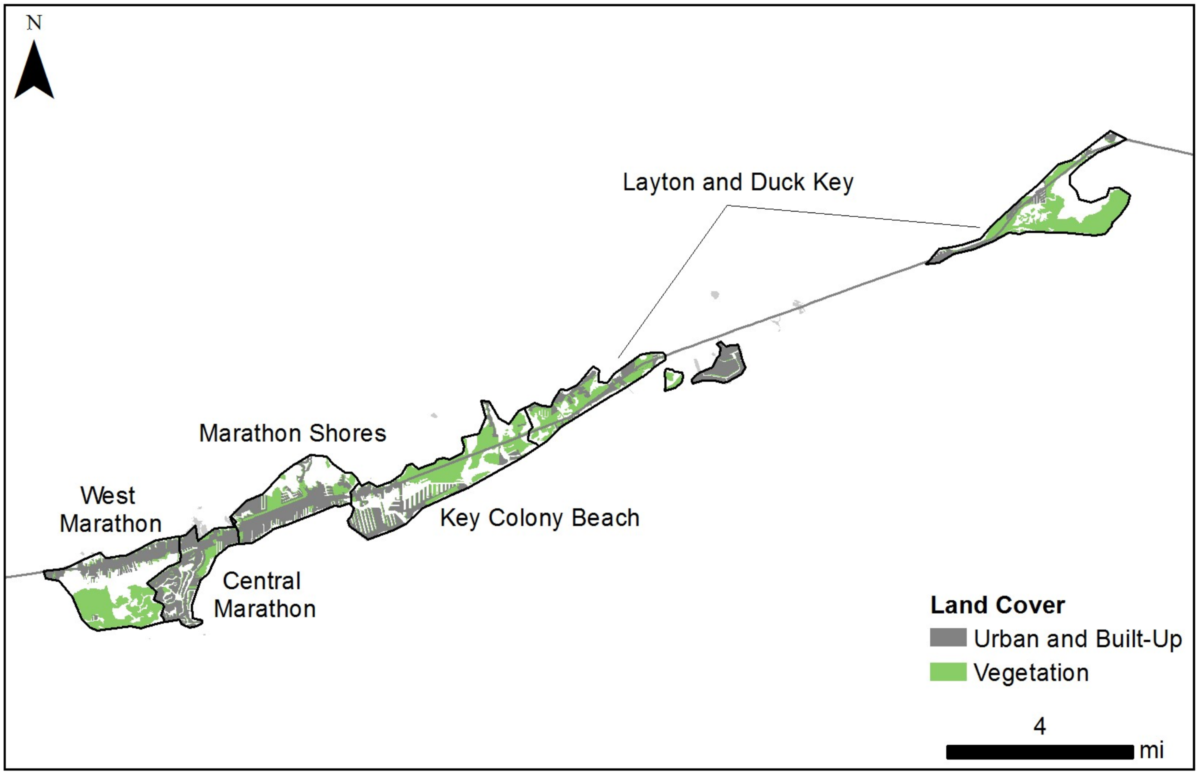


Figure 3.3. Census tracts in the Middle Keys showing vegetated and built land cover.

Lower Keys

The Lower Keys stretch from Big Pine Key to Key West and include 14 census tracts, seven of which are located within the City of Key West (Figure 3.4). The population of the Lower Keys totals around 46,000 residents of which about 25,000 live within the Key West city limits. This makes the Lower Keys the most populous area of the Florida Keys and Key West the largest population center. The most populous census tract in Key West and the entire Florida Keys is New Town East and the least populated is Old Town Key West (Table 3.1). The Lower Keys and Key West are concerned with pedestrian traffic safety and walkability of communities, because as like in many rural communities, sidewalks and other pedestrian safety features of the built environment are not present in many of the residential areas. Many Lower Keys neighborhoods have transitioned from mobile homes to elevated (pile supported) homes in recent years based on resilience standards in local building codes. Stormwater management in the neighborhoods is of primary concern for the local governments, as well as for property owners. Tourism is a primary employer throughout the region, along with the school district, government, and utility services. Key West is the focal point of the County's tourism industry and the County-seat.

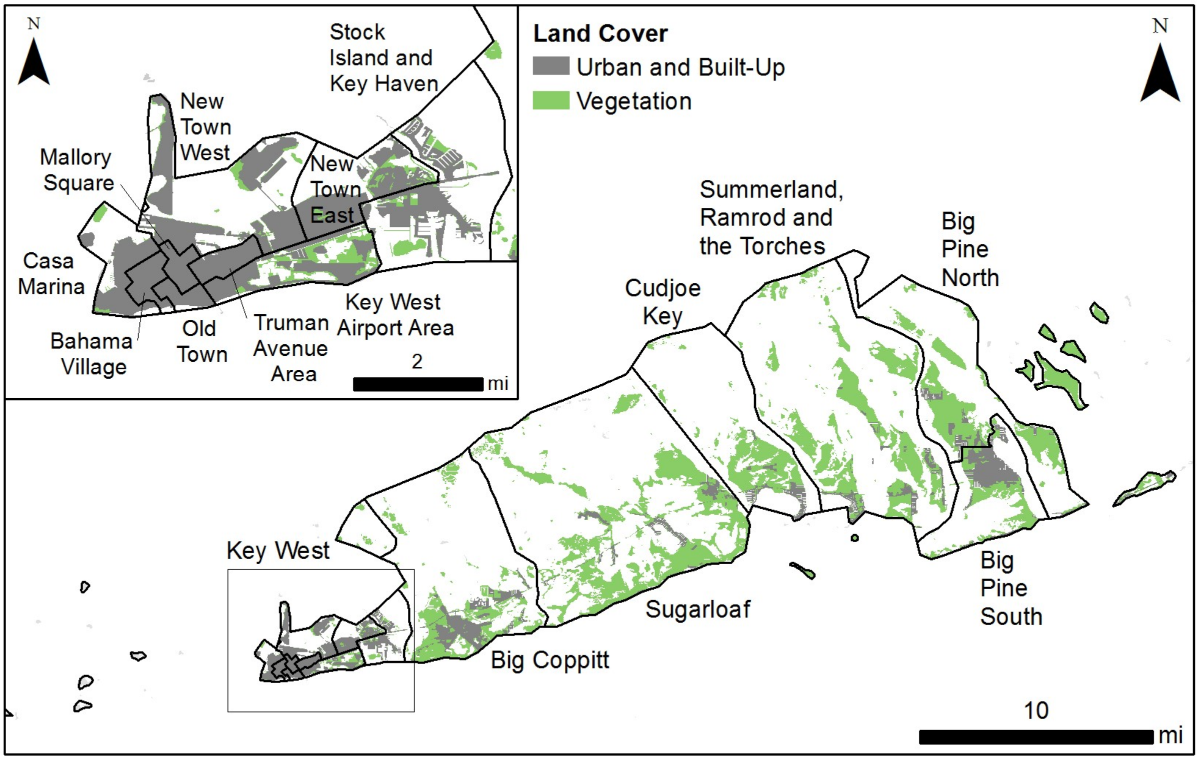


Figure 3.4. Census tracts in the Lower Keys showing vegetated and built land cover.

B. Social vulnerability

Social vulnerability describes those characteristics of the population that intervene between natural processes and the built environment to redistribute the risks and impacts of natural hazards across space (Birkmann 2006, Cutter et al. 2003). In other words, social vulnerability provides the human context on which hazards operate and creates an uneven capacity for preparedness, response, recovery, and adaptation to environmental threats in and across communities. Vulnerability is understood to be inherent within social systems, independent of hazards (Cutter et al. 2000 and 2003). In order to fully understand and characterize the impacts of climate change hazards on places, measures of the physical hazard and the environment must be combined with the social, economic, and demographic factors that influence the ability of a community to prepare, respond, recover, and ultimately adapt (Cutter et al. 2000).

The CDC social vulnerability index (SVI) uses US Census data to determine the social vulnerability of every census tract based on 15 social factors grouped into four themes: 1) socioeconomic status, 2) household composition and disability, 3) minority status and language, and 4) housing and transportation (Flanagan et al. 2011). The latest SVI data release is the CDC SVI 2018 which represents a five-year average of data from 2014-2018. We obtained CDC SVI data at the census tract level for Monroe County. To represent social vulnerability by census tract we used the overall tract summary ranking variable. Below we present the data by census tract for each variable incorporated in the SVI and organized by theme.

Socioeconomic status includes income, poverty, employment, and education variables. Economically disadvantaged populations are disproportionately affected by disasters. The poor are less likely to have the income or assets needed to prepare for a possible disaster or to recover after such a disaster (Cutter et al. 2003).

Table 3.2. Monroe County Socioeconomic variables by census tract ordered north to south. CDC.

	Socioeconomic			
Tract Name	**Persons below poverty**	**Civilian (age 16+) unemployed**	**Per capita income**	**Persons (age 25+) with no high school diploma**
North Key Largo and Ocean Beach	12.26%	3.02%	$129,749	3.49%
Sexton and Lake Surprise	13.67%	0.79%	$34,988	4.25%
Pennecamp Park Area	19.66%	2.01%	$31,280	14.16%
Rock Harbor	17.03%	0.00%	$49,019	5.68%
South Key Largo	13.00%	2.46%	$50,922	4.86%
Tavernier	5.54%	1.16%	$40,669	6.21%
East Islamorada	7.04%	0.84%	$60,175	5.16%
West Islamorada	7.48%	1.46%	$55,121	3.11%
Key Colony Beach	3.04%	0.45%	$69,180	3.04%
Layton and Duck Key	17.63%	0.13%	$46,230	4.11%
Marathon Shores	16.79%	1.25%	$42,331	8.20%
Central Marathon	8.26%	3.28%	$39,079	6.26%
West Marathon	17.61%	0.95%	$27,736	12.92%
Big Pine South	16.44%	1.51%	$33,187	6.98%
Big Pine North	7.27%	1.18%	$37,847	5.50%
Cudjoe Key	9.75%	1.28%	$53,961	3.00%
Summerland, Ramrod, and the Torches	7.73%	0.00%	$54,240	6.36%
Sugarloaf	4.28%	2.84%	$54,399	2.70%
Big Coppitt	7.80%	5.47%	$34,499	6.31%

Stock Island and Key Haven	13.10%	0.99%	$27,754	16.03%
New Town East	17.82%	2.72%	$27,912	8.14%
Key West Airport Area	9.76%	0.51%	$48,808	3.66%
New Town West	4.95%	2.46%	$30,217	3.40%
Truman Avenue Area	11.90%	1.19%	$44,769	3.63%
Mallory Square	7.64%	0.26%	$49,920	6.60%
Bahama Village	18.56%	0.86%	$53,085	6.09%
Casa Marina	2.48%	0.00%	$62,974	2.02%
Old Town Key West	13.37%	1.70%	$89,553	9.04%

Household composition and disability includes age, single parenting and disability variables. Household composition is defined to include children under 18, persons over 65, and single parent households. Persons with disabilities are also included. People in any of these categories are more likely to require financial support, transportation, medical care, or other assistance during disasters (Flanagan et al. 2011).

