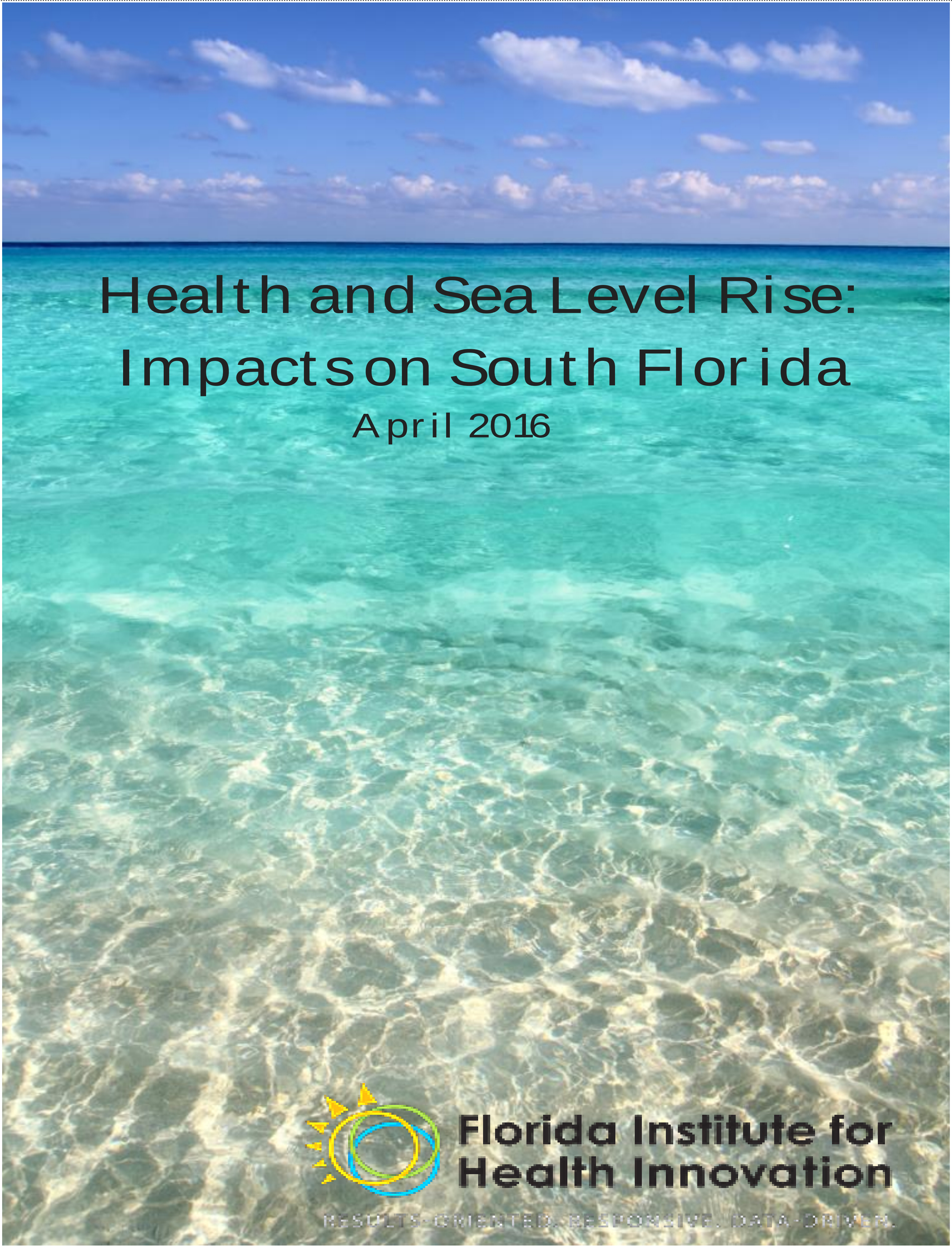

Health and Sea Level Rise: Impacts on South Florida

April 2016

Florida Institute for Health Innovation

RESULTS-ORIENTED. RESPONSIVE. DATA-DRIVEN.

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EXECUTIVE SUMMARY

There exist on-going local efforts by universities, government, and non-governmental organizations (NGOs) researching the issue of sea-level rise adaptation in Florida. These agencies include NOAA, the Southeast Florida Regional Climate Change Compact, FDOT, the Metropolitan Planning Agency, The South Florida Regional Planning Council, Florida International University, the University of Miami and Florida Atlantic University, the lead for the State University System Climate Initiative. The focus of much of this work in South Florida has been to understand the physical and economic vulnerability, as well as to develop adaptation strategies for the natural and built environments [1,2,3,4,5,6,9,10]. Within these efforts, there has been limited attention to the relationship between sea-level rise and human health. Yet, both nationally and internationally focused sea-level rise studies have underscored that the effects on human health are a major component to understanding sea-level rise vulnerability and for designing adaptation plans; these include The National Climate Assessment, the Intergovernmental Panel on Climate Change (IPCC), the Centers for Disease Control (CDC) Building Resilience Against Climate Effects (BRACE) program, and the National Institutes of Health (NIH) Climate Change and Human Health program. While these programs assess and seek to understand health outcomes associated with climate change, they do not consider health as a risk factor. This study has considered health as a risk factor as well as an outcome that would contribute to and be affected by the negative effects of climate change. Health, as measured by chronic conditions, infectious disease, and access to care, was considered in relationship with sea-level rise as both an outcome and risk factor to vulnerability.

The Florida Institute for Health Innovation (FIHI), previously the Florida Public Health Institute, was awarded a two-year grant from the Kresge Foundation to (1) identify the communities in Southeast Florida (Palm Beach, Broward, Miami-Dade, and Monroe) that will be most vulnerable to sea-level rise impacts in the coming decades; (2) identify specific potential public health risks and correlate these risks to identified populations under a 2030 and 2060 sea-level rise scenario; (3) share this information with local decision makers to create more robust adaptation plans that include human health considerations; and (4) develop a technical assistance guidebook and toolkit that can be shared with other coastal communities. This research was informed by and follows the 2012 Regional Climate Action Plan and the 2014 Regional Climate Action Plan, Health Impact Assessment.

FIHI, the South Florida Regional Planning Council (SFRPC), and Florida Atlantic University, Center for Environmental Studies (FAU,CES) conducted research and engaged the professional community to learn and share about the relationship between sea-level rise and health in Southeast Florida. This report presents those results. The research was composed of in-depth analyses for four research objectives and a final objective to share findings and collect qualitative input. The first three studies were to define vulnerabilities within the region using the following definitions: (1) geographic vulnerability, defined as land having a high risk of flooding due to sea-level rise and its relationship with groundwater; (2) social vulnerability, defined as areas demonstrating lower socioeconomic status, as measured by levels of educational attainment, income below the federal poverty line, and non-white population; and (3) medical vulnerability, defined based on rates of emergency department visits and hospitalizations due to chronic obstructive pulmonary disease, asthma, and pneumonia, giardiasis, as well as healthcare access to 330 health centers. This was followed by an effort to (4) overlay the results to identify "hot-spots" in the region that could be considered for Adaptation Action Areas. Finally, (5) extensive outreach was conducted.

The research team developed sea-level-groundwater rise projection maps that display geographic vulnerability at the property level under specified scenarios. The model used to determine the sea-level rise and groundwater relationship was validated by previous studies discussed in this report [48]. These projections were utilized in the mapping project to then identify populations in Southeast Florida most vulnerable to the impacts of sea-level rise based on social vulnerability and health data. A comprehensive Social Vulnerability Index (SVI) was created to represent social vulnerability as a single variable in the region and was mapped by ZIP code. Medical vulnerability was expanded from the original health risk factor variables (COPD, asthma, pneumonia) to include acute infectious diseases, such as giardiasis.

Populations demonstrating high risk for all of these vulnerabilities will be particularly vulnerable to the negative effects of sea-level rise. Adaptation, mitigation and resiliency efforts must be prioritized for these populations. The key components of our methodology and findings as well as strategy recommendations were summarized into a toolkit. The toolkit will be shared with local climate change initiatives, coastal communities, both regional and national, and via the Kresge Climate Adaptation Knowledge Exchange website (cakex.org). Finally, our maps and findings were shared through an extensive outreach effort which established a cross-sectoral network for gleaning insight and created an opportunity for our team to communicate sector-specific information, based on health and vulnerability data.

Outreach included national speaking engagements, networking events, climate change conferences, and meetings with and/or presenting to diverse regional and local agencies. Key topics included considerations for human health, sea-level rise projections, and social vulnerability. Topics were tailored to fit a context relevant to the audience, addressing outcomes specific to each sector. The result of these outreach activities was a vibrant, inclusive discussion that has informed mitigation and adaptation planning across sectors and the toolbox strategies that will be shared. Groups were extremely receptive to our message; the overall response was a new commitment, across sectors and the region, to include sea-level rise and health into planning. Outreach activities additionally expanded the collaborative, regional network of individuals who will address adaptation, mitigation and resiliency building within their sectors. Professionals in the region rapidly understood that sea-level-groundwater rise is an important issue for the region that will affect many populations and sectors across South Florida. Similarly, there was a new understanding that pre-existing vulnerabilities can be a barrier to adaptive capacity.

In summary, the study revealed several important facts:

1. When considered according to our framework, there are large populations who currently demonstrate at least one vulnerability - social, medical, or geographic - to sea-level rise, with many of these vulnerabilities overlapping.
2. Sea-level rise has a direct influence on groundwater and, thus, will cause groundwater levels to rise as the sea rises, increasing the number of geographically vulnerable people.
3. With time, there will be an increasing number of people who are likely to be impacted by the flooding effects of sea-level rise, who are also socially and medically vulnerable.
4. At present, those residing in higher socioeconomic status areas have a high risk of vulnerability to sea-level rise. Over time, this land may no longer be viable.
5. There is a need to access more granular data to better understand the health effects of sea-level rise, as they manifest over time. Geographic vulnerability can be evaluated at the property level, and demographic data at the Census block level; much of the health data has only been available at the county or ZIP code level which limits the ability to identify more specific populations representing vulnerability to all three factors.
6. Sea-level rise requires a constant conversation across sectors in South Florida for the development of comprehensive mitigation and adaptation strategies. A large portion of this project was focused on establishing a rapport with diverse sectors to learn their impressions of these findings as well as to glean additional considerations. Health care practitioners are essential to this conversation.
7. Adaptive capacity and resiliency building require a regional collaborative effort and will not be as effective if localized.

To add to the knowledge-base developed through regional research and efforts, including those resulting from this project, key health-related recommended studies are highlighted below and further discussed in the *Recommendations* section of this report:

- → *Develop a specific message for Southeast Florida about climate change and health that describes the present.*
- → *Coastal areas should begin planning for the impacts of water from flooding, sea-level rise and other impacts in order to safeguard their community's social, cultural, environmental and economic resources in the future.*
- → *Future outreach will need to include a compelling and comprehensive public health case, emphasizing economic resiliency.*
- → *Health data should be collected more frequently, such as monthly, to allow testing for association with monthly weather patterns such as changes in water levels, rain amounts, or temperature and for relationships with socio-economic vulnerability.*
- → *Health data monitoring systems should include increased reporting on and evaluation of emerging disease related to sea-level rise.*
- → *Expand analysis to include variables representing a broader depiction of the interaction between social vulnerability, health and climate change, as more data becomes available.*
- → *Conduct longitudinal analyses that determine the impact of sea-level rise on health outcomes.*
- → *Develop methods to assess the impacts of sea-level rise on health conditions.*
    - o *An effort should be developed to engage health practitioners in what to look for, how to communicate information, and how to increase awareness of long term trends.*
    - o *Evaluate current data overseas regarding disease incidence and develop predictive models of growth in southeast Florida.*
    - o *Develop tools to assess the impacts of sea-level rise to chronic conditions given that little impacts could be discerned in this project.*
- → *Engage health practitioners in identifying conditions or illness associated to climate change, how to communicate information, and how to increase awareness of long-term trends.*

INTRODUCTION

NASA's Goddard Institute for Space Studies (GISS) estimates that global temperatures have increased nearly 1° Fahrenheit, 0.5° Celsius, since 1975. Much of the conjecture explaining this increase has focused on greenhouse gases, particularly carbon dioxide. Greenhouse gas emissions from human activities such as the burning of fossil fuels have become trapped in the earth's atmosphere, warming the planet [7,8]. By the end of the century, global temperatures are projected to rise by 1.8 to 4°Celsius [8]. This global temperature increase is projected to lead to further environmental changes including altered precipitation patterns; the melting of ice caps, sheets and glaciers; heating and acidification of oceans; and more frequent extreme weather events i.e. stronger storms, heat waves and droughts [7,8].

Climate change impacts will be felt globally, but more local areas and populations are recognized as particularly vulnerable to climate change impacts [8,11,12]. The Southeast Florida region, with its low-lying coasts, subtropical climate, porous ground, and particular water hydrology, is one of the world's most vulnerable areas. Climate change threatens both the built and natural environment as well as densely populated and highly diverse populations [11,13]. With 6.6 million people, Southeast Florida constitutes one-third of the state's total population, and has among the highest rates of projected population growth [14]. The region's largest city, Miami, ranks among the top 10 cities in terms of most exposed populations to the effects of climate change [1].

Sea-Level Rise in South Florida

Global temperature rise has been directly linked to the melting of ice caps, ice sheets, and glaciers. Sea-level rise is expected to continue, due to the increasingly significant loss in ice mass and the thermal expansion of the oceans [7,20,27]. This increase is expected to reach three feet by 2100 [11,29,30,31,32]. The U.S. Army Corps of Engineers used Key West tidal data from 1913-1999 to project future levels of sea-level rise. Results showed that the sea-level in Southeast Florida will rise one foot from the 2010 to 2040, and could rise two feet by 2060 [33].

Sea-level rise is a climate impact that has proof of occurrence. During the past 100 years, an increase in sea level has been observed (See **Figure 1**), and is expected to have significant consequences for coastal areas. The combination of sea-level rise and population growth makes it essential for continued improvement to and innovation in flood management strategies for these areas [10,15,16,17,18,19]. Various researchers have confirmed sea-level rise impacts on coastal and island environments [10,13,15,16,19,20,21,22,23,24,25,26]. Gregory et al. similarly found that within the last two decades, the global rate of sea-level rise has been larger than the 20th-century time-mean [27]. In addition to melting ice caps and glaciers, there are increasing contributions to global sea-level rise from the effects of groundwater depletion, reservoir impoundment, and loss of storage capacity in surface waters due to siltation [28,95].

Coastal populations are particularly at-risk due to erosion, inundation and storm surge; however, interior populations are also susceptible to rising water tables and extended periods of inundation. Studies have demonstrated that sea-level rise causes saltwater intrusion, which is a direct threat to coastal potable well fields. Additionally, reduced aquifer storage may lessen the capacity by which soil can absorb precipitation and floodwaters, and thus increases the risk of groundwater flooding. Losing that depth lowers the ability of the aquifer to maintain its soil storage capacity [34]. Chang et al. describes this as an overall "lifting process" by which there is a 1:1 ratio in water table elevation directly correlated to sea-level rise [52]. Because the water table in a coastal area is just above sea-level, storm surge and extreme high tides can exhibit some direct influence. Sea-level rise, the associated loss of soil storage capacity, and more intense storms will overwhelm the current storm water infrastructure. Tebaldi et al. estimated an increase in extreme weather in which today's 100-year event will likely occur every 20 years by 2050 [4].

Southeastern Florida has a complex geology. The region is underlain by a porous fresh-water bearing limestone rock, the Biscayne aquifer. The aquifer is mainly recharged by rainwater and is the major source of Southeast Florida's potable water, serving a population of approximately 5 million people. The aquifer both sustains the region by providing drinking water and makes the region highly vulnerable to sea-level rise. As sea-level increases, the saltwater does not only surface along the coastline, it also seeps in from the sea floor pushing from below against the freshwater supply in the aquifer. As a result, the saltwater and freshwater meet at a boundary that goes inland for up to several miles. As the sea-level rise moves along the boundary inland, it also lifts the boundary closer to the surface. Saltwater moves through the porous limestone, infiltrating freshwater drinking wells and pushing freshwater to saturate soils just below ground level.

Sea-level rise threatens livelihood in Southeast Florida. Projections indicate the potential for severe damage to Southeast Florida's energy systems, transportation infrastructure, agricultural lands, and the largest wetlands in North America, which host a delicate ecosystem [7,10]. Too often, generalized adaptation solutions are the only solutions offered [2,35,36]. Sea-level rise is a slow, steady creep that requires, not a reaction, but robust and thorough decision-making, coupled with adaptive, collaborative planning to prevent stranded infrastructure and failed construction projects [10]. Without careful planning and action, important infrastructure will fail to persevere. This can be avoided with improved data to guide decisions and prioritized adaptation actions. Zhang observes Southeast Florida's non-linear trends in terms of area, population, and property value exposed at each increment of sea-level rise [10]. Analysis of non-linear inundation reveals each county in the region has a unique threshold beyond which losses take off exponentially. It is therefore dangerous for decision-makers to have a "wait-and-see" attitude as these tipping points approach.

Climate Change, Health and Risk Factors

Climate change has the potential to create a serious threat to public health in terms of health outcomes and disease patterns [39]. Although strategies for prevention, mitigation and adaption for climate change will help lessen negative health impacts, human health will continue to be affected by present climate change conditions [40,41,42]. It is expected that climate change will both aggravate existing health risks and conditions and facilitate emerging disease, with varying impacts and direct and indirect effects [41]. It is projected that populations with pregnant women, children, the elderly, co-morbid conditions, low socio-economic status, and geographic vulnerabilities will be most affected [42]. This context would yield varying health impacts, felt to different degrees, dependent on action taken to mitigate and adapt, with considerations for vulnerability [1,13,43,44].

Chronic Conditions: Asthma, COPD and Respiratory Diseases

Seasonal climate changes and poor air quality from air pollutants like particulate matter, tropospheric ozone, nitrogen dioxide, caused by carbon dioxide, and rising temperatures have the potential to impact lung function and the incidence and prevalence of asthma, respiratory allergies, COPD, and airway diseases [45]. Extreme heat events increase particulate matter in the air and the chances of harmful algal blooms, which carry a potential to become aerosolized. Wildfires, similarly, release respiratory irritants and carcinogenic substances into the air. Increased carbon dioxide is strongly associated with increases in pollen production, earlier flowering periods, and longer pollen seasons for some allergenic plants [45]. Increased rainfall and flooding, along with rising temperatures, can lead to the growth of mold and fungi indoors [46]. These factors can then exacerbate asthma, respiratory allergies, and airway diseases, thereby compounding their effects.

Vector-borne and Zoonotic Diseases

Vector-borne diseases were the leading cause of death between the 17th century and early 21st century [83]. Mortality from these significantly decreased in the 20th century due to advances in medicine and vector control programs [83]. However, since the 1970s, there has been an emergence of many vector-borne diseases such as malaria, plague, dengue fever, Lyme disease, and West Nile Virus. Although a direct link with sea-level rise and an increase in vector-borne disease has not yet been determined, it must be considered that sea-level and groundwater rise might influence these types of diseases by providing mosquitoes with more breeding grounds.

Many of the vector-borne and zoonotic diseases that once caused significant morbidity and mortality in the United States, such as yellow fever, have been controlled. However, vectors still threaten health in the form of emerging disease or those that maintain a prevalence in populations, such as Lyme disease [50]. The transmission of vector-borne diseases depends on a number of factors including social, economic, ecological, climatic conditions, and human immunity [51]. Given this, climate variability is highly likely to affect the transmission, incidence, and geographic range of vector-borne diseases [50,51]. Warming global temperatures, sea-level rise, and changing precipitation patterns present the perfect environment for the development and reproduction of a variety of vectors, such as those that carry Chagas and West Nile. As environments warm, larger areas, especially when inundated with standing groundwater, become ideal conditions for these vectors to flourish [50].

Many mosquito-driven, vector-borne diseases, including malaria and dengue fever, are some of the most sensitive diseases to climate change [57]. Considered with the common infrastructure effects of climate change, such as human migration, expanded areas of standing water, and interruption of health services, mosquito-driven disease transmission is positioned to be amplified [57]. Further, population movement due to changing environments, like rising seas and increased groundwater and flooding, could expose new populations to vector-borne and zoonotic diseases [50]. Modeling of the effects of climate change on vector-borne diseases projects that climate change will increase future transmission; though these models do not take into account non-climatic, public health prevention measures that could off-set transmission [51].

A study performed by Ramasamy in Sri Lanka demonstrated that certain species of mosquitoes can propagate in waters with a salinity of 18 ppt [58]. The species studied by Ramasamy demonstrated that mosquitoes can and will breed in waters that contain salt. It also demonstrates that mosquitoes can and will breed in almost any type of container, large or small, containing water, fresh or brackish, even those left along the coastline as litter. Although the study took place in Sri Lanka, the species of mosquito species that were included in the study are present in the Southeastern United States [88]. These species of mosquito are known to transmit the arbo-viruses causing dengue, yellow fever, and chikungunya among many others [58].

A vector-borne disease of recent concern for Southern Florida is dengue. Dengue is primarily transmitted to humans from the bite of an infected *Aedes aegypti* or *Aedes albopictus* mosquito after the female mosquito bites an infected human [86]. Of particular concern to the highly populated Southeast Florida region, is the fact that *Aedes aegypti* is adapted to living around humans and the domestic structures located in highly populated regions. This species can lay eggs in artificial containers, that are often inadvertently left lying around as garbage, which allow the mosquito to breed uninhibited year-round in the warm climate. In 2014, there were 5 locally acquired and 9 imported cases of dengue fever in Miami-Dade County, 3 imported cases in Broward County, and 2 imported cases in Palm Beach County [86].

Contamination and Waterborne Diseases

Heavy precipitation, rising temperatures and flooding have all been associated with waterborne disease outbreaks in the U.S. [59,60]. The increasing frequency and severity of storm surges and sea-level rise will thus increase the risk and frequency of populations being exposed to waterborne disease pathogens [59]. This exposure could lead to serious health outcomes, including gastrointestinal illnesses, other chronic and extended illnesses, and even death [44]. Certain populations are particularly vulnerable to these impacts - individuals with low socioeconomic status, the disabled, elderly, children, people with chronic diseases, residents of mobile homes, or people living in areas with outdated drainage systems. Rising temperatures may also lead to an increase in the frequency of harmful algal blooms. Algal blooms coupled with runoff from heavy precipitation often contaminate recreational waters, causing people in coastal communities to be exposed to contaminated water, and thus, negative health effects [44,59].

Research is still uncertain on the magnitude to which climate change will affect subsurface groundwater [61]. Climate variability increases demands on water management, leading to growing challenges for wastewater treatment and water supply, as well as deficiencies in storm drainage and storage. Failure to address these challenges heightens risks that include water contamination and diminished freshwater resources, with a new set of vulnerabilities in areas with coastal aquifers [44]. Flooding in urban areas can also lead to the contamination of surface waters from sewage treatment systems that cannot handle the inundation, placing humans at risk of disease-causing bacteria [61]. Rising sea levels may also impact existing infrastructure used to reduce saltwater intrusion into water supplies limiting the availability of freshwater supplies for communities and their surrounding natural ecosystems [24]. A lack of available freshwater resources often leads to population displacement, exposing populations to the physical and mental health effects that accompany displacement [61]. Ultimately, the relationship between flooding and water supply protection is a very delicate one.

Cryptosporidiosis, caused by *Cryptosporidium parvum*, is a single-celled protozoan parasite and one of the most common waterborne diseases in people in the United States [82]. The most common sources of infection have been found to be due to direct contact with feces from animals or humans, contaminated water, or contaminated food. Giardiasis, caused by *Giardia intestinalis*, was the second most common cause of parasitic human diarrheal disease and is the most common waterborne disease in the United States. Common sources of infection are contaminated food, water, hands, and inanimate objects [82]. Similarly, there have been cases of outbreaks in the United States caused by the failure of municipal water treatment plants to filter out the organism from contaminated water. Giardiasis was the acute illness most strongly correlated with ineffective water treatment, when several diseases (including salmonella and cryptosporidiosis) were analyzed.

Many studies have demonstrated that rising sea levels will likely increase the salinity in coastal waters including coastal estuaries, lagoons, marshes, and mangroves [59]. Water is considered fresh water if the salinity is less than 0.5 ppt (parts per thousand), brackish if between 0.5-30 ppt, and saline if greater than 30 ppt [59]. Changes in salinity can affect the growth of microorganisms and vectors that utilize water as breeding grounds. It has been demonstrated that extremes in salinity can affect the growth of *Vibrio spp.* Vibriosis epidemics have been associated with environmental changes related to global warming, specifically, changes in temperature and salinity [87]. Salinity too high or too low can decrease the amount of *Vibrio* in the environment [87]. Thus, increases in salinity secondary to salt water intrusion could potentially increase the incidence of vibriosis cases in Southern Florida.

There are many species of *Vibrio*, but those of greatest clinical importance - *V. vulnificus*, *V. parahaemolyticus*, and *V. cholerae*. *V. vulnificus* and *V. parahaemolyticus* - are transmitted primarily through eating raw or undercooked shellfish, but may also be contracted through open wounds with contaminated sea water [82]. *V. parahaemolyticus* is the leading cause of bacterial diarrhea associated with seafood consumption in Florida and can occur year around [84]. *V. vulnificus* is the leading cause of death in the United States related to seafood consumption and nearly always associated with raw Gulf Coast oysters [84]. Finally, *V. cholerae* is the causative agent of cholera outbreaks and epidemics [84]. There has been research that has shown that *Vibrio* illnesses, including cholera and those due to seafood and wound contaminations, are increasing around the world and this may be due to an increased sea surface temperature (SST) which can promote the propagation of *Vibrio* in coastal and brackish waters [84]. An increase in global temperature and sea-level rise has the potential to increase the exposure of humans to these waterborne illnesses by increasing the geographic area in which they exist and also by lengthening the timeframe during which these organisms are most abundant.

Social Vulnerability

Socioeconomic status, as measured by educational level, income, or occupation-related variables, has a confirmed association with health outcomes [96,97,98,99,100]. More recently, this research has been expanded to decipher the connection between socioeconomic status and sea-level rise as well as other climate change factors [101,102,103,104]. A well-known and continuously developing measure of social vulnerability is the Social Vulnerability Index (SVI) [53,54]. A social vulnerability index describes the vulnerability of communities when confronted with environmental change or hazards and allows local decision-makers to identify communities that may require more support in preparing or recovering from environmental change. Populations that reside in low-lying, compromised areas and who have predisposed vulnerabilities will be particularly susceptible to limited resources and decreased capacity to recover from sea-level rise impacts. Most indices have specifically focused on disaster and displacement risk related to major hurricanes [68,69], population evacuation assistance needs [74], community recovery and resilience [75,76], and sustainability (ESI) [77,78,79]. Yet, health and social vulnerability as indices still remains largely unexplored.

Cutter et al. created a social vulnerability index based on a hazards of place model [105,106]. This social vulnerability index was created by reducing more than 40 census-derived county level socioeconomic variables into 11 factors using principle component analysis. These factors were then used additively to create categories of social vulnerability risk, which were mapped at the county level. The researchers were able to provide a comparison of social vulnerability among all US counties. Schmidtlein et al. tested the social vulnerability index and found it to be stable, even when methods of construction were varied [107]. The social vulnerability index has been used to understand the social antecedents of leisure time physical inactivity [108], and the CDC's Agency for Toxic Substances and Disease Registry's Geospatial Research, Analysis, and Services Program utilizes the social vulnerability index to identify communities who are at greatest risk in the event of a natural disaster [109].

A social vulnerability index (SVI) is used to represent a combination of socioeconomic variables. It has been used in other research to provide a holistic representation of socioeconomic status [105, 107,108], as it is accepted that different aspects of social class or socioeconomic status are captured by different measures [110,111].

Logistics Summary

The objective was to produce detailed maps of geographic vulnerability based on groundwater and sea-level rise data and LiDAR mapping; analyze and map data for health risk factors and outcomes; create an index and maps describing social vulnerability; to overlay the results of these three studies; and conduct extensive outreach, providing a set of comprehensive recommendations for different sectors and policy-makers. This work was strongly guided by the 2014 Health Impact Assessment, our partnerships, and steering committee.

The project team conducted this research from the end of 2013 through December 2015 and was led by FIHI. In-person meetings, during the second year, were held once a month and team calls were held once a month, resulting in bi-weekly team meetings. Meetings provided an opportunity to discuss research progress and results and to share new research and ideas.

Regional Climate Action Plan

This study sought to build upon many of the successful efforts within the region, one of these being the RCAP led by the Southeast Florida Regional Climate Change Compact. The Compact Work Group had produced GIS-based analysis for sea-level rise as a preliminary assessment, that did not include other possible impacts associated with sea-level rise, such as groundwater. These mapping efforts were followed by preliminary maps considering health in the HIA. The maps produced for this study represent a much deeper analysis of all previous work with new considerations. Further, this study based much of the outreach messaging on the RCAPs underscoring that cooperation is vital among the region and agencies for prioritizing public policy and designing and implementing adaptation measures [144].

This study directly addressed many of the recommendations outlined in the 2012 Regional Climate Action Plan which preceded the Health Impact Assessment. These recommendations are outlined below:

SP-3: Incorporate "Adaptation Action Area" definition (as provided for in Florida law) into municipal and/or county Comprehensive Plans, to provide a means to identify those areas deemed most vulnerable to sea-level rise and other climate change impacts including, but not limited to, extreme high tides, heavy local rain events and storm surge for the purpose of prioritized funding and adaptation planning.

SP-4: Develop criteria in collaboration with municipal and county planning authorities for the purpose of defining Adaptation Action Areas as well as other areas requiring adaptation improvements related to coastal flooding and sea-level rise that may include, but not be limited to:

- Areas below, at, or near mean higher high water
- Areas which have a hydrological connection to coastal waters
- Other areas impacted by climate related drainage/flood control issues

SP-5: Conduct new or utilize existing vulnerability analysis and other technical tools as they are developed as a means for identifying Adaptation Action Areas as well as other areas requiring adaptation improvements related to coastal flooding and sea-level rise, to provide guidance for adaptation planning efforts in areas especially at-risk to sea-level rise, tidal flooding and other related impacts of climate change.

SP-7: Develop sea-level rise scenario maps to be considered for inclusion in appropriate Comprehensive Plans and/or regional planning documents as determined by the appropriate local government to guide municipal and county government climate adaptation planning efforts and continue to update regional and local planning efforts as more data becomes available and scientific projections are refined.

SP-8: Identify locations within Adaptation Action Areas or similarly vulnerable areas where targeted infrastructure improvements, new infrastructure or modified land use and/or development practices could reduce vulnerability and/or improve community resilience.

PO-1: Provide outreach to residents, stakeholders and elected officials on the importance of addressing climate change adaptation and preparedness and develop a program to educate specific interest groups about the Compact, Regional Climate Action Plan, and the benefits of Adaptation Action Areas.

PO-2: Collaborate among counties, municipalities and appropriate agencies to develop and carry out outreach programs to increase public awareness about hazards exacerbated by climate change, mitigation efforts and adaptation strategies to minimize damage and risk associated with climate change.

2014 Health Impact Assessment

This grant allowed us the opportunity to build upon the HIA in several significant ways. The team was able to update the sea-level rise model used to the modified bathtub, which was informed by LiDAR mapping and data collection. Social vulnerability was more deeply analyzed expanding variables then developing the Social Vulnerability Index, which provides a more robust representation. Finally, health data was further explored in a sub-index and data analysis and then used to determine hot-spots for vulnerability.

The Regional Climate Action Plan Health Impact Assessment was completed to ensure that human health was considered throughout the Compact update and implementation process. This effort was also led by FIHI. The HIA was completed in 2014 and comprehensively assessed the 110 recommendations proposed to determine the effects of climate change on regional health. It produced findings and recommendations that described local health implications of climate change in each of the six sections of the Climate Change Compact's Action Plan: (1) Sustainable Communities and Transportation Planning, (2) Water Supply, (3) Management and Infrastructure, Natural Systems and Agriculture, (4) Energy and Fuel, (5) Risk Reduction and Emergency Management, and (6) Outreach and Public Policy. The compact revealed the distribution of health outcomes and presented an opportunity to minimize further negative health outcomes. The HIA models were expanded upon to generate a more granular analysis of the region which allowed the identification of “hot-spots” for vulnerability. The HIA also used a bathtub model for sea-level rise projections, which was modified to yield more accuracy in this project.

The HIA highlighted that of professionals surveyed in the region, 81% were not aware of the health impacts of climate change. Nearly 50% of professionals reported they were not aware of health benefits from implementing mitigation strategies. When asked in the survey the best way to prioritize public health, the responses were to raise public awareness, create incentive-based strategies, educate the public and emphasize co-benefits. Focus groups were also hosted in which participants expressed concerns about sea-level rise and sewage contamination (following flooding, weak hydrological infrastructure, displacement, salt-water intrusion on freshwater resources and the threat it poses to the nuclear plants), roads flooding, and whether funds would be allocated to strengthen sewage lines and pipes. Given these results, the outreach component of this project was significantly expanded to ensure professionals in the region, not only became aware of health impacts of climate change, but were able to understand how those impacts could affect their work.

The HIA summarized data for the region on health effects related to sea-level rise, as outlined by the CDC, including COPD, foodborne, waterborne, vector-borne, zoonotic, mental health and stress-related disorders. The results of the HIA guided this study in narrowing the health variables for consideration, based on case data and data availability. This allowed our team to more deeply analyze and map the health variables described for the region, which were then compared to and mapped with data for geographic vulnerability and social vulnerability.

The HIA summarized data for water sources, in the four counties, for housing units as well as the percentage of housing units with sewage disposal. This informed the investigation of water related contamination, although, ultimately, there was not sufficient data to include this information in the final analysis.

The Southeast Florida Regional Climate Change Compact's Health Impact Assessment (HIA) was successful in weaving health considerations into the Climate Change decision-making process. The HIA has added value to the growing body of research on climate change in South Florida, by comprehensively assessing the recommendations to determine the effects of climate change on health in the region and the distribution of those effects throughout the population. The HIA also indicated clear next steps for understanding the complex relationship between sea-level rise, health and other factors that influence this relationship. It became evident that a complementary environmental impact assessment would be of great value. Other components for research were identified as food supply, extreme heat, mental health issues, and economic factors that may encourage migration of socially vulnerable people to geographically vulnerable areas.

Partnerships

BRACE

The Florida Department of Health (FDOH) was awarded a four-year grant by the CDC for the BRACE, Building Resilience against Climate Effects, project. The BRACE team conducted a statewide study assessing the possible health implications of climate change in Florida to inform the improvement of the public health sectors ability to respond to climate variability. BRACE has used a bathtub model approach in their sea-level rise modeling and has conducted comparative analysis for a range of climate change variables across the state of Florida.

The FIHI Program Manager for this grant served on the advisory board for BRACE from 2013 to 2015. Quarterly meetings were held with the BRACE Program Manager and Data Analyst to share any new findings, describe general research and any new health data results. BRACE also provided several datasets for this study and was given updates on progress. The BRACE Program Manager additionally served on the steering committee for this project. Finally, the modified bathtub model method used in this study was shared with the BRACE team.

Florida Climate Institute

The Florida Climate Institute (FCI) is a multi-disciplinary network of national and international research and public organizations, scientists, and individuals who seek to better understand climate change and variability. The FCI is led by the FAU, Center for Environmental Studies (CES) and has seven member universities – Florida Atlantic University (FAU); Florida State University (FSU); the University of Central Florida (UCF); the University of Florida (UF); the University of Miami (UM); Florida International University (FIU) and the University of South Florida (USF). While the FCI only met once during the grant period for a working meeting with the compact, updates on grant progress were shared at that meeting. Further, internal reviews of maps and indices were conducted by FAU, CES FCI members.

Southeast Florida Regional Climate Change Compact

The Southeast Florida Regional Climate Change Compact (SFRCCC) was created in January 2010 to coordinate mitigation and adaptation activities for Southeast Florida. The compact has served as a convener, thought leader, educational resource, and legislative advisor since its inception. The compact had released a report titled *Analysis of the Vulnerability of Southeast Florida to Sea Level Rise* which provides an inventory of property and infrastructure vulnerable at different sea-level rise scenarios. They also worked with state and federal legislators to realize the amendment of Florida law to designate Adaptation Action Areas, defined as areas particularly vulnerable to climate change impacts. During the establishment of the compact the group committed to the following action items:

- *Joint legislative policy development*
- *Development of a regional GHG baseline*
- *Development of regionally consistent SLR projections for the coming decades*
- *Development of Preliminary Inundation Mapping*
- *Development of a Regional Climate Action Plan*
- *Coordination of an Annual Leadership Summit*

At least one member of the compact has attended each steering committee meeting hosted during the project and all outputs were shared with the Compact steering committee members. These members provided a great deal of guidance and feedback on all planning and results. In the second year of the study, the project team presented findings and recommendations to the SFRCCC during the FCI-Compact working meeting. Additionally, the Compact will be provided with a copy of the final report as well as the toolbox resource for adaptation planning.

Finally, the Regional Climate Action Plan recommendations strongly guided and influenced the development of this research especially those associated with sea-level rise, detailed in the RCAP report.

Steering Committee

A multi-organization steering committee was assembled that reflected the Regional Climate Action Plan Health Impact Assessment steering committee. The committee met as-needed in 2013 and 2014 and quarterly in 2015, with a final meeting in January 2016. The committee advised on how to best integrate research findings into the rest of the region through outreach recommendations and also provided feedback on deliverables. Steering Committee meetings were held in-person at the South Florida Regional Planning Council Offices.

Members

Colin Polsky, PhD *Director FAU, Center for Environmental Studies*
Virginia Walsh, PhD, PG *Chief, Hydrogeology, Miami-Dade Water and Sewer*
Meredith Jagger, MS *Program Manager, Building Resilience Against Climate Effects*
Dr. Maribeth Gidley – *Ocean Chemistry and Ecosystems Division, CIMAS, NOAA*
Anamarie Garces, MPH *CEO, Urban Health Solutions*
Nancy Schneider, MBA, MA *Senior Program Officer, Institute for Sustainable Communities (Implementation of SFRCCC)*
Vicki Boguszewski, MPH, CHES Public Health Analyst
Dr. Jennifer Jurado, *Director, Broward County Environmental Planning and Community Resilience Division*
Michael Zygnerski, MS *Water Resources Assessment Program Manager, Broward County*

Student Engagement

The project team contacted Dr. Virginia McCoy of Florida International University to request that her PhD students create a catalogue of health outcomes associated with sea-level rise and public health. Students were asked to identify one human health factor that could be a potential challenge for any region facing climate change in the coming decades, based on the literature. Students were then asked to enumerate the mechanism by which the selected factor might become problematic in any place and characterize the extent to which the mechanism is present in South Florida, based on data. Finally, students were requested to catalogue the factors that would allow some conclusions to be drawn about the adaptive capacity of the population in question, based on the identified vulnerabilities. The result was a library of seven summaries of health factors associated with climate change and sea-level rise. Topics included dengue, algal blooms, West Nile Virus, campylobacteriosis, giardiasis, chikungunya, and cholera.

The team felt it was important to engage students to complete research parallel to the study research. This was an opportunity to increase the information collected for the study and also to challenge current public health students to explore the present implications of sea-level rise and human health.

Challenges

One of the greatest challenges in this grant was the turnover during the project. The original grant-writers, Nicole Hammerer (FAU), Keren Bolter (FAU), Debora Kerr (FIHI) and Dr. Barry (FAU), either transitioned positions or retired. These positions were then replaced by FAU scientists and lecturers Fred Bloetscher and Diana Mitsova and FIHI Program Manager, Mirine Dye. The director position at the FAU, Center for Environmental Studies (CES) was filled by Dr. Colin Polsky when Dr. Barry retired. In the spring of 2015 FIHI transitioned the program manager position again from Mirine Dye, MPH to Kristin Garces, MPH. Dr. Katherine Chung joined the project in May 2015 as the epidemiological advisor. Keren Bolter transitioned back to the project in July 2014. Finally, Jim Murley, of the South Florida Regional Planning Council was appointed as the Chief Resiliency Officer in Miami-Dade and thus transitioned leadership to Isabel Cosio Carballo.

As noted in the original grant, there were several technical challenges related to the layering of data due to the various formats and different levels of data. One of the main barriers was that much of the health data was available only at the county level or by ZIP-code. Without more granular health data, analysis had to be limited to identifying socially and geographically vulnerable hot-spots within a medically vulnerable ZIP code, indicating a larger population than may actually be medically vulnerable. Additionally, while the original objectives outlined the exploration of chronic disease it soon became evident that infectious disease would represent an increased risk in populations. Given this, a request was submitted to Kresge in the early spring of 2015 to include infectious diseases in analysis. This opportunity was leveraged to engage Florida International University, Public Health PhD students to identify infectious diseases that may serve as risk factors and demonstrate health outcomes.

The previous Kresge Program Officer, John Nordstrom, had sent an email (***Appendix K***) stating: based on the information provided by the first FIHI program manager he understood "FIHI does not intend to produce a map, and that is fine." The data and resources to produce the originally described maps were not available until December 2015; however, the decision was ultimately made to produce the hot-spot maps, which comprehensively depict the results of these three research objectives and provide a wealth of information that can be rapidly understood with regional and national stakeholders.

Opportunities

In late 2015, Mayor Gimenez of Miami-Dade County created a position to address sea-level rise in Miami-Dade. This was in response to concerned citizens, at the 2016 budget hearings, who lobbied for the prioritization of sea-level rise and funds to support the investigation of addressing sea-level rise in the county. Jim Murley of the South Florida Regional Planning Council, who served on this project, was extended an offer to serve in this position as the Chief Resilience Officer for Miami-Dade County. Mr. Murley will serve by coordinating efforts to make Miami-Dade a more resilient community as it faces the impacts of sea-level rise and climate change issues.

Research Objectives: Five Projects in One

FIHI, the South Florida Regional Planning Council (SFRPC), and Florida Atlantic University (FAU) explored the relationship between sea-level rise and health through four studies that allowed in-depth analysis, providing quantitative measurements, and a fifth seeking robust qualitative feedback on results.

The research team designed five different project objectives: to (1) determine geographic vulnerability, (2) social vulnerability and (3) medical vulnerability (4) to overlay these vulnerabilities identifying "hot-spots"

(5) and to share these results locally, regionally and nationally. The measurements for these include (1) geographic vulnerability, defined as land having a high risk of flooding due to sea-level rise and its relationship with groundwater; (2) social vulnerability, defined as areas demonstrating lower socioeconomic status, as measured by levels of educational attainment, income below the federal poverty line, and non-white population; and (3) medical vulnerability, defined based on rates of emergency department visits and hospitalizations due to chronic obstructive pulmonary disease, asthma, and pneumonia, giardiasis, as well as healthcare access to 330 health centers. These projects were guided and informed by the results from the 2014 RCAP Health Impact Assessment.

Each of the five separate project components builds on the others. The first and foundational project used GIS to create maps of projected sea-level rise using the modified bathtub model. The research team produced maps that demonstrated the geographic risk of sea-level rise for Palm Beach County, Broward County, Monroe County and Miami-Dade County. This component of the study provided decision-makers and planners with data on who is most at risk for sea-level rise in the coming years.

The second portion of the project was the creation of the social vulnerability index. The index helped to identify those geographic areas that are vulnerable to negative environmental effects due to having a large proportion of individuals of lower socioeconomic status. The resulting social vulnerability index (SVI) was mapped at the ZIP code level for each of the three counties.