Table 3.3. Monroe County Housing Composition/ Disability variables by census tract ordered north to south. CDC.

	Housing Composition/Disability			
Tract Name	**Persons aged 65 and older estimate**	**Persons aged 17 and younger**	**Civilian non-institutionalized population with a disability estimate**	**Single parent household with children under 18**
North Key Largo and Ocean Beach	49.72%	4.91%	11.89%	1.89%
Sexton and Lake Surprise	16.78%	19.76%	17.13%	7.67%
Pennecamp Park Area	28.90%	13.26%	13.79%	1.67%
Rock Harbor	24.12%	20.46%	9.06%	2.33%
South Key Largo	37.06%	6.85%	13.88%	0.88%
Tavernier	19.60%	18.44%	12.10%	1.86%
East Islamorada	31.21%	12.34%	13.57%	1.16%
West Islamorada	28.58%	9.00%	8.49%	0.63%

Key Colony Beach	37.24%	9.13%	4.66%	1.61%
Layton and Duck Key	31.54%	8.61%	9.68%	1.86%
Marathon Shores	19.97%	21.70%	12.25%	4.80%
Central Marathon	26.51%	8.77%	8.51%	2.34%
West Marathon	22.61%	9.50%	12.73%	1.58%
Big Pine South	25.56%	14.52%	14.15%	1.70%
Big Pine North	19.74%	16.73%	14.72%	3.31%
Cudjoe Key	31.13%	7.68%	9.85%	0.69%
Summerland, Ramrod, and the Torches	28.04%	11.91%	10.38%	2.71%
Sugarloaf	19.44%	13.77%	11.91%	2.98%
Big Coppitt	12.53%	19.76%	6.85%	4.63%
Stock Island and Key Haven	13.37%	20.16%	13.01%	4.60%
New Town East	10.40%	19.81%	4.86%	3.05%
Key West Airport Area	23.00%	9.39%	19.12%	1.74%
New Town West	11.70%	25.56%	9.21%	2.21%
Truman Avenue Area	9.70%	15.44%	4.73%	1.81%
Mallory Square	15.72%	5.52%	7.27%	1.37%
Bahama Village	27.49%	11.81%	13.46%	6.21%
Casa Marina	24.45%	7.35%	5.15%	0.09%
Old Town Key West	19.13%	16.64%	6.29%	2.23%

Minority status and language includes race, ethnicity, and English language proficiency variables. The social and economic marginalization of certain ethnic groups has made these populations more vulnerable at all stages of disaster (Cutter et al. 2003). For individuals with limited English proficiency, disaster communication can be very difficult.

Table 3.4. Monroe County Minority Status/ Language variables by census tract ordered north to south. CDC.

	Minority Status/Language	
Tract Name	Minority (all persons except white, non-Hispanic)	Persons (age 5+) who speak English "less than well"
North Key Largo and Ocean Beach	8.11%	1.60%
Sexton and Lake Surprise	28.57%	1.80%
Pennecamp Park Area	34.85%	8.26%
Rock Harbor	17.16%	2.61%
South Key Largo	18.33%	0.59%
Tavernier	26.75%	4.38%
East Islamorada	14.69%	0.53%
West Islamorada	5.83%	0.82%
Key Colony Beach	30.44%	0.00%
Layton and Duck Key	21.54%	3.38%
Marathon Shores	51.67%	7.82%
Central Marathon	38.55%	13.70%
West Marathon	59.28%	17.04%
Big Pine South	21.32%	1.39%
Big Pine North	24.59%	3.31%
Cudjoe Key	8.13%	0.84%
Summerland, Ramrod, and the Torches	6.69%	1.73%
Sugarloaf	17.07%	2.42%
Big Coppitt	48.97%	0.00%
Stock Island and Key Haven	60.90%	13.90%
New Town East	46.03%	5.76%
Key West Airport Area	29.05%	0.84%
New Town West	42.61%	2.05%

Truman Avenue Area	47.52%	4.52%
Mallory Square	28.40%	6.01%
Bahama Village	38.93%	0.33%
Casa Marina	21.42%	1.19%
Old Town Key West	17.30%	1.44%

Housing and transportation includes housing structure, crowding, and vehicle access variables. Housing quality is an important factor in determining disaster vulnerability since poorly constructed or mobile homes are more vulnerable to storms and other hazards. Multi-unit housing as well as crowding within housing units can make evacuation difficult (Tierney 2006). Finally, transportation out of a disaster zone is problematic for individuals and families without access to a vehicle.

Table 3.5. Monroe County Housing Type/ Transportation variables by census tract ordered north to south. CDC.

	Housing Type/Transportation				
Tract Name	Housing in structures with 10 or more units	Mobile homes	At household level (occupied housing units), more people than rooms	Households with no vehicle available	Persons in group quarters estimate
North Key Largo and Ocean Beach	15.47%	4.62%	0.00%	1.98%	11.04%
Sexton and Lake Surprise	12.53%	24.19%	0.22%	2.89%	0.22%
Pennecamp Park Area	1.77%	29.06%	2.12%	0.90%	0.13%
Rock Harbor	3.48%	1.10%	0.96%	2.01%	0.59%
South Key Largo	25.64%	20.73%	0.00%	0.94%	1.99%
Tavernier	10.62%	17.32%	1.30%	0.95%	0.42%
East Islamorada	16.34%	0.46%	0.74%	1.46%	3.53%
West Islamorada	19.96%	6.97%	1.01%	1.20%	1.27%
Key Colony Beach	46.55%	0.36%	0.90%	0.90%	0.54%
Layton and Duck Key	6.30%	28.56%	0.66%	3.05%	11.07%
Marathon Shores	4.40%	5.62%	2.52%	1.64%	0.00%

Central Marathon	22.72%	6.77%	0.38%	4.64%	0.38%
West Marathon	5.89%	31.60%	2.03%	8.55%	17.35%
Big Pine South	0.40%	7.97%	2.56%	1.79%	2.60%
Big Pine North	0.95%	0.77%	0.00%	1.12%	0.00%
Cudjoe Key	0.49%	18.23%	1.38%	0.54%	0.00%
Summerland, Ramrod, and the Torches	1.27%	11.33%	0.88%	0.75%	0.00%
Sugarloaf	0.00%	4.51%	0.93%	0.00%	0.00%
Big Coppitt	3.56%	17.88%	1.29%	0.48%	0.00%
Stock Island and Key Haven	3.37%	11.84%	3.62%	3.57%	0.00%
New Town East	8.59%	5.31%	3.14%	1.97%	12.39%
Key West Airport Area	34.34%	0.56%	0.25%	3.60%	2.05%
New Town West	4.24%	0.00%	0.38%	2.17%	4.34%
Truman Avenue Area	0.00%	1.01%	1.90%	4.05%	2.14%
Mallory Square	1.08%	0.52%	1.97%	7.19%	0.85%
Bahama Village	7.70%	0.37%	1.19%	15.64%	0.00%
Casa Marina	28.40%	1.38%	0.00%	8.18%	10.39%
Old Town Key West	1.57%	7.99%	0.66%	7.21%	1.05%

C. Medical vulnerability

While social vulnerability focuses on socio-economic determinants, medical vulnerability focuses on health and medical determinants. Based on epidemiology and disaster surveillance literature, Morath (2010) identified three dimensions of medical vulnerability that contribute to a potential for harm: individual medical needs, community healthcare access, and health system capability.

Individual medical needs
This category of medical vulnerability focuses on individuals who are dependent on the public healthcare system for medication, medical treatment, equipment, or supervision from skilled medical professionals to maintain quality of health and life (Morath 2010). Individuals with chronic diseases are dependent on the healthcare system and several types of diseases have been shown to be particularly relevant to climate change hazards. Cardiovascular (Luber et al. 2006), respiratory (Szekely et al. 2015) renal disease (Semenza et al. 1999) and diabetes (Schwartz 2005) prevalence and deaths have all been shown to have a positive relationship

with ambient temperatures. In addition, respiratory diseases are exacerbated due to particulate matter and decreased air quality during and after storms. Loss of electricity during storms can impact dialysis procedures necessary for advanced renal diseases.

We estimated medical need by census tract based on publicly available information on death counts of climate-relevant diseases, which is a proxy for the prevalence of these diseases within each census tract. We downloaded this data for Monroe County at the census tract level from the Florida Department of Health Community Health Assessment Resources Tool Set (CHARTS) (http://www.flhealthcharts.com/Charts/default.aspx). Under "Causes of Death by Category" we selected all "Cardiovascular Diseases (I00-I99)", all "Respiratory Diseases (J00-J99)", all "Urinary Tract Diseases (N00-N99)", and "Diabetes Mellitus (E10-E14)" under the "Nutritional and Metabolic Diseases (E00-E99)" category. To align with the SVI 2018 data, we calculated a five-year average from 2014-2018 and summed the averages for each disease category to obtain an overall average for each census tract (Table 3.6).

Table 3.6. Five-year average (2014-2018) counts of death from climate relevant diseases by census tract, ordered north to south.