The third project was an identification of health risk factors and health outcomes and the analysis and mapping of this data for the four counties – Palm Beach, Broward, Monroe and Miami-Dade. This resulted in the identification of medically vulnerable ZIP codes by disease or condition.

The fifth component of the project was outreach and the creation of a toolbox – which were a critical part of the work that was done. Throughout the project, there was formalized communication with constituents and colleagues. These sessions consisted of a two-way dialogue where the findings of the overall project were shared and discussed, but the very important opinions and viewpoints of those who were the focus of outreach were voiced and fed back to the project team. A toolbox was created, which is another formalized method of outreach to constituents and colleagues on the findings, relevance, and applications of the overall project.

The results of these projects were then overlaid to identify hot-spots for vulnerability. ZIP codes with high levels of risk for all three components were identified, with geographic and social vulnerability more granularly displayed within a medically vulnerable ZIP Code for communities in Southeast Florida (Palm Beach, Broward, Miami-Dade, and Monroe). This component of the project served as a culmination of the other components, as it utilized the results of the sea-level rise mapping and social vulnerability index to further pinpoint geographic risk. These results allowed the team to **(1)** identify communities most vulnerable to sea-level rise impacts in the coming decades; **(2)** identify specific potential public health risks and correlate these risks to identified populations under a 2030 and 2060 sea-level rise scenario; **(3)** share this information with local decision makers to create more robust adaptation plans that include human health considerations; and **(4)** develop a technical assistance guidebook and toolkit that can be shared with other coastal communities, which were the goals of this study.

Background

In order to determine communities most at risk, researchers at FIHI and FAU created and analyzed maps that depicted data at the most granular level available **to identify areas that will be most vulnerable to sea-level rise by 2030 and 2060 using United States Army Corps of Engineers (USACE) projections**. GIS mapping was used to develop these maps that demonstrated groundwater and sea-level rise by property. Data used for this was based on soil tension measurements which revealed the risk for standing water or flooding. These maps aimed to identify vulnerable populations in terms of likelihood of physical exposure.

Regional Geographic Vulnerability to Sea-Level Rise

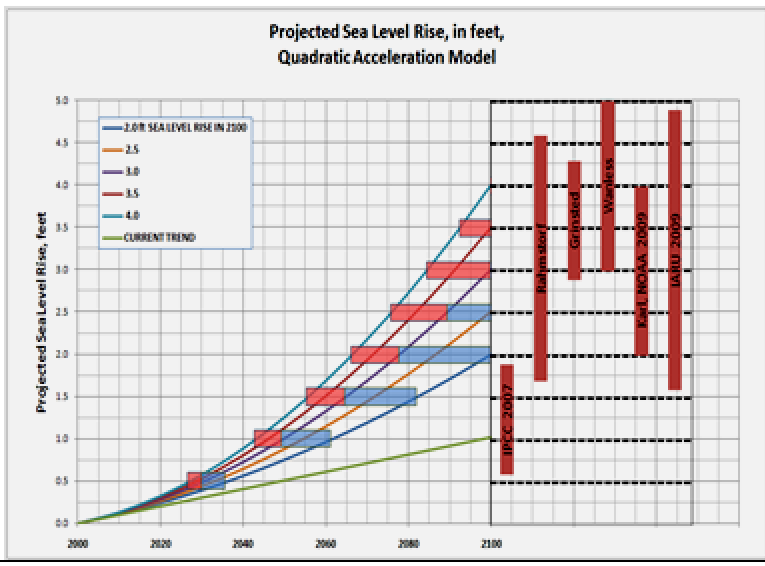

Figure 2: *Prediction of sea-level rise using a Quadratic Acceleration Equation; The graph outlines the average, and 1 and 2 standard deviations from the average of the current models; The horizontal bars outline the ranges when the sea-level rise could occur (Heimlich, et al. 2009).*

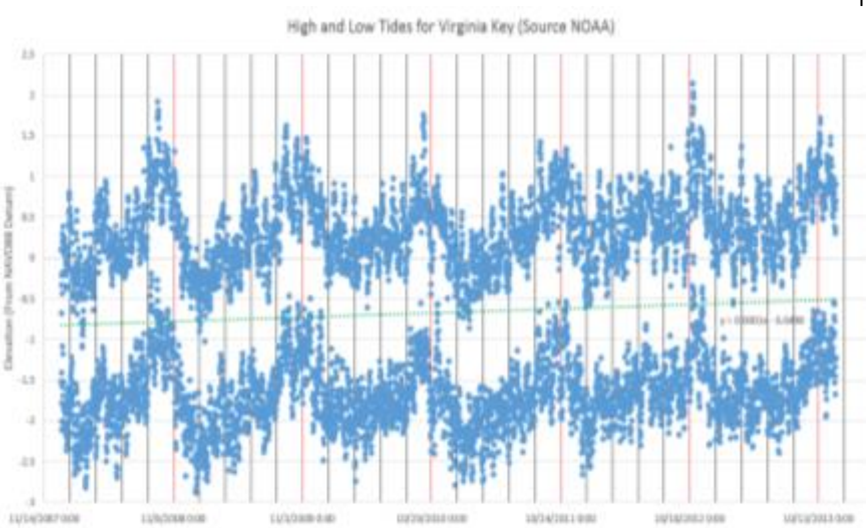

Figure 3*.6 years of high tides at the Virginia Key tidal stations (2007-2013). The highest tides each year occur in the mid-Fall (October). Note the overall trend (green dotted line) is upward.*

This study used an approach that avoids the uncertainty of adding timelines to sea-level rise projections. The investigators used, instead, current conditions plotted at incremental increases of 1, 2, and 3 feet of sea-level rise using data from the US Army Corps of Engineers to make projections. The increments worked as threshold values and support planning considerations by providing planners the ability to know, ahead of time, where the next set of vulnerable areas will be. This allows for a conservative, proactive approach utilizing observed and future sea levels (**See Figure 2**). These sea-level benchmarks provide a planning tool to inform infrastructure design and project completion and can be further refined as sea-level rise progresses.

Prior to compiling data, local community needs were assessed to define an acceptable level of service (LOS) for the community. In this context, a level of service (LOS) is defined as how often it is acceptable for flooding to occur in a community on an annual basis. **Figure 3.** is a summary of high tide data from 2008 to 2013 depicting that in Southeast Florida king tides occur annually in October. While storms may alter this pattern slightly, these would be atypical events. **Figure 4.** shows the same data, tides in order of height, graphed from lowest to highest. This illustrates how the highest tides are much higher than the average. This translates to communities as increased flooding, longer durations of standing water, and a diminished LOS. LOS plans are usually in place, however, when all environmental and infrastructure factors are not taken into consideration there is often a loss of confidence in the plan or the plan fails. Sea-level rise is one of these essential considerations and this mapping can inform LOS plan changes. Planning in this way allows for a long-term LOS that can be defined and used for near-term planning through comparative analysis of flooding frequency. For example, 1% flooding frequency translates to 4 flood days per year. In Miami Beach, the flood level is nearly 2 feet NAVD 88, well above the mean high tide (**See Figure 5**). If sea-level rises one foot, the line will move downward one foot (dashed red line), and similarly for two feet (black dashed lines).

Previously, impacts of flooding or infrastructure damage were the focus in coastal regions, assessed using average mean tides, or, mean high tides. These efforts assumed a bathtub approach, which assumes that flood and groundwater will stabilize horizontally to match the elevation of the ocean tides, to determine vulnerability [62]. Bathtub models generally overlay areas of low elevation with projected sea-level rise, relying on Light Detection and Ranging (LiDAR) to create surface topography. This scenario is used by many governmental organizations due to the ease of data acquisition and model creation. The main disadvantages of this type of model is that it does not consider urban water control infrastructure such as dikes and canals, or that groundwater levels can lead to underestimation of inundation because they do not identify low-lying inland areas that might flood at an earlier time than areas along the coast as a result of higher groundwater tables. Bathtub models also do not account for natural and anthropogenic processes, such as, erosion, accretion, beach nourishment and seawalls.

The means to identify infrastructure vulnerable to sea-level rise requires detailed topographic information to assign units of elevation and to indicate inundation vulnerability. Topography is a key parameter that influences many of the processes involved in coastal change, and thus, up-to-date, high-resolution, high-accuracy elevation data are required to model the coastal environment. Previous approaches to modeling inundation from simulated sea-level rise have been limited by coarse-resolution elevation datasets (surveys, field spot elevations, United States Geological Survey (USGS) maps) as opposed to high resolution electronic imagery [5,6,63,66]. Communicating the importance of sea-level rise to local entities requires better data [25,64,65]. LiDAR is available in many areas, but the coarse vertical definition, plus or minus 1 to 2 feet, is not as useful for coastal areas where inches matter.

As time has progressed, high resolution LiDAR has become available for most of South Florida and is used in determining current bathtub models. Currently, multiple organizations have implemented a methodology that uses the influence of a tidal surface elevation in modeling the vulnerability to sea-level rise. The methodology as described by NOAA is an adjusted bathtub model that takes into account local and regional tidal variability and hydrological connectivity. In this model type, a water datum such as the mean higher high water (MHHW) datum is considered as the base datum elevation. This scenario is used by many governmental organizations due to the ease of data acquisition and model creation. The main disadvantages of this type of model is that it does not consider urban water control infrastructure such as dikes and canals, or that groundwater levels can lead to underestimation of inundation because they do not identify low-lying inland areas that might flood at an earlier time than areas along the coast as a result of higher groundwater tables [90]. Unfortunately, these current bathtub models may be misleading in Southern Florida due to the extensive canal and dike systems that exist to control flooding [62]. In addition, South Florida is underlain by a very porous, fresh-water bearing limestone rock, the Biscayne aquifer that is connected directly to the Atlantic Ocean. As sea-level increases, flood impacts will be compounded by pressure from the ocean pushing from below against the fresh water supply and thus maintaining higher groundwater levels.

Modified Bathtub Model

A modified bathtub model considers more than just static elevation to determine sea-level rise vulnerability. Groundwater levels build in elevation, as one moves away from the coast. The importance of the groundwater table in the model is that it is responsible for determining the soil storage capacity which is the ability of local soils to absorb flood waters. As soil storage capacity is lost, due to rising groundwater levels, local and areal flooding increases. As a result, it is important to include the groundwater table in sea-level rise models for Southern Florida, to accurately identify the areas that will likely be inundated as sea levels rise over the coming years. Utilizing groundwater tables in sea-level rise models will help identify potential hazards to water, drainage, and sewer infrastructure that may be compromised in times of storm surge and flooding due to increased sea levels. Water, sewer, storm-water and transportation infrastructure in low-lying inland areas may be compromised faster and more severely due to the loss of soil storage capacity. Projecting groundwater levels will identify infrastructure with a greater vulnerability to this kind of flooding.

Methodology

The most important factor in determining sea-level rise vulnerability is the initial land surface elevation. As the elevation increases, the effects of sea-level rise induced problems are reduced, especially in regions that have high coastal ridges that continue to decrease in elevation as you travel inland. The first step in this analysis was locating and obtaining the best vertical resolution digital elevation model (DEM) available. The majority of LiDAR (Light detection and ranging) derived DEM information was conducted by the Florida Department of Emergency Management (FDEM) with a vertical accuracy of seven inches. The FDEM does not directly store the DEM data, but instead distributes the data out to other public organizations to act as the repository of the data. The primary repository agency of the data was determined to be the National Oceanographic and Atmospheric Administration (NOAA), with the coverage map shown as the areas in red in **Figure 9**.

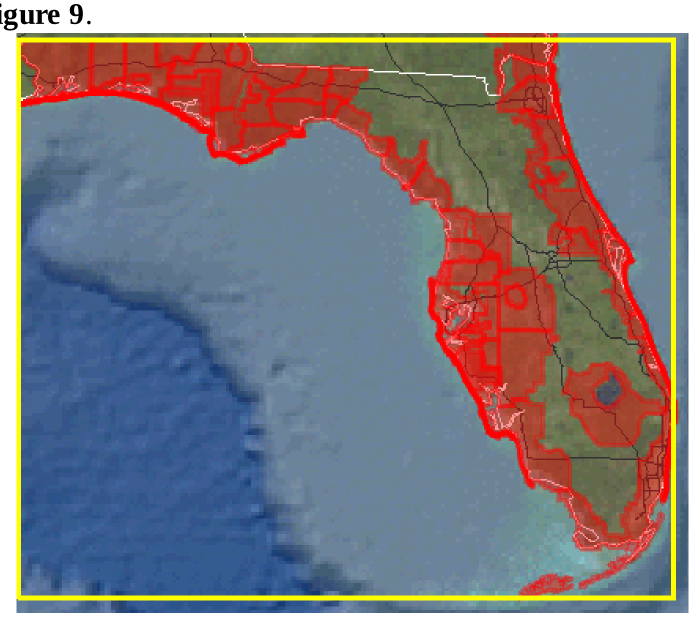

FIGURE 9. NOAA LIDAR DATA COVERAGE AREA

The NOAA downloading server uses a tiling system method for storing the data. The download system also enforces a maximum data batch request size limit of one gigabyte of data per request packet. The dataset for the state of Florida had to be broken down into multiple requests.

This required manually defining the data request segments and recompiling the tiled data back into a single DEM using three-foot cell size resolution. Three-foot resolution is the smallest cell size available for download using the Digital Coast server. All data requested from the NOAA Digital Coast was made using the same parameters. An additional download parameter of the data was that only the last returns of LiDAR data were requested. Ground return, commonly called last return values, represents the ground surface elevation values as shown as the fifth return. Three-foot cell size for the DEM was requested to allow for the ability to create higher resolution drill down analysis in regions of high vulnerability.

The DEM sensitivity analysis was conducted to determine the optimal size resolution for use on the project. Though the native three-foot resolution would bring the best results, the high resolution created issues in data management for calculating model results and rendering the data results. DEM data points were resampled from the native three-foot resolution into different cell size resolution using different resampling techniques in the ArcGIS resample toolset. Upon review of the new raster dataset (composed of a matrix of cells/pixels organized into a grid where each cell contains a value), numerous data gaps were observed. The data gaps represented areas that displayed an inadequate number of radar return data points. This made it challenging to accurately determine the bare earth elevation resulting in a null value assigned to the cell. The majority of the data gaps occurred where bare earth returns could not be calculated, such as building sites. The algorithm fills in null values within the raster data by interpolating a rectangular three-cell by three-cell average value to apply to the missing cell. To minimize the amount of error introduced into the project, the three-foot cell size DEM's had the algorithm applied prior to being resampled into fifty-foot cells. Once in fifty-foot cells, the algorithm to fill the gaps was applied a second time to fill larger gaps. The three methods of resampling considered were using nearest neighbor, bilinear, and cubic methods. The nearest neighbor method works by determining an average value using a rectangular neighborhood grid (See **Figure 10**).

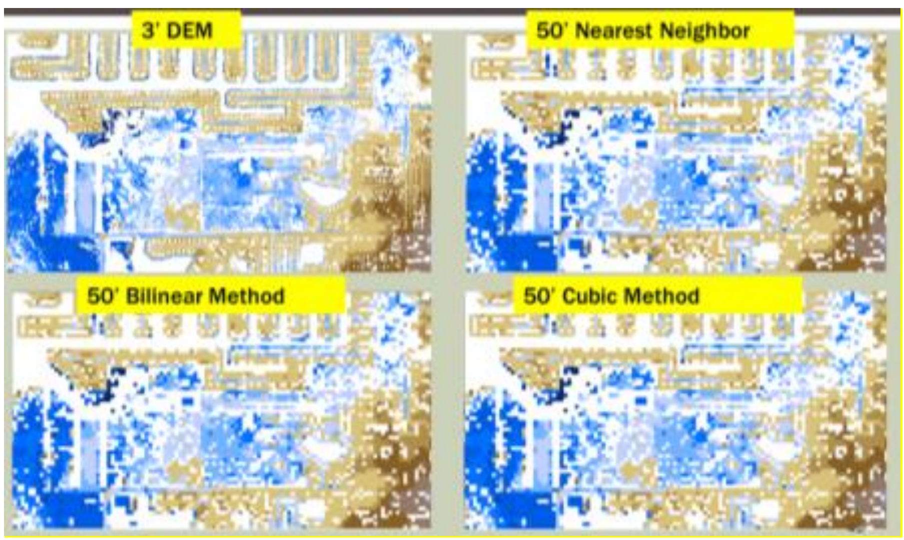

FIGURE 10. EXAMPLE RESAMPLING TECHNIQUE RESULTS

The bilinear method uses a distance weighted average method for determining the new cell value. The cubic method creates a cubic convolution through the 16 nearest cell centers to create a fitted, smooth-curve interpolation. A differential value map was created by subtracting the raster cell values from each of the resampled datasets against each other. The difference map was intended to indicate the raster cell value of difference between the different interpolation methods. The results of the comparisons indicated that between the different resampling methods for Miami-Dade County that no difference was indicated by return values of zero's. As a result, a decision was made to use the nearest neighbor method due to the quicker processing time required to resample the data.

The resulting resampled DEM data was then tested against 150,000 data cells values to determine what cell size to use on the project using a base three-foot resolution cell size for comparison. Based on the results, the 40-foot resampled cell size produced the best results for maintaining the standard deviation at the level of native elevation accuracy at the largest cell size, while still allowing for reasonable processing times.

Additional data sources for DEM retrieval were obtained from the St. Johns River Water Management District (SJRWMD) and the South Florida Water Management District (SFWMD). The advantage of the DEM's from the water management districts was that the data was already processed and distributed in fifty-foot cell sizes making retrieval more efficient for obtaining the cells and eliminated the processing need for the NOAA files. For consistency, all elevation data grids were converted to fifty-foot cells for all datasets. The base source of the DEM data used by water management districts was based on the FDEM data, thus, no conflict of input data was expected. Another advantage of the water management district DEM's was that additional pre-processing was conducted to fill missing data gaps using focal statistic operators. Focal statistical operators work by calculating statistics over a specified neighborhood region (ESRI). The NOAA dataset DEM's had to be processed using focal statistics to create more complete dataset. Filling the data gaps was necessary to minimize the amount of null value data cells in order to create a more continuous base DEM data source.

Because there were different data sources and methods required to download the DEM data, a process was developed to reassemble the data. A major issue when recompiling the data was that all of the individual tiles of NOAA data had to be mosaicked back into larger pieces that could then be modified to create a complete state DEM model. To mosaic the tiles together, a new file geo-database was created to represent each download packet retrieved from NOAA.

The selected spatial reference for the dataset was changed to match the native spatial reference from which the data was retrieved. The data tiles were then loaded into the newly created raster dataset within the ArcCatalog. The number of tiles that could be loaded into each raster matched the original packet sizes from NOAA which was approximately twelve tiles.

The final model step was to take the compiled and processed DEM and extract out specific inundation areas based on specific sea-level rise depths. The symbology was modified to classify the data into two groups, those with values below a designated elevation and those above the designated elevation by manually specifying break values. Development of the surface topography included "ground-truthing" - tying it to local benchmarks and transportation plans and USGS groundwater and NOAA tidal data from local monitoring stations. These were then correlated to groundwater data.

Inland groundwater builds up due to friction while traveling toward the low lying hydraulic base (to the sea). The buildup of water creates a scenario that is not captured in the bathtub model in that the soil storage capacity is reduced, in some cases, resulting in permanent inundation prior to when it would be expected to occur under a bathtub model. The first step for creating the model was incorporating a groundwater surface elevation (hydraulic gradient) dataset into the model. The initial step included determining if a current groundwater surface elevation model for all of Florida was already available. Data points for determining the ground water surface were created by using the historical USGS well site records for groundwater levels. In order to be considered, the gauging station had to have a minimum of 35 years of continuous data. Only stations currently in use were considered to ensure the data incorporated the current time period. The well records had to be tabulated into a new database to allow functional transformation into a geographical information system (GIS).

Based on the results of the database and large seasonal swings in the ground water surface, three separate scenarios were determined to be considered to encompass the effects of different sea-level rise intervals. The determined levels consisted of the ninetieth percentile monthly average which showed the high levels each year. A comparison of different tidal gauges located in different quadrants of the study region showed a high correlation between the stations with matching peaks and troughs. The inner connectivity of the groundwater table was thought to be an important factor in determining the relevance of an interpolated groundwater surface elevation. If it was deemed that localized man-made events played a strong role in influencing the groundwater table, then an interpolation would not provide a reasonable expectation of future groundwater table behavior. A correction to the database values had to be completed to convert hydraulic head values from NGVD 1929 to NAVD 1988. The conversion process relied on determining the conversion factors created by NOAA of transformation values at the geo-referenced locations for the data.

Various interpolation methods were used to determine the surface that produced the best results. Some of the interpolation methods considered were Inverse Distance Weighting (IDW), ordinary kriging, co-kriging, and kernel density functions. The resulting interpolation that produced the best performance measures was the ordinary kriging, which was then applied to the model as the groundwater surface elevation. The output groundwater surface model was created as a raster image using 50 ft. cells, which matched the elevation sensitivity analysis for optimal mapping unit size. Part of the issue with the initial interpolation was that there were no well sites near the coastal shore to curve the interpolation results to sea level. To correct for the coastal bias, additional created data points were added to the dataset. The first interpolation of created data points was located along the ocean interface with an assigned groundwater elevation of zero. Interpolations of the groundwater table surface were analyzed using multiple iterations of elevations between zero and one foot of groundwater elevation above the zero datum. Additional calibration involved off-setting the created data points to the east of the coastline. The results indicated that the best model to use consisted of a five hundred foot coastal offset with 0.7 feet of elevation for the created data points. Groundwater surface models were created using the ninetieth percentile. Future groundwater surface elevation models were created by adding a specified height to the existing groundwater table. The assumption made was that an increase in sea-level rise would shift the starting point of the hydrological gradient, the ocean coast interface, by the same distance along the entire gradient line. The final inundation model was created in GIS by subtracting the groundwater surface model from the digital elevation model, with the difference in elevation being the soil storage capacity of water.