Census tract	Cardiovascular	Diabetes	Respiratory	Renal	Total
North Key Largo and Ocean Beach	4.4	0.2	2.2	0.4	7.2
Sexton and Lake Surprise	6.8	0.4	2	0	9.2
Pennecamp Park Area	10.4	1.2	2.4	0.6	14.6
Rock Harbor	7.6	0.4	2.8	1	11.8
South Key Largo	8.4	1	0.4	1	10.8
Tavernier	6.2	0.4	0.4	0	7
East Islamorada	15.6	1	3.4	0.8	20.8
West Islamorada	5.8	0.6	2.2	0.2	8.8
Key Colony Beach	5.4	0	1.2	0.2	6.8
Layton and Duck Key	5.8	0.6	2	0.2	8.6
Marathon Shores	6.8	0.6	1.8	0	9.2
Central Marathon	7.2	0.4	1.2	0.2	9
West Marathon	6	0.2	1.4	0.2	7.8
Big Pine South	6.8	0.4	1.4	0.6	9.2
Big Pine North	3.4	0	0.4	0	3.8
Cudjoe Key	5.6	0	1	0.4	7
Summerland, Ramrod, and the Torches	6.6	0.4	2.8	0.4	10.2

Sugarloaf	3.6	0.2	1.2	0.2	5.2
Big Coppitt	5.4	0.8	1.2	0.4	7.8
Stock Island and Key Haven	9.8	0.8	3	0.4	14
New Town East	18.8	0.6	6	1.2	26.6
Key West Airport Area	11.6	0.6	2.2	0.4	14.8
New Town West	14.4	1	4.4	1	20.8
Truman Avenue Area	7.8	0.6	1.2	0.4	10
Mallory Square	7.2	0.2	1.2	0.6	9.2
Bahama Village	10.2	0.2	1.6	0.4	12.4
Casa Marina	1	0	0.6	0	1.6
Old Town Key West	3.2	0.2	0.8	0.4	4.6

Community healthcare access

This category of medical vulnerability focuses on individuals or communities with limited access to healthcare resources, either through direct local scarcity of healthcare providers or through financial proxies, such as insurance status (Morath 2010). We estimated local scarcity of healthcare providers by calculating the total number of healthcare facilities within a five-mile radius of communities within each census tract. The healthcare facilities of the Florida Keys are discussed in detail in Section 4.

Figure 3.5. Temporary facilities at Fishermen's Community Hospital in Marathon while the main facility is rebuilt following hurricane storm damage. Photo: Shoreline Conservation Initiative.

Health system capability

This category of medical vulnerability relates to resources maintained by the local healthcare system to prepare for emergencies and help build medical surge capacity during disasters. Although information relevant to health system capability at the census tract level was not available, regionally-relevant information is discussed below.

Recognizing that the most commonly prepared-for hazard is a hurricane, emergency shelters within Monroe County are designated for storms of Categories 1 and 2. Monroe County's Emergency Management Department indicates that for hurricanes of Category 3 or higher, no shelters will be available and evacuation orders apply to all. After an evacuation has been ordered, anyone choosing to stay will not be able to get medical, fire rescue, or law enforcement assistance until storm conditions subside, roads are made passable, and equipment is operable. In the event that evacuations can be ordered in advance of disasters through public health warning systems, mainland shelters in Miami-Dade County open to receive Monroe County residents. Shelter partners include Florida International University and the Miami-Dade County Civic Center.

Monroe County operates emergency services in the unincorporated areas of the County and incorporated areas operate emergency services in their jurisdictions in partnership with the County. Because there are no trauma centers, trauma treatment facilities, or other highly specialized emergency care services within the Monroe County healthcare system, a public-private partnership was established to provide helicopter transport of trauma victims and high-risk patients out of the County to the nearest treatment facility.

4. Health and community infrastructure

A. Medical care facilities

For the purpose of this report, medical facilities located within Monroe County are divided into four main categories: Hospitals, Primary Care, Urgent Care, and Emergency Medical Services (EMS). The availability of each type of facility varies throughout the Keys, which in turn affects the vulnerability each community has to certain types of emergencies. The four facility types are described as follows:

Hospitals are the largest and best-equipped medical facilities in Monroe County, as well as the least-abundant. These facilities will be the most important medical resource for the community when faced with a major disaster or other emergency. As such, identifying vulnerabilities and implementing resilience strategies in these facilities should be considered the highest priority.

Primary care facilities provide an important subset of medical services, particularly in support of the prevention of chronic illnesses. These facilities can also be considered the second line of defense, along with Urgent Care facilities, when the community is faced with a large-scale emergency or disaster. A notable scenario would be if the Fishermen's Community Hospital were to experience catastrophic damage, the nearest hospital for residents of the Middle Keys could be over 40 miles away. In this case it would be critical for Primary Care facilities to have implemented resilience strategies and continue operating to fill the medical needs of the community.

Urgent care facilities provide an important alternative to hospitals and primary care facilities, particularly for the treatment of minor injuries and illnesses. These facilities will also be critically important if a hospital is damaged or otherwise not accessible. These facilities are likely better equipped to provide emergency care than primary care facilities, and therefore should implement resilience strategies that allow them to continue to provide those services through a disaster or emergency situation.

Emergency Medical Services (EMS) such as ambulance, fire, and rescue will become increasingly important as climate change related hazards become more frequent and widespread. They are also a critical lifeline for community members who live in remote areas away from hospitals and urgent care facilities.

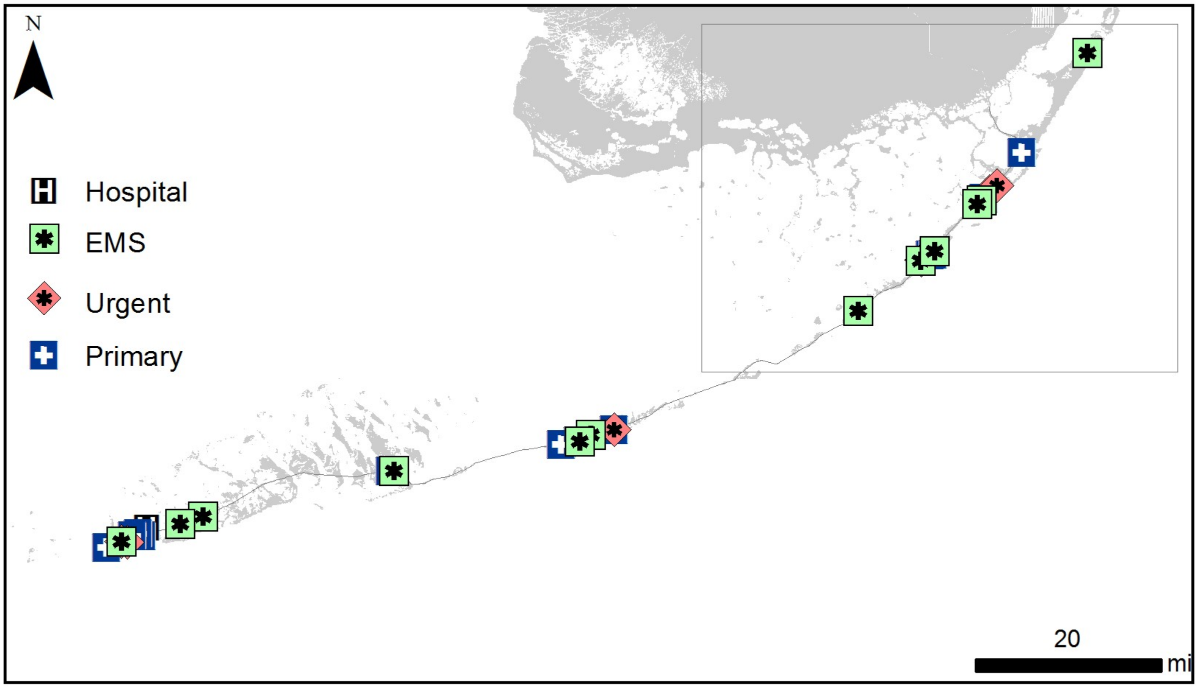
In the following sections we describe and list the healthcare facilities in each region of the Florida Keys. In the tables provided, we also indicate potential flooding of each facility due to both storm surge and sea level rise. Projected flooding from hurricane storm surge was based on storm surge zones from the Florida Statewide Regional Evacuation Studies (https://www.floridadisaster.org/res) and provided by the Florida Geographic Information Office (https://www.floridagio.gov/). These storm surge zones are a compilation of The National Weather Service (NWS) National Hurricane Center (NHC) hydrodynamic SLOSH model outputs which simulate storm surges along the U.S. East and Gulf Coasts. Projected flooding from sea level rise was based on the 2020 updated sea level rise projections for 2040, 2070, and 2100 downloaded from the University of Florida GeoPlan Center's Sea Level Scenario Sketch Planning Tool (https://sls.geoplan.ufl.edu/). To align with the Unified Sea Level Rise Projection for Southeast Florida (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact), 2020), we selected the NOAA Intermediate-High Curve.

Upper Keys

In the Upper Keys there is one hospital, three community health clinics, and a number of private care providers and urgent care facilities (Figure 4.1). The hospital is an affiliate of the large and regionally extensive Baptist Health Network, and the clinics are operated by Community Health of South Florida, Inc. (CHI) and the Good Health Clinic. CHI will also soon be opening a second facility in Key Largo. In addition to medical care facilities, the Upper Keys have several EMS service providers. Most of these facilities are expected to experience storm surge flooding from a Category 3 storm based on the storm surge zone within which they are located, with one urgent care and two EMS providers located within storm surge zones 4 or 5 (Table 4.1). None of the healthcare facilities in the Upper Keys will be affected by flooding from sea level rise with the exception of one urgent care and one EMS facility expected to experience flooding from sea level rise by the year 2100 (Table 4.1).

Table 4.1. Medical care facilities in the Upper Keys. The storm surge zones represent the maximum inundation zones for the category of storm indicated (Saffir-Simpson hurricane wind scale, Category 1-5) corresponding to the location of each facility. The SLR flooding year represents the year that each facility location is expected to experience flooding based on the NOAA Intermediate-High Curve projections of MHHW for 2040, 2070, and 2100.