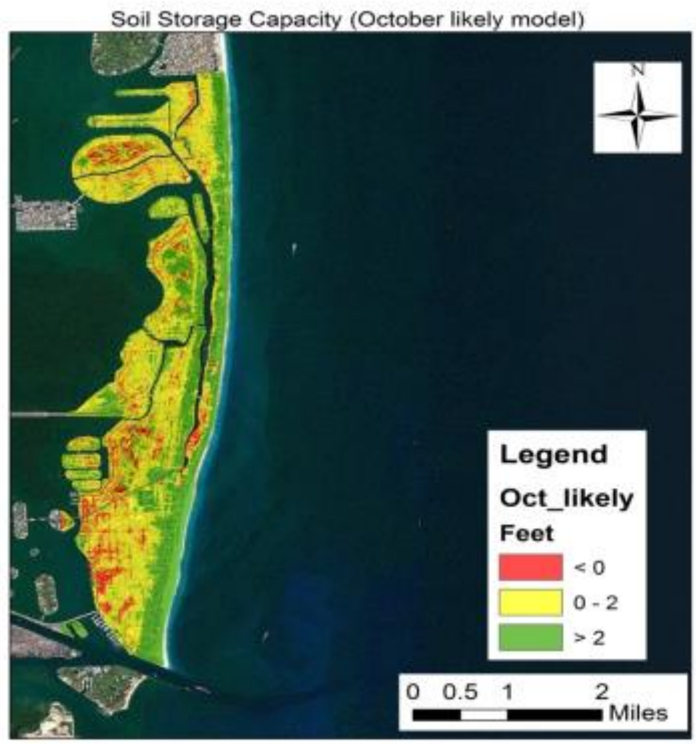

***Figure 12**: Modified Bathtub model for Miami Beach*

This methodology was first verified through a similar project in Miami Beach [62,109] in which it demonstrated the ability to provide a high level of accuracy (**See Figure 8, 11, 12**). For flood prediction purposes for Miami Beach, based on the LOS and soil saturation in low lying areas, the bathtub and modified approach were used (**see Figures 11 and 12**) to show that the latter is more realistic.

The goal of this effort was not to model groundwater flow, but to identify the critical areas and their correlated vulnerabilities. Hence, vulnerability here is defined in terms of the distance from the land elevation to the top of the groundwater table. The three classifications delineate where the difference between topography and groundwater is organized into levels of: extremely vulnerable (below 0 ft.), potentially vulnerable (0-2 ft.), and not vulnerable (>2 ft.). The term "potentially vulnerable" is used for areas that need further investigation considering the uncertainty of drainage and storm-water improvements that might affect levels. The groundwater levels are the result of investigating all USGS and other monitoring wells, with at least 30 years of data, to determine the critical junctures that would increase vulnerability to surface flooding. Romah, similarly, plotted the data on groundwater fluctuations [91]. As noted in **Figures 4-6**, the peaks usually occur in October. By plotting groundwater levels from smallest to highest, the peaks generally occurred about the same time between wells. As the greatest vulnerability to flooding occurred when the groundwater was closest to the surface, the 99th percentile (4 days/yr.) was used to Krig[1] the GIS Layer of groundwater levels to match the tidal data. The topographic LiDAR layer and the groundwater maps were used to determine the difference between land height and peak groundwater elevation, essentially indicating whether the soil can absorb water or is too saturated to do so.

LiDAR Sea-Level Rise Mapping

Figure 7 is an outline of layers used by FAU for the Kresge project. The data was gathered for all four counties using LiDAR mapping. The first step in the analysis was locating and obtaining the best vertical resolution digital elevation model (DEM) available. The majority of LiDAR (Light detection and ranging) derived DEM information used in the model was conducted by the Florida Department of Emergency Management (FDEM).

Figure 13 demonstrates the difference between 3-ft and 10-ft. tiles depicting the challenge for horizontal accuracy discussed in the *Methodology* section. The final inundation model was created in GIS by subtracting the groundwater surface model from the digital elevation model with the difference in elevation being the soil storage capacity. **Figure 14** outlines this process.

US Census data for 2010 comes in a variety of forms. The initial download by the Department of Civil, Environmental and Geomatics Engineering was by census blocks. Census blocks encompass a large number of parcels, so scaling of tract data differed from the property and the sea-level rise mapping. A series of maps was developed as a means to identify socially vulnerable areas. A caveat was the need to define threshold values that could provide separation between areas.

The property appraiser's office in each county has data records by parcel and the parcels are in GIS shape files. The initial direction was to focus on Monroe County. This data was downloaded for Monroe County (also Miami-Dade and Broward Counties). The properties have a series of codes attached to them that define land use, and identify parcels with homestead, disability and other characteristics. These were thought to be useful for mapping purposes.

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[1] Kriging is an interpolation tool used in ArcGIS (for more, see support.esri.com/en/knowledgebase/GISDictionary/term/kriging)

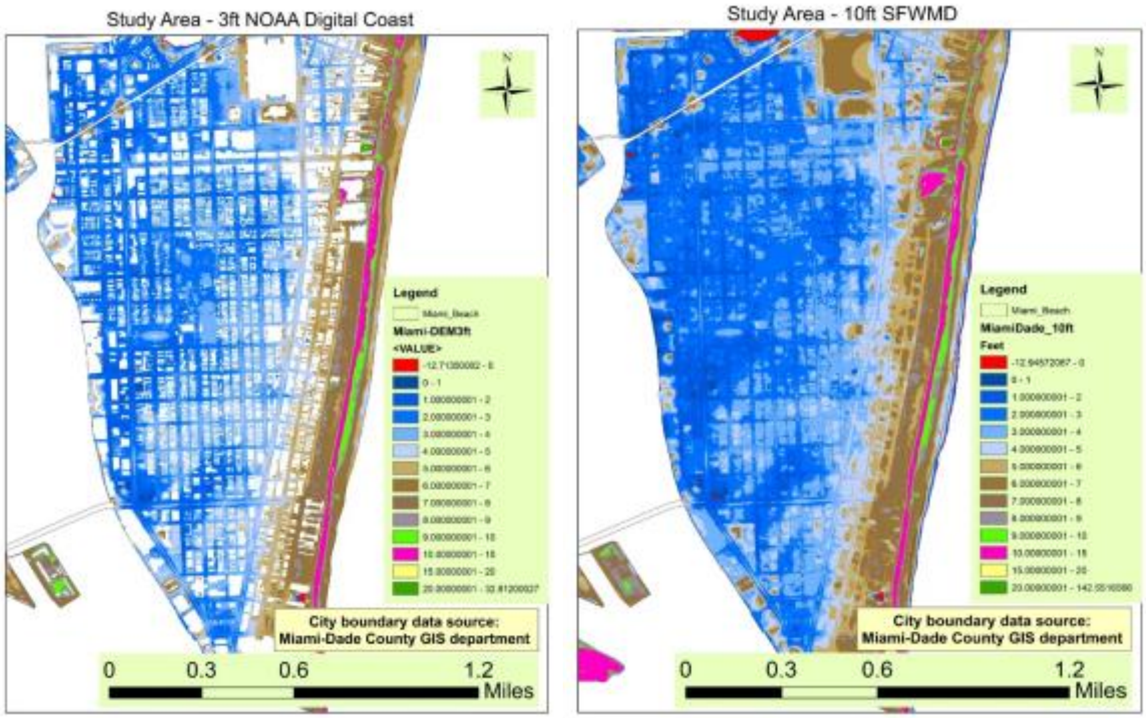

Figure 13. Comparison of LiDAR horizontal data

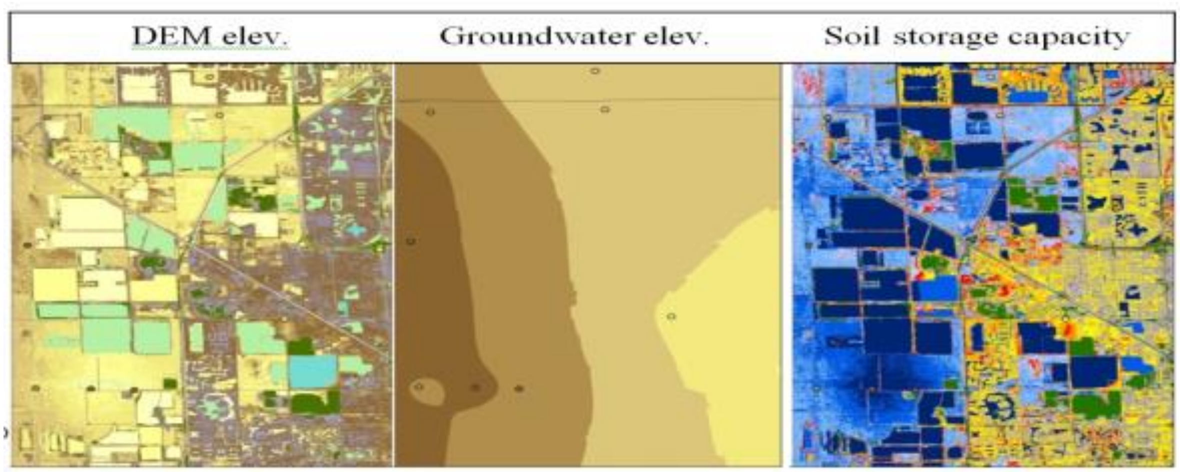

Figure 14. Soil storage calculation (surface elevation - groundwater elevation = storage)

Results

Maps

First, sea-level rise data was analyzed, as shown in **Table 1 in Appendix B**, summarizing the statistics for current, 1-, 2-, and 3-foot sea-level rise scenarios, depicting vulnerable and potentially vulnerable land, or areas most likely to flood or have standing water. As a result, projecting groundwater levels also indicated infrastructure with a greater vulnerability for flooding where water, sewer, storm-water and transportation infrastructure in low-lying inland areas may be compromised faster due to the loss of soil capacity. Compromises in these structures could potentially expose populations to disease. **Figure 15**. in **Appendix**

A compares these numbers directly, illustrating that more land is vulnerable as sea-level rises. Likewise, in **Figure 16, Appendix A**, the potentially vulnerable land increases up to 3 feet, where, at this level, much of the land has transitioned to a vulnerable status displayed by box plots. **Figure 17, Appendix A** includes P-P Plots, which compare cumulative distribution function of a dataset, demonstrating that the sea-level rise data is not fully normally distributed, something more clearly shown on the Q-Q Plots, which compares the quartiles of a data distribution, in **Figure 18, Appendix A**. Because maps were produced displaying a single data set, rather than overlaid, communities were identified as at-risk based on the ZIP code interpretation of vulnerability.

The sea-level rise vulnerability maps for the four counties - Broward, Miami-Dade, Palm Beach, and Monroe are outlined below.

Appendix C. **Figures 19-22** depict vulnerable and potentially vulnerable areas in Palm Beach County. Through outreach it was determined that many believed that Palm Beach County is far less vulnerable to sea-level rise than other Southeast Florida counties due to higher ground. However, the groundwater levels in Palm Beach County reveal that the sea-level rise impacts are already a challenge and will become more so over time. Of note, the inundation that will occur toward the West in the form of standing water.

Figures 23-26 in **Appendix D** depict the same information for Miami-Dade and Broward counties. Similarly, the understanding of risk may be somewhat negated due to the fact that the coastline is still being developed. As noted, sea-level rise will occur over time, yet many of the effects are seen presently in the form of king tides, flooding and long periods of standing water. Through outreach it was determined that while many sectors are including the effects of sea-level rise in their planning in Miami-Dade and Broward, none encountered during outreach were including groundwater considerations. Miami-Dade and Broward, similar to Palm Beach County, demonstrate greater vulnerability moving West as soil becomes saturated. Many of these geographically vulnerable areas, including those toward the West are more affluent neighborhoods, which raises the question of population migration and displacement.

Figures 27-31 in **Appendix E** depict Miami Beach. Each of these figures demonstrates that the expanse of impact of sea-level rise and groundwater are significantly higher than bathtub model projections. These maps represent the opportunity for comparison with current bathtub models that may not fully present vulnerable areas. By not considering groundwater, these models may provide a false sense of security for vulnerable neighborhoods and guide incomplete adaptation strategies.

Figures 32-39 in **Appendix F** depict Monroe County by ZIP code. Monroe County is comprised of long, narrow land with multiple ZIP codes. The arrangement for Monroe County was altered to show ZIP code changes on one graph. The percent of the area subject to inundation risk is depicted in each figure, as quite significant. More poignantly, the maps display that Monroe will see inundation much sooner. Given that this county hosts many tourists and has an economy that is highly reliant on tourism, standing water and sea-level rise both threaten health through the opportunity for introduction of new vector-borne and waterborne disease and economic stability as tourist destinations become inundated. This will not only impact the county, but the larger region of Southeast Florida.

These maps not only identify the areas prone to flooding due to groundwater, storm-water intrusion or ponding rainwater, but also areas where sewers and septic tanks could intersect with flooding (which describes all of South Florida). The toolbox for infrastructure identifies sealing sewers as a priority. Likewise, septic systems will need to be phased out, but this is a political will issue and prior effort to locate maps of septic area were not successful. Salt water intrusion is not affected by sea-level rise in South Florida as a result of the porous geology and increasing groundwater table. Storm surge data is currently highly unreliable. Another Kresge grantee was in the process of developing surge data. That data may be available soon, but was not available for this project. Its use is uncertain given the current sea-level rise vulnerability data acting as a surrogate for surge along the coast.

These figures are the first step in shedding light on the impacts of sea-level rise and groundwater in the region. It is recommended that the base GIS map be updated with layers of information for water mains, sewer mains, canals, catch basins, weirs and storm-water facilities. Updating these maps with critical infrastructure will not only provide a more comprehensive view of points where health may be impacted, but also a view of the vulnerability of critical infrastructure. All systems, both community and other, should be included in this view as it will provide a great detail of, not only infrastructure risks, but can provide insight for public health prevention planning.

Methodology

An index for social vulnerability was developed for this project to demonstrate social vulnerability for the region and build upon recent developments in measuring and quantifying various aspects of community vulnerability [53,55,66,67,68,69,70,71,72,73]. The application of this index to sea-level rise projections will allow the opportunity to develop mitigation and adaptation strategies before major environmental changes occur.

Preliminary Maps

Table 2 in **Appendix B** summarizes the statistics for education, poverty, and other socio-economic elements used to develop the maps and the social vulnerability index for this project. Preliminary maps for social vulnerability variables were generated to provide individual depictions of population characteristics that can be used for understanding communities, in addition to the SVI which provides more of a 'big picture.' **Figures 40-49** in **Appendix G** include the preliminary maps displaying data for race, education and poverty in the 4 counties. At first glance, these maps indicate vulnerable populations almost opposite those that present as geographically vulnerable in the GIS Maps. Some populations, however, toward the West and long the coastline do demonstrate higher vulnerability. These are further explored in the hot-spot maps in this report.

Vulnerability Model Index

Table 26 in **Appendix B** lists the variables used to construct the social vulnerability index (SVI). Few existing indices have accounted for the health status of the affected populations. In addition, there is growing attention to the anticipated health risks, such as waterborne diseases, resulting from prolonged ponding conditions related to the effects of floods and sea-level rise [80]. The emphasis regarding populations for this project was focused on health and social denominators. To accomplish this, a composite measure to quantify health-related vulnerability was developed to understand observed health data gaps and how to potentially fill them. This sub-measure included variables such as incidence of chronic and acute health conditions in conjunction with socio-economic variables and physical exposure to the anticipated effects of sea-level rise. The proposed index should be understood as a framework developed to bridge outcomes that relate to past, present and future conditions. **Figure 54 in Appendix A.** displays a flow chart of the index components.

The Factor analysis and social vulnerability index were not an original objective of the grant; however, it became evident that these would be essential in describing the information that may not necessarily be clearly portrayed in the maps. Population characteristics were provided by the FDOH and were obtained from Florida CHARTS and the US Census Bureau. Florida CHARTS is maintained by the FDOH Division of Public Health Statistics and Performance Management. Estimates are provided by the FDOH Office of Health Statistics and Assessment, and are available from 1970 through the present and up to five years into the future (http://www.floridacharts.com/charts/). All denominator data for calculations performed at the county-level use Florida Charts data, and the annual population estimates available for the specific county of interest.

There are several population-based surveys that are undertaken by the US Census Bureau on a regular basis. Most of this data are free and available for download and use from the website (http://www.census.gov or http://factfinder2.census.gov). County-level and ZIP code-level data are available for population information. However, ZIP code-level data is based on ZIP Code Tabulation Areas (ZCTAs), which are generalized representations of the ZIP code service areas used by the Census Bureau. All denominator data for calculations done at the ZIP code level use 2010 Decennial Census population data. This is the best estimate available for ZIP code level analysis. Therefore, rates for 2005 use health data from 2005, but population estimates based on 2010 census data. Another caveat is related to unavailable ZIP codes. For example, individuals who provide a PO Box address at intake will have a ZIP code that is specific to their postal office box addresses. The US Census does not provide population estimates for such ZIP codes. Other ZIP codes may be specific to government addresses. Again, no population estimates are available and such ZIP codes are excluded from rate calculations.

Socio-economic data at the ZIP code level was accessed from the U.S. Bureau of the Census – American FactFinder. The data included variables from the Census 2010 and the American Community Survey [92,93]. The variables included in the analysis are derived from eight tables including social characteristics, characteristics of the population 65 and over, disability characteristics, educational attainment, median income, poverty status, race/ethnicity, and health insurance coverage.

Index Construction and Analysis

The Index was created using the z-score approach. A z-score approach is an appropriate technique for variable sampling distributions that satisfy the normality assumptions. A z-score indicates how much a particular observation deviates from the mean relative to the standard deviation. A z-score is calculated as follows:

$$z - score = \frac{o_i - \mu}{s}$$

The Kolmogorov-Smirnov test-statistic and other statistical techniques were used to test the hypothesis that the observed data had an approximately normal distribution. Data transformation and/or windsorization (i.e. trimming of the tails to the 97.5th percentile) were performed if outliers or extreme values that distorted the distribution were present [79]. Truncation was used to remove the effects of the outliers on the mean and the standard deviation. Truncation to the 99th percentile preserves the extreme values in the tails of the distribution, allowing them to still represent "best" and "worst" practices, but reducing their undue effect on the aggregation algorithm.

To better understand the differences between the regions, demographic and health data were managed, summarized, and analyzed with XLStat®. Correlation analysis was used to indicate whether the variables were related to other variables on an individual basis. However, correlation analysis works best when there are a limited number of variables, as opposed to the 24 variables identified. To address this problem, factor analysis (FA), which dates from Spearman, was used [93]. There are two main types of FA: Exploratory factor analysis (EFA) and Confirmatory factor analysis (CFA). XLStat® uses EFA to reveal the potential existence of underlying factors within data containing a very large number of measured variables.

Using XLStat®, an add-on to EXCEL®, statistical analysis was conducted for the sea-level rise potential, demographics, and disease incidences. Frequencies of all variables were calculated.

Principal Component Analysis

Statistical analysis was conducted for the development of the index and principal component analysis. PCA was conducted to combine variables on two fronts: diseases and demographic factors. These were also plotted with sea-level rise vulnerability. The results are shown in **Table 3, 4 and 5 in Appendix B**. There was relatively high commonality between most of the social and health factors.

Principal Component Analysis (PCA) is a popular multivariate technique, mainly used to reduce the dimensionality of *p* multi-attributes to two or three dimensions. PCA is a special case of factor analysis (where k, the number of factors, equals p, the number of variables). While FA assumes a number of factors, PCA is used to reduce the number of variable to factor sets, while maximizing the unchanged variability in order to obtain independent (non-correlated) factors. The mathematics of PCA use an orthogonal transformation to convert observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. PCA uses a multivariate statistical parameter called an eigenvalue - a measure of the amount of variation explained by each principal component. PCA summarizes the variation in a correlated multi-attribute to a set of uncorrelated components, each of which is a particular linear combination of the original variables. PCA is the simplest of the true eigenvector-based multivariate analyses. A Scree Plot is a simple line segment plot that shows the fraction of total variance in the data as explained or represented by each component.

For disease versus demographics, PCA found that 6 factors represented 80% of the variability among variables. These were lower education levels, education, older age, and poverty relating to diabetes and pneumonia and graphed as Factor 1. Factor 2 was COPD. Factor 3 was negative for giardiasis, and Factor 4 was a negative with heart disease.

All data was graphed on a Varimax PCA. Virtually all health and social data were located on the right side of the circle, while wealth was on the left. Wealthier people are more likely to live in areas susceptible to sea-level rise, and are likely to have better access to medical care. It should be noted that similar results were found for COPD, pneumonia, and asthma – poorer, elderly populations were more susceptible to negative health outcomes. Wealth was opposite of health risks. This is clear in **Figure 55**, **Appendix A**. It is important to note that PCA is not indicative of correlative relationships.

Figure 56 is a Scree plot developed for sea-level rise and disease incidence. Factor 1 was primarily derived from demographic factors – poor, elderly, lower education, etc. None were significant. The sea-level rise parameters were all negative. Factor 2 was related to sea-level rise vulnerability, albeit none of great significance (**See Table 6, Appendix B**). The principal component analysis did not generate useful results when all factors were used. However, a Varimax plot for factor 1 and factor 2 (**See Figure 57**) depicts sea-level rise parameters as greater than 90 degrees from demographics, indicating that these factors are not correlated. The correlation matrix (**Table 7**, **Appendix B**) demonstrates negative correlations for disease and sea-level rise. The findings confirm that the socially vulnerable do not live in the areas where sea-level rise is the most extreme problem, specifically neighborhoods with high socio-economic status, newer homes, or homes on the water.

The Varimax plot in **Figure 55, Appendix A** visually depicts the results of the PCA analysis. **Figure 58, Appendix A** utilizes a graphical tool whereby red and orange dots are strong correlations (variables shown when scrolling over individual tiles). The sea-level rise vulnerability factors are not red and orange with social and health issues.

Figure 59, **Appendix A** indicates results when the sub-indices are used to compare sea-level rise. This demonstrates health access and health status among other variables depicted together and above median income opposite these variables with sea-level rise variables rotating from the second to first quadrant.

Results

The results of these efforts were the series of maps previously discussed and the use of the Social Vulnerability Index in the final hot-spot maps which is indicated by rings and displays this information summarized into a single variable.

Background

Health was analyzed as an outcome, risk factor and contributor to social vulnerability. To look at health as an outcome, incidence rates of locally acquired cryptosporidiosis, salmonellosis, and giardiasis were calculated and mapped. To examine health as a potential risk factor for the negative effects of sea-level rise, hospitalization and emergency department visit rates for heart disease, asthma, and pneumonia were calculated and mapped. Finally, variables including disability were included as a sub-index in the SVI.

Health conditions were considered as both outcomes and as potential modifiers of sea-level rise effects. Social and economic variables are often considered as measures of vulnerability, but pre-existing co-morbidity, disability or lack of healthcare access also impart vulnerability to a particular population [53,54,55,56]. If someone has a chronic disease such as heart disease or asthma, there would be an expected exacerbation of ill effects due to sea-level rise sequelae such as flooding, poor water quality, or decreased food supply. Similarly, a disabled individual or an individual who had difficulty accessing the healthcare system would be expected to have more difficulty avoiding the consequences of rising sea levels.

Asthma

Each disease provides differing information on the risk of sea-level rise adverse effects. Asthma is an atopic condition characterized by hyperactivity of the bronchial airways, which often occurs in response to some environmental trigger. Asthma is a chronic disease that is particularly prevalent in lower socioeconomic communities [112,113,114]. Racial/ethnic as well as socioeconomic disparities in asthma prevalence, exacerbation, and hospitalization are well documented [112,113,114,115]. In our framework, asthma is analyzed as a chronic disease that is directly and indirectly linked to sea-level rise. As a disease of environmental exposures and triggers, asthma rates would be expected to increase as a result of sea-level rise, and more broadly, climate change [116,117]. In fact, increasing rates of asthma have been noted in association with climate change-related factors such as increased air pollution [118,119,120]. Sea-level rise might directly cause an increase in asthma rates through an increase in water levels leading to higher levels of mold.

By virtue of its complicated relationship with socioeconomic factors [112,114, 121], asthma also presents as a pre-existing risk factor which identifies individuals and by extension, communities, that will most likely be negatively impacted by the effects of sea-level rise. As sea-level rise is thought to impact on access to healthcare by affecting transportation systems, and also to impact on housing quality, then it follows that those communities with higher rates of asthma are more likely to be negatively affected by sea-level rise.

Chronic Obstructive Pulmonary Disease (COPD)

Chronic obstructive pulmonary disease is a long-term disease of the lungs which largely stems from smoking [122]. While asthma has a significant impact on pediatric as well as adult populations, COPD mostly affects older adults. In elderly adults, COPD can cause frequent hospitalizations and can increase the risk for pneumonia. In particular, COPD is often a co-diagnosis along with cardiovascular disease, osteoporosis, anxiety, depression and malnutrition [123]. Like asthma, COPD rates are likely to increase as a result of sea-level rise and climate change more broadly [124]. These rates will be affected by increases in air pollution and water-borne diseases. Indirectly, there will be greater hardship on individuals with COPD due to sea-level rise, as transportation systems are affected and access to care becomes more difficult. Accordingly, COPD is likely a risk factor for an individual to experience negative effects due to sea-level rise. Individuals with COPD are likely to have less resilience in light of medical or environmental impacts. COPD thus might burden individuals with a greater degree of vulnerability to the effects of sea-level rise and climate change. This vulnerability is further impacted by an association between COPD and lower socioeconomic status [125,126].

Pneumonia

Pneumonia is an infectious disease that affects the lungs. It has its most serious effects in the elderly, with patients over age 65 having higher rates of hospitalization and mortality due to pneumonia [127]. Studies have shown an association between exposure to particulate matter, nitrogen dioxide, and pneumonia [120,128]. In addition, ozone and air pollution in general, have been shown to be associated with pneumonia incidence [129]. Pneumonia is also an important marker because there are modifiable factors such as good nutrition and immunization, which can decrease the incidence, morbidity, and mortality associated with pneumonia [127]. Here, once again, would be a mechanism of indirect impact from sea-level rise as decreased transportation, decreased access to healthcare, and lower quality of food and water supplies, are likely to have impact on pneumonia rates, accordingly. As such, pneumonia is a respiratory disease process that might be impacted by sea-level rise and climate change, but which also might act as a pre-existing risk factor for negative effects due to sea-level rise. As with the other health conditions, pneumonia morbidity and mortality are worsened by lower socioeconomic status [127,130].

Methodology

Incidence rates are used when reporting cases of illness from the Merlin notifiable disease surveillance system; in this study only crude incidence rates were provided. For those diseases with only a few cases reported during the observation period, as in the instance with the infectious diseases reviewed in this study, rates may be unreliable and sometimes difficult to interpret. In this study only giardiasis presented enough cases to allow interpretation. (**See Figure 63 and 64**, **Appendix H**). Though the Health Impact Assessment outlined some vector-borne and waterborne diseases increasing in the number of reported cases, the number of cases was not significant enough to be mapped by ZIP code for this study. This underscored the need for more granular health data especially since cases tend to be under-reported.

Health data was obtained through the Florida Department of Health (FDOH), Division of Disease Control and Health Protection, Bureau of Epidemiology. Data was accessed from the FDOH Bureau of Epidemiology's notifiable disease reporting system, Merlin. The data used for this study included the following variables: case definition, case classification, event date, county of residence, and ZIP code of residence. The data was limited to the time period of interest for this project which was the first quarter of 2005 through fourth quarter of 2012 and for only the counties of Palm Beach, Broward, Miami-Dade, and Monroe.

Data on the locally acquired cases of cryptosporidiosis, salmonellosis, and giardiasis were analyzed for 2005-2012 for Palm Beach County, Miami-Dade County, and Broward County. Data for Monroe County on any of the reviewed diseases were unavailable due to either no cases reported or an RSE rate of greater than 30, which indicates the data are potentially unreliable. In addition, data for dengue fever, West Nile Virus, and vibriosis for all four counties could not be obtained due to no or low incidence of locally acquired cases. Statistical analysis was conducted for the disease data. Note that chronic disease like COPD, asthma, heart conditions, and pneumonia were additionally analyzed.

Correlations were assessed among variables on two fronts: diseases and their association with demographic factors, and diseases and their association with sea-level rise vulnerability. This was done to test the hypothesis that there is an association between medical and other forms of vulnerability.

Figure 65 demonstrates the pathways in which climate change might exert an impact on health outcomes while these represent different levels of inundation, it is recommended that all be considered as a part of all planning with a health lens. **Figure 66** provides a conceptual framework which illustrates the potentially modifying effect of health on the negative consequences of sea-level rise. Health will ultimately be highly related to resiliency and adaptive capacity.

Results

Burden of Disease Sub-Index

For those diseases with only a few cases reported during the observation period, as in the instance with some of the diseases reviewed in this study, rates were difficult to interpret. This may also occur when there are no cases reported for a given location during the period of interest. The FDOH used relative standard error (RSE) as a way of measuring the reliability for statistical estimates.

The health sub-index relies on health data by ZIP code for four counties (Broward, Miami-Dade, Monroe and Palm-Beach) obtained from the Florida Department of Health. The health data encompassed 195 ZIP codes and include the number of cases treated in emergency departments and the number of hospitalizations for asthma, COPD (chronic obstructive pulmonary disease), heart failure, myocardial infarction, pneumonia, and *Giardia* over a period of eight years (2005 – 2012) which were the initial targets of this project as defined in the proposal. Because there is little literature to suggest that sea-level rise will impact chronic conditions, such as diabetes, variables were limited to only those identified as increasing in the HIA, supported by the literature as demonstrating a potential association with sea-level rise and providing sufficient data to permit analysis.

Additional health data was acquired for the purposes of the index to provide a broader understanding of health vulnerability as it includes both direct effects, such as waterborne diseases, and indirect effects, such as increased exposure to risk factors, and chronic/acute health conditions which can be associated with various age, income, and race/ethnicity groups [80]. Collecting both sets of data provided a broader understanding of who is vulnerable beyond low-income households and those living below the poverty line, who traditionally have been the focus of population-related vulnerability assessments. The data were made available as spreadsheets which were further processed to create database files that were imported into ArcGIS and joined to the spatially referenced ZIP Code Tabulation Areas (ZCTAs). **Table 8**. in **Appendix B** outlines the potential vector and waterborne illnesses for South Florida. This list was generated in 2014 and does not represent more recent potential illnesses.

Vector-borne and Waterborne Disease

Ultimately, the issue with waterborne and vector-borne diseases is that their incidence can increase significantly. **Figure 67** in **Appendix A** is an example, gleaned from very limited literature, of what incidence of giardia might look like as sea levels rise. Obviously, this assumes conditions are not altered, for example through more storm-water pumping, etc. What the data reveal is some organisms are seasonal – salmonella has enough data to demonstrate this (**See Figure 68-75, Appendix A**). It is difficult to delineate the true relationship without data collected not only annually but seasonally as this will provide greater insight into whether or not there is a direct link between sea-level rise and illnesses associated to seasonal organisms. It is important that this be further addressed with improved reporting, data collection and communication between health practitioners and sea-level rise analysts who currently do not have a protocol for communication.

With this in mind, understanding the effects that sea-level rise may have on susceptible populations will aid in finding solutions to mitigate its effect. With the recent cases of dengue fever and the newly arrived chikungunya fever in southern Florida, it is ever more important to continue research into climate change and sea-level rise and its implications on the environment and populations. Public health officials can utilize this study to innovate more precise ways for monitoring and diagnosing waterborne and vector-borne illnesses. Currently, many waterborne and vector-borne diseases go undiagnosed. Knowing a potential for harm exists for local communities, health care officials may consider educating patients and providing additional testing that is not routinely performed. This will allow epidemiologists to better track and potentially mitigate the potential for these diseases to become more prevalent in Southeast Florida.

Water Contamination

As of December 2015, the team found that complete septic tank maps were not available. Some maps containing partial information were available but found to not be GIS-compatible. Due to this, water contamination analysis was not included.

There are a number of issues that might affect drinking water quality. However, Bloetscher et al. and Heimlich et al. focused on the impacts to drinking water utilities as a result of sea-level rise [11,12]. From that study, the water plants were the least at-risk facilities due to elevation. Likewise, the wells were located away from industrial and septic areas, and generally on high ground, but have been moving away from the coast due to saltwater intrusion caused by the digging of drainage canals. Very few people in Miami-Dade, Broward or Monroe County have individual wells. They get water from the same public utility systems.

Wastewater plants are slightly different for the region. There are four large plants located on the coast. Surge is a more likely stressor than a steady rise, given that the design criteria for construction plants generally causes them to be located at higher ground, mounded on the coast. However, significant leakage into the sewer system can occur during heavy rains from inflow, which can overwhelm the plants and draw in saltwater, complicating efforts toward reuse of the wastewater for irrigation. Sealing the sewers, via the G7 program is suggested [62]. There are 400,000 septic tanks in the four counties. Efforts have caused the abandonment of most of the septic tanks in Monroe County. Broward County is converting areas on a regular basis. The issue from septic areas is that the higher groundwater table in the summer and fall can encourage leakage into the soil or septic drain-field failure. This is an artifact condition of the past and will likely to resolve with time. Septic tank maps were housed on County websites at one time, but efforts to secure comprehensive maps for this project were unsuccessful. Coastal waterways (many septic tanks are located near canals) can become contaminated as a result. The Counties monitor this as a part of their MS4 permits.

Access to Healthcare

In addition, data related to the number of Section 330-funded Health Centers serving ZCTAs, total number of health center patients served by those centers, unserved (by Health Centers), low-income population, health center penetration of low-income population, and health center penetration of total population were accessed from the Unified Data System (UDS) Mapper (http://www.udsmapper.org/index.cfm) [94]. UDS Mapper is a web-service funded by the Health Resources and Services Administration, U.S. Department of Health and Human Services, and developed in collaboration with John Snow, Inc. and the Robert Graham Center (http://www.udsmapper.org/index.cfm).

Health Mapping

Table 9. in **Appendix B** summarizes the statistics for all health variables assessed. Diabetes was ultimately excluded from the study due to the lack of support from the literature. **Figure 76**. in **Appendix A** is a set of box plots for COPD, asthma, and heart conditions. These demonstrate there is wide variation among most of the variables. **Figures 80-83** in **Appendix H** depict where these populations are by ZIP code. The data reveal that there are variations across the region, but their relationship with other factors needs further elucidation.

Figures 50-53 in **Appendix G** shows access to 330 health facilities as a measure for health access. These maps demonstrate that socially vulnerable people live in certain areas of the community, and that those areas correspond to the same populations identified as socially vulnerable based on demographic characteristics that were analyzed. These areas also tend not to correspond to geographic vulnerability, though, similar to social vulnerability variables, some of these do overlap, especially given geographic vulnerability data was the most specific of three types of data analyzed.

Figures 119-122 depict variables for chronic disease, cases treated in the ER and hospitalizations, health disparity, as measured by a health disparity index, and infectious disease, depicted as giardiasis and pneumonia. These maps are important as they indicate that chronic disease is shown less prevalent in many of the ZIP codes demonstrating high social vulnerability and low geographic vulnerability and is more prevalent in ZIP codes that tend to have higher geographic vulnerability. The health disparity index corresponds to social vulnerability as does the map for infectious disease. The asthma maps (**Figures 80-83**) also more closely resemble the health disparity and infectious disease maps. This indicates that the conditions that are most likely to be exacerbated by sea-level rise in terms of increased vectors, increased particulate matter (outcomes that will most likely result over the coming decades) remain on the cusp of affecting much larger populations as sea-level rise creeps into those communities, while those conditions that will be more impacted in terms of access to care, etc. are already facing the initial stages of sea-level rise. The overlap or hot-spots portion of this report discusses this in more detail but, ultimately, this describes a very delicate situation.

Mitigating Health Effects

Mitigation will largely rely on the collection of health data by season, annually and at a more specific level than ZIP code to understand emerging trends in infectious disease and how those overlay with more granular chronic disease data. Further, mitigation strategy will, similarly, rely on the inclusion of health care professionals who are partners in collecting this data. It is essential that these individuals be included in the conversation and made aware of the geographically vulnerable areas and how those areas will expand over time. Practitioners should also be encouraged to join this effort.

To have made health outcome projections about exposure to mold, infectious disease, impacted chronic conditions, occurrence of exposure to contaminated water supplies, occupancy of flooding related injury, and mental health issues related to property damage and displacement required more granular data. In the future, it will be important to analyze this data and correlate it to geographic data and for accurate health projections by community.

RESEARCH HOT-SPOTS: OVERLAY OF GEOGRAPHIC, SOCIAL AND MEDICAL VULNERABILITY RESULTS

If one thinks of the social, political and natural systems as layers, one can better envision the world as one where all things share space, but move at different speeds. Change is constant, but not consistent. The natural environment changes relatively slowly, and people have less ability to affect nature in the short-term. The built environment changes relatively quickly, with new development replacing the old on a cycle of about 30-50 years. Infrastructure, such as transportation networks, storm-water systems, water treatment systems, and energy providers, can take longer, sometimes up to 50 years to retrofit. This is the layer that takes the longest, has the most impact on our future ability to cope with impacts and adapt to change, and is the layer that should be the focus of planning efforts now.

Methodology

Social Vulnerability and Health Mapping

Defining vulnerable people can be accomplished by identifying specific thresholds for each variable and creating a map where these variables coincide. For example, in Key West this process was utilized. **Figure 84** outlines the area in blue in Key West with population percentage greater than 50% minority. **Figure 85** outlines in red the areas in Key West with a population with greater than 20% of people aged 65 years or older. However as noted in **Figure 86** these two areas do not coincide which means either the variables are not correlated or the threshold values are not set properly.

A second attempt to address this issue is shown in **Figure 87**. Here variable thresholds were set as transparencies, where multiple coincident variables, above a given threshold will create a darkened area. The variables and thresholds were set as age percentage > 20 and Minority percentage > 30. The darkened square indicates where this happens. Note in this figure, the square that was missing in **Figure 86** is highlighted because the threshold values were adjusted. Also important to note, is the degree to which the factors needed to be separated to create differentiation which represent very small differences.

To better understand the differences between the regions, the collected data was managed, summarized, and analyzed with XLStat, which is a post processor. This package takes spreadsheet data and can conduct sophisticated statistical analyses like principle component, and factor analysis without having to use of other programs like SPSS and SAS, which are more traditional. Correlation analysis was used to indicate whether the variables for sea-level rise, social data and health data are related to other variables on an individual basis.

Ultimately, policy-makers will need more information to prioritize resources and to address the most drastically needed improvements. For example, a major goal to reduce economic vulnerability requires identifying where economic activity occurs and where potential jobs exist. At-risk populations, valuable property (tax base) and emergency response may be drivers, which means data from other sources must be considered in tandem. **Figure 7.** in **Appendix A** outlines the levels of data that can be obtained for most communities.

Figure 88 is a third effort with the same intention. The variables are set as follows:

- → 3 shades of blue and hollow represent different amounts of overlap
- → The darker the more overlaps
    - o Clear = No positives
    - o Light Blue = 1

- Medium = 2
- Darker Blue = All 3 requirements met

In **Figure 88** the same square is highlighted, but again the threshold values assigned to the variables are a critical component.

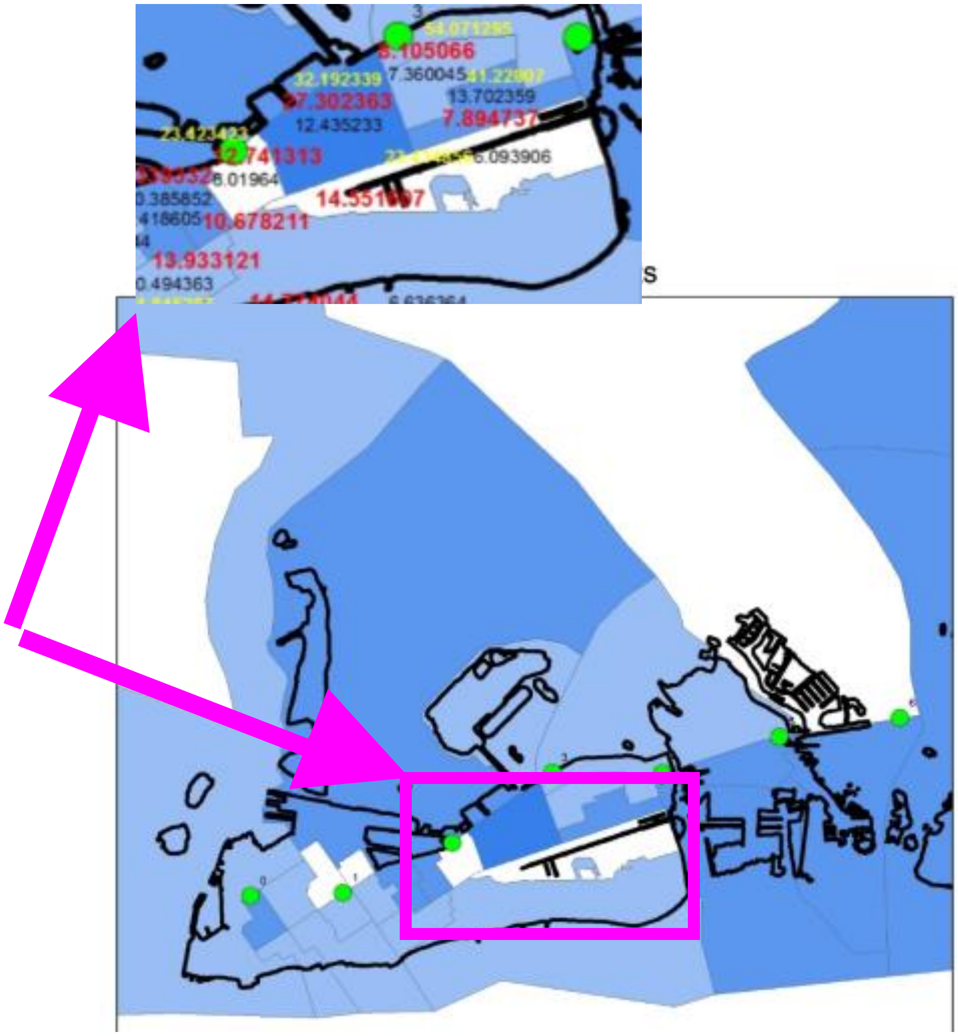

Figure 88. Overlay transparency map in Key West.

The next step was to overlay the identified critical census block over the parcel map with hospitals and medical centers identified (See **Figure 89**).

At this point, FIHI noted three important issues that impacted the efforts. The first was that disease data was only available by ZIP code or county, and that more specific data that would identify clusters of people might violate HIPPA. A third issue was that FIHI could not identify a source that might be able to reduce the ZIP code data to a finer grid. As a result, FAU was required to roll-up all data to ZIP code level. The ZIP code roll-up had two benefits to the project. The first was that all data would be at the same scale. Scale-up from parcel level to ZIP code is a significant step and a ZIP code might include over 10,000 parcels.

FAU's Civil Engineering group calculated sea-level rise risk areas by ZIP code over the four scenarios (0, 1,2, and 3 ft. sea-level rise). Disease data was conveyed by FIHI to FAU for use in further analysis, and similar maps were created for the diseases of interest. The next step was to redevelop the query to the ZIP code. The initial process was to find uninsured persons. There were 114 ZIPs with Uninsured > 20%. The next was to find where areas with >20% uninsured persons and median household income under $50,000. There were 81 ZIP codes that met these criteria. The next was to find where areas with >20% uninsured persons, education less than 9th grade and median household income under $50,000. There were 34 ZIP codes that met these criteria. The next was to find where areas with >20% uninsured persons, education less than 9th grade, reported speaking English less than very well, and median household income under $50,000. There were 22 ZIP codes that met these criteria. Of note, the thresholds were created for each variable and results were altered if the thresholds changed. The next was to find where areas with >20% uninsured persons, education less than 9th grade, reported speaking English less than very well, had a population of greater than 5% without a vehicle and median household income under $50,000. There were 7 ZIP codes that met these criteria.