Name	Facility Type	Storm Surge Zone	SLR Flooding Year
Mariners Hospital	Hospital	3	
CHI Tavernier	Primary Care	3	
CHI Key Largo	Primary Care	3	
Good Health Clinic	Primary Care	3	
Key Largo VA clinic	Primary Care	3	
Advanced Urgent Care	Urgent Care	3	
ASAP urgent care	Urgent Care	1	2100
A-1 Urgent Care	Urgent Care	4	
Islamorada Fire Rescue Dept. (Station 21)	EMS	1	2100
Tavernier Fire Rescue Dept.	EMS	3	
Key Largo Fire Rescue Dept.	EMS	4	
Ocean Reef Public Safety Dept.	EMS	2	
Key Largo Volunteer Ambulance Corps	EMS	5	
Islamorada Fire Rescue Dept. (Station 20)	EMS	3	



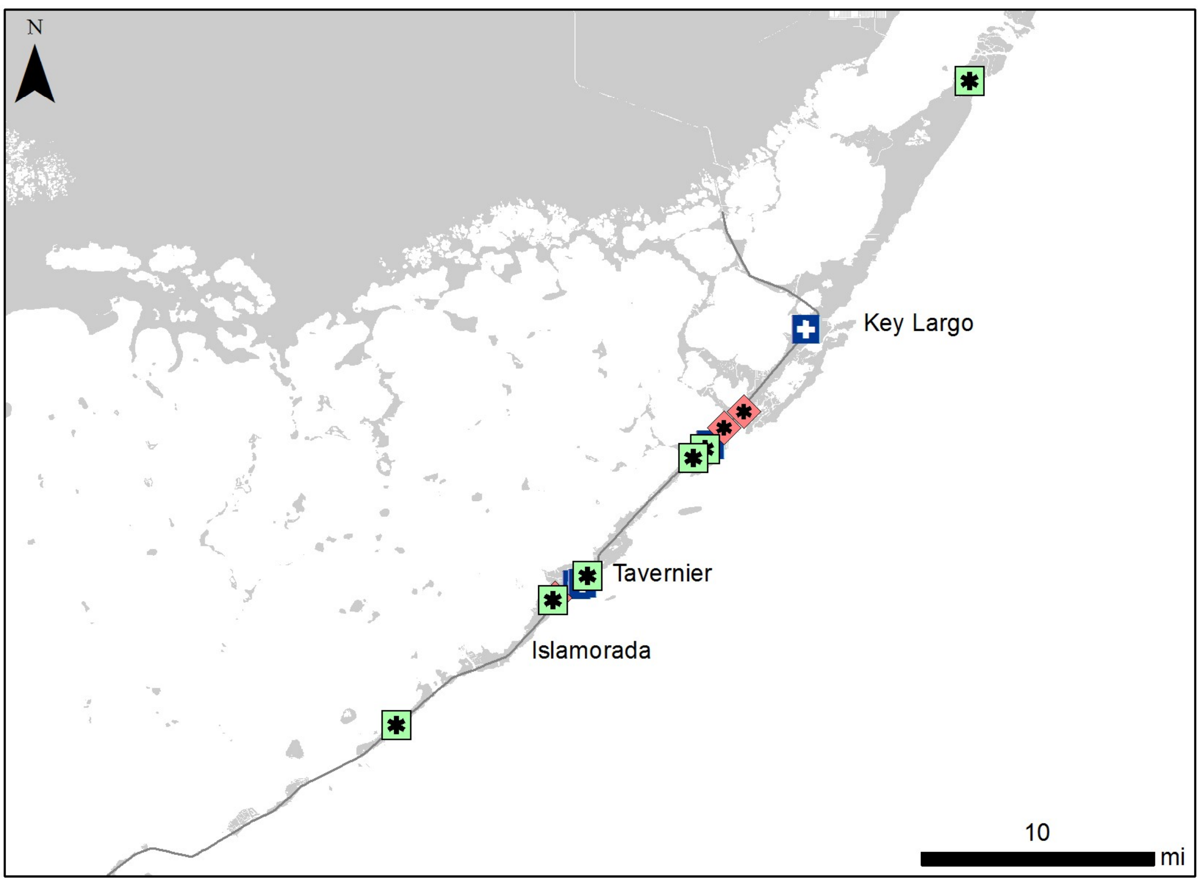


Figure 4.1. Medical facility locations across the Florida Keys (upper panel), and in the Upper Keys (lower panel).

Middle Keys

The Middle Keys have one hospital, three community health clinics, and a number of private care providers and urgent care facilities (Figure 4.2 & 4.3). The Fishermen's Community Hospital is also an affiliate of the Baptist Health Network. The three community health clinics are operated by Community Health of South Florida, Inc., the Baptist Network, and Good Health Clinic. Limited private care providers, urgent care, and EMS services also exist within the Middle Keys. The hospital is expected to experience storm surge flooding from a Category 4 storm. The clinics and urgent care facilities are generally less resilient, expected to experience storm surge flooding from Category 1 or 2 storms (Table 4.2). Several facilities are projected to experience flooding from sea level rise by the year 2070, while the CHI clinic in Marathon may be inundated by the year 2100 (Table 4.2).

Figure 4.2. Community Health of South Florida (CHI) clinic in Marathon. Photo: Shoreline Conservation Initiative.

Table 4.2. Medical Care Facilities in the Middle Keys. The storm surge zones represent the maximum inundation zones for the category of storm indicated (Saffir-Simpson hurricane wind scale, Category 1-5) corresponding to the location of each facility. The SLR flooding year represents the year that each facility location is expected to experience flooding based on the NOAA Intermediate-High Curve projections of MHHW for 2040, 2070, and 2100.

Name	Facility Type	Storm Surge Zone	SLR Flooding Year
Fishermen's Community Hospital	Hospital	4	
Baptist Health	Primary Care	2	
CHI Marathon	Primary Care	2	2100
Good Health Clinic	Primary Care	1	2070
Advanced Urgent Care	Urgent Care	1	2070
Marathon Fire Rescue Station	EMS	4	
Monroe County Fire Rescue	EMS		2070

Lower Keys

The Lower Keys have one hospital, four community health clinics, and a number of private care providers and urgent care facilities (Figure 4.3). The hospital, Lower Keys Medical Center, is vulnerable to flooding from hurricane storm surge, only rated to remain dry up to a Category 2 storm (Table 4.3). With the large, concentrated population in the Lower Keys that this hospital serves, the susceptibility to storm surge should be a primary target for mitigation. The Lower Keys is home to four community health clinics that are open to the public, as well as 2 urgent care facilities and several EMS service providers. The new Key West CHI clinic is not projected to experience flooding until a Category 3 storm (Table 4.3). The other clinics and urgent care facilities are generally less resilient, expected to experience flooding during Category 1 or 2 storms. The EMS facilities are also generally vulnerable, with most of the providers susceptible to Category 1 storm surge. Most of the facilities in the Lower Keys are projected to undergo flooding by either 2070 or 2100 (Table 4.3).

Table 4.3. Medical Care Facilities in the Lower Keys. The storm surge zones represent the maximum inundation zones for the category of storm indicated (Saffir-Simpson hurricane wind scale, Category 1-5) corresponding to the location of each facility. The SLR flooding year represents the year that each facility location is expected to experience flooding based on the NOAA Intermediate-High Curve projections of MHHW for 2040, 2070, and 2100.

Name	Facility Type	Storm Surge Zone	SLR Flooding Year
Lower Keys Medical Center	Hospital	2	2100
Big Pine Medical	Primary Care	1	2070
Key West VA Clinic	Primary Care	4	
CHI Key West	Primary Care	3	2100
Rural Health Network of Monroe County	Primary Care	2	2100
Keys Medical Group	Primary Care	1	2100
Advanced Urgent Care	Urgent Care	1	2070
Key West Urgent Care	Urgent Care	1	2070
Keys Emergency Medical Services Inc	EMS	1	2100
American Medical Response	EMS	1	2070
Big Coppitt Fire Rescue	EMS	3	
Naval Air Facility Key West Fire and Rescue Services (3 stations)	EMS	1	2100

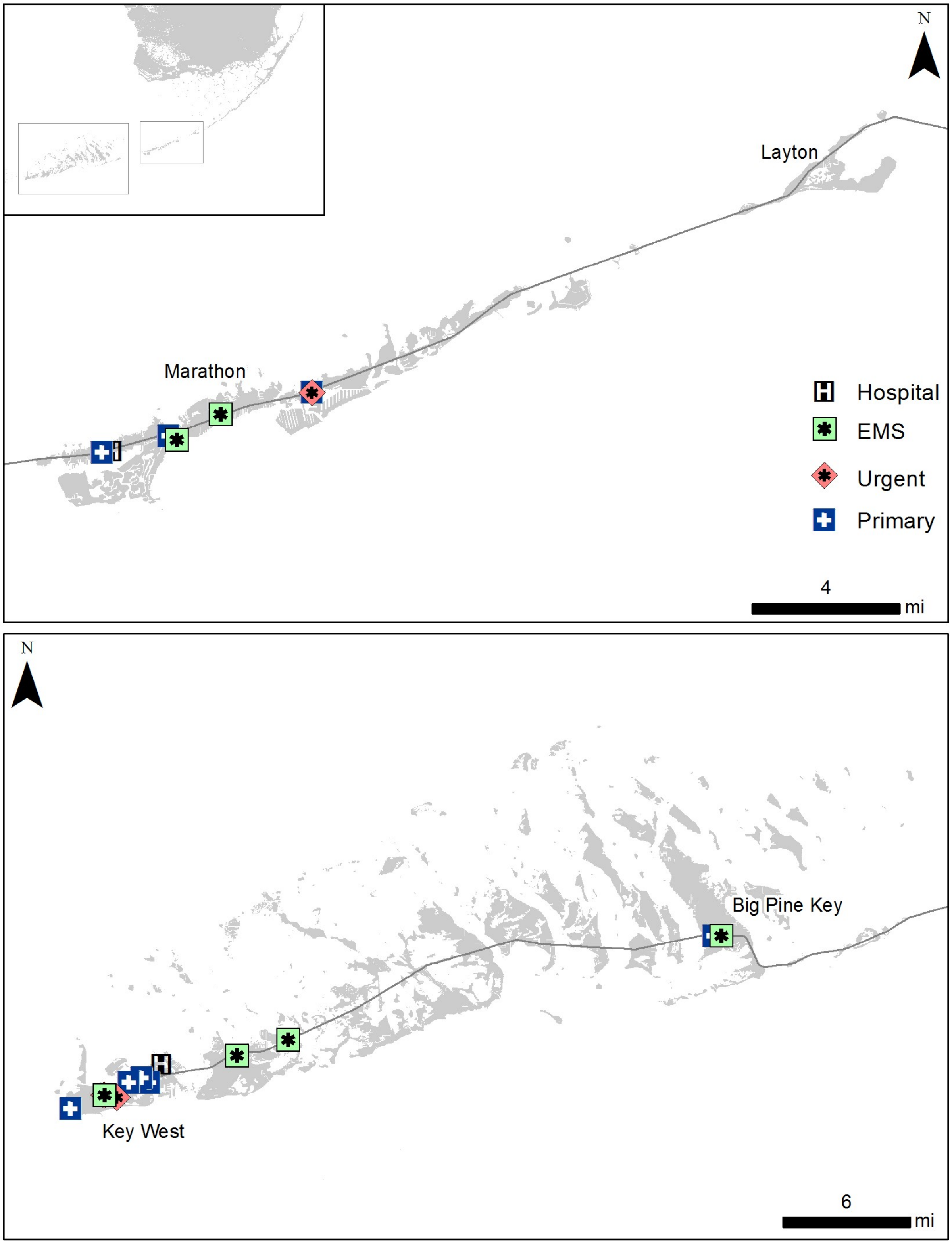


Figure 4.3. Medical facility locations in the Middle (upper panel) and Lower (lower panel) Keys