The representatives from the South Florida Regional Planning Council noted that the ZIP codes highlighted did not conform to where they knew the vulnerable people were. 33122 had a low disease rate. 33009 (Hallandale Beach) has portions vulnerable to sea-level rise, but those are expensive homes and the disease incidence is middle range. 33022 (Hollywood) has the highest incidence range, but excludes the sea-level rise vulnerable lake homes, and is primarily a middle class community (See **Figure 90**). None of these would appear to indicate the coincident vulnerable populations sought. That was the commentary when this was first presented and it was suggested that a different method be pursued given the lack of information provided.

The same concept was applied to the Keys after the sea-level rise mapping was revised for the Keys. The Keys (Monroe County) are highly vulnerable to sea-level rise throughout and the population is relatively homogenous. These maps proved uninformative for the purposes of the project as well.

Concurrently, analysis was conducted about the coincidence of chronic disease and sea-level rise. Little data of conditions that could be associated with sea-level rise existed for this. However, there does exist much more data suggesting that acute diseases might become more prevalent. The Kresge Program Officer was contacted by the FIHI Program Manager at this point and a request to investigate infectious disease was approved. The literature provided several diseases that are associated with sea-level rise. These were:

- Giardiasis (flooding)
- Cryptosporidiosis (flooding)
- Vibriosis
- Salmonella
- Malaria
- Campylobacteriosis
- E. Coli
- Dengue (water)
- Chikungunya (water)
- West Nile Virus (water),
- Vibriosis (water)

All have been experienced in South Florida or the Caribbean. However, data for Monroe County on the reviewed diseases was unavailable due to either no cases reported or due to an RSE rate of greater than 30 which potentially indicates the data is unreliable. In addition, data for dengue fever, West Nile Virus, and vibriosis for all four counties could not be obtained due to no cases reported or the low incidence of locally acquired cases.

For those diseases with only a few cases reported during the observation period, as in the instance with the diseases reviewed in this study, rates may be unreliable and could be difficult to interpret. This may also occur when there are no cases reported for a given location during the period of interest. As previously noted, the FDOH uses relative standard error (RSE) as a way of measuring the reliability for statistical estimates. For rates, this calculation can be simplified by taking the inverse of the square root of the total number of cases and multiplying by 100. When the RSE is large, it indicates that the rate is imprecise. The FDOH chose a cut-point of 30, such that rates with an RSE greater than 30 in this report should be considered unreliable. This is the cut-off used by several CDC programs. The FDOH suppressed all crude rates as well as case counts for strata with an RSE > 30. All health data was collected and completed by the FDOH.

The resulting maps from this effort were, similarly, deemed uninformative, for the following reasons:

- *ZIP code data were the only available data provided to FAU for the diseases*
- *Census blocks are a finer grid that should expose more vulnerable neighborhoods; ZIP codes can obscure these neighborhoods by averaging with the entire communities. The specificity of the social vulnerability is lost at the ZIP code level.*
- *The sea-level rise risk data is even further diluted at the ZIP code level.*

Given the inability to further specify data from ZIP codes to census blocks the next step was to attempt to identify correlations with XLSTat®. In addition to this, members of FAU's urban planning department and FIHI worked to develop a social and health vulnerability index since many factors appeared to be correlated. The medical, social and sea-level rise vulnerability data that were made available as spreadsheets were further processed to create dBase files that were imported into ArcGIS and joined to the spatially referenced ZIP Code Tabulation Areas (ZCTAs). The health, social and sea-level rise vulnerability factors were correlated with XLStat®. The resulting correlations identified that ZIP codes vulnerable to sea-level rise and socially and medically vulnerable ZIP codes were inversely correlated, as previously discussed. The results of these efforts reinforced that, in order to produce informative maps, vulnerabilities would need to be depicted individually, but on the same map in the form of hot-spots, within a ZIP code, rather than as highlighted ZIP codes.

Hot-spots: Overlapping Risks

The goal of overlapping risks was to determine nexus points or "hot-spots," which are highlighted by health data by ZIP code, sea-level rise scenarios by property, and socio-economic data by ZIP code. Researchers at the FIHI and FAU denoted a place as "vulnerable" if it lies at the intersection of:

1. *Locations likely to be inundated from sea-level rise by 2030, 2060, and 2100, based on United States Army Corps of Engineers (USACE) projections;*
2. *Locations with low socioeconomic indicators; and*
3. *Demonstrating vulnerability to disease (e.g. respiratory illness, cardiovascular disease, giardiasis, etc.), as measured by 2010 Census and 2013 Florida Health Department data.*

By determining areas most affected by disease related to sea-level rise as well as demonstrating social vulnerability, actions may be taken to mitigate the negative effects sea-level rise might have on specific groups living in Southern Florida.

Background

In this portion of the study, the investigators virtually overlaid the social vulnerability maps, health maps, and sea-level rise maps. In particular, ZIP-coded social vulnerability quintiles, the health maps individually,[2] and the soil capacity at 1 foot of sea level rise were compared and overlaid to identify ZIP codes where there existed an overlap indicating the highest risk for each category. The goal in doing so was to identify ZIP codes that are particularly vulnerable to ill-effects due to sea-level rise.

In summary, examining baseline health data as we did in this study provides consideration of specified diseases (COPD, pneumonia, asthma) as both risk factors for ill-effects due to climate change and as potential outcomes which over time, may be exacerbated by climate change. Any association among these variables – as represented by the nexus points or "hot-spots" where we see an increased risk of all of these factors concurrently, provides valuable information about who is most likely to be negatively impacted by sea-level rise both directly and indirectly.

Social Vulnerability

Socioeconomic status, as measure by educational level, income, or occupation-related variables, has been shown to be associated with health outcomes [96,97,98,99,100]. Meanwhile, there has also been research on a connection between socioeconomic status, sea level rise, and climate [101,102,103,104]. This study examined the potential relationship between socioeconomic status and sea-level rise with a health layer.

While we created maps of many different social variables individually, such as, "percent low income," and "percent living below the poverty level," one very important product of this project was the creation of a social vulnerability index (SVI), which represents a combination of socioeconomic variables. The methodology and background for creation of the SVI in this project has been previously presented in this report. The social vulnerability index has been used in other research settings to provide a holistic representation of socioeconomic status [105,107,108], as it is accepted that different aspects of social class or socioeconomic status.

Methods

US Census data from 2007-2011 was the source of social data utilized in this study. The variables that were chosen for the social vulnerability index represent different components of socioeconomic status. Variables used include living below the poverty level, educational level, language spoken at home, income, employment status, receipt of food stamps, and race. The methodology used to create the social vulnerability index (SVI) has been previously discussed. The SVI was divided into quintiles and the quintiles were mapped according to zip codes. The zip codes with the highest SVI quintile were identified.

The three health risk variables: asthma, COPD, and pneumonia, were mapped individually by ZIP code. The data source for the health variables was the Florida Department of Health. Age-adjusted emergency department (ED) visit rates were calculated for the years 2005-2012. These rates were divided into quintiles,

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[2] Disease rates mapped were the combined asthma age-adjusted ED visit rates from 2005-2012, number of visits per 1000 residents, divided into quintiles; the chronic obstructive pulmonary disease (COPD) age-adjusted ED visit rates from 2005-2012 - the combined number of cases per 1000 residents, divided into quintiles; and the combined pneumonia age-adjusted ED visit rates from 2005-2012, number of visits per 1000 residents, divided into quintiles.

and the quintiles were mapped according to ZIP codes. The ZIP codes with the highest quintile for each health variable were identified.

The soil capacity was projected for 1 foot of sea-level rise, according to a methodology that has previously been presented in this report. Soil capacity was then divided into three categories: less than 0 feet, 0-2 feet, and > 2 feet, with the less than 0 feet category representing the highest level of risk for flooding due to sea-level rise. These three categories of soil capacity were then mapped according to ZIP codes. The ZIP codes with the highest level or risk (the lowest soil capacity) were identified.

In this study, soil capacity was mapped for the current situation, at 1 foot of sea level rise, at 2 feet of sea-level rise, and at 3 feet of sea-level rise. For the overlay analysis, 1 foot of sea-level rise was chosen because at this level, there was still variation in exposures to varying soil capacities among ZIP codes. By 2 or 3 feet of sea-level rise, most ZIP codes had the highest level of risk represented within the ZIP code boundaries. While many ZIP codes had the highest level of risk represented at 1 foot of sea-level rise, there were still some ZIP codes that did not include any areas with the highest level or risk.

Each of the health variables was overlaid with the SVI maps and soil capacity maps. Thus ZIP codes that had the highest asthma ED visit rates, the highest SVI, and the lowest soil capacity concurrently were identified. ZIP codes with the highest COPD ED visit rates, the highest SVI, and the lowest soil capacity concurrently were identified. Similarly, ZIP codes with the highest pneumonia ED visit rates, the highest SVI, and the lowest soil capacity concurrently were identified. In this manner, we were able to identify "hot-spots" which were ZIP codes with the highest level of risk on the three components.

Results

ZIP codes with the highest level of concurrent risk for the health measure, SVI, and soil capacity at 1 foot of sea-level rise were identified. We found the corresponding cities represented by each ZIP code, and whether or not these cities were bordered by the ocean (coastal). See **Tables 10-18** for results and **Figures 91-118** for maps.

The cities which correspond to the ZIP codes with the highest overlapping risks in Palm Beach are: for asthma - West Palm Beach, Lake Worth, and Boynton Beach; for COPD - West Palm Beach and Lake Worth; and for pneumonia - West Palm Beach, Lake Worth, and Boynton Beach. The cities which correspond to the areas with the highest overlapping risk in Broward are: asthma - Deerfield Beach, Pompano Beach, Fort Lauderdale, Hollywood, and Hallandale Beach; for COPD - Pompano Beach and Fort Lauderdale; for pneumonia - Pompano Beach, Fort Lauderdale, and Hollywood. In Miami-Dade County, the cities which correspond to the ZIP codes with the highest overlapping risks are: for asthma – Miramar (which lies at the border of Broward and Miami-Dade counties), Opa Locka, Miami, Hialeah, and Homestead; for COPD – Homestead; and for pneumonia – Hialeah, Miami, and Homestead.

Asthma had the greatest number of ZIP codes that overlapped the highest quintile of ED visit rates with the highest risk for social vulnerability and soil capacity (the highest number of "hot-spots"). This was true for Broward, Miami-Dade, and Palm Beach counties. COPD had the lowest number of ZIP codes that were "hot-spots." Thus, in order to increase the sensitivity of using this type of analysis to identify ZIP codes at risk for overlapping risk, asthma would provide the best health outcome to consider, as it is the most inclusive health variable. Given the previously discussed link between asthma exacerbations and lower socioeconomic status [112], this makes sense, as a higher rate of ED visits for asthma in a particular area could potentially be caused by some other, unmeasured aspects of social class. As measured by SVI, we know that these are the ZIP codes with a high proportion of individuals of lower socioeconomic status, but our study now tells us that individuals in these ZIP codes also have higher rates of pre-existing asthma as measured by ED visits, as well as a greater risk of sea-level rise as measure by soil capacity projections.

Despite a belief that sea-level rise will have its greatest impact on coastal areas, it is interesting to note that most of the "hot-spot" ZIP codes are non-coastal. In Palm Beach County the coastal ZIP codes with the highest overlapping risks were for asthma: 33404 (West Palm Beach), and 33435 (Boynton Beach); for COPD: 33404 (West Palm Beach); and for pneumonia: 33404 (West Palm Beach), and 33435 (Boynton Beach). All other ZIP codes were non-coastal. In Broward County the coastal ZIP codes with the highest overlapping risks were for asthma: 33441 (Deerfield Beach), 33064 (Pompano Beach), and 33009 (Hallandale Beach); and for pneumonia: 33064 (Pompano Beach). All other ZIP codes were non-coastal. In Miami-Dade County, all of the ZIP codes with the highest overlapping risks were non-coastal.

Discussion

The results of this study are being reviewed and the research team has created a plan for further dissemination of the findings. The knowledge that emerged from this analysis is useful to planners and public health officials, in preparing their communities for, and increasing resilience to, the negative effects of sea-level rise. The methodology of overlaying maps of health factors, socioeconomic factors, and sea-level rise related factors, can be replicated for other geographic locations. We are providing a tool to help in the difficult task of preparing for the ill-effects of sea-level rise.

Each of the measures: social vulnerability, health (asthma, COPD, and pneumonia ED visits), and soil storage capacity, were mapped by ZIP codes and overlaid to identify hot-spots. Zip codes were utilized because this was the smallest level at which all variables were available. Ideally, a more granular level than the ZIP code would provide even more information about community risks for adverse effects due to sea-level rise. In future studies, a more local level of data should be acquired and analyzed.

In this analysis, we grouped health data from 2005-2012 together in order to look at the current situation cross-sectionally, which does not allow any inferences on the direction of the effect, nor on the impact of time. We examined geographical associations through overlaying the maps, but we did not examine changes in disease rates over time, as they relate to sea-level rise, or socioeconomic status. In a future study, we would analyze the 2005-2012 data longitudinally through a Poisson-type of regression analysis [131], or simply by creating separate maps by year of data and comparing over time. The limiting factor for this approach would be the number of visits or cases, which would be decreased by analyzing each year separately. However, by analyzing the trend over time, greater knowledge would be gained regarding cause and effect, the directionality of the association, and the change over time.

Hot Spots: ZIP Codes with the Highest Level of Risk for Disease, Social Vulnerability and Soil Capacity

Palm Beach County Hot Spots - Asthma		
Zip Code	**City**	**Coastal**
33404	West Palm Beach	Coastal
33407	West Palm Beach	Non-Coastal
33417	West Palm Beach	Non-Coastal
33460	Lake Worth	Non-Coastal
33435	Boynton Beach	Coastal

Table 10: Zip codes with the highest level of risk for asthma ED visits, social vulnerability, and soil capacity: Palm Beach County.

Palm Beach County Hot Spots - COPD		
Zip Code	**City**	**Coastal**
33404	West Palm Beach	Coastal
33407	West Palm Beach	Non-Coastal
33461	Lake Worth	Non-Coastal
33460	Lake Worth	Non-Coastal

Table 11: Zip codes with the highest level of risk for COPD ED visits, social vulnerability, and soil capacity: Palm Beach County.

Palm Beach County Hot Spots - Pneumonia		
Zip Code	**City**	**Coastal**
33404	West Palm Beach	Coastal
33407	West Palm Beach	Non-Coastal
33417	West Palm Beach	Non-Coastal
33460	Lake Worth	Non-Coastal
33435	Boynton Beach	Coastal

Table 12: Zip codes with the highest level of risk for pneumonia ED visits, social vulnerability, and soil capacity: Palm Beach County.

Broward Hot Spots - Asthma		
Zip Code	**City**	**Coastal**
33441	Deerfield Beach	Coastal
33064	Pompano Beach	Coastal
33060	Pompano Beach	Non-Coastal
33311	Fort Lauderdale	Non-Coastal
33020	Hollywood	Non-Coastal
33023	Hollywood	Non-Coastal
33009	Hallandale Beach	Coastal

Table 13: Zip codes with the highest level of risk for asthma ED visits, social vulnerability, and soil capacity: Broward County

Broward Hot Spots - COPD		
Zip Code	**City**	**Coastal**
33060	Pompano Beach	Non-Coastal
33311	Fort Lauderdale	Non-Coastal

Table 14: Zip codes with the highest level of risk for COPD ED visits, social vulnerability, and soil capacity: Broward County.

Broward Hot Spots - Pneumonia		
Zip Code	**City**	**Coastal**
33064	Pompano Beach	Coastal
33060	Pompano Beach	Non-Coastal
33311	Fort Lauderdale	Non-Coastal
33312	Fort Lauderdale	Non-Coastal
33020	Hollywood	Non-Coastal

Table 15: Zip codes with the highest level of risk for pneumonia ED visits, social vulnerability, and soil capacity: Broward County.

Miami-Dade County Hot Spots - Asthma		
Zip Code	**City**	**Coastal**
33025	Miramar	Non-Coastal
33055	Opa Locka	Non-Coastal
33056	Opa Locka	Non-Coastal
33169	Miami	Non-Coastal
33054	Opa Locka	Non-Coastal
33167	Miami	Non-Coastal
33013	Hialeah	Non-Coastal
33147	Miami	Non-Coastal
33150	Miami	Non-Coastal
33142	Miami	Non-Coastal
33030	Homestead	Non-Coastal
33034	Homestead	Non-Coastal

Table 16: Zip codes with the highest level of risk for asthma ED visits, social vulnerability, and soil capacity: Miami-Dade County.

Miami-Dade County Hot Spots - COPD		
Zip Code	**City**	**Coastal**
33030	Homestead	Non-Coastal

Table 17: Zip codes with the highest level of risk for COPD ED visits, social vulnerability, and soil capacity: Miami-Dade County.

Miami-Dade County Hot Spots - Pneumonia		
Zip Code	**City**	**Coastal**
33013	Hialeah	Non-Coastal
33147	Miami	Non-Coastal
33150	Miami	Non-Coastal
33142	Miami	Non-Coastal
33030	Homestead	Non-Coastal
33034	Homestead	Non-Coastal

Table 18: Zip codes with the highest level of risk for pneumonia ED visits, social vulnerability, and soil capacity: Miami-Dade County.

Future Mapping Considerations

A sample map protocol for refining this effort was developed and is described below:

1. Recreate the census block data
2. Identify a color scheme with transparency shading
3. Recalculate the PCA correlations and components with XLStat to reduce the factors to map
4. Recalculate the vulnerability indices
5. Identify the threshold values of interest in the social factors
6. Create maps in GIS
7. Identify “hot-spots” for vulnerable populations

OUTREACH

Outreach was developed as the final objective of this study **to initiate the conversation with local, regional and national groups and stakeholders about the intersection of health, sea-level rise and social vulnerability, with sector-specific messages.** While uncertainties in the scale, timing, and location of climate change impacts can make decision-making difficult, response strategies can be effective if planning is initiated early. Because vulnerability can never be estimated with 100% accuracy, the conventional *anticipation* approach should be replaced or supplemented with one that recognizes the importance of building *resiliency*. Florida's crucial interdependent water management systems and water resources, that play an important role in assuring the region's habitability, will likely be impacted by storm surges exacerbated by rising sea levels during extreme weather events [12].

HIA Public Health Messaging Framework

The Health Impact Assessment provided guidance on how to convey the sea-level rise and health impacts message. The assessment describes populations as feeling climate change and health messaging too technical, because it is usually framed in scientific terms and presented as more of an environmental problem. The HIA recommends framing sea-level rise in terms of daily life impacts, with a focus on public health effects. The HIA additionally recommends the creation of a health framework to redefine the impacts of climate change, increasing the ability for people to understand the impacts through terms that are more familiar [143]. This was included in outreach messaging and is previously discussed in this report. Finally, the report recommends to target decision-makers at all levels – elected officials, business leaders, and other leaders within the region - which were the target audiences for outreach.

The HIA report provided six recommendations that informed the Regional Climate Action Plan how to best incorporate health considerations into the current policies and protocols. These messages were echoed in our findings and shared and expanded upon during outreach. They included:

1. *Integrate public health planning with municipal and regional planning to prepare Southeast Florida for the broader impacts of climate change.*
2. *Educate the public and elected officials on health outcomes associated with climate change.*
3. *Include heat vulnerability, health and socio-economic factors when developing vulnerability mapping or determining priority zones.*
4. *Encourage, foster and support investigative work to fully understand the impacts and economic costs attributed to climate change and health.*
5. *Establish health-related metrics to use when planning for adaptation strategies to mitigate climate change effects.*
6. *Revisit city and county development plans and revise based on heat vulnerability mapping a specific amount of shade trees or canopy to increase safe active access to goods in extreme heat.*

Message

During initial outreach at the end of 2014 it was discovered that the conversation surrounding the intersection of geographic, social, and medical vulnerability was not happening among many groups and professions. Given the results of our research, extensive outreach was planned in lieu of focus groups and grew into a main objective for this grant. The research team found, in South Florida, people were not communicating nor aware of these issues as they relate to sea-level rise, nor how groundwater will rise as the sea rises. Outreach was extended to be the focus of the second, third, and fourth quarters of the grant for 2015. Outreach engagements are outlined in **Tables 19-21, Appendix B** and included, not only meetings with professional groups, but main-stream media interviews, national networking opportunities for climate change topics, and academic publications. The team, further, intends to submit manuscripts to a variety of journals to ensure outreach extends beyond the region.

Sea-level rise and its impacts remain a much debated topic despite increasing evidence of increased high tide flood events. Outreach efforts had to achieve a fine balance of informing without alarming and presenting long-term impacts while relaying short to mid-term urgency. A crucial aspect of the outreach strategy was to provide a health framework that would resonate with non-health professionals and speak to the economic implications. Another important consideration was which stakeholders would be approached and in what time-frame. Stakeholder meetings and presentations were scheduled based on recommendations from the Steering Committee and from colleagues within the region.

Outreach efforts evolved over time to reflect audience composition and research status. Early presentations focused on introducing the project and differentiating from concurrent sea-level rise and climate change studies. For the second-round of presentations, SFRPC and FIHI staff examined how health could be defined more broadly. A table developed by the American Planning Association (**Table 22, Appendix B**), summarizing health topics within a planning context was identified and became the framework for discussing impacts outside of the health community. Sea-level rise impacts on human health were discussed in the context of understanding vulnerability and adaptation strategies for the natural and built environment. This yielded a variety of perspectives and further informed recommendations.