B. Non-medical critical infrastructure

Community infrastructure on which medical facilities rely is important to consider in order to achieve a comprehensive understanding of climate change related hazards to healthcare facilities and related services. In Monroe County, vulnerabilities to non-medical infrastructure revolve primarily around flooding due to low elevation, and the precariousness of having a single utility and transportation corridor on which the entire length of the Florida Keys rely. Specific vulnerabilities are covered extensively in resources like the Monroe County Local Mitigation Strategy (Wood Environment and Infrastructure Solutions, Inc. 2020), the USACE Florida Keys Coastal Storm Risk Management Feasibility Study (USACE. 2020), and the Greenkeys! Sustainability Action Plan (Monroe County, 2016). Critical infrastructure vulnerable to climate change related hazards in the Florida Keys include:

- Telecommunications
- Roadways
- Fire / EMS
- Schools
- Airports
- Sea Ports
- Electrical Infrastructure
- Water Treatment & Distribution
- Stormwater & Wastewater
- Solid waste facilities

Infrastructure at the highest risk of flooding in Monroe County include transportation infrastructure like roads and airports, as well as critical facilities located at low elevations. Facilities like schools are also important to consider when building resilience, because destruction of, or damage to those types of facilities can delay a community's ability to fully recover from disasters. The single corridor that contains the primary transportation route, electrical supply, water supply, and data connection presents a unique challenge to the Florida Keys. At the overall County level, strengthening the infrastructure that comprises the corridor may be the most effective single goal for building resilience for the Keys.

The water supply to the keys is particularly vulnerable. Water is pumped from the Biscayne aquifer located north of Monroe County, which has its own set of unique vulnerabilities to climate change. Saltwater infiltration as well as surface contamination from flooding and/or pollution are hazards that will continue to accelerate with climate change. Vulnerabilities to the Biscayne Aquifer are covered in additional detail in the Origins and Delineation of Saltwater Intrusion in the Biscayne Aquifer and Changes in the Distribution of Saltwater in Miami-Dade County, Florida (USGS 2014) and section HA-730G of the Ground Water Atlas of the United States (USGS 1990).

5. Mapping health vulnerability under climate change

A. Analysis methods and data sources

This vulnerability assessment was conducted following the CDC's guidance in their *Assessing Health Vulnerability to Climate Change* guidance document (Manangan et al. 2014). A comprehensive effort was made to identify all publicly available data relevant to climate change hazards and associated health impacts at the smallest possible administrative unit. Data representing vulnerability to climate change hazards as well as social and medical vulnerability were assembled at the census-tract level. Climate change hazard measures included 1) projected flooding from hurricane storm surge, 2) projected flooding from sea level rise, and 3) vulnerability to extreme heat. Across the Florida Keys there is little variation in susceptibility to hurricane landfall/ winds, so this was not included in the analysis with the assumption that exposure is generally consistent along the island chain. Wildfires and reduced air quality are other climate related hazards that are much less relevant in the Florida Keys compared to other areas of the country and were not included. Social vulnerability was represented by the SVI, medical vulnerability was represented by climate relevant disease burden and community access to healthcare.

Projected flooding from hurricane storm surge was calculated by using the storm surge zones from the Florida Statewide Regional Evacuation Studies (https://www.floridadisaster.org/res) and provided by the Florida Geographic Information Office (https://www.floridagio.gov/). These storm surge zones are a compilation of The National Weather Service (NWS) National Hurricane Center (NHC) hydrodynamic SLOSH model outputs which simulate storm surges along the U.S. East and Gulf Coasts. For the purpose of this analysis, we selected the storm surge zone representing flooding impacts from a Category 1 hurricane. We then calculated the percent land area with projected flooding in each census tract.

Projected flooding from sea level rise was calculated using the 2020 updated sea level rise projections downloaded from the University of Florida GeoPlan Center's Sea Level Scenario Sketch Planning Tool (https://sls.geoplan.ufl.edu/). To align with the Unified Sea Level Rise Projection for Southeast Florida (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact), 2020), we selected the NOAA Intermediate-High Curve and for the purpose of this analysis, the year 2040. We then calculated the percent land area with projected flooding in each census tract.

Vulnerability to extreme heat was represented by percent of built land cover by census tract. Neighborhoods with sparse vegetation have been associated with higher ambient temperatures (Harlan et al. 2006) which can increase heat exposure for individuals. We used a statewide land use/ land cover dataset downloaded from the Florida Department of Environmental Protection (https://geodata.dep.state.fl.us/) to calculate percent impervious surfaces by census tract. At the scale of the Florida Keys, there is little variation in temperatures and we assumed that climatological exposure is generally consistent.

Social vulnerability was represented by the CDC's Social Vulnerability Index (SVI) which was discussed in detail in Section 3B. We downloaded the most current SVI data for Florida census tracts in shapefile format from the federal Agency for Toxic Substances and Disease Registry (https://www.atsdr.cdc.gov/placeandhealth/svi/index.html). The latest SVI data release is the CDC SVI 2018 which represents a five-year average of data from 2014-2018. For the purpose of this analysis, we used the overall tract summary ranking variable which represents a percentile ranking of all census tracts in the state of Florida.

For medical needs, we were limited to publicly available data on climate relevant diseases. We utilized combined death counts due to cardiovascular, respiratory, and renal diseases as well as diabetes. Each of these disease categories are susceptible to climate hazards through increases in heat, stress, and electricity-dependent treatments. We downloaded this data for Monroe County at the census tract level from the Florida Department of Health Community Health Assessment Resources Tool Set (CHARTS) (http://www.flhealthcharts.com/Charts/default.aspx). Death counts by census tract were converted to a percentage of total population for each census tract. To represent vulnerability in terms of community healthcare access, we calculated scarcity of healthcare providers in terms of total number of healthcare facilities (hospitals, EMS, urgent care, primary care) located within a five-mile radius of the developed areas within each census tract, defined by the statewide land use/ land cover dataset referenced earlier.

Data for each of the above measures was classified by geometric interval classification into four scores (1-4) with a higher score indicating higher vulnerability. This classification scheme was implemented in ArcGIS and the algorithm creates geometric intervals by minimizing the sum of squares of the number of elements in each class. This ensures that each class range has approximately the same number of values and that the change between intervals is fairly consistent. This is an improvement over the quartile classification method which misrepresents values if the underlying distribution is skewed. An example of this is our storm-surge and SLR flooding datasets where the majority of census tracts in the Florida Keys are highly vulnerable due to low elevations. The geometric interval classification more accurately depicted these patterns compared to other classification methods. Scores for the number of healthcare facilities were reversed so that a higher score reflected a lower number of facilities and, therefore, higher vulnerability. In this way, all six variables represented risk/vulnerability for health impacts from climate change hazards. Finally, the scores for each climate health vulnerability measure were added together in an overlay analysis to provide an index of climate health vulnerability which was also classified into four scores for mapping purposes.

B. Results

Percent inundation by census tract from flooding due to storm surge from a Category 1 hurricane ranged from 8% to 97%. Vulnerability to storm surge is highest in the Lower Keys with the exception of Key West (Figure 5.1). Layton and Duck Key are also highly vulnerable to storm surge due to low elevations. Key West has generally low vulnerability to storm surge except for the area around the airport. The Upper Keys generally have medium-low vulnerability to storm surge (Figure 5.1). Percent inundation by census tract from flooding due to sea level rise based on the NOAA Intermediate-High Curve for the year 2040 ranged from 0% to 76%. Vulnerability to sea level rise is similar to storm surge in the case of the Lower Keys, high and decreasing towards Key West which has low vulnerability (Figure 5.1). North of the Lower Keys, the highest vulnerability to flooding from sea level rise is in West Marathon and North Key Largo. Percent of built land cover by census tract, an indicator of vulnerability to extreme heat, ranged from 1% to 100%. Vulnerability to extreme heat is highest in the most urbanized areas including most of Key West as well as Central Marathon and Marathon Shores, East Islamorada, and Rock Harbor (Figure 5.1).

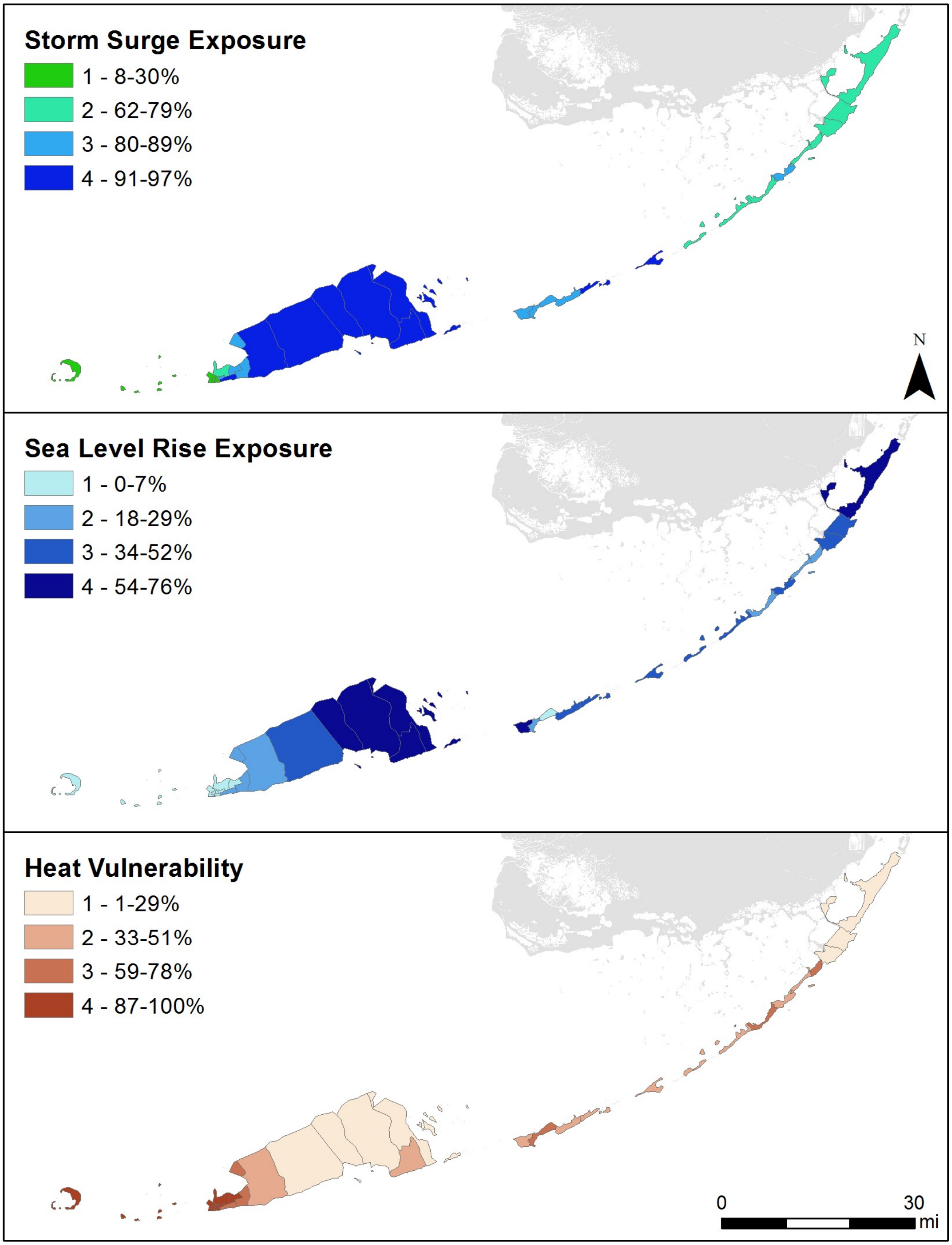


Figure 5.1. Census tract vulnerability rankings with indicator ranges shown for storm surge (% inundation), sea level rise (% inundation), and extreme heat (% urbanization).

The CDC SVI indicated the census tracts of the Florida Keys ranged from 7% to 81% in terms of social vulnerability relative to all census tracts in Florida. Social vulnerability is highest in the Sexton/Lake Surprise areas of Key Largo in the Upper Keys; West Marathon and Marathon Shores in the Middle Keys; and the Stock Island, Key Haven and New Town East communities of Key West (Figure 5.2). Percentage of total population of each census tract that died from climate relevant diseases, an indication of medical vulnerability, ranged from 0.15% to 0.68%. Medical vulnerability was high across much of the Upper Keys with the exception of Pennecamp Park and Tavernier and the Middle Keys with the exception of Marathon Shores and Central Marathon (Figure 5.2). The Lower Keys had generally low medical vulnerability except for Old Town Key West which was highly vulnerable and Bahama Village, New Town West and East, and the Airport area which all had medium-high medical vulnerability. Finally, the number of healthcare facilities located within a five-mile radius of the developed areas within each census tract ranged from 2 to 12 facilities. Lack of healthcare access was highest in the more remote communities including North Key Largo and West Islamorada in the Upper Keys; Layton and Duck Key in the Middle Keys; and the Big Pine communities, Summerland, Ramrod, and the Torches, as well as Sugarloaf in the Lower Keys (Figure 5.2).

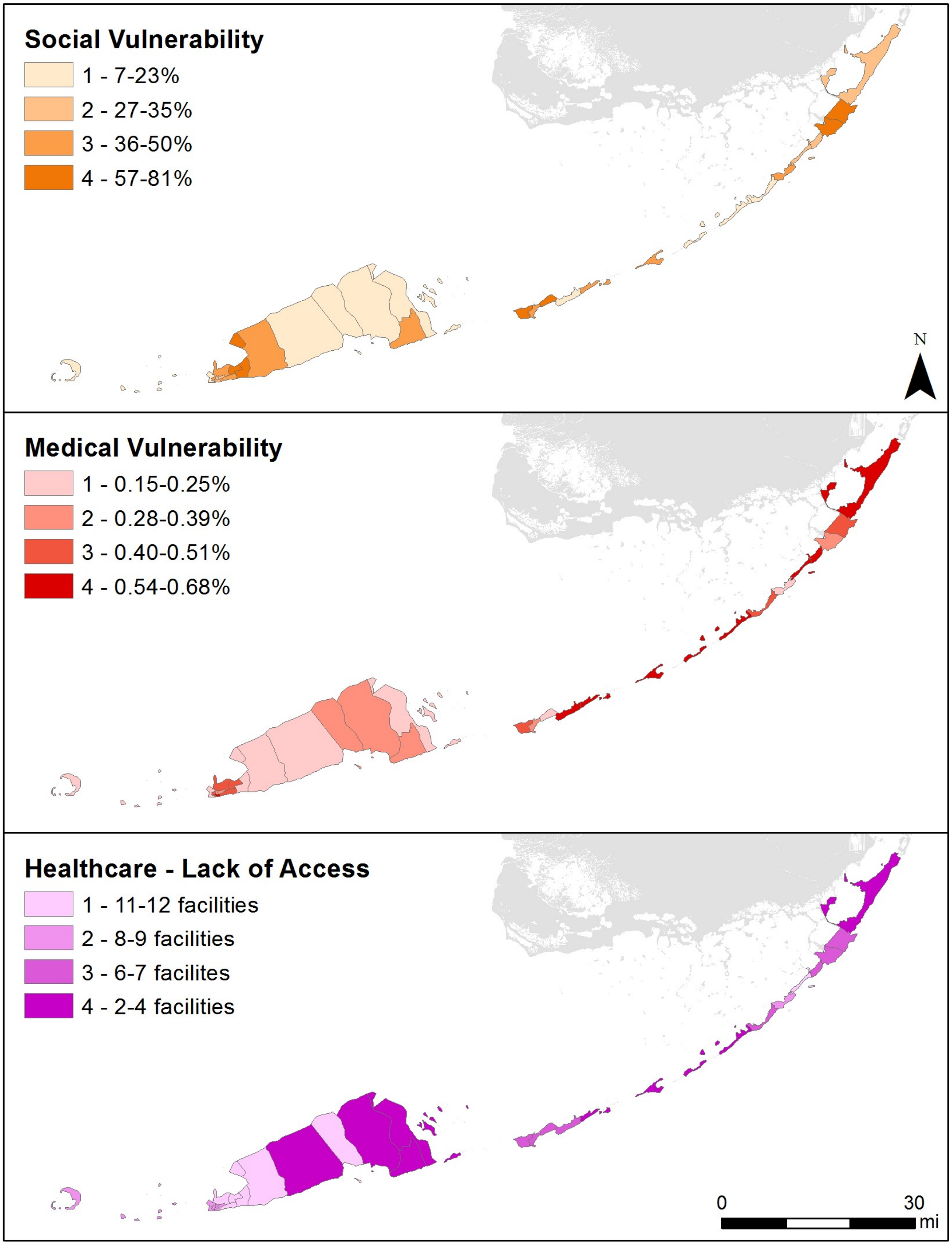


Figure 5.2. Vulnerability rankings with ranges shown for social (SVI percentile ranking), medical (% population deaths from climate relevant diseases), and access to healthcare (number of healthcare facilities within 5 mi).

When combining all six vulnerability measures into a composite index of vulnerability to health impacts from climate change, North Key Largo, Layton and Duck Key, West Marathon, and Big Pine South emerge as the communities with the highest vulnerability (Figures 5.3 & 5.4). Conversely, South Key Largo, Cudjoe Key, Big Coppitt, and Casa marina are the communities with the lowest vulnerability (Figures 5.3 & 5.4).

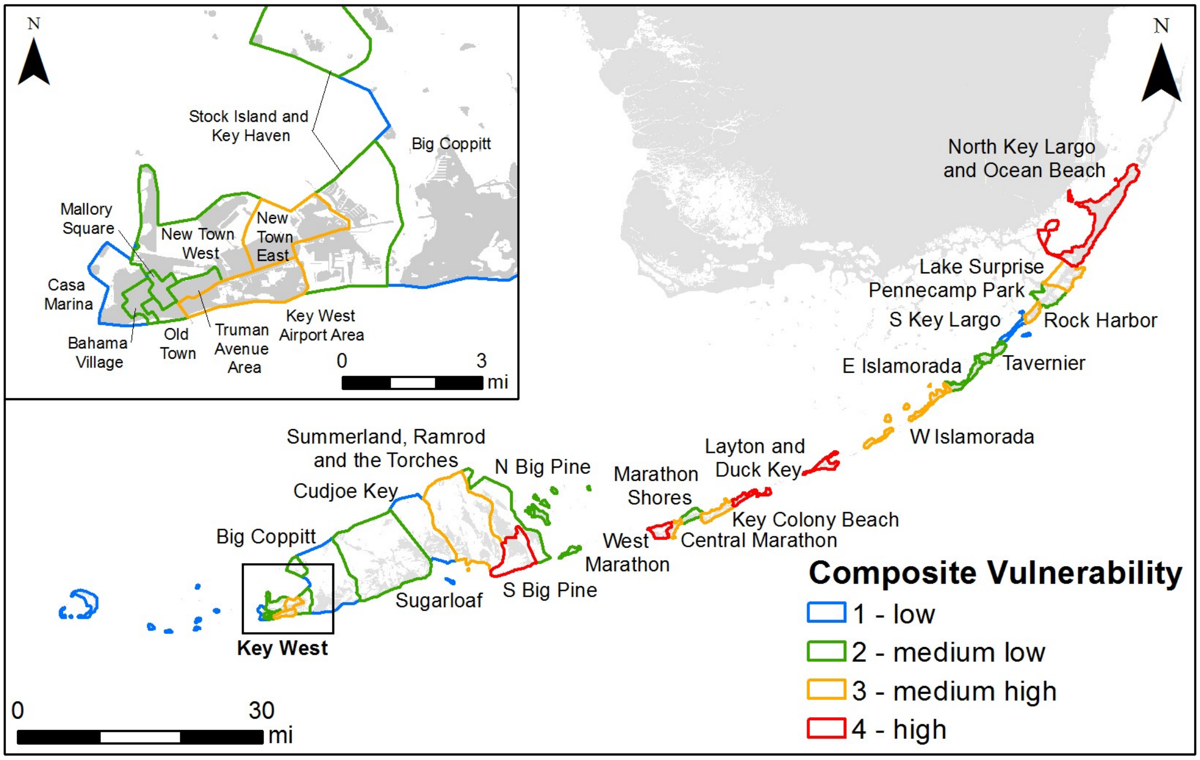


Figure 5.3. Composite index map for climate and health vulnerability by census tract.