SFRPC and FIHI staff carefully considered geographical distribution to ensure outreach was taking place locally, regionally and state-wide with some national speaking and networking opportunities. Diversity in stakeholder expertise was also important to ensure a comprehensive range of perspectives. SFRPC and FIHI staff worked to identify agencies that dealt with the project areas, such as transportation, water and sewer infrastructure, and environmental issues. Project team members considered which stakeholders would value and address the long-range nature of the impacts while sharing how the information shared would be put into practice. Planners were ideal because the planning community understands preparing for long-term planning.

The South Florida Regional Planning Council's mission is to identify the long-term challenges and opportunities facing Southeast Florida and assist the region's leaders in developing and implementing creative strategies that result in more prosperous and equitable communities, a healthier and cleaner environment, and a more vibrant economy. The Council leads the Southeast Florida Regional Partnership which is a voluntary, broad-based collaboration of more than 200 public, private, and civic stakeholders from across Southeast Florida. It was through this network that the SFRPC established many of the outreach opportunities. The SFRPC staff leveraged their agency role as intergovernmental coordinators and regional conveners to schedule presentations. The decision was made to join the agenda of existing meetings instead of creating separate forums. Many of the stakeholders engaged, conducted and attended meetings that SFRPC staff were directly involved or interacted with the group members.

Key messages shared at these meetings were:

- *As ground water and sea-levels rise, geographically vulnerable areas will expand with time*
- *There are current populations that are geographically vulnerable to sea-level rise and socioeconomically or medically vulnerable; these size of these populations will increase over time*

- *Health data should be collected at monthly and even more temporally granular intervals, in order to facilitate assessment for temporal associations between vector and waterborne diseases and episodes of flooding*
- *An emerging concern is that socially vulnerable people will not have resources to react*
- *Sea-level rise is a 100-year issue, so many changes will occur in both the environment and infrastructure as the sea rises, though effects can be felt now*
- *It is essential to begin planning now to develop the redevelopment message and to address the physical vulnerability problem*
- *Adaptation must be coordinated and strategies must be incremental*
- *Efforts should be made to diminish impacts to both socioeconomically and geographically vulnerable populations*
- *This is an issue that affects a variety of sectors, thus requiring collaboration and cooperation*

To rapidly communicate the relationship between sea-level rise, health and social vulnerability **Figures 60-62** were developed to demonstrate the regions challenges for adaptive capacity as this intersection grows. Discussions were guided to include topics such as the relationship between health and sea-level rise; hard infrastructure solutions for flood and property protection; soft infrastructure solutions that included economic, health, cultural, and social considerations; tools that can be used to help protect water resources from the impacts of climate change; adaptive planning efforts; and how our findings relate to other research in the region. The results of these discussions were summarized into toolbox strategies.

These key themes were highlighted to raise awareness among key stakeholders and policy-makers of the correlation between non-chronic health impacts, socioeconomic factors, and geographically vulnerable populations. The presentations were designed to gather insight, and specifically tailored to each individual audience. Messages for specific groups are summarized below, outlining key focus points:

Sector	Key Planning Themes
Planner issues	• Potential population migrations – Lower SES to Geographically vulnerable areas • Changes in values of housing • Consider social vulnerability vs adaptive capacity • Connectivity of communities/economic opportunities • Prevent an increase in social vulnerability due to worsening economic circumstances
Public Works	• Strengthen shorelines; Seal sewers; Remove septic tanks • Monitor for disease - Water treatment to prevent infectious diseases; Assess and protect air quality; Improve drainage; Facilitate access to care for vulnerable populations
Public Health Professionals	• Preparedness must occur in the face of scientific uncertainty; Modeling changes in disease patterns;Tracking of disease; Risks require management • Reduce risks to health; assess sea-level rise and allergen data; conduct more Health Impact Assessments; provide data and recommendations to decision-makers; All vulnerabilities should be examined given sea-level rise and flooding
Transportation (Adaptive Capacity)	• Access to Emergency services; Access to health services • Connectivity of communities • Connectivity of economic opportunities • Asset value vs vulnerability/protection
Intergovernmental	• Cooperation • Social vulnerability vs adaptive capacity • Connectivity of communities; Connectivity of economic opportunities; Crime; Migration issues; Transportation/Water/Sewer/Stormwater Cooperation

Figure 123. *Key Planning Themes by Sector*

FIHI's collaboration with the Public Health Ph.D. advisor at Florida International University to engage in a research project with PhD students was also considered as a component of outreach.

Lessons Learned

All groups and stakeholders targeted for outreach had not considered groundwater rise in relationship to sea-level rise. While most did consider that socio-economically vulnerable populations would be affected and, perhaps, health would be impacted, none displayed an understanding of what the specific health impacts may be. Further, it is important to note that the health message did not resonate alone, however, when shared within the context of the complete findings, did tend to resonate with audiences. These outreach opportunities allowed our team to develop a network of concerned groups, beyond that established by the Compact, who were interested in remaining informed about this research and the final results for their planning.

A main take-away message from the outreach was the region is looking for strong leadership in elucidating the full impacts of climate change in the region. Further, a single message alone does not resonate, perhaps because the impacts will not touch only one factor, such as health, rather they will have extensive impacts on a variety of factors with economic, environmental and structural implications

Outreach strategies are critical for increasing sea-level rise awareness and for promoting adaptation; the toolbox represents a culmination of findings and outreach that are placed in a regional and community context.

A change in behavior is more likely when risk communication empowers residents and stakeholders. The toolbox and guide have been developed as a set of hard and soft infrastructure planning considerations and recommendations and key components for successful adaptation. The maps are also included in the toolbox as a reference guide for planning purposes and pre-empting and managing public health issues.

The toolbox and guide were created to provide local decision makers and partners tangible recommendations for addressing sea-level rise with considerations for health and social vulnerability so future adaptation plans will be more robust, including human health considerations. The extensive outreach conducted by the team allowed the gathering of information to inform a toolbox of strategies that could be used to help mitigate health risks to vulnerable populations. These strategies can be applied to most coastal communities, though specificity is needed to determine applicability.

The toolbox and guide can be applied to improve the regional resiliency to sea-level rise. It is recommended that this begin with addressing hard and soft infrastructure systems in short-term and long-term planning. While not an exhaustive list, these were informed by some of the discussions during outreach or driven by the findings of this study.

Hard Infrastructure

When seas begin to rise, roadways will be the first areas that will see more frequent flooding since roadways are traditionally built at elevations lower than the finished floor of structures. In addition, most infrastructure systems are located within the roadways (water, sewer, storm-water, power, etc.). As a result, there is a need to prioritize where funds are spent on transportation infrastructure and other major investments. **Table 23** outlines hard infrastructure solutions for flood and property protection. Catastrophic flooding would be expected during heavy rain events because there is nowhere for the runoff to go. The vulnerability of transportation infrastructure will require the design of more resistant and adaptive infrastructure and network systems. This would, in turn, involve the development of new performance measures to assess the ability of transportation infrastructure (e.g., roadways, bridges, rail, sea ports, airports) in preparation for sea-level rise and to enhance resilience standards and guidelines for design and construction of transportation facilities. Specifically, considerations must include retro-fitting, material protective measures, rehabilitation and, in some cases, the relocation of a facility to accommodate sea-level rise impacts. As they are related, groundwater is, similarly, expected to have a significant impact on flooding in these low-lying areas as a result of the loss of soil storage capacity. While previously overlooked, our study demonstrates that groundwater needs to be an important consideration in planning efforts for improved regional resiliency to sea-level rise.

At the center of these planning efforts should also exist the provision for an adequate drainage system, designed to accommodate increased volume of water. This provision will be critical in protecting the roadway base. As noted, most base courses are installed above the water table. As long as the base stays dry, the roadway surface will remain stable. As soon as the base is saturated, the roadway can deteriorate. FDOT and most municipalities rely heavily on exfiltration trenches or French drains. These systems work because the perforated piping is located above the water table, thereby allowing water to leach out; however, they cease to function if they are located below the water table. As the water table rises, exfiltration systems in low-lying areas will cease to work as they become submerged. Because these systems will not be viable as sea levels rise, future storm water systems should be designed like sanitary sewers with tight piping, with minimal allowances for infiltration, and adequately sized pumping stations that permit discharge points and means for associated treatment of the storm-water. Discharges of storm-water to water bodies may portend poorly to vital seagrasses and reefs, so some effort will be required to determine the level of treatment needed to protect the ecosystem in the face of excessive water levels. Drainage wells could be an essential component to improving drainage systems. These wells require splitter boxes and filters to remove solids, regular inspections, and regular maintenance which would all need to be included in budget considerations.

Water would be a second priority for long-term, hard infrastructure planning. A number of strategies can be considered for improving water supplies, although the applicability will vary from one location to the next. **Table 24** summarizes tools that can be used to help protect water resources from the impacts of climate change, which would in turn protect public health via drinking water supplies.

Soft Infrastructure

Table 25 outlines efforts to address social issues and health. Important to this are outreach, a communication protocol between health professionals and climate scientists, and improved data collection and analysis for diseases with preliminary indication that they may be associated with sea-level rise. If information is not conveyed to those treating people who are ill and protocol does not account for a changing environment and subsequent impacts, the system fails. The current strategy does not facilitate communication adequately nor does it outline a need for analyzing health data at a more granular level. In addition to this, outreach to vulnerable populations is notoriously difficult and is a challenge that must be overcome. It is additionally essential to identify effects of long-term chronic conditions as they may affect residents seasonally. The data did not lend itself to being thoroughly discerned in this project. For example, there is insufficient evidence to determine if presence of mold resulting from water and increases in pollen has affected the incidence of asthma, the only data available was the number of cases of asthma in the region. Finally, an effort should be developed to engage health practitioners in developing long-term strategies to address the effects of climate change and communicate them to the public.

Much focus has been spent on the causes of sea-level rise and the potential flooding caused by the same. Tidal flooding can be used as a surrogate for estimating the social and economic impacts of sea-level rise on communities. By performing vulnerability assessments, coastal areas can begin planning for the impacts of climate change to safeguard their community's social, cultural, environmental and economic resources. Policies need to focus on both mitigation of and adaptation to the causes and effects of climate change. Policy formulation should be based on sound science, realizing that policy decisions will be made and administered at the local level to better engage the community and formulate local decisions.

Making long-term decisions will be important. Businesses look at long-term viability when making decisions about relocating enterprises. The insurance industry, which has traditionally been focused on a one-year vision of risk, will consider long-term risks and not insuring property rebuild in risk-prone areas. The Pew Center report on climate change indicates that the socioeconomic implications of climate change on water supplies and demands, or the lack thereof, will be directly related to the ability of water managers and planners to act on required plans, infrastructure and development changes in the near term [89]. Deyle, et al. outline that the need for planning will be especially important given the competition for scarce public dollars allocated toward adapting water supplies to climate changes over the next 20 to 100 years [35].

Current projects on the timeframe of sea-level rise will likely require alteration due to uncertainty in the rate of warming, deglaciation, and other factors. When planning long-term 50-100 years in the future, many factors will play a role. From the perspective of the authors, to allow flexibility in the analysis due to the range of increases within the different time periods, an approach that uses incremental increases of 1, 2, and 3 feet of sea-level rise was considered for the scenarios. The increments can work as threshold values in planning considerations in terms of allowing planners the ability to know ahead of time where the next set of vulnerable areas will be to allow a for proactive response approach that can be matched to the observed future sea levels. Hence as sea level benchmarks are met, certain infrastructure should be completed and new infrastructure planned.

The toolbox and guide will be shared with all contacts made during outreach, hosted on the SFRPC, FIHI, and FAU, CES websites, uploaded to the Kresge CAKE site, and shared with the South Florida Regional Climate Change Compact, Resilient Miami, and local legislators.

Table 23: Hard Infrastructure Improvements for South Florida

Implementation Strategy	***Benefits***	***Cost***	***Barriers to Implementation***	***Point when Action may need to be Abandoned***
Exfiltration Trenches	Excess water drains to aquifer, some treatment provided	$250/ft.	Significant damage to roadways for installation, maintenance needed, clogging issues reduce benefits	If groundwater table is above exfiltration piping, the exfiltration efficiency diminishes quickly
Infiltration Trenches	Excess water gathered from soil and drained to pump stations, creating storage capacity of soil to store runoff, soil treatment	$250/ft. plus pump station	Significant damage to roadways for installation, maintenance needed, clogging issues, costs for pump station	Complete inundation means pumps run constantly and may pump the same water over and over
Install stormwater pumping stations in low lying areas to reduce storm water flooding (requires studies to identify appropriate areas, sites and priority levels)	Removes water from streets, reduces flooding	Start at $1.5 to 5 million each, number unclear without more study	NPDES permits, maintenance cost, land acquisition, discharge quality	When full area served is inundated (>3-5 ft. SEA-LEVEL RISE)
Added dry retention	Removes water from streets, reduces flooding	$200K/ac	Land availability, maintenance of pond, discharge location	When full area served is inundated
Armoring the sewer system (G7 program)	Keeps stormwater out of sanitary sewer system and reduces potential for disease spread from sewage overflows. Major public health solution	$500/manhole	limited expense beyond capital cost	none

Central sewer installation in OSTDS areas	Public health benefit of reducing discharges to lawns, canals and groundwater from septic tanks	$15,000 per household	Cost, assessments against property owners	none
Raise roadways	Keeps traffic above floodwaters	$2 - 4 million/lane mile	Runoff, cost, utility relocation	When full area served is inundated
Class V gravity wells	Means to drain neighborhoods	$250K ea.	Needs baffle box, limited flow volume (1 MGD)	When full area served is inundated
Class I injection wells	Means to drain neighborhoods, 15 MGD capacity	$6 million	Needs baffle box	When full area served is inundated
Bioswales	Means to drain neighborhoods, provides treatment of water	$0.5 million/mi	land area, flow volume, maintenance	When full area served is inundated
Raise sea walls	Protects property	$.1-1 million/lot	Private property rights, neighbors	n/a
Relocate Wellfields westward/horizontal wells	$20 million assuming locations can be permitted in Biscayne aquifer	$20 million assuming locations can be permitted in Biscayne aquifer	Cost, concern over saltwater intrusion east and west, inundation of wellfields, permitting by SFWMD	When well is inundated
Salinity/lock structures	Keeps sea out, reduces saltwater intrusion	Up to $10 million, may require ancillary stormwater pumping stations at $2-5 million each	SFWMD, western residents, private property rights arguments	n/a – solution to retard sea encroachment and saltwater intrusion

Regional relocation of locks to Pump stations	Creates regional system to use coastal ridge to protect inland property, keeps saltwater out	$200 million ea.	SFWMD, western residents, private property rights arguments	n/a – solution to retard sea encroachment and protect property which can exist at levels below sea level
Pump to Everglades via Regional system	huge volume of water can be removed from urban area and used to recharge Biscayne aquifer	unknown	Water quality	When full area served is inundated
Pump to Tide	huge volume of water can be removed from urban area	unknown	Water quality to reefs, sea grasses, etc.	When full area served is inundated

Table 24. Tools for Protection Water Resources from Climate Change Impacts

Water Resource Adaptation Alternatives
Water conservation • Reducing requirements for additional treatment capacity and development of alternative water supplies (AWS)
REDUCING THE IMPACT OF SEA-LEVEL RISE ON EXISTING WATER SOURCES • Hydrodynamic barriers: aquifer injection/ infiltration trenches to counteract saltwater intrusion using treated wastewater • Horizontal wells • Salinity structures and locks control advance of saltwater intrusion • Relocation of wellfields when saltwater intrusion or other threats render wellfield operations impractical
Gaining access to alternative water resources • Desalination of brackish waters • Regional alternative water supplies • Capture and storage of storm-water in reservoirs and impoundments • Aquifer storage and recovery (ASR)
Wastewater reclaim and reuse • Irrigation to conserve water and recharge aquifer • Industrial use and for cooling water • Indirect aquifer recharge for potable water
Storm-water management • Reengineering canal systems, control structures and pumping

Table 25: Soft Infrastructure Improvements for South Florida

Implementation Strategy	***Benefits***	***Cost***	***Barriers to Implementation***
Prioritize a data collection strategy that allows for more granular data and seasonal data	Allows the opportunity to quantify the health effects of sea-level rise	Will vary	Challenges with HIPPA rules
Create policies that protect socially vulnerable populations from forced migration due to sea-level rise	Lessens risk of socially vulnerable people moving to vulnerable areas	Unknown	Pressure from developers, rental properties at risk
Redevelopment control ordinances and policies	Reduces competition for land by removing land from redevelopment	Unknown	Pressure from developers, rental properties at risk, property rights issues.
Public acquisition of at-risk property	Reduces potential for migration to vulnerable property by taking property out of circulation	May provide short term income	Public resistance or public support
Increased data collection of sea-level rise or flood related vector and waterborne diseases	More complete datasets for analysis	Unknown	Adherence to data collection protocol
Increased and improved reporting tools for small populations of infected individuals that permit monthly/weekly reporting vs annually	Increased avenues for data reporting	Unknown	Community and professional buy-in
Educate health practitioners to understand the potential association of disease patterns with high tide/king tide events and develop protocol to track illness patterns	Practitioners looking for, collecting and reporting data associated to sea-level rise	Unknown	HIPPA rules, competing priorities for practitioners
Provide preventive measures for subject illnesses where available	Reduced risk or severity of symptoms		Public resistance or public support; budget; adherence

Improved reporting tools for health departments to collect data on illnesses of concern with sea-level rise	Health department has the opportunity to analyze data	Unknown	HIPPA rules
Develop a community-based protocol for communicating risks	Informs residents about their vulnerability to sea-level rise health outcomes	Unknown	Access to target populations; establishing relationships with the community; prioritizing health outcomes due to sea-level rise
Continued and extensive outreach about the relationship between sea-level rise, health and social vulnerability	Though this study focuses on South Florida the message is one that will resonate nationally and internationally with any community facing the effects of climate change	Unknown	Access to target populations, public interest, support
Develop state Data Commons where the public, organizations and researchers have access to a variety of datasets	This can be used to better understand the complex effects and intersections of sea-level rise with a variety of factors	Unknown	Ensuring quality of data contributed; state buy-in; educating populations about the resource
Conduct an economic vulnerability assessment	Can associate the effects and intersections of sea-level rise with economic outcomes and costs	Unknown	Support
Prioritize RCAP recommendations for Water Supply, Management and Infrastructure adding a health lens.	Mitigate the negative health effects connected with water supply and contamination due to sea-level rise	Unknown	Political will, Support, Funding
Prioritize RCAP recommendations for Natural Systems adding a health lens.	Mitigate the negative health effects connected with changes in the natural environment due to sea-level rise	Unknown	Political will, Support, Funding
Prioritize RCAP recommendations for Agriculture adding a health lens.	Mitigate the negative health effects connected with food supply due to sea-level rise	Unknown	Political will, Support, Funding

Conduct a comparative risk assessment for health (previously recommended in the Health Impact Assessment).	Will determine tipping points for disease in the region	Unknown	Funding

Guidelines for Planning: Adaptation and Mitigation

The recommendations for adaptation, mitigation and resiliency planning are meant to build upon other work in the region including the Health Impact Assessment and Regional Climate Action Plan. Because the RCAP and HIA focus on specific recommendations, these are meant to serve as a set of guidelines for consideration during planning and implementation. This information was shared also with a variety of local decision-makers, representing diverse sectors, to begin the conversation of adaptation with considerations for human health.

In addition to these messages, it is essential that planners, policy-makers and public health professionals be cognizant of impending environmental and population changes. The impacts on health require study over time to truly understand the effects and how to prepare and protect populations. Outlined below are key components to successful adaptation and mitigation strategies revealed during our research, supported by the literature with a health lens applied.

Resilience Strategy: Incorporating adaptation and mitigation strategies into public health policy is crucial to reducing climate change vulnerability and poor health outcomes. Climate change adaptation and mitigation strategies, policies, and protocols should focus on short and long-term changes with an emphasis on sustainable development and protection of public health and community viability [141]. Adaptation refers to adapting systems and building resilience in response to anticipated climate stimuli and their effects in order to reduce harm or exploit benefits [138,139]. Mitigation is the preventive approach of implementing policies, strategies, and protocols that work to reduce current and future impacts [141]. While the two strategies both work towards the same goal of resilient communities through preventing the effects of climate change, the timeframes and distribution of benefits of the two strategies vary. Adaptation can be both reactive and proactive to the effects of climate change, working locally in short timeframes to directly create benefits. Mitigation is more long-term and proactive in preventing the effects of climate change [141,142].

Identify Co-Benefits: Climate change adaptation and mitigation strategies which are aligned with public health strategies often have co-benefits. Health-focused climate change strategies can directly and indirectly have environmental co-benefits and climate change adaptation and mitigation policies will often have a favorable impact on health outcomes [135,138,139]. Many mitigation policies reducing greenhouse gases will have co-beneficial health effects of reducing morbidity and mortality, especially from chronic illness such as asthma [138]. For example, mitigative policies reducing individual vehicular use by encouraging the use of public transportation, walking, or biking would also directly help address the U.S. obesity epidemic [137]. Focusing on implementing policies that maximize these co-benefits can help to benefit health outcomes and prevent climate change [138].

Understand Systemic Effects: A variety of effective climate change strategies must be considered in terms of how they impact one another and how disparate systems may be connected. For example, the access to clean drinking water is a fundamental issue when addressing public health protection. Likewise, the lack of contact with contaminated water is a fundamental concern in trying to reduce vector and waterborne disease. As a result, protection from contact with contaminated waters is the first line of defense. Since virtually all residents are connected to potable water systems that are routinely tested, the waters supply risks are generated via temporal storm events as opposed to sea-level rise. Similarly, saltwater intrusion is less affected by sea-level rise than groundwater levels which may increase infiltration into sanitary sewers, storm sewer and septic drain-fields, absorbing capacity of these system and consuming the available capacity for their intended purpose. Results in Dania Beach and Hollywood identify a correlation between higher groundwater tables and septic areas near water bodies as opposed to lesser impacts in sewered areas. Septic tank failure is an indicator of changing conditions. Water infrastructure in imperative for any public health protection. Additionally, access via roads and public transportation are imperatives for protection of the public health, as is the lessening of standing water.