The communities with the highest overall health vulnerability to climate change are more rural communities with a low level of access to healthcare facilities (Figure 5.4). These communities are vulnerable to flooding from storm surge and sea level rise as well as social and medical factors. Conversely, vulnerability to extreme heat is relatively low due to less urbanization (Figure 5.4). The two communities with the lowest vulnerability to climate change are both located in Key West (Figure 5.4). Relatively high elevations in Key West make these communities less vulnerable to flooding, though since they are urban areas, vulnerability to extreme heat is of greater concern.

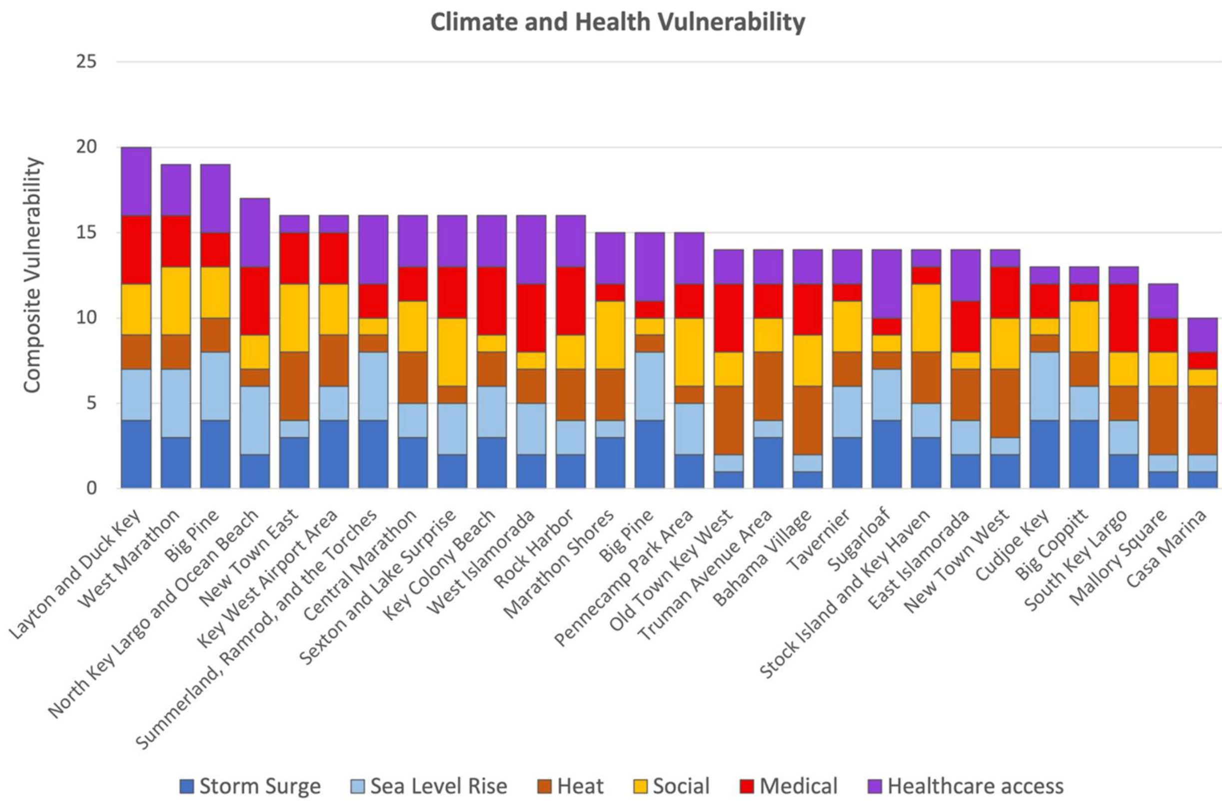


Figure 5.4. Composite index chart for climate and health vulnerability. Census tracts are ordered from highest to lowest vulnerability. Contributions from each of the six vulnerability categories are indicated by the respective colors shown in the legend.

6. Risk mitigation and resilience strategies

A. Planning & health facility improvements

There are a number of strategies that healthcare facilities and healthcare systems can use to better prepare for the effects of climate change. Physical resilience strategies like flood prevention and utility improvements can mitigate the effects of extreme weather and sea level rise and help reduce interruption of normal operations. Planning and training for emergencies and coordinating with the broader medical community can also strengthen a facility's ability to maintain services through natural disasters and other emergencies.

Physical resilience strategies adopted at the facility level are a frontline defense against climate change related hazards such as flooding, which is especially relevant in the Florida Keys. These strategies, when implemented correctly, have the potential to completely prevent some of the most detrimental effects of these hazards. They can be a targeted and effective way to safeguard the availability and reliability of medical services in the community. Primary examples of physical resilience strategies for medical facilities are:

- Flood Prevention
    - Small Scale Ring Walls
    - Deployable flood control
    - Drainage, rain infiltration, and stormwater retention improvements
    - Elevating and/or Relocating Structures
- Flood Resilience
    - Installation of flood-proof and/or decentralized wastewater treatment
    - Elevating Critical Equipment
    - Dry/Wet Floodproofing
    - Installation of flood-proof Electricity, Water, and Data Infrastructure
- Facility Improvements
    - Installation of renewable energy / backup generator systems
    - Installation of water catchment and purification systems
    - Installation of secondary/backup data connections
    - Installation/procurement of backup cooling and heating systems
    - Installation of windows that can be opened, insulation of walls and pipes

Flood prevention generally includes efforts to prevent the occurrence of flooding at a medical facility, by controlling stormwater runoff and preventing floodwaters from entering the facility. Maintaining adequate stormwater systems can be considered the first priority in this regard. Effectively blocking floodwaters from entering a facility may be more difficult and costly but is still an important approach in some circumstances. Flood resilience includes efforts to mitigate the potential damage caused by flooding. The primary ways to approach flood resilience are elevating critical equipment and buildings, and using flood-resistant or flood-proof equipment and building materials. Elevation of properties, such as the newly constructed Baptist Health facility in Marathon, the Stock Island fire station, or the rebuilt residences of Big Pine Key support the sustainability of communities and reduces infrastructure vulnerabilities which could negatively impact health.

Figure 6.1. Floodwall protecting Our Lady of Lourdes Hospital in Binghamton, New York. FEMA.

Facility improvements not specifically related to flooding can also help to improve a facility's resilience. In particular, installation of backup systems and the ability to operate “off-grid” can help maintain a facility's ability to continue normal operations when community infrastructure is damaged or unavailable. It is important to highlight that the effectiveness of these systems is only as good as their ability to be operated successfully during an emergency. Perpetual maintenance and training are essential with these systems to maintain their readiness. Supply chain vulnerabilities should also be considered, like fuel in the case of fossil-fuel-powered backup generators.

A facility can also incorporate many physical improvements that both reduce the facility's impact on the natural environment, and make it more resilient to extreme heat events. Incorporating features like permeable pavement can contribute to flood mitigation and stormwater management. Green spaces contribute to a reduction of the heat island effect in the wider community. Shaded spaces, windows that can be opened for ventilation, and adequate insulation increase resilience to extreme temperatures.

In addition to physical resilience strategies, emergency planning and coordination play a substantial role in the ability for a facility to remain resilient in the face of climate change related hazards. Typical examples of these strategies include communication and coordination between facilities, sharing staff between facilities, and bolstering emergency plans.

Knowing how to communicate and who to communicate with before an emergency occurs is crucial to successfully maintaining operations through the duration of an extreme event. In order to maintain the highest level of health care services for the community, facilities should coordinate by sharing plans, personnel, equipment, facilities, and other resources. Emergency plans at the facility level are also a critical resource during emergencies. Typical chains of command may be disrupted and key personnel unavailable during an emergency. The availability of equipment and resources may also be disrupted. Emergency plans drafted for individual facilities can provide important guidance on navigating these types of challenges.

B. Community healthcare resilience

Many of the same resilience strategies discussed above can also be incorporated on a broader, community level. Community-scale projects can provide resilience to the populations healthcare facilities serve, as well as the facilities themselves. Many of these types of strategies have already been considered in depth for Monroe County, in resources such as the Monroe County Local Mitigation Strategy (Wood Environment and Infrastructure Solutions Inc. 2020), the USACE Florida Keys Coastal Storm Risk Management Feasibility Study (USACE 2020), and the Greenkeys! Sustainability Action Plan (Monroe County 2016). Primary examples of physical resilience strategies that can be implemented at the community level are:

- Flood Prevention
    - Floodwalls
    - Storm Surge Barriers
    - Breakwaters
    - Seawalls
    - Drainage, infiltration, and stormwater retention improvements
    - Elevation of transportation infrastructure (roadways, seaports, rail, airports)
    - Elevating and/or Relocating Structures

- Flood Resilience
    - Elevating Critical Equipment
    - Dry/Wet Floodproofing
    - Flood Proof Electricity, Water, and Data Infrastructure
    - Replace/improve flood-sensitive wastewater infrastructure
    - Floodable infrastructure

- Nature-based Strategies
    - Mangrove restoration
    - Wetland restoration
    - Coral reef restoration
    - Beach restoration
    - Living shorelines

- Other Infrastructure Improvements
    - Fortify Electricity, Water, and Data Infrastructure
    - Installation of renewable energy / microgrids

Flood prevention strategies at the community level can range from small scale drainage improvements to large seawalls, floodwalls, and other structures. The primary objective of each of these strategies is typically either 1) to prevent floodwaters from entering an area, 2) to create adequate drainage out of an area, or 3) to elevate infrastructure above the flood level when 1 or 2 is not adequate or feasible.