Seek Cost-effectiveness: Adaptation and mitigation strategies which focus on cost effectiveness are important for the health sector. Some adaptation and mitigation strategies have already demonstrated success in terms of benefits exceeding costs [136]. For example, early warning systems for extreme heat events have proven to be a much more cost effective policy to decrease morbidity and mortality than to treat heat-related illness [135,137]. Cost-benefit analyses have been conducted to determine the economic valuation of lowering greenhouse emissions (a mitigation strategy) in terms of the associated health impacts from reduced air pollution. While results varied on exact cost savings, all calculations determined that the cost savings of health benefits made up for a substantial portion of the costs of mitigation [133].

Collaborative Process: Responses to the health impacts of climate change are not isolated to the public health sector [133,134]. Climate change adaptation and mitigation strategies impacting health outcome strategies ripple multiple benefits across multiple sectors. Approaches for addressing these issues must be cross-sectoral and include stakeholders from transportation, building and housing, energy production, land-use planning, and other divisions [89]. Adaptation activities must include a full range of stakeholders from the community, government, and public and private sectors to ensure effective implementation [37]. Choosing to implement mitigation strategies that engage key stakeholders from multiple sectors will help to overcome implementation barriers in creating a more cohesive sustainable development.

Apply Scientific Framework for Leveraged Capacity: Adaptation planning must merge scientific understanding with political and institutional capacity on an appropriate scale and horizon. According to Mukheibir and Ziervogel [132], there are 10 steps to consider when creating an adaptation strategy at the municipal level. To summarize, the steps are as follows:

1. Assess current climate trends and future projections for the region (defining the science).
2. Undertake a preliminary vulnerability assessment of the community and communicate results through vulnerability maps (using GIS and other tools).
3. Analyze vulnerability spatially, by overlaying development priorities with expected climate change on GIS maps to identify hot-spots where adaptation activities should be focused.
4. Survey current strategic plans and development priorities to reduce redundancy and understand institutional capacity.
5. Develop an adaptation strategy that focuses on highly vulnerable areas. Make sure the strategy offers a range of adaptation actions that are appropriate to the local context.
6. Prioritize adaptation actions using tools such as multi-criteria analysis (MCA), cost-benefit analysis (CBA) and/or social accounting matrices (SAM).
7. Develop a document which covers the scope, design and budget of such actions (what they call a Municipal Adaptation Plan (MAP)).
8. Engage stakeholders and decision-makers to build political support. Implement the interventions prioritized in the MAP.
9. Monitor and evaluate the interventions on an ongoing basis.
10. Regularly review and modify the plans at predefined intervals.

The strengths of using this framework include the initial focus on location-specific science, the use of both economic and social evaluation criteria, and the notion that the plan is not a fixed document, but rather a process that evolves in harmony with a changing environment. The final two steps recur at iterative intervals by the community with associated adjustments made.

Community Modeling to Identify Priority Areas: Based on findings of the vulnerable areas, it is recommended to develop a variety of scenarios whereby a set of options are utilized to address potential health risks resulting from sea-level rise in the community. The goal is to identify successful flood mitigation strategies used by other cities that face similar drainage and construction problems. **Figure 124** outlines a simplified flow chart used as a basis for the evaluation, noting all can be GIS layers in a model. The GIS system can be used to identify hot-spots where adaptation and communication activities should be focused. This effort can also identify critical data gaps in data, which, when filled, can enable more precise identification of at-risk infrastructure and predictions of impacts on physical infrastructure and communities. Data quality varies by community. Scales can also be different which complicates the process as it did for this project.

Recommendations: Next Steps

Recommendations were developed as next steps to continue to build upon the previously mentioned work in the region and would further support the growing body of knowledge and research surrounding climate change and health in the region. Developing the following recommendations allows the opportunity to garner increased political will and would add to the information that leaders are able to share with stakeholders and communities.

Use flooding as a surrogate for understanding the social and economic impacts of climate change. Flooding will alter incidence patterns of disease for waterborne, vector-borne, and foodborne illnesses. Coastal flooding, air and water quality, ecology, and agriculture each represent pathways to new disease patterns [56]. To determine preventive strategy requires a comprehensive vulnerability assessment of coastal areas to safeguard communities against the social, cultural, environmental and economic impacts [57,58]. Resilience strategies must focus on both mitigation and adaptation strategies in order to address both the causes and effects of climate change. Policy formulation should be based upon sound science, realizing that informed decision-making at the local level will better engage the community and increase adaptive capacity. Flooding allows the opportunity to project additional sea-level rise health outcomes.

Develop a specific message for Southeast Florida about climate change and health that describes the present. In inspiring policy and immediate action, the message of sea-level rise projections and potential health risks alone often did not resonate; what was of most interest was the more immediate impacts of climate change within a greater context of multiple, immediate effects along with health. To develop this message requires the identification of a more specific sea-level rise and health impacts pathway. In addition, these impact pathways will will need an analytical-policy architecture examined over time. To be specific, the populations and diseases in question will be dynamic so sustained monitoring will be required to map the exposures, sensitivities and response/policy effectiveness over space and time.

Coastal areas should begin planning for the impacts of water from flooding, sea-level rise and other impacts in order to safeguard their community's social, cultural, environmental and economic resources in the future. Tools that include parameters to assess vulnerability for social and geographic situations can be useful to develop infrastructure and policies. In addition, social issues are rarely static, and geographic vulnerability is known to be in flux. As a result, any analysis of current conditions should include a focus on future mitigation and adaptation strategies. Such policy formulation should be informed by sound science, and both policy and science should be administered on the local scale to better engage the community and formulate local decisions.

Planning and implementation for sustainable water supplies will require an understanding of how Florida water resources are affected by climate change. The Pew Center report on climate change indicates that the socioeconomic implications of climate change on water supplies and demands, or the lack thereof, will be directly related to the ability of water managers and planners to act on required plans, infrastructure and development changes in the near term [88]. Given South Florida's delicate water system this will be a priority for the region.

Future outreach will need to include a compelling and comprehensive public health case, emphasizing economic resiliency. Outreach efforts will need a three-pronged focus; 1. awareness, 2. change, and 3. preparedness and should be expanded to include the business community and elected officials. As previously mentioned, the health message alone did not resonate, however, the more outcomes shared in addition to health the more groups were able to connect direct impacts with their own professions and work.

Health data should be collected more frequently, such as monthly, to allow testing for association with monthly weather patterns such as changes in water levels, rain amounts, or temperature and for relationships with socio-economic vulnerability. As noted, South Florida's human population varies substantially across both time and geographic space. Community composition, ethnic or socio-economic signatures, based on observed changes, will continue to significantly change over time. The collection of longitudinal health data will help to elucidate hypothesized associations and will be essential for appropriate mitigative and adaptive strategy development for population health.

In the context of sea-level rise, the built and natural environments must be considered through a systems approach. The social, political, and natural systems serve as layers, as in a GIS map, while these change at different rates they will each be affected by sea-level rise. Long-term decisions that consider this systems approach are essential to local governments and businesses as they examine long-term viability, particularly in respect to relocating and maintaining development. This is already occurring in the insurance industry. It is in the community's interest to develop a planning framework to adapt to sea-level rise and protect vulnerable infrastructure through a long-term plan.

Health data monitoring systems should include increased reporting on and evaluation of emerging disease related to sea-level rise. Sea-level rise carries with it numerous public health risks, either directly or through mediators. In addition to those previously mentioned, new health threats can be linked to water quality changes (i.e. salt water intrusion and increased urban runoff) and lowered drainage capacity due to high ground water levels. Human exposure to toxins will increase through recreational water related activities, this coupled with exposure to extreme temperatures and flooding that can increase vector exposures. Flooding events, similarly, will cause housing dislocation, limited healthcare access, and compromised food supply.

Expand analysis to include variables representing a broader depiction of the interaction between social vulnerability, health and climate change, as more data becomes available. Future topics for research should include food supply and production, heat, mental health, particulate matter, pesticide exposure, live births under 2500 grams, dengue, malaria, West Nile, vibriosis, all enteric diseases, chikungunya, Zika, all arbo-viruses, algal blooms, all water contamination, wastewater treatment, water supply, water bacteria levels, saltwater intrusion, nutritional deficiencies, economic factors and population migration. Salinity measurements should also be tracked as they impact the number of contaminant organisms in the water systems. Currently, the data on these is either not available, not reported, or reported in such low numbers that analysis cannot be conducted.

Analyze vulnerability spatially, by overlaying development priorities with expected climate change on GIS maps to identify hot-spots where adaptation activities should be focused. This effort includes identification of the critical data gaps which, when filled, will enable more precise identification of at-risk infrastructure and predictions of impacts on physical infrastructure and communities. Since roadways and other infrastructure are normally designed for a 50 to 100-year service life and are rarely abandoned, long-term planning for climate impacts is critical. Storm events may create temporal impacts that damage infrastructure and make it impossible to access certain services, for example, health services. Roadways are useful for predictive purposes since most other public infrastructure uses them.

Plan resilience strategies to focus on both mitigation and adaptation strategies in order to address both the causes and effects of climate change. Policy formulation should be based upon sound science, realizing that informed decision-making at the local level will better engage the community and increase adaptive capacity.

Ensure any climate change research out of the region has policy implications. Florida has a delicate situation regarding the political will for addressing climate change. While some acknowledge the threat, it will be important for the region to guide policy through sound research and data. The standard for the region, given the threat of sea-level rise, should be that any research conducted should result in the implementation of new policy and strategies based on findings.

Conduct comparative cost analysis to determine the costs to businesses and industry. The economic case for sea-level rise will be a unifying one especially given the political climate in South Florida. A comparative cost analysis will demonstrate how industry such as tourism, real estate and development and local businesses will be affected.

Model population migration. Such work has been undertaken in Cincinnati, OH among other areas in the United States. These models should be reviewed to determine if sufficient data exists to evaluate potential patterns of migration. Models of population migration may help predict how quickly the socially vulnerable will be exposed to geographic vulnerability. Bayesian statistical methods are recommended.

Develop a probability model that combines sea-level rise and property value. This would include sea-level rise as it affects the amount of livable property, projected increases in population, projected property values, and future economic activity. This type of effort would complement migration studies in defining the "tipping point" for socio-economically vulnerable populations.

Conduct longitudinal analyses that determine the impact of sea-level rise on health outcomes. Southeast Florida is currently best positioned to conduct a cohort study as we are experiencing the beginning stages of sea-level and groundwater rise. A population exposed to sea-level rise could be followed and compared to an area not exposed to sea-level rise. These groups could be followed over time to assess for the development of climate change-related health conditions.

Overlay maps and conduct tests of geographic association among the vulnerability factors. While it appears that there are many areas with a confluence of more than one vulnerability factor, the question of the association among these factors can be answered statistically using methodologies that are appropriate for GIS-based data. Statistical tests would be done for geographic association.

Develop methods to assess the impacts of sea-level rise on health conditions. This project yielded preliminary insight into the health conditions that are thought to be exacerbated by sea-level rise. Asthma rates, for example, will likely increase in the presence of higher mold counts. Incidence rates of infectious diseases such as salmonella and giardia will also likely increase due to expansion of mosquito populations. A) There is a need for continued longitudinal collection of these health data to assess for trends over time. This is entirely appropriate as the effects of sea-level rise are long term and will manifest over many years. B) In addition to yearly data collection, which is already the norm, health data collection at monthly intervals would facilitate a query into an association between disease rates and rainfall patterns. C) Currently, health data is available at the ZIP code level. However, mapping of health data at more granular levels will facilitate greater insight into geographic associations between health and sea-level rise.

- ***An effort should be developed to engage health practitioners in what to look for, how to communicate information, and how to increase awareness of long term trends.*** In this project, the conversation between climate researchers and health practitioners has initiated a new relationship between these two sectors. In order to adequately elucidate the intricacies of the two-way relationship between human health and sea-level rise, it will require effective collaboration and communication between health care practitioners and climate researchers.

- ***Evaluate current data overseas regarding disease incidence and develop predictive models of growth in southeast Florida.*** Limited data might suggest another Bayesian exercise, but the application would need further evaluation given altered conditions that exist in southeast Florida.

- ***Develop tools to assess the impacts of sea-level rise to chronic conditions given that little impacts could be discerned in this project.*** Asthma, for example, would figure to increase in the presence of mold resulting from water and increases in pollen. Health data tracking is not sufficient for this type of analysis (the need is by month or preferably day to match with rainfall events), and the data is not available in this manner. There is a need to adjust disease reporting to permit more granular analysis of trends.

Identify successful flood mitigation strategies used by other cities that face similar drainage and construction problems. Scenarios should be developed based on identified vulnerabilities and cost-effectiveness. This allows for the development of a framework to evaluate the impacts of climate change on infrastructure and economic development, as they are intrinsically intertwined. **Figure 124.** outlines a simplified flow chart that describes this and is further discussed below.

Framework for Identifying Vulnerable Populations

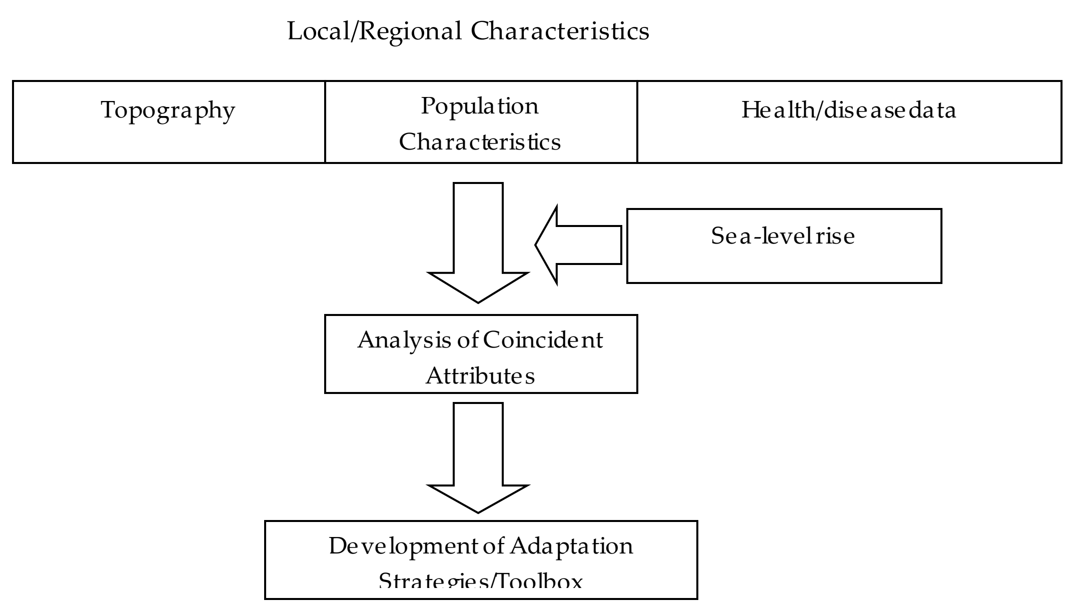

Figure 124. Analytical framework

The strength of this framework lies in the proposed holistic and incremental approach to understanding climate change impacts which entails understanding of combined social and health vulnerabilities in the context of higher exposure of the physical infrastructure to hazards. As such, it combines physical vulnerability with health indicators and social evaluation criteria, and conveys the notion that a plan is not a fixed document, but rather a process that evolves with the changing environment.

The development of options requires an understanding of the community. Each community is different. Topographic modeling of the impacts of sea-level rise must be undertaken in a manner that provides, useful, accurate data. Crude maps and low resolution LiDAR are not sufficient. Census block data is more useful that lower resolution tract or ZIP code data for identifying pockets of vulnerable people. Changes in demographics between census events complicate the analysis. Finally, community health data is needed at a fine resolution.

These results are funneled through analysis to a set of options that can guide local officials to community solutions. Since water is the first line of defense, many initial projects are local infrastructure: pipes, water mains, sealing sewers, replacing septic tanks. These types of projects are currently underway in Southeast Florida. These options are identified in **Tables 23 and 24**. The reduction of flooding and standing water reduces the potential for vectors and waterborne disease development. At the center of these planning efforts should also exist the provision for adding resilience and adaptive capacity measures to each component of the framework.

CONCLUSIONS

This study, following the Health Impact Assessment, elucidated the intersection between sea-level rise, public health, and vulnerable populations in Southeast Florida given present to 2100 projections. Our team was able to geographically map vulnerability to sea-level rise impacts in the coming decades, identify specific potential public health risks, and the populations that would be most affected by these outcomes. This information was then shared with a variety of local decision-makers, representing diverse sectors, to begin the conversation of adaptation given the risks to human health.

Based on current projections, there is no doubt that sea levels will continue to rise. With this in mind, knowing the effects that sea-level rise may have on socially vulnerable populations may aid in finding solutions to mitigate its effect. With the recent cases of dengue fever and the newly arrived chikungunya fever and Zika virus in southern Florida, it is ever more important to continue research into climate change and sea-level rise and its implications on the environment. Public health officials can utilize this study to innovate more precise ways for monitoring and diagnosing waterborne and vector-borne illnesses. Currently, many waterborne and vector-borne diseases go undiagnosed. Knowing a potential for harm exists for local communities, health care officials may consider educating patients and providing additional testing that is not routinely performed. This will allow epidemiologists to better track and potentially mitigate the potential for these diseases to become more prevalent in Southeast Florida.

This project's research not only provides the foundation for future studies on health, but can also inform adjustments to current and future infrastructure planning and provides considerations for social vulnerability.

The conclusions of this effort confirmed the following:

1. When considered according to our framework, there are large populations who currently demonstrate social, medical, or geographic vulnerability to sea-level rise; few today who are socially vulnerable and medically vulnerable are also geographically vulnerable, however this may not remain constant over time.
2. Sea-level rise has a direct influence on groundwater and, thus, will cause groundwater levels to rise as the sea rises, increasing the number of geographically vulnerable people.
3. With time, there is an increasing number of people who are likely to be impacted by the flooding effects of sea-level rise, who are also socially and medically vulnerable.
4. At present, those residing in higher socioeconomic status areas have a high risk of vulnerability to sea-level rise. Over time, this land may not no longer be viable.
5. There is a need to access more granular data to better understand the health effects of sea-level rise, as they manifest over time. Geographic vulnerability can be evaluated at the property level, and demographic data at the Census block level; much of health data has only been available at the county level which limits the ability to identify populations representing vulnerability to all three factors.
6. Sea-level rise requires a constant conversation across sectors in South Florida for the development of comprehensive mitigation and adaptation strategies. A large portion of this project was focused on establishing a rapport with diverse sectors to learn their impressions of these findings as well as to glean additional considerations. Health care practitioners are essential to this conversation.
7. We must expand how we define vulnerability to include all factors that would influence the population's adaptive capacity for sea-level rise.
8. There should be enhanced monitoring and reporting of vector diseases.
    - **a.** South Florida's human population varies substantially across both time and geographic space. Communities with a certain ethnic or socio-economic signature today may have a

completely different composition in a decade or generation. Thus we should continue to collect health data longitudinally as this will help to elucidate hypothesized associations.

   b. Health data should be mapped at the block group or census tract level.

   c. Health data should be collected monthly if possible, to help assess for associations with monthly weather and water-level variations.

9. Adaptation needs take different forms depending on location.
   a. This can include the installation more coastal salinity structures, the raising of road beds, abandoning some local roads, increasing storm water pumping, and adding storm water retention to address many of the problems.

   b. Better monitoring and reporting of sea-level rise-related diseases

   c. Expand the scope of health data that is considered.
10. The number of people moving to southeast Florida will continue to increase the current population (estimated to be 9 million by 2050), which in turn will increase the number of socially, medically, and geographically vulnerable people.
11. Given the limited land available, altered patterns for redevelopment will increase competition for higher ground, challenging the ability of socially vulnerable populations to remain in their current locations. Population movement will likely create an increase in the intersection of vulnerability as socially vulnerable people move to more geographically vulnerable areas.
12. Sea-level rise will decrease available land, increase competition for development, require added infrastructure (and costs) and increase risk to socially vulnerable populations.
13. Health data related to incidence of waterborne, foodborne, and vector-borne diseases can be collected at greater intervals, and finer grid, in Southeast Florida., The adaptive capacity to deal with potential increases in illness will require more specific reporting, data collection and analysis, tracking and public health solutions (access, treatment) than currently exists.
14. Adaptive capacity depends on funding; Taxes collected for storm-water fees, business activities and property assessment should be considered.

This project has provided FAU, FIHI, and SFRPC an unusual opportunity to explore some of the cutting-edge theoretical and methodological dimensions of a crucial 21st-Century policy question: How can a growing metropolitan area exposed to significant and increasing sea-level rise avoid some of the associated negative human health impacts? We now have the analytical basis for generating innovative, and sustained projections of which Southeast Florida communities appear to be at greatest risk of health impacts linked with sea-level rise. Our analytical framework has been applied to produce preliminary results, which we have shared with interested stakeholders locally, regionally and nationally.

Through the outreach efforts our research team was confronted with a substantial demand for refined projections using our methodology. Accordingly, in 2016, we plan to submit grant proposals that, if successful, will permit us to leverage our progress to date, and produce a second-generation effort that will continue to apply this work and maintain momentum across the region, nationally, and internationally. We found the data require an expanded analysis to determine true correlations between sea-level rise and specific health outcomes. The impacts on health require study over time to truly understand the effects and how to prepare and protect populations further practitioners must be involved in this process. Still, the sea-level rise and population health research has led us to distinct conclusions on how to prepare and lead South Florida through one of the greatest transitions and resilience-building efforts it will face.

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