Particular focus should be paid to vulnerable infrastructure that is essential for the community's access to healthcare and other emergency services. Preventing flooding of roads that lead to medical facilities or are part of an evacuation route is one notable example. Monroe County has undertaken the task of compiling elevation data for its 300 miles of County roads, embarked on pilot projects to determine the viability of raising particular sections of roads for which maintenance of service is a high-priority, and contracted for the development and implementation of a comprehensive County road elevation plan. This last project is of paramount importance because while construction codes requiring elevation above base flood are achieving a standard for buildings, many of the roads or access routes remain vulnerable to inundation. As adaptations are made to accommodate raised road infrastructure, new drainage areas are needed for the displaced water.

When flooding cannot be prevented, which is often the case with storm surge flooding in coastal and island communities, flood resilience strategies must be employed. As with flood prevention strategies, priority should be given to projects that directly protect the community's access to healthcare and emergency services. Projects that prevent damage to electricity, water, internet, and other utilities are particularly important. One creative example of flood mitigation infrastructure is the "Water Square" in Benthemplein, Rotterdam, shown in Figure 6.2, below. This installation acts as a stormwater retention basin during storms but returns to usable community space when dry.

As of January 2021, Monroe County has implemented a program of managed retreat to buy repetitively flooding private properties and retire the related building and development rights. Purchased properties will be converted to permanent conservation land, which may be utilized for stormwater retention and management. Additionally, Monroe County and its Municipal partners are enforcing resilient-focused building codes requiring elevation of properties and hurricane rated infrastructure standards. The City of Key West has begun to implement strategies to improve drainage and thus reduce vulnerability to vector borne diseases (Dvorak et al. 2018).

Figure 6.2. The Water Square in Benthemplein, Rotterdam. De Urbanisten.

In addition to flooding, utilities should also be protected from potential damage by wind and other extreme weather. Microgrids and other decentralized systems can help lessen the impact of extreme weather on communities by localizing the impact of damage. The Florida Keys Electric Cooperative, operating in the Middle Keys, and Key West City Hall both utilize large solar arrays to generate renewable energy, and have electric vehicle (EV's) charging stations at their facilities to service their vehicle fleets. Many private tourism properties and residences accommodate EV's as well. Transitioning to renewable energy is anticipated to reduce dependence on mainland sources and increase resilience of Keys communities.

In early 2020, the Florida Keys Aqueduct Authority received funding to upgrade the Stock Island Water Treatment Plant, a desalination plant originally constructed in the 1960's and upgraded at twenty-year intervals since, according to the FKAA website. The desalination plant serves as a source of potable water when the pipeline from the mainland which services the County fails, as occurred during a 2017 extreme weather event.

Coordination and planning at the community level and within government have the potential to accelerate and ease the implementation of the resilience strategies discussed above. By the same token, a lack of proper planning and a failure to understand the potential effects of climate change related hazards by communities and governments can nullify efforts that have been made. Examples of ways that communities and governments can coordinate resilience to climate change hazards are:

- Land Use Planning, watershed improvement, maintaining & expanding green spaces
- Buyout/ Acquisition/ Eminent Domain
- Designate facilities that are disaster-ready
- Designate facilities that can be utilized as cooling centers during extreme heat events
- Designate what services will be available at specific facilities
- Encourage development of additional facilities in communities that lack adequate emergency care
- Encourage qualified individuals to live and work in the community to provide a deeper well of staff
- Emergency Plans
- Emergency/Early Warning Systems

The Monroe County Board of County Commissioners appointed volunteer members from various educational and professional backgrounds to a Climate Change Advisory Committee active from 2009-2020, which advised the Board on issues related to climate change. These included the development of dedicated staff positions, considerations for solar infrastructure, and development of Adaptation Action Area designation criteria, a grant funded partnership with the Florida Department of Environmental Protection. In 2012, the County formed the Office of Sustainability which is led by the County's Chief Resilience Officer. The Cities of Key West and Marathon also have Sustainability Managers on staff and the City of Key West has developed an Energy Manager position to manage and reduce energy consumption.

Strategies that inform communities on how to communicate and coordinate resources immediately following a disaster are critically important. Many facilities and community members rely on the government or other organizations to provide resources and assistance immediately following an extreme weather event or other emergency. Coordinated planning and regular drills help to ensure recovery begins quickly and efficiently, and that avoidable secondary hazards do not occur.

The Monroe County Alert System is designed to relay information during emergencies and is available to businesses and residents alike. During disaster situations, local government and organization partners have stations within the Emergency Operations Center from which to command their post and provide their assigned emergency support function. The Florida Department of Health serves as the health and medical liaison to coordinate emergency operations with healthcare facilities such as the three hospitals, various clinics, and smaller private practices. Healthcare providers in the Florida Keys from private practices to large health networks are responsible for determining their position in the coordinated response, applying all of the best practice and communication resources provided through the larger network, and maintaining a continuity of operations plan (COOP).

C. Resources and funding

Resources and funding for climate change resilience efforts can be found through State, Federal, and private sources.

A few primary sources of funding for climate change and sea level rise resilience projects are the US Department of Agriculture (USDA), the National Fish and Wildlife Foundation (NFWF), and the Federal Emergency Management Agency (FEMA).

Relevant USDA Programs and their potential applications include:

- Water & Waste Disposal Loan & Grant Program
  - Stormwater drainage improvements
  - Land-acquisition
- Community Facilities Direct Loan & Grant
  - Elevation or relocation of critical infrastructure
- Single Family Housing Repair Loans & Grants
  - Installation of waterproof, mold-resistant materials
  - Elevation of homes Property drainage improvements

Relevant NFWF programs and their potential applications include:

- Five Star and Urban Waters Restoration Grant Program
  - Stormwater drainage projects
  - Drainage ditch improvements
- National Coastal Resilience Fund
  - Nature-based solutions
- Resilient Communities Program
  - Stormwater drainage projects
  - Drainage ditch maintenance and improvements

Relevant FEMA programs and their potential application include:

- Pre-Disaster Mitigation (PDM) Program
  - Stormwater drainage projects
  - Drainage ditch improvements
  - Elevation of homes
  - Elevation or relocation of critical infrastructure
- Flood Mitigation Assistance (FMA) Grant Program
  - Flood risk mitigation for structures insured by the National Flood Insurance Program (NFIP)
- Hazard Mitigation Grant Program (HMGP)
- Preparedness Grants
- Building Resilient Infrastructure and Communities (BRIC)

Relevant state-funded grants include:

- Land and Recreation Grants
- Florida Resilient Coastlines Program (FRCP) resilience grants
- Beaches Funding Program
- Division of Water Restoration Assistance

Relevant grants and loans are also available through:

- Community Development Block Grant – Mitigation (CDBG-MIT)
    - Purchase of at-risk properties for conversion to green space

Training programs:

- NOAA Digital Coast Academy
- National Disaster Preparedness Training Center
- NOAA Adaptation Planning for Coastal Communities

Planning tools/guides:

- NOAA Digital Coast
- FEMA Flood Maps
- FEMA Coastal Construction Manual
- Florida Adaptation Planning Guidebook
- NFIP CRS Guide & 2021 Addendum
- TNC Coastal Resilience Tools

Governments and health-care providers in the Florida Keys cannot afford to delay preparations for climate related hazards which are already occurring and expected to increase in the future. Indeed, many risk mitigation and resilience strategies are already in place or in the process of being implemented. While city and county governments are responsible for community resilience as a whole, healthcare providers must also address vulnerabilities specific to their facilities and supply chains. The information presented in this report is intended to help identify these vulnerabilities and suggest strategies for mitigation and preparedness to improve health and community resilience to climate change.

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Appendix 1 - Online tools and data sources

Table A1. Online tools and data sources related to climate change hazards and human health. Tools are categorized into those related to flooding (from sea level rise and other sources), other climate change hazards (Hazards), health, infrastructure, and a combination of these (Multiple). Also indicated is whether data is available for download (Data) and whether the tool is specific to Florida or nationwide.

Tools & Data Sources	Category	Data	Florida
Florida Sea Level Scenario Sketch Planning Tool	Flooding	X	X
Sea Level Rise and Coastal Flooding Impacts	Flooding	X	
Coastal Resilience Mapping Portal	Flooding		
National Storm Surge Hazard Maps	Flooding	X	
Sea Level Trends	Flooding	X	
Sea-Level Change Curve Calculator	Flooding	X	
Inundation Analysis Tool	Flooding	X	
Storm Surge Inundation Map	Flooding		
Coastal Inundation Dashboard	Flooding	X	
SURGEDAT: The World's Storm Surge Data Center	Flooding	X	
FloodFactor	Flooding		
Flooding days projection tool	Flooding		
U.S. Climate Extremes Index	Hazards	X	
Climate Explorer	Hazards	X	
Coastal Emergency Risks Assessment (CERA)	Hazards	X	
Coastal Change Hazards (CCH) Portal	Hazards	X	
Regional Climate Change Viewer (RCCV)	Hazards	X	
AirNow	Hazards		
US Wildfire Map	Hazards		
FL Health CHARTS	Health	X	X
Florida Environmental Public Health Tracking	Health	X	X
UDS Mapper	Health	X	
CDC's Social Vulnerability Index (SVI)	Health	X	
Sea Level Scenario Sketch Planning Tool	Infrastructure	X	X
Energy Infrastructure with FEMA National Flood Hazard	Infrastructure		

Homeland Infrastructure Foundation-Level Data (HIFLD)	Infrastructure	X	
Geospatial Assessment Tool for Operations & Response (GATOR)	Multiple		X
Florida Division of Emergency Management GeoPortal	Multiple	X	X
NOAA Digital Coast	Multiple	X	
Coastal Flood Exposure Mapper	Multiple		
Gulf TREE	Multiple		
Populations, Infrastructures, and Exposures Visualization Tool (PIE Viz)	Multiple	X	
The National Risk Index	Multiple	X	
CDC National Environmental Public Health Tracking Network	Multiple	X